ENGINEERING CALCULATIONS AND ANALYSIS REPORT

Project:	ATR Life-Time Extension Project			**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation						
Performer:	D. T. Clark	**Date:**	09/30/2008	**Checker:**	M. J. Russell	**Date:**	09/30/2008

e1. Index Codes

Building/Type: TRA-670 SSC ID: ATR PCS Site Area: 533

2. Quality Level: 1

3. Objective/Purpose:

The objective and purpose of this analysis is to perform a seismic evaluation of the Advanced Test Reactor's Primary Coolant System piping and components, using updated seismic data.

4. Conclusions/Recommendations:

Evaluation of the three primary coolant system piping models indicates that the piping, components, and supports in general, meet their acceptance criteria. There are some piping components and supports that have D/C values in excess of 1.0. Many of these over unity components and supports have been accepted based on previous component evaluation, plastic analysis, and application of inelastic energy absorption factors. Tables 5 through 11 identify piping components that are acceptable and others that are qualified by comparison to similar components qualified by plastic analysis. Table 10 identifies supports that need to be upgraded for the PCS piping to meet the acceptance criteria. Table 11 identifies supports that must be removed from the piping system. For more information, please refer to the "Conclusions and Recommendations" section.

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1 Review and Approval are required. See LWP-10200 for definitions and responsibilities.
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Introduction

In-structure response spectra and time history information has been recently updated for the Advanced-Test Reactor (ATR) to include the latest knowledge of site-specific seismic behavior [2, 17]. This information will allow the Primary Coolant System (PCS) to be reevaluated using modern methods and reflect the updated seismic information. The analysis of record for the ATR PCS was originally performed in 1975 [1] and revised with a final evaluation in 1979 [6].

Purpose and Scope

The purpose of this analysis is to perform a seismic evaluation ATR's Primary Coolant System piping using modern methods, data, and applicable codes.

The scope of the analysis is to evaluate the PCS piping and components corresponding to piping diameters ranging from approximately 4-inches and above. The PCS evaluated piping is terminated and restrained at the ATR reactor vessel nozzles, and other nozzles for tanks, pumps, and heat exchangers, within the PCS. Piping models are also terminated at grouted penetrations through concrete walls and floors, and at branch points from larger piping which meet decoupling criteria. The scope also considers pressure boundaries on valves and pumps, and extends to the pump anchorage. The scope does not include the evaluation of the ATR facility (or super structure), PCS reactor vessel, tanks, pumps, heat exchangers, or any other interfacing equipment items associated with the PCS piping boundaries.

A previous PCS support evaluation [3] was performed that determined the support and anchorage capacities of the PCS. Within that evaluation, all of the support anchorage capacities were determined, but only a subset of anticipated highly loaded supports capacities were determined. The support subset was based on a recent Leak Before Break analysis [4], in which approximately 30% of the PCS supports were identified as potentially the most highly stressed. Thus, the scope of this PCS seismic evaluation also includes the determination of the remaining support capacities, which was not included in the previous support capacity and Leak Before Break analyses [3, 4].

The work of the PCS piping evaluation follows a multi-step approach. The analysis includes the following subtasks for each of PCS piping model:

1. Develop piping model
2. Develop tools to automate piping analysis and organized results
3. Perform piping analysis
4. Evaluate piping components and supports within each model
5. Perform additional analyses for elements not qualified with standard methods (if required)
6. Recommend modifications that may be required to meet the acceptance criteria.

The tools needed to automate the piping analysis (Item 2 above) were developed as part of the first (or pilot) model evaluation and then applied to each of the remaining PCS model evaluations. Tool functions remained the same in subsequent applications.

Quality Level

The TRA-670 Primary Coolant System (including supports) is identified as a Quality Level 1 system, as established by the Life Extension Program (LEP).

Natural Phenomena Hazard (NPH) Performance Category

The PCS is evaluated for PC-4 seismic loading, as established by LEP.

Design Inputs

Pressure and temperature inputs to the PCS piping are defined as the maximum values between 2-pump and 3-pump normal operation, as found in the ATR PCS piping Design Specification [8, Sect. 7]. Table 1 lists the resulting pressure and temperature values used in this analysis.

Table 1 – Pressure and temperature ranges for 2 and 3-pump PCS operational conditions.

Piping Sections	Pressure (psig)		Temperature (^oF)	
	3-Pump	2-Pump	3-Pump	2-Pump
Reactor Vessel Outlet to Heat Exchanger Inlet	~254	~272	~167	~163
Heat Exchanger Outlet to Pump Suction	~246	~253	~125	~125
Pump Discharge to Butterfly Control Valve	~390	~400	~125	~125
Butterfly Control Valve to Reactor Vessel Inlet	~374	~376	~125	~125
Relief Valve Piping – Vessel Nozzle to Pressure Relief Valves and Drain Valves	~350	~361	~125	~125
Non-running Pump Inlet Lines(s)	~246	~253	~80	~80

As can be seen, 2-pump operation has the largest pressure values while 3-pump operation has the largest temperature values. These bounding pressure and temperature values are used in the analyses.

Literature Search Results

A thorough review of documentation related to the ATR PCS piping and its components has been conducted. PCS inspections [5], piping support analysis [3], other piping and equipment drawings, SAR-153 [7], and other related PCS reports, have been reviewed and applied appropriately. Individual document and drawing references are documented in each respective PCS model Appendix.

Structural System or Component (SSC) Description

The ATR PCS is a light water, forced flow, closed loop system, which functions to remove reactor generated heat. Figure 1 shows an isometric view of the majority of the PCS piping. A few of the smaller auxiliary lines are not shown for clarity.

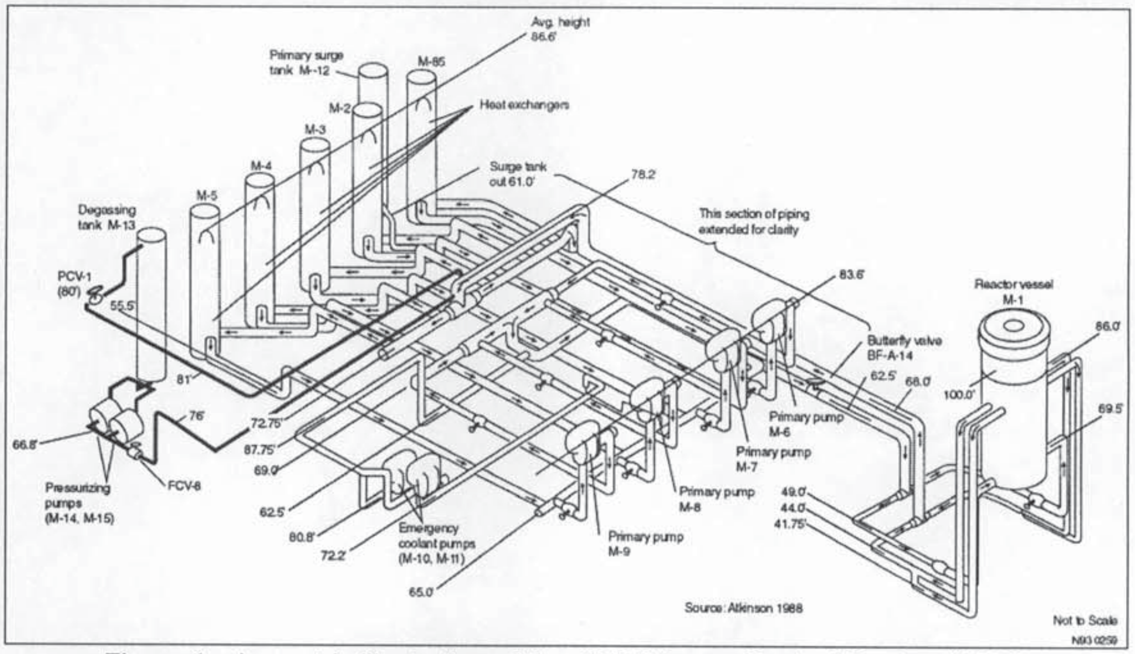


Figure 1 – Isometric illustration of the ATR Primary Coolant System (PCS).

The piping attached to and in close proximity of the Reactor Vessel is fabricated from 304L stainless steel. The remaining piping (away from the reactor vessel) is constructed from 304 stainless steel.

The PCS piping is terminated at the nozzles of the reactor vessel, six pumps (four primary pumps & two emergency pumps), five heat exchangers, the surge and degassing tanks, and at grouted penetrations in concrete walls and floors. Smaller piping is also terminated at branch points from larger piping if decoupling criteria are met.

The PCS piping was initially constructed in 15 to 35-ft segments, where all components associated with a run of pipe, including pipe components, valves, and other piping features, were fabricated together and delivered as such. These segments are also called spool pieces. The associated drawings have been renamed to current INL naming conventions, but are frequently referred to as the spool drawings. Figure 2 shows an example of a spool drawing.

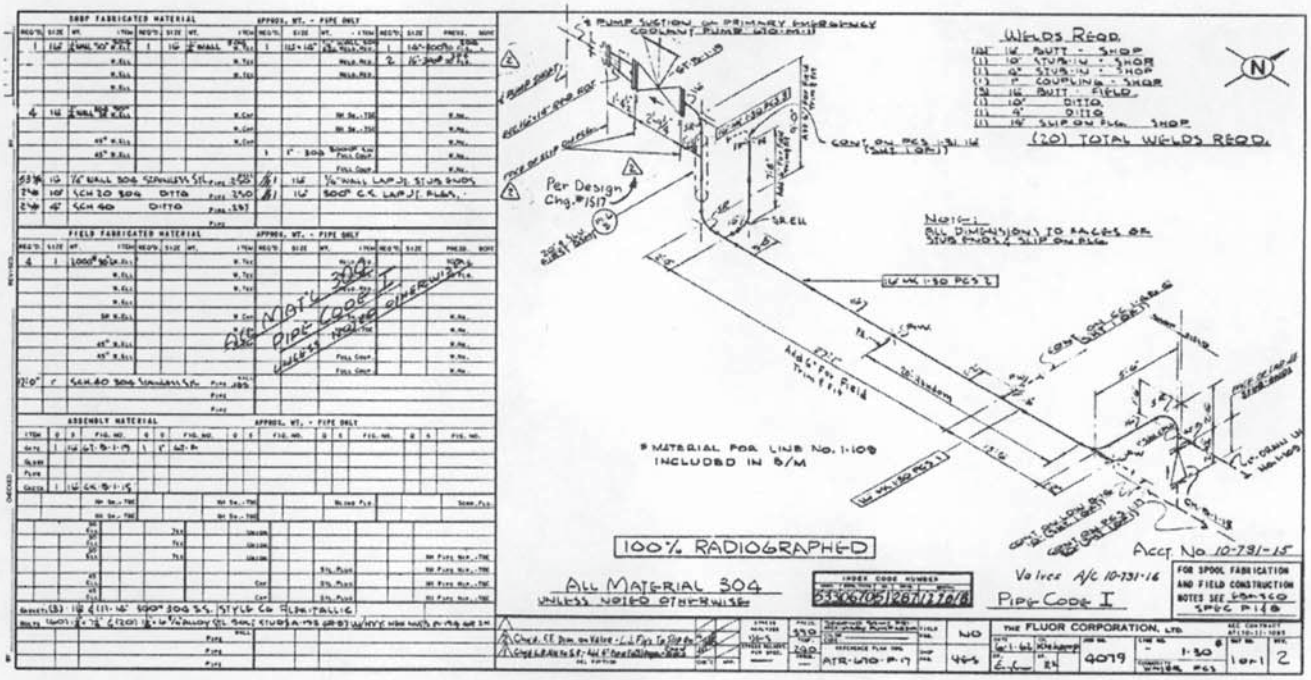


Figure 2 – Example of a typical spool drawing that identified piping components within a spool segment.

As shown in Figure 2, a spool drawing identifies materials of construction, fitting types, component designations, pipe diameters & thickness, and applicable segment and component lengths for each spool segment. Thus, the initial PCS piping (constructed in the early 1960s) is composed of many spool segments which have been field welded together and are held in place by many field constructed supports. The majority of the PCS piping is still as it was originally constructed, but some larger components have been replaced while others have been reinforced.

The original analysis of record for the ATR PCS [1] provided a framework for its analysis. Hereafter referred to as Davidson's analysis, it divided the PCS piping into six individual piping sections. From the six divisions, six Finite Element (FE) models were created and evaluated individually. Throughout the past years at the INL, other PCS analyses [4] have followed Davidson's original six model PCS approach. Figure 3 shows a schematic overview of the original six models and Figures 4 to 9 are isometric sketches illustrating each of the six original models. These sketches are meant to show the individual components of the piping system in a single sketch. This is accomplished by giving up scaling: Longer runs of piping are truncated so that components can be presented at a larger scale. Note that the sketches include spool piece numbers that can be used to quickly identify the spool drawings applicable to a particular area of the piping.

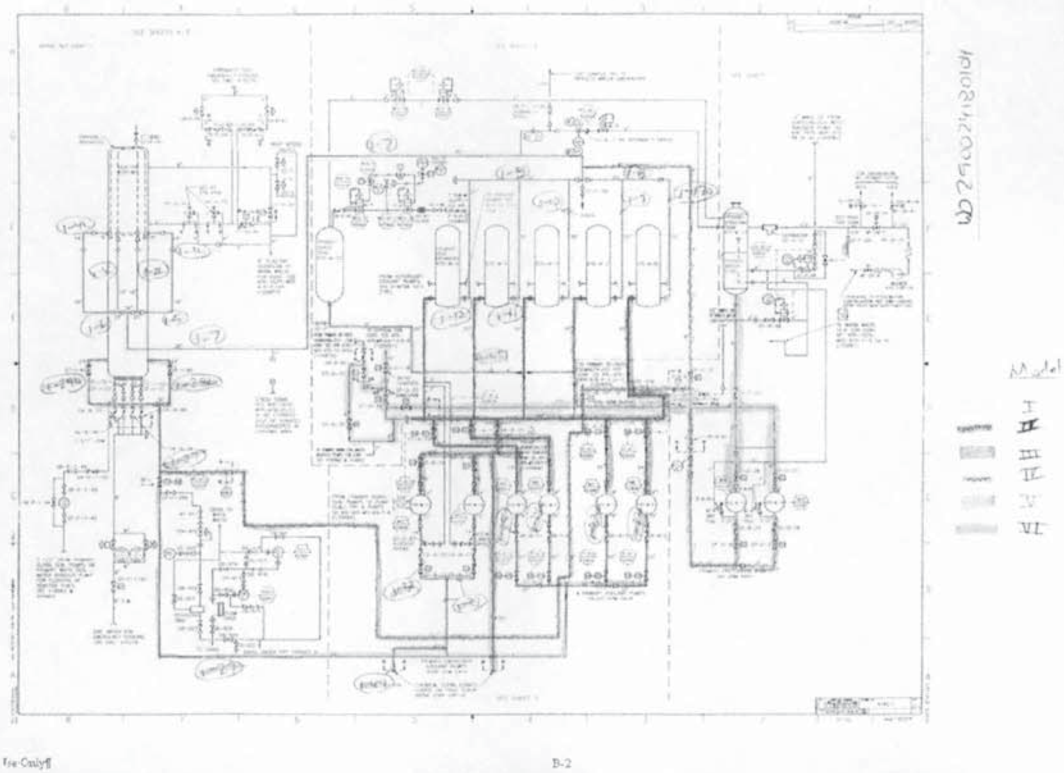


Figure 3 – PCS schematic overview showing various colors to depict each of the original six model divisions.

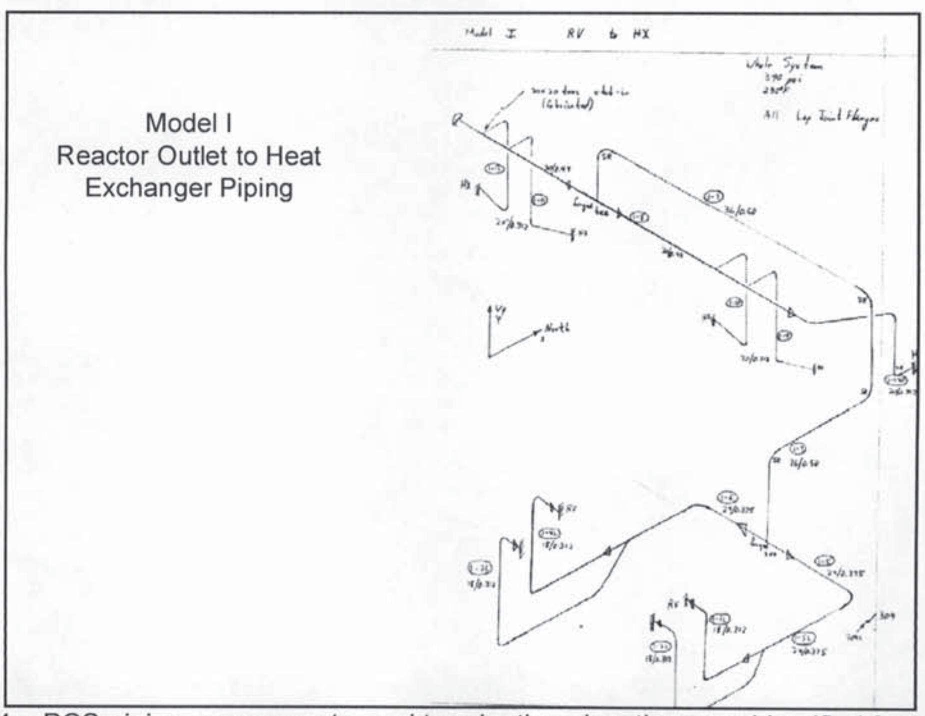


Figure 4 – PCS piping, components, and terminations locations are identified for Model I.

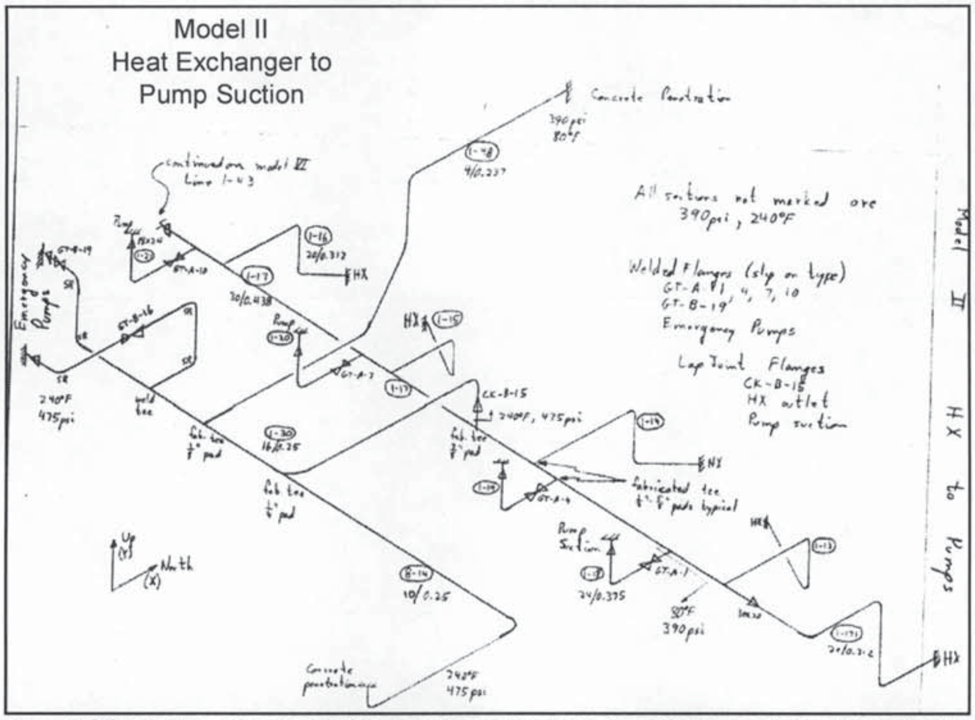


Figure 5 – PCS piping, components, and terminations locations are identified for Model II.

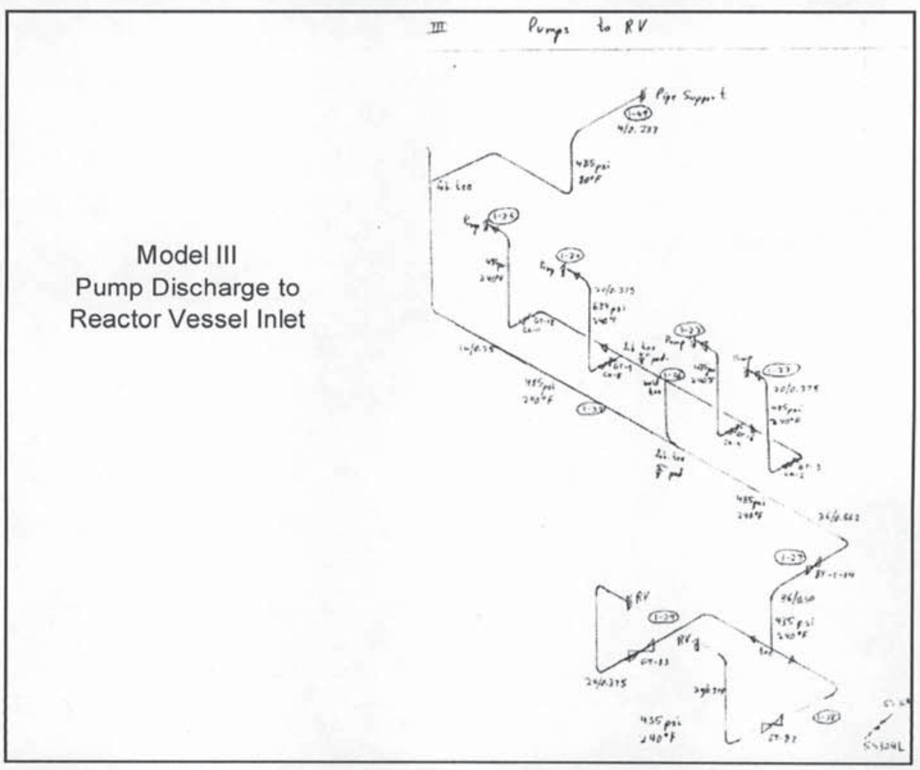


Figure 6 – PCS piping, components, and terminations locations are identified for Model III.

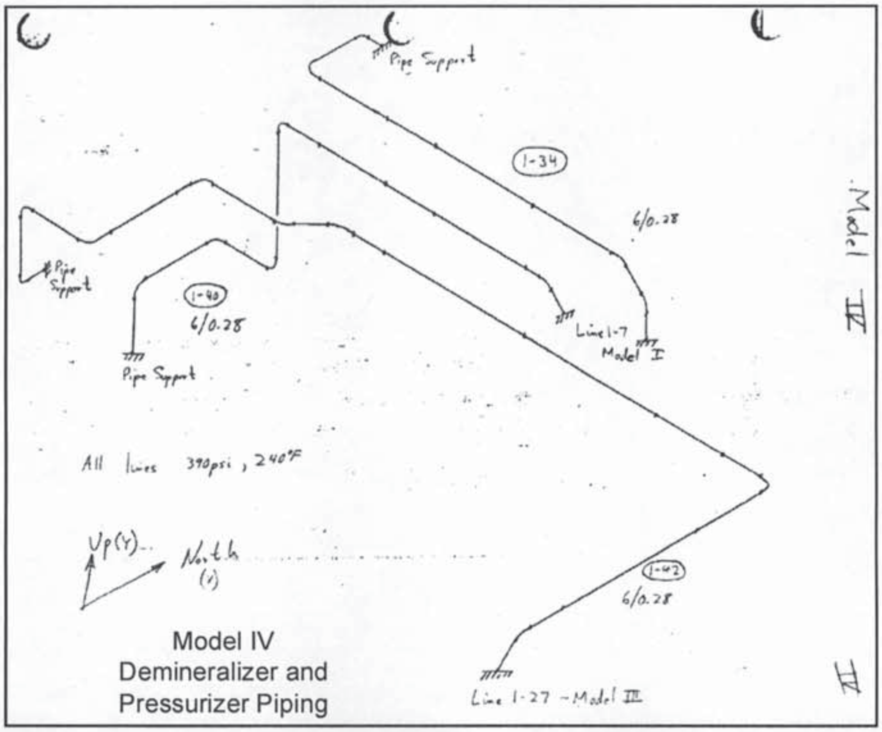


Figure 7 – PCS piping, components, and terminations locations are identified for Model IV.

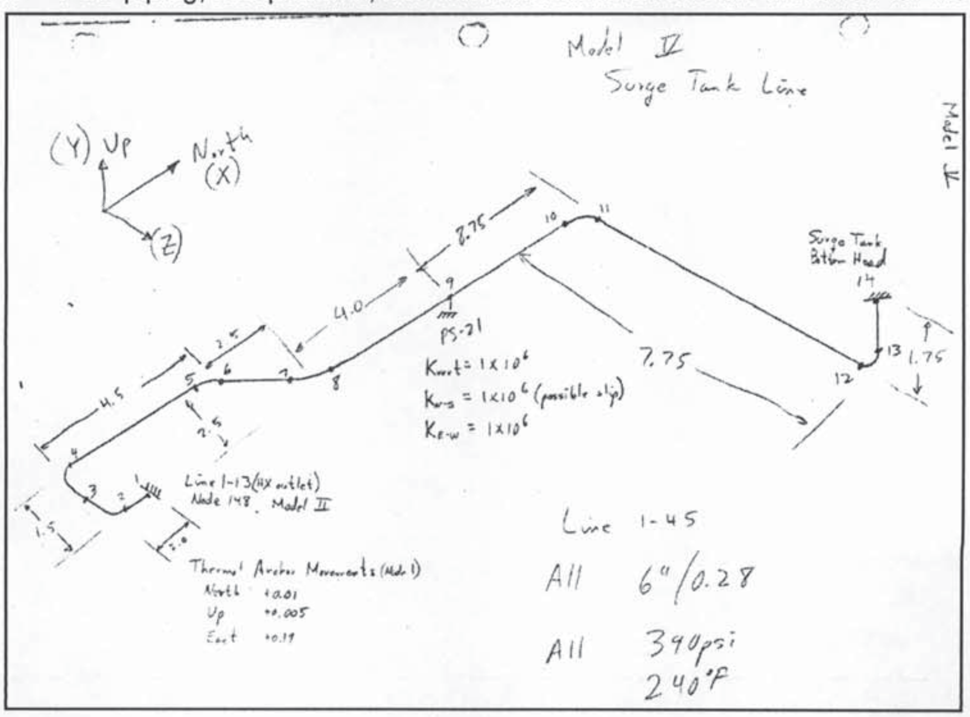


Figure 8 – PCS piping, components, and terminations locations are identified for Model V.

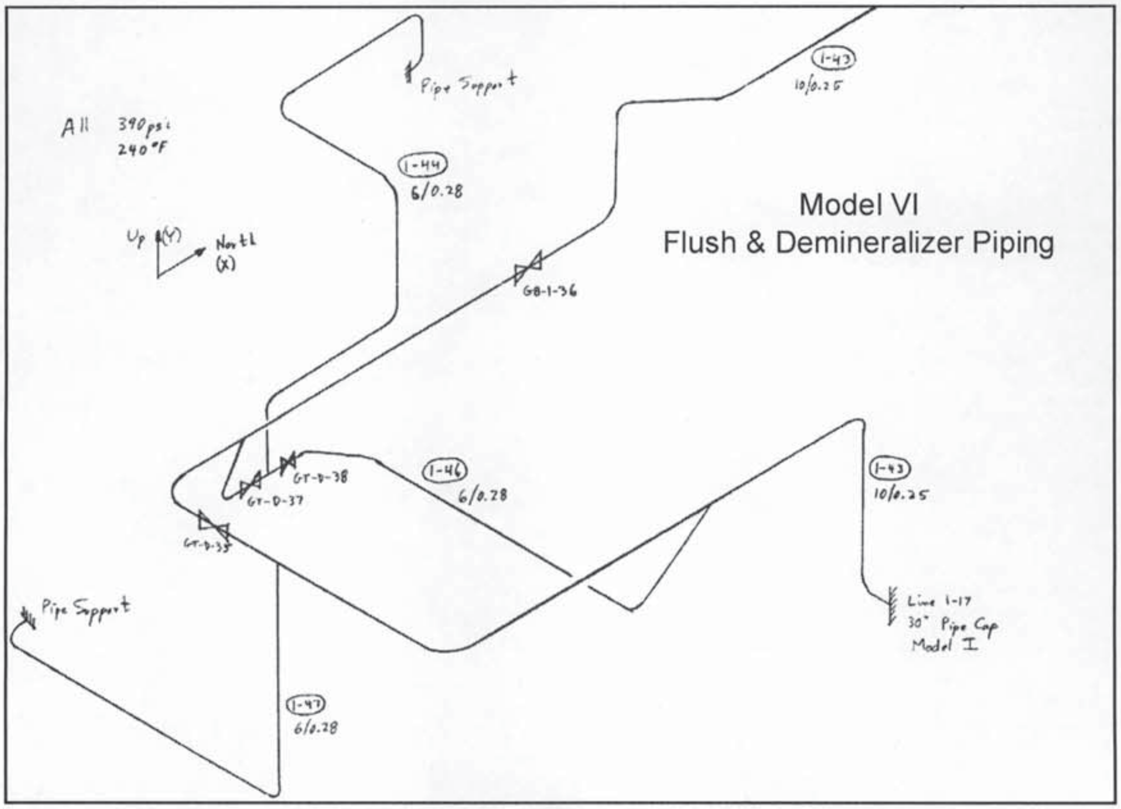


Figure 9 – PCS piping, components, and terminations locations are identified for Model VI.

Prior to this seismic analysis, an in-plant walkdown of the PCS system was performed and its results (containing a large set of digital pictures) are documented in report no. INL/INT-07-12839 [5]. Within the in-plant walkdown report it was concluded that most of the PCS piping is constructed from "listed" (or standard) components. "Listed" components have been constructed to ASTM Standards found on a list of Standards in the ASME Code for which simplified analysis procedures are provided in that Code. The Code provides more detailed analysis procedures for components not found on the list ("unlisted"). A few of the components were reinforced or not constructed to Standards listed in the ASME Code, and were therefore identified to be "unlisted" (or nonstandard). Evaluation of such components is within the scope of this analysis. Figure 10 shows an example of an unlisted component and the finite element model used to determine its elastic force-deformation characteristics. The models were also used to calculate stress indices for the components, or for plastic analyses of the components using loading extracted from the linear analyses of the systems containing them.

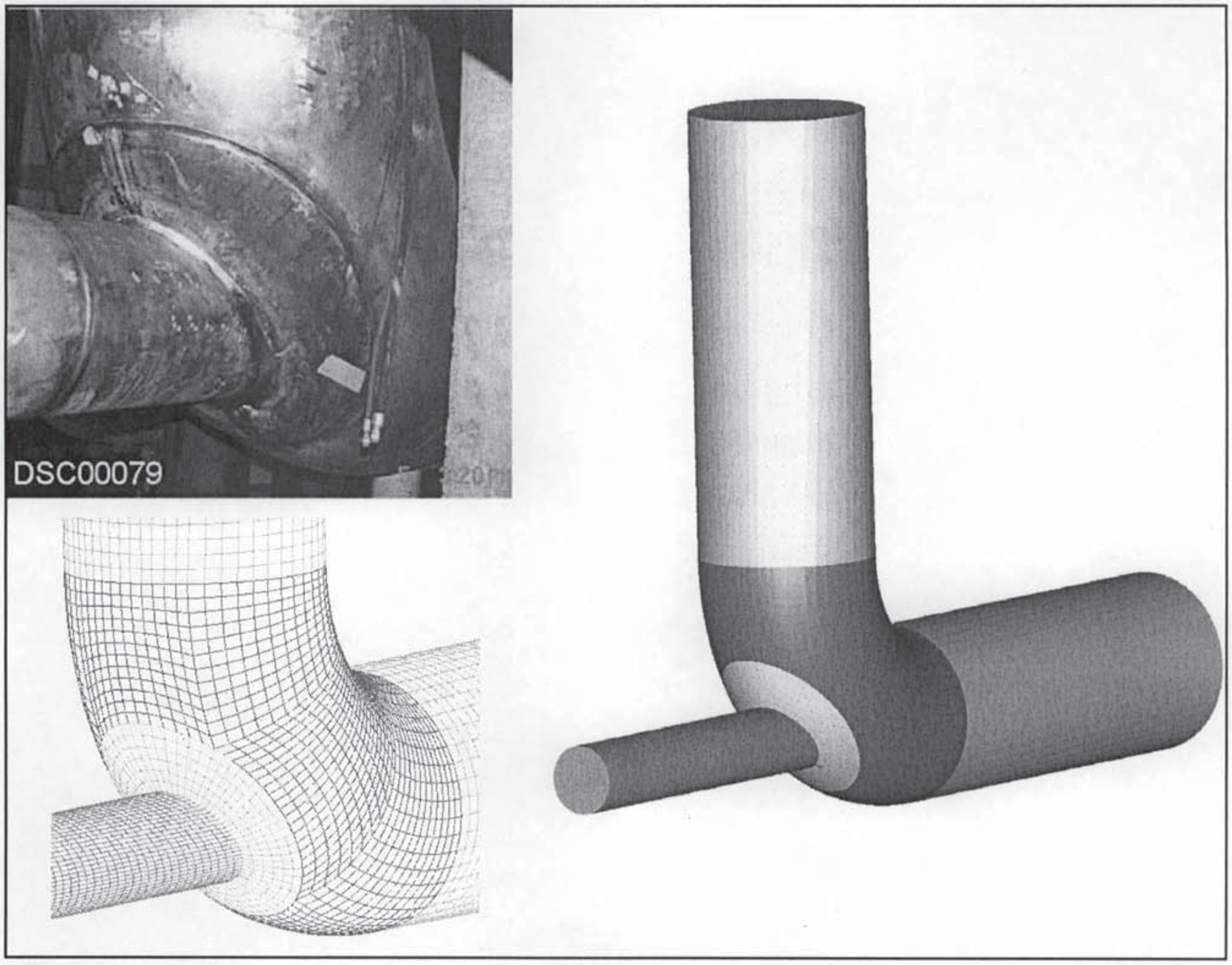


Figure 10 – A picture of a typical unlisted component and accompanying solid and FE models are shown.

Dramatic improvements in computer software and hardware have been made since the time of the original analyses. This allows the current analysis of much larger models than could have been analyzed at the time of the original analyses. It made possible the consolidation of the six models used in the original Davidson analysis to a smaller number. In addition to the computational efficiency associated with fewer computer runs generating fewer files, it allowed elimination of artificial model terminations with attendant uncertainty and hence conservatism applied in boundary conditions at those terminations. As part of the consolidation effort, a study of each of the six original models was performed that identified the number of supports, spring hangers, elbows, tees, valves, unlisted components, etc. This information was used to logically combine models. A reduced set of three models was derived, from which a "pilot" model was selected. This model was the first model evaluated, and hence a showcase for the methods to be used in the analysis. Figure 11 shows a graph used to determine model combinations and select a pilot model candidate.

Component Distribution Overview

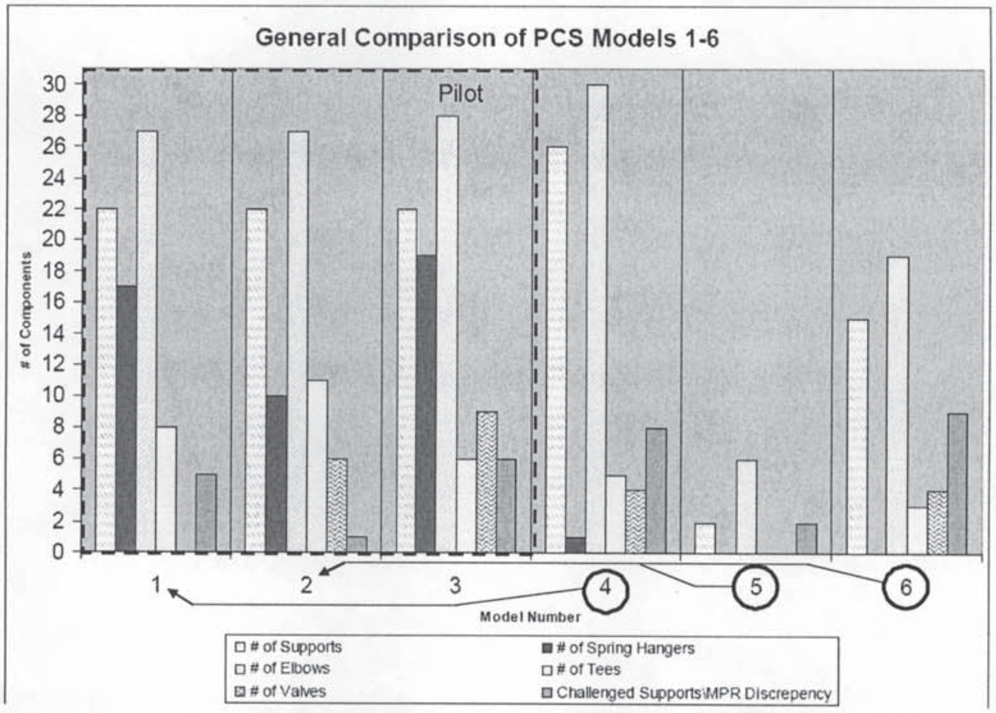


Figure 11 – Graph indication component features between original six models.

Figure 11 compares the number of piping fittings and components for each of the original six PCS models. From viewing other PCS piping drawings and the above graph, it is logical to incorporate Model 4 into Model 1, since it attaches to Model 1. Likewise, Models 5 and 6 are a good fit with Model 2. Thus, the dotted box surrounding the first three models represents the models that are evaluated in this analysis. The first model evaluated in this analysis is Model 3, also referred to in this report as the "pilot" model. The pilot model was selected as being representative of all the models, in that it contained a good selection of component types (supports, elbows, valves, tees, etc.). From the three PCS models, it also appeared to be the smallest model and suggested to be a good candidate to help the PCS analysis get started during the creation and refinement of the automation tools. Figure 12 is a refinement of Figure 3, where the original six models are reduced and combined into three models. As shown in Figure 12, Model 3 (pilot) is shown in blue, Model 256 (also referred to as Model 265) is shown in pink, and Model 14 is shown in green.

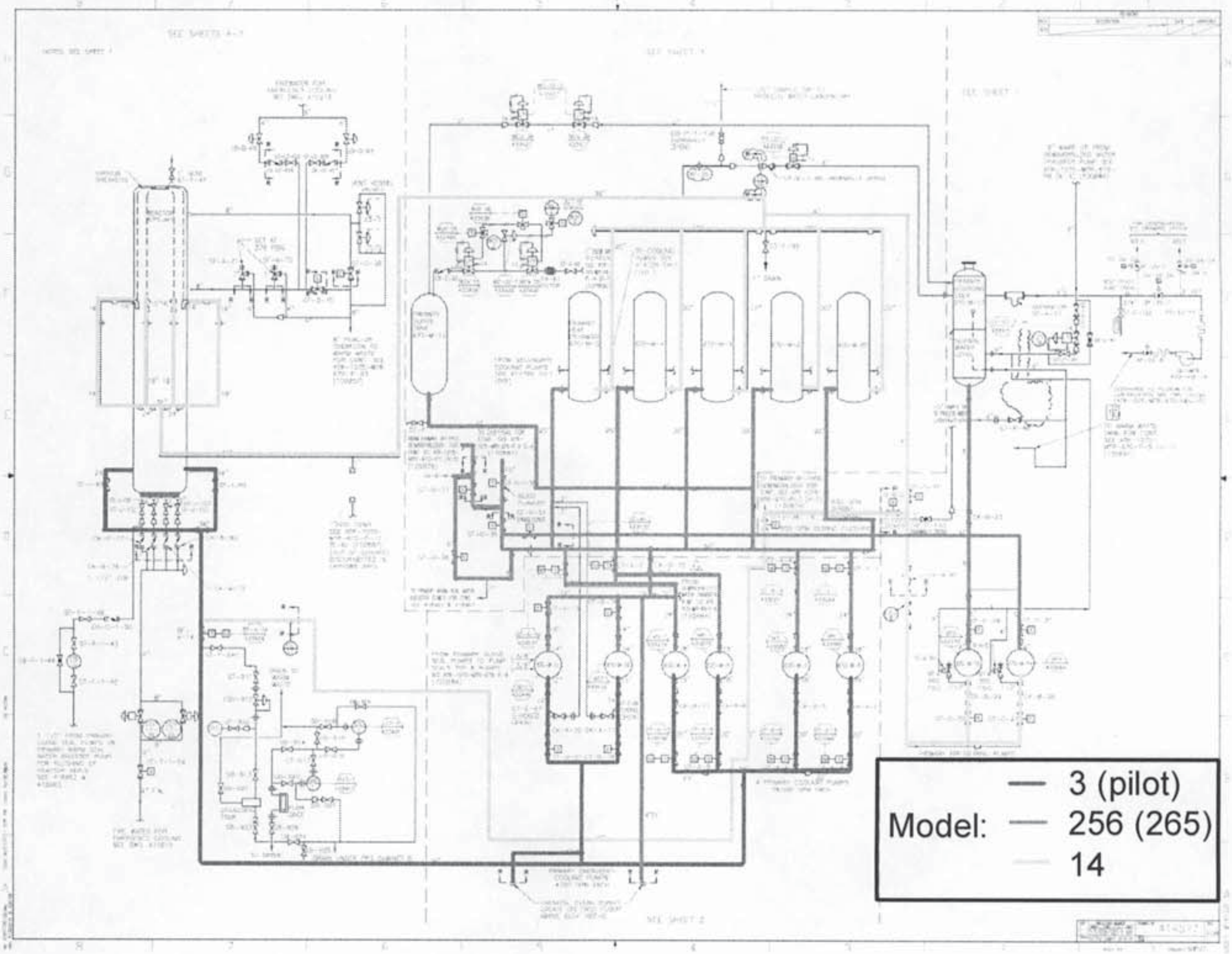


Figure 12 – PCS schematic showing original 6 models reduced and combined into 3 models.

Acceptance Criteria

Piping components and supports are considered acceptable if the demand to capacity (D/C) ratio calculated, as describe in the following sections, is less than 1.0. In additional cases where piping components and support D/C ratios are over unity, their acceptance may be based on plastic analysis, use of inelastic energy absorption factors of 1.25 (per Limit State C), or be bounded by enveloping plastic analysis of other components.

Capacities

Criteria for capacities are based on DOE-STD-1020-2002 [25], in which guidance from ASCE/SEI 43-05 [13] has been used. Linear elastic piping component capacities were established using ASME III NB-3600 [9], consistent with the provisions of DOE-1020-2002.

In a few cases, demands and capacities of components were established by a plastic analysis as described in NB-3213.24 of ASME III. Component capacities were determined by applying limits upon inelastically computed stress in accordance with F-1341.2. F-1322.1 was applied in determining if the system analysis needed adjustment. The effect of component plastic response on system behavior was shown to be insignificant.

The criteria selected for the pipe support capacities are the strength provisions of the AISC Steel Construction Manual, 13th Edition [14]. This is also consistent with ASCE/SEI 43-05 and DOE-1020-2002. Capacities for structural concrete embedments are based on Appendix B of ACI 349 [15]. Snubber capacities are based on vendor rated loads. Sample support capacities have been previously calculated [3].

Modeling

Moment and force demands are calculated using a nonlinear large displacement implicit ABAQUS [16] beam analysis. Straight pipe is modeled with B31 beam elements and elbows are modeled with B32 parabolic beam elements. The beam element material properties are elastic (with no material plasticity). Nonlinearities associated with gaps, buckling and uplift effects in the supports are modeled using nonlinear springs. This modeling is described in detail in the PCS model evaluation Appendices. Equipment nozzles are modeled as anchor points, with the restraint load time histories extracted for follow-on analysis of the equipment and their supports. An example of a piping beam model (Model 256) is shown in Figure 13.

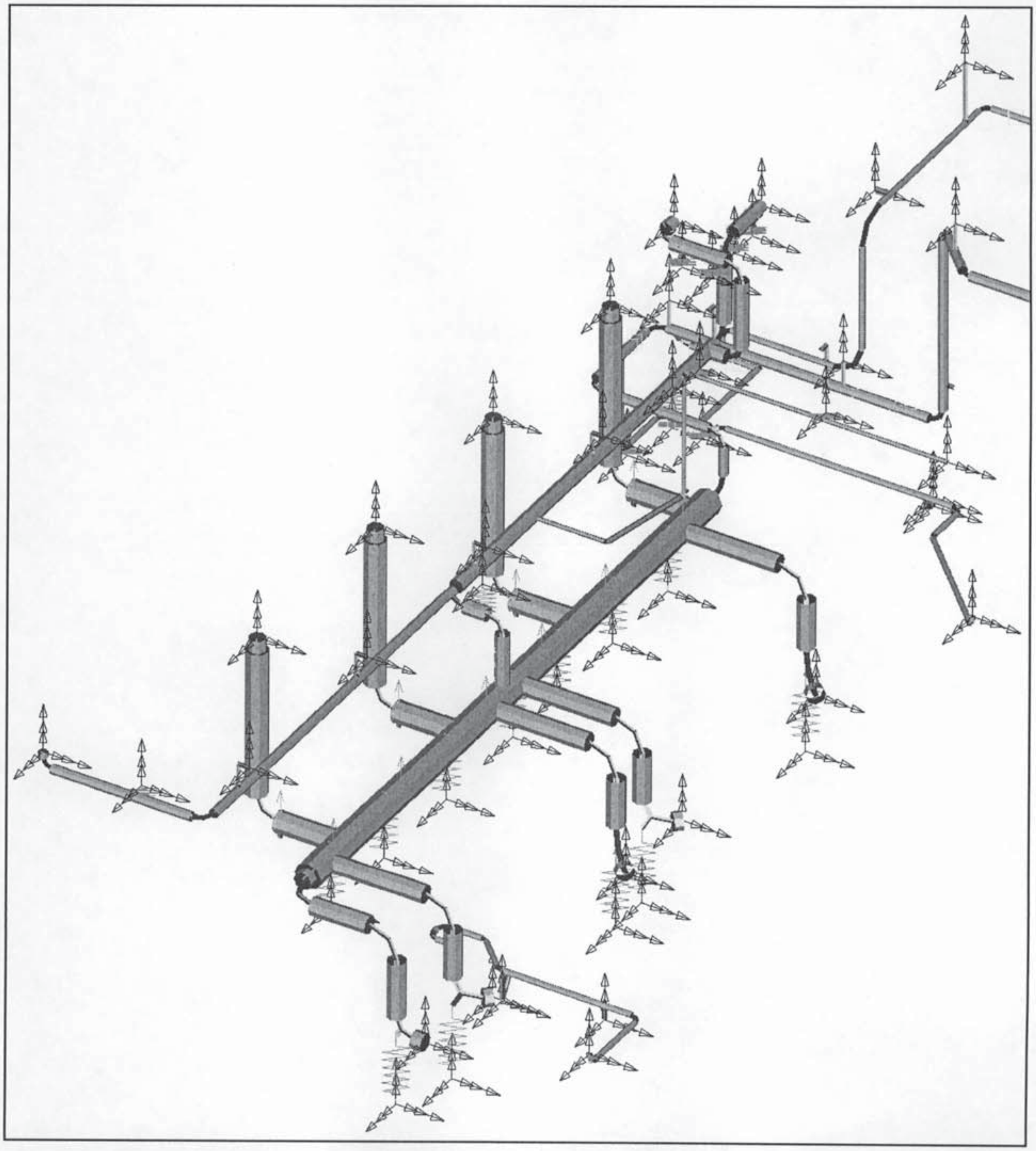


Figure 13 – Model 256 piping model is shown as example for typical finite element piping configurations.

The models of the piping are established using flexibility factors and stress indices from ASME III, NB-3600. Similarity between listed and unlisted components was used to establish factors and indices where reasonable (e.g., slip-on flanges for lap joint flanges). Factors and indices for the remaining components were generated using detailed finite element analysis. Pressure stiffening of elbows was included. An example of an unlisted component within Model 256 is shown in Figure 14.

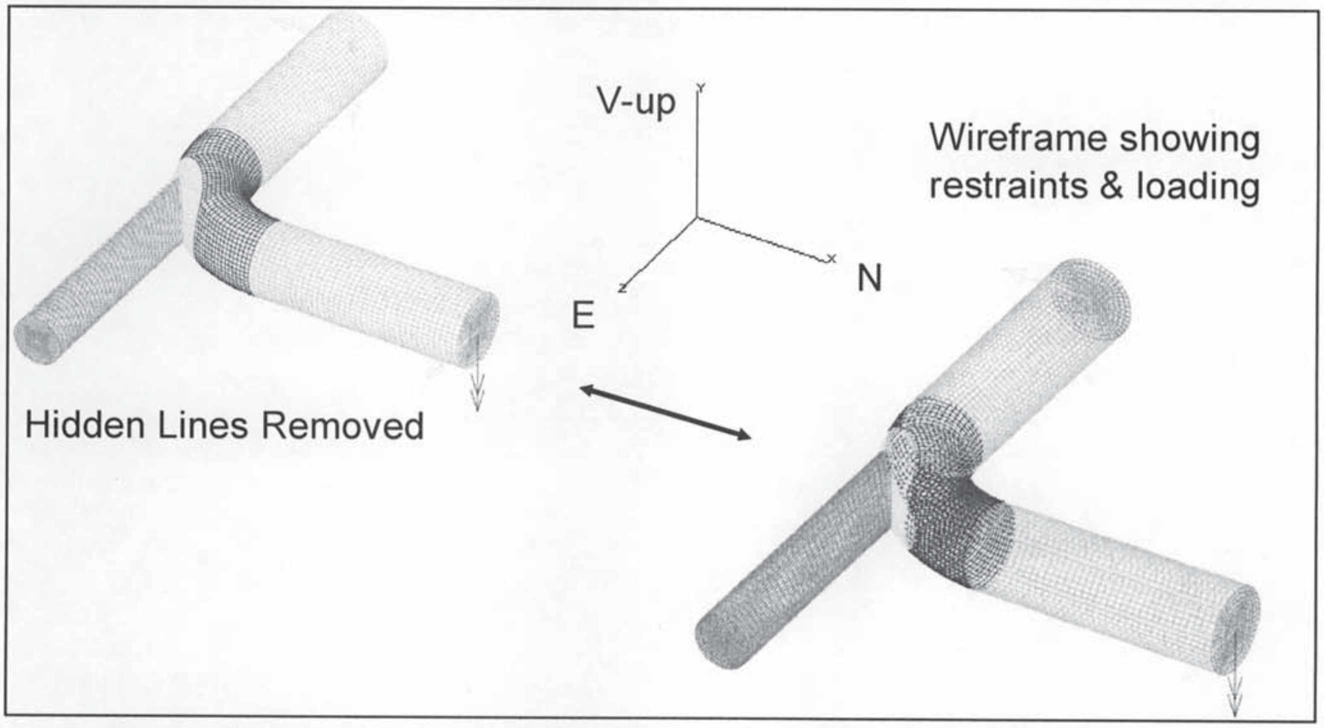


Figure 14 – Model 256's unlisted elbow component finite element model is shown as an example.

Modeling complied with the provisions of ASME III, Appendix N. Model geometry was based on the drawings and specifications used in the construction (identified in each respective PCS model Appendix), corroborated by extensive walkdown of the piping and supports [17]. The models were constructed using the I-DEAS software [18]. Post-processing of the ABAQUS analysis results was done with the MathCAD software [19] and Excel spreadsheet software [20].

Mass Distribution

Distributed mass beam elements are used throughout all piping models with lumped-mass elements accounting for flanges, valves, and other specified piping equipment. Beam elements representing piping nominal 6-in and less in diameter must be 3-ft long or less, 8-in pipe must be 4-ft long or less, between 10-in and 14-in must be 5-ft long or less, and larger piping must be 6-ft long or less. These values are based on the mass point spacing limitations of the NUPIPE-II software [21]. This piping analysis software has been widely used in the analysis of nuclear piping at INL.

Damping

A modal damping value of 5% is applicable to this evaluation, as listed in Table 3-2 of ASCE/SEI 43-05 (and in Table N-1230-1 of ASME Section III, Appendix N). To accommodate support nonlinearity (gaps and lift-off), the finite element model runs are performed with direct time integration which does not allow modal damping to be used. Instead, Rayleigh damping is used. Justification for the Rayleigh damping values used is provided for each model. This process is documented in Appendix A.

Decoupling Criteria

Branch piping with a moment of inertia at or less than 1/25th that of the run piping may be decoupled and analyzed in a separate model.

Material Properties

The PCS piping is fabricated from two stainless steel materials. The piping attached to the reactor vessel nozzles and other piping fittings and components in close proximity to the reactor are fabricated from 304L stainless steel. The remainder (or most of the PCS piping) is fabricated from 304 stainless steel. As indicated in Table 1, most of the PCS models have an operational temperature of 125°F. Only one (or one portion) of the three models has a high temperature of 167°F. Table 2 identifies the stainless steel material properties at both temperatures, using linear interpolation between known temperature values.

Table 2 – PCS piping stainless steel material properties at 125°F and 167°F.

SST Grade	Symbols	Property Values (125°F / 167°F)	Property Descriptions
304 & 304L	v	0.30 / same	Poisson's Ratio [9, Sect. NB-3683.1(b)]
304 & 304L	E	28.0E+6 psi / 27.7E+6 psi	Modulus of Elasticity [10, Table TM]
304 & 304L	ρ	0.28 lb/in^3 / same	Mass Density [11, Table A-5]
304	Sy	28.35 ksi / 26.12 ksi	Material Yield Strength [10, Table Y-1]
304	Sm	20 ksi / same	Maximum allowable Stress Intensity [10, Table 2A]
304L	Sy	23.85 ksi / 22.26 ksi	Material Yield Strength [10, Table Y-1]
304L	Sm	16.7 ksi / same	Maximum Allowable Stress Intensity [10, Table 2A]
Other Useful Materials	ρw	62.4 lb/ft^3 / same	Water Density [12, Table A.6]

The piping supports are fabricated from carbon steel. Carbon steel material properties are defined in Appendix B. Appendix B evaluates (among other items) the remaining PCS piping supports not previously analyzed [3].

Some of the unlisted components require a plastic analysis. Plastic material properties are derived or referenced in Appendix F.

Loads and Load Combinations

Weight, pressure, thermal, and seismic loads are considered in the analysis. Weight loads include the weight of the piping, associated flanges and valves, and the weight of the water coolant contained in the system. Spring hanger loads are applied as constant forces opposing the weight loads. Thermal expansion loads are applicable only to supports and will only be used in calculating support demands. System pressures and temperatures associated with Level A operating conditions are used to define the pressure and weight loads. These are the conditions under which an earthquake is most likely to occur.

Input Motion Selection

Seismic response was defined by application of in-structure time histories taken from a Soil-Structure Interaction (SSI) analysis of the ATR Substructure [2, 17] to the piping support points. Since SSI motion was not defined for every pipe support point, a selection process was needed to establish the time histories to be applied. This process was based on number of factors. Proximity was considered, tempered by the nature of the structure in the vicinity of the support. In-plane motion defined at the center of a diaphragm is appropriate for most of the diaphragm, but out-of-plane motion is less and less applicable as the pipe support location is moved from the center to the edge. Directionality was considered. For instance, only vertical motion was considered in defining the input motion to long rod hangers. These factors were used to establish sets of time histories applicable to each piping system. Response spectra were then calculated and compared for each set. Time histories with bounding spectra were selected to represent groups of time histories with similar spectra. Table 3 identifies the support point sets selected for each of the three PCS models. Point numbering is from the Probabilistic Soil-Structure Interaction analyses (PSSI) [2, 17].

Table 3 – Time History support point sets selected for each PCS model, based on SSI analysis [2, 17].

	*Model 3 (Pilot)		*Model 256		*Model 14	
Selected Direction Point(s)	E-W	319, 552, 1577	E-W	542	E-W	315, 547, 1577
	N-S	552, 815, 1372	N-S	552, 815	N-S	315, 542, 547, 552, 1340
	V	552, 1577	V	552, 892, 4119	V	892, 1577

* Time history point (or PSSI Node) selection basis and justification, is described in Appendix A.2.

Figure 15 is a drawing section view (running North/South) of the ATR building structure [26] through the reactor center, and shows the floor levels where much of the PCS piping is installed.

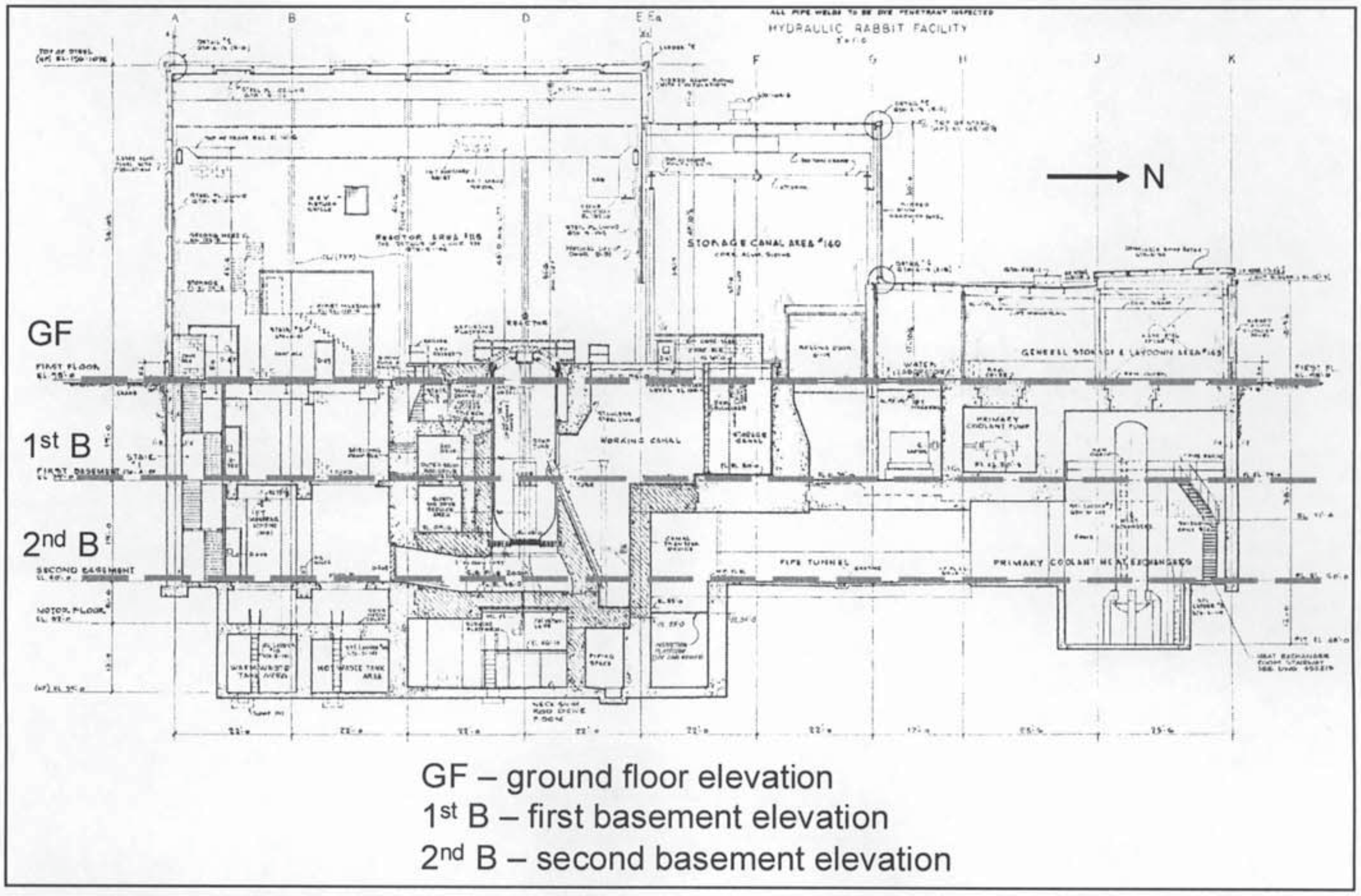


Figure 15 – This is a North/South cut away side view of ATR building taken through the reactor centerline

Figures 16 through 19 are reprints from PSSI analyses showing corresponding point number locations within Table 3 or the floors identified in Figure 15. Point set locations are circled with colors corresponding to those of Figure 12 (i.e., pilot/blue, 256/pink, 14/green) that reflect selection for each of the three models. Details of the time history selection process are provided for each model in Appendix A.2.

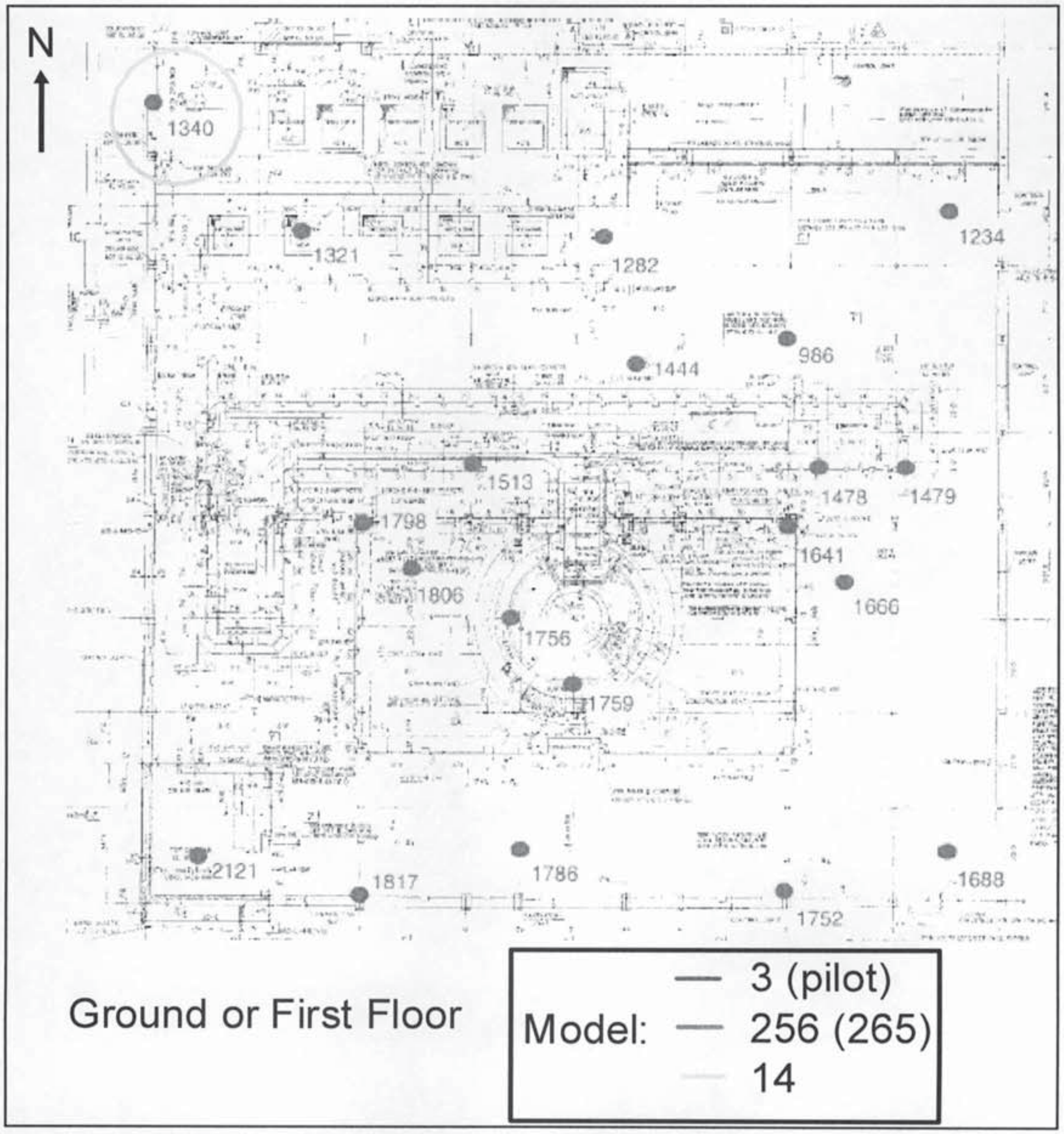


Figure 16 – Reprint of PSSI point selection locations shown on a planar view of the ground floor.

Figure 16 shows that PSSI point 1340 is selected for Model 14.

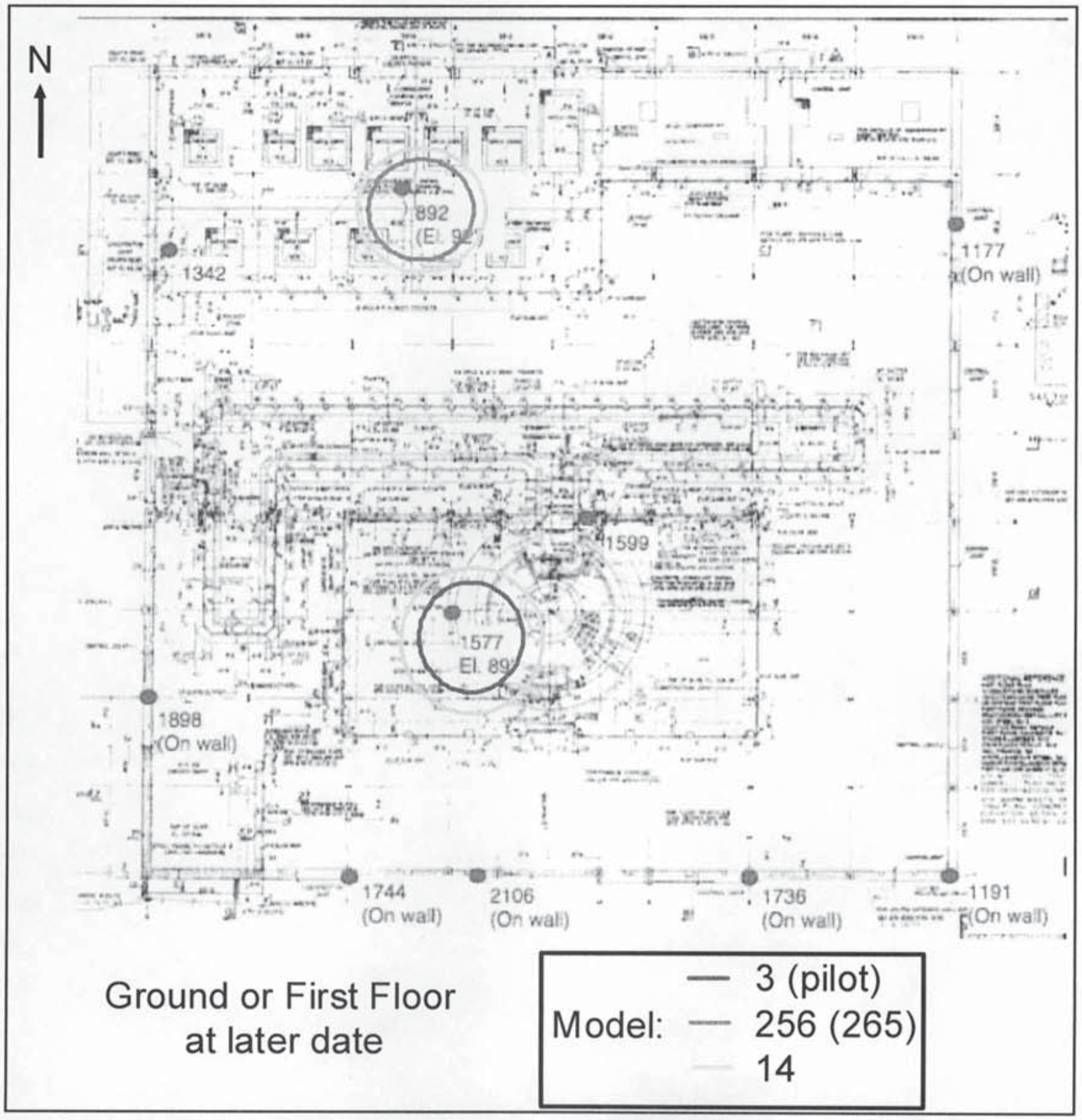


Figure 17 – Reprint of new PSSI 1577 point selections shown on a planar view of the ground floor.

Figure 17 identifies the vicinity in which PSSI points 1577 and 882 are located. Note that the data for this point was documented in a report [17] published subsequent to that defining data for all the other points. Point 1577 is located within the Capsule Nozzle Trench area (between ground and 1st basement elevations) and positioned at the reactor's anchorage to the ATR building structure. Data for this point defined motion at the inlet and outlet reactor nozzles in Models 3 and 14. Point 882 is located at the floor elevation above the Heat Exchanges and provides time history input for vertical restraints of Models 256 and 14.

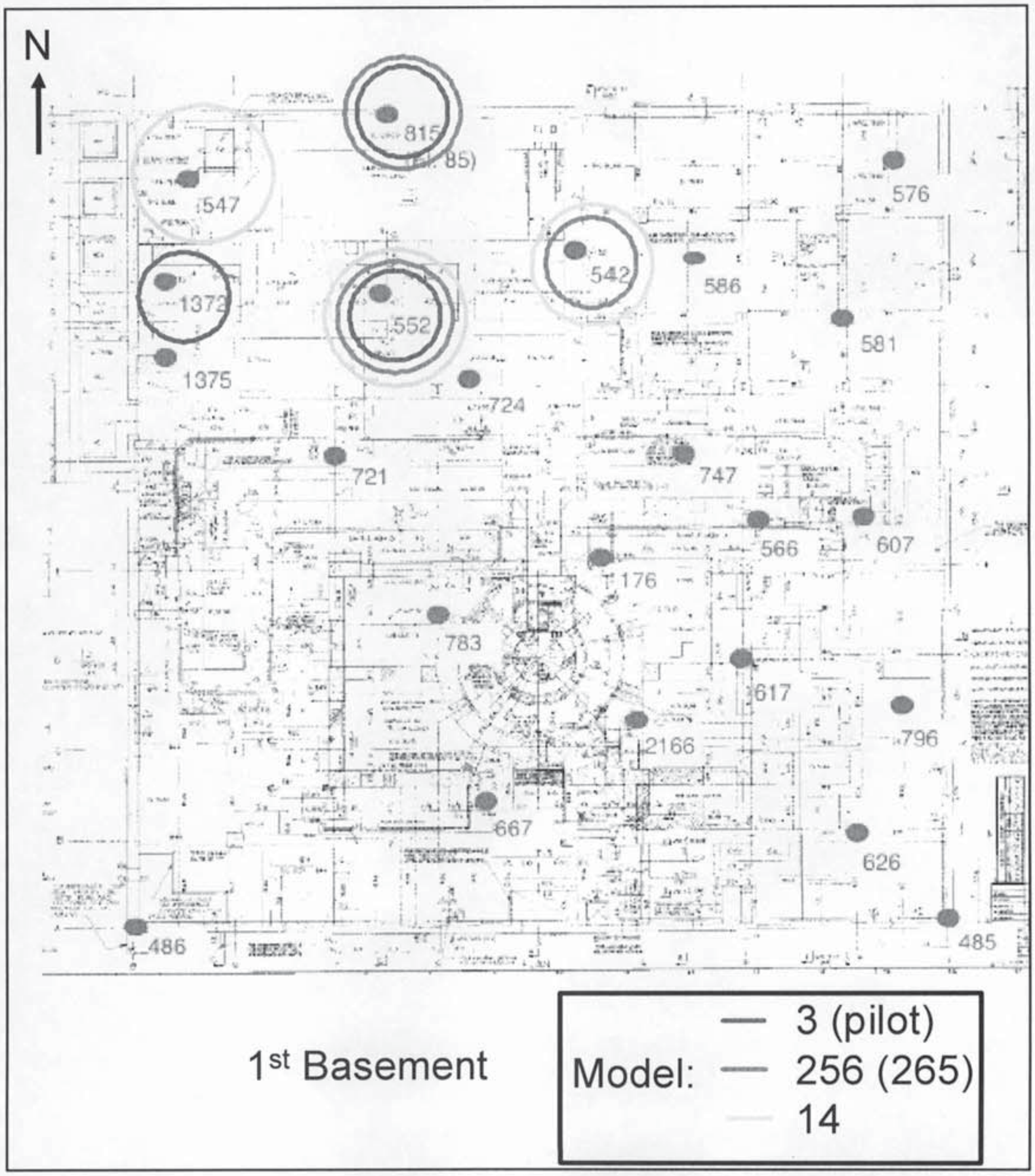


Figure 18 – Reprint of PSSI point selection locations shown on a planar view of the first basement.

Figure 18 shows several PSSI point selection locations related to the first basement. As can be seen, all three models use PSSI point 552 as part of their time history selection sets.

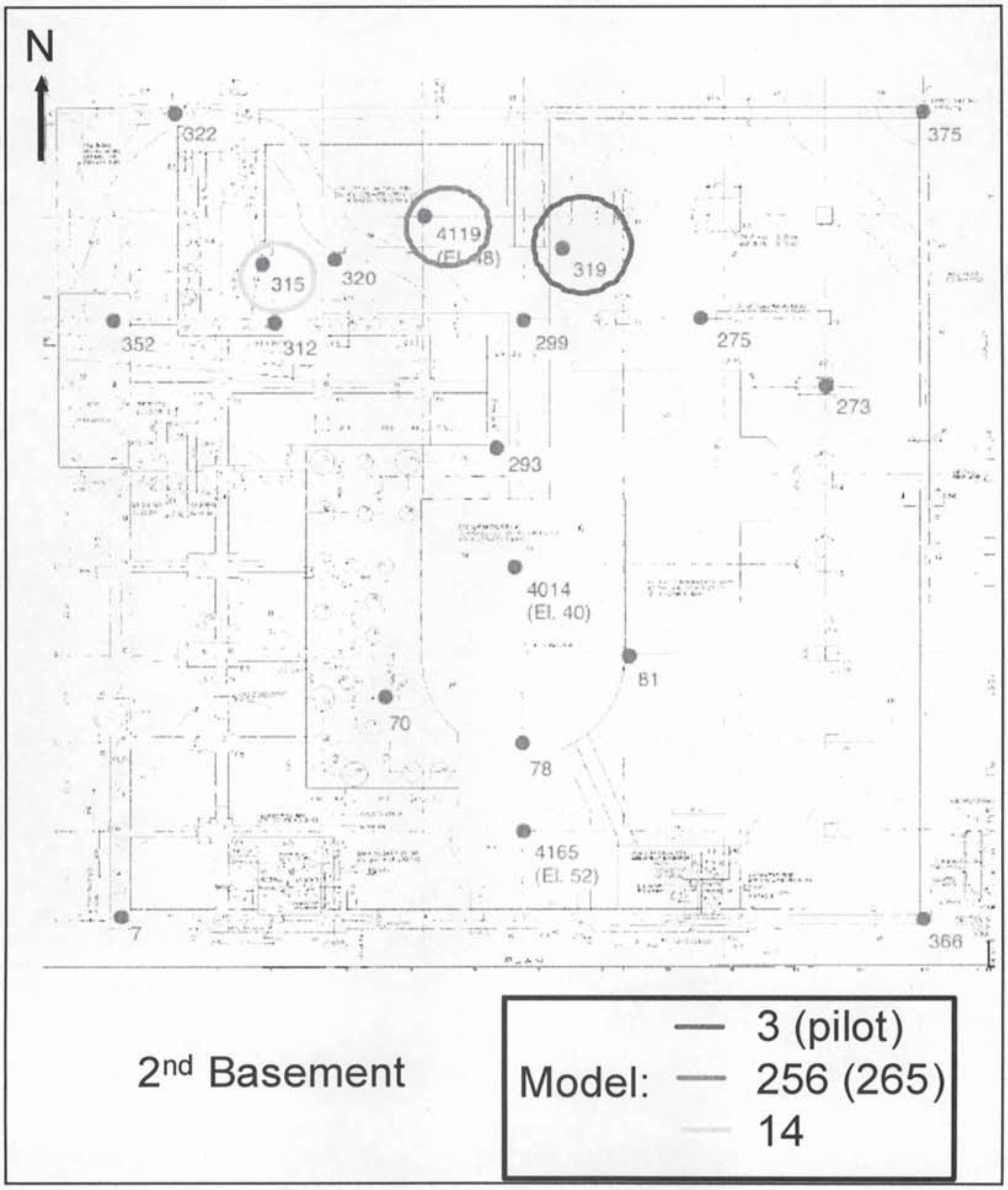


Figure 19 – Reprint of PSSI point selection locations shown on a planar view of the second basement.

As shown in Figures 16 through 19, PSSI points selected for each of the three PCS piping models are found on all three floor elevations. All points selected (or circled) correspond to points identified in Table 3.

Figures 20 through 27 illustrate bounding time history response spectra at the 80% non-exceedence accordance probability level corresponding to PSSI points selected of each PCS model and orthogonal direction. Figures 20 through 22 correlate to response spectra for PSSI points selected of the Pilot model in the E-W, N-S, and Vertical directions. Figures 23 and 24 shows the response spectra of points selected for all directions to Model 256 and Figures 25 through 27 illustrates response spectra for PSSI points selected for Model 14. All response spectra shown correlate to PSSI points selected for each PCS model, as listed in Table 3.

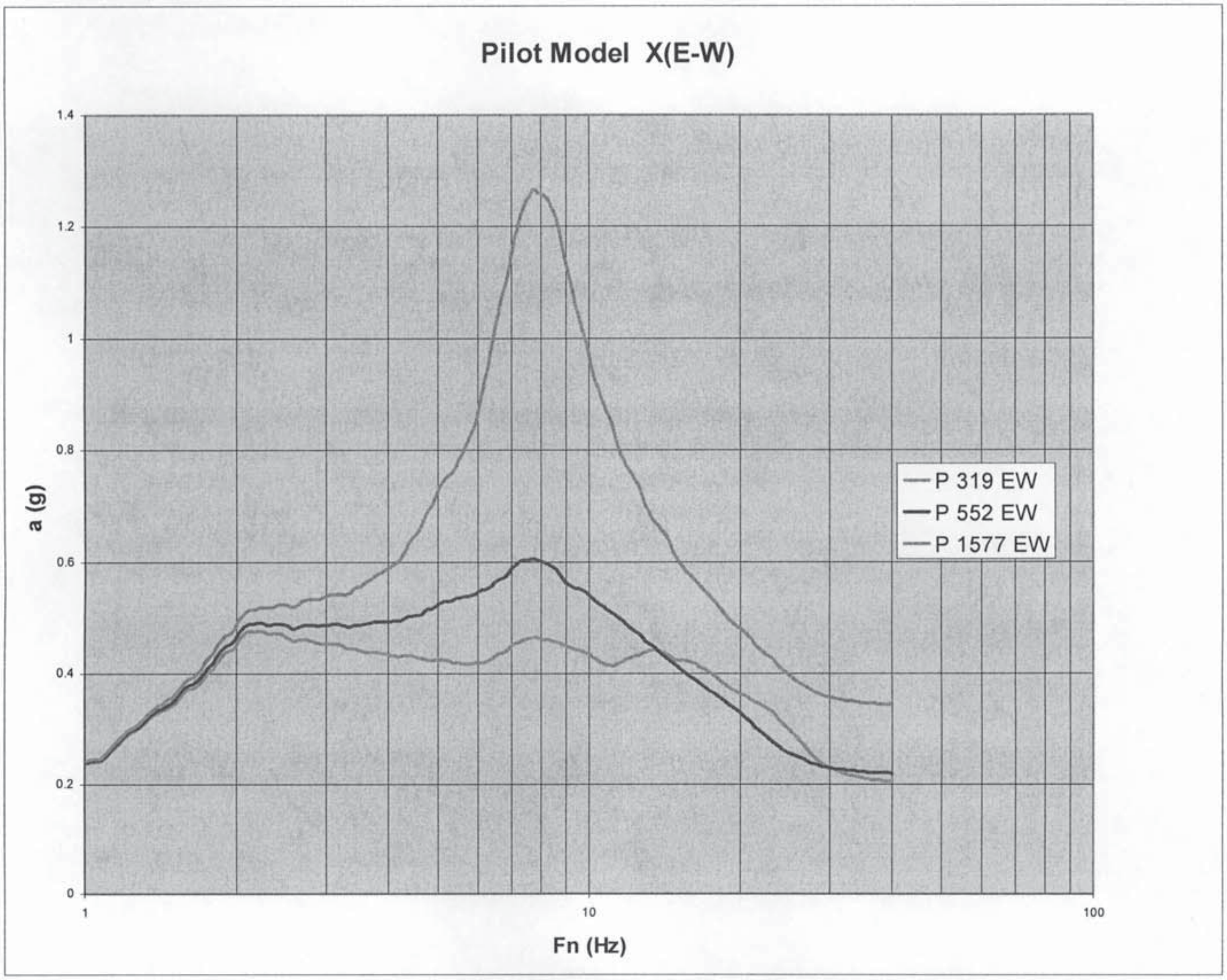


Figure 20 – Pilot model response spectra for PSSI point selected in E-W direction.

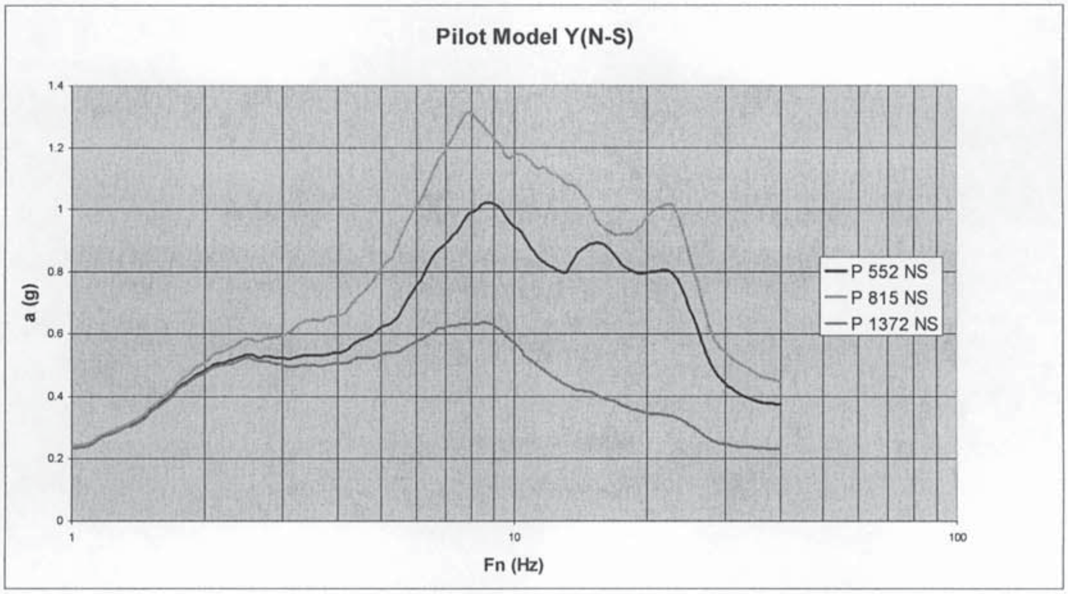


Figure 21 – Pilot model response spectra for PSSI point selected in N-S direction

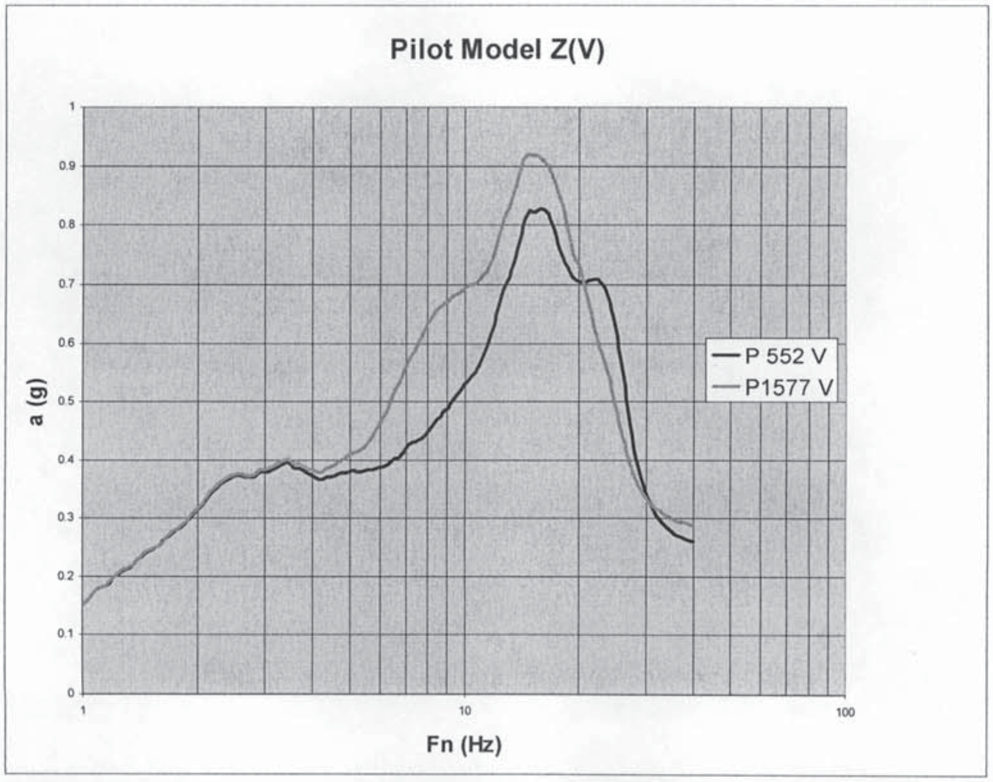


Figure 22 – Pilot model response spectra for PSSI point selected in Vertical direction

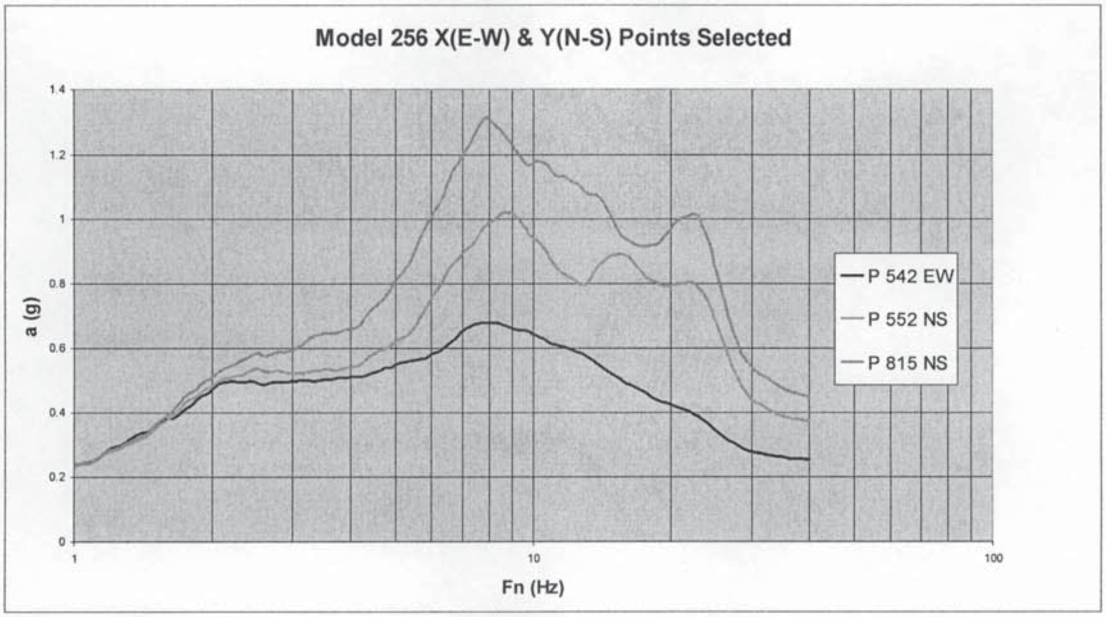


Figure 23 – Model 256 response spectra for PSSI point selected in EW and NS directions.

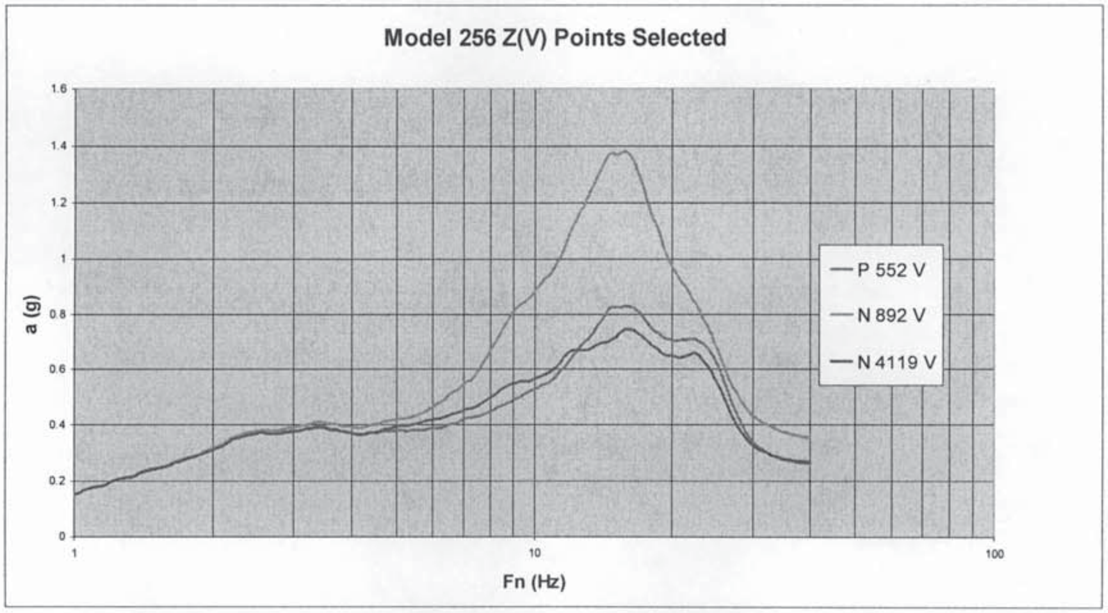


Figure 24 – Model 256 response spectra for PSSI point selected in Vertical direction.

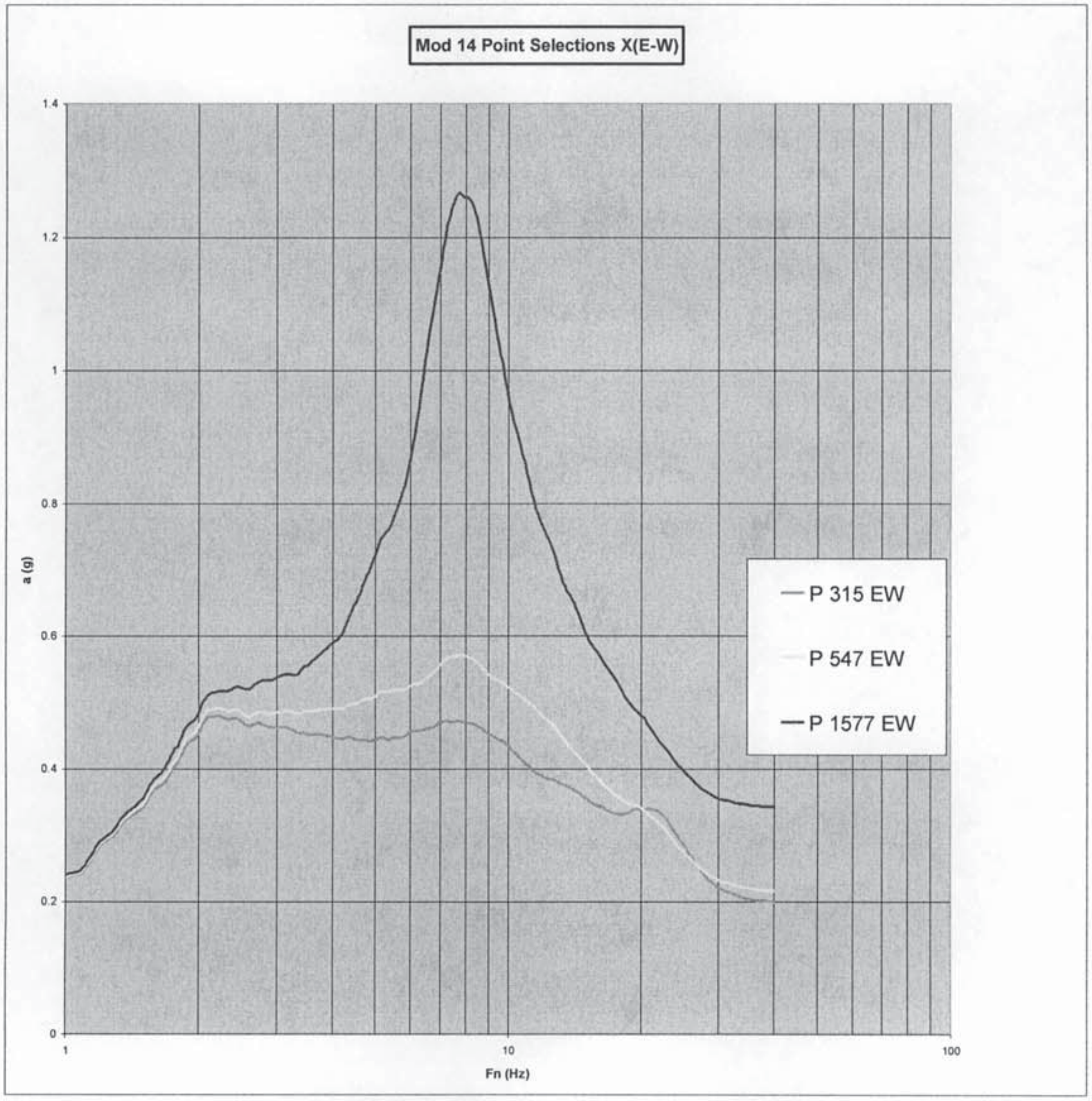


Figure 25 – Model 14 response spectra for PSSI points selected in E-W direction.

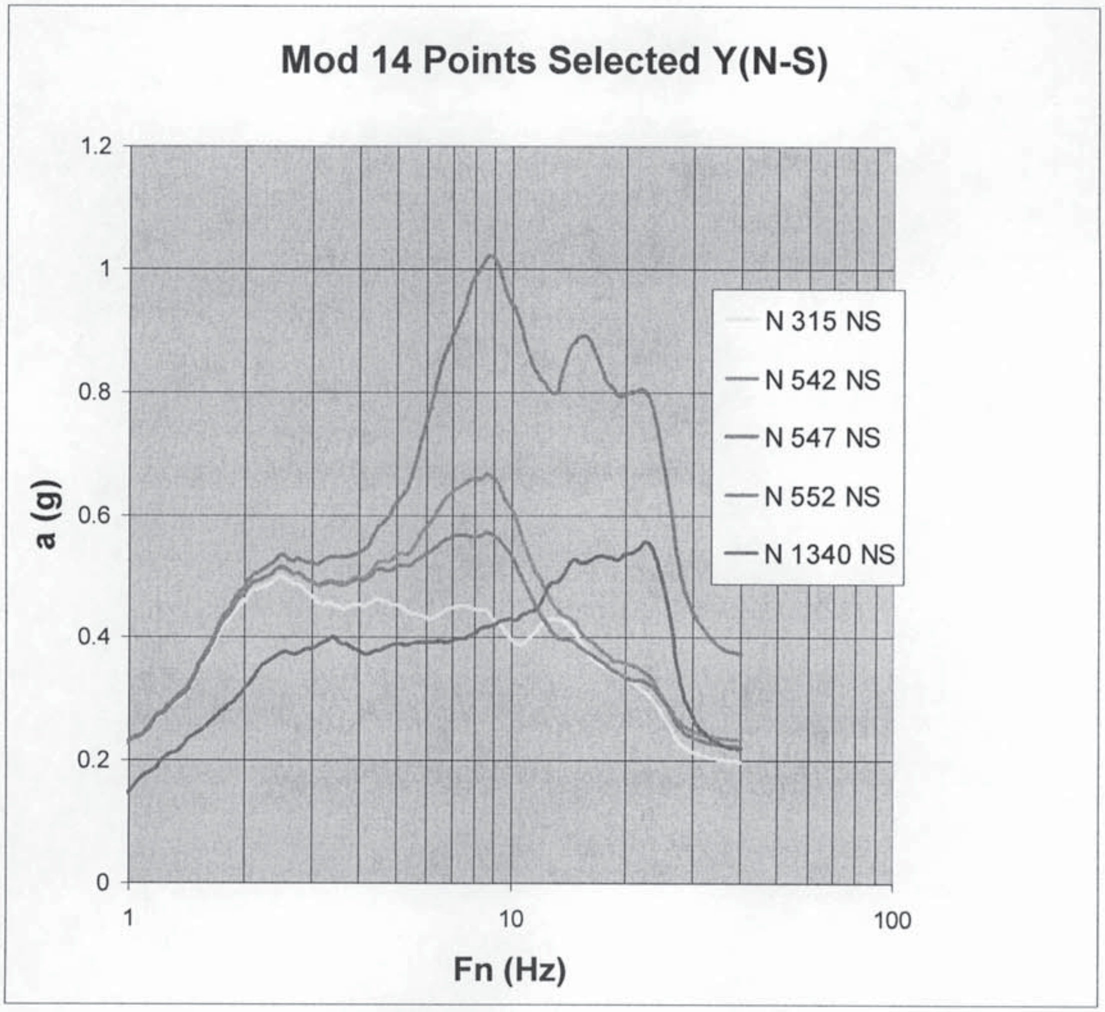


Figure 26 – Model 14 response spectra for PSSI points selected in N-W direction

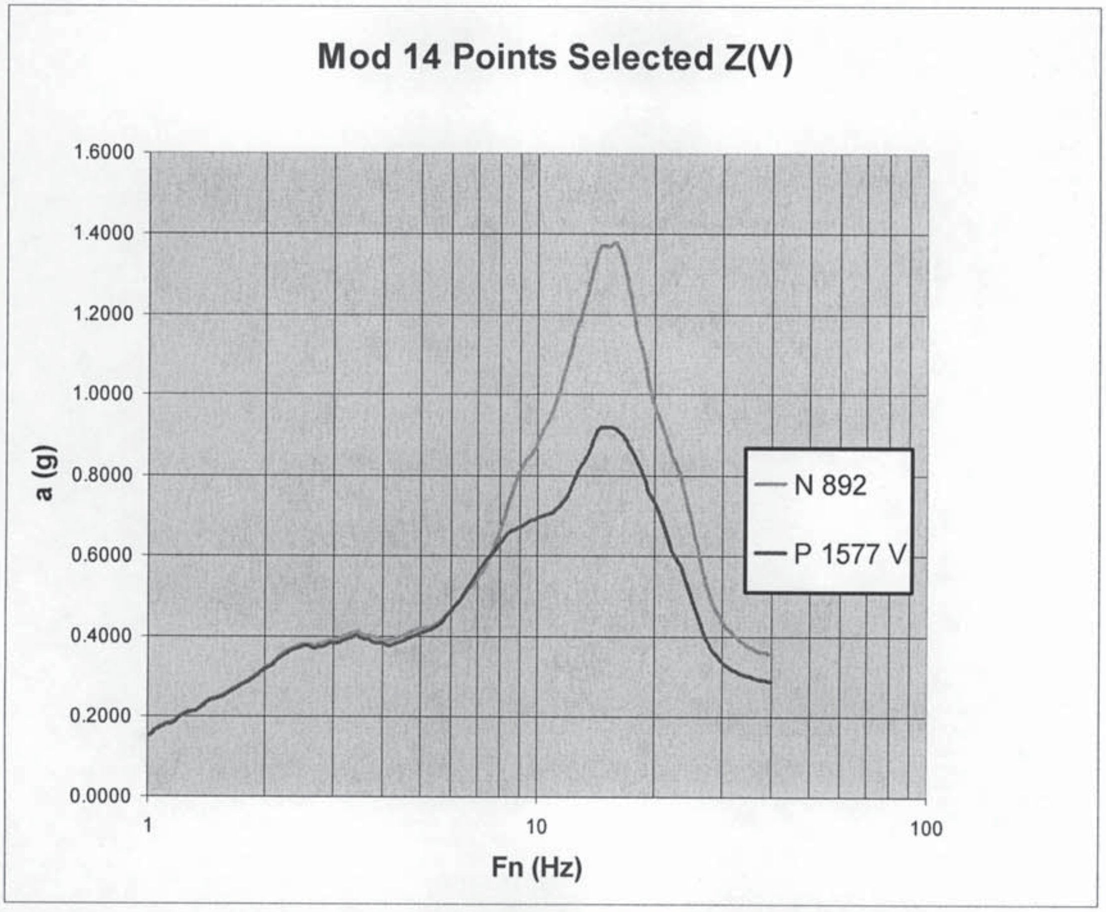


Figure 27 – Model 14 response spectra for PSSI points selected in Vertical direction

As indicated in Figure 18 and Table 3, PSSI point 552's time histories are utilized in every model. Point 552 is situated at the first basement elevation of the primary pumps and is also positioned near the main body of all PCS piping models. The primary pumps are each housed in heavy concrete structures, in which point 552 is located mid-way (East to West) between all four primary pumps. In this area, portions of all piping models are in close vicinity with each other.

Input Motion Conditioning

Every time history is re-sampled to a 0.005-sec input interval using a frequency based algorithm and drift corrected using a least squares approach. Processing of the time histories is detailed in Appendix A. Time histories are also truncated to a reduced time span. The truncation is based on review of the cumulative energy curves and the relative amplitude of the acceleration versus time. The cutoff is beyond the shoulder of the cumulative energy curve (i.e., where it has begun its asymptotic approach to its maximum value). The cutoff ensures inclusion of times of significant acceleration, velocity and displacement. The cutoff time has been established for enough of the time histories to be used to corroborate that it varies little among all of the time histories. This work is described in Appendix A.3.

Maximum demands for each component/support type in the models for each set of time histories is grouped and sorted, with the 26th highest value (or the 7th value down from the maximum) taken as the demand associated with the 80th percentile Non-Exceedence Probability (NEP) input. This demand is used in calculating the demand to capacity ratio.

Demand caused by seismic anchor motions is inherent in the response of the piping systems to the various time history motions applied to them. Further consideration of seismic anchor motion is not necessary.

Load Combinations

Load combinations are per DOE-STD-1020-2002 [25]. Nonseismic loads (weight and/or thermal expansion) are combined directly with seismic loads. This is accomplished in the analysis by applying the weight load as an initial static step, followed by the dynamic seismic loads.

For piping components, ductility will preferably be addressed, if required, through the limit analysis provisions of Section II, Division 1, Appendix F, as discussed under "Capacities" above. Alternatively, F_μ values up to Limit State C (Project Direction) may be used. If this is done, the value needed to achieve a Demand to Capacity of 1.0 will be calculated, and reported with a comparison showing it to be less than the Limit State C value. A demonstration will be required that the performance of the subject component under these loads will not compromise the system analysis producing said loads.

Loads applied to the primary and emergency pump anchorage is obtained from each pump's two nozzle termination nodes. For example, the primary pumps are serviced by both Models 3 (pilot) and 256. The discharge pump nozzle serves as a termination point for the Pilot model. The suction pump nozzle serves as a termination point for Model 256. Each pump is a heavily constructed structure and assumed to be rigid, allowing each pump's anchorage to be evaluated without evaluating the pump itself. Thus each pump anchorage loading (forces and moments) is extracted from the two sets of model termination points and applied to each corresponding pump anchorage.

Assumptions

1. Unless specifically specified on respective drawings, all PCS piping, fittings, components and supports, are based on nominal dimensions.
2. All PCS piping, fittings, and components, are modeled with no corrosion effects. Recent and past piping thickness inspections have indicated that there is insignificant or no corrosion occurring on the PCS.
3. All fillet weld sizes correspond to the minimum thickness of the base members joined, unless designated differently on the drawings. This is standard engineering practice.
4. All of the valves in the PCS are manually operated with negligible eccentricities. Therefore, all valve mass has been modeled at the pipe centerline.
5. Lap joint flange stress indices are approximated to as-welded girth weld stress intensities, as justified by INL analysis EDF-TRTSB-ATR-061 [23].
6. Dimensions of PCS piping, fittings, components, and supports not supplied by their respective drawings, were scaled from pictures.
7. All piping tee components not specified as a W-Tee on their respective drawing, were treated and modeled as pipe branches.
8. PCS Pump heavy structures are considered to be rigid.

Computer Code Validation

Four computer software codes were used throughout the entire PCS piping analysis and four computers (using all four software codes) were used to complete the PCS piping analysis.

Two software codes were used to create and solve FE models. The IDEAS Simulation software [18] was used as a FE pre-processor to generate solid models and associated FE piping beam and unlisted component shell and solid meshes. Associative boundary conditions were applied to these IDEAS meshes and then transmitted to a text editor for editing of software commands, and then read into ABAQUS Standard, Version 6.7-5 [16]. ABAQUS Standard verified the IDEAS meshes, performed the solution runs, and generated post-processing results for each PCS model. ABAQUS Standard and Explicit, version 6.7-5 has been verified following company procedures and documented in ECAR-202 [24]. A scanned image of the verification's ECAR title and signature page is provided in Appendix A.

Calculations were also done using Microsoft Excel software [20] and the MathSoft Mathcad software [19] on a variety of platforms. This analysis software can be independently verified by visual inspection or hand calculation during the checking process. Such inspections and calculations have been done for the software by the technical checkers of this ECAR.

The four computers utilized in this ECAR are:

1. Dell Precision 690 workstation, which has 4 CPUs, 8 GB RAM, and runs on dual Linex and Windows platforms.
2. Dell Precision 490 workstation, which has 4 CPUs, 3 GB RAM, and runs on dual Linex and Windows platforms.

3. Dell Precision T5400, which has 8 CPUs, 8 GB RAM, and runs on dual Linex and Windows platforms.

4. Dell Precision M20 Laptop, which has 1 CPU, 1 GB RAM, and runs on Windows platform.

Calculations

The work flow of the majority of effort of this ECAR is identified within Table 4. Table 4 lists steps to a simplified approach for describing how a single PCS model is evaluated. Thus, this approach is repeated until all of the three PCS models have been evaluated.

Table 4 – Step-by-step iterative approach to evaluate each PCS model (using the Pilot as an example.)

Steps	Description (Notes)	ECAR Section Documentation
1	Select a PCS model to evaluate. The pilot (or Model 3) is evaluated first, followed by Model 256, and Model 14 last.	Report Main Body
2	a. Create a preliminary linear piping beam model (using IDEAS software) utilizing all necessary drawings and point location time histories for model input. b. While creating preliminary beam model, identify all unlisted or field-fabricated piping components. c. Model preliminary linear beam model's unlisted and field-fabricated components with listed (or standard) components within I-DEAS beam model.	Appendix B (Pilot Model)
3	Perform following items in parallel with step 2 a. Identify selected model location PSSI point time history sets and develop damping curves for selected model application. b. Start creation of IDEAS solids and FE meshes of identified unlisted and field-fabricated components	a: Appendix A (Common Items) b: Appendix F (Unlisted Components)
4	a. Transmit IDEAS piping or beam model to text editor and modify line commands so that they may be read and solved by ABAQUS Standard. b. Perform 32 ABAQUS Standard "preliminary" time history solution realizations for selected PCS model. c. Complete IDEAS solids and FE meshes of identified unlisted and field-fabricated components associated with selected PCS model.	a & b: Appendix B (Pilot Model) c: Appendix F (Unlisted Components)

5	a. Transmit ABAQUS preliminary solution results using automated analysis tools to Mathcad to sort through results to identify the 80th percentile results. b. Using Mathcad and Excel, perform a cursory D/C review to identify potential piping or support concerns. c. Provide preliminary moment reactions from listed components used to represent unlisted components.	a & b: Appendix B (Pilot Model) c: Appendix F (Unlisted Components)
6	Perform tasks in conjunction and parallel to step 5. a. Apply preliminary moment reactions to IDEAS unlisted and field-fabricated component FE meshes and prepare for component characteristic solution runs. b. Transmit I-DEAS unlisted and field-fabricated FE meshes, with preliminary boundary conditions, to text editor and modify line commands so that they may be read into ABAQUS Standard. c. Perform approximately 14 to 20 ABAQUS Standard solution runs (depending on PCS model) and obtain deflection and maximum tresca stresses characteristic data for each of the unlisted and field-fabricated components. d. Transmit component results to Mathcad and determine flexibility factors (FF) and stress indices (SI) of each component. The FF is used to determine component ductility by calculating effective moment of inertias. SI is used to evaluate the components' acceptance to code, using linear methods. 1. If D/C ratios are significantly over unity, then plastic material analysis is performed to evaluate identified component and determine appropriate characteristic data.	Appendix F (Unlisted Components)
7	a. Adjust IDEAS piping beam model to account for unlisted and field-fabricated components with true FF and effective moment of inertias, thus elimination preliminary listed (or standard) components b. Rerun 32 ABAQUS Standard solution realizations and transmit results to Mathcad for 80th percentile load determination and piping and support D/C values. (This 2nd updated solutions reflect realistic piping, components and support D/C values, for FF and SI data of the unlisted components are included in the realizations and reflects the most realistic condition of the existing piping system arrangement).	Appendix B (Pilot Model)

8	a. Evaluated 2nd model solutions runs and D/C results to determine next step. b. If 2nd model adheres to acceptance code, the next IDEAS piping beam model is started. If some items are slightly over unity, refinement calculations or justifications are determined, while Model 256 I-DEAS piping beam model is created. c. If selective components significantly exceed unity, the PCS team scrutinizes the results, proposes a recommended model arrangement (added reinforcement or removal of selected components, etc.) and a 3rd PCS piping model is rerun on ABAQUS and re-evaluated for acceptance.	Appendix B (Pilot Model)
9	a. Technically check selected PCS model calculations and results. PCS piping conclusions and recommendations, along with D/C results, are documented in appropriate report sections. b. Repeat steps 2 through 9, till all three PCS models completed.	Report Main Body Appendix B (Pilot Model)

The ECAR report format correlates with the work-flow evaluation of the PCS.

Appendix A defines common items that are used throughout every PCS model evaluation. It includes:

a. Analysis plan
b. PCS model PSSI point selections
c. Time history and damping curve development
d. ABAQUS Standard verification
e. Overview discussion on the D/C ratio calculation
f. Elbow-element sensitivity calculations.

Appendix B creates piping beam models and evaluates the PCS pilot model. It includes:

a. Evaluated PCS support capacities that have not been previously determined in past analyses

b. Creates piping beam model

c. Performs solution runs

d. Determines D/C results in which evaluation of the pilot model takes place.

Appendix C creates piping beam models and evaluates the PCS Model 256. Appendix D creates piping beam models and evaluates the PCS Model 14. Appendixes C and D (Models 256 and 14) follow similar format of Appendix B.

Appendix E evaluates the anchorage for the PCS pumps and miscellaneous calculations. It includes:

a. Evaluate four primary and two emergency pumps, by combining nozzle reactions from all interfacing PCS models.

b. Perform miscellaneous calculations and evaluates supports PR-1 and PR-2 and the branch joint between lines 1-27 and 1-42.

   1. Supports PR-1 and PR-2 share the same anchorage and their load input is retrieved from Models 3 and 14 solution response.

   2. Load inputs for piping branch joint between 1-27 and 1-42 lines, are also obtained from Models 3 and 14 solution responses.

Appendix F identifies and evaluates all PCS model's unlisted components.

a. Creates break-out FE models of unlisted and field fabrication components for each PCS beam model

b. Using preliminary (or first set of 32 realization) results, determines flexibility factors (FF) and stress indices (SI) of unlisted and field-fabricated component for each PCS model. FF and SI values applied for 2nd set of solution realizations.

c. Evaluates each of the PCS model's unlisted and field-fabricated components for linear acceptance. If required, performs and evaluates plastic material analysis of unlisted and field-fabricated components which do not adhere to traditional acceptance methods and correlates flexibility factor data back to the linear piping model.

d. Correlation between plastic component analysis results and those of the corresponding portions of the linear beam model is as follows.

   1. The shell model used to determine flexibility factors for the unlisted component includes plastic material properties and large displacement effects. A corresponding beam model is created by extracting the portion of the linear elastic system model corresponding to the shell model. Both models are subjected to rotations consistent with the 80th percentile results, with resulting rotations compared to determine if acceptable correlation (within 20%) still exists.

Appendix G identifies the Independent Peer Reviewer's comments on this analysis and the authors' resolutions.

Conclusions and Recommendations

Evaluation of the three PCS piping models indicate that the majority of the ATR PCS piping and supports meet their acceptance criteria based on the results of the elastic analysis. D/C ratio's for the piping components are generally low, despite a number of unlisted components that appear to be challenged when analyzed with standard elastic methods. These components are shown to be acceptable with generous margin when plastically analyzed.

Table 5 below lists bounding D/C ratio's for the flanges attaching piping to the major PCS components. The low values are representative of typical piping components.

Table 5 – Results for flanged joints in proximity to the major PCS equipment.

Area	PCS Model [ID]	Elastic D/C
Reactor Outlet	14 [RV(1-4L)]	0.61
Heat Exchanger Inlet	14 [FL(1-12)]	0.22
Heat Exchanger Outlet	256 [FL(1-24A)]	0.13
Primary Coolant Pump Inlet	256 [(FL(1-19C)]	0.35
Primary Coolant Pump Outlet	3 [FL(1-25A)]	0.25
Reactor Inlet	3 [RV(1-28)]	0.27
Emergency Coolant Pump Inlet	256 [(FL(1-30E)]	0.20
Emergency Coolant Pump Outlet	3 [FL(1-33A)]	0.22

Table 6 lists the components which have been plastically analyzed. They generally have the highest elastic D/C ratios (no accident), but have much lower D/C ratio's based on the results of the plastic analysis. Figures 28 through 30 below are plots of the membrane plastic strain field developed during the earthquake for the components. Note the low magnitude of strain, and the very limited region in which plastic strain occurred. See Appendix F for details of the plastic analyses.

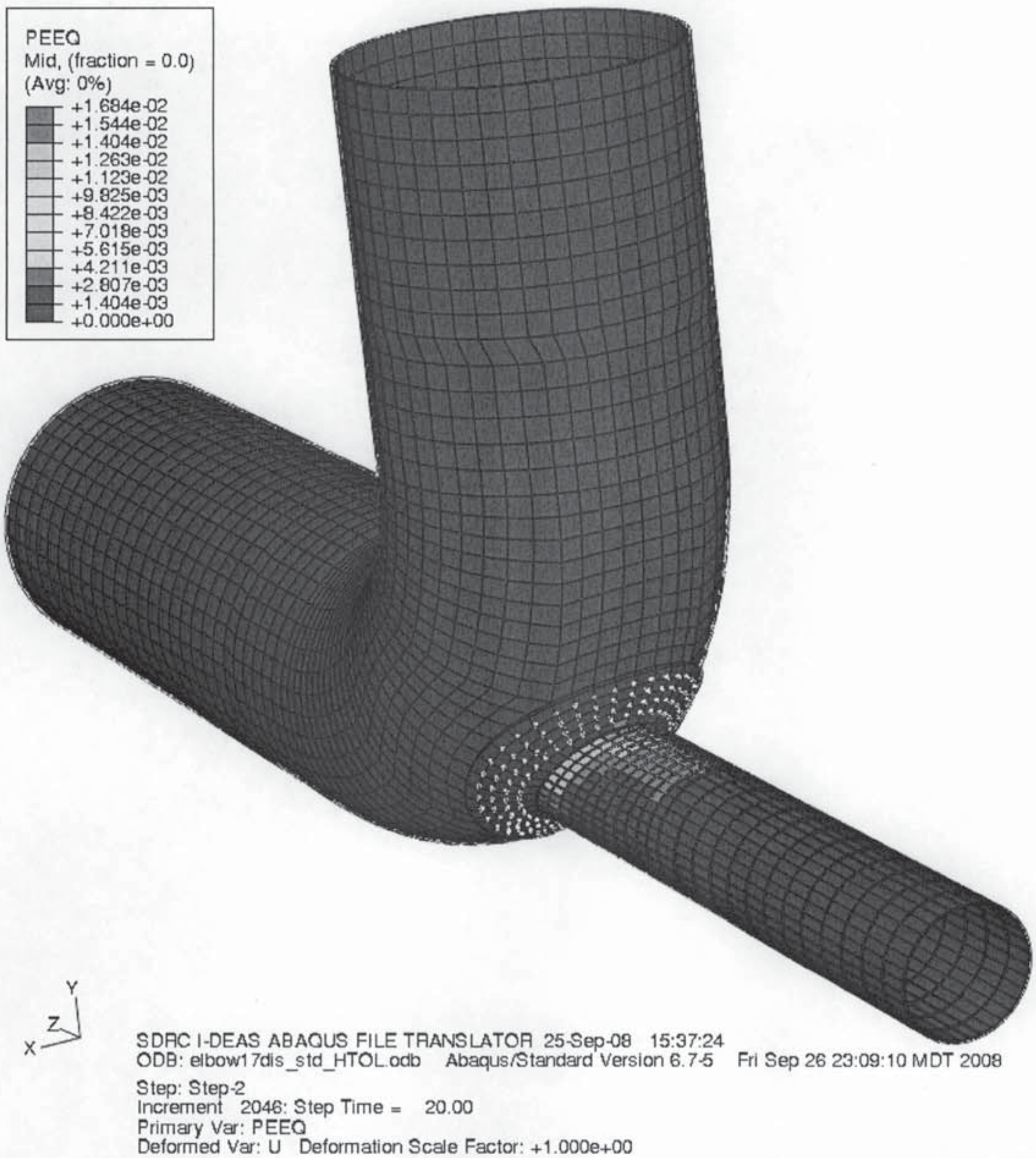
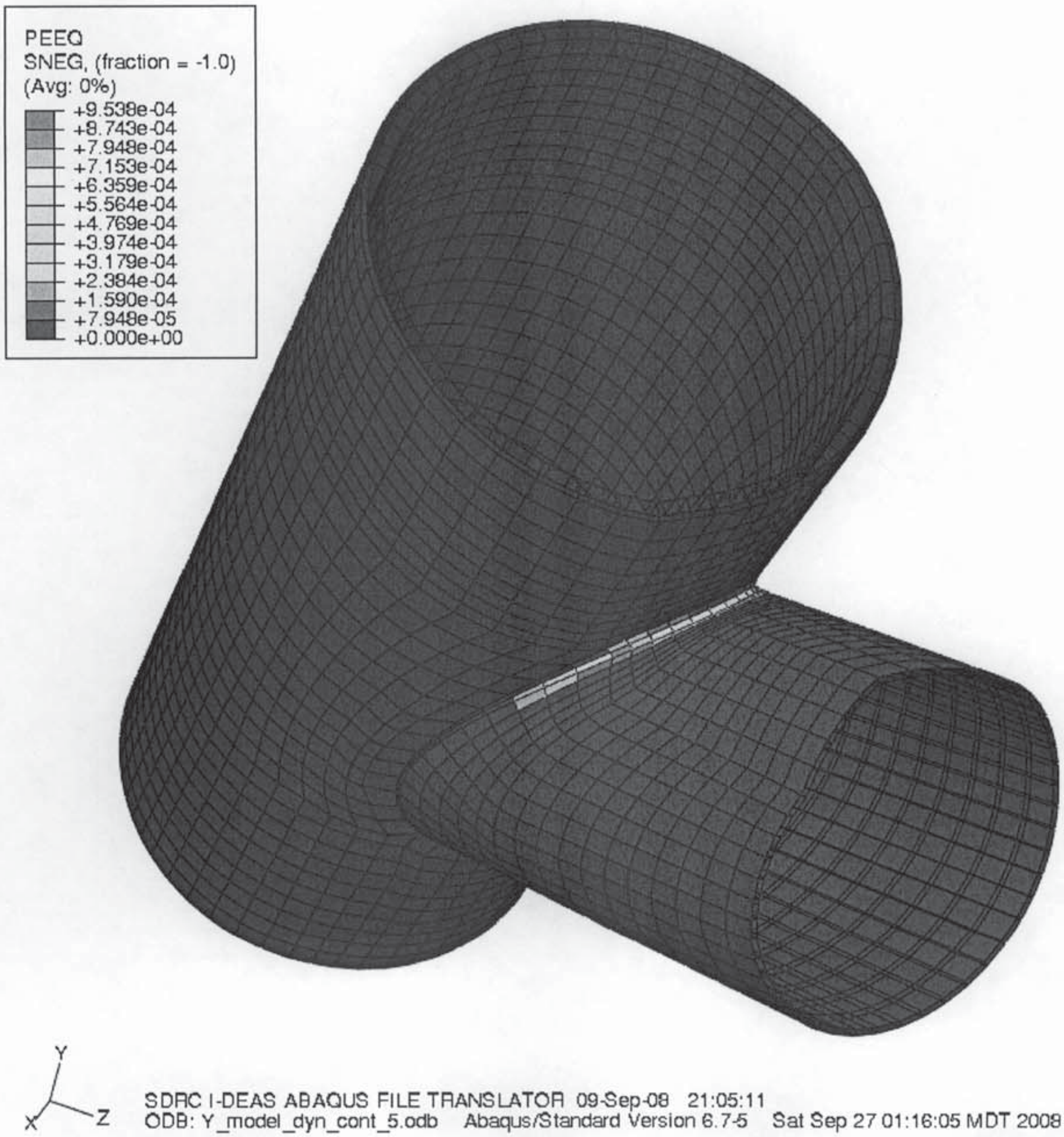


Figure 28 -Plastic equivalent strain shown in the 36-in elbow with a 14-in branch located in the pilot model.



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Step: Step-2
Increment 4000: Step Time = 20.00
Primary Var: PEEQ
Deformed Var: U Deformation Scale Factor: +1.000e+00

Figure 29 – Plastic equivalent strain shown in the Wye located in Model 14.

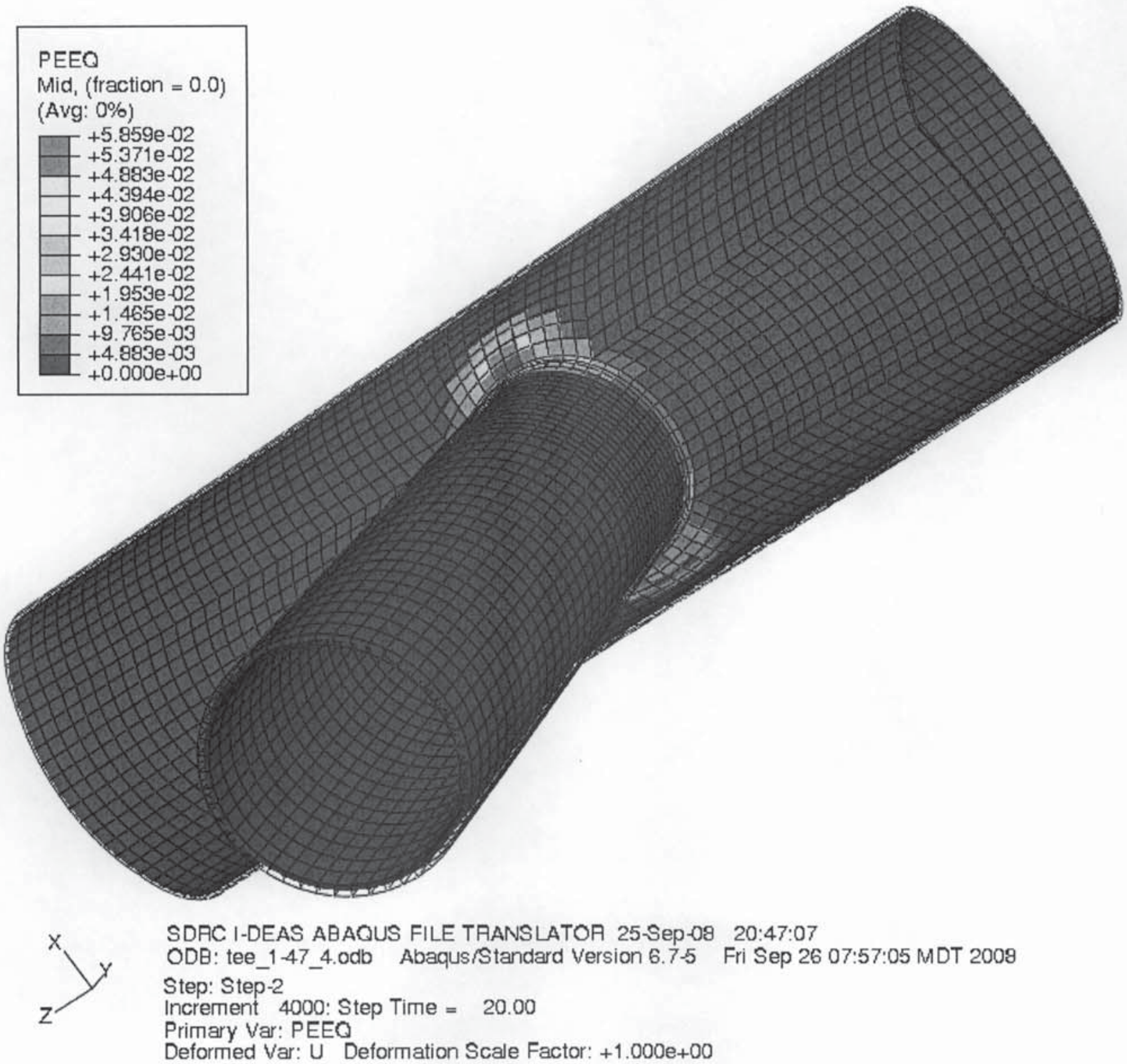

Figure 30 – Plastic equivalent strain shown in the 10-in by 6-in branch located in Model 256.

Table 6 – Plastic analysis results

Piping Component	PCS Model [ID]	D/C		Flexibility Factor Comparison
		Elastic	Plastic	Beam/Plastic Model Graphs
24-in X 18-in 45° Branch	14 [FAB_BR(1-2L, -3L)]	1.44	0.23	See page F-425
10-in X 6-in Branch	256 [T(1-47)]	1.94	0.49	See page F-473
36-in Elbow with 14-in Branch	3 [FAB BRANCH(1-27)]	2.15	0.14	See page F-70
16-in Elbow with 10-in Branch	256 [FAB BRANCH(1-30)]	0.93	0.01	See page F-217

Table 7 identifies the unlisted components lacking explicit plastic analysis, and listed components with D/C ratios in excess of 1.0 (Note that all of the components with D/C ratios above 1.0 are in piping beyond the hydraulic boundary). Unlisted components in the Table can not be qualified with the elastic analysis because they lack the shell analysis necessary to establish Code Stress Indices. The elastic D/C ratio is calculated using a Demand based on similarity between the unlisted and listed components. This aids in the comparison to the components qualified by plastic analysis. This comparison involves geometric similarity and significant bounds on loading.

Table 7 – Components qualified by comparison to those qualified by plastic analysis.

Piping Component	PCS Model [ID]	Elastic D/C	Comments
30-in X 20-in Branch	14 [T(1-10)]	0.71	Unlisted. Enveloped by the 10-in X 6-in Branch and the 24-in X 18-in 45° Branch.
30-in X 20-in Branch	14 [T(1-11)]	0.76	
30-in X 20-in Branch	14 [T(1-12)]	0.70	
2-in Termination	14 [(1-37)]	1.25	Pressurizing Pump nozzle
2-in Termination	14 [(1-38)]	1.15	
6-in X 4-in Branch	14 [T(1-77)]	1.10	Unlisted. Enveloped by the 10-in X 6-in Branch.
30-in X 20-in Branch	14 [T(1-9)]	0.73	Unlisted. Enveloped by the 10-in X 6-in Branch and the 24-in X 18-in 45° Branch.
16-in Elbow with 10-in Branch	256 [Fab Branch (1-30)]	0.82	Unlisted. Enveloped by the 36-in Elbow with 14-in Branch
30-in X 20-in Branch	256 [T(1-13)]	0.42	Unlisted. Enveloped by the 10-in X 6-in Branch and the 24-in X 18-in 45° Branch.
30-in X 20-in Branch	256 [T(1-14)]	0.43	
30-in X 20-in Branch	256 [T(1-15)]	0.39	
30-in X 20-in Branch	256 [T(1-16)]	0.45	
30-in X 24-in Branch	256 [T(1-18)]	0.39	
30-in X 24-in Branch	256 [T(1-19)]	0.42	

Piping Component	PCS Model [ID]	Elastic D/C	Comments
30-in X 24-in Branch	256 [T(1-20)]	0.37	
30-in X 24-in Branch	256 [T(1-21)]	0.39	
30-in X 16-in Branch	256 [T(1-30)]	0.84	
16-in X 16-in Branch	256 [T(1-31)]	0.60	Unlisted. Enveloped by the 10-in X 6-in Branch and the 24-in X 18-in 45° Branch.
36-in X 20-in Branch	3 [FAB(1-23)]	0.38	
36-in X 20-in Branch	3 [FAB(1-24)]	0.40	

The maximum pump anchorage D/C ratio was 0.59, less than 1.0 (See Appendix E.3).

Table 8 lists all pipe supports with an elastic D/C ratio greater than 1.0, and identifies their dispositions. Table 9 summarized the application of Inelastic Energy Absorption Factors done per SEI/ASCE 43-05 [13] provisions.

Table 8 – Disposition of Pipe Supports with elastic D/C ratios > 1.0. .

Support ID [PCS Model]	Elastic D/C	Disposition
MS-1 [14]	1.20	Upgrade the support (See Table 10).
PR-2A [14]	1.81	These supports are analyzed in more detail in Appendix E.4, where loads for upgrade are established (See Table 10).). Upgrade of this support is recommended.
PR-2D [14]	1.78	
PS-19 [14]	2.13	Upgrade the support (See Table 10).
PS-20A [14]	1.27	Use Inelastic Energy Absorption Factors (Table 9).
PS-7 [14] [256]	1.11	This support is analyzed in more detail in Appendix E.9, where loads for upgrade are reported (See Table 10). Upgrade of this support is recommended.
PS-8H [14]	1.05	This pipe stanchion is 39-in from an HX nozzle (Dwg. 127008). Transferring 105% of its 14.7 kip capacity (Pg. D.4-9) to the HX nozzle generates 573 kip-in. Adding this to the 664 kip-in maximum demand on the nozzle (Pg. D.4-63) raises the D/C ratio to 0.43, still < 1.0. The support is OK.
RH-21xB [14]	1.14	DC ratio was based on an apportioned anchorage capacity between supports RH-21xB and RH-26. When the combined loads were considered, DC = 0.94 (pg. E.8-2). Support is OK.
TB1 [14]	3.0	Upgrade the support (See Table 10).
TB2 [14]	2.55	Upgrade the support (See Table 10).
WTS [14]	2.89	Upgrade the support (See Table 10).
Tunnel Res [14]	2.01	Upgrade the support (See Table 10).
RH-19 [256]	1.97	Upgrade the support (See Table 10).
RH-25B [256]	1.06	Use Inelastic Energy Absorption Factors (Table 9).
U-Bolt North[256]	1.26	Upgrade the support (See Table 10).
PR-1(East) [3]	2.05	These supports are analyzed in more detail in Appendix E.4, where loads for upgrade are established (See Table 10). Upgrade of this support is recommended.
PR-1(West) [3]	1.57	

Table 9 – PCS supports qualified by application of Inelastic Energy Absorption Factors.

Support [Model ID]	Fμ for D/C = 1.0	Ductile Capacity / non ductile Capacity	Comments
PS-20A [14]	1.26	2.06	The ductility factor is close enough to the 1.25 limit that load redistribution need not be considered.
RH-25B [14]	1.06	1.09	Doesn't meet 1.25 Margin of ductile Capacity against non ductile Capacity, but non ductile capacity exceeds elastic demand, and overload is slight.

Table 10 identifies supports that need to be upgraded. Design loads are provided for the upgrades. Note that a positive load is applied to the support in the indicated direction.

Table 10 – Loads for pipe design upgrades.

Support [Model ID]	Line #	Load Direction	Capacity Type	80th Percentile Loading (kips)
PR-2A [14]	1-1L	E(Z)	TEN	5.8[1]
	1-1L	W(-Z)	COM	4.4
PR-2D [14]	1-4L	E(Z)	COM	5.4
	1-4L	W(-Z)	TEN	5.7
PR-1 (West) [3]	1-28	E (Z)	TEN	5
	1-28	W (-Z)	COM	4.9
PR-1 (East) [3]	1-29	E (Z)	TEN	6.5
	1-29	W (-Z)	COM	6.3
MS-1 [14]	1-7	Up-South	TEN	31.5
	1-7	Down-North	COM	36.8
Tunnel Restraint [14]	1-27	W (-Y)	NA	16.9
	1-27	E (Y)	NA	12.6
TB2 [14]	1-39	E(Z)	COM	1.2

[1] Loads that drive the upgrade are highlighted.

Support [Model ID]	Line #	Load Direction	Capacity Type	80th Percentile Loading (kips)
	1-39	W(-Z)	TEN	2.0
	1-39	V(Y)	FLEXURE	2.5
TB1 [14]	1-41	NS(X)	FLEXURE	2.8
	1-41	E(Z)	COM	1.2
	1-41	W(-Z)	TEN	1.1
PS-19 [14]	1-42	N(X)	COM	1.5
	1-42	S(-X)	TEN	1.4
	1-42	V(Y)	FLEXURE	1.2
PS-7 [14]	1-41	V(Y)	FLEXURE	2.5
	1-41	V(-Y)	FLEXURE	1.8
	1-41	N(X)	TEN	1.2
	1-41	S(-X)	COM	1.7
PS-7[256]	1-44	V(Y)	FLEXURE	0
	1-44	V(-Y)	FLEXURE	4
	1-44	N(X)	TEN	1.2
	1-44	S(-X)	COM	1.2
WTS [14]	1-77	V(Y)	TEN	1.7

A number of supports were not credited with any load capacity in the analysis. These supports, listed in Table 11, need to be removed. The hold-down supports (PR-6's, -7 and -8) will not significantly affect the performance of the piping during an earthquake and may be left installed.

Table 11 – Supports that need to be removed.

Support [Model ID]	Support [Model ID]
MS-4	AIS [256]
MS-5	AIWS [256]
MS-6	RH-22A [256]
MS-7	RH-22B [256]
MS-8	RH-30 [256]
RH-16C [14]	RH-32 [256]

The piping and supports of the ATR PCS will meet the requirements of NB-3600 of Section III of the ASME Code [9], and will maintain an intact pressure boundary during and after a PC-4 earthquake, provided the listed upgrades are completed.

It should be noted that some of the photographs that are used within this report have the words "Official Use Only" or "OUO" printed on them. These photographs were obtained from previous analyses [3 and 5] that at the time of their issue were OUO. Since that time, they have been down graded such that they are no longer OUO, but a few still reside in this report. Therefore, all OUO photographs that may be viewed within this report, are no longer OUO and are acceptable for viewing without changing the stated wording on the photographs.

PE Stamp

References

Each of the six Appendixes (A through F) have their own independent reference sections,

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2. Carl J. Costantino and Associates, "Probabilistic Soil-Structure Interaction Analysis of TRA-670", CJC-INC-C-003, Revision 0, November 2007.

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18. I-DEAS Simulation, Electronic Data Systems, Maryland Heights, MO.

19. Parametric Technology Corporation, MATHCAD Calculation software.

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23. Edition, Chicago, IL, 2005.

24. EDF-TRTSB-ATR-081, "Stress Analysis of ATR Primary Coolant Pump Discharge Piping," Revision 0, September, 1983.

25. ECAR-202. "Software Validation Report for the ABAQUS/Sandand and ABAQUS/Explicit Version 6.7-5," Revision 0, May, 2008.

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Revision ID: 0
Effective Date: 9/30/2008

Engineering Calculations and Analysis Report

ATR Primary Coolant System Piping Seismic Evaluation

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Volume 1 of 5

Report Main Body, Appendix A, Appendix G

Idaho National Laboratory

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Appendix A

Common Items Applicable to All Piping Models

Contents

Appendix A.1
Analysis Plan

Background

The analysis of record for the Advanced Test Reactor (ATR) Primary Coolant System (PCS) is outdated. It was originally performed in 1975 and revised in 1979 [1]. In-structure response spectra and time history information has been recently updated for the ATR to include the latest knowledge of site-specific seismic behavior [2]. This information will allow the PCS to be reevaluated using modern methods and data.

Task Description

A multi-step approach will be used. The analysis includes the following subtasks:

- Develop piping models
- Develop tools to automate piping analysis
- Perform piping analyses
- Evaluate piping components and supports
- Perform additional analyses for elements not qualified with standard methods (if required)
- Recommend modifications that may be required to meet the acceptance criteria.

Criteria

Piping components and supports are considered acceptable if the demand to capacity ratio as described below is less than 1.0.

Capacities

Criteria for capacities are based on ASCE/SEI 43-05 [3]. Piping component capacities are established using ASME III NB-3600 [18], consistent with the provisions of ASCE/SEI 43-05.

When the elastically calculated D/C > 1.0, the capacities of components may be established by a plastic analysis as described in NB-3213.24 of ASME III. Component capacities will be determined by applying limits upon inelastically computed stress in accordance with F-1341.2. This approach is preferred to the application of ductility factors described under "Loads and Load Combinations" below. F-1322.1 will be applied in determining if the system analysis needs adjustment. It is expected that component plastic response will typically be localized and will not significantly affect the system behavior, but this judgment will be made case by case.

The criteria selected for the pipe support capacities are the strength provisions of the AISC Steel Construction Manual, 13 Edition [4], also consistent with ASCE/SEI 43-05. Capacities for structural concrete embedments are based on Appendix B of ACI 349 [5]. Snubber capacities are based on vendor rated loads. Sample support capacities have been previously calculated [6].

Modeling

Moment and force demands are calculated using a nonlinear large displacement implicit ABAQUS [7] beam analysis. Straight pipe is modeled with B31 beam elements, elbows with B22 beam. Elastic material properties are modeled. Nonlinearities associated with gaps, buckling and uplift effects in the supports are modeled using nonlinear springs. This modeling will be described in detail in the documentation. Equipment nozzles are modeled as anchor points, with the restraint time histories extracted for later analysis of the equipment and their supports.

The models of the piping are established using flexibility factors and stress indices from ASME III, NB-3600. Similarity between listed and unlisted components will be used to establish factors and indices where reasonable (e.g., slip-on flanges for lap joint flanges). Factors and indices for the remaining components will be generated using finite element analysis. Pressure stiffening of elbows is included.

Modeling complies to the provisions of ASME III, Appendix N, consistent with ASCE/SEI 43-05.

Model geometry is based on the drawings and specifications used in their construction (See Tables A-1.2 and A.1-3), and on an extensive walkdown of the piping and supports [8].

The models are constructed using the I-Deas software [9]. Post-processing of the ABAQUS analysis results is done with the MATHCAD software [10].

Computer Code Validation

Computer codes will be validated as required by the INL procedures governing analysis work [15].

Mass Distribution

In order to ensure an adequate mass distribution of the piping models, maximum element lengths were imposed as listed in Table A.1-1 below. These values are based on the mass point spacing limitations of the NUPIPE-II software [14], piping analysis software widely used in the analysis of nuclear piping at INL. The spacing was modified to reflect the beam model used in ABAQUS.

Table A-1.1 Maximum Pipe Lengths

Diameter (in)	Thickness (in)	Length (ft)	Diameter (in)	Thickness (in)	Length (ft)
2.375	0.154	1.8	18	0.312	4.2
4.500	0.237	2.4	18	0.375	4.3
6.625	0.280	2.9	20	0.312	4.4
10.75	0.250	3.4	20	0.375	4.5
12.75	0.250	3.6	24	0.375	4.8
14.00	0.250	3.7	30	0.438	5.3
16.00	0.250	3.9	36	0.500	5.8
16.00	0.312	4.0	36	0.5625	5.9

Eccentric Masses

All of the valves in the PCS are manually operated with negligible eccentricities. Therefore, all valve mass has been modeled at the pipe centerline.

Damping

Material damping consistent with a 5% modal damping is used, as listed in Table 3-2 of ASCE/SEI 43-05 (and in Table N-1230-1 of ASME Section III, Appendix N). Rayleigh damping is applied to ensure that slightly conservative damping is applied in the analysis. Justification for the values used will be provided in every case, such justification being based on a comparison considering the dynamic characteristics of the piping and the frequency content of the input excitation. A time history will be selected from among the 32 in a given population based on its 5% acceleration spectrum being representative of an 80th percentile Non Exceedence Probability (NEP) for the specta of the population. This spectrum will be compared to a spectrum calculated using the same time history, but for the Rayleigh Damping parameters selected. The parameters shall be 2 Hz for the lower bound value, and no less than 11 Hz for the upper bound value. The average difference between the two spectra, calculated in a log-normal frequency space ranging from 1.5 to 40 Hz, must show the Rayleigh damping to be slightly conservative. This process will be documented in the final report.

Decoupling Criteria

Branch piping with a moment of inertia at or less than 1/25th that of the run piping, may be decoupled and analyzed in a separate model. Piping extending through three pairs of orthogonal supports beyond the hydraulic boundary may be terminated.

Material Properties

Material properties for the materials of construction listed on the piping and support drawings are taken from ASME II. Modulus of Elasticity values are taken at the most likely coincident temperature (Level A conditions) while maximum allowable stress intensities are taken at design temperatures.

Material behavior for plastic analysis will be modeled in accordance with F-1323.3 of ASME Sec III Appendix F. The shape of the true-stress true-strain curve shall be based upon published test data for the material modeled, with yield and ultimate strength taken from Section II, Part D, Subparts 1 and 2 at the expected material temperature.

Material properties for the weld filler used in pipe supports are taken from AWS D1.1 [13] for the matching weld filler.

Loads and Load Combinations

Weight, pressure, thermal expansion, and seismic loads (both inertial and due to anchor motion) are considered in the analysis.

Weight loads include the weight of the piping, associated flanges and valves, and the weight of the water contained in the system. Spring hanger loads are applied as constant forces opposing the weight loads.

Thermal expansion loads are applicable only to supports and will only be used in calculating support demands. System pressures and temperatures associated with Level A operating conditions are used to define the pressure and weight loads. These are the conditions under which an earthquake is most likely to occur.

Seismic response is established using in-structure time histories provided from a Soil-Structure Interaction (SSI) analysis of the ATR Substructure [2]. Individual time histories for support points judged to have the strongest motion applied to each piping model in each coordinate direction are selected for the analysis, the judgment being based on comparison of the associated response spectra. Thirty two sets of statistically independent time histories will be used to analyze each model. Each of the thirty two analyses involves the simultaneous application of three orthogonal input time histories.

Every time history will be repopulated to a 0.005-sec input interval using a frequency based algorithm. Every time history will be drift corrected using a least squares approach. Modifications to the time histories will be detailed and justified in the final report. Time histories will also be truncated to a reduced time span. Such truncation will be based on review of the cumulative energy function, and acceleration, velocity and displacement functions of the time histories. The cutoff will not be before the shoulder of the cumulative energy function (e.g. where it has begun its asymptotic approach to its maximum value). The cutoff will ensure inclusion of times of significant acceleration, velocity and displacement. The cutoff time will be established for enough of the time histories to be used to corroborate that it will vary little among all of the time histories. This work will be described in the analysis documentation.

Fourier phase spectra will be calculated for the input motions to demonstrate that there is sufficient de-correlation among the time histories for the nonlinear analysis being performed.

Maximum demands for each component/support type in the models for each set of time histories will be grouped and sorted, with the 26th highest value (or the 7th value down from the maximum) taken as the demand associated with the 80th percentile NEP input. This demand will be used in calculating the demand to capacity ratio.

Demand caused by seismic anchor motions will be calculated and either shown negligible or combined with the seismic inertial stress intensities by Square-Root-of-the-Sum-of-the-Squares (SRSS).

Load combinations are per AISC/SEI 43-05. Nonseismic loads (weight and/or thermal expansion) are combined with seismic loads reduced by an inelastic Energy Absorption Factor (F_μ). Limit state D F_μ 's (1.0) will generally be used for support components, with higher values (ASCE/SEI 43-05 Table 8-1), applied on an individual basis and justified. The ductility factor needed to achieve a Demand to Capacity ratio of 1.0 will be calculated, and shown to be less than the Limit State C values.

For piping components, ductility will preferably be addressed, if required, through the limit analysis provisions of Section II, Division 1, Appendix F, as discussed under "Capacities" above. Alternatively, F_μ values up to Limit State C (Project Direction) may be used. If this is done, the value needed to achieve a Demand to Capacity of 1.0 will be calculated, and reported with a comparison showing it to be less than the Limit State C value. A demonstration will be required that the performance of the subject component under these loads will not compromise the system analysis producing said loads.

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Authors: M. J. Russell **Date:** 09/30/08 **Checker:** S. R. Jensen **Date:** 09/30/08

Reports and Interfaces

Results of the analysis will be documented in a checked and peer reviewed Engineering Calculations and Analysis Report, as required by LWP 10200 [15]. The peer review will be performed independently of the INL, and will be documented in a separate document.

Specific topics to be included in the final report include:

1. The modeling of nonlinearities in the analyses will be described in detail.

2. Dampings used in the model will be detailed and justified.

3. Modifications to the time histories (Repopulation of 0.005-sec input data, drift corrections, and truncation) will be detailed and justified in the final report.

4. Locations selected for definition of input time histories will be identified and justified.

Table A-1.2 – Selected ATR Piping Drawings

Drawing	Rev	TR-570 Model	Alternate Id	Title
127007	1	Model I	LINE 1-10, 1-12	PIPING SPOOL-PRIMARY COOLANT WATER
127064	2	Model I	LINE 1-170	PIPING SPOOL-PRIMARY COOLANT WATER
127001	3	Model I	LINE 1-1L,2L,3L,4L	PIPING SPOOL-PRIMARY COOLANT WATER SH 1 OF 2
127002	5	Model I	LINE 1-1L,2L,5L,5	PIPING SPOOL PRIMARY COOLANT WATER SHEET 2 OF 2
127003	5	Model I	LINE 1-3L,4L,6L,6	PIPING SPOOL PRIMARY COOLANT WATER SHEET 2 OF 2
127004	8	Model I	LINE 1-7 ATR-670-P-17	PIPING SPOOL-PRIMARY COOLANT WATER
127005	4	Model I	LINE 1-8	PIPING SPOOL-PRIMARY COOLANT WATER
127006	1	Model I	LINE 1-9, 1-11	PIPING SPOOL-PRIMARY COOLANT WATER
127008	3	Model II	LINE 1-13,14,15,16,17	PIPING SPOOL-PRIMARY COOLANT WATER
127065	1	Model II	LINE 1-171	PIPING SPOOL-PRIMARY COOLANT WATER
127009	1	Model II	LINE 1-18,19,20,21	PIPING SPOOL-PRIMARY COOLANT WATER
127018	2	Model II	LINE 1-30	PIPING SPOOL-PRIMARY COOLANT WATER
127019	2	Model II	LINE 1-31	PIPING SPOOL-PRIMARY COOLANT WATER
127037	1	Model II	LINE 1-48	PIPING SPOOL-PRIMARY COOLANT WATER
127839	1	Model II	LINE 8-14	PIPING SPOOL-LOW PRESS DEM WATER
127010	1	Model III	LINE 1-22	PIPING SPOOL-PRIMARY COOLANT WATER
127011	2	Model III	LINE 1-23, 24	PIPING SPOOL-PRIMARY COOLANT WATER
127012	1	Model III	LINE 1-25	PIPING SPOOL-PRIMARY COOLANT WATER
127014	2	Model III	LINE 1-27	PIPING SPOOL-PRIMARY COOLANT WATER SH 1 OF 2

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Drawing	Rev	TR-570 Model	Alternate Id	Title
127015	3	Model III	LINE 1-27	PRIMARY COOLANT WTR SH 2 OF 2
127016	2	Model III	LINE 1-28, 28L	PIPING SPOOL-PRIMARY COOLANT WATER
127017	4	Model III	LINE 1-29, 29L	PIPING SPOOL-PRIMARY COOLANT WATER
127020	5	Model III	LINE 1-32 & 33	PCS-PRIMARY COOLANT WATER
127038	1	Model III	LINE 1-49	PIPING SPOOL-PRIMARY COOLANT WATER
127025	3	Model IV	LINE 1-39	PIPING SPOOL-PRIMARY COOLANT WATER
127026	1	Model IV	LINE 1-40	PIPING SPOOL-PRIMARY COOLANT WATER
127027	2	Model IV	LINE 1-41	PIPING SPOOL-PRIMARY COOLANT WATER SH 1 OF 2
127028	1	Model IV	LINE 1-41	PIPING SPOOL-PRIMARY COOLANT WATER SH 2 OF 2
127029	3	Model IV	LINE 1-42	PIPING SPOOL-PRIMARY COOLANT WATER
127052	3	Model IV	LINE 1-77	PIPING SPOOL-PRIMARY COOLANT WATER
127033	1	Model V	LINE 1-45	PIPING SPOOL-PRIMARY COOLANT WATER
127030	1	Model VI	LINE 1-43	PIPING SPOOL-PRIMARY COOLANT WATER
127032	1	Model VI	LINE 1-44	PIPING SPOOL-PRIMARY COOLANT WATER SH 2 OF 2
127031	5	Model VI	LINE 1-44 1/2	PIPING SPOOL PRIMARY COOLANT WATER
127034	1	Model VI	LINE 1-46	PIPING SPOOL-PRIMARY COOLANT WATER
127035	5	Model VI	LINE 1-47	PIPING SPOOL-PRIMARY COOLANT WATER SH 1 OF 2

Table A-1.3 Selected ATR Piping Specifications

ATR Specification P-1, "ATR Specification for Piping and Hangers, Primary Coolant System - PCS", Revision 12, March 1967.
ATR Specification P-2, "ATR Specification for Valves, Primary Coolant System - PCS", Revision 13, April 1967.

Appendix A.2
PCS Model PSSI Point Selections

The purpose of this section is to select time history input for each of the three PCS models.

Seismic response was defined by application of in-structure time histories taken from a Soil-Structure Interaction (SSI) analysis of the ATR Substructure [2, 19] to the piping support points. Since SSI motion was not defined for every pipe support point, a selection process was needed to establish the time histories for each PCS model application. This process was based on a number of factors. Proximity was considered, tempered by the nature of the structure in the vicinity of the support. In-plane motion defined at the center of a diaphragm is appropriate for most of the diaphragm, but out-of-plane motion is less and less applicable as the pipe support location is moved from the center to the edge. Directionality was considered. For instance, only vertical motion was considered in defining the input motion to long rod hangers. These factors were used to establish sets of time histories applicable to each piping system. Response spectra were then calculated and compared for each set. Time histories with bounding spectra were selected to represent groups of time histories with similar spectra. Point numbering is from the Probabilistic Soil-Structure Interaction analyses (PSSI) [2, 19].

The following steps are followed to determine appropriate PSSI point selections for each of the three PCS models.

- Identify PSSI point candidates for each orthogonal direction corresponding to the PCS model under investigation.
- For each PCS model, plot and compare candidate point response spectra curves and apply bounding curve amplitude and frequency band as basis for PSSI point selection. Follow this step for each model orthogonal direction
- Along with selected bounding response spectra, consider physical aspects (principal supports, etc.) of each PCS model. Conservatively envelope point candidates (for each orthogonal direction) into a reduced selection set of points and provide justification as to why one point candidate is selected over another.
- Identify the bounding set of PSSI points selected for each PCS model.

The following subsections contain information used to select appropriate PSSI points for each of the three PCS models.

A.2.1 Pilot model PSSI point selections
A.2.2 Model 256 PSSI point selections
A.2.3 Model 14 PSSI point selections
A.2.4 PCS model PSSI point selections summary

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A.2.1 – Pilot Model PSSI Point Selections

The purpose of this section is to select time history input corresponding to PSSI points for the pilot model (also referred to as Model 3).

The Pilot model addresses pump outlet to reactor vessel inlet piping and its corresponding supports, as shown in Figure A.2.1-1. The Pilot model is composed of piping diameters ranging from 4-in up through 36-in (i.e., 4-in, 14-in, 20-in, 24-in, & 36-in). Although shown in Figure A.2.1-1, preliminary calculations demonstrate that N-S supports MS-5, -7, -8, added too much stiffness to piping and have been removed (part of Recommendations section in main report) from the Pilot model. Support PR-11 was shown to exceed its capacity on previous calculations and its failure is inconsequential to the Pilot model

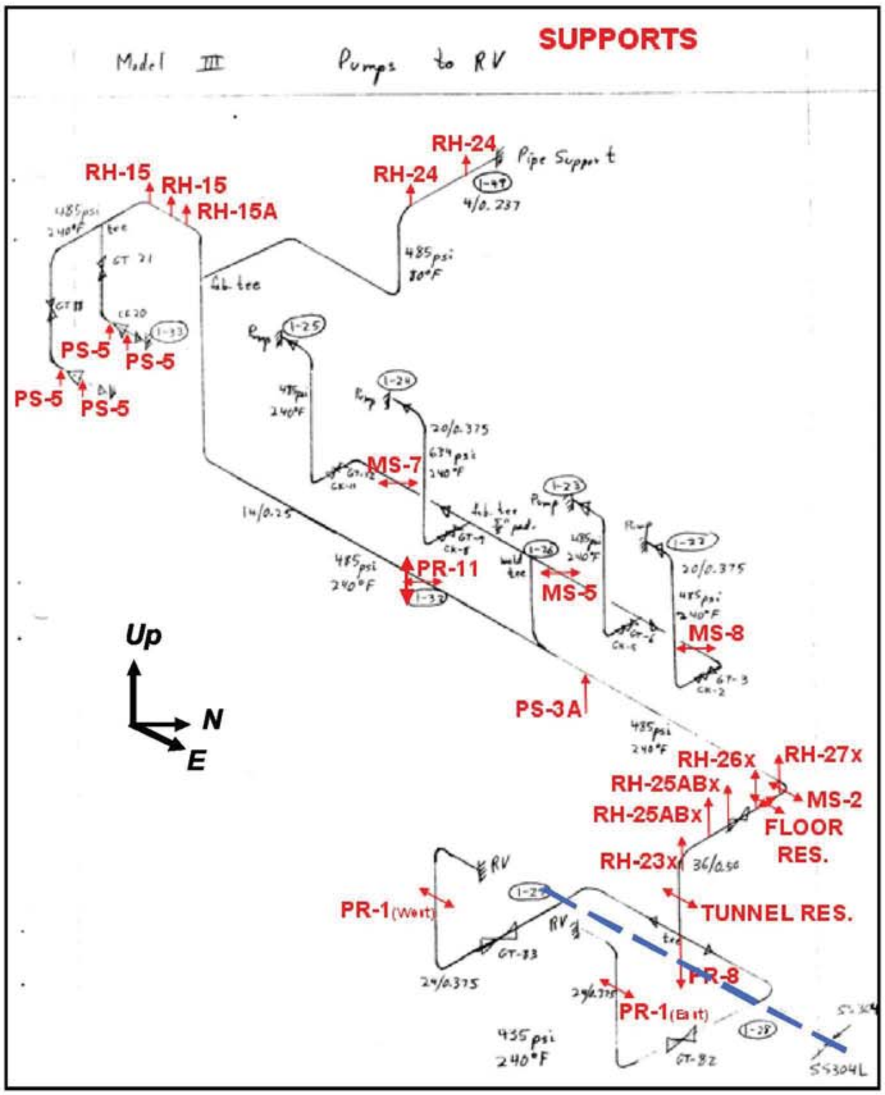
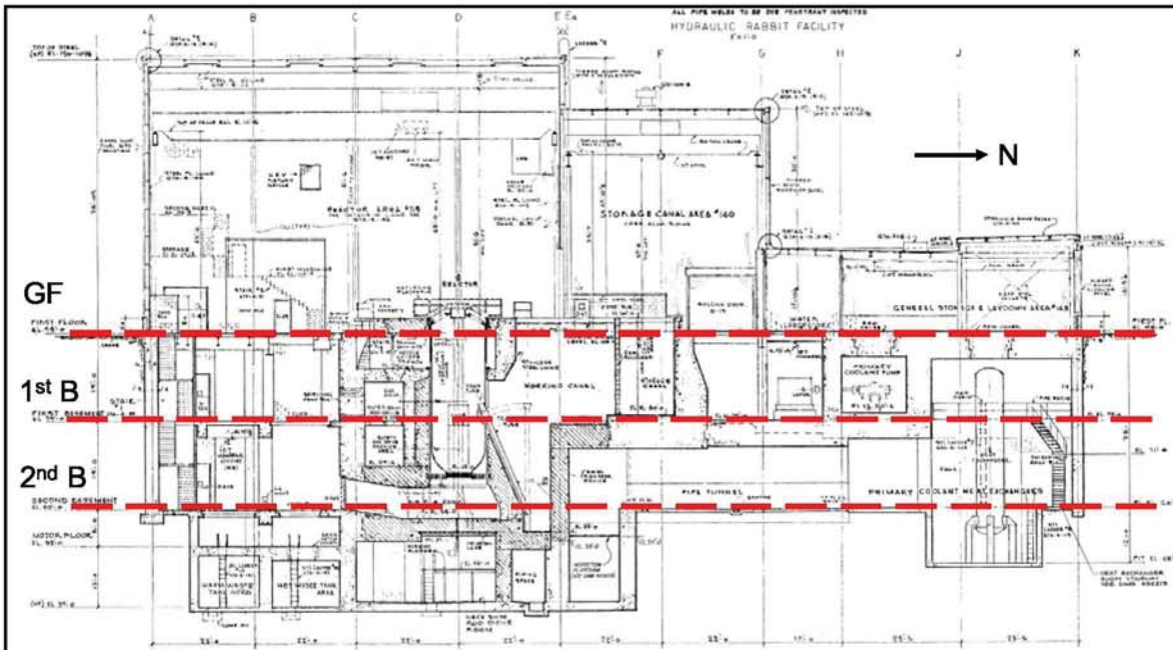


Figure A.2.1-1 – Pilot beam model and supports illustrated.

The Pilot model piping is primarily composed of 304 stainless steel. Piping in the near vicinity of the reactor vessel is fabricated from 304L stainless steel. The dashed blue line (in Figure A.2.1-1) shows the boundary between 304 and 304L stainless steels.

Figure A.2.1-2 is a drawing section view (running North/South) of the ATR building structure [20] through the reactor center, and shows the floor levels where much of the PCS piping is installed.



GF – ground floor elevation
1st B – first basement elevation
2nd B – second basement elevation

Figure A.2.1-2 – North/South cut-away side view of the ATR reactor and building.

Figures A.2.1-3 through A.2.1-5 are reprints from the analyses [2, 19] showing corresponding PSSI point locations corresponding to each orthogonal direction within the Pilot model. A set of PSSI point candidates for each of the three directions (E-W, N-S, Vertical directions) are chosen based on proximity/direction relative to dominant pipe supports. Pilot model PSSI point candidates are designated by different shapes corresponding to each of the orthogonal directions, as overlaid on each ATR floor elevation.

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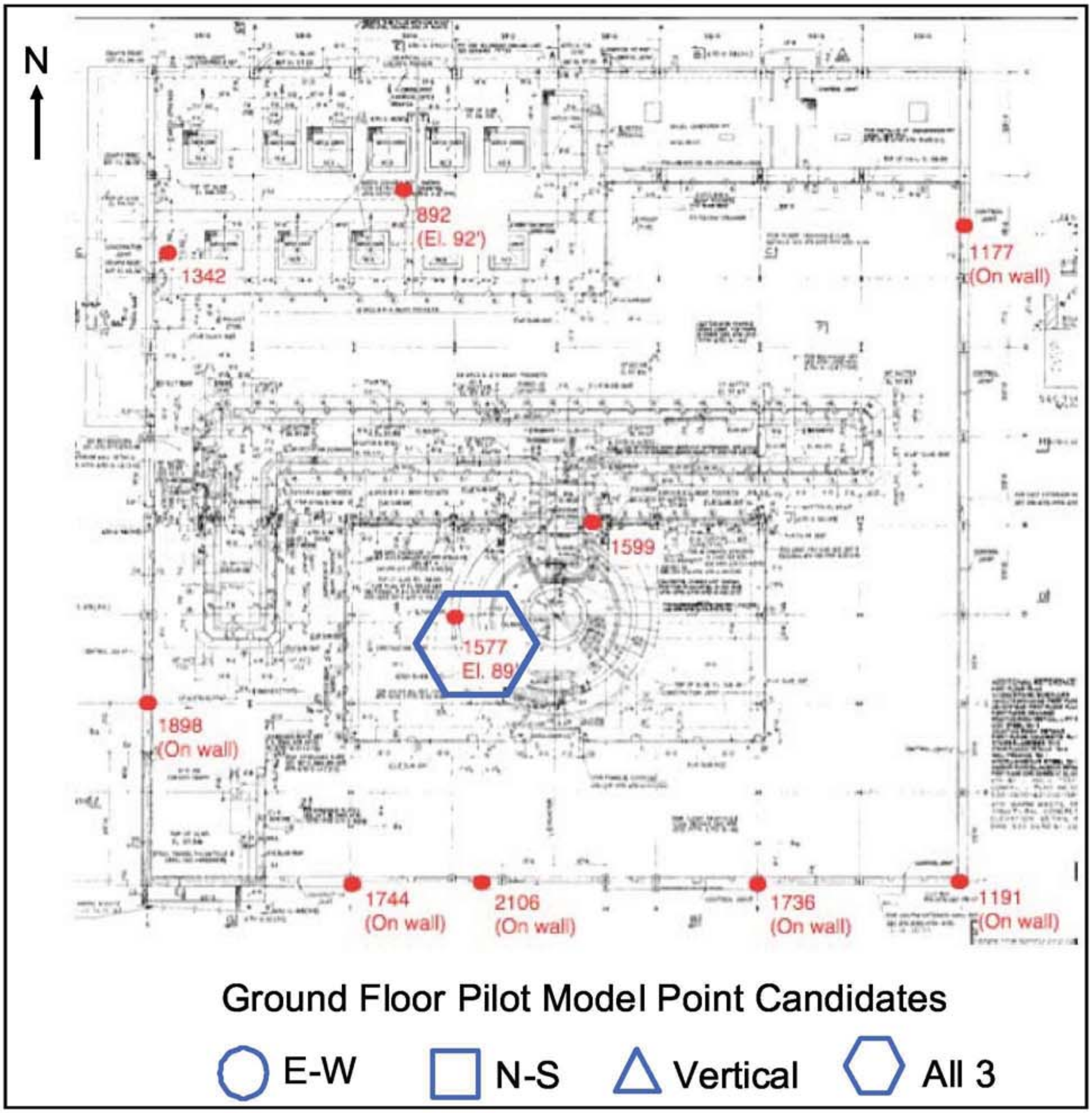

Figure A.2.1-3 – Ground floor Pilot model PSSI point candidates.

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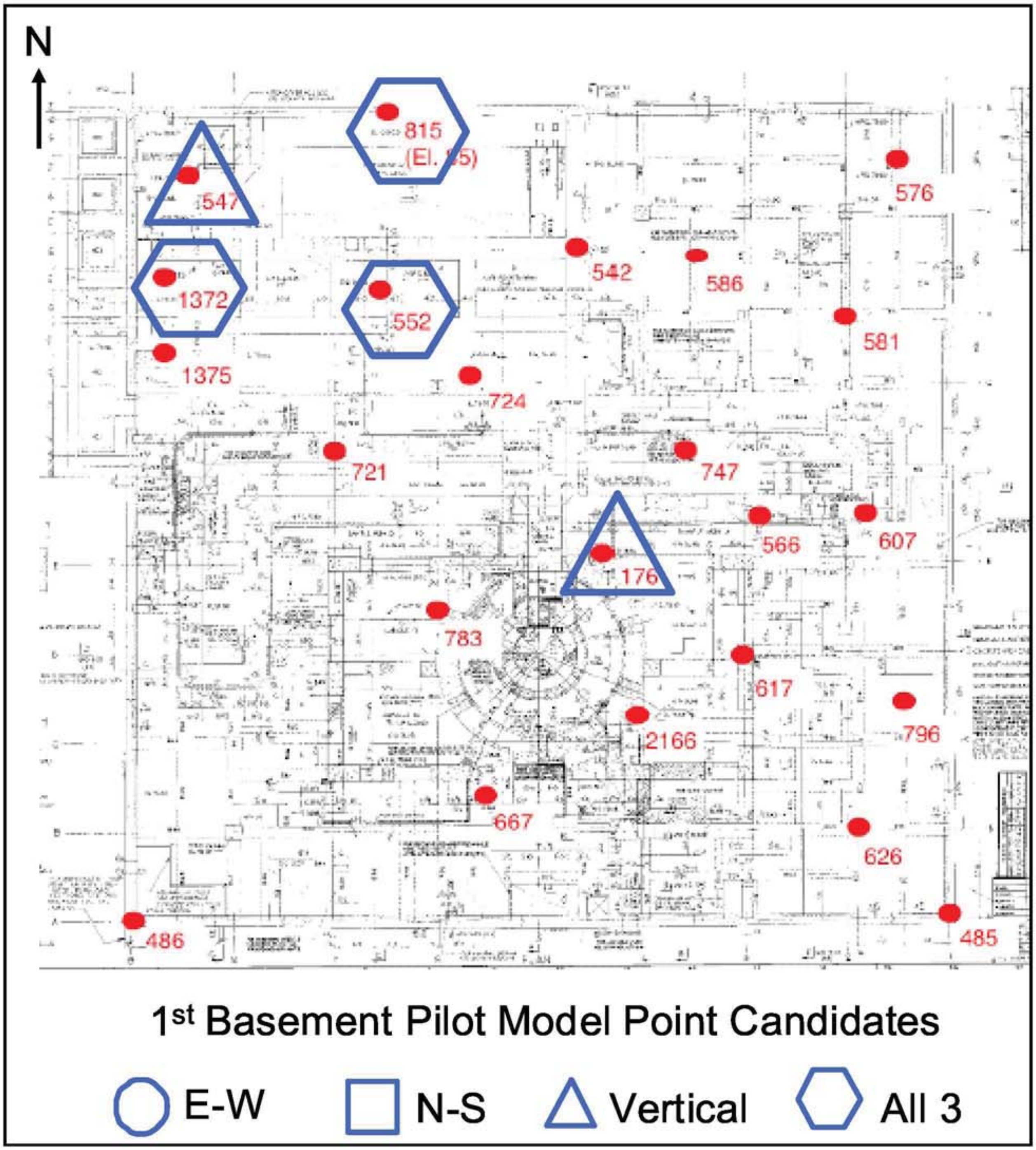

Figure A.2.1-4 – First basement Pilot model PSSI point candidates.

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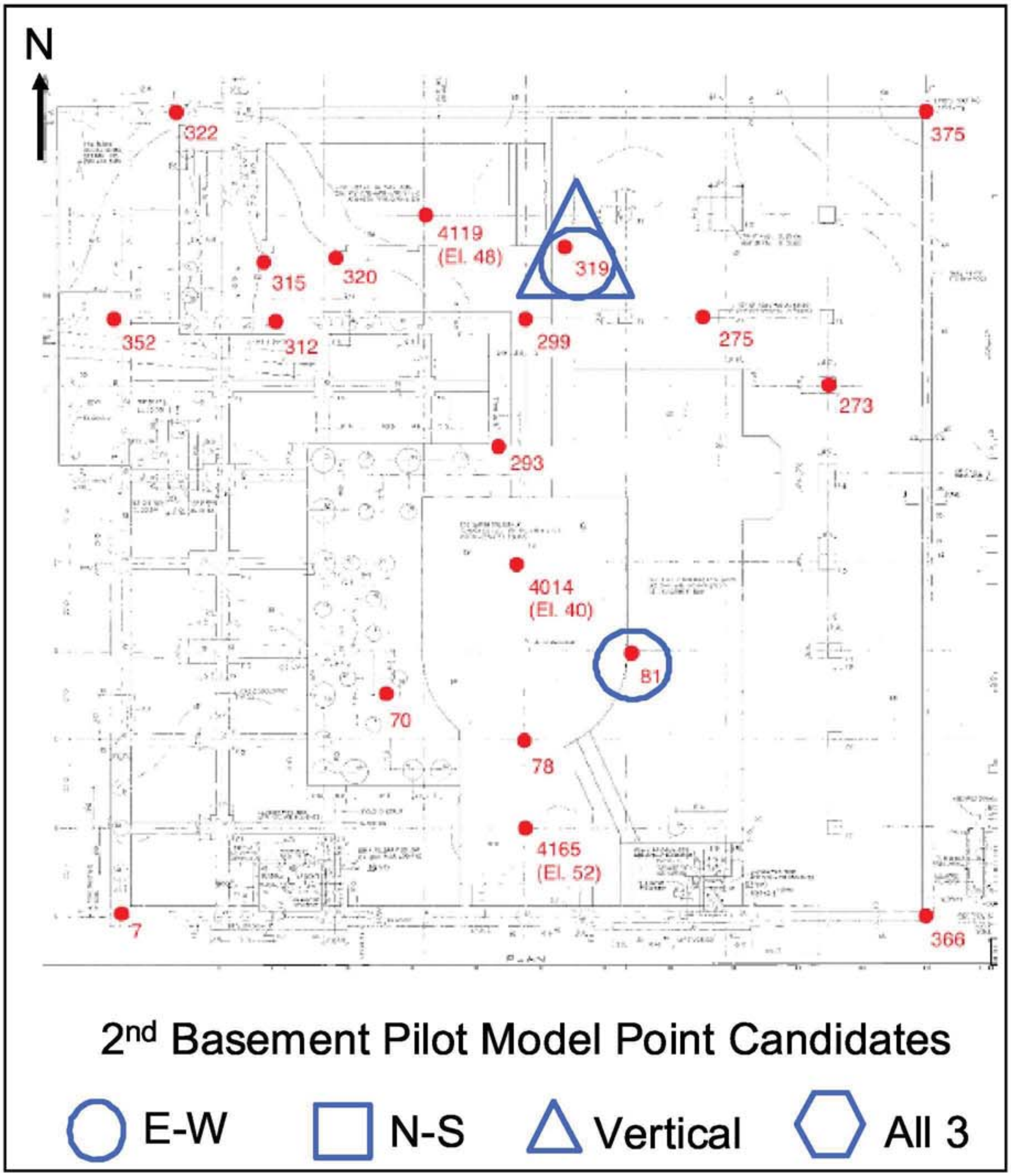

Figure A.2.1-5 – Second basement Pilot model PSSI point candidates.

The Pilot model is distributed between all three floors with some supports attached below the 2nd basement. Table A.2.1-1 lists the Pilot model PSSI point candidates for the East-West (E-W) direction and provides a physical description corresponding to the location within the Pilot model for each point candidate.

Table A.2.1-1 – Summary of Pilot Model's PSSI point candidates in E-W direction.

Pilot Model PSSI Point Candidates for E-W Direction	
E-W Point Candidates	**Description**
81	Point 81 is located below the 2nd basement near lateral supports PR-1 and PR-2. There are four PR-2 supports with a pair located on both the east and west side of the reactor vessel. There is one PR-1 support located near each PR-2 pair. Support PR-1 is associated with the Pilot model and PR-2 is associated with Model 14.
319	Point 319 is located on the North side of the tunnel's East wall at the level of the second basement. It is in the vicinity of the E-W MS-2 snubber. This location is near the E-W center of the 14 model's header.
552	Point 552 is located on the 1st basement floor, centered between the four primary pumps. This point is central to all Piping models and is a candidate for all orthogonal directions.
815	Point 815 is located near the center of the North wall of the facility. Lines 1-43 (10-in piping) and 1-48 (4-in diameter piping) are part of the 256 model which terminate at grouted penetrations in this wall This point is a candidate for all orthogonal directions.
1372	Point 1372 is located on the 1st basement floor, close to the two emergency pumps. This point is a candidate for all orthogonal directions.
1577	Point 1577 is located within the Capsule Nozzle Trench area (between ground and 1st basement elevations) and positioned at the reactor's anchorage to the ATR building structure. Data for this point defines motion at the inlet reactor nozzles in the Pilot model. This point is a candidate for all orthogonal directions.

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As shown in Table A.2.1-1, the Pilot model has six PSSI point candidates in the E-W direction. Figure A.2.1-6 illustrates the combined response spectra for the E-W point candidates.

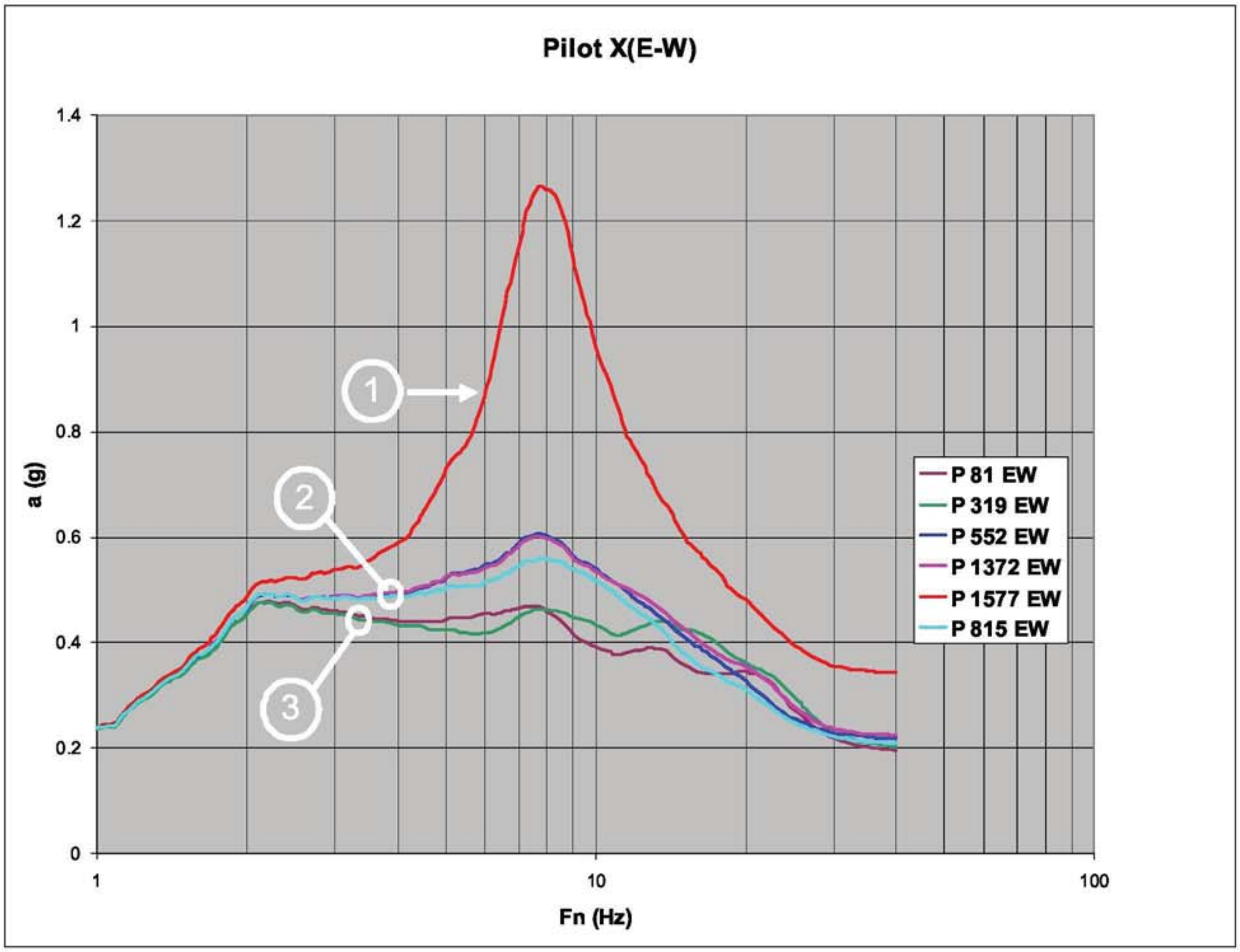

Figure A.2.1-6 – Pilot model point candidates for E-W direction.

As shown in Figure A.2.1-6, there appears to be three sets (hereafter referring to numbers within circles of identified figure) of response spectra point candidates that are close to each other in amplitude and shape. Clearly, point 1577's response spectra (set 1) dominates all point candidates and is selected as one point time history input for the Pilot model in the E-W direction. A closer look at the remaining point candidates (sets 2 & 3) is required to identify other PSSI point selections for the E-W direction. Figures A.2.1-7 and A.2.1-8 illustrates response spectra curves for set 2 and set 3, respectively.

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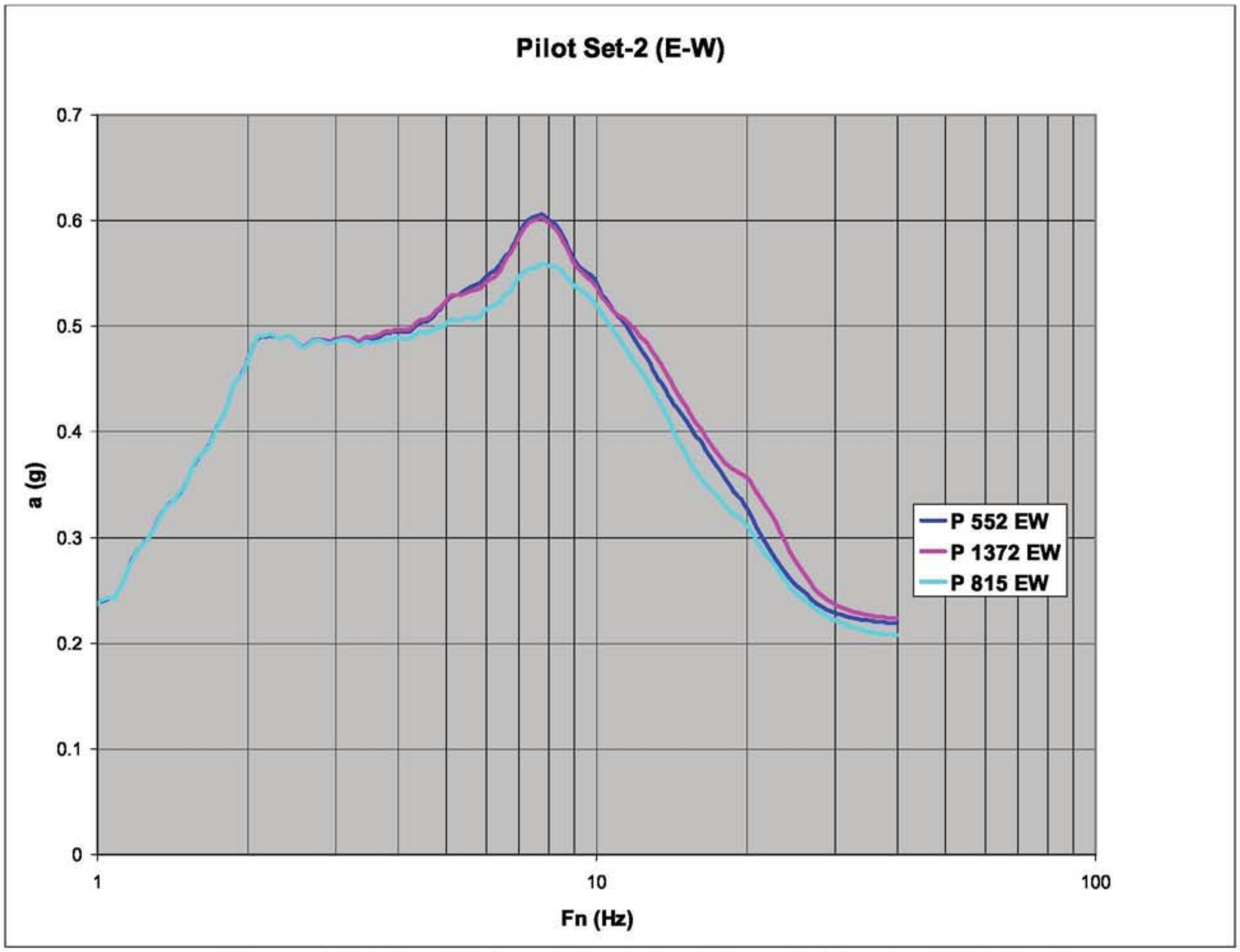

Figure A.2.1-7 – Pilot model set-2 point candidates for E-W direction.

As shown in Figure A.2.1-7, all three point candidates' response spectra are very similar and any of the three curves could possibly be justified and selected for time history input. Point 552 (blue curve) has a slight amplitude increase over 1372 (magenta curve), but 1372 has a slightly wider frequency band. Point 815 (cyan curve) response spectrum is enveloped by the other two points. Point 1372 is located at the two emergency pumps towards the outskirts of the Pilot model, whereas point 552 is positioned midway between the four primary pumps and located in the central section of the Pilot model's large sized piping (24-in, 24-in, and 36-in). Thus, based on physical location aspects, point 552 is another PSSI point selection for the Pilot model in the E-W direction.

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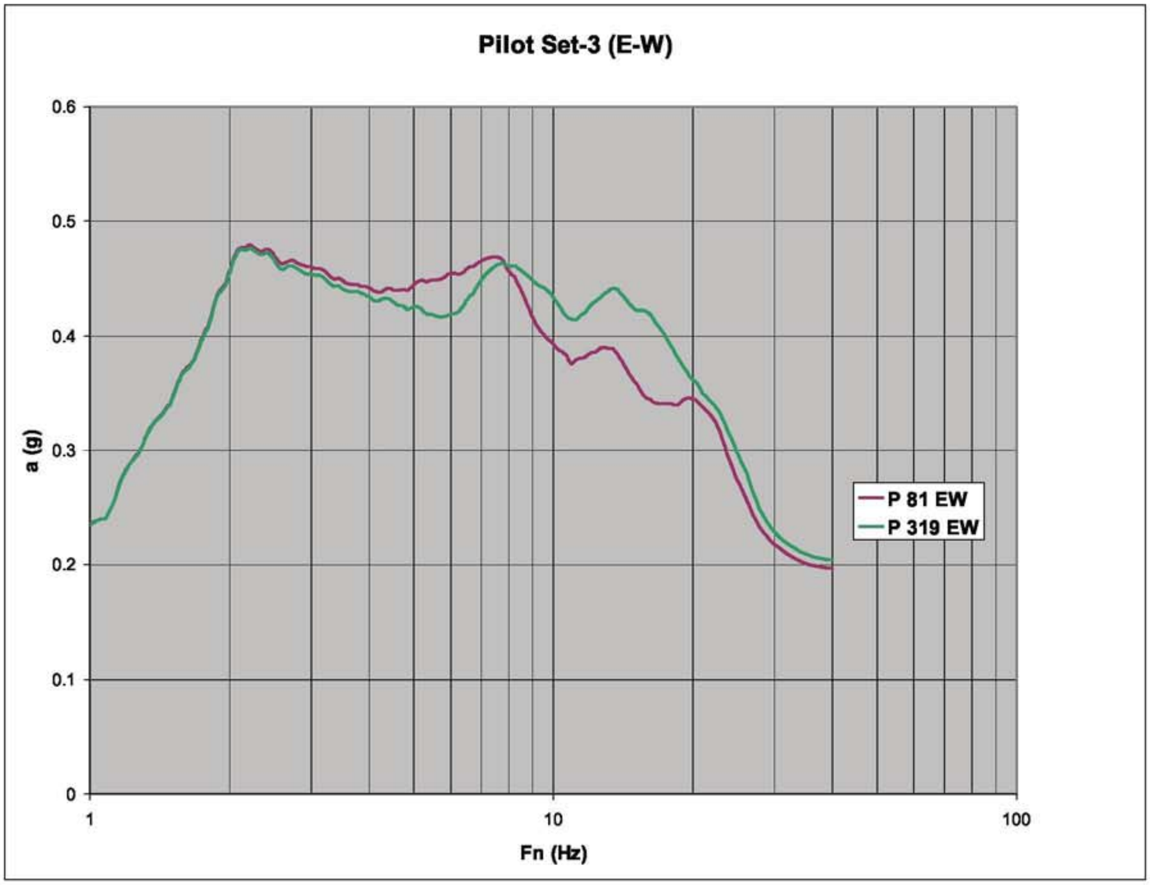

Figure A.2.1-8 – Pilot model set-3 point candidates for E-W direction.

As shown in Figure A.2.1-8, the two point candidates' response spectra are similar. Both points 81 (brown curve) and 319 (green curve) appear to share the highest amplitude at around 1-Hz with 81 dominating input up to about 7.5 Hz, and 319 dominating beyond. The cumulative effective mass plot for this model, Figure A.3.3.2-2, indicates that 55% of the models effective mass participates at frequencies below 7.5 Hz. This slightly favors the Point 81 spectrum. Figure A.2.1-9 shows a reprint of Figure A.3.3.2-1, with dashed lines reflecting indicating values.

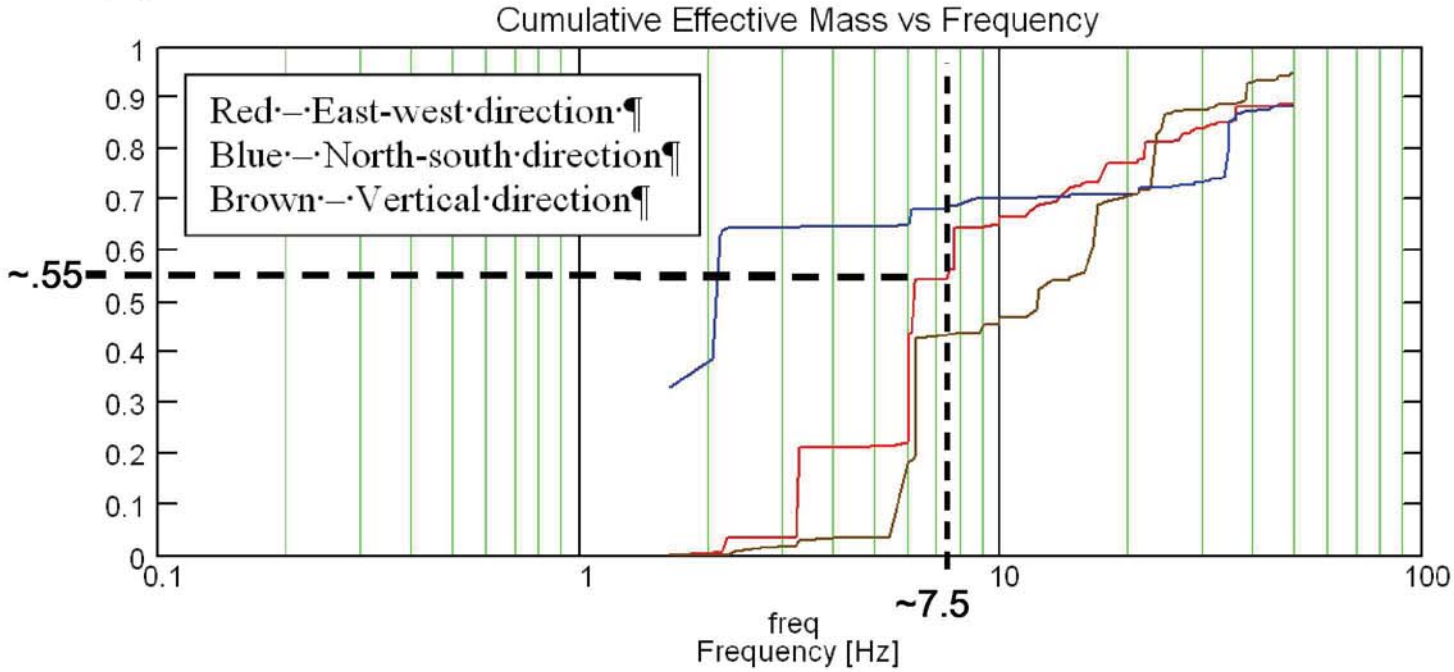

Figure A.2.1-9 – Reprint of Figure A.3.3.2-2 showing the cumulative effective mass vs frequency, of the Pilot model set-3 point candidates for E-W direction.

As Figure A.2.1-9 indicates, point 81 has a slight advantage over point 319. Point 81 is located at the reactor floor near the PR-1 supports and is near the outskirts of Model 3. Point 319 is located near supports MS-2 (snubber) and floor region on the 2nd basement floor, which are principal E-W supports for the Pilot model's central large sized piping section. Thus, based on physical location aspects, point 319 is another PSSI point selection for the Pilot model in the E-W direction.

From the three sets of point candidates' response spectra curves (shown in Figure A.2.1-6), the three PSSI points selected for the Pilot model's E-W direction are points 319, 552, and 1577. Figure A.2.1-10 shows the response spectra for the three PSSI point selections, which are used for the Pilot model's E-W time history input.

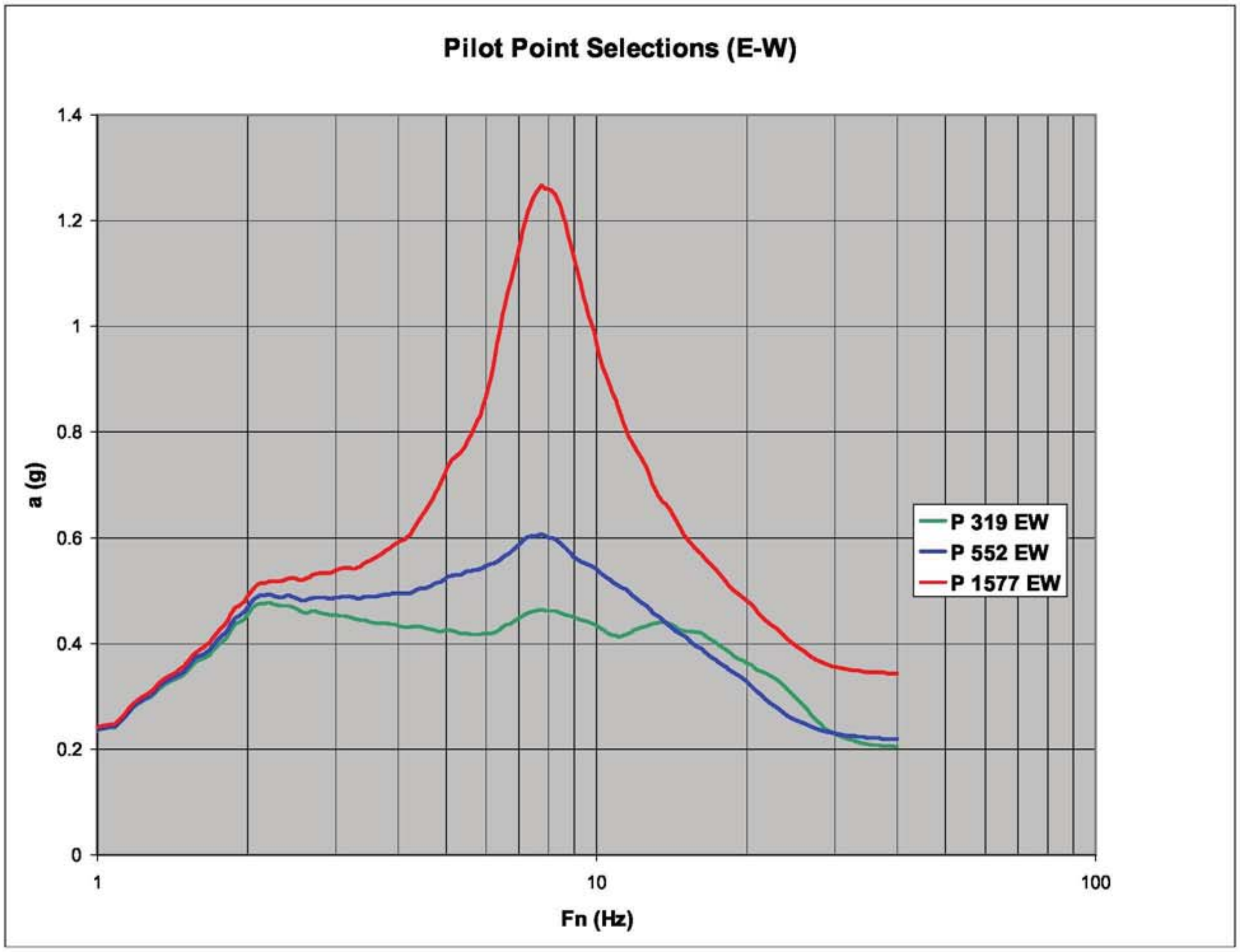

Figure A.2.1-10 – Pilot model's PSSI point selections for the E-W direction.

Point 1577 (red curve) is the response spectrum where the reactor vessel attaches to the ATR building structure, in which defined motion is applied at the Pilot model's inlet nozzle. Point 319 (green curve) is located near two principal supports (MS-2 and Floor Region) that provide E-W restraint to the Pilot model's central piping lines near the 2nd basement floor. Point 552 (blue curve) is located at the primary pumps and provides lateral restraint for the Pilot model's central piping system. These three points (319, 552, and 1577) form bounding time history inputs to the Pilot model.

Table A.2.1-2 lists the Pilot model PSSI point candidates for the N-S direction and provides a physical description corresponding to the location within the Pilot model for each point candidate.

Table A.2.1-2 – Summary of Pilot Model's PSSI point candidates in N-S direction.

Pilot Model PSSI Point Candidates for N-S Direction	
N-S Point Candidates	**Description**
552	Point 552 is located on the 1st basement floor, centered between the four primary pumps - previously described in Table A.2.1-1.
815	Point 815 is located near the center of the North wall of the facility. Lines 1-43 (10-in piping) and 1-48 (4-in diameter piping) are part of the 256 model which terminate at grouted penetrations in this wall This has been previously described in Table A.2.2-1.
1372	Point 1372 is located on the 1st basement floor, close to the two emergency pumps – previously described in Table A.2.1-1.
1577	Point 1577 is located within the Capsule Nozzle Trench area (between ground and 1st basement elevations) and positioned at the reactor's anchorage to the ATR building structure. Data for this point defines motion at the inlet reactor nozzles in the Pilot model – previously described in Table A.2.1-1.

As shown in Table A.2.1-2, the Pilot model has four PSSI point candidates in the N-S direction. Figure A.2.1-11 illustrates the combined response spectra for the N-S point candidates. As previously described, preliminary calculations demonstrated that N-S supports MS-5, -7, and -8 added too much stiffness to piping and have been removed (part of Recommendations section in main report) from the Pilot model evaluation, leaving less PSSI point candidates to choose from in the N-S direction.

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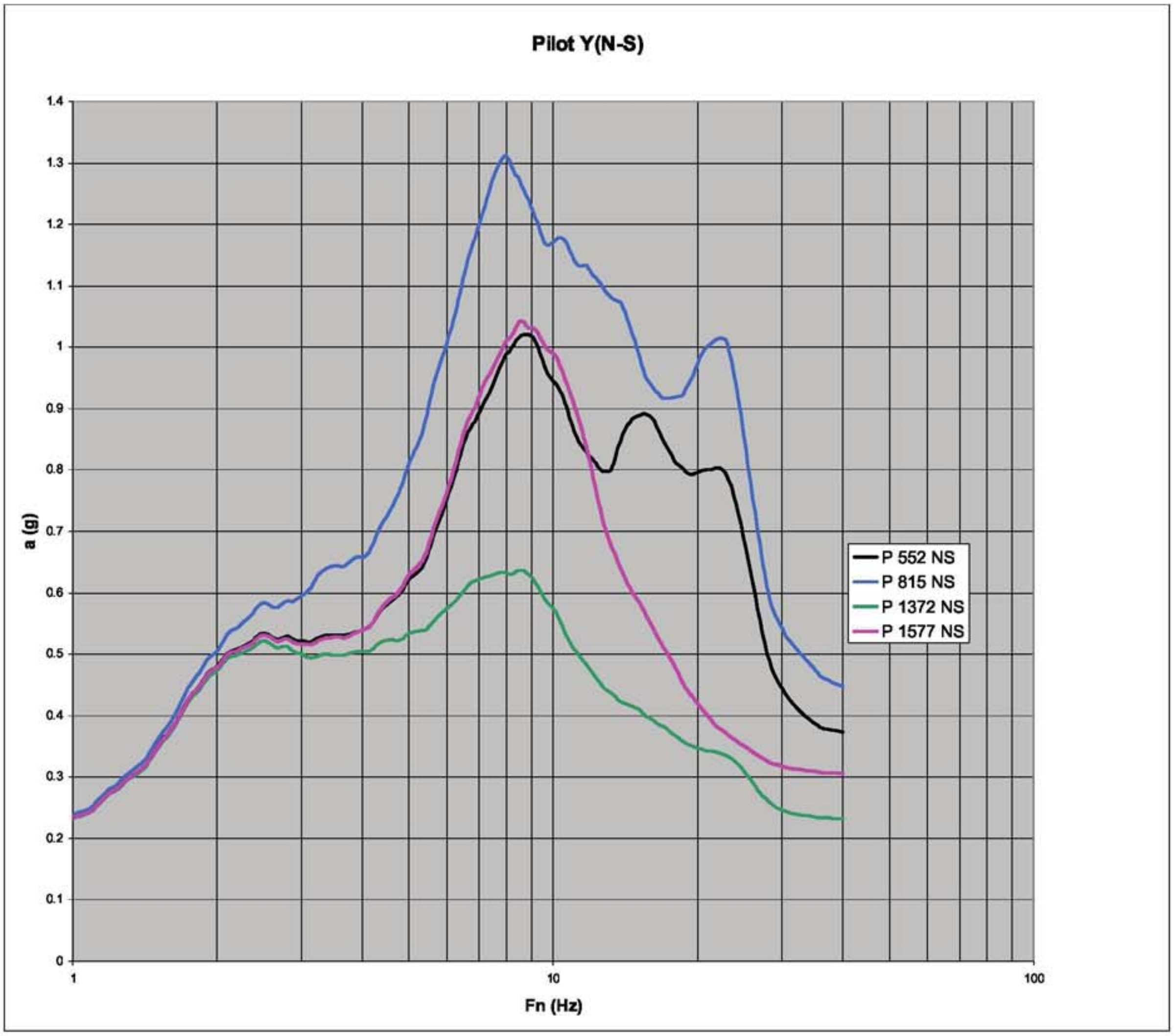

Figure A.2.1-11 – Pilot model point candidates for N-S direction.

As shown in Figure A.2.1-11, there appears to be only two response spectra curves in close proximity with each other. Point 1577 (magenta) is located within the reactor vessel's anchorage and point 552 (black) is near the middle of the primary pumps. The curves fall within 6% of each other under 12 Hz, but the Point 552 spectrum exceeds the point 1577 spectrum by as much as 30% above 12 Hz. The cumulative effective mass plot for this model, Section A.3.3.1, indicates that 30% of the models effective mass participates at frequencies above 12 Hz. The point 552 data is select based on this information. Thus, three PSSI points are selected for the Pilot model in the N-S direction. Figure A.2.1-12 shows the response spectra for the three PSSI point selections, which are used for the Pilot model's N-S time history input.

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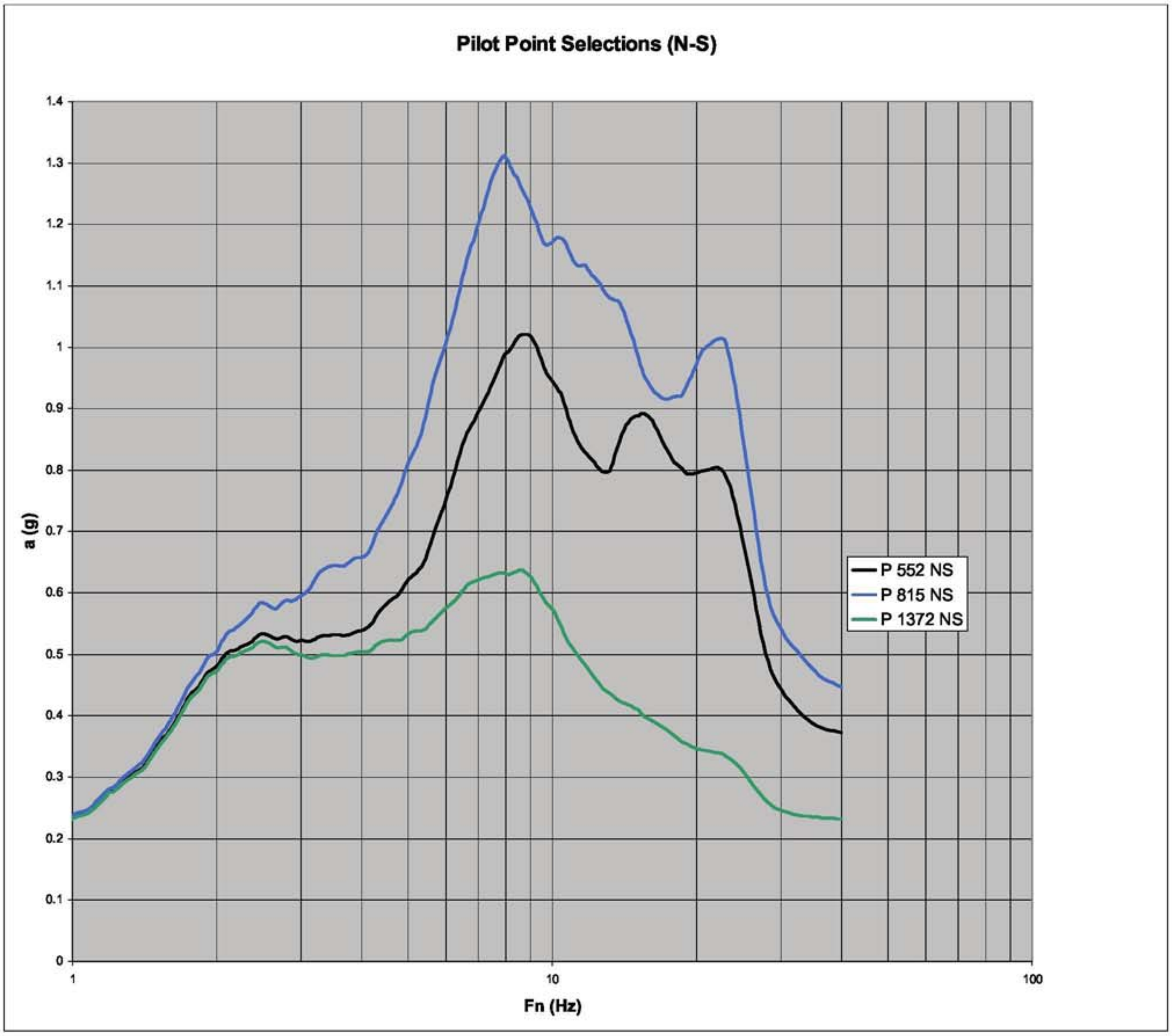

Figure A.2.1-12 – Pilot model's PSSI point selections for the N-S direction.

Starting at the highest response spectrum amplitude, PSSI point 815 (blue curve) is located on the building's north wall and serves as the time history input for line 1-49 (4-in diameter piping) that is terminated at an interior grouted wall penetration near point 815. Point 552 (black curve) is located at the primary pumps and provides lateral restraint for the Pilot model's central piping system. Point 1372 (green curve) is located in the vicinity of the two emergency pumps. These three points (552, 815, and 1372) form bounding time history inputs to the Pilot model in the N-S direction.

Table A.2.1-3 lists the Pilot model PSSI point candidates for the Vertical direction and provides a physical description corresponding to the location within the Pilot model for each point candidate.

Table A.2.1-3 – Summary of Pilot Model's PSSI point candidates in Vertical direction.

Pilot Model PSSI Point Candidates for Vertical Direction	
Vertical Point Candidates	**Description**
176	Point 176 is located at the 1st basement elevation, in the vicinity of the South tunnel end near support RH-23x.
319	Point 319 is located on the 2nd basement floor near the Floor Restraint support. The floor restraint is modeled as a non-linear spring, for it has a 0.75-in gap before it becomes loaded in the +V (upward) direction.
547	Point 547 is located above the 1st floor elevation near line 1-49 wall penetration and the RH-24 vertical supports.
552	Point 552 is located on the 1st basement floor, centered between the four primary pumps - previously described in Table A.2.1-1.
815	Point 815 is located just above the 1st basement floor at the North wall of the facility, which is beyond the scope of the PCS system. Line 1-49 (4-in diameter piping) is part of the Pilot model and is terminated at a grouted wall penetration – previously described in Table A.2.1-1.
1372	Point 1372 is located on the 1st basement floor, close to the two emergency pumps – previously described in Table A.2.1-1.
1577	Point 1577 is located within the Capsule Nozzle Trench area (between ground and 1st basement elevations) and positioned at the reactor's anchorage to the ATR building structure. Data for this point defines motion at the inlet reactor nozzles in the Pilot model – previously described in Table A.2.1-1.

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As shown in Table A.2.1-3, the Pilot model has seven PSSI point candidates in the Vertical direction. The Pilot model has several rod hangers and various types of vertical supports. Figure A.2.1-13 illustrates the combined response spectra for the Vertical point candidates.

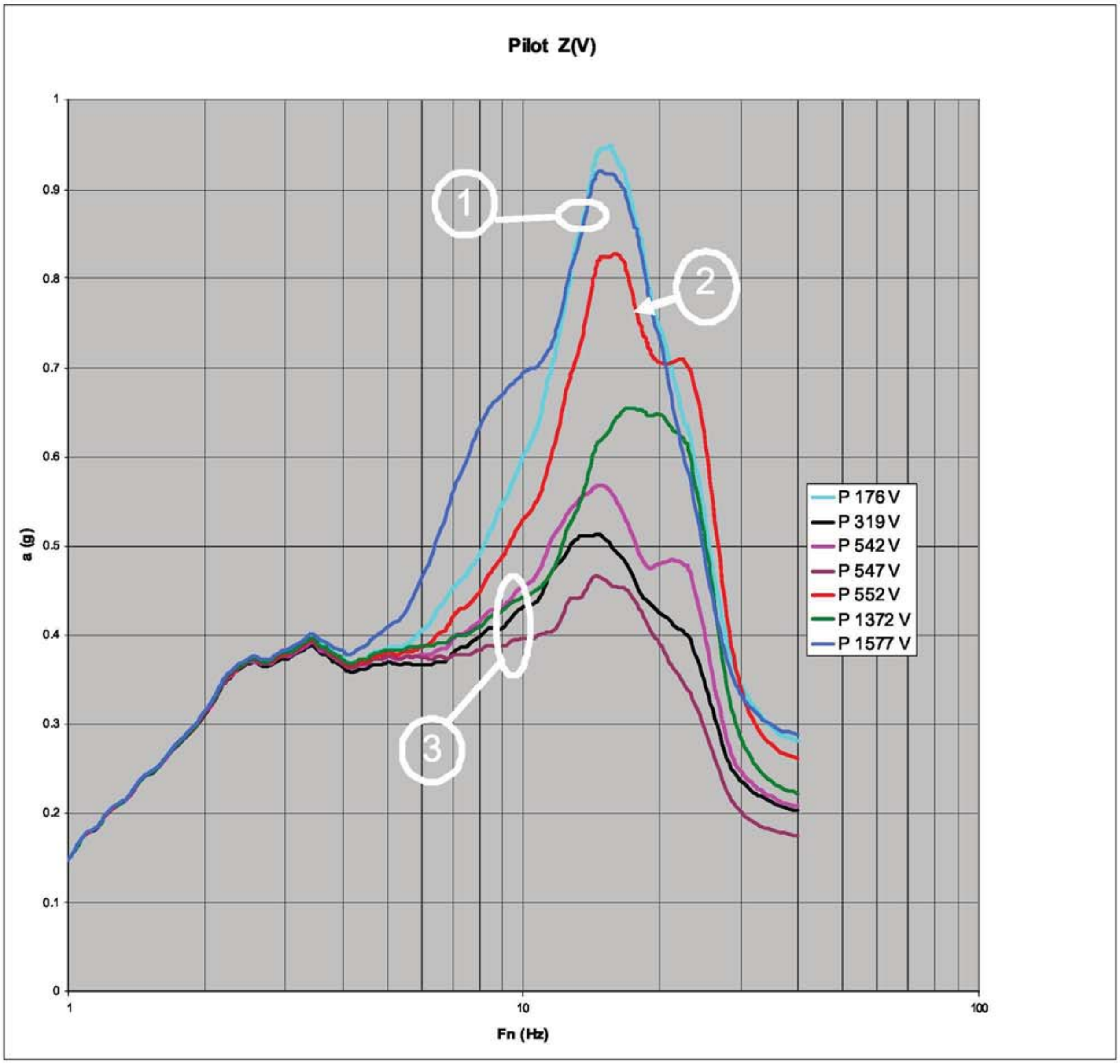

Figure A.2.1-13 – Pilot model point candidates for Vertical direction.

As shown in Figure A.2.1-13, there appears to be three sets of response spectra point candidates that are in close proximity to each other in amplitude and shape. Figures A.2.1-14 (set 1) and A.2.1-15 (sets 2 & 3) are plotted separately and scrutinized more closely.

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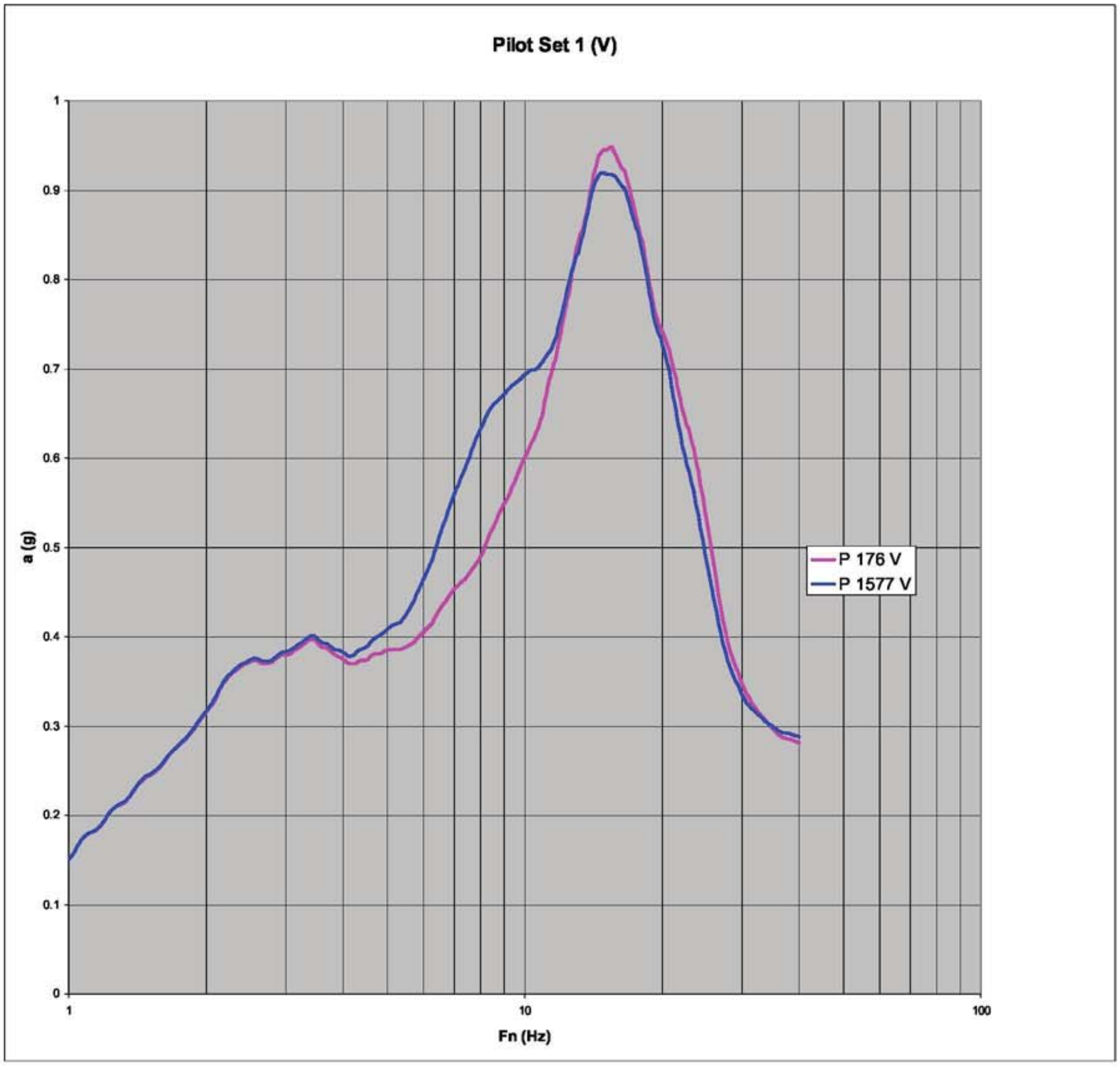

Figure A.2.1-14 – Pilot model set 1 point candidates for Vertical direction

As shown in Figure A.2.1-14, Point 1577 (blue curve) envelopes Point 176 (magenta curve) in the frequency range 0 – 13 Hz, exceeding it by a maximum of 30% near 8 Hz. Point 176 envelopes above 13 Hz, up to a maximum of 10% at 25 Hz. The cumulative effective mass plot for this model, Section A.3.3.2, indicates that 55% of the effective mass participates at frequencies under 13 Hz. It also shows a significant mode (22% of the total mass) at 6 Hz, where the Point 1577 spectrum is 17% higher, versus modes representing 15% of the total mass in the 22 to 24 Hz range. This favors the Point 1577 data. Point 176 is located on the 1st basement, in the vicinity of the southern tunnel opening near support RH-23x. Point 1577 is located between ground and 1st basement elevations and positioned at the reactor's anchorage to the ATR building structure and defines motion at the inlet reactor nozzles in the Pilot model. Actually, support RH-23x is located closer to the elevation of point

1577, for it resides on the 1st basement elevation. Based on physical location RH-23x (elevation) aspects and widest frequency band, point 1577 is the first PSSI point selected for the Pilot model in the Vertical direction.

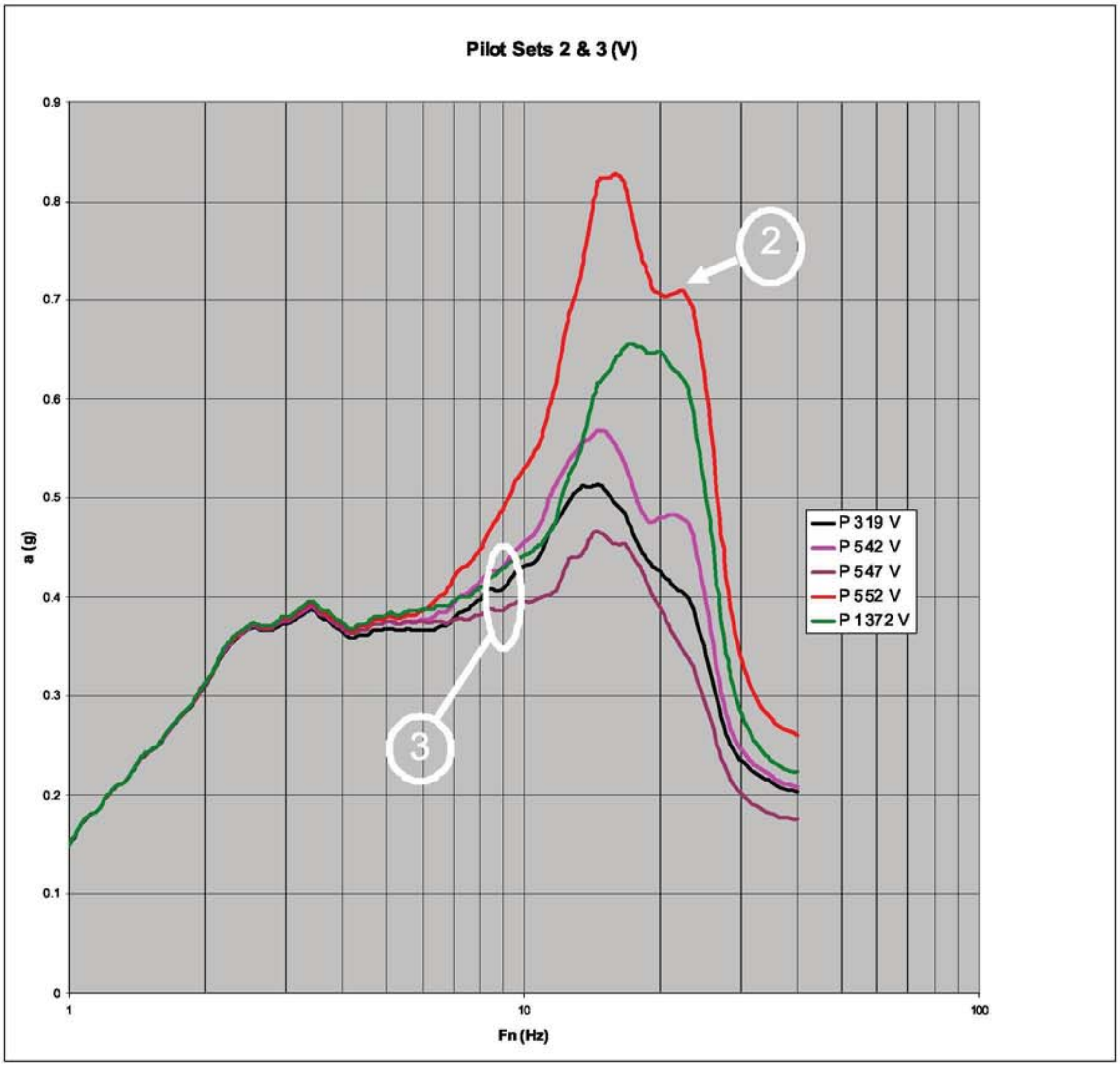

Figure A.2.1-15 – Pilot model sets 2 & 3 point candidates for Vertical direction

As shown in Figure A.2.1-15, the Point 552 spectrum envelopes all other spectra except for that of Point 1372 below 6 Hz. However, this lack of envelopment is never more than 1%, so Point 552 data is a conservative envelope of the suite of spectra. .

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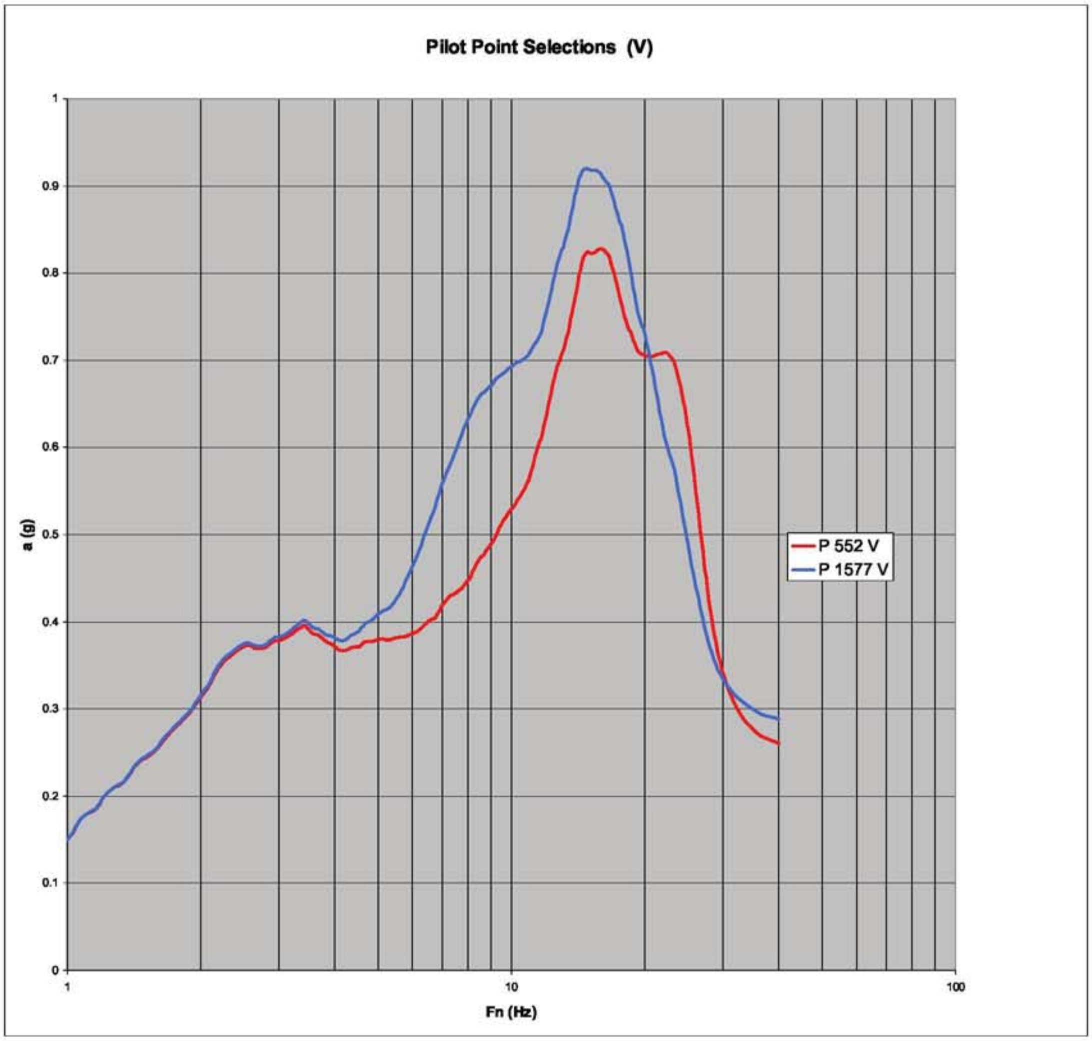

Figure A.2.1-16 – Pilot model's PSSI point selections for the Vertical direction.

These two points (552 and 1577) form bounding time history inputs to the Pilot model in the Vertical direction. Table A.2.1-4 lists the Pilot model's the orthogonal direction PSSI points selections.

Table 2.1-4 – Summary of Pilot model PSSI point selections.

Pilot Model PSSI Point Selections		
E-W	N-S	Vertical
319, 552, 1577	552, 815, 1372	552, 1577

A.2.2 – Model 256 PSSI Point Selections

The purpose of this section is to select PSSI points corresponding to time history input for Model 256 (also referred to as Model 265).

Model 256 is comprised of three original Davidson's models, with Model 2 being the primary piping, Models 5 and 6 attaching to Model 2. Model 256 addresses heat exchanger outlet to pump suction, with surge piping terminating at the surge tank nozzle (Model 5) and flush piping terminating at wall penetrations (Model 6), as shown in Figures A.2.2-1 through A.2.2-3. Model 256 is composed of piping diameters ranging from 4-in up through 30-in (i.e., 4-in, 6-in, 10-in, 20-in, 24-in, & 30-in).

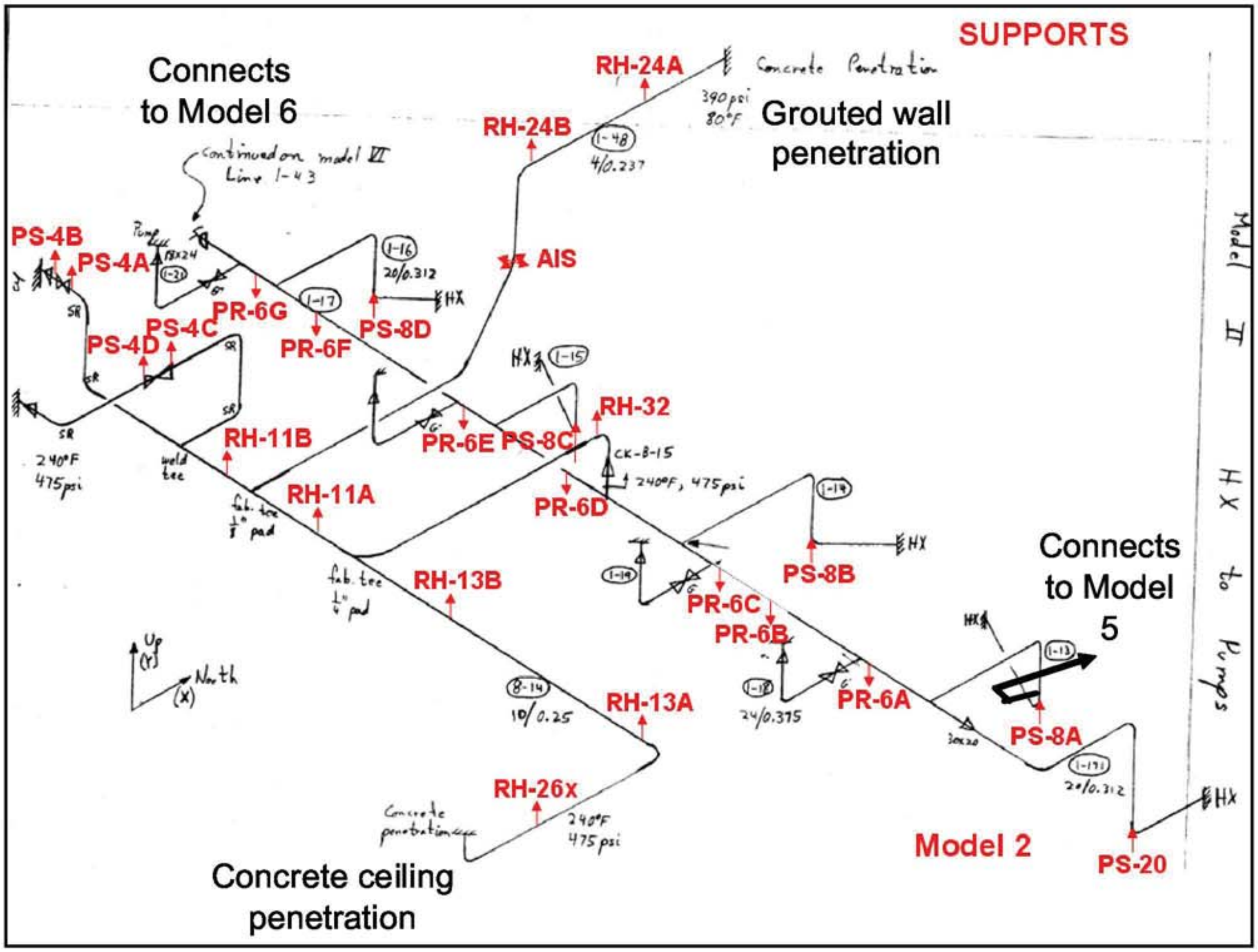

Figure A.2.2-1 – A portion of Model 256, showing original Model 2 and connections to Models 5 and 6.

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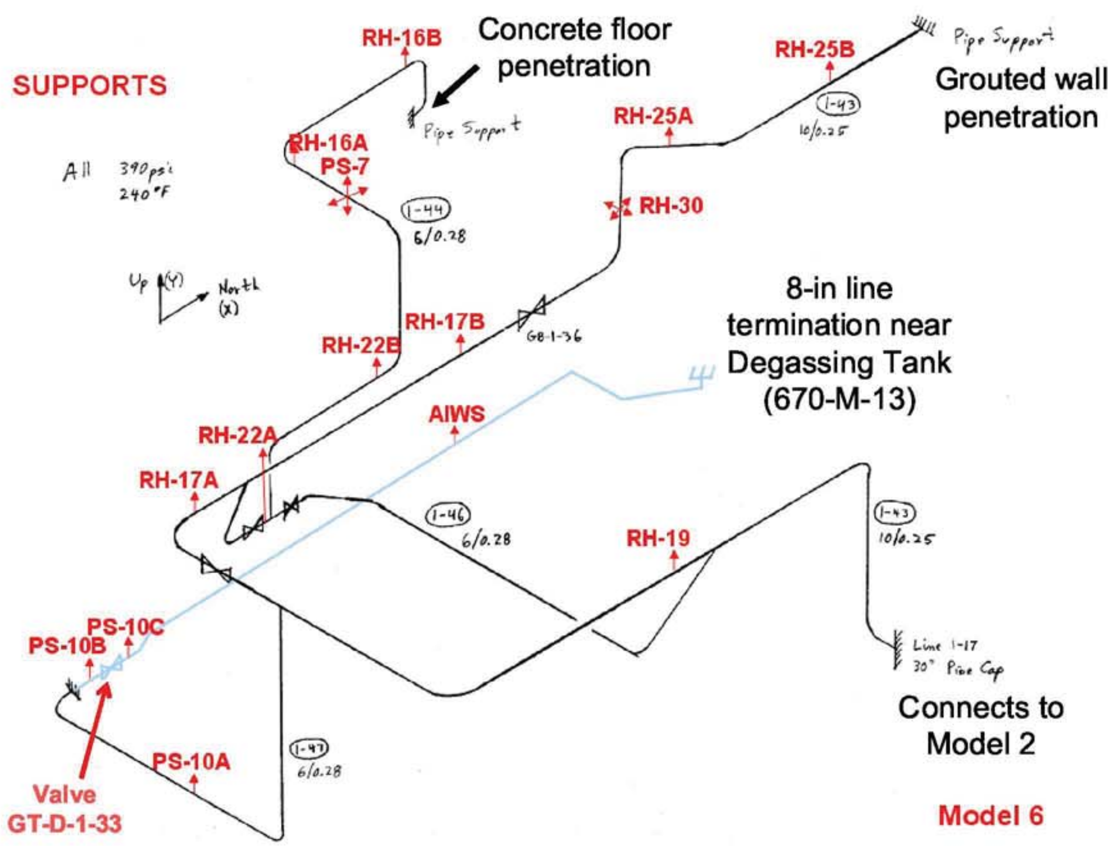

Figure A.2.2-2 – A portion of Model 256, showing original Model 6 beam and connection to Model 2.

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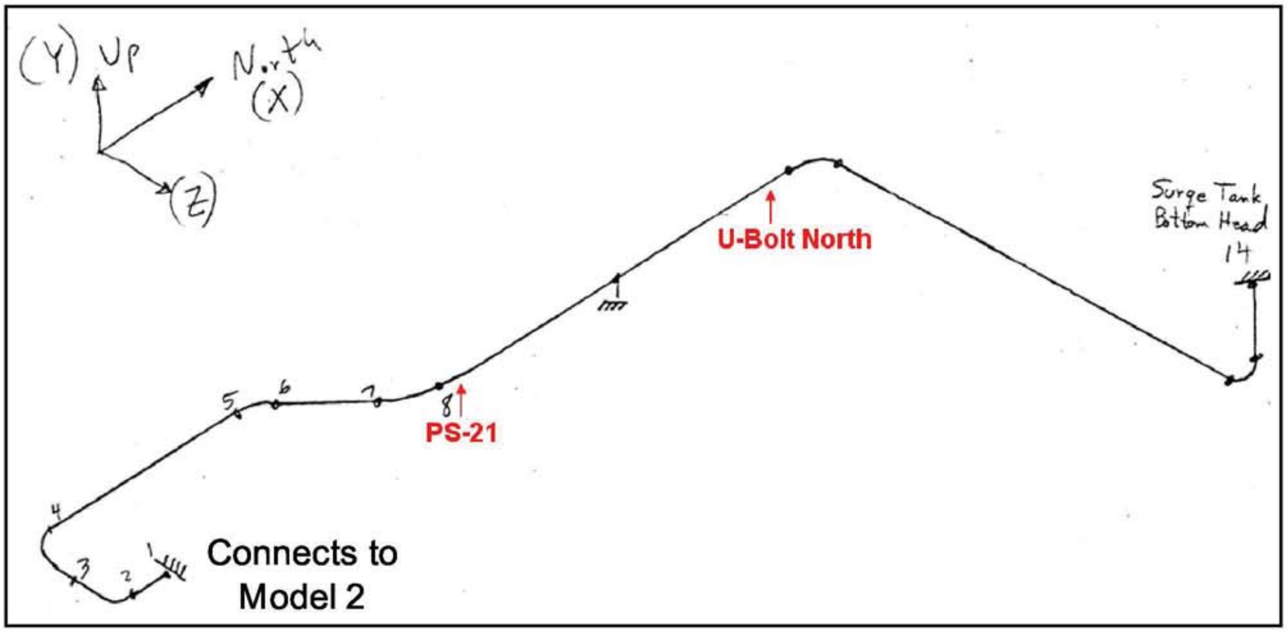

Figure A.2.2-3 – A portion of Model 256, showing original Model 5 and connection to Model 2.

All of Model 256 is composed of 304 stainless steel and is situated away from the reactor vessel. Much of its piping is located between the first and second basements positioned under the four primary pumps.

Figures A.2.2-4 through A.2.2-7 show reprints of the analyses [2, 19] showing PSSI points with time histories located near the supports of Model 256. A set of PSSI point candidates for each of the three model coordinate directions (E-W, N-S, Vertical directions) are chosen with respect to dominant Model 256 supports. PSSI point candidates are designated by different shapes corresponding to each of the model coordinate directions.

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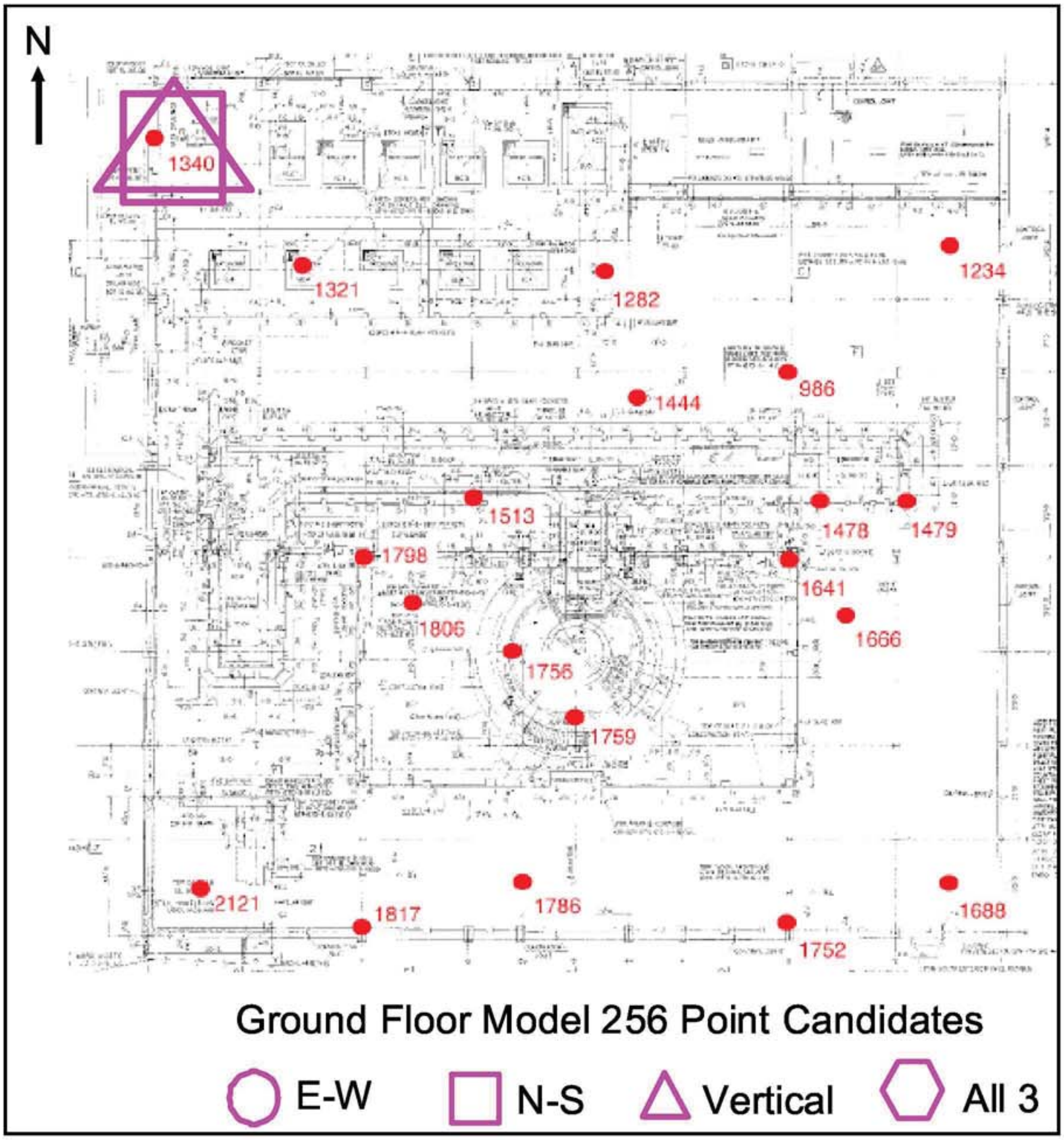

Figure A.2.2-4 – Ground floor 256 model's PSSI point candidates.

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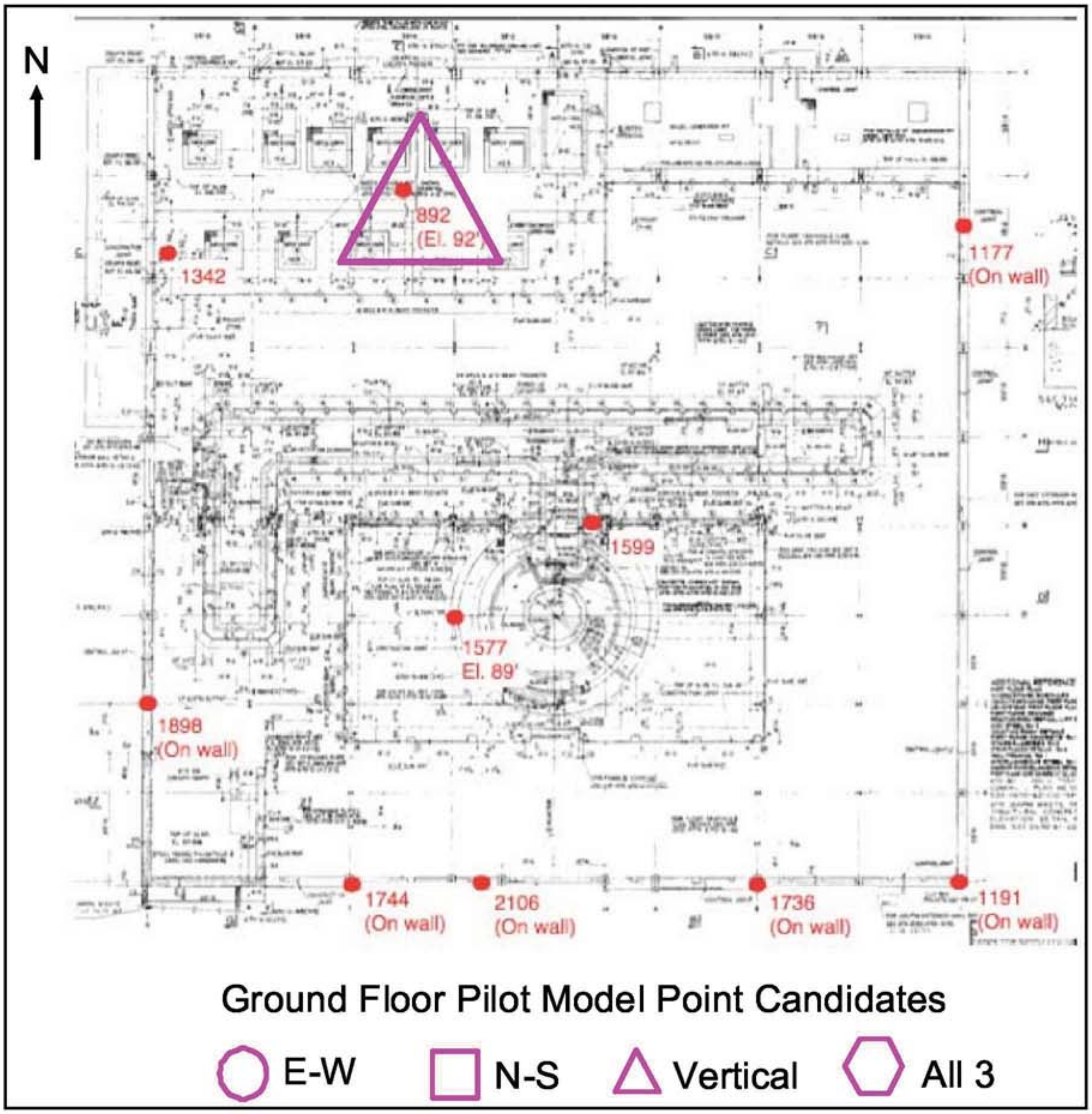

Figure A.2.2-5 – Ground floor 256 model's PSSI point candidates

Note that the data for this point was documented in a report [19] published subsequent to that defining data for all the other points.

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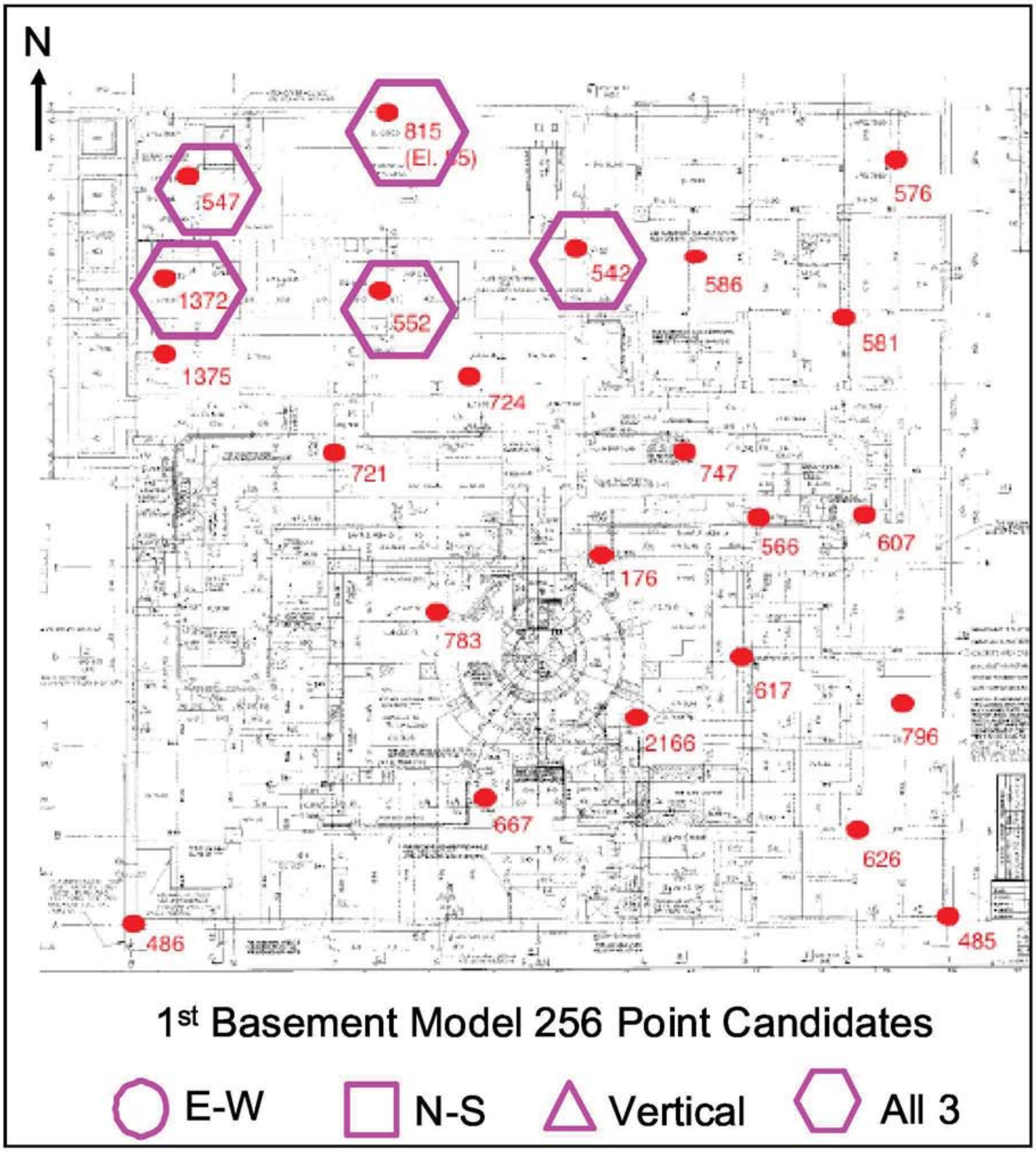

Figure A.2.2-6 – First basement 256 model's PSSI point candidates.

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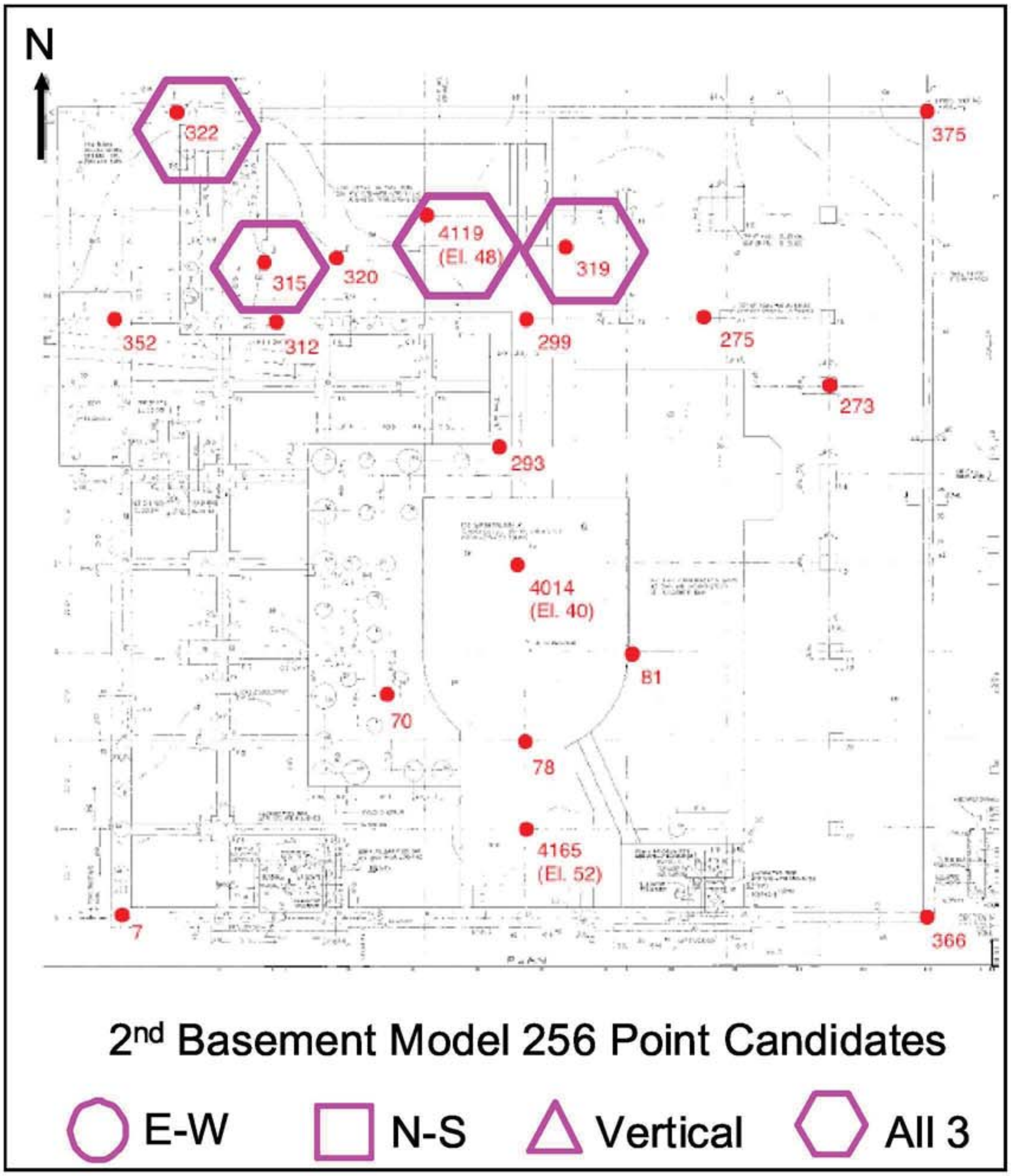

Figure A.2.2-7 – Second basement 256 model's PSSI point candidates.

Model 256 points are distributed between all three floor elevations. Table A.2.2-1 lists Model 256's PSSI point candidates for the E-W direction and provides a physical description corresponding to the location within Model 256 for each point candidate.

Table A.2.2-1 – Summary of 256 Model's PSSI point candidates in E-W direction.

Model 256 PSSI Point Candidates for E-W Direction	
E-W Point Candidates	**Description**
319	Point 319 is located at the 2nd basement elevation on the East wall of the piping tunnel near Grid J. It is the closest node to the supports for the pressurizer piping and vessel (Model 6).
322	Point 322 is located on the 2nd basement at the West end of the North outside wall. This point provides input to supports for piping that branches off of Valve GT-D-1-33.
542	Point 542 is located on an East wall at the tunnel's North end and is in the vicinity of the East end Primary Coolant Pump nozzles. This point is a candidate for all orthogonal directions.
547	Point 547 is located at the 1st basement elevation near line 1-44's grouted concrete floor penetration. As an anchor point, this point is a candidate for all orthogonal directions.
552	Point 552 is located on the 1st basement floor, centered between the four primary pumps. This point is central to all Piping models and is a candidate for all orthogonal directions
815	Point 815 is located near the center of the North wall of the facility. Lines 1-43 (10-in piping) and 1-48 (4-in diameter piping) are part of the 256 model which terminate at grouted penetrations in this wall This point is a candidate for all orthogonal directions.
1372	Point 1372 is located on the 1st basement floor, close to the two emergency pumps. This point is a candidate for all orthogonal directions.
4119	Point 4119 is located below the 2nd basement floor where the 256 piping connects to and terminates at the heat exchanger's outlet nozzles. This point is a candidate for all orthogonal directions.

As shown in Table A.2.2-1, Model 256 has eight PSSI point candidates in the E-W direction. Figure A.2.2-8 illustrates the combined response spectra for the E-W point candidates.

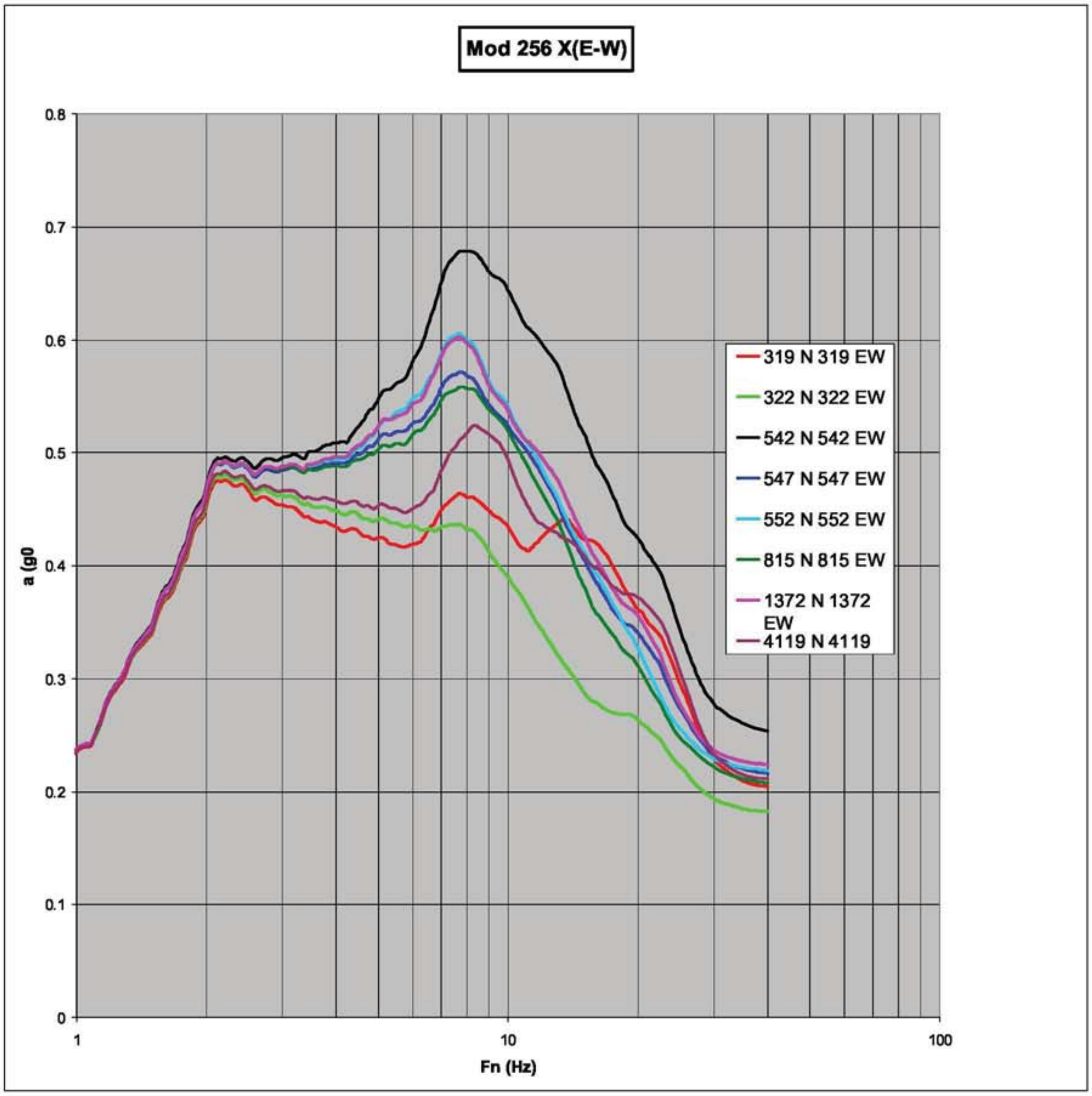

Figure A.2.2-8 – Model 256's point candidates for E-W direction.

As shown in Figure A.2.2-8, the Point 542 spectrum (black) envelopes all other spectra. Thus, 542 is the lone PSSI point selection for Model 256 in the E-W direction.

Table A.2.2-2 lists Model 256 PSSI point candidates for the N-S direction and provides a physical description corresponding to the location within Model 256 for each point candidate.

Table A.2.2-2 – Summary of 256 Model's PSSI point candidates in N-S direction.

Model 256 PSSI Point Candidates for N-S Direction	
N-S Point Candidates	**Description**
319	Point 319 is located at the 2nd basement elevation on the East wall of the piping tunnel near Grid J. It is the closest node to the supports for the pressurizer piping and vessel (Model 6).
322	Point 322 is located on the 2nd basement at the West end of the North outside wall. This point provides input to supports for piping that branches off Valve GT-D-1-33– previously described in Table A.2.2-1.
542	Point 542 is located on an East wall at the tunnel's North end and is in the vicinity of the East end Primary Coolant Pump nozzles. This point is a candidate for all orthogonal directions.
547	Point 547 is located at the 1st basement elevation near line 1-44's grouted concrete floor penetration. As an anchor point, this point is a candidate for all orthogonal directions – previously described in Table A.2.2-1.
552	Point 552 is located on the 1st basement floor, centered between the four primary pumps – previously described in Table A.2.2-1.
815	Point 815 is located near the center of the North wall of the facility. Lines 1-43 (10-in piping) and 1-48 (4-in diameter piping) are part of the 256 model which terminate at grouted penetrations in this wall. This has been previously described in Table A.2.2-1.
1340	Point 1340 is located at the ground floor and is near rod hanger supports RH-15, -24 and -25 that supports both 4-in and 6-in diameter piping. Point 1340 is on the North-West outskirts of Model 256.
1372	Point 1372 is located on the 1st basement floor, close to the two emergency pumps – previously described in Table A.2.2-1.
4119	Point 4119 is located below the 2nd basement floor where the 256 piping connects to and terminates at the heat exchanger's outlet nozzles – previously described in Table A.2.2-1..

As shown in Table A.2.2-2, Model 256 has nine PSSI point candidates in the N-S direction. Figure A.2.2-9 illustrates the combined response spectra for the N-S point candidates. As previously described, preliminary calculations demonstrated that N-S supports MS-5, -7, and -8 added too much stiffness to piping and have been removed (part of Recommendations section in main report) from the Pilot model evaluation, leaving less PSSI point candidates to choose from in the N-S direction.

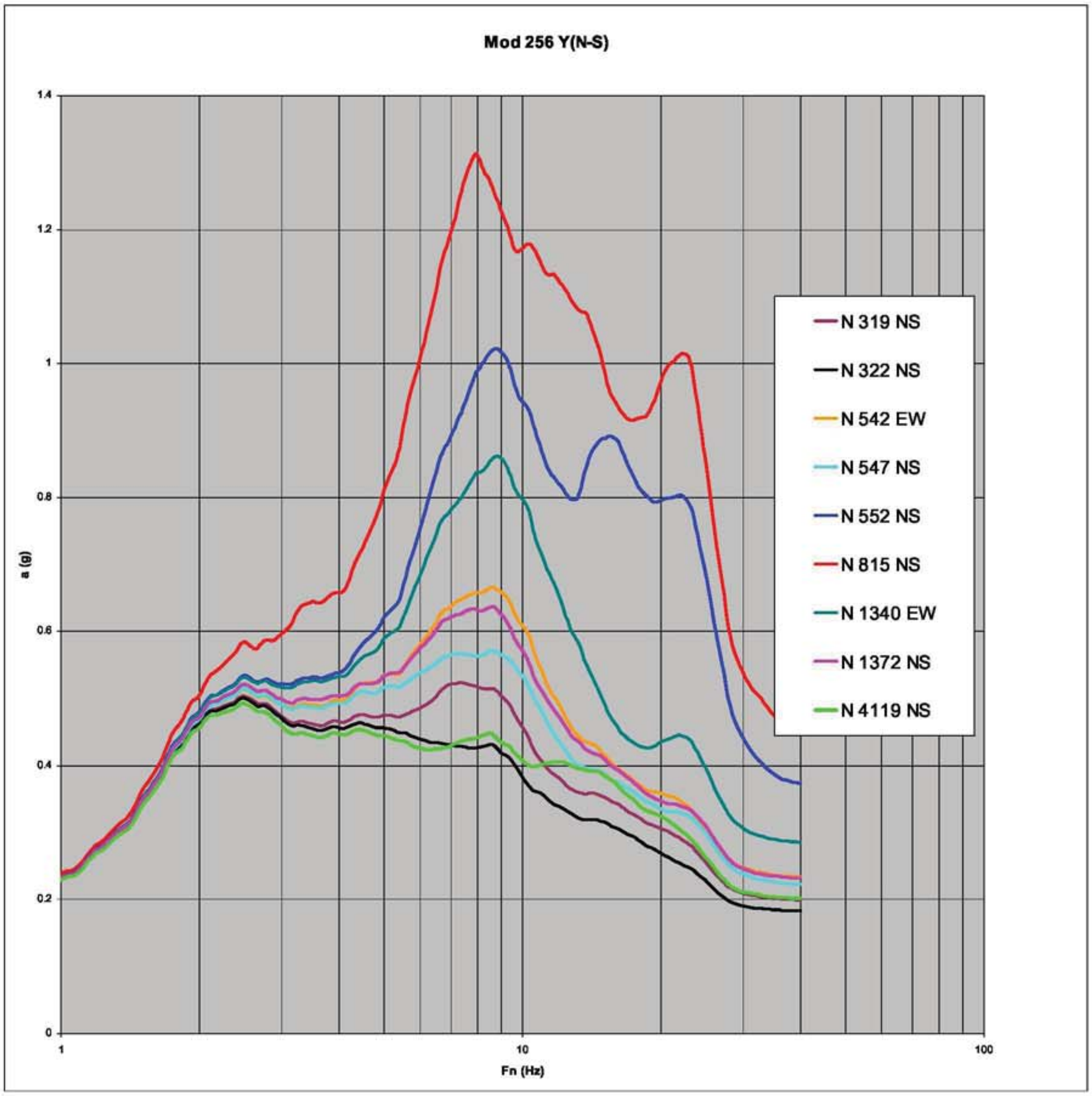

Figure A.2.2-9 – Model 256's point candidates for N-S direction.

As shown in Figure A.2.2-9 two response spectrum curves envelope all the others. Points 815 (red) and 552 (blue) have strong response. Point 815, is used to apply response to Lines 1-43 (10-in piping) and 1-48 (4-in diameter piping) that terminate at a North Wall grouted penetration. These lines are on the outskirts of Model 256. Point 552 is located on the 1st basement floor, centered between the four primary pumps and is central to Model 256 piping system. It also envelopes other lower response curves. These two PSSI points are selected for Model 256 in the N-S direction. Figure A.2.2-10 shows the response spectra for the two PSSI point selections.

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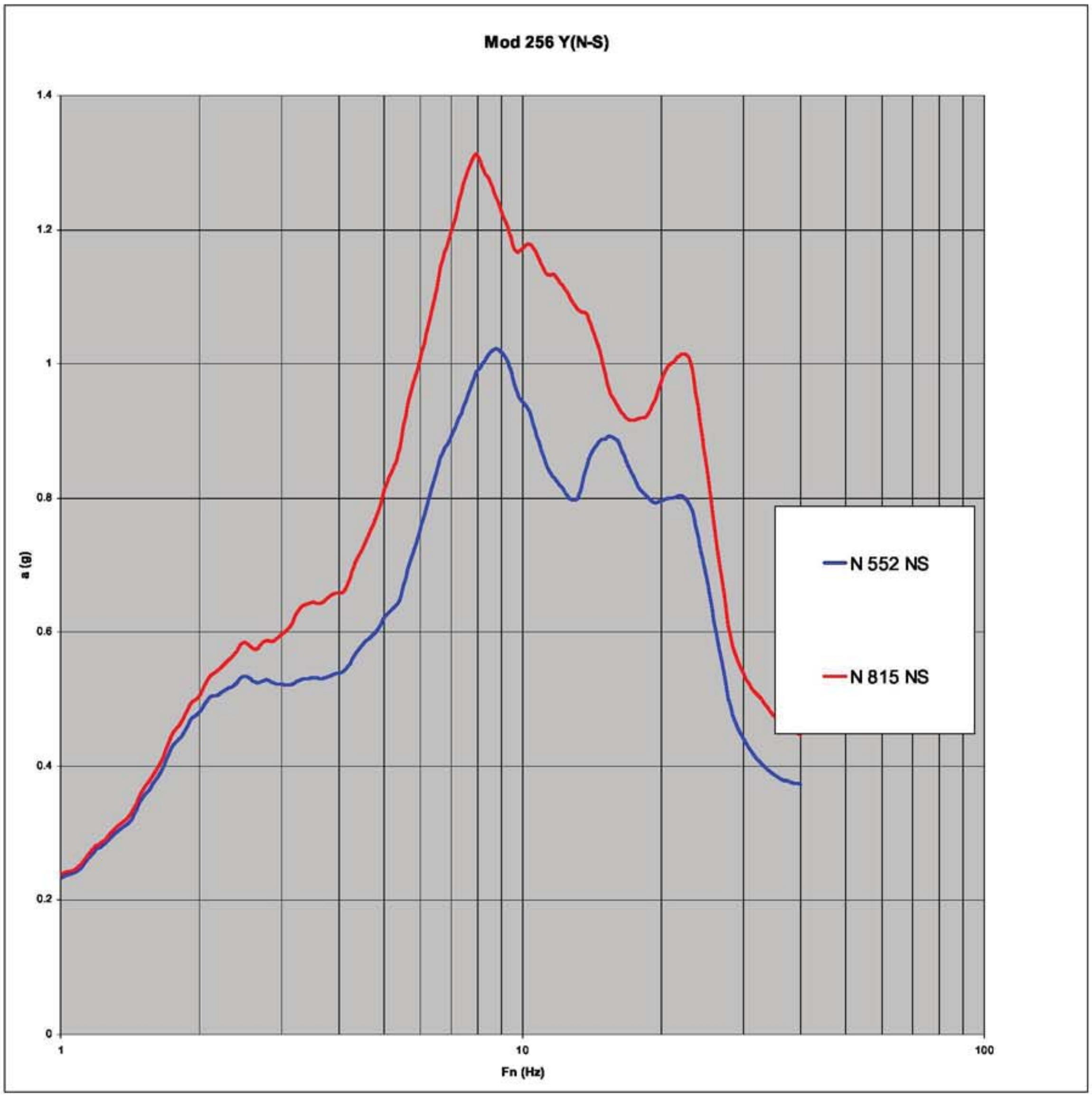

Figure A.2.2-10 – Model 256's PSSI point selections for the N-S direction.

Table A.2.2-3 lists Model 256 PSSI point candidates for the Vertical direction and provides a physical description corresponding to the location within Model 256 for each point candidate.

Table A.2.2-3 – Summary of Pilot Model's PSSI point candidates in Vertical direction.

Model 256 PSSI Point Candidates for Vertical Direction	
Vertical Point Candidates	**Description**
315	Point 315 is located on the 2nd basement floor at an interior West concrete wall, where tie-back supports TB1 and TB2 are. In this vicinity, the piping is mostly 6-in diameter. TB1 restrains E-W and N-S directions and TB2 restrains E-W and Vertical directions.
319	Point 319 is located at the 2nd basement elevation on the East wall of the piping tunnel near Grid J. It is the closest node to the supports for the pressurizer piping and vessel (Model 6).
322	Point 322 is located on the 2nd basement at the North outside wall. This point provides input to supports and piping that branch off into a grouted brick wall – previously described in Table A.2.2-1.
542	Point 542 is located on an East wall at the tunnel's North end and is in the vicinity of the East end Primary Coolant Pump nozzles. This point is a candidate for all orthogonal directions.
547	Point 547 is located above the 1st floor elevation near line 1-49 grouted wall penetration – previously described in Table A.2.2-1.
552	Point 552 is located on the 1st basement floor, centered between the four primary pumps - previously described in Table A.2.2-1.
815	Point 815 is located just above the 1st basement floor at the North wall of the facility, which supports line 1-49 (4-in diameter piping) that is terminated at a grouted wall penetration – previously described in Table A.2.2-1.
892	Point 892 is located on the North wall of the Primary Coolant pump cubicles some 6-ft below the first floor. It is near rod hangers RH-14A, -14Aa, -14Ab, -14Ac (Vertical) and PS-20A (Vertical). These are all supports for 6-in piping.
1340	Point 1340 is located at the ground floor and is near rod hanger supports RH-15, -24 and -25 that supports both 4-in and 6-in diameter piping. Point 1340 is on the North-West outskirts of Model 256.
1372	Point 1372 is located on the 1st basement floor, close to the two emergency pumps – previously described in Table A.2.2-1.
4119	Point 4119 is located below the 2nd basement floor where the 256 piping connects to and terminates at the heat exchanger's outlet nozzles – previously described in Table A.2.2-1.

As shown in Table A.2.2-3, Model 256 has eleven PSSI point candidates in the Vertical direction. Model 256 has several rod hangers and various types of vertical supports. Figure A.2.2-11 illustrates the combined response spectra for the Vertical point candidates.

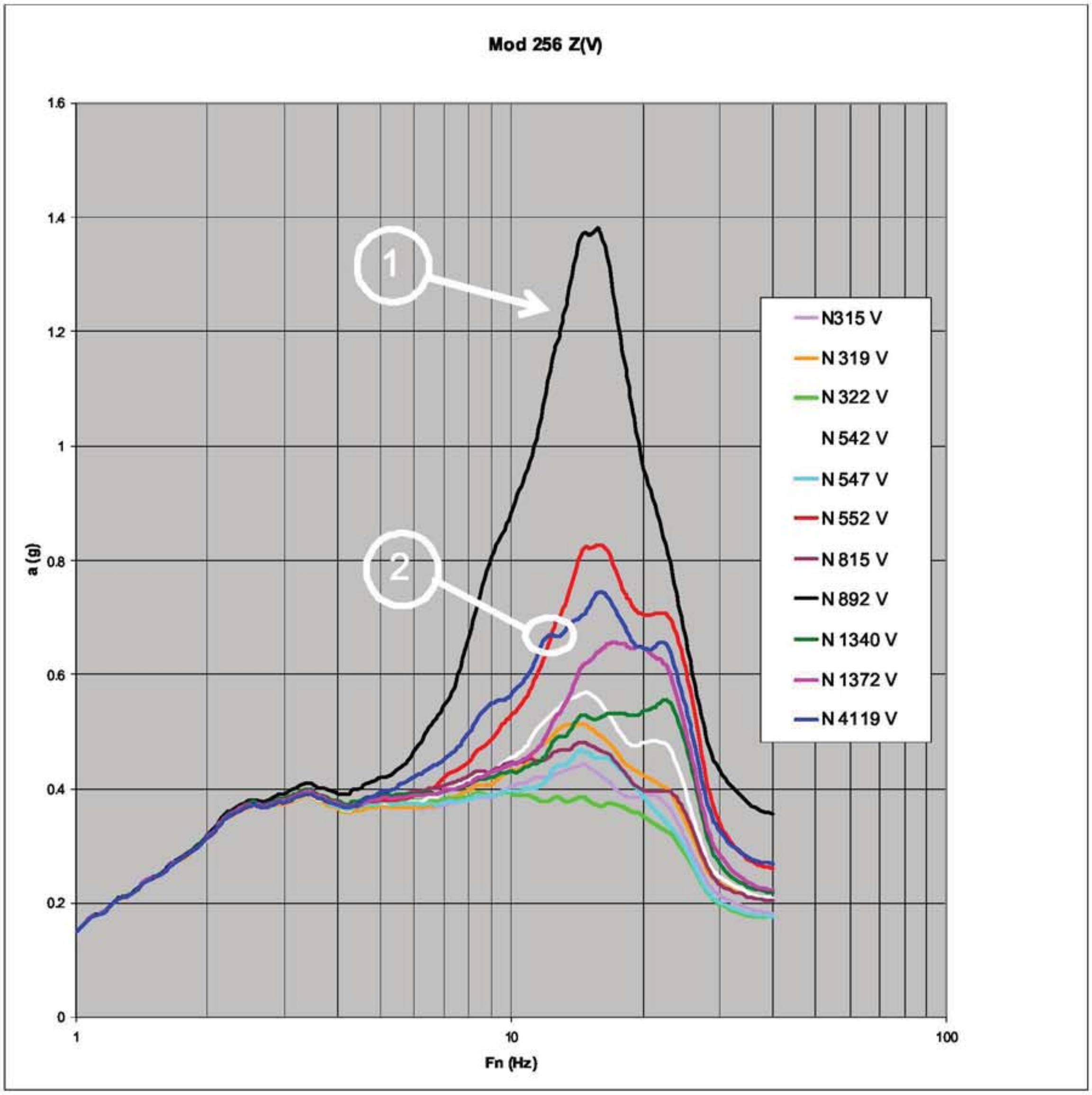

Figure A.2.2-11 – Model 256's point candidates for Vertical direction.

As shown in Figure A.2.2-11, three response spectrum curves (points 892, 552, and 4119) envelope remaining point candidates, with point 892 (black curve) response spectrum dominating. Figure A.2.2-12 (set 2, number 2 circled in Figure A.2.2.11) is plotted separately and scrutinized more closely.

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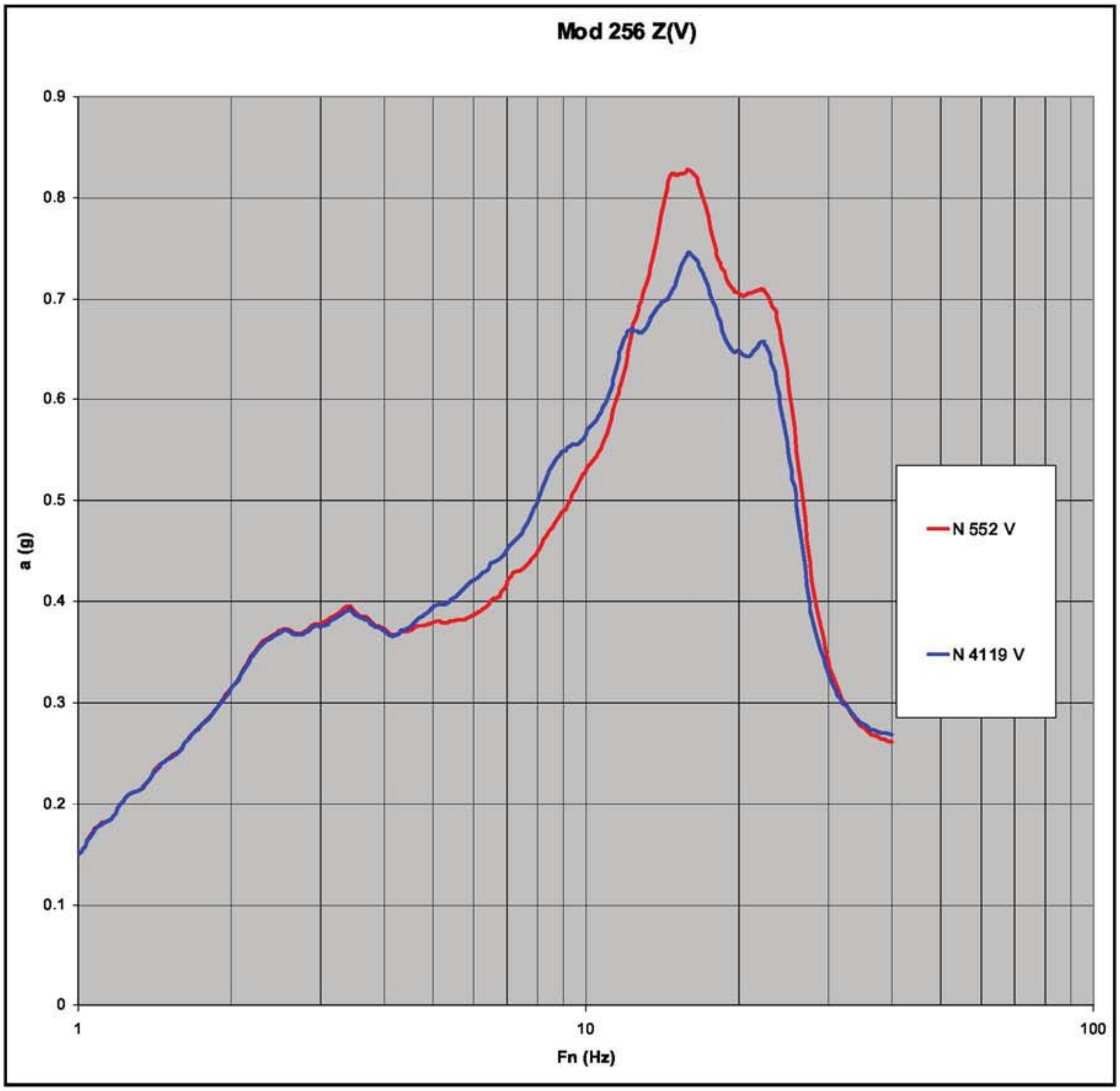

Figure A.2.2-12 – Model 256 set 2 point candidates for Vertical direction

As shown in Figure A.2.2-12, Point 4119 (blue curve) envelopes Point 552 (red curve) in the frequency range 4.2 – 10.3 Hz, exceeding it by a maximum of 9% near 9 Hz. Point 552 envelopes above 10.3 Hz, up to a maximum of 11% at 16 Hz. The cumulative effective mass plot for this model, Section A.3.3.2, indicates that ~42% of the effective mass participates at frequencies under 10.3 Hz, leaving most of the remaining cumulative effective mass above 10.3 Hz. This slightly favors Point 552. Point 4119 is located below the 2nd basement floor at the heat exchanger nozzles (model termination locations). Point 552 is located on the 1st basement floor, centered between the four primary pumps and is central to Model 256 piping and most of its vertical supports. Based on physical location aspects, both points (552 and 4119) in addition to point 892 are the PSSI point selections for Model 256 in the Vertical direction. Figure A.2.2-13 shows the response spectra for these three PSSI point selections. Table A.2.2-4 lists the orthogonal direction PSSI point selections for Model 256.

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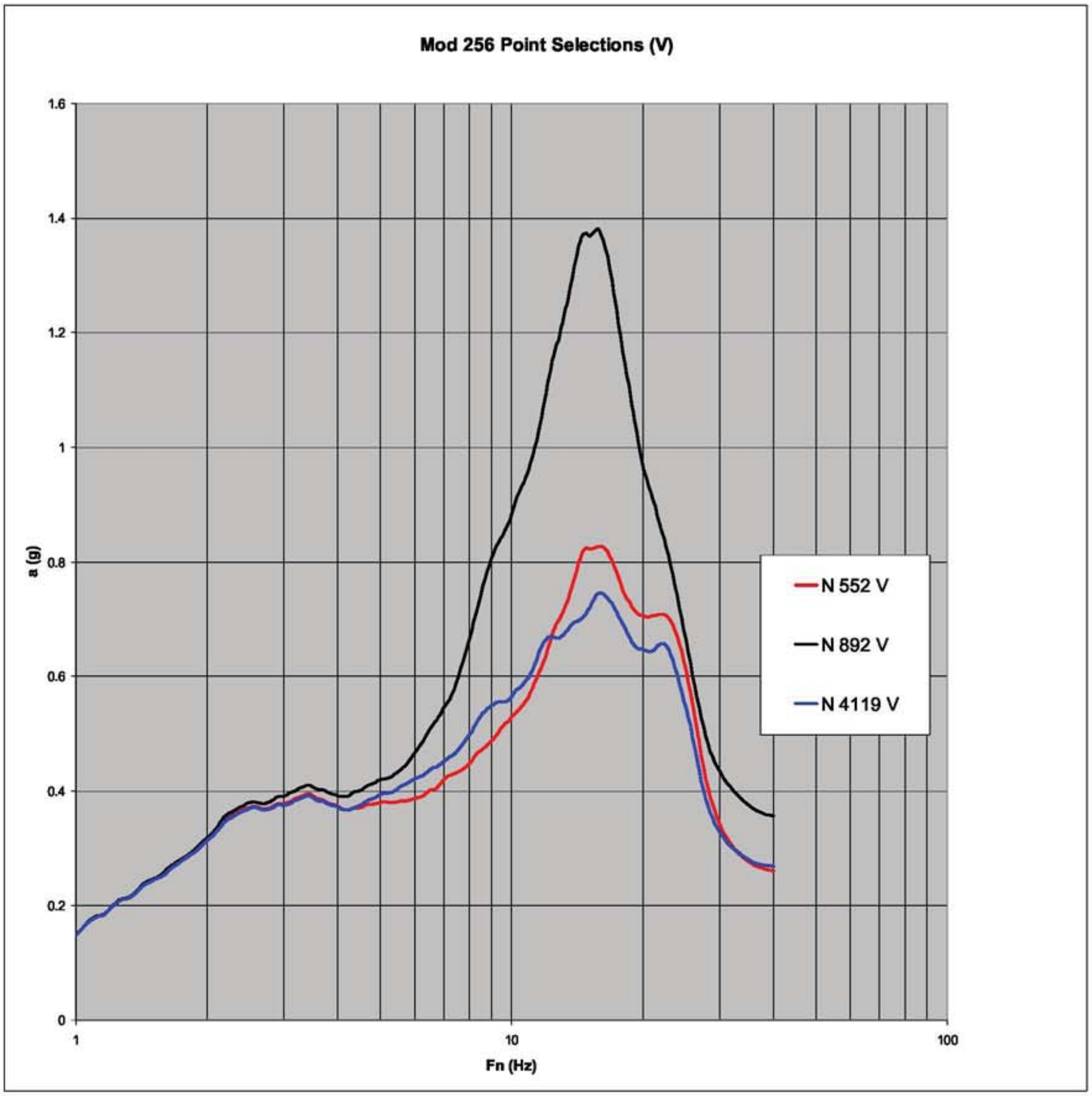

Figure A.2.2-13 – Model 256 PSSI point selections for Vertical direction

Table 2.1-4 – Summary of Model 356 PSSI point selections.

Model 256 PSSI Point Selections		
E-W	N-S	Vertical
542	552, 815	552, 892, 4119

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A.2.3 – Model 14 PSSI Point Selections

The purpose of this section is to select PSSI points corresponding to time history input for Model 14.

Model 14 is comprised of two original Davidson's models, with Model 1 being the primary piping and Model 4 connecting to Model 1. Model 14 addresses reactor vessel outlet to heat exchanger piping (Model 1) with demineralizer and pressurizing piping (Model 4) connecting to Model 1 and terminating at various wall and floor penetrations, as shown in Figures A.2.3-1 and A.2.3-2. Model 14 is composed of piping diameters ranging from 6-in up through 36-in (i.e., 6-in, 18-in, 20-in, 24-in, 30-in, & 36-in). Although shown in Figure A.2.3-1, preliminary calculations demonstrate that E-W support MS-6 and N-S support MS-4 added too much stiffness to piping and have been removed (part of Recommendations section in main report) from the Model 14.

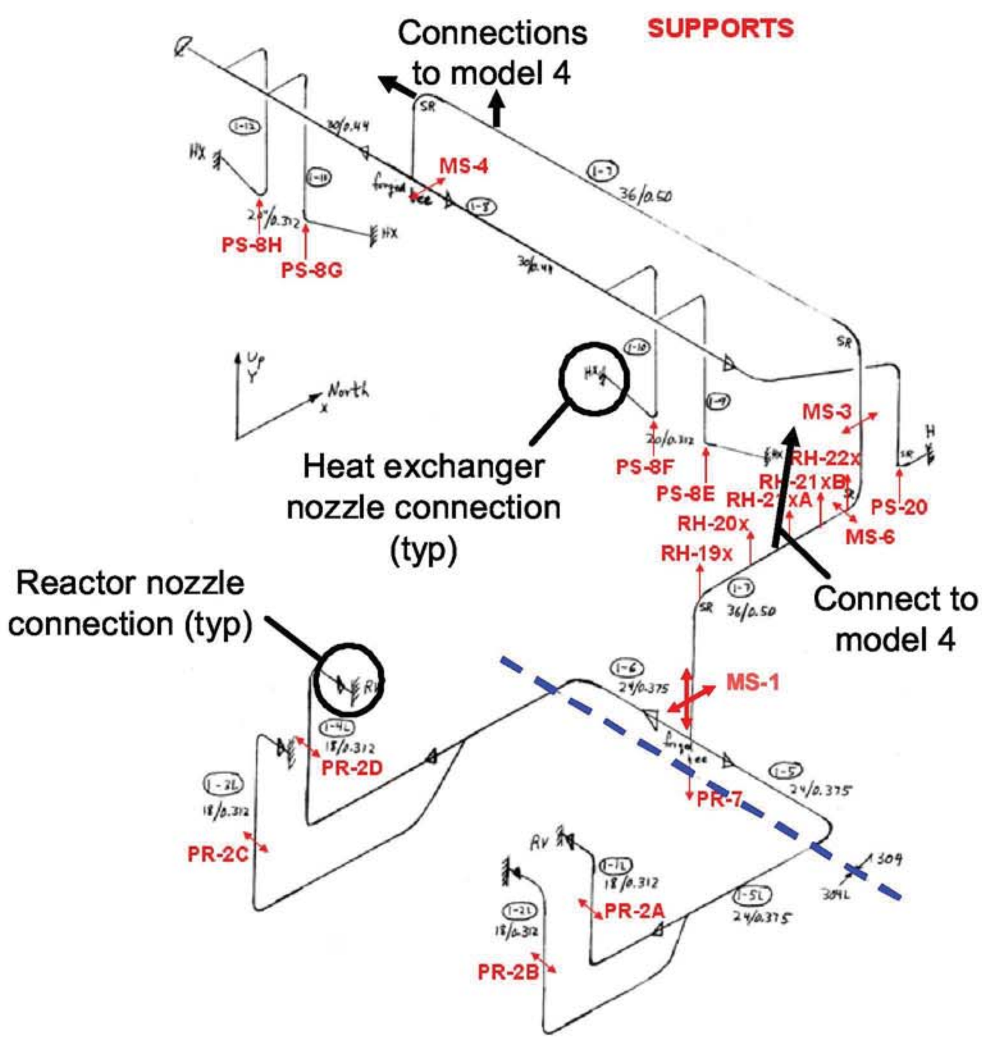

Figure A.2.3-1 – Piping section of Model 14, showing original 1 beam model and connections.

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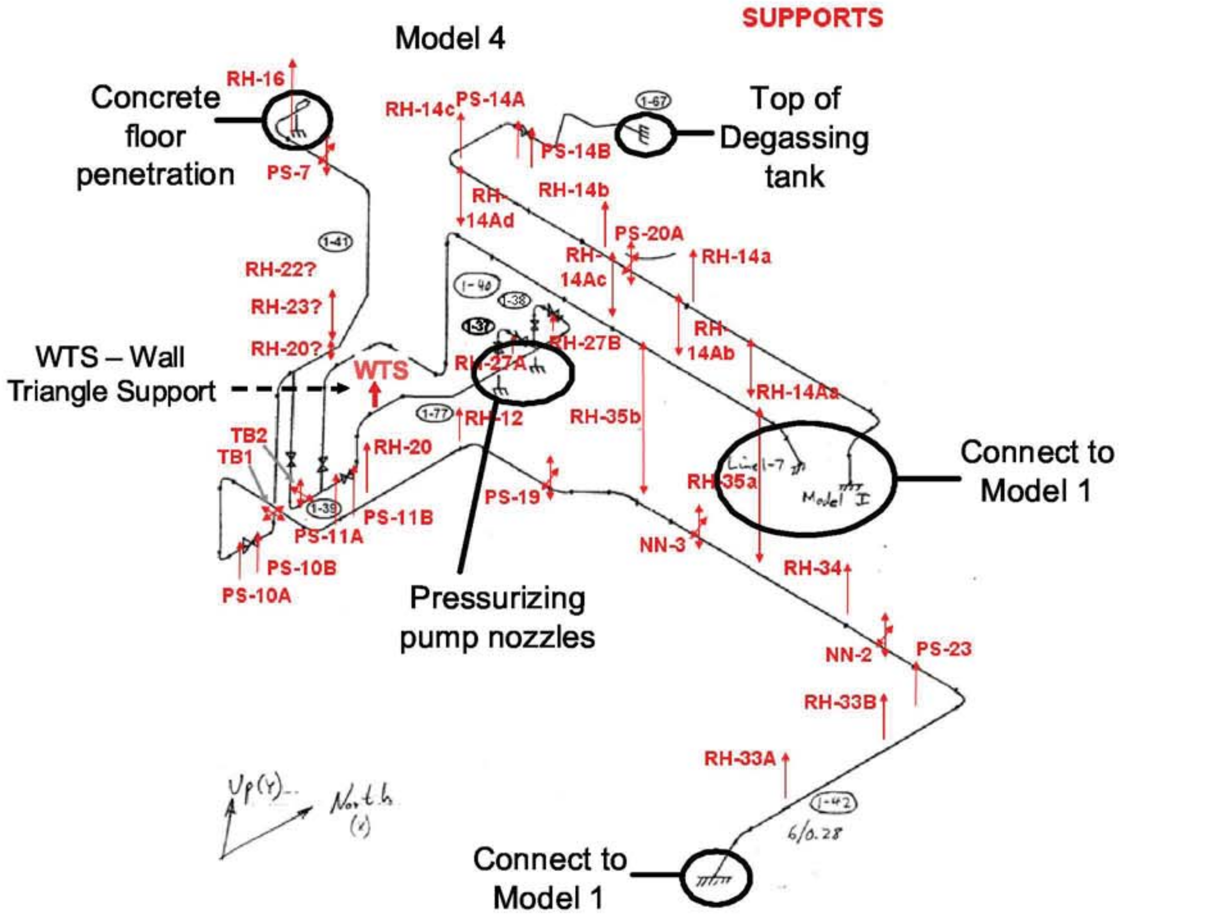

Figure A.2.3-2 – Piping section of Model 14, showing original 4 beam model with terminations.

Model 14 piping is primarily composed of 304 stainless steel. Piping in the near vicinity of the reactor vessel is fabricated from 304L stainless steel. The dashed blue line (in Figure A.2.3-1) shows the boundary between 304 and 304L stainless steels.

Figures A.2.3-3 through A.2.3-6 are reprints of the analyses [2, 19] showing PSSI points corresponding to each orthogonal direction within Model 14. A set of PSSI point candidates for each of the three Model 14 coordinate directions (E-W, N-S, Vertical) are chosen with respect to dominant supports. Figures A.2.3-3 and A.2.3-4 show different points on the first (or ground floor). Figure A.2.3-4 is an additional set of points for the ground floor, created at a later date than Figure A.2.3-3. Model 14 PSSI point candidates are designated by different shapes corresponding to each of the orthogonal directions.

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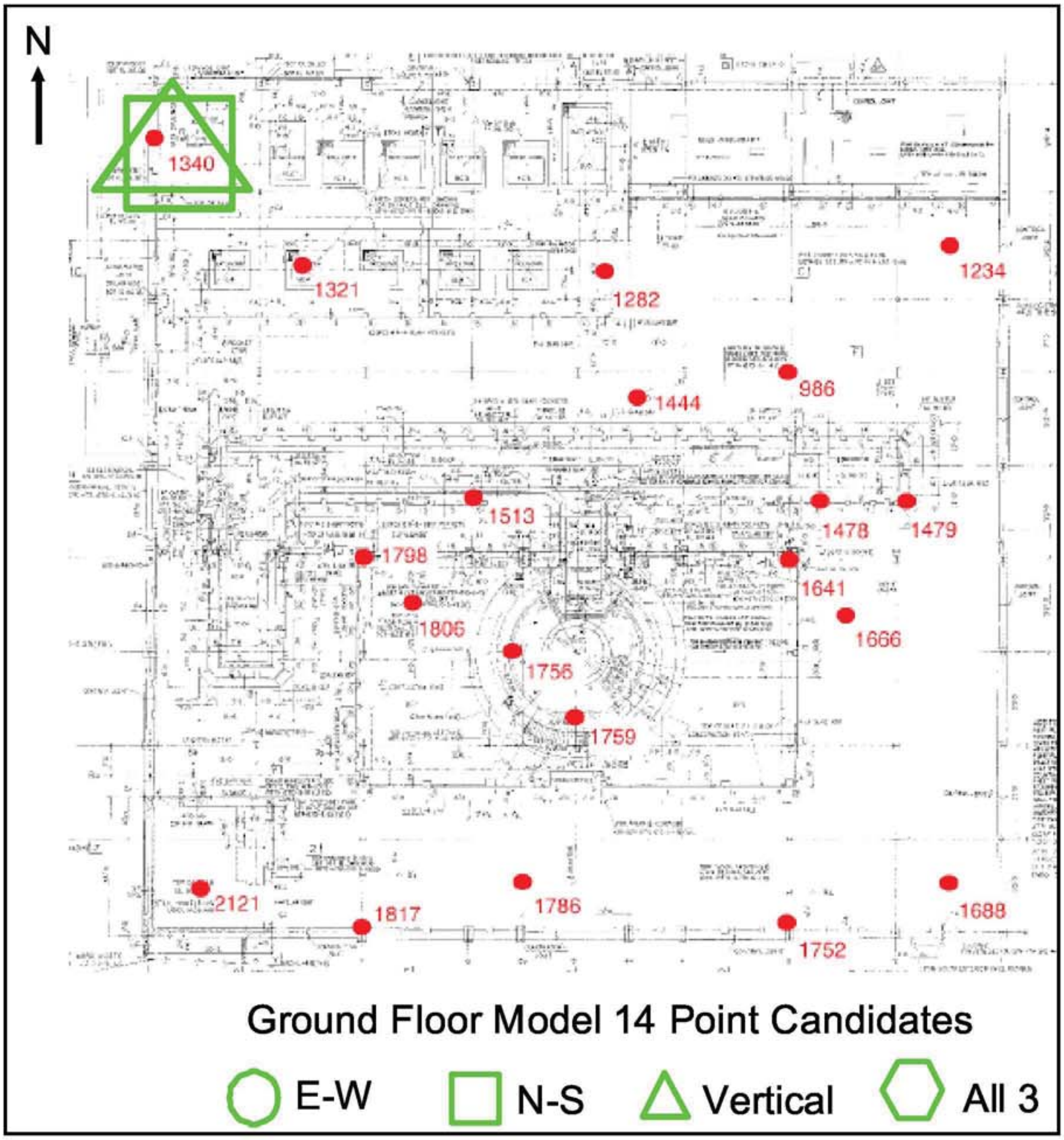

Figure A.2.3-3 – Ground floor 14 model's PSSI point candidates.

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Title:	ATR Primary Coolant System Seismic Evaluation						
Authors:	D. T. Clark	**Date:** 09/30/08	**Checker:**	M. J. Russell		**Date:**	09/30/08

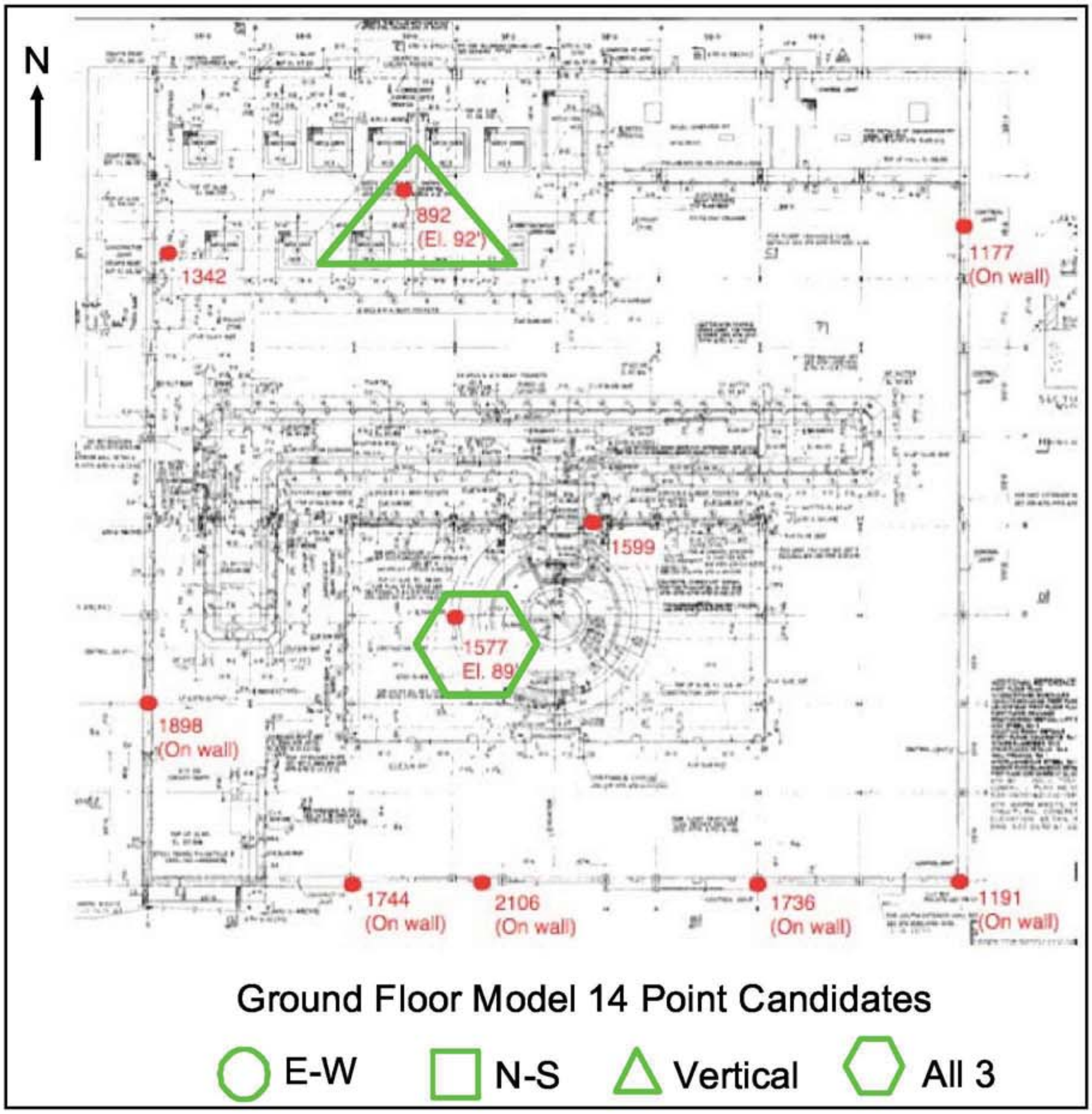

Figure A.2.3-4 – Additional Ground floor 14 model's PSSI point candidates, created at later date.

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Authors:	D. T. Clark	**Date:** 09/30/08	**Checker:** M. J. Russell	**Date:**	09/30/08

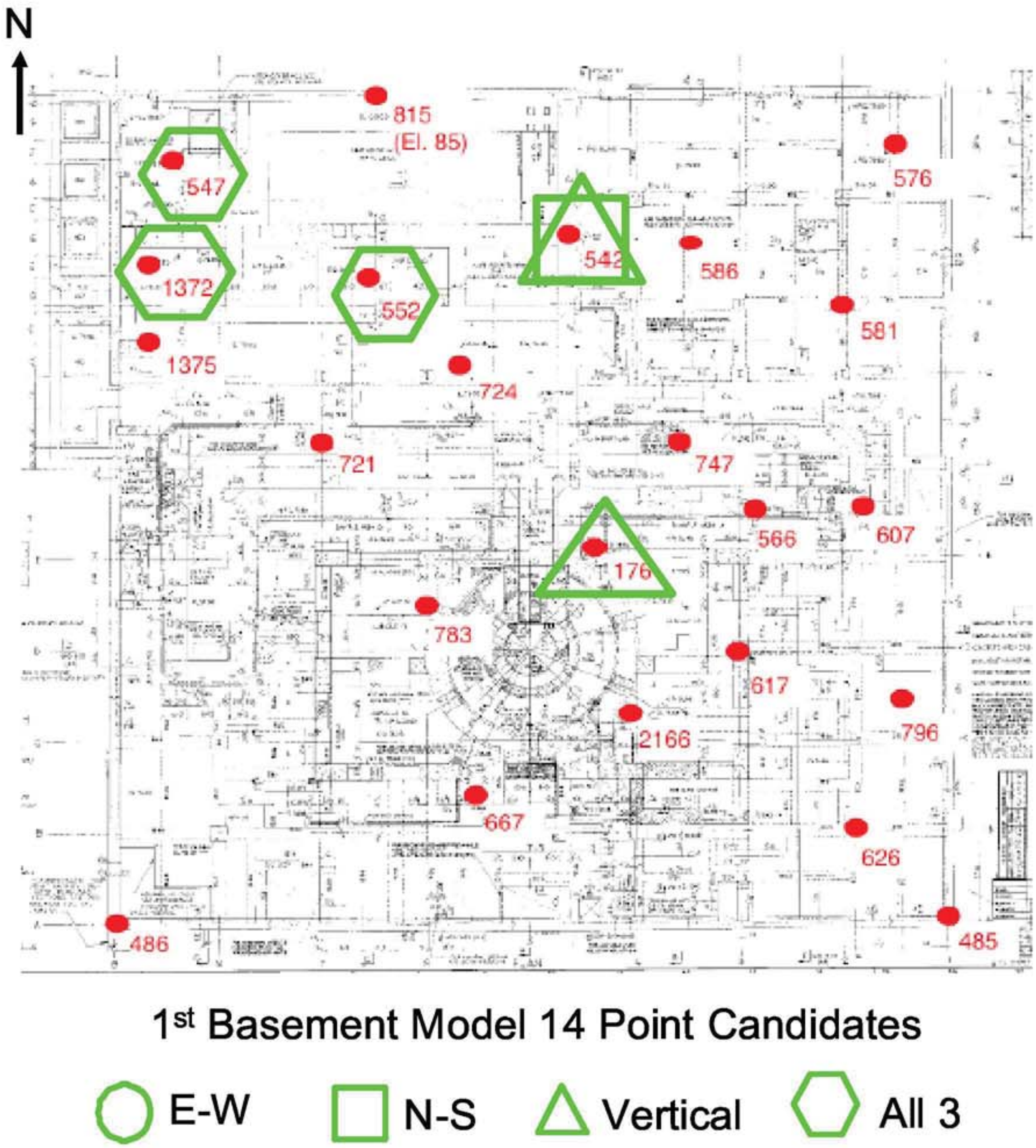

Figure A.2.3-5 – First basement 256 model's PSSI point candidates.

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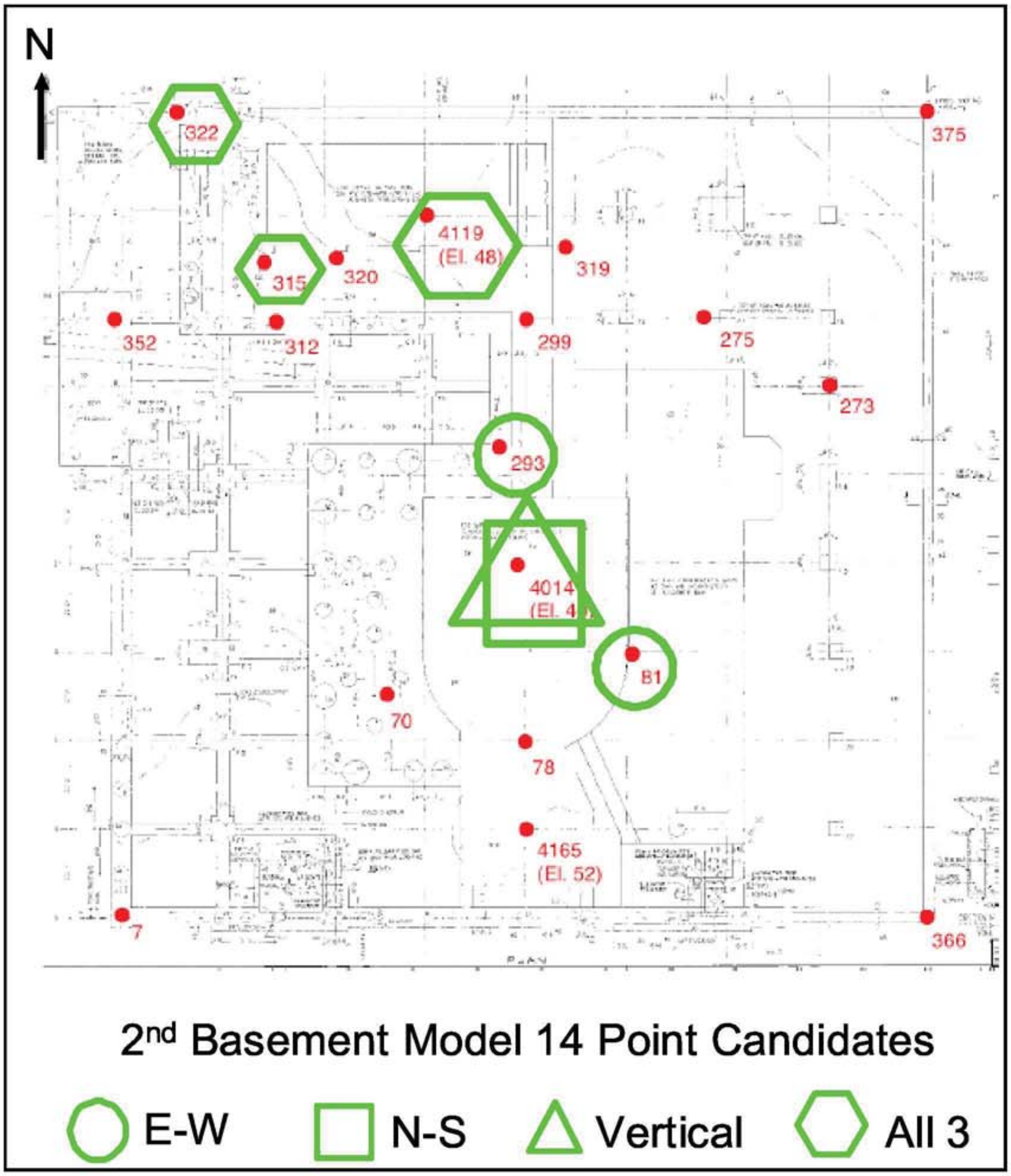

Figure A.2.3-6 – Second basement 14 model's PSSI point candidates.

Model 14 points are distributed between all three floor elevations. Table A.2.3-1 lists Model 14's PSSI point candidates for the E-W direction and provides a physical description corresponding to the location within Model 14 for each point candidate.

Table A.2.3-1 – Summary of 14 Model's PSSI point candidates in E-W direction. (here)

Model 14 PSSI Point Candidates for E-W Direction	
E-W Point Candidates	**Description**
81	Point 81 is located below the 2nd basement near lateral supports PR-1 and PR-2. There are four PR-2 supports with a pair located on both the east and west side of the reactor vessel. There is one PR-1 support located near each PR-2 pair. Support PR-1 is associated with the Pilot model and PR-2 is associated with Model 14.
293	Point 293 is located on the second basement at the South end of the West wall of the piping tunnel.
315	Point 315 is located on the 2nd basement floor at an interior West concrete wall, where tie-back supports TB1 and TB2 are. In this vicinity, the piping is mostly 6-in diameter. TB1 restrains E-W and N-S directions and TB2 restrains E-W and Vertical directions.
322	Point 322 is located on the 2nd basement at the West end of the North outside wall. This point provides input to supports for piping that branches off Valve GT-D-1-33 – previously described in Table A.2.2-1.
547	Point 547 is located at the 1st basement elevation near line 1-49 grouted wall penetration and the PS-14A and -14B vertical supports.
1577	Point 1577 is located within the Capsule Nozzle Trench area (between ground and 1st basement elevations) and positioned at the reactor's anchorage to the ATR building structure. Data for this point defines motion at the outlet reactor nozzles in Model 14.
4119	Point 4119 is located below the 2nd basement floor where the 14 piping connects to the heat exchanger's inlet nozzles and near vertical supports PS-8E, -8F, -8G, -8H and -20.

As shown in Table A.2.3-1, Model 14 has seven PSSI point candidates in the E-W direction. Figure A.2.3-7 illustrates the combined response spectra for the E-W point candidates.

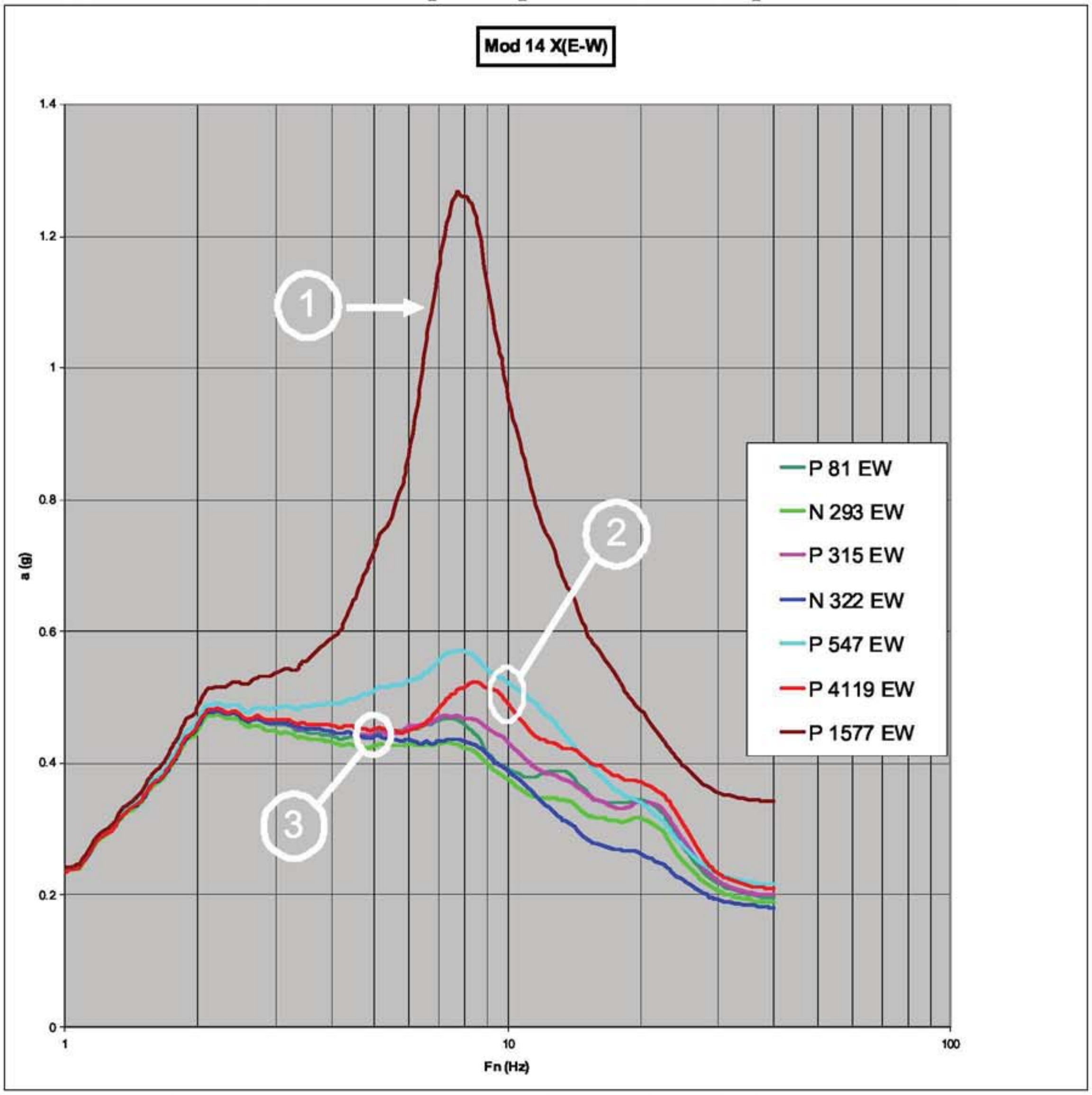

Figure A.2.3-7 – Model 14's point candidates for E-W direction.

As shown in Figure A.2.3-7, there are three sets of response spectra point candidates that are close to each other in amplitude and shape. Clearly, point 1577's response spectra (set 1) dominates all PSSI point candidates and is selected as one point time history input for Model 14 in the E-W direction. For set 2, point 547's response spectrum envelopes point 4119 from 0 to 10.6 Hz, which accounts for 72% of the cumulative effective mass (Section A.3.3.3). Thus, point 547 is selected as a second point time history input for Model 14's E-W direction. A closer look at the remaining point candidates (set 3) is required to identify other PSSI point selections for the E-W direction. Figure A.2.3-8 illustrates response spectra curves for set 3.

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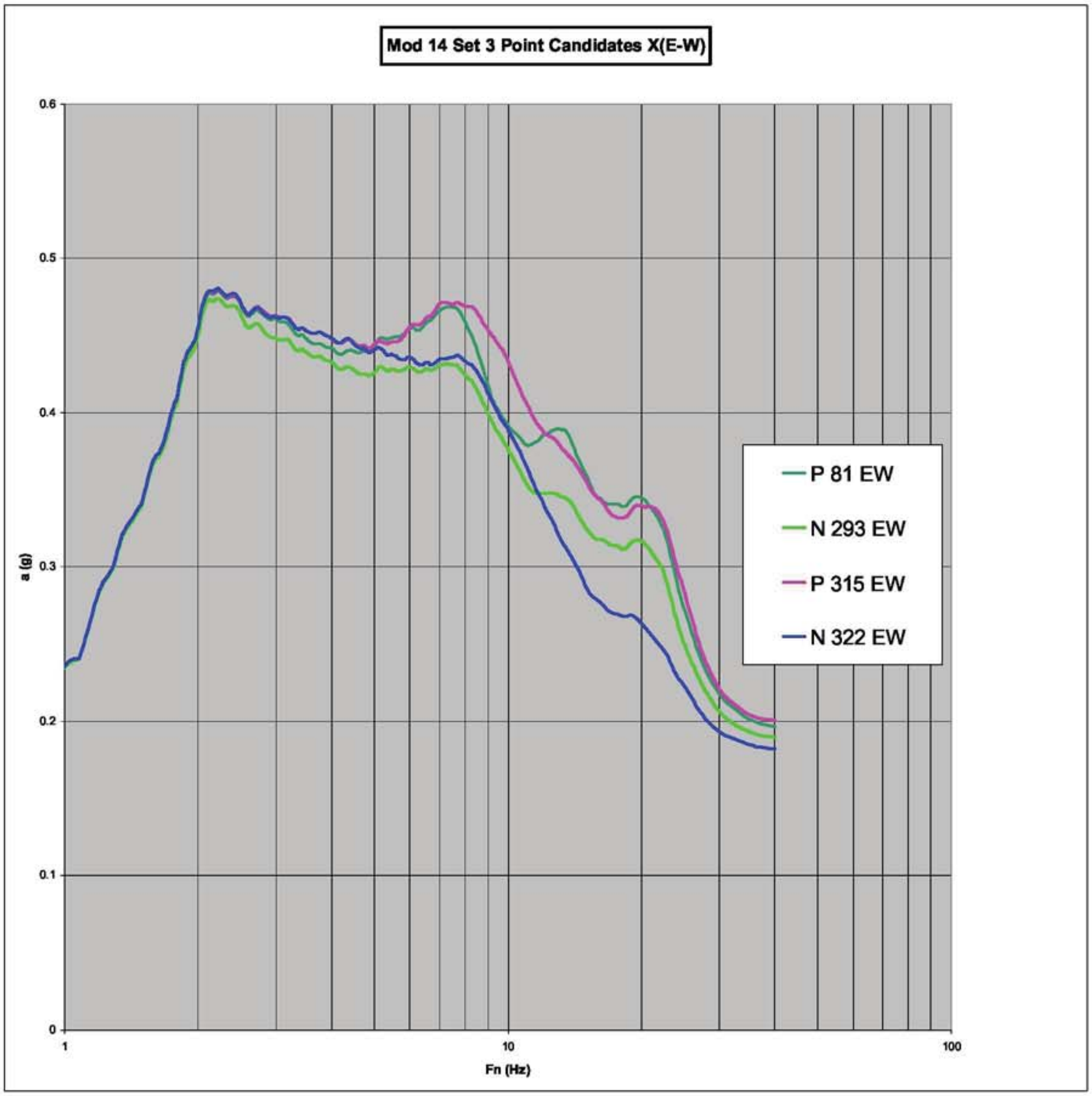

Figure A.2.3-8 – Model 14's set 3 point candidates for E-W direction.

As shown in Figure A.2.3-8, Point 315 (magenta) envelopes Points 293 (green) and 322 (blue). Point 315 envelopes Point 81 in the frequency range 0 – 10.3, exceeding it by a maximum of 11% near 10 Hz. Point 81 envelopes above 10.3 Hz through 11 Hz, up to a maximum of 5% at 20.4 Hz. The cumulative effective mass plot for this model, Section A.3.3.3, indicates that 72% of the effective mass participates at frequencies under 10.3 Hz. This favors the Point 315 data. Thus, based on cumulative effective mass and spectral envelopment, point 315 is the last PSSI point selected for Model 14 in the E-W direction. Figure A.2.3-9 shows the response spectra for the three PSSI point selections, which are used for Model 14's E-W time history input.

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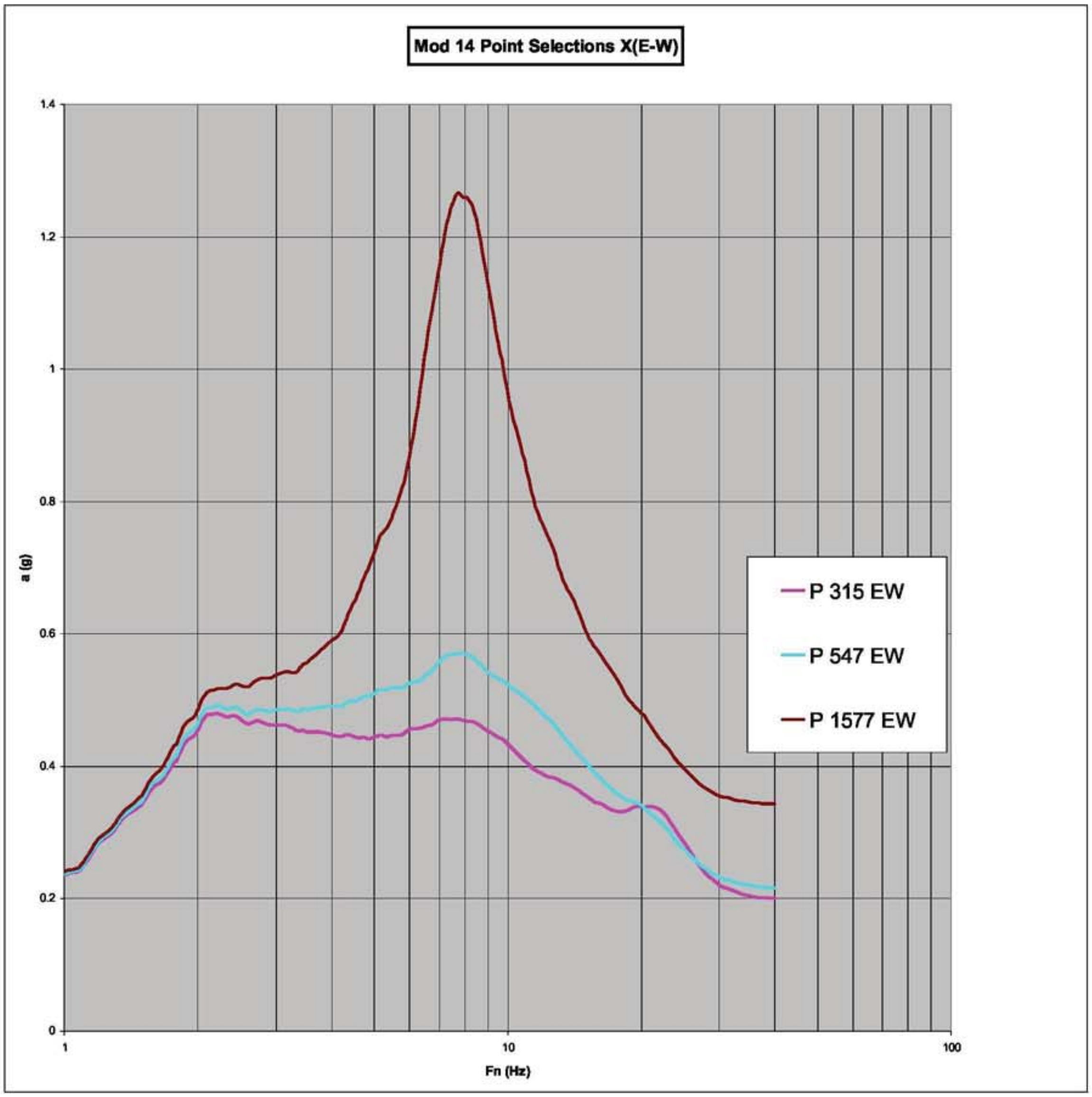

Figure A.2.3-9 – Model 14's PSSI point selections for the E-W direction.

Table A.2.3-2 lists Model 14 PSSI point candidates for the N-S direction and provides a physical description corresponding to the location within Model 14 for each point candidate.

Table A.2.3-2 – Summary of 14 Model's PSSI point candidates in N-S direction.

Model 14 PSSI Point Candidates for N-S Direction	
N-S Point Candidates	**Description**
315	Point 315 is located on the 2nd basement floor at an interior West concrete wall, where tie-back supports TB1 and TB2 are – previously described in Table A.2.3-1.
322	Point 322 is located on the 2nd basement at the West end of the North outside wall. This point provides input to supports for piping that branches off Valve GT-D-1-33 – previously described in Table A.2.2-1.
542	Point 542 is located on an East wall at the tunnel's North side and is close to the N-S support MS-3 snubber. This location is near the center of the 14 model's larger diameter piping lines.
547	Point 547 is located above the 1st floor elevation near line 1-49 grouted wall penetration – previously described in Table A.2.3-1.
552	Point 552 is located on the 1st basement floor, centered between the four primary pumps. This location is central to Model's 14 main piping – previously described in Table A.2.3-1
1340	Point 1340 is located at the ground floor and is near rod hanger supports RH-14Ad, -14c and-16 and support PS-7. Point 1340 is on the North-West outskirts of Model 14.
1577	Point 1577 is located within the Capsule Nozzle Trench area (between ground and 1st basement elevations) and positioned at the reactor's anchorage to the ATR building structure. Data for this point defines motion at the outlet reactor nozzles in Model 14.
4014	Point 4014 is located below the 2nd basement near snubber MS-1, which restrains the piping at an angle including both N-S and Vertical motion.
4119	Point 4119 is located below the 2nd basement floor where Model 14 piping connects to and terminates at the heat exchanger's inlets nozzles – previously described in Table A.2.3-1..

As shown in Table A.2.3-2, Model 14 has nine PSSI point candidates in the N-S direction. Figure A.2.3-10 illustrates the combined response spectra for the N-S point candidates.

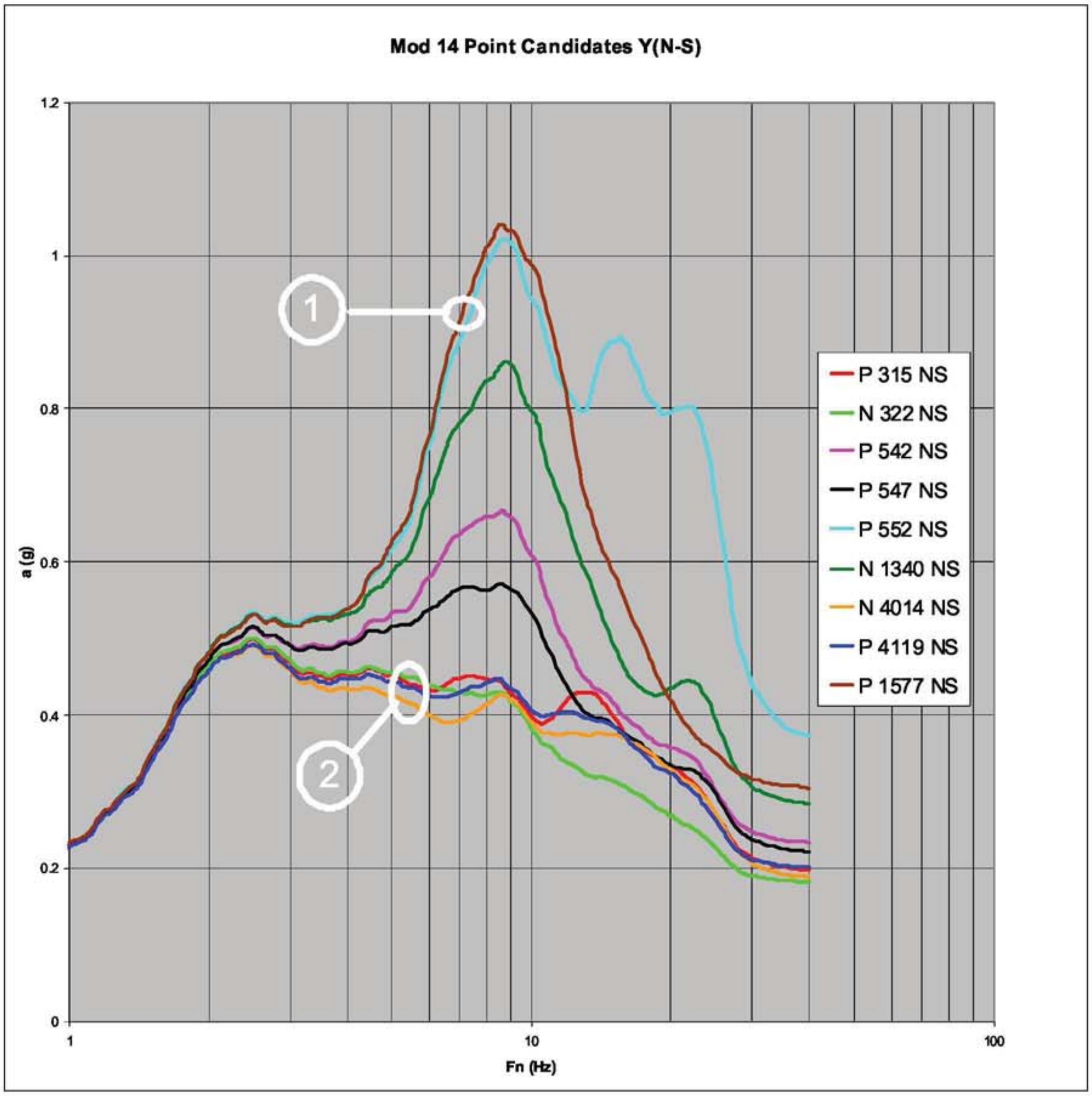

Figure A.2.3-10 – Model 14's point candidates for N-S direction.

Unlike previous PCS models and directions, Model 14 N-S direction has very few supports. Thus, physical locations within Model 14 are targeted, more so than enveloping response spectra. Figure A.2.3-10 shows set 1 that is comprised of two PSSI Points (1577-brown and 552-cyan) which are similar in amplitude and shape until 10.3 Hz, where there is a distinct change of shape. Point 552 is centered between the four primary pumps located at Model 14's center and is close to the N-S support MS-4 snubber. PSSI Point 552 is selected in this case for input based on physical location and having a wider frequency band than Point 1577.

Other PSSI point response spectrum curves are also selected, targeting specific N-S supports within Model 14. Point 542 (magenta) is selected because it is close to the N-S MS-3 snubber support.

Point 547 (black) is selected because it is close to a grouted wall penetration near the pressurizing pumps, located in the North-West corner of the 1st basement. Point 1340 (dark green) is selected for its position near a N-S support on the North West outskirts of Model 14. Set 2 point response spectra are closely spaced and require further scrutiny. Figure A.2.3-11 shows set 2 point candidates.

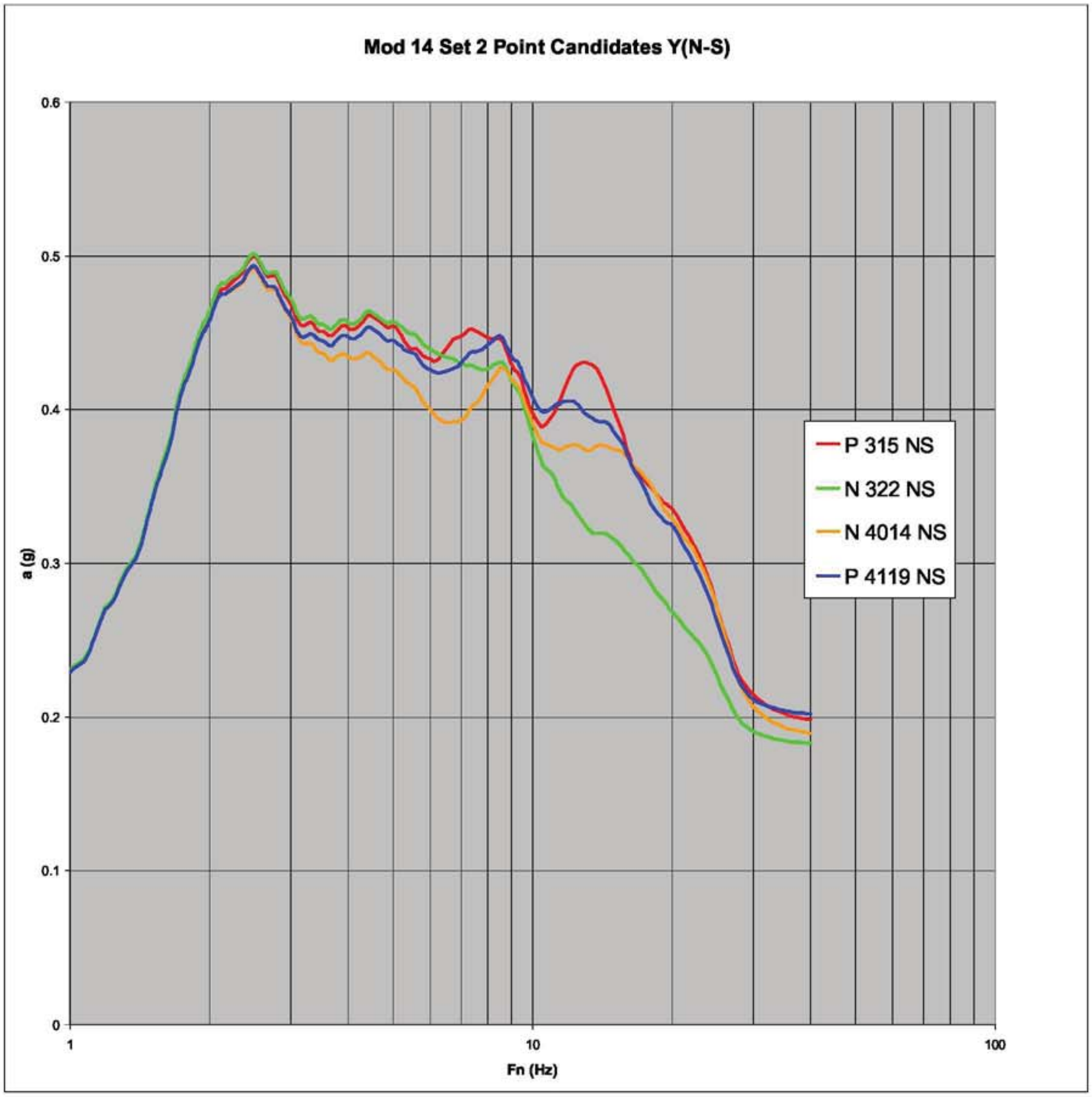

Figure A.2.3-11 – Model 14's set 2 point candidates for N-S direction.

As shown in Figure A.2.3-11, Point 315 (red) envelopes Point 4014 everywhere except for a negligible excursion (less than 1%) near 17 Hz. It envelopes Point 4117 (blue) everywhere under 32 Hz, except for a short (2%) excursion from 8 to 11 Hz. Point 315 is enveloped by Point 322 under 6 Hz, by 2% at most. It envelopes Point 322 above 6 Hz, by up to 25%. Figure A.3.3-2 indicates that

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around 40% of the modal mass is participating under 6 Hz. All of these factors support the selection of Point 315 as final Point for input to the model.

Figure A.2.3-12 shows the response spectra for the five PSSI point selections to be used for Model 14's N-S time history input.

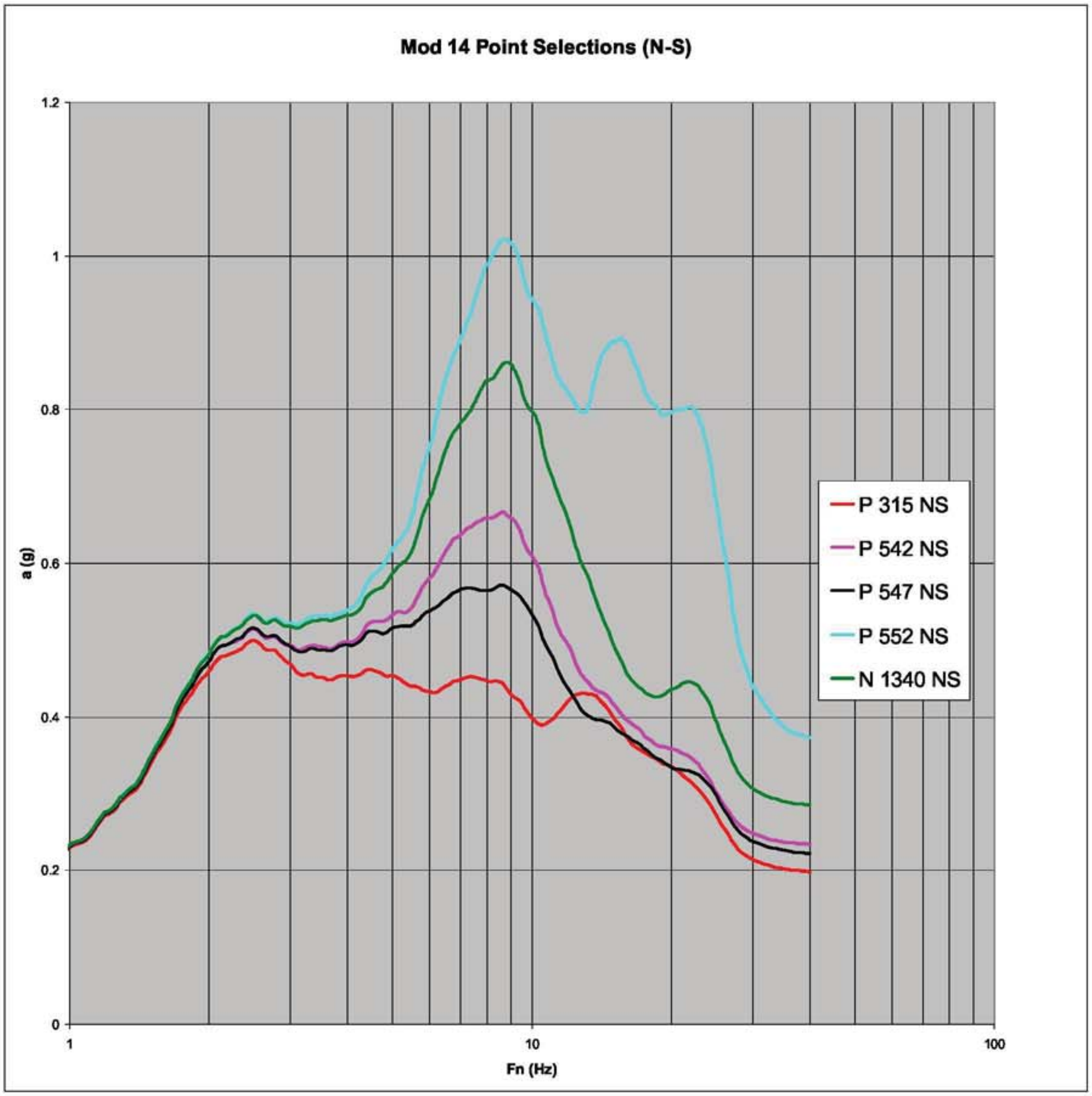

Figure A.2.3-12 – Model 14's PSSI point selections for N-S direction.

Table A.2.3-3 lists Model 14 PSSI point candidates for the Vertical direction and provides a physical description corresponding to the location within Model 14 for each point candidate.

Table A.2.3-3 – Summary of 14 Model's PSSI point candidates in Vertical direction.

Model 14 PSSI Point Candidates for Vertical Direction	
N-S Point Candidates	**Description**
176	Point 176 is located on the underside (or ceiling) of the 1st basement, in the vicinity of the Southern tunnel opening near support RH-23x.
315	Point 315 is located on the 2nd basement floor at an interior West concrete wall, where tie-back supports TB1 and TB2 are. – previously described in Table A.2.3-1.
542	Point 542 is located on an East wall at the tunnel's North side and is close to the N-S support MS-3 snubber. This location is near the center of the 14 model.'s larger diameter piping lines.
547	Point 547 is located above the 1st floor elevation near line 1-49 grouted wall penetration – previously described in Table A.2.3-1.
552	Point 552 is located on the 1st basement floor, centered between the four primary pumps and is close to the N-S support MS-4 snubber. This location is central to Model's 14 main piping – previously described in Table A.2.3-1
892	Point 892 is located on the North wall of the Primary Coolant pump cubicles some 6-ft below the first floor. It is near rod hangers RH-14A, -14Aa, -14Ab, -14Ac (Vertical) and PS-20A (Vertical). These are all supports for 6-in piping.
1340	Point 1340 is located at the ground floor and is near rod hanger supports RH-14Ad, -14c and-16 and support PS-7. Point 1340 is on the North-West outskirts of Model 14.
1372	Point 1372 is located on the 1st basement floor, close to the two emergency pumps.
1577	Point 1577 is located within the Capsule Nozzle Trench area and defines motion at the outlet reactor nozzles in Model 14.
4014	Point 4014 is located below the 2nd basement floor and near Vertical support MS-1 snubber.
4119	Point 4119 is located below the 2nd basement floor where Model 14 piping connects to and terminates at the heat exchanger's inlets nozzles – previously described in Table A.2.3-1.

As shown in Table A.2.3-3, Model 14 has eleven PSSI point candidates in the Vertical direction. Figure A.2.3-13 illustrates response spectra for the Vertical point candidates.

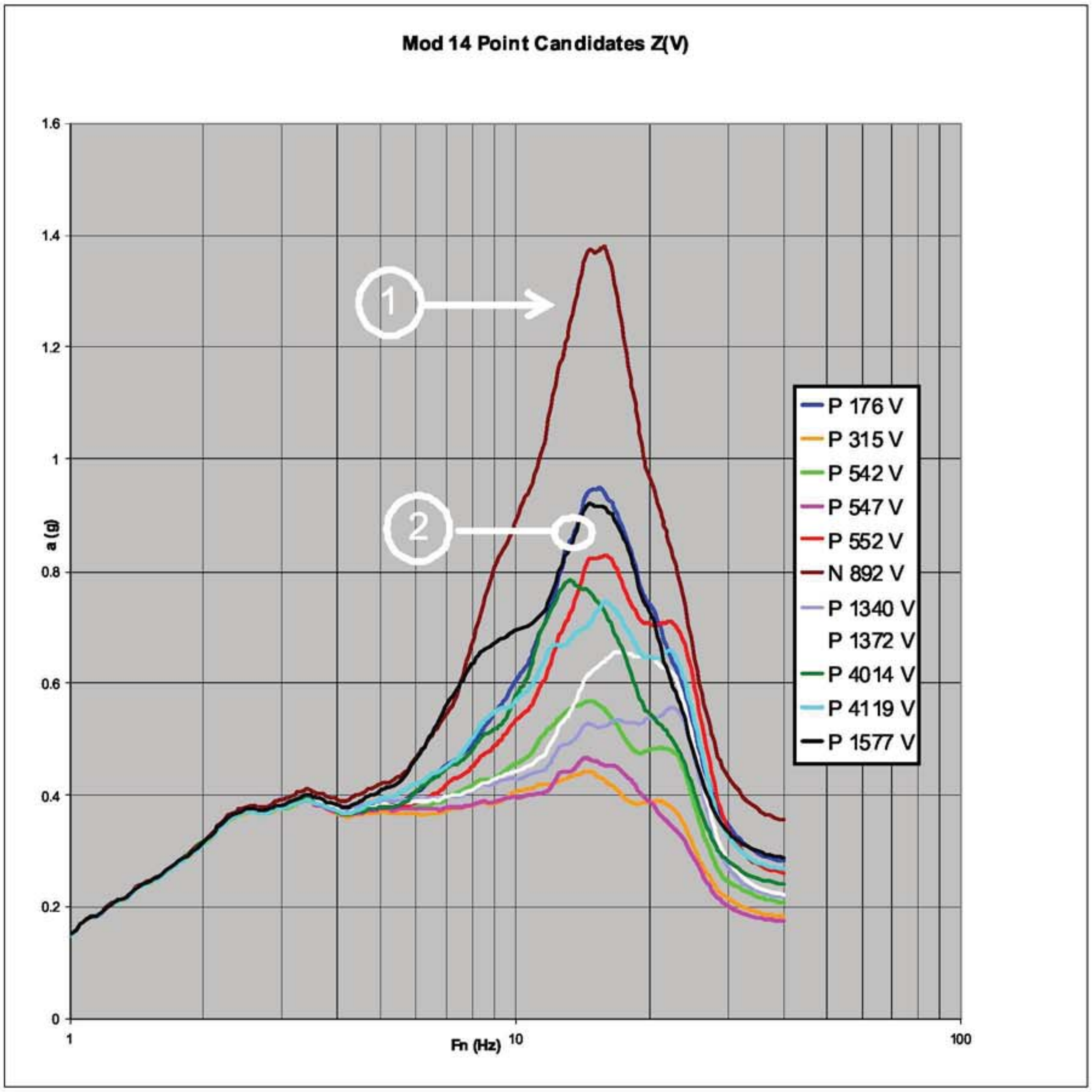

Figure A.2.3-13 – Model 14's PSSI point candidates for the Vertical direction.

Model 14's Vertical direction has numerous PSSI point input to select from. Most of the vertical supports are rod-hangers with just a few horizontal supports. Clearly, points 176 (blue), 1577 (black) and 892 (brown) envelope all remaining response spectra, with point 892 dominating. A closer look at points 176 and 1577 (set 2 in the Figure) response spectra is merited. This is done in Figure A.2.3-14.

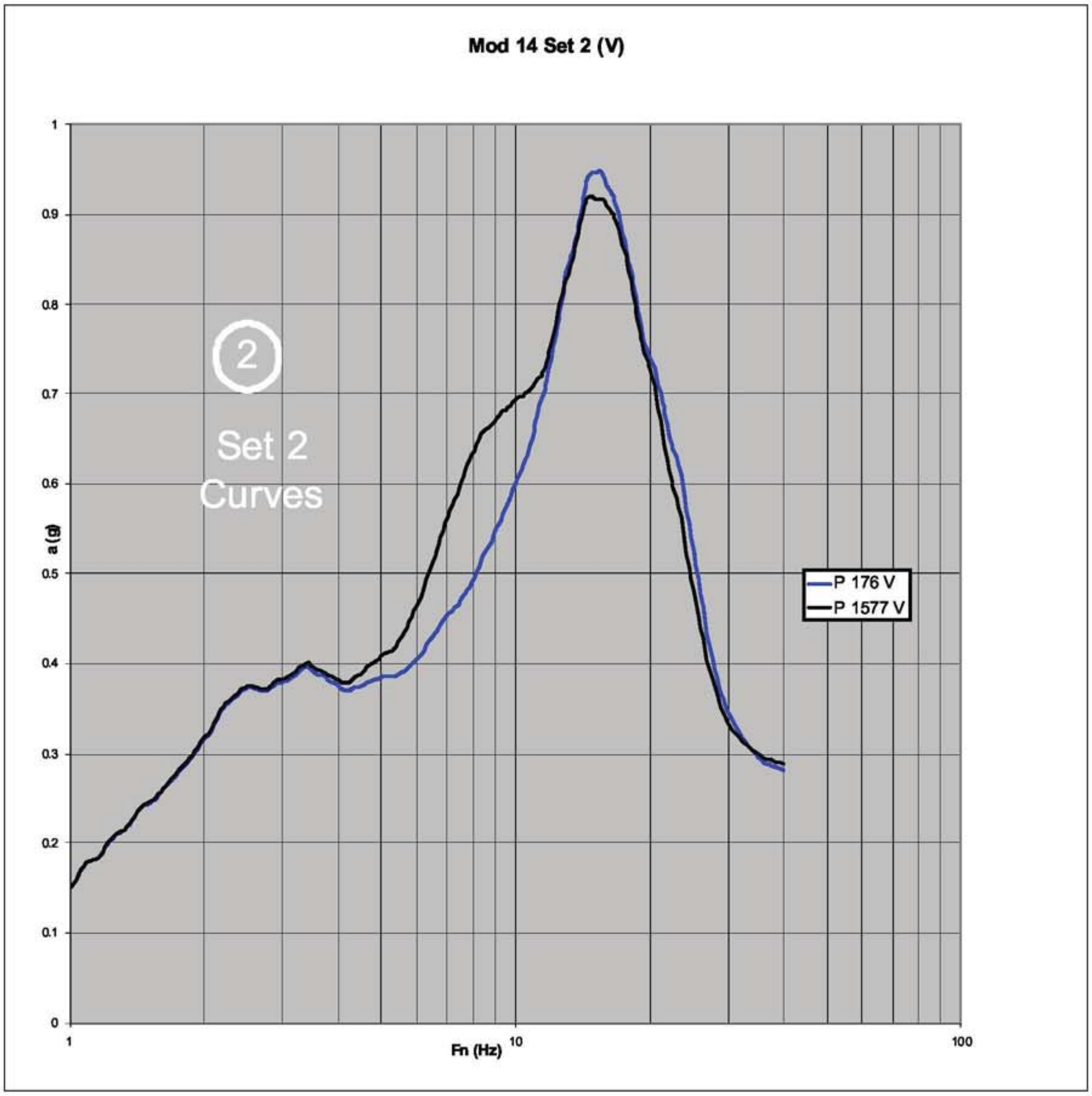

Figure A.2.3-14 – Model 14's set 2 PSSI point candidates for the Vertical direction.

Figure A.2.3-14 is a duplicate of Figure A.2.1-14 (Pilot Model Vertical) and has already been evaluated, demonstrating that PSSI point 1577 (black) governs. The Pilot and Model 14 both terminate at the reactor vessel's inlet and outlet nozzles and are governed by point 1577 which is located within the Capsule Nozzle Trench where the vessel is anchored. Both Model piping lines are held by supports at the South end of the tunnel near point 176 (blue). As previously justified, point 1577 has been selected based on physical location, stiffened outlet nozzles, widest frequency band, and cumulative effect mass response at dominating frequencies. Figure A.2.3-15 shows the response spectra for the two PSSI point selections (892 and 1577), which are used for Model 14's Vertical time history input. Table a.2.3-4 summarizes Model 14's PSSI Point selections.

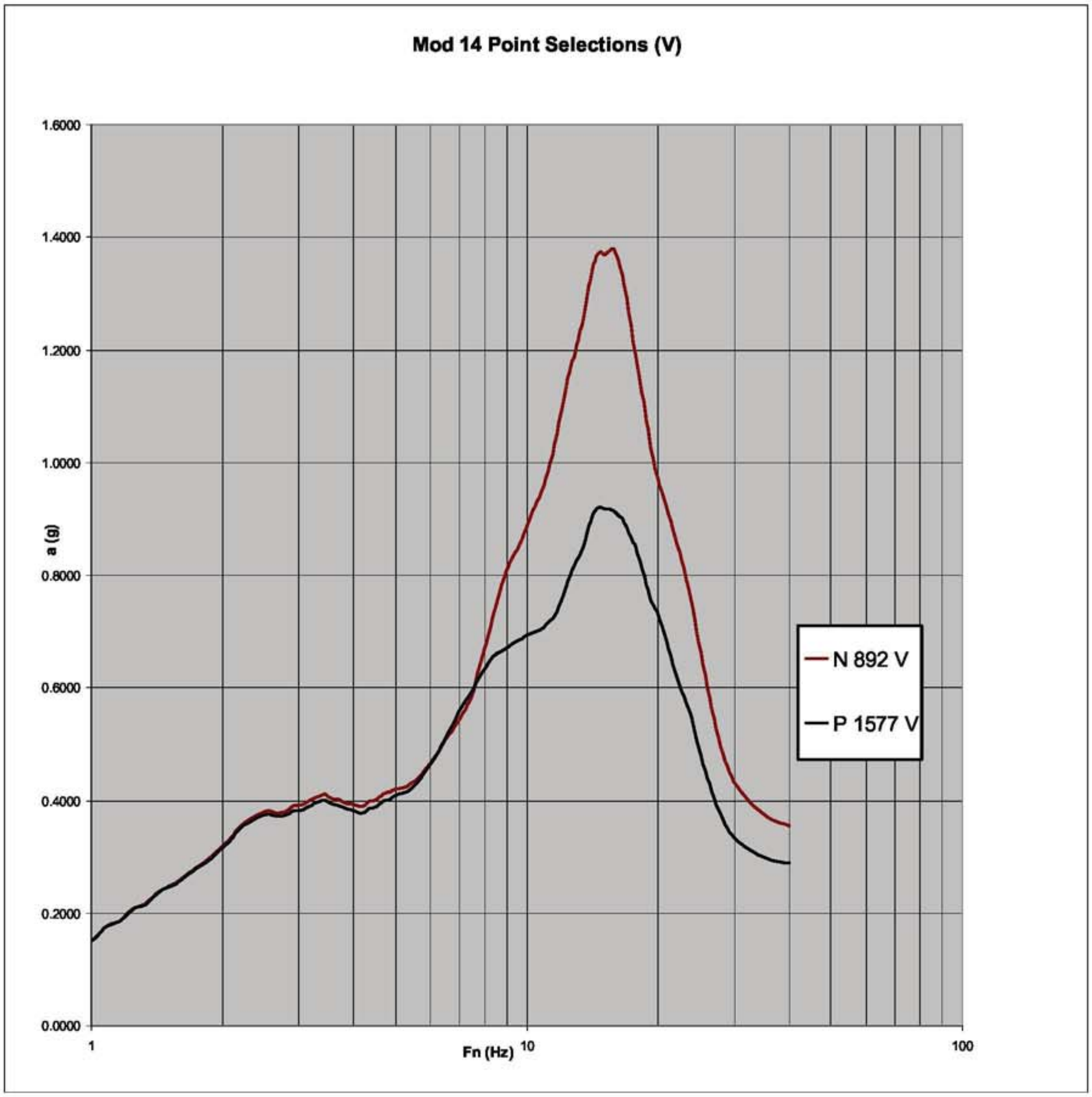

Figure A.2.3-15 – Model 14's PSSI point selections for the Vertical direction

Table A.2.3-4 lists the orthogonal direction PSSI point selections for Model 14.

Table 2.3-4 – Summary of Model 14 PSSI point selections.

Model 14 PSSI Point Selections		
E-W	N-S	Vertical
315, 542, 1577	315, 542, 547, 552, 1340	892, 1577

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A.2.4 – PCS Model PSSI Point Selections Summary

The purpose of this section is to summarize the PSSI points selected for each model.

Table 2.4-1 identifies all point candidates, how they are restrained in each PCS model's direction, and summarizes the PSSI point selections for each of the three models.

Table 2.4-1 – Summary of PSSI point candidates & selections used within PCS models.

Point Candidates	**Model 3**		**Model 256**		**Model 14**	
81	x	ew			x	ew
176	x	v			x	v
293					x	ew
315			x	all	x	all
319	x	ew/v	x	all		
322			x	all	x	all
542	x	v	x	all	x	ns/v
547	x	v	x	all	x	all
552	x	all	x	all	x	all
815	x	all	x	all		
892			x	v	x	v
1340			x	ns/v	x	ns/v
1372	x	all	x	all	x	all
1577	x	all			x	all
4014					x	ns/v
4119			x	all	x	all
Selected PSSI Points	**EW**	319, 552 1577	EW	542	EW	315,547, 1577
	NS	552, 815, 1372	NS	552, 815	NS	315, 542, 547, 552, 1340
	V	552, 1577	V	552, 892, 4119	V	892, 1577,

Appendix A.3
Time History and Model Damping Development

One output of the engineering calculation "Probabilistic Soil-Structure Interaction Analysis of TRA-670 [2] (called the PSSI from here forward) is acceleration time histories. These time histories occur at defined locations in the TRA-670 substructure. For each defined location, nine time histories are output. The nine time histories consist of the motions in three directions output for each of the three earthquake directions. One purpose of this section of Appendix A is to describe the process used to convert each set of nine acceleration time histories into a form used as input for each ABAQUS TRA-670 piping model. The portion of the time history used for ABAQUS evaluation is also established.

As discussed in the body of this ECAR, the desired modal damping value for the TRA-670 piping models is 5%. However, the TRA-670 piping models are evaluated with direct dynamic time history analysis which doesn't provide an option for modal damping. Consequently, Rayleigh damping is used. Another purpose of this section of Appendix A is to describe the process used to develop appropriate Rayleigh damping values for each ABAQUS TRA-670 piping model.

The final purpose of this appendix is to validate programs used in this appendix that require validation.

The following sections (listed below) contain information used to evaluate the time histories and model damping development.

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A.3.1 – Time History Conversion Calculation

Conversion of time histories from the PSSI output to a form that can be used as ABAQUS input occurs in four basic steps. First, the PSSI output data is converted to a form that can be manipulated in Mathcad. Second, the time step of the data is reduced from 0.01 seconds to 0.005 seconds. Third, the drift in the velocity and displacement is minimized. Fourth, the acceleration time histories are organized into the form needed for an ABAQUS input file.

In order to demonstrate the time history conversion process, the complete process will be documented for the east-west motion for the output from the PSSI node 81. A similar approach is used on all of the time histories. Because the Mathcad is written to process multiple nodes at once, the calculation variables contain more data than is plotted to show PSSI node 81 results.

Table A.3.1-1 below shows the format of the PSSI time histories output. For each of the 32 realizations, the PSSI supplied three files named "TimeHistories_X.txt, "TimeHistories_Y.txt, and "TimeHistories_Z.txt representing single direction seismic runs for east-west, north-south, and vertical directions respectively. Each of these files is organized with x-, y-, and z-direction acceleration time histories output in order for the first output node. This process is then repeated for all of the nodes output.

Table A.3.1-1 – PSSI format for the output time histories.

```
Motion input
Dir. 1 - Realization 1 TH
  ACCELERATION RECORD IN THE  X-DIRECTION AT NODAL POINT NO.     7
  NO. OF POINTS = 4096

 0.003865 0.008706 0.011275 0.010047 0.007263 0.004656 0.001224-0.003105       1
-0.005323-0.003733-0.001433-0.002364-0.006320-0.010787-0.015106-0.019430       2
-0.021935-0.021036-0.018790-0.018288-0.018823-0.017362-0.013658-0.010000       3
                                                        .
                                                        .
                                                        .
-0.000427-0.000201 0.000118-0.000074-0.000329-0.000078 0.000227 0.000031     510
-0.000209 0.000028 0.000297 0.000114-0.000078 0.000141 0.000332 0.000150     511
 0.000032 0.000215 0.000269 0.000117 0.000182 0.000235-0.000083 0.000528     512
Motion input
Dir. 1 - Realization 1 TH
  ACCELERATION RECORD IN THE  Y-DIRECTION AT NODAL POINT NO.     7
  NO. OF POINTS = 4096

 0.000116 0.000017-0.000196-0.000301-0.000143 0.000190 0.000492 0.000601       1
 0.000419-0.000057-0.000638-0.001009-0.000967-0.000549 0.000085 0.000734       2
 0.001101 0.000897 0.000167-0.000620-0.000969-0.000781-0.000304 0.000193       3
                                                        .
                                                        .
                                                        .
```

For ease of import into Mathcad, spaces were added in front of "-" signs and blank line were removed. The modified files appear as in Table A.3.1-2 below.

Table A.3.1-2 – Modified format for the output time histories.

```
Motion input
Dir. 1  - Realization 1 TH
  ACCELERATION RECORD IN THE  X -DIRECTION AT NODAL POINT NO.      7
  NO. OF POINTS = 4096
 0.003865 0.008706 0.011275 0.010047 0.007263 0.004656 0.001224 -0.003105       1
 -0.005323 -0.003733 -0.001433 -0.002364 -0.006320 -0.010787 -0.015106 -0.019430      2
 -0.021935 -0.021036 -0.018790 -0.018288 -0.018823 -0.017362 -0.013658 -0.010000      3
                                        .
                                        .
                                        .
```

The modified files were named "TimeHistories_X_mod.txt, "TimeHistories_Y_mod.txt, and "TimeHistories_Z_mod.txt and were imported into Mathcad as variables "Acc_x, "Acc_y, and "Acc_z respectively. When read into Mathcad, the first seven lines of data appear as shown below.

Acc_x =

	0	1	2	3	4	5	6	7	8	9	10
0	0	0	0	0	0	0	0	0	0	0	0
1	0	1	0	0	1	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	7
3	0	0	0	0	4096	0	0	0	0	0	0
4	0.00386	0.00871	0.01127	0.01005	0.00726	0.00466	0.00122	-0.00311	1	0	0
5	-0.00532	-0.00373	-0.00143	-0.00236	-0.00632	-0.01079	-0.01511	-0.01943	2	0	0
6	-0.02193	-0.02104	-0.01879	-0.01829	-0.01882	-0.01736	-0.01366	-0.01	3	0	0

In the array above, the first acceleration time history data is in columns 0 – 7 for 512 rows, starting at row 4. The time step is 0.01 seconds and moving across each successive row represents forward movement in time. Column 10, row 2 is where the PSSI node number is put and this pattern is consistent throughout the array. Knowing this, the acceleration data can be gathered and arranged with simple subroutines. A first subroutine "sw is defined to convert an array containing one acceleration time history into a vector containing the same acceleration time history.

$$sw(A) := \left| \begin{array}{l} a \leftarrow 0 \\ \text{for } j \in 0..\, rows(A) - 1 \\ \quad a \leftarrow stack\left[a, \left(A^T\right)^{\langle j \rangle}\right] \\ a \end{array} \right.$$

Next, a vector of the desired node output and the time step are defined.

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$$Nd := \begin{pmatrix} 81 \\ 176 \\ 315 \\ 319 \\ 320 \\ 322 \\ 542 \\ 547 \\ 552 \\ 815 \\ 1282 \\ 1340 \\ 1372 \\ 4014 \\ 4119 \end{pmatrix}$$ Nodes being output.

$\Delta t_i := 0.01$ Time step.

(Note: PSSI nodes 892 and 1577 data were gathered from a second set of PSSI files requested at a later date in Additional Hazard Consistent In-Structure Response Spectra [19]. These files were named the same name and processing was performed in the same way. Organization was maintained by having them in different file directories.)

Having these definitions, a second subroutine "acc is defined to gather and organize the acceleration data for the defined nodes. The first "for loop in "acc is performed to put time values into column 0. The second "for loop performs the gathering and organization function. Recognizing that the only nonzero values in column 10 are the PSSI node numbers, the first three variables are defined to locate the acceleration time histories for a given node number. The "match command is used for this task. Each "match command produces a vector with three rows that locate the three acceleration arrays for the given PSSI node. Next, the "subroutine command is used to gather each acceleration time history. The "A_x, "A_y, and "A_z variables are formed by adding the acceleration time history arrays for a given direction from the "Acc_x, "Acc_y, and "Acc_z variables. Finally, the arrays are converted to vectors with the subroutine "sw and augmented to the output array named "out. Fig. A.3.1-1 shows the acceleration data for PSSI node 81.

$$
\begin{aligned}
acc := \; & \text{for } i \in 0..2^{12} \\
& \quad out_i \leftarrow i \cdot \Delta t_i \\
& \text{for } i \in 0..\text{last}(Nd) \\
& \quad ind_x \leftarrow \text{match}\left(Nd_i, Acc_x^{\langle 10\rangle}\right) \\
& \quad ind_y \leftarrow \text{match}\left(Nd_i, Acc_y^{\langle 10\rangle}\right) \\
& \quad ind_z \leftarrow \text{match}\left(Nd_i, Acc_z^{\langle 10\rangle}\right) \\
& \quad A_x \leftarrow \text{submatrix}\left(Acc_x, ind_{x_0}+2, ind_{x_0}+513, 0, 7\right) \ldots \\
& \quad\quad + \text{submatrix}\left(Acc_y, ind_{y_0}+2, ind_{y_0}+513, 0, 7\right) \ldots \\
& \quad\quad + \text{submatrix}\left(Acc_z, ind_{z_0}+2, ind_{z_0}+513, 0, 7\right) \\
& \quad A_y \leftarrow \text{submatrix}\left(Acc_x, ind_{x_1}+2, ind_{x_1}+513, 0, 7\right) \ldots \\
& \quad\quad + \text{submatrix}\left(Acc_y, ind_{y_1}+2, ind_{y_1}+513, 0, 7\right) \ldots \\
& \quad\quad + \text{submatrix}\left(Acc_z, ind_{z_1}+2, ind_{z_1}+513, 0, 7\right) \\
& \quad A_z \leftarrow \text{submatrix}\left(Acc_x, ind_{x_2}+2, ind_{x_2}+513, 0, 7\right) \ldots \\
& \quad\quad + \text{submatrix}\left(Acc_y, ind_{y_2}+2, ind_{y_2}+513, 0, 7\right) \ldots \\
& \quad\quad + \text{submatrix}\left(Acc_z, ind_{z_2}+2, ind_{z_2}+513, 0, 7\right) \\
& \quad out \leftarrow \text{augment}\left(out, sw(A_x), sw(A_y), sw(A_z)\right) \\
& out
\end{aligned}
$$

		Node 81			Node 176			Node 315			• • •
	t	H1	H2	V	H1	H2	V	H1	H2	V	

acc =

	0	1	2	3	4	5	6	7	8	9
0	0	0	0	0	0	0	0	0	0	0
1	0.01	0.0033	-0.0007	-0.0108	0.0003	0.0007	-0.0096	0.0045	-0.0052	-0.014
2	0.02	0.0085	-0.0065	-0.0165	0.0035	-0.0017	-0.0184	0.0092	-0.0079	-0.0174
3	0.03	0.0124	-0.0145	-0.0197	0.0091	-0.0086	-0.0235	0.0113	-0.0114	-0.0192
4	0.04	0.0115	-0.0218	-0.0243	0.0131	-0.0174	-0.027	0.0099	-0.0158	-0.0232
5	0.05	0.0075	-0.0264	-0.0313	0.0132	-0.0251	-0.0319	0.0082	-0.0191	-0.0292

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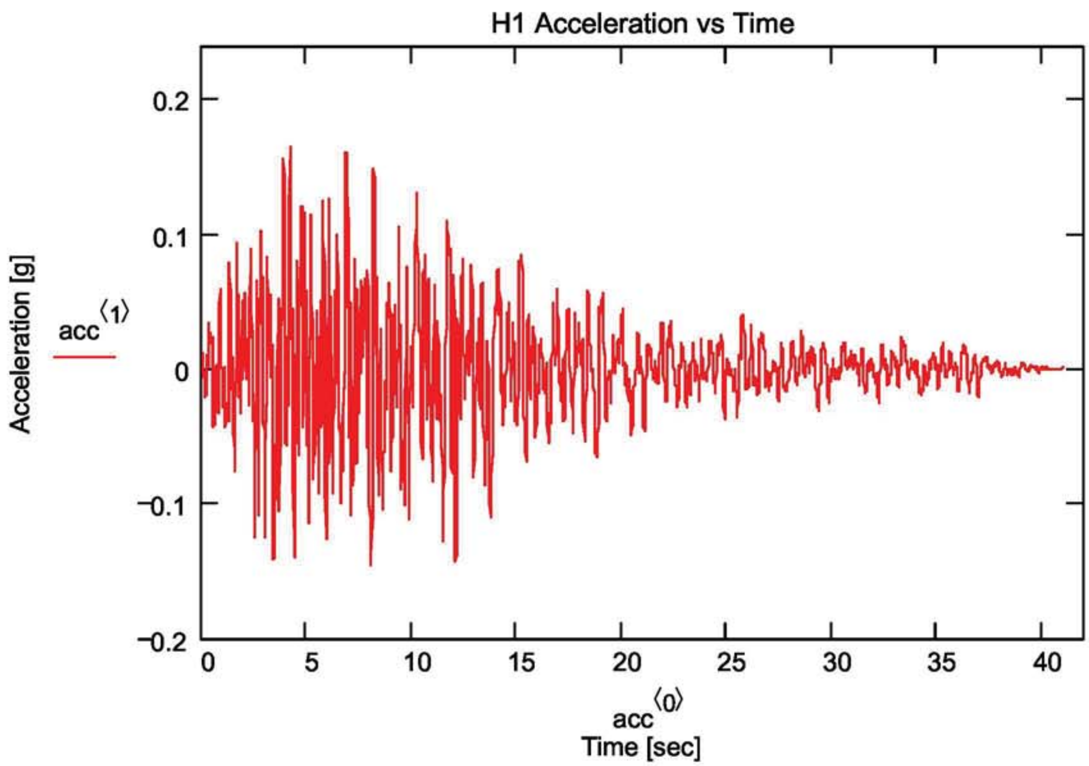

Fig. A.3.1-1 – PSSI node 81 east-west acceleration time history.

Fig. A.3.1-2 shows the data in Fig. A.3.1-2 converted to units of in/sec^2. (which are the units output to ABAQUS).

$$acc_{sc'} := acc \cdot \frac{g}{\frac{in}{sec^2}} \qquad acc_{sc'}^{\langle 0 \rangle} := acc^{\langle 0 \rangle}$$ Unit conversion definition

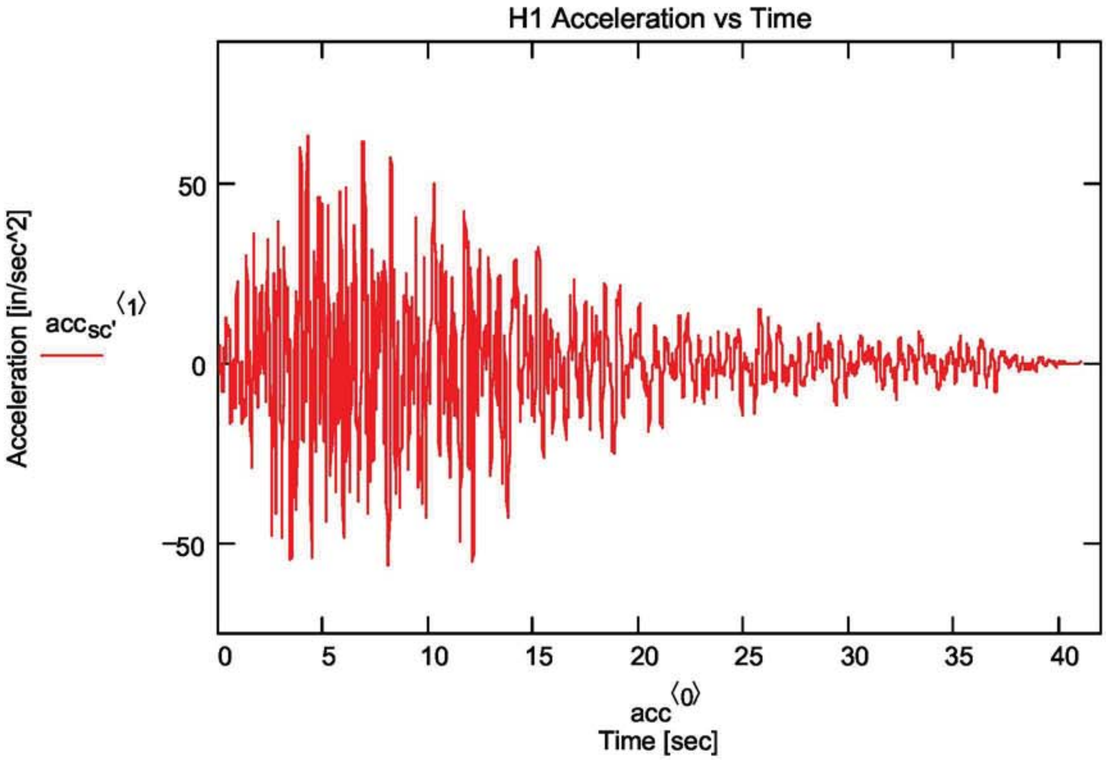

Fig. A.3.1-2 – PSSI node 81 east-west acceleration time history with converted units.

The time step for the data in Fig. A.3.1-2 is 0.01 seconds. The desired time step for evaluation is 0.005 seconds. To add data points, four steps are performed. First, the time history is taken into the frequency domain with a fast Fourier transform. Second, the Nyquist frequency is doubled and zero amplitude is applied to all of the added frequencies. Third, the amplitudes are scaled with the square roots of the numbers of data points. Fourth, the data is transformed back to the time domain with an inverse fast Fourier transform.

In performing the addition of data, the following variables are defined.

$\Delta t_i = 0.01$ Initial time step.

$N_{oi} := \text{last}\left(acc_{sc'}^{\langle 1 \rangle}\right)$ Initial number of data points.

$N_{oi} = 4096$

$f_{Nyi} := \frac{1}{2 \cdot \Delta t_i}$ Initial Nyquist frequency.

$f_{Nyi} = 50$

$i_i := 0 .. \frac{1}{2} \cdot N_{oi}$ Initial counting variable.

$f_{i_{i_i}} := \frac{i_i \cdot f_{Nyi}}{\frac{1}{2} \cdot N_{oi}}$ Initial frequency plotting variable.

$\Delta t := 0.005$ Modified time step.

$N_o := 2 \cdot N_{oi}$ Modified number of data points.

$N_o = 8192$

$f_{Ny} := \frac{1}{2 \cdot \Delta t}$ Modified Nyquist frequency.

$f_{Ny} = 100$

$i := 0 .. \frac{1}{2} \cdot N_o$ Modified counting variable.

$f_i := \frac{i \cdot f_{Ny}}{\frac{1}{2} \cdot N_o}$ Modified frequency plotting variable.

Next, two subroutines are defined. The first subroutine "fft_{accsc}` is written to transform the array of accelerations to the frequency domain using fast Fourier Transforms. The second subroutine "fft_{accsc} is written to double the Nyquist frequency and apply zero amplitude to all of the added frequencies.

$$
\begin{aligned}
fft_{accsc'} := \; & out \leftarrow f_i \\
& \text{for } i \in 1 .. \text{cols}(acc_{sc'}) - 1 \\
& \quad out^{\langle i \rangle} \leftarrow \text{fft}\left(\text{submatrix}\left(acc_{sc'}^{\langle i \rangle}, 1, N_{oi}, 0, 0\right)\right) \\
& out
\end{aligned}
$$

$$fft_{accsc} := \begin{vmatrix} out \leftarrow fft_{accsc'} \\ out_{last(f),0} \leftarrow 0 \\ out^{\langle 0 \rangle} \leftarrow f \\ out \end{vmatrix}$$

Defining and plotting amplitudes yields the results shown in Fig. A.3.1-3.

$fft_{accsc'1_{i_i}} := \left| \left(fft_{accsc'}{}^{\langle 1 \rangle} \right)_{i_i} \right|$ Initial frequency amplitudes.

$fft_{accsc1_i} := \left| \left(fft_{accsc}{}^{\langle 1 \rangle} \right)_i \right|$ Frequency amplitudes after doubling the Nyquist frequency and zeroing the added frequency amplitudes

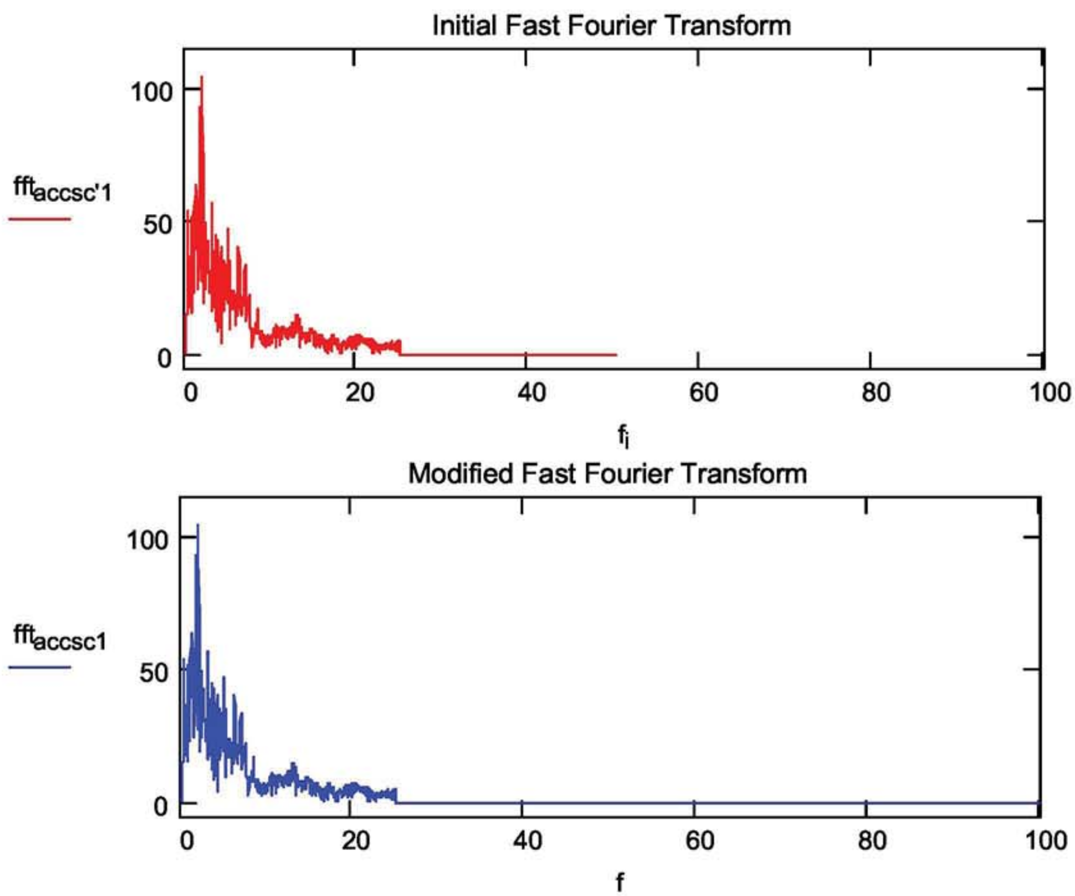

Fig. A.3.1-3 – Fast Fourier transform showing added frequency amplitudes.

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One additional subroutine "acc_{sc} is written to complete the time history modification. This subroutine first scales the frequency amplitudes with the square roots of the numbers of data points. It next adds the appropriate time vector to column zero. Finally, it stacks a row zero that is populated with zeros. This is cosmetic (and it is done to the initial time history also for display). This causes the last data point to occur at a time equal to the time step times the number of points ($\Delta t \cdot N_o$ or $\Delta t_i \cdot N_{oi}$). Fig. .2.1-4 shows the initial and modified time histories.

$$
acc_{sc} := \left|
\begin{array}{l}
\text{for } i \in 1 .. \text{cols}(fft_{accsc}) - 1 \\
\quad out^{\langle i \rangle} \leftarrow \text{ifft}\left(fft_{accsc}{}^{\langle i \rangle}\right) \cdot \dfrac{\sqrt{N_o}}{\sqrt{N_{oi}}} \\
\text{for } i \in 0 .. N_o \\
\quad t_i \leftarrow i \cdot \Delta t \\
out''_{0,\text{cols}(fft_{accsc})-1} \leftarrow 0 \\
out \leftarrow \text{stack}(out'', out') \\
out^{\langle 0 \rangle} \leftarrow t \\
out
\end{array}
\right.
$$

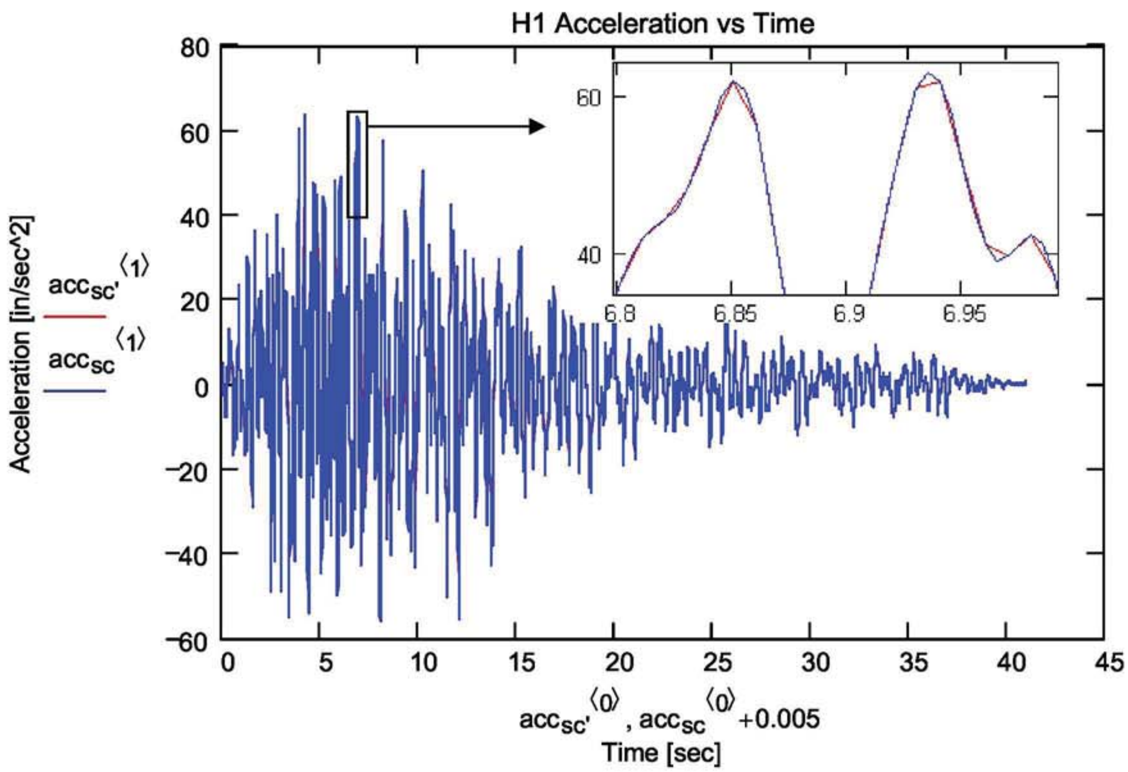

Fig. A.3.1-4 – Initial (red) and modified (blue) acceleration time histories.

Having added the extra data points, drift correction is performed. The drift is inherent to the PSSI output data. Drift correction is performed to reduce the relative motion error between PSSI nodes used for piping model input. This allows multiple PSSI node time histories to be used in a single piping analysis that spans over a large area. The expectation is that this drift correction will reduce the error while not adversely affecting the accuracy of the time histories. Acceptability of the drift correction will be judged based on how significantly the time histories have been changed. Acceptability will also be judged based on the relative motion time histories being reasonable.

The first step in drift correction is to identify the drift by integrating the acceleration time history into velocity and displacement time histories. This is performed using the trapezoid rule numerical integration as shown below.

$$a = \frac{dv}{dt} \qquad v_i = v_{i-1} + \frac{a_i + a_{i-1}}{2} \cdot \Delta t$$ Velocity numerical integration.

$$x = \frac{dx}{dt} \qquad x_i = x_{i-1} + \frac{v_i + v_{i-1}}{2} \cdot \Delta t$$ Displacement numerical integration

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The subroutine "int$_E$ is written to perform the trapezoid rule numerical integration. It first defines column zero as the time and row zero as populated with zeros. Then it performs a trapezoid rule numerical integration on the rest of the array.

$$
\mathrm{Int}_E(a) := \left| \begin{array}{l} out^{\langle 0 \rangle} \leftarrow a^{\langle 0 \rangle} \\ out_{rows(a)-1,\, cols(a)-1} \leftarrow 0 \\ \text{for } i \in 1 .. rows(a)-1 \\ \quad \text{for } j \in 1 .. cols(a)-1 \\ \quad\quad out_{i,j} \leftarrow out_{i-1,j} + \dfrac{a_{i,j} + a_{i-1,j}}{2} \cdot \Delta t \\ out \end{array} \right.
$$

Using subroutine "int$_E$, velocity and displacement time histories can be defined. Fig. A.3.1-5 shows the result of these integrations.

$vel_{sc} := \mathrm{Int}_E(acc_{sc})$ Velocity time history.

$dis_{sc} := \mathrm{Int}_E(vel_{sc})$ Displacement time history

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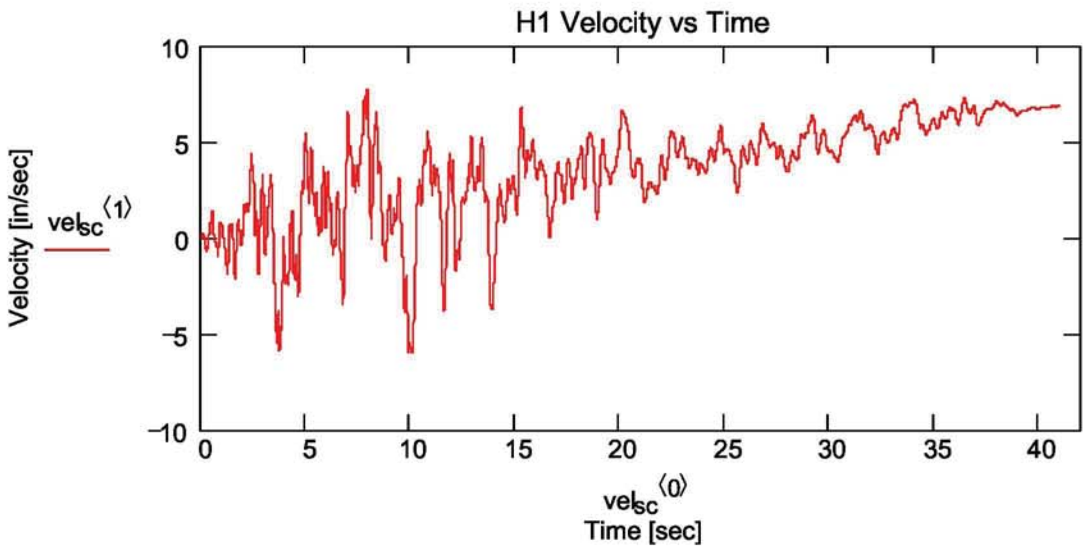

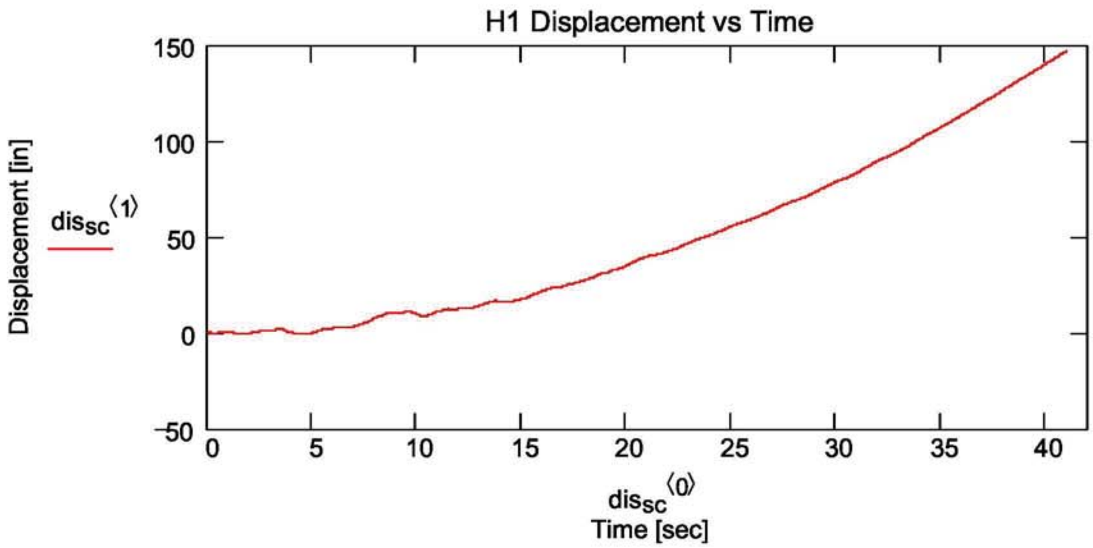

Fig. A.3.1-5 – Velocity and displacement time histories.

Realistic seismic velocity and displacement traces have to return to near zero (assuming an arbitrary cut-off at sufficiently low residual values) at the end of the earthquake. These traces have “drifted off of that expected end point. To establish the acceleration and velocity correction values, a least squares curve fit is performed on the displacement time history as shown below.

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Start with the (constant acceleration) displacement equation where "u" is displacement at a point in time "t," " u_o" is initial displacement constant, " v_o" is initial velocity constant, and " a_o" is a constant acceleration.

$$u = u_o + v_o \cdot t + \frac{1}{2} \cdot a_o \cdot t^2$$

Considering: $u(0) = 0$ ==> $u_o = 0$

Rewriting the equation with constants:

$$u = C_0 \cdot t + C_1 \cdot t^2$$

Curve fit equation.

Where: Velocity constant = C_0 and Acceleration constant = $2 \cdot C_1$

Minimize: $$f(t) = 0 = \sum_{i=0}^{last(t)} \left(C_0 \cdot t_i + C_1 \cdot t_i^2 - u_i\right)^2$$

$$\frac{\partial}{\partial C_0}\left[\sum_{i=0}^{last(t)} \left(C_0 \cdot t_i + C_1 \cdot t_i^2 - u_i\right)^2\right] = \sum_{i=0}^{last(t)} 2 \cdot t_i \cdot \left(C_0 \cdot t_i + C_1 \cdot t_i^2 - u_i\right) = 0$$

$$\frac{\partial}{\partial C_1}\left[\sum_{i=0}^{last(t)} \left(C_0 \cdot t_i + C_1 \cdot t_i^2 - u_i\right)^2\right] = \sum_{i=0}^{last(t)} 2 \cdot t_i^2 \cdot \left(C_0 \cdot t_i + C_1 \cdot t_i^2 - u_i\right) = 0$$

$$\begin{pmatrix} \sum_{i=0}^{last(t)} t_i^2 & \sum_{i=0}^{last(t)} t_i^3 \\ \sum_{i=0}^{last(t)} t_i^3 & \sum_{i=0}^{last(t)} t_i^4 \end{pmatrix} \cdot \begin{pmatrix} C_0 \\ C_1 \end{pmatrix} = \begin{pmatrix} \sum_{i=0}^{last(t)} u_i \cdot t_i \\ \sum_{i=0}^{last(t)} u_i \cdot t_i^2 \end{pmatrix}$$

$$\begin{pmatrix} C_0 \\ C_1 \end{pmatrix} = \begin{pmatrix} \sum_{i=0}^{last(t)} t_i^2 & \sum_{i=0}^{last(t)} t_i^3 \\ \sum_{i=0}^{last(t)} t_i^3 & \sum_{i=0}^{last(t)} t_i^4 \end{pmatrix}^{-1} \cdot \begin{pmatrix} \sum_{i=0}^{last(t)} u_i \cdot t_i \\ \sum_{i=0}^{last(t)} u_i \cdot t_i^2 \end{pmatrix}$$

Least squares curve fit to establish the constants.

Recognizing the summation pattern, a curve fit subroutine is written as shown below. The "Fit_{accoff} subroutine accepts time "t and displacement "u and its output is a vector containing the optimized constants for velocity and acceleration.

$$Fit_{accoff}(t,u) := \left| \begin{array}{l} \text{for } i \in 0..1 \\ \quad \left| \begin{array}{l} B_i \leftarrow \displaystyle\sum_{p=0}^{last(t)} u_p \cdot \left(t_p\right)^{i+1} \\ \text{for } j \in 0..1 \\ \quad A_{i,j} \leftarrow \displaystyle\sum_{p=0}^{last(t)} \left(t_p\right)^{i+j+2} \end{array} \right. \\ A^{-1} \cdot B \end{array} \right.$$

The "Fit_{accoff} subroutine is used to define all of the velocity and acceleration constants into the variable "C_a as shown below.

$$C_a := \left| \begin{array}{l} \text{for } j \in 1..\,cols\left(dis_{sc}\right) - 1 \\ \quad out^{\langle j \rangle} \leftarrow Fit_{accoff}\left(dis_{sc}{}^{\langle 0 \rangle}, dis_{sc}{}^{\langle j \rangle}\right) \\ out \end{array} \right.$$

The velocity and acceleration constants for the PSSI node 81 east-west acceleration time history are shown below.

$$C_a{}^{\langle 1 \rangle} = \begin{pmatrix} -2.921 \times 10^{-3} \\ 0.087 \end{pmatrix}$$

Having the acceleration and velocity constants, a subroutine "Acc_{off}' is defined to remove the associated acceleration drift from all of the time histories. Subroutine "int_E is then used to calculate the velocity and displacement time histories.

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$$Acc_{off}(a, u, t, C_a) := \left| \begin{array}{l} out \leftarrow a^{\langle 0 \rangle} \\ \text{for } j \in 1..\, cols(a) - 1 \\ \quad out^{\langle j \rangle} \leftarrow a^{\langle j \rangle} - 2 \cdot C_{a_{1,j}} \\ out \end{array} \right.$$

$$acc_{ao} := Acc_{off}\left(acc_{sc}, dis_{sc}, acc_{sc}^{\langle 0 \rangle}, C_a\right)$$

Acceleration time history after constant acceleration adjustment.

$$vel_{ao} := Int_E(acc_{ao})$$

Velocity time history after constant acceleration adjustment.

$$dis_{ao} := Int_E(vel_{ao})$$

Displacement time history after constant acceleration adjustment.

Fig. A.3.1-6 shows the time history curves after constant acceleration adjustment. For this time history, the necessity of velocity offset is not obvious. There is a significant velocity offset in the vertical time history of this same PSSI node (and many others), however. For information, Fig. A.3.1-7 shows the time history curves after constant acceleration adjustment for the vertical time histories of PSSI node 81.

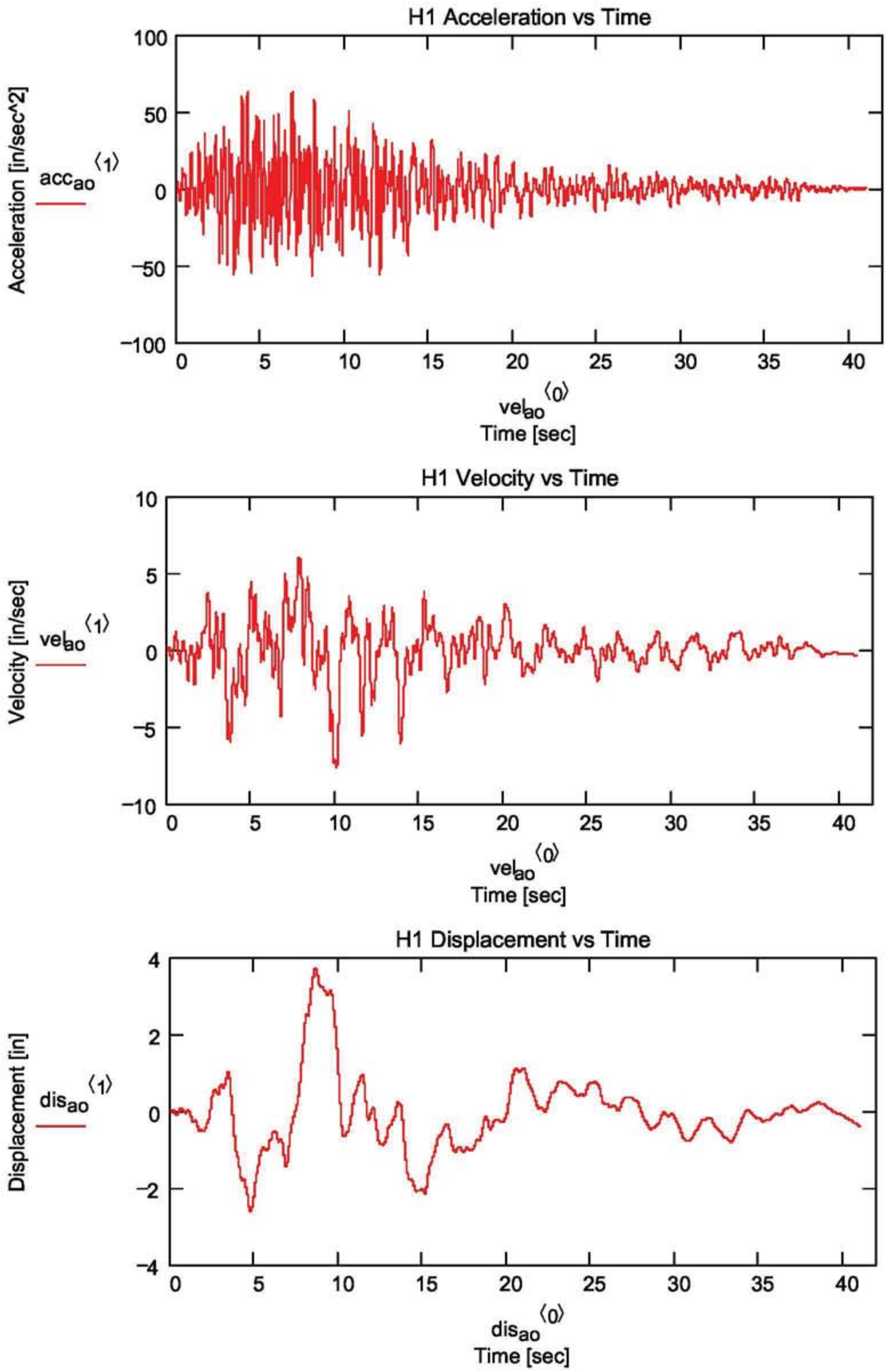

Fig. A.3.1-6 – Time history curves after constant acceleration adjustment.

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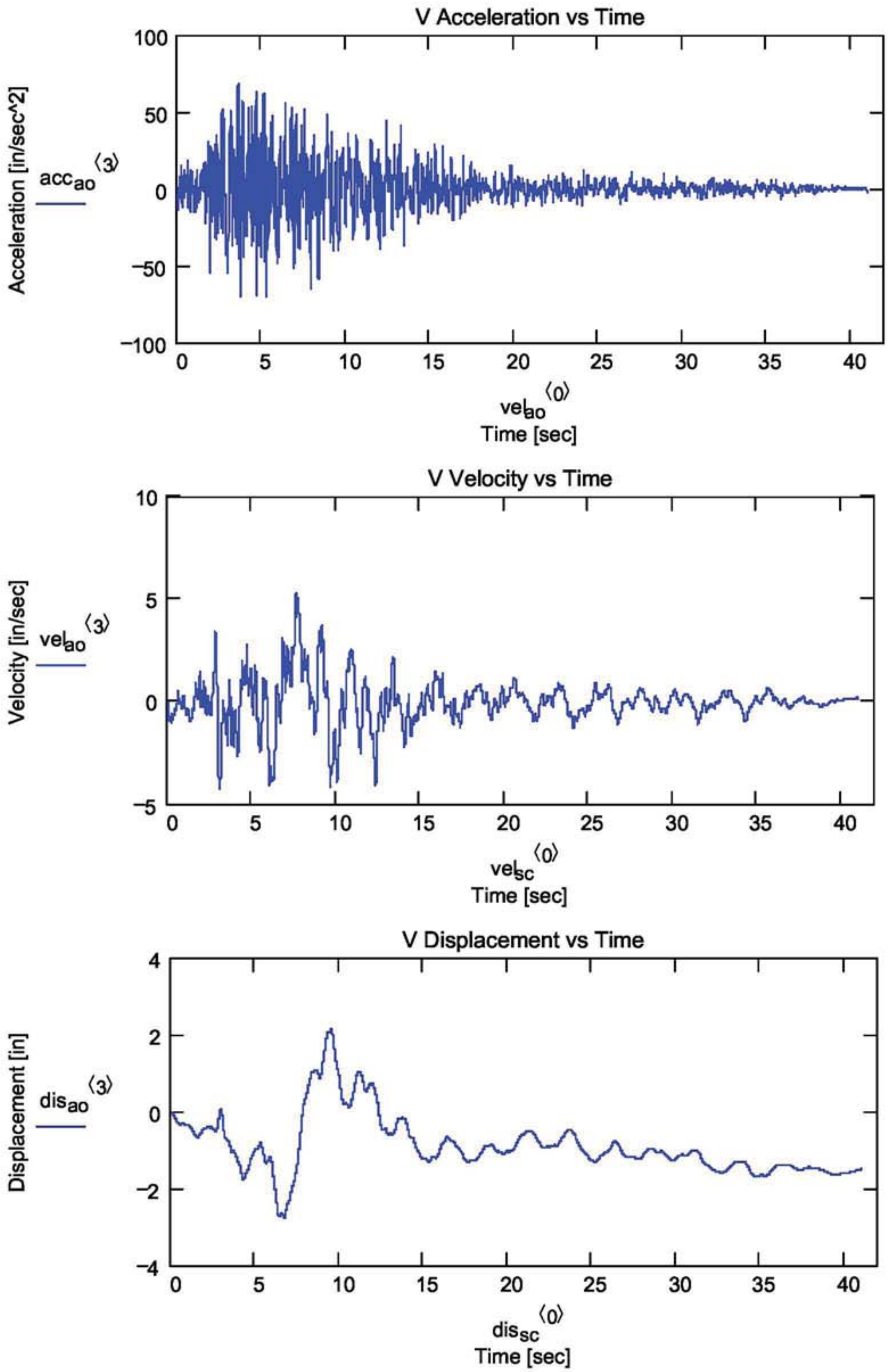

Fig. A.3.1-7 – Adjusted PSSI node 81 vertical time history curves.

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The velocity constant is more difficult to incorporate considering that it must be incorporated with a modification to the acceleration time history. The incorporation strategy is to adjust the acceleration time history with a smooth polynomial curve starting and ending near the start of the acceleration time history. The initial conditions for the polynomial are zero displacement, velocity, acceleration, and jerk. The end conditions for the polynomial are a displacement equal to the velocity constant multiplied by the end time, a velocity equal to the velocity constant, an acceleration equal to zero, and a jerk equal to zero. The initial conditions are enforced by dropping all polynomial terms lower than a constant multiplied by time to the fourth power. The remaining constants ("C_{p0}, "C_{p1}, "C_{p2}, and "C_{p3}) are calculated as shown below.

$$u_p(t) = C_{p0} \cdot t^4 + C_{p1} \cdot t^5 + C_{p2} \cdot t^6 + C_{p3} \cdot t^7$$ Displacement polynomial.

$$v_p(t) = \frac{du_p}{dt} = 4 \cdot C_{p0} \cdot t^3 + 5 \cdot C_{p1} \cdot t^4 + 6 \cdot C_{p2} \cdot t^5 + 7 \cdot C_{p3} \cdot t^6$$ velocity polynomial.

$$a_p(t) = \frac{dv_p}{dt} = 12 \cdot C_{p0} \cdot t^2 + 20 \cdot C_{p1} \cdot t^3 + 30 \cdot C_{p2} \cdot t^4 + 42 \cdot C_{p3} \cdot t^5$$ Acceleration polynomial.

$$j_p(t) = \frac{da_p}{dt} = 24 \cdot C_{p0} \cdot t + 60 \cdot C_{p1} \cdot t^2 + 120 \cdot C_{p2} \cdot t^3 + 210 \cdot C_{p3} \cdot t^4$$ Jerk polynomial.

at time t_1 ==> $u_p(t_1) = v_1 \cdot t_1$ $v_p(t_1) = v_1$ $a_p(t_1) = 0$ $j_p(t_1) = 0$

Substituting and solving for the constants:

$$v_1 \cdot t_1 = C_{p0} \cdot t_1^4 + C_{p1} \cdot t_1^5 + C_{p2} \cdot t_1^6 + C_{p3} \cdot t_1^7$$

$$v_1 = 4 \cdot C_{p0} \cdot t_1^3 + 5 \cdot C_{p1} \cdot t_1^4 + 6 \cdot C_{p2} \cdot t_1^5 + 7 \cdot C_{p3} \cdot t_1^6$$

$$0 = 12 \cdot C_{p0} \cdot t_1^2 + 20 \cdot C_{p1} \cdot t_1^3 + 30 \cdot C_{p2} \cdot t_1^4 + 42 \cdot C_{p3} \cdot t_1^5$$

$$0 = 24 \cdot C_{p0} \cdot t_1 + 60 \cdot C_{p1} \cdot t_1^2 + 120 \cdot C_{p2} \cdot t_1^3 + 210 \cdot C_{p3} \cdot t_1^4$$

$$\begin{pmatrix} t_1^4 & t_1^5 & t_1^6 & t_1^7 \\ 4 \cdot t_1^3 & 5 \cdot t_1^4 & 6 \cdot t_1^5 & 7 \cdot t_1^6 \\ 12 \cdot t_1^2 & 20 \cdot t_1^3 & 30 \cdot t_1^4 & 42 \cdot t_1^5 \\ 24 \cdot t_1 & 60 \cdot t_1^2 & 120 \cdot t_1^3 & 210 \cdot t_1^4 \end{pmatrix} \cdot \begin{pmatrix} C_{p0} \\ C_{p1} \\ C_{p2} \\ C_{p3} \end{pmatrix} = \begin{pmatrix} v_1 \cdot t_1 \\ v_1 \\ 0 \\ 0 \end{pmatrix}$$

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$$\begin{pmatrix} C_{p0} \\ C_{p1} \\ C_{p2} \\ C_{p3} \end{pmatrix} = \begin{pmatrix} t_1^{\,4} & t_1^{\,5} & t_1^{\,6} & t_1^{\,7} \\ 4\cdot t_1^{\,3} & 5\cdot t_1^{\,4} & 6\cdot t_1^{\,5} & 7\cdot t_1^{\,6} \\ 12\cdot t_1^{\,2} & 20\cdot t_1^{\,3} & 30\cdot t_1^{\,4} & 42\cdot t_1^{\,5} \\ 24\cdot t_1 & 60\cdot t_1^{\,2} & 120\cdot t_1^{\,3} & 210\cdot t_1^{\,4} \end{pmatrix}^{-1} \cdot \begin{pmatrix} v_1\cdot t_1 \\ v_1 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} 20\cdot v_1\cdot t_1^{\,-3} \\ -45\cdot v_1\cdot t_1^{\,-4} \\ 36\cdot v_1\cdot t_1^{\,-5} \\ -10\cdot v_1\cdot t_1^{\,-6} \end{pmatrix}$$

Defining displacement, velocity, and acceleration:

$$u_p(t, v_1, t_1) := 20\cdot v_1\cdot t_1^{\,-3}\cdot t^4 + -45\cdot v_1\cdot t_1^{\,-4}\cdot t^5 + 36\cdot v_1\cdot t_1^{\,-5}\cdot t^6 + -10\cdot v_1\cdot t_1^{\,-6}\cdot t^7$$

$$v_p(t, v_1, t_1) := 4\cdot\left(20\cdot v_1\cdot t_1^{\,-3}\right)\cdot t^3 + 5\cdot\left(-45\cdot v_1\cdot t_1^{\,-4}\right)\cdot t^4 + 6\cdot\left(36\cdot v_1\cdot t_1^{\,-5}\right)\cdot t^5 + 7\cdot\left(-10\cdot v_1\cdot t_1^{\,-6}\right)\cdot t^6$$

$$a_p(t, v_1, t_1) = 12\cdot\left(20\cdot v_1\cdot t_1^{\,-3}\right)\cdot t^2 + 20\cdot\left(-45\cdot v_1\cdot t_1^{\,-4}\right)\cdot t^3 + 30\cdot\left(36\cdot v_1\cdot t_1^{\,-5}\right)\cdot t^4 + 42\cdot\left(-10\cdot v_1\cdot t_1^{\,-6}\right)\cdot t^5$$

$$a_p(t, v_1, t_1) := -60\cdot v_1\cdot t^2\cdot t_1^{\,-6}\cdot(7\cdot t - 4\cdot t_1)\cdot(-t_1 + t)^2$$

Having the necessary polynomial equations, the next step is to determine the time duration of the polynomial. The duration needs to be short so that it does not occur during the strong motion (cumulative energy ratio of 5% - 75%); however, it must have enough time step points to produce a stable result. Engineering judgment and scoping calculations were used to establish that a time duration of 0.3 seconds (or 60 time steps) produced stable results with a margin of conservatism. Additionally, Fig. A.3.2-2 below is used to establish that all of the curves for cumulative energy ratios are less than 1% at 0.5 seconds. Consequently, 0.3 seconds can be considered an acceptable time duration. Fig. A.3.1-8 shows the resulting polynomial motions along with the desired motions for velocity and displacement. The curves are plotted for a 0.3 seconds time duration at 0.005 second time steps and they represent the correction needed for the east-west acceleration time history of PSSI node 81.

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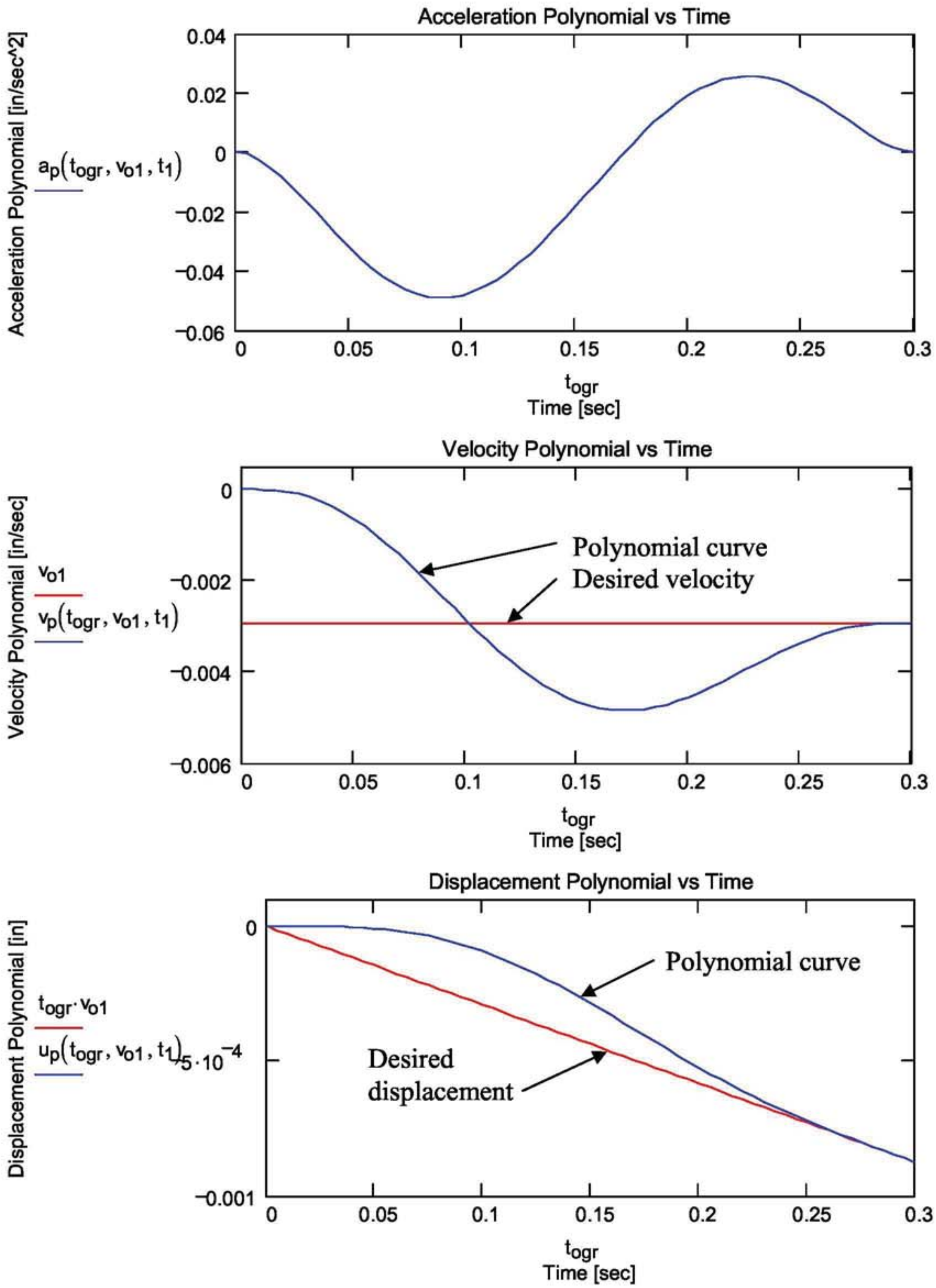

Fig. A.3.1-8 – Polynomial motions along with the desired motions for velocity and displacement.

The subroutine "Acc_{poly} is written to apply a polynomial adjustment to an acceleration time history. The subroutine starts with a "while loop that determines the duration of the adjustment. Next, the acceleration polynomial is defined for the time duration. Zeros are then defined for all the remaining acceleration time steps. This is done so that the final step of subtracting the acceleration polynomial time history from the acceleration time history can be performed. The subroutine "Acc_{poly_all} is then written to perform the polynomial adjustment to all of the acceleration time histories.

$$Acc_{poly}(t, a, v, x, t_1, v_{o1}) := \left| \begin{array}{l} p \leftarrow 0 \\ \text{while } t_p < t_1 \\ \quad p \leftarrow p + 1 \\ \text{for } i \in 0..\, p \\ \quad a_{umod_i} \leftarrow a_p(t_i, v_{o1}, t_p) \\ a_{umod_{last(t)}} \leftarrow 0 \\ a - a_{umod} \end{array} \right.$$

$$Acc_{poly\_all}(a, v, x, t_{lo}, C_a) := \left| \begin{array}{l} out \leftarrow a^{\langle 0 \rangle} \\ \text{for } j \in 1..\, cols(a) - 1 \\ \quad out^{\langle j \rangle} \leftarrow Acc_{poly}\left(a^{\langle 0 \rangle}, a^{\langle j \rangle}, v^{\langle j \rangle}, x^{\langle j \rangle}, t_{lo}, C_{a_{0,j}}\right) \\ out \end{array} \right.$$

$acc_{ad} := Acc_{poly\_all}(acc_{ao}, vel_{ao}, dis_{ao}, t_{lo}, C_a)$ Adjusted acceleration time history.

The velocity and displacement are then integrated as shown below. Fig. A.3.1-9 shows plots of the modified time histories.

$vel_{ad} := Int_E(acc_{ad})$ Velocity time history.

$dis_{ad} := Int_E(vel_{ad})$ Displacement time history.

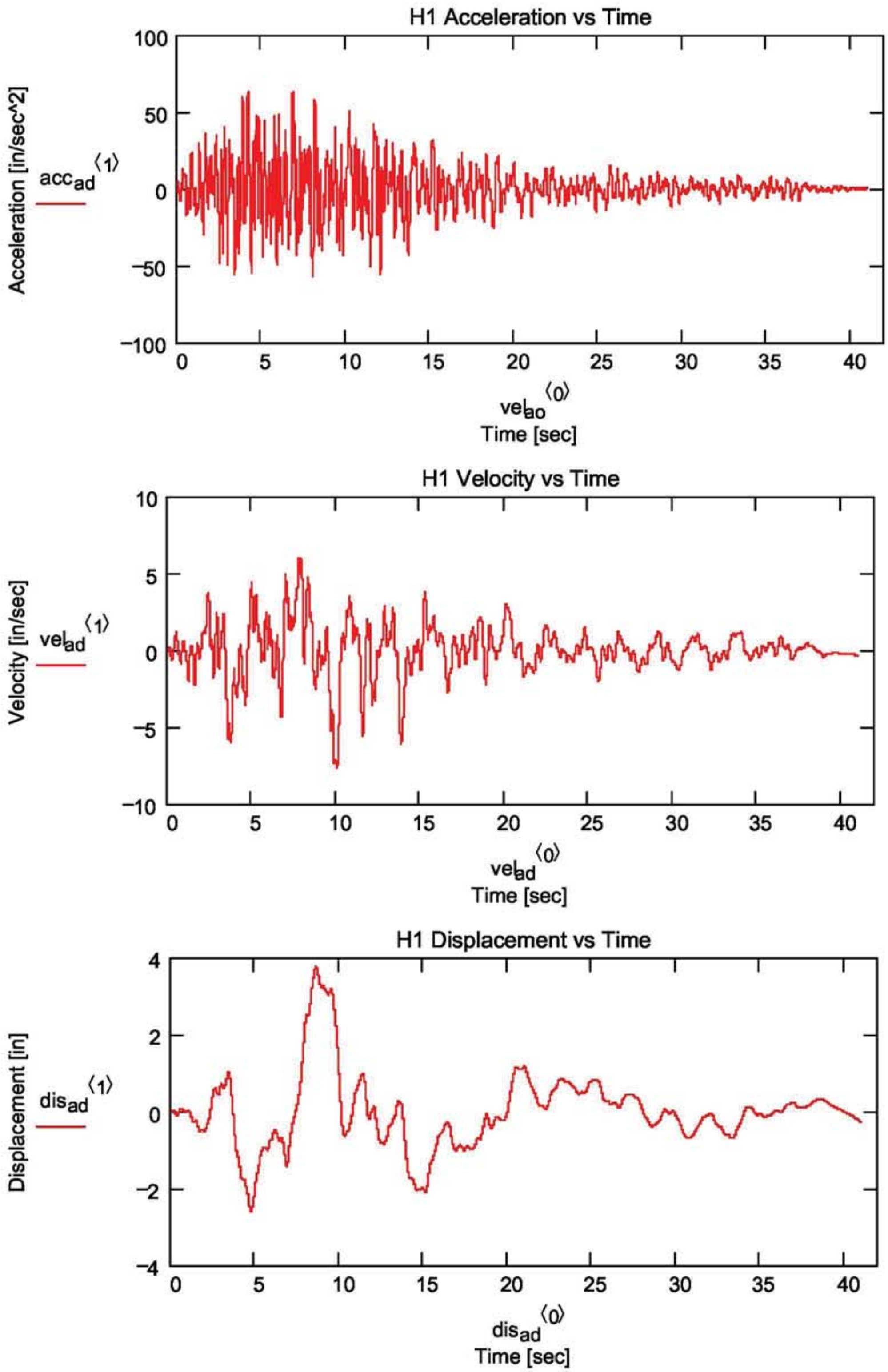

Fig. A.3.1-9 – Velocity drift corrected time history curves.

Fig. A.3.1-10 – Fig. A.3.1-12 show the drift corrected east-west, north-south, and vertical displacement time histories for PSSI node 81 and the additional 14 PSSI nodes evaluated at the same time. Given the stiffness of the substructure, the global displacements are very similar. These figures demonstrate the adequacy of the drift correction.

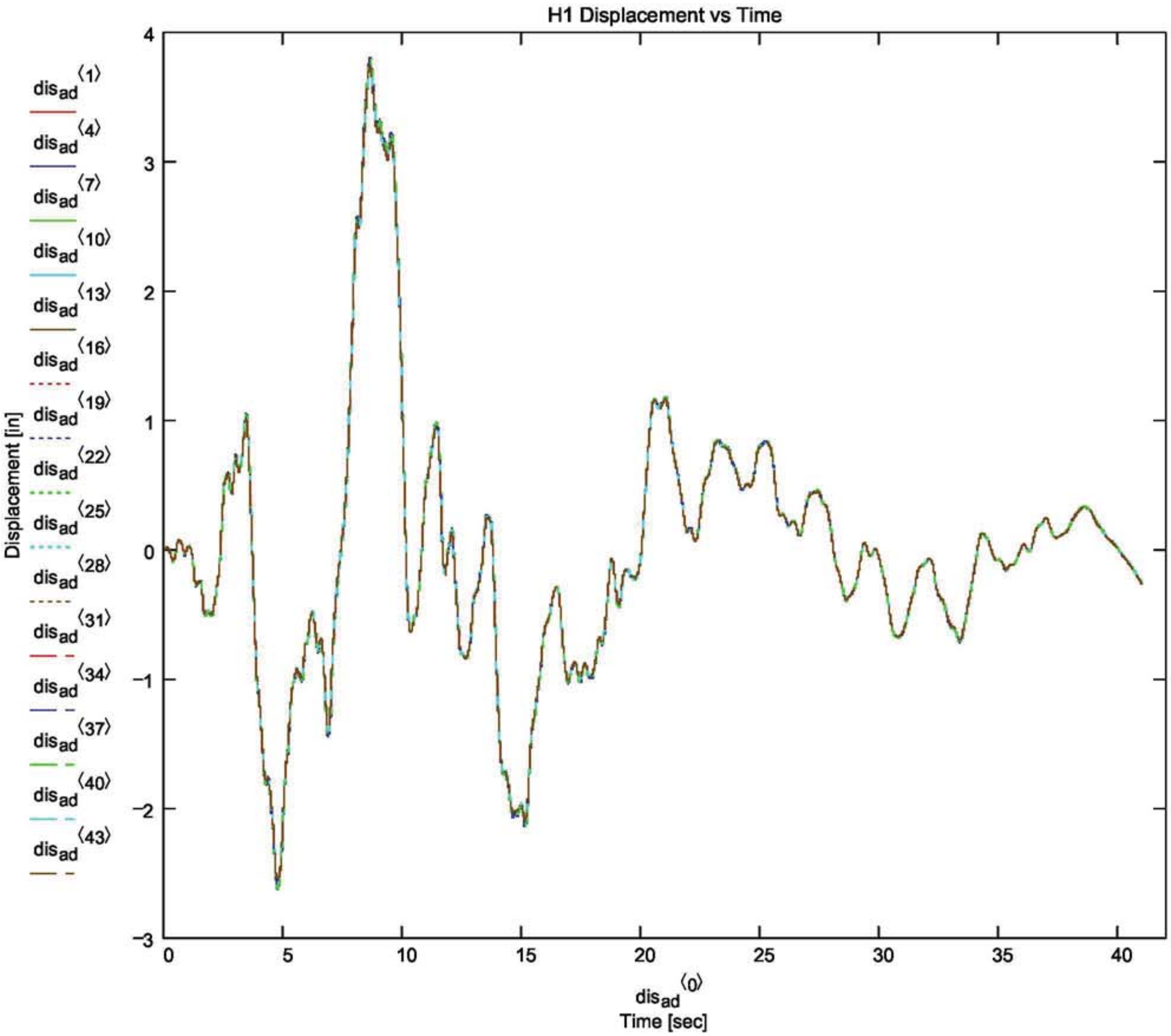

Fig. A.3.1-10 – East-west drift corrected time history curves.

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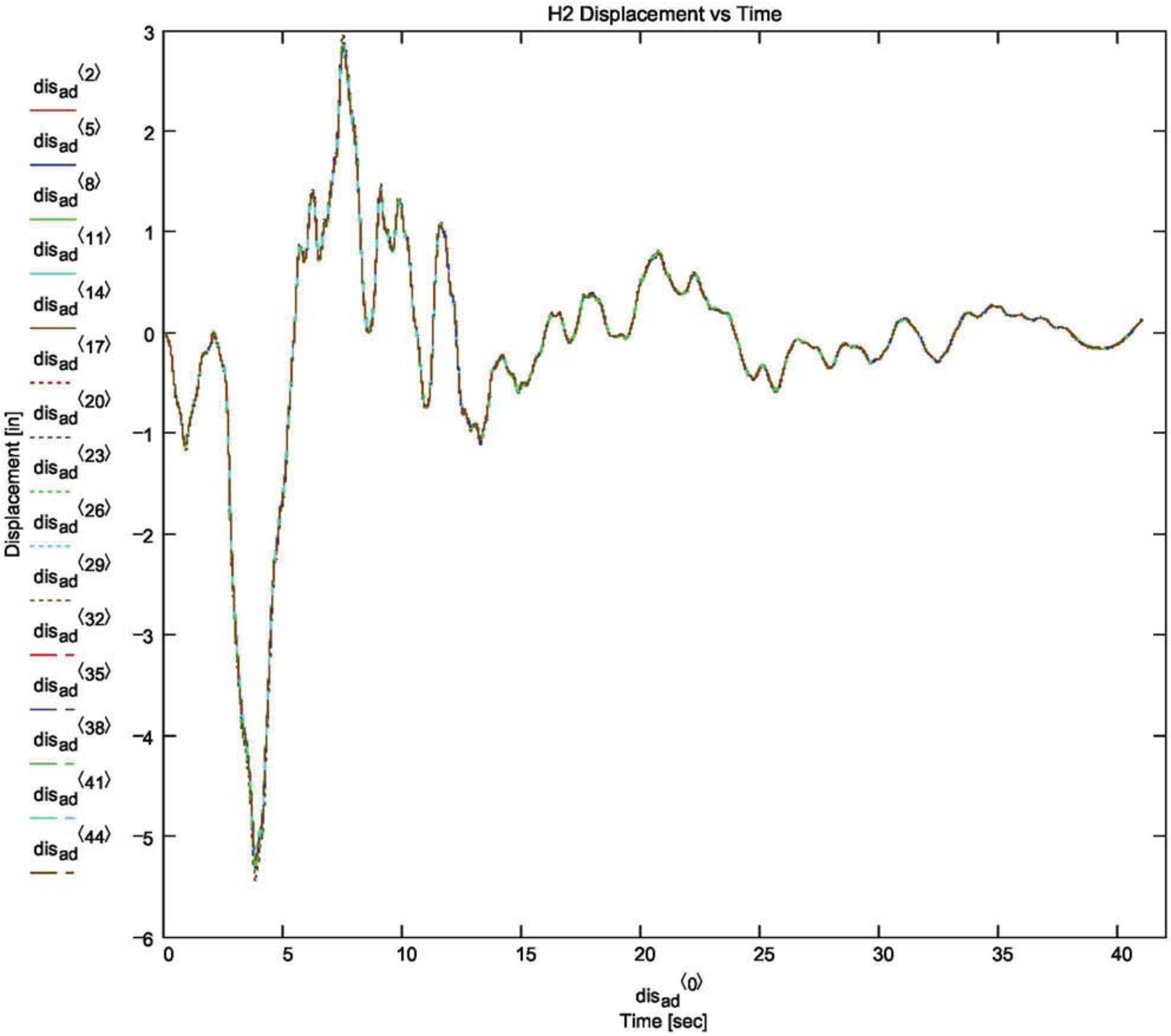

Fig. A.3.1-11 – North-south drift corrected time history curves.

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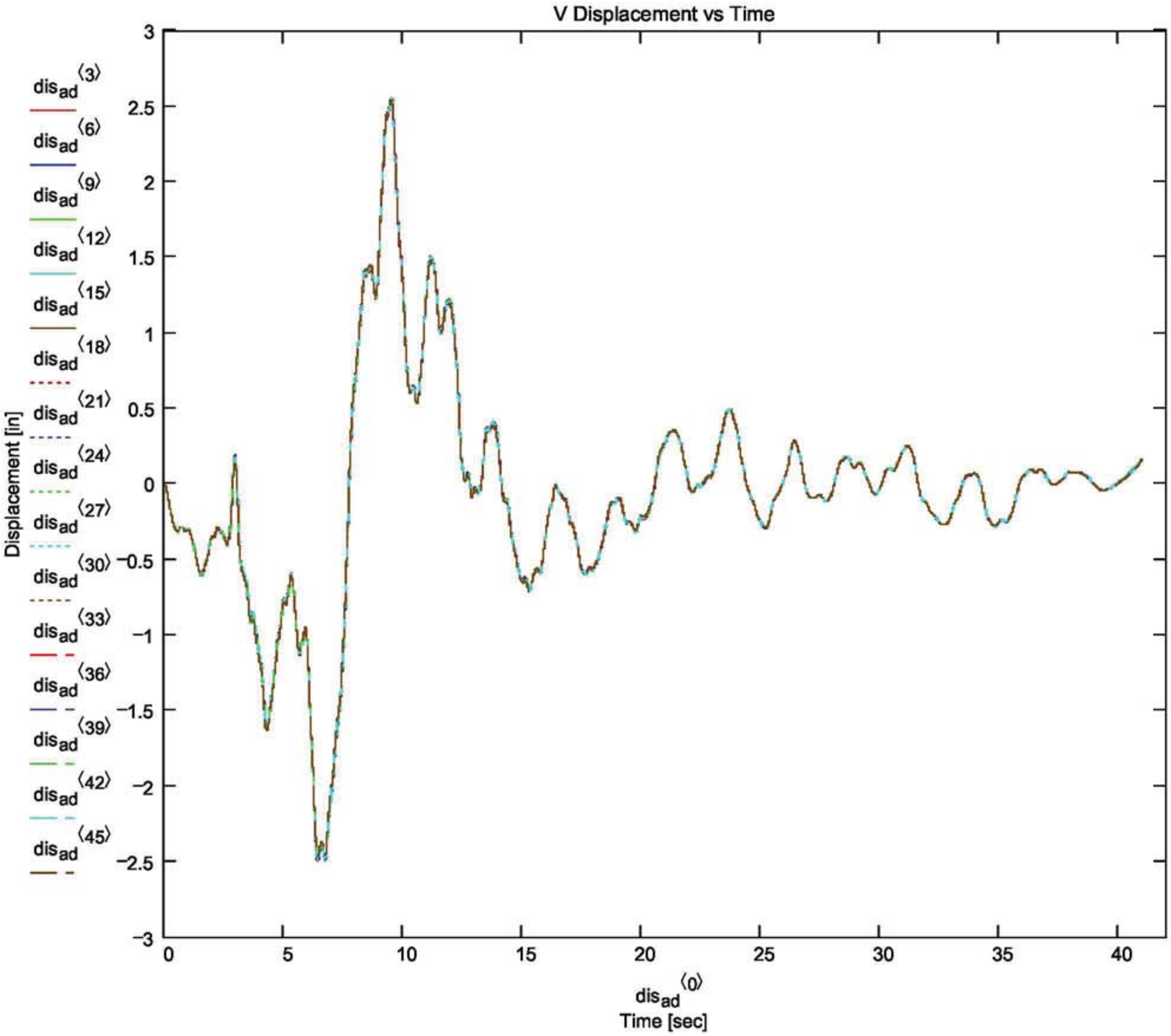

Fig. A.3.1-12 – Vertical drift corrected time history curves.

For further information, the drift corrected acceleration time histories for PSSI nodes 892 and 1577 are read into the Mathcad file and augmented to the variable "acc_{ad} to produce the variable "acc_{ad_all}. Velocity and displacement are then calculated as below.

$vel_{ad\_all} := Int_E(acc_{ad\_all})$ Velocity time history.

$dis_{ad\_all} := Int_E(vel_{ad\_all})$ Displacement time history.

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Fig. A.3.1-13 – Fig. A.3.1-15 show the difference between the lowest elevation node (PSSI node 4119) and all of the other PSSI nodes. These plots show reasonable relative motion after drift correction.

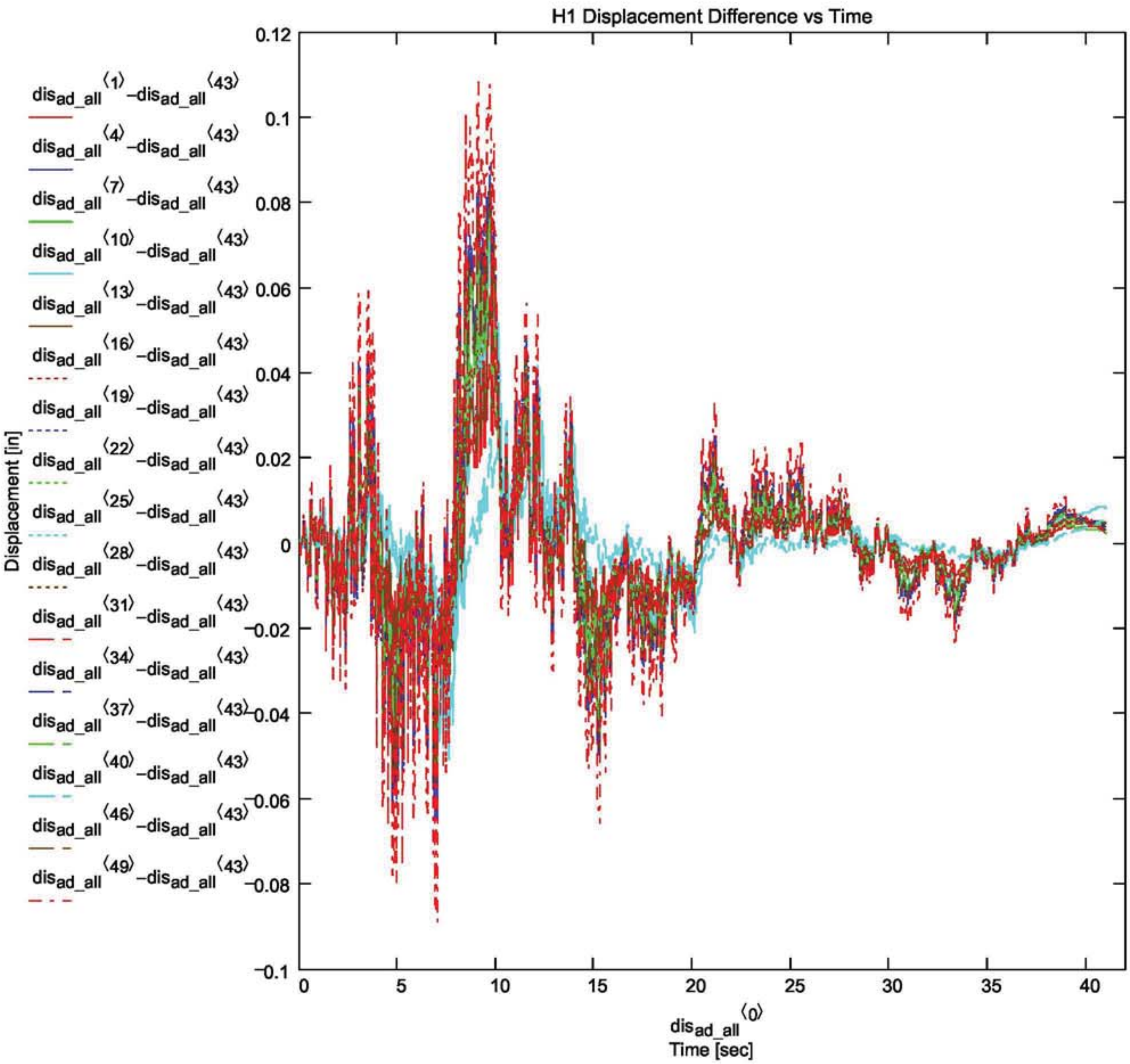

Fig. A.3.1-13 – East-west differences in drift corrected time history curves.

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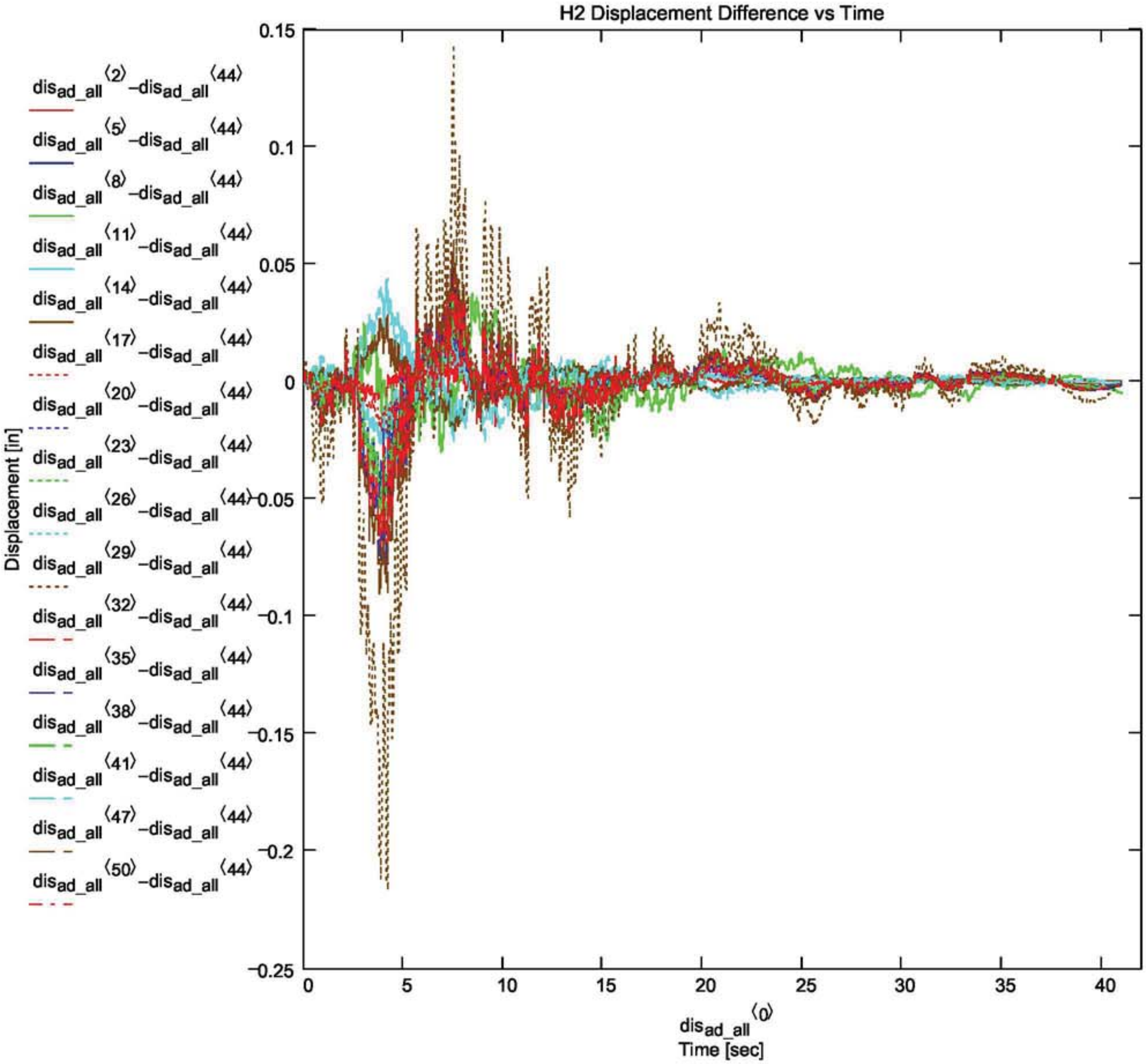

Fig. A.3.1-14 – North-south differences in drift corrected time history curves.

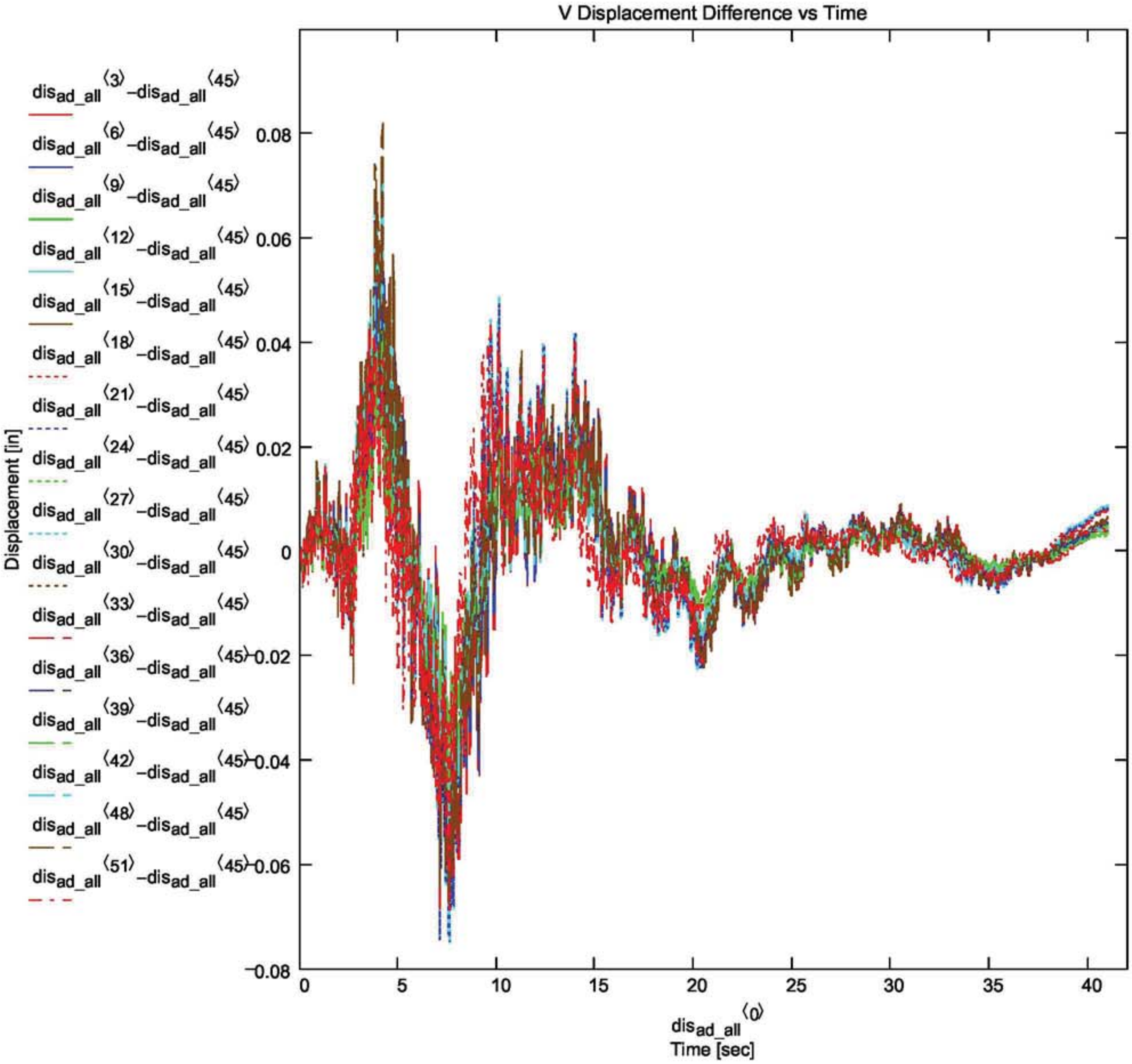

Fig. A.3.1-15 – Vertical differences in drift corrected time history curves.

Considering Fig. A.2.1-10 – Fig. A.2.1-15, the drift appears to have been accurately removed.

To demonstrate the significance of the change to the time histories caused by the drift correction, the fast Fourier transforms before and after drift correction are calculated and compared in Fig. A.2.1-16. The fast Fourier transform of the difference is also calculated and it shows that drift correction has caused an insignificant change to all but the lowest frequency in the fast Fourier transform.

$fftacc_{sc} := \mathrm{fft}\left(\mathrm{submatrix}\left(acc_{sc}^{\langle 1 \rangle}, 1, \mathrm{last}\left(acc_{sc}^{\langle 1 \rangle}\right), 0, 0\right)\right)$ Fast Fourier transform of the data before drift correction.

$fftacc_{ad} := \mathrm{fft}\left(\mathrm{submatrix}\left(acc_{ad}^{\langle 1 \rangle}, 1, \mathrm{last}\left(acc_{ad}^{\langle 1 \rangle}\right), 0, 0\right)\right)$ Fast Fourier transform of the drift corrected data.

$acc_{gr'} := acc_{ad}^{\langle 1 \rangle} - acc_{sc}^{\langle 1 \rangle}$

$fftacc_{gr} := \mathrm{fft}\left(\mathrm{submatrix}\left(acc_{gr'}, 1, \mathrm{last}\left(acc_{gr'}\right), 0, 0\right)\right)$ Fast Fourier transform of the difference in the above curves.

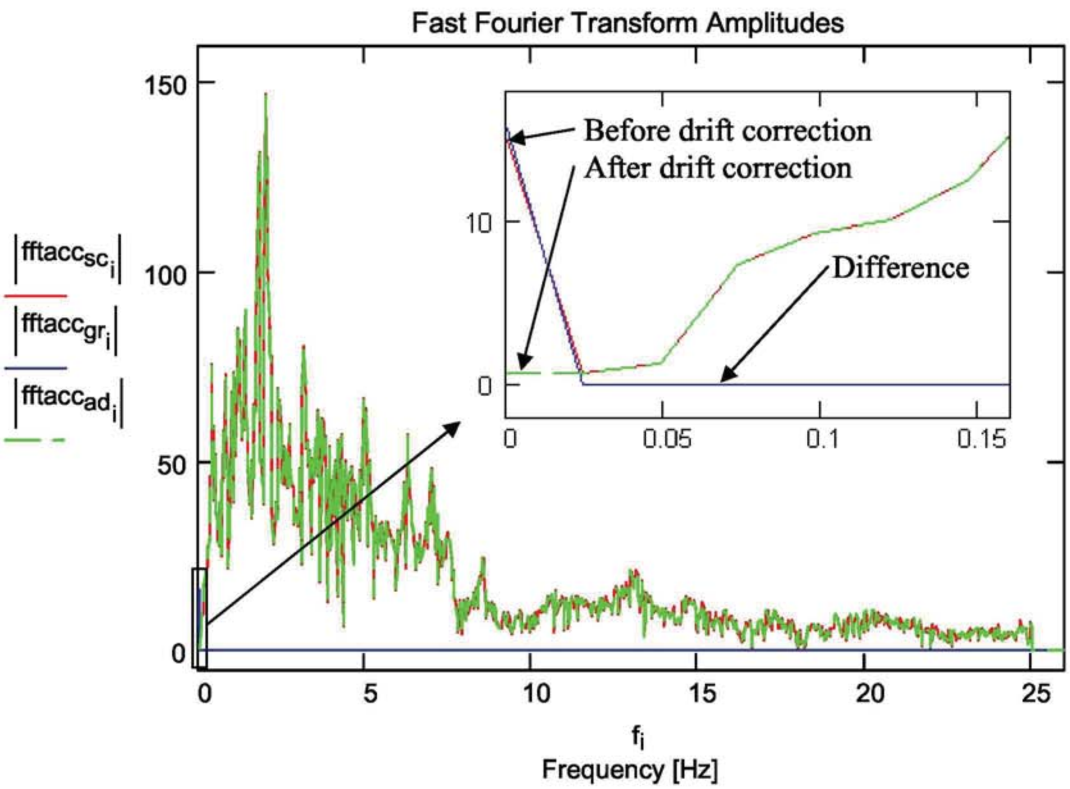

Fig. A.3.1-16 – Fast Fourier transform comparison.

Given the results shown in Fig. A.2.1-10 – Fig. A.2.1-16, the drift correction is judged to be acceptable.

After drift correction, the only remaining step is to rearrange the time histories into a form that can be put into an ABAQUS input file. In an ABAQUS input file, the time history is organized in rows that each contains four time and acceleration pairs. The subroutine "In_Amp which is shown below is written to perform this task. It accepts time and acceleration vectors as input and outputs an array correctly formatted for ABAQUS.

```
In_Amp(t, a) := | i ← 0
                | j ← 0
                | k ← 0
                | while  i < rows(t)
                |     | Out_{j,k} ← t_i
                |     | Out_{j,k+1} ← a_i
                |     | i ← i + 1
                |     | k ← k + 2
                |     | if  k > 6
                |     |     | k ← 0
                |     |     | j ← j + 1
                | Out
```

Having numerous acceleration time histories to process, one further subroutine "In_Tot was written. This subroutine accepts an array (with similar formatting to "acc_{ad}) and uses the subroutine "In_Amp to produce ABAQUS formatted arrays for all of the time histories contained in the input array. The ABAQUS formatted arrays are then stacked with a row of zeros before each new array. The row of zeros makes final text editing for ABAQUS input easier.

```
In_Tot(acc) := | space_{0,7} ← 0
               | out ← space
               | for  i ∈ 1 .. cols(acc) − 1
               |     | dat ← In_Amp(acc^⟨0⟩, acc^⟨i⟩)
               |     | out ← stack(out, dat, space)
               | out
```

A.3.2 – Time History Duration Calculation

The time histories have 40.96 seconds of data. All of this data is put in the ABAQUS input files in the "*AMPLITUDE portion of the input file. However for efficiency in run time, a reduced time period is evaluated as defined in the "*STEP portion of the input file. This reduced time is allowed by ASCE 4 [17] as long as sufficient strong motion duration is included. For this evaluation, the acceleration time history and cumulative energy ratio plots are used in determining the needed time duration. Acceptable time duration relative to the acceleration time history is based in part on inclusion of the strong motion. Acceptable time duration relative to cumulative energy is based on being beyond the "shoulder .

The acceleration time histories and cumulative energy studied for time duration selection are from PSSI node 542 for east-west time histories and from PSSI node 552 for north-south and vertical time histories. These are selected because they supply input to the largest portion of model mass in the piping models. Although the most important points are analyzed, the characteristics sought in them are thought to be uniform among all of the histories because they all originate from the same analysis, an analysis of a very stiff monolithic structure. The first is processed to define the characteristics, the second to confirm the uniformity expected.

Fig. A.2.2-1 shows the data points for the thirty-two sets of east-west, north-south, and vertical acceleration time histories (as established using the process described in Section A.2.1 above). (For plotting ease, all of the acceleration data for a given direction were stacked into a single vector. An appropriate time vector was established in a similar manner.)

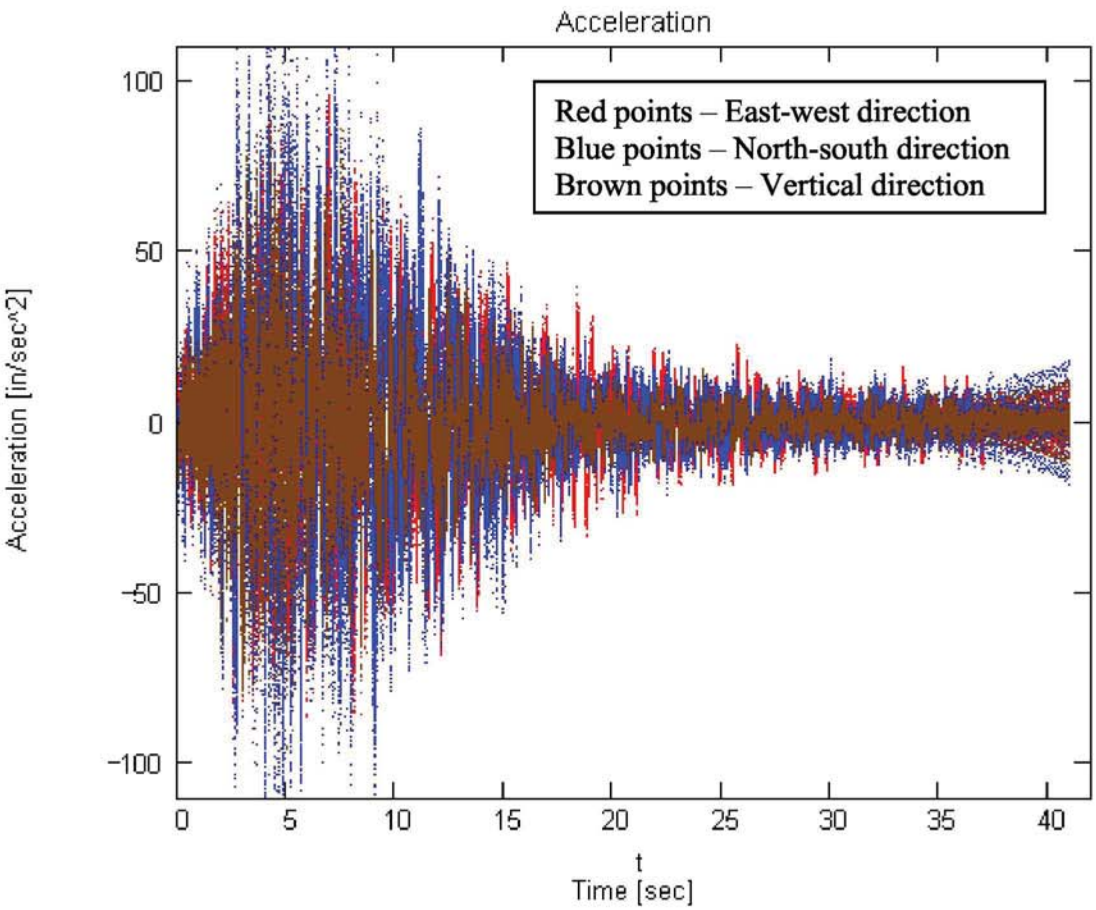

Fig. A.3.2-1 – All of the time history duration acceleration time histories.

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The cumulative energy for the acceleration time histories shown in Fig. A.3.2-1 can be found using ASCE 4, Equation 2.4-2 [17].

$$E(t) = \int_0^t a(\tau)^2 \, d\tau \qquad \text{Cumulative energy}$$

The "a in the integral is acceleration and the "t is time. To perform the integration, subroutine "e_t is written to perform a trapezoidal rule numerical integration. This subroutine begins by setting the output to zero at a time equal to zero (with the squared acceleration and time step terms to address potential ambiguity if units are defined). A "for loop then performs the trapezoidal rule numerical integration.

$$e_t(a, \Delta t) := \left| \begin{array}{l} out_0 \leftarrow 0 \cdot \left[(a_0)^2 \cdot \Delta t\right] \\ \text{for } i \in 1 .. \text{rows}(a) - 1 \\ \quad out_i \leftarrow out_{i-1} + \dfrac{(a_{i-1})^2 + (a_i)^2}{2} \cdot \Delta t \\ out \end{array} \right.$$

Considering that the plot data in Fig. A.3.2-1 is gathered into one vector per direction, a second subroutine "e_{t_all} is written to calculate all of the cumulative energy plots for a given direction. The input for this subroutine is the vector containing all of the acceleration time histories in a direction, the time step, and the vector containing the stacked time vectors corresponding to the acceleration time histories. The subroutine initially uses the "match command to establish all of the start points and end points of the stacked time vectors. The "submatrix command is then used to gather the single acceleration time history from the stacked acceleration time histories and the subroutine "e_t is used to produce one cumulative energy curve. The curve is divided by its maximum value to produce a cumulative energy ratio. A "for loop is next performed to generate the remaining cumulative energy ratio curves and stack them into a single vector. This vector is the output for the subroutine.

$$
\begin{aligned}
e_{t\_all}(a_{all}, \Delta t, t) := \;& t_i \leftarrow \text{match}(0, t) \\
& t_f \leftarrow \text{match}\left(t_{t_{i_1}-1}, t\right) \\
& a \leftarrow \text{submatrix}\left(a_{all}, t_{i_0}, t_{f_0}, 0, 0\right) \\
& ce \leftarrow e_t(a, \Delta t) \\
& ce_{all} \leftarrow ce \cdot \max(ce)^{-1} \\
& \text{for } i \in 1 .. \text{last}(t_i) \\
& \quad a \leftarrow \text{submatrix}\left(a_{all}, t_{i_i}, t_{f_i}, 0, 0\right) \\
& \quad ce \leftarrow e_t(a, \Delta t) \\
& \quad ce_{all} \leftarrow \text{stack}\left(ce_{all}, ce \cdot \max(ce)^{-1}\right) \\
& ce_{all}
\end{aligned}
$$

The subroutine "e_{t_all} is used to produce the data points for the thirty-two sets of east-west, north-south, and vertical cumulative energy ratios. This data is plotted in Fig. A.3.2-2.

Near the end of many time histories in Fig. A.3.2-1, there is a noticeable growth of the time history amplitude. This abnormality is part of the PSSI output. It can be observed as a lower post "shoulder level with an increase near the end of the curve in the cumulative energy ratio (in Fig. A.3.2-2). For this evaluation, it will be viewed as model error and its affects will be treated as such in the time history duration calculation. This represents a part of the time history which will not be used in the piping model evaluations (as it is outside the evaluated time history duration identified below). Consequently, this abnormality should not adversely affect the model results.

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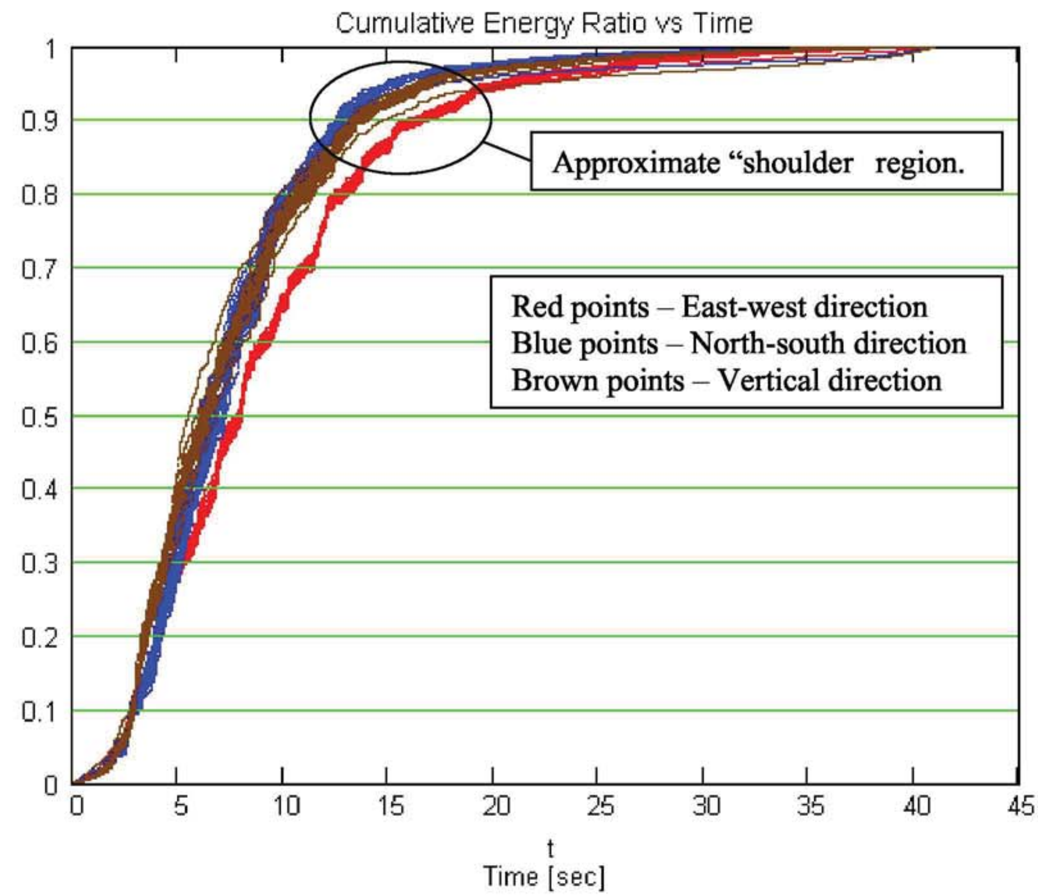

Fig. A.3.2-2 – Cumulative energy for all of the time history duration time histories.

Considering the acceleration time histories in Fig. A.3.2-1, a point in time 20 seconds into the seismic event is beyond the strong motion and the motion that follows is gradually decreasing (ignoring the abnormal amplitude growth at the end of some time histories). Fig. A.3.2-2 shows that 20 seconds is also beyond the "shoulder and at a point where the cumulative energy ratio is greater than 90%. Consequently, 0 - 20 seconds is an acceptable time history duration.

A.3.3 – Rayleigh Damping Constants Calculation

The piping model runs are all performed with direct integration and Rayleigh damping. Rayleigh damping follows the equation

$$\xi_i = \frac{\alpha}{2 \cdot \omega_i} + \frac{\beta \cdot \omega_i}{2}$$

where the subscript "i indicates a specific mode, ξ is the modal damping, ω is the natural frequency, and α and β are Rayleigh damping constants. The purpose of this section is to establish the Rayleigh damping constants for each model.

Finding the Rayleigh damping constants is a multi-step problem. First, the 5% damping response spectra are found for the thirty-two sets of east-west, north-south, and vertical acceleration time histories (as established using the process described in Section A.3.3.1 below). Second, a modal analysis is run on the given piping model in a gravitationally loaded state to establish the effective mass versus natural frequency. Third, the 80th percentile time histories for each direction are established relative to the response spectra and effective mass. Fourth, the effective mass is used to establish the lower point where the Rayleigh damping curve crosses the 5% damping curve. Fifth, Rayleigh damping constants are found that cause the Rayleigh damping curve to cross the 5% damping curve at the selected lower point and a reasonable upper point. Sixth, the Rayleigh damping response spectra are found using the 80th percentile time histories and the Rayleigh damping constants. The seventh step is to generate a cumulative weighted response curve. This uses the curve generated by subtracting the 5% damping response spectra from the Rayleigh damping response spectra. The weighted response is then the effective mass at each natural frequency multiplied by the difference in response spectra at that natural frequency (corresponding to the effective mass). These values are then summed for the significant effective mass values in all three directions. If the sum produces a positive number, then the Rayleigh damping values are considered acceptable.

A.3.3.1 – Rayleigh Damping Constants for Model 3

In the first step for calculating Rayleigh damping constants for Model 3, the 5% damping response spectra are found for the thirty-two sets of east-west, north-south, and vertical acceleration time histories (as established using the process described in Section A.3.1 above). The time histories are from PSSI node 542 for east-west time histories and from PSSI node 552 for north-south and vertical time histories (These points are central to all of the models and are used for establishing damping in all of them). The response spectra analyses are performed with the ReSpect (see Appendix A.3.4 for validation) program with a separate report (.rpt text file) file for each run. Each report file contains 10 columns (columns 0 – 9). Column 0 is time, column 1 is east-west acceleration, column 2 is vertical acceleration, column 3 is north-south acceleration, column 4 is east-west displacement, column 5 is vertical displacement, column 6 is north-south displacement, column 7 is east-west velocity, column 8 is vertical velocity, and column 9 is north-south velocity. The output of ReSpect is a print (.prn text file) file containing 5% damping response spectra at 300 frequency points between 0.1 Hz and 100 Hz. Each print file contains 19 columns (columns 0 – 18). Column 0 is frequency, column 1 is relative east-west displacement, column 2 is relative east-west velocity, column 3 is relative east-west acceleration, column 4 is relative north-south displacement, column 5 is relative north-south velocity, column 6 is relative north-south acceleration, column 7 is relative vertical displacement, column 8 is relative vertical velocity, column 9 is relative vertical acceleration, column 10 is total east-west displacement, column 11 is total east-west velocity, column 12 is total east-west acceleration, column 13 is total north-south displacement, column 14 is total north-south velocity, column 15 is total north-south acceleration, column 16 is total vertical displacement, column 17 is total vertical velocity, and column 18 is total vertical acceleration. (The variable ordering for the ReSpect program was driven by the output format for ABAQUS.)

The thirty-two print files containing all of the response spectra are read into a single Mathcad file. The total acceleration response spectra are extracted for each direction and written out as three Excel files (to reduce the volume of unneeded data). Further processing is done in another Mathcad file. In the new Mathcad file, the Excel files are read into three variables named "RS_05_{H1}, "RS_05_{H2}, and "RS_05_{V} , defined for the east-west, north-south, and vertical total response spectra respectively. Column 0 for each file is frequency and column number and realization number match for the rest of the columns.

For the second step, effective mass values for the Model 3 modes are needed. To accomplish this, a modal analysis is run with the input file "model3_fr_9-26-08.inp in ABAQUS (as shown in Fig. A.3.3.1-1) to find all natural frequencies occurring between 0 Hz and 50 Hz. (The response spectra show very close to rigid body response for natural frequencies above 50 Hz. Consequently, the above 50 Hz natural frequencies are not considered significant for the damping calculation.) Upon completion of the model runs, effective mass in all three directions versus frequency are gathered from the "model3_fr_9-26-08.dat file and read into the Mathcad variable "dat`. Column 0 in the variable "dat` is the number assigned to each mode. Columns 1 – 6 are the effective masses for the 1 – 6 directions (where the 1-direction is north-south, the 2-direction is vertical, the 3-direction is east-west, and the remaining directions are rotational and not needed). Column 7 is not used and has zeros in it. Column 8 is the natural frequencies associated with the effective mass values. The last three rows of the variable "dat` are a row of zeros, a row with the summed effective mass values, and a row with the total model mass (repeated for only the 1-, 2-, and 3-direction effective mass columns). Below are the last 6 rows of the variable "dat`.

dat' =

	0	1	2	3	4	5	6	7	8
95	96	0.088	$4.992\cdot10^{-4}$	0.033	$9.24\cdot10^{4}$	467.89	$6.25\cdot10^{4}$	0	47.231
96	97	0.05	0.012	0.015	$1.529\cdot10^{5}$	$2.202\cdot10^{5}$	$1.056\cdot10^{4}$	0	49.286
97	98	0.048	$2.677\cdot10^{-3}$	0.392	$6\cdot10^{4}$	$6.445\cdot10^{3}$	$1.968\cdot10^{4}$	0	49.744
98	0	0	0	0	0	0	0	0	0
99	0	506.81	549.95	511.66	$3.758\cdot10^{8}$	$5.331\cdot10^{8}$	$7.91\cdot10^{8}$	0	0
100	0	583.057	583.057	583.057	0	0	0	0	0

The array "dat` is then used to define the following variables.

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$m_{tot} := dat'_{rows(dat')-1,1}$ $\quad m_{tot} = 583$ — Total model mass.

$freq := submatrix(dat', 0, rows(dat') - 4, 8, 8)$ — Frequency.

$m_{eh1} := submatrix(dat', 0, rows(dat') - 4, 3, 3)$ — Effective mass in the east-west direction.

$m_{eh2} := submatrix(dat', 0, rows(dat') - 4, 1, 1)$ — Effective mass in the east-west direction.

$m_{ev} := submatrix(dat', 0, rows(dat') - 4, 2, 2)$ — Effective mass in the east-west direction.

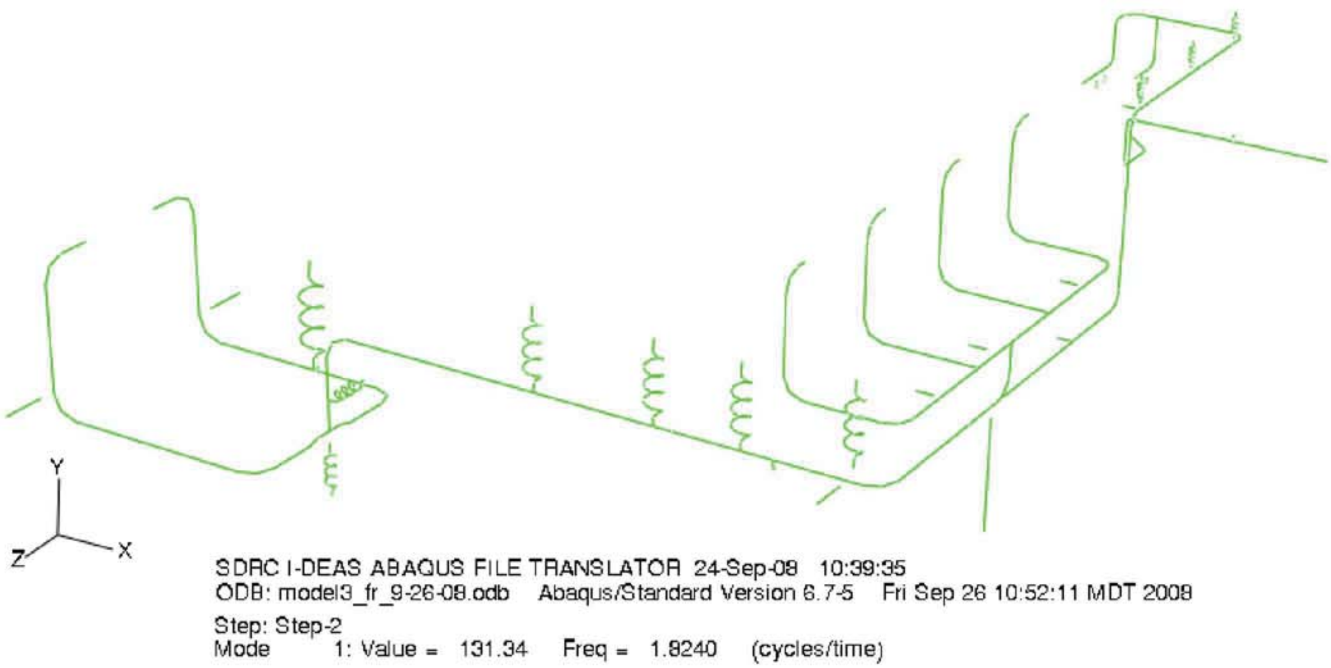

Fig. A.3.3.1-1 – Modal analysis for Model. 3.

Additional cumulative effective mass percentage variables are defined for plotting purposes (due to cumulative effective mass percentage being an easier plot for visualization of the model's effective mass). This is calculated with the subroutine "M_{esum}. This subroutine accepts an effective mass vector and total mass scalar. It simply sums the effect mass as a function of frequency and divides the sum by the total mass to establish a percentage.

$$M_{esum}(m_e, m_{tot}) := \left| \begin{array}{l} sum \leftarrow 0 \\ \text{for } j \in 0 .. rows(m_e) - 1 \\ \quad \left| \begin{array}{l} sum \leftarrow m_{e_j} + sum \\ out_j \leftarrow \dfrac{sum}{m_{tot}} \end{array} \right. \\ out \end{array} \right.$$

$M_{eh1} := M_{esum}(m_{eh1}, m_{tot})$ Cumulative effective mass in the east-west direction.

$M_{eh2} := M_{esum}(m_{eh2}, m_{tot})$ Effective mass in the east-west direction.

$M_{ev} := M_{esum}(m_{ev}, m_{tot})$ Effective mass in the east-west direction.

Fig. A.3.3.1-2 shows the effect mass and cumulative effective mass percentage versus frequency.

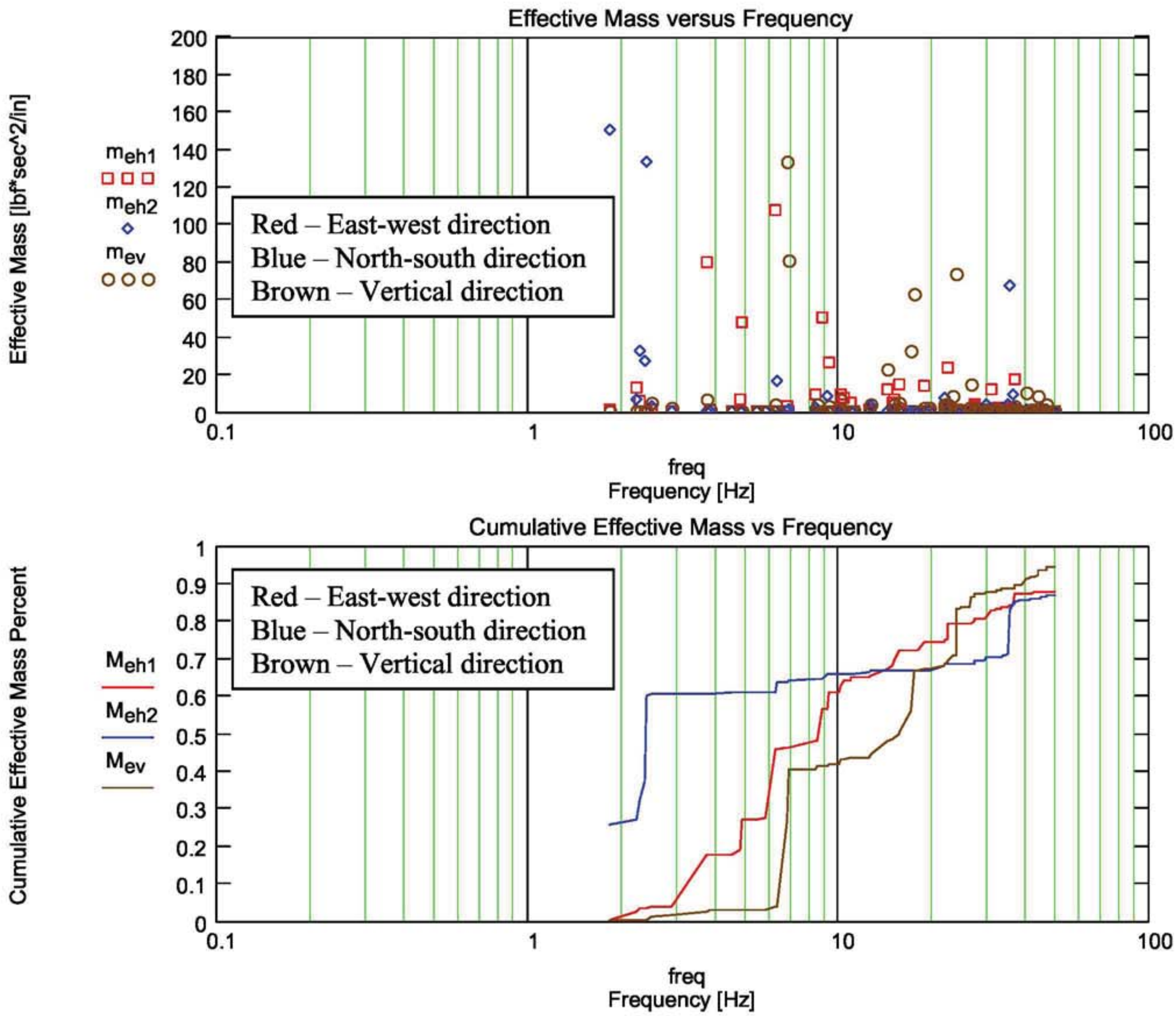

Fig. A.3.3.1-2 – Effect mass and cumulative effective mass percentage versus frequency.

The third step is to establish the 80th percentile response spectrum. To do this, a subroutine "P80wt is written. This subroutine accepts a response spectra array, a frequency vector that corresponds with the effective mass vector, and an effective mass vector. The output is a two column array where column zero is the ordered realization numbers and column 1 is the values used to decide the order. The subroutine starts with a "for loop that populates a vector with the sequentially ordered realization numbers. Next, a "for loop populates a vector with the base 10 logarithm values for the response spectra frequencies. Then, a "for loop is performed to define the variable "dat. This variable contains the effective mass multiplied by the response at the natural frequency of that effective mass. The response is found by log-linear interpolation. The curve being interpolated is the given realization response spectrum versus the base 10 logarithm of the frequency. The point where the interpolation takes place is the given base 10 logarithm of the effective mass frequency. Once the effective mass multiplied by the response has been calculated for all of the realizations, a "for loop is performed to sum all of the values for each realization. This serves as an indication of model response for each realization. Finally, the realization numbers vector is augmented with the sum of the effective mass multiplied by response vectors. The output is this array sorted by the sum.

$$P80wt(RS, f_e, m_e) := \left| \begin{array}{l} \text{for } i \in 0..\, cols(RS) - 2 \\ \quad ord_i \leftarrow i + 1 \\ \text{for } i \in 0..\, last(RS^{\langle 0 \rangle}) \\ \quad f_{log_i} \leftarrow \log(RS_{i,0}) \\ \text{for } j \in 1..\, cols(RS) - 1 \\ \quad \text{for } i \in 0..\, last(f_e) \\ \quad\quad dat_{i,j-1} \leftarrow m_{e_i} \cdot linterp\left(f_{log}, RS^{\langle j \rangle}, \log\left(f_{e_i}\right)\right) \\ \text{for } i \in 0..\, cols(dat) - 1 \\ \quad out_{s_i} \leftarrow \sum (dat)^{\langle i \rangle} \\ csort(augment(ord, out_s), 1) \end{array} \right.$$

Having the "P80wt subroutine, the 80th percentile realizations can be selected.

$$P80_{H1} := P80wt(RS\_05_{H1}, freq, m_{eh1})_{round(32 \cdot 80 \cdot \%)-1,\, 0}$$

Eightieth percentile realization for east-west motion.

$$P80_{H1} = 27$$

$$P80_{H2} := P80wt(RS\_05_{H2}, freq, m_{eh2})_{round(32 \cdot 80 \cdot \%)-1,\, 0}$$

Eightieth percentile realization for north-south motion.

$$P80_{H2} = 22$$

$$P80_{V} := P80wt(RS\_05_{V}, freq, m_{ev})_{round(32 \cdot 80 \cdot \%)-1,\, 0}$$

Eightieth percentile realization for vertical motion.

$$P80_{V} = 1$$

For graphing purposes, subroutine "RS_a is written. It accepts the response spectra array containing the 32 realizations and stacks them into a two column array with column 0 being frequency and column 1 being response spectra.

$$RS_a(RS) := \left| \begin{array}{l} out \leftarrow augment\left(RS^{\langle 0\rangle}, RS^{\langle 1\rangle}\right) \\ \text{for } j \in 2..\, cols(RS) - 1 \\ \quad out \leftarrow stack\left(out, augment\left(RS^{\langle 0\rangle}, RS^{\langle j\rangle}\right)\right) \\ out \end{array} \right.$$

$RS_{aH1} := RS_a\left(RS\_05_{H1}\right)$ Graphing variable for all east-west response spectra.

$RS_{aH2} := RS_a\left(RS\_05_{H2}\right)$ Graphing variable for all north-south response spectr

$RS_{aV} := RS_a\left(RS\_05_{V}\right)$ Graphing variable for all vertical response spectra.

Fig. A.3.3.1-3 shows the response spectra data for all 32 realizations as data points. It also shows the response spectra realizations selected as 80th percentile. For additional information, the 80th percentile east-west, north-south, and vertical time histories and cumulative energy ratio are shown in Fig. A.3.3.1-4 - Fig. A.3.3.1-7. The variables are defined as shown below using previously defined subroutines.

$\Delta t = 0.005$ Time step.

$vel := Int_E\left(augment\left(t, a_{80h1}, a_{80h2}, a_{80v}\right)\right)$ Velocity time histories for all three directions

$dis := Int_E(vel)$ Displacement time histoies for all three directions.

$v_{80h1} := vel^{\langle 1\rangle}$ East-west velocity time history.

$v_{80h2} := vel^{\langle 2\rangle}$ North-south velocity time history.

$v_{80v} := vel^{\langle 3\rangle}$ Vertical velocity time history.

$x_{80h1} := dis^{\langle 1\rangle}$ East-west displacement time history.

$x_{80h2} := dis^{\langle 2\rangle}$ North-southdisplacement time history.

$x_{80v} := dis^{\langle 3\rangle}$ Vertical displacement time history.

$E_{80h1} := e_t\left(a_{80h1}, \Delta t\right)$ East-west cumulative energy time history.

$E_{80h2} := e_t\left(a_{80h2}, \Delta t\right)$ North-southcumulative energytime history.

$E_{80v} := e_t\left(a_{80v}, \Delta t\right)$ Vertical cumulative energytime history.

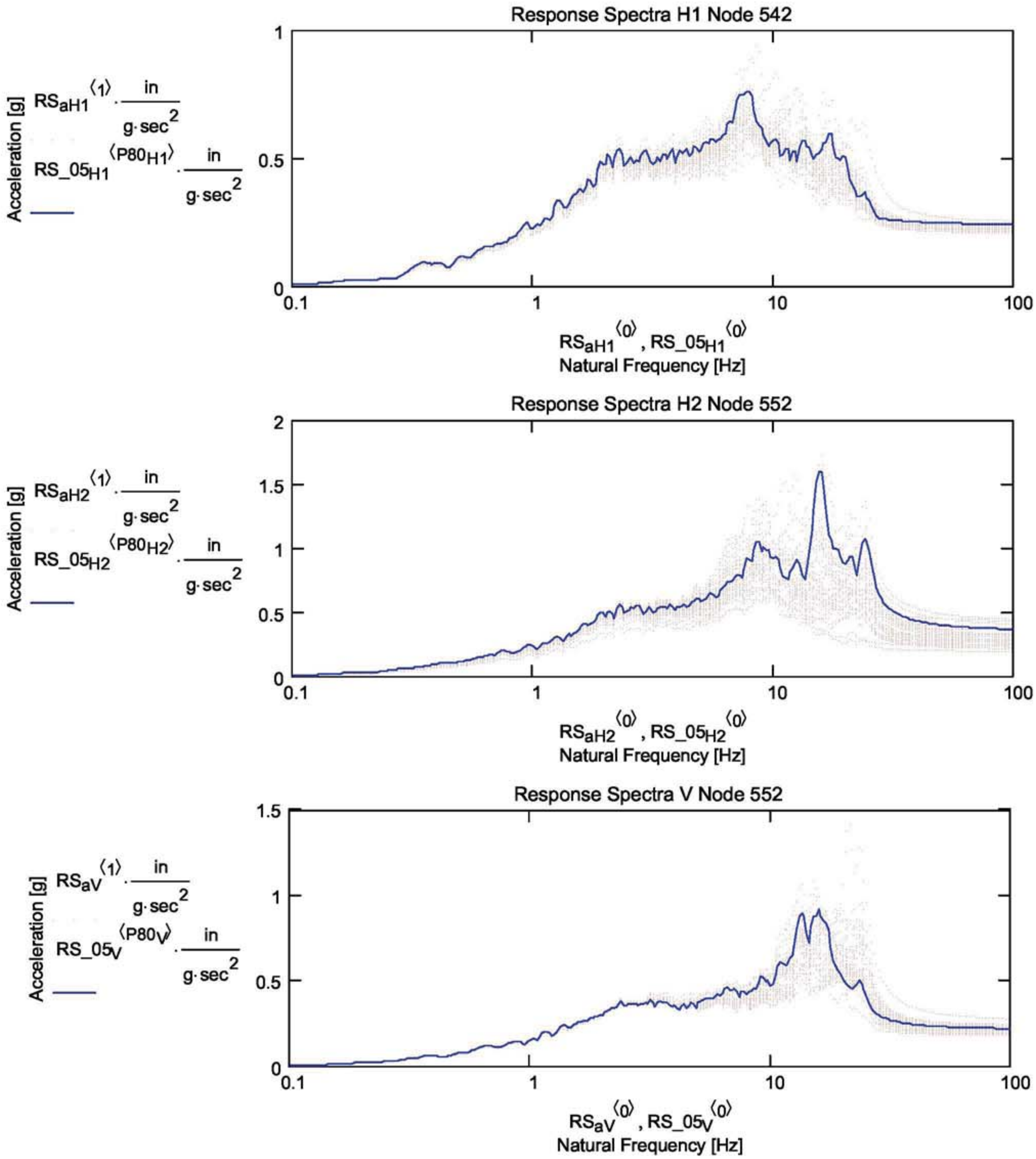

Fig. A.3.3.1-3 – All realizations (red) and 80th percentile (blue) 5% damping response spectra.

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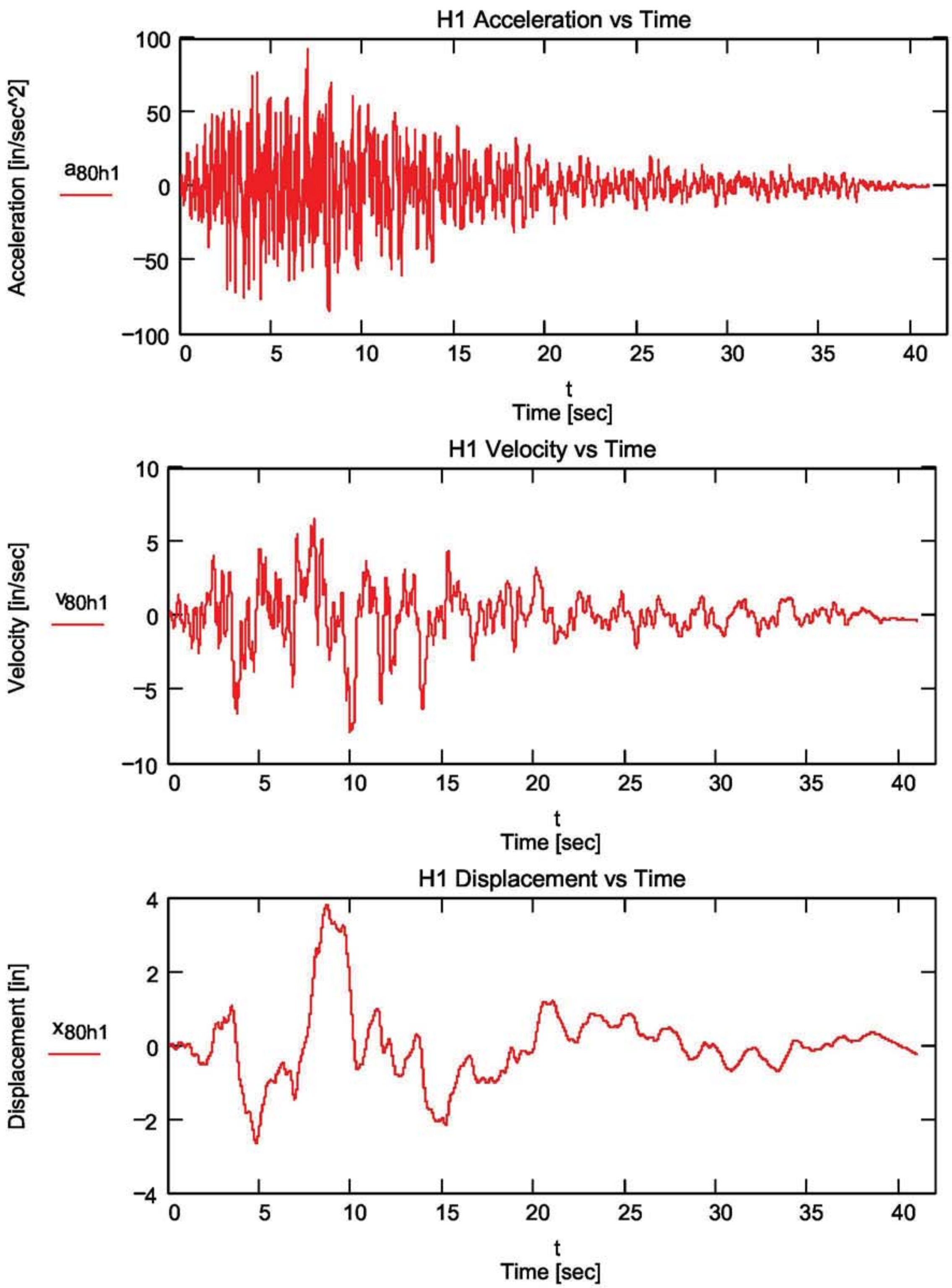

Fig. A.3.3.1-4 – East-west 80th percentile time histories.

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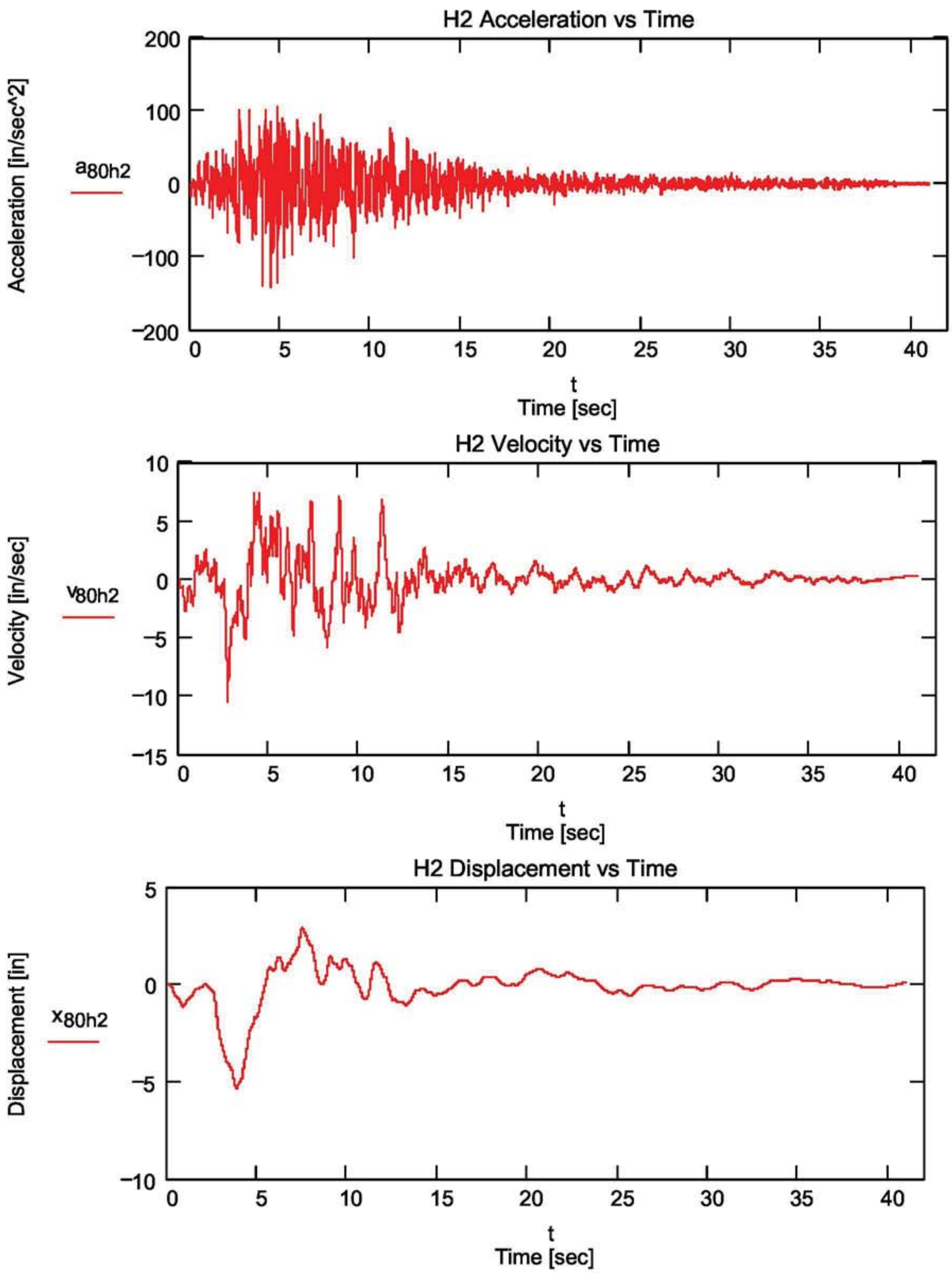

Fig. A.3.3.1-5 – North-south 80th percentile time histories.

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Authors:	R. E. Spears	**Date:**	09/30/08	**Checker:**	M. J. Russell	**Date:**	09/30/08

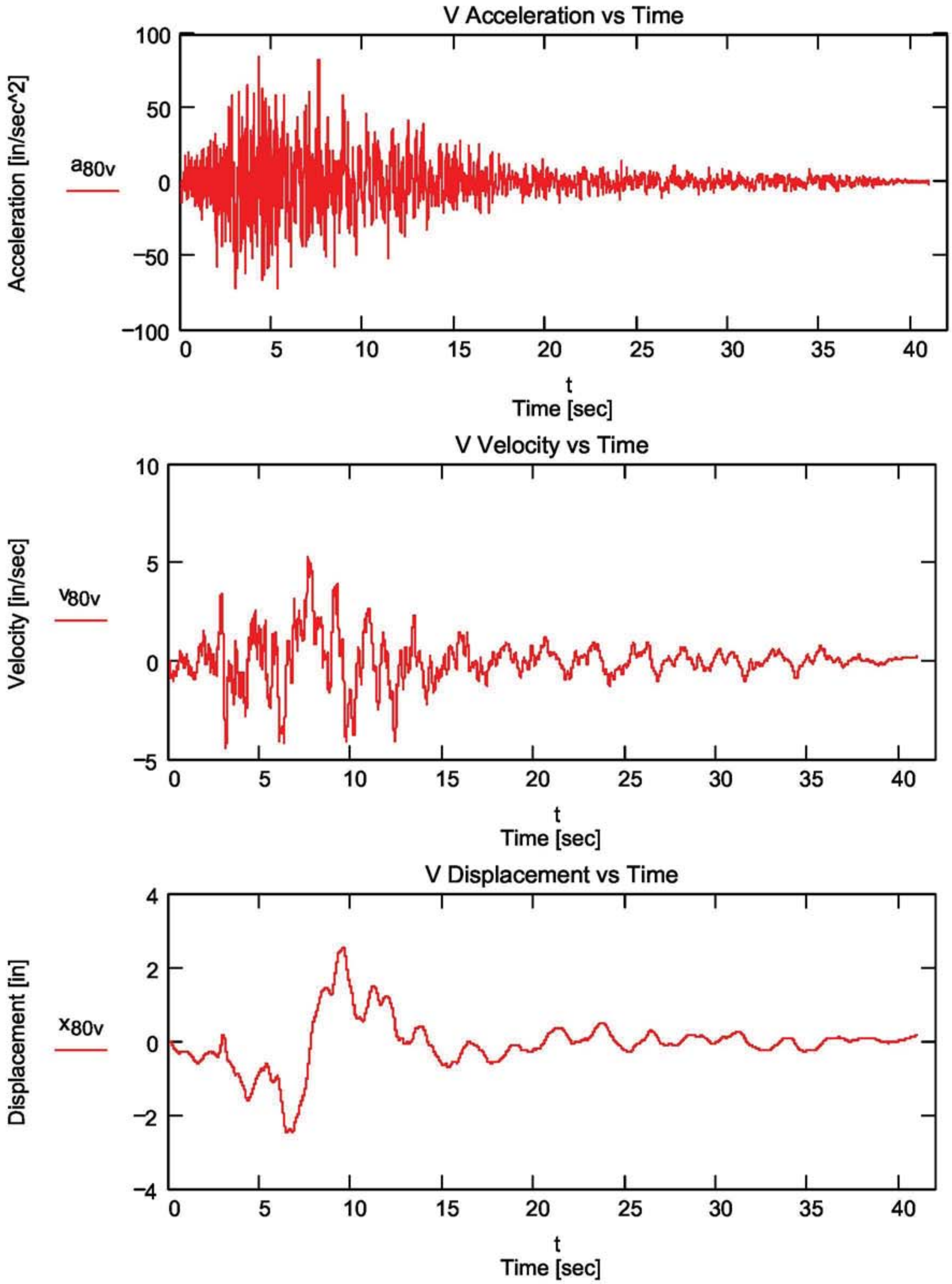

Fig. A.3.3.1-6 – Vertical 80[th] percentile time histories.

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Authors:	R. E. Spears	**Date:** 09/30/08	**Checker:** M. J. Russell	**Date:**	09/30/08

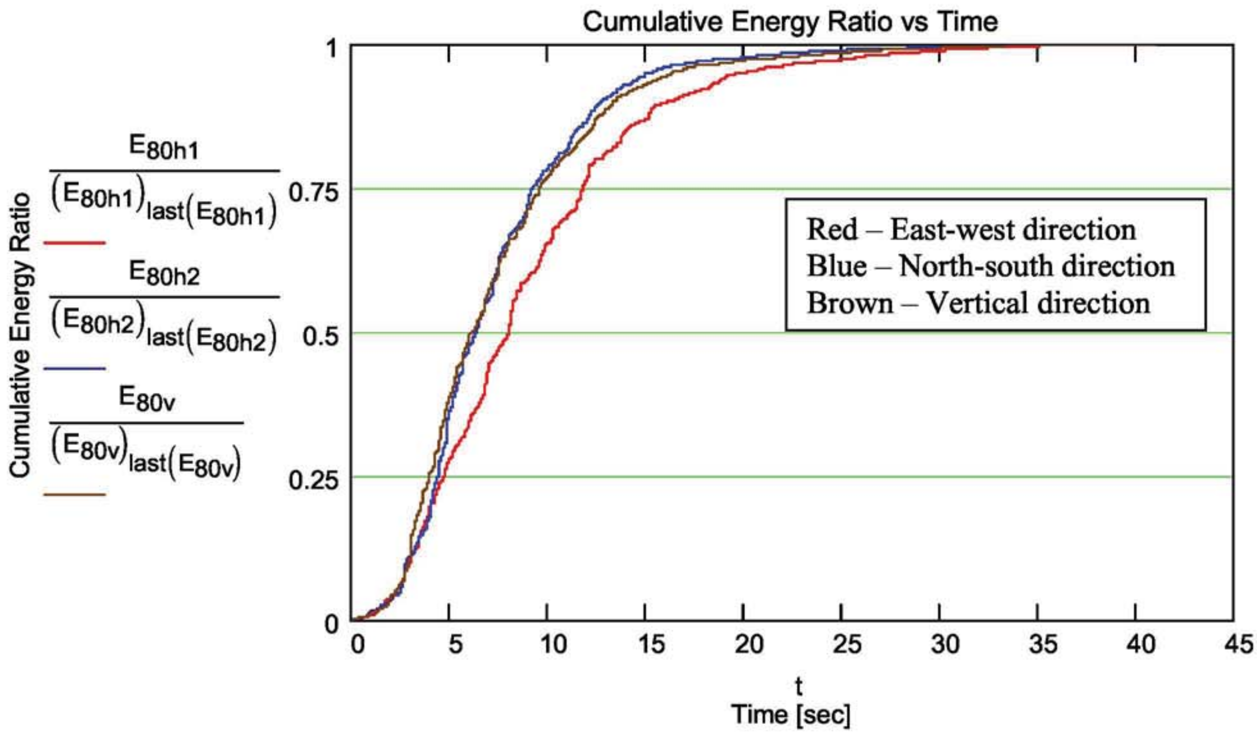

Fig. A.3.3.1-7 – Cumulative energy ratio versus time for 80th percentile data.

For further information, the 80th percentile east-west, north-south, and vertical fast Fourier transform amplitudes are shown in Fig. A.3.3.1-8 based on the variable definitions below.

$ffta_{80h1} := fft(submatrix(a_{80h1}, 1, last(a_{80h1}), 0, 0))$ H1 Fast Fourier transform

$ffta_{80h2} := fft(submatrix(a_{80h2}, 1, last(a_{80h2}), 0, 0))$ H2 Fast Fourier transform

$ffta_{80v} := fft(submatrix(a_{80v}, 1, last(a_{80v}), 0, 0))$ V Fast Fourier transform.

$\Delta t = 0.005$ Time step.

$f_{Ny} := \frac{1}{2 \cdot \Delta t}$ $\quad f_{Ny} = 100$ Nyquist frequency.

$j' := 0 .. last(ffta_{80h1})$ Graph counting variable.

$f_{o_{j'}} := \frac{j' \cdot f_{Ny}}{last(ffta_{80h1})}$ Output angular velocity.

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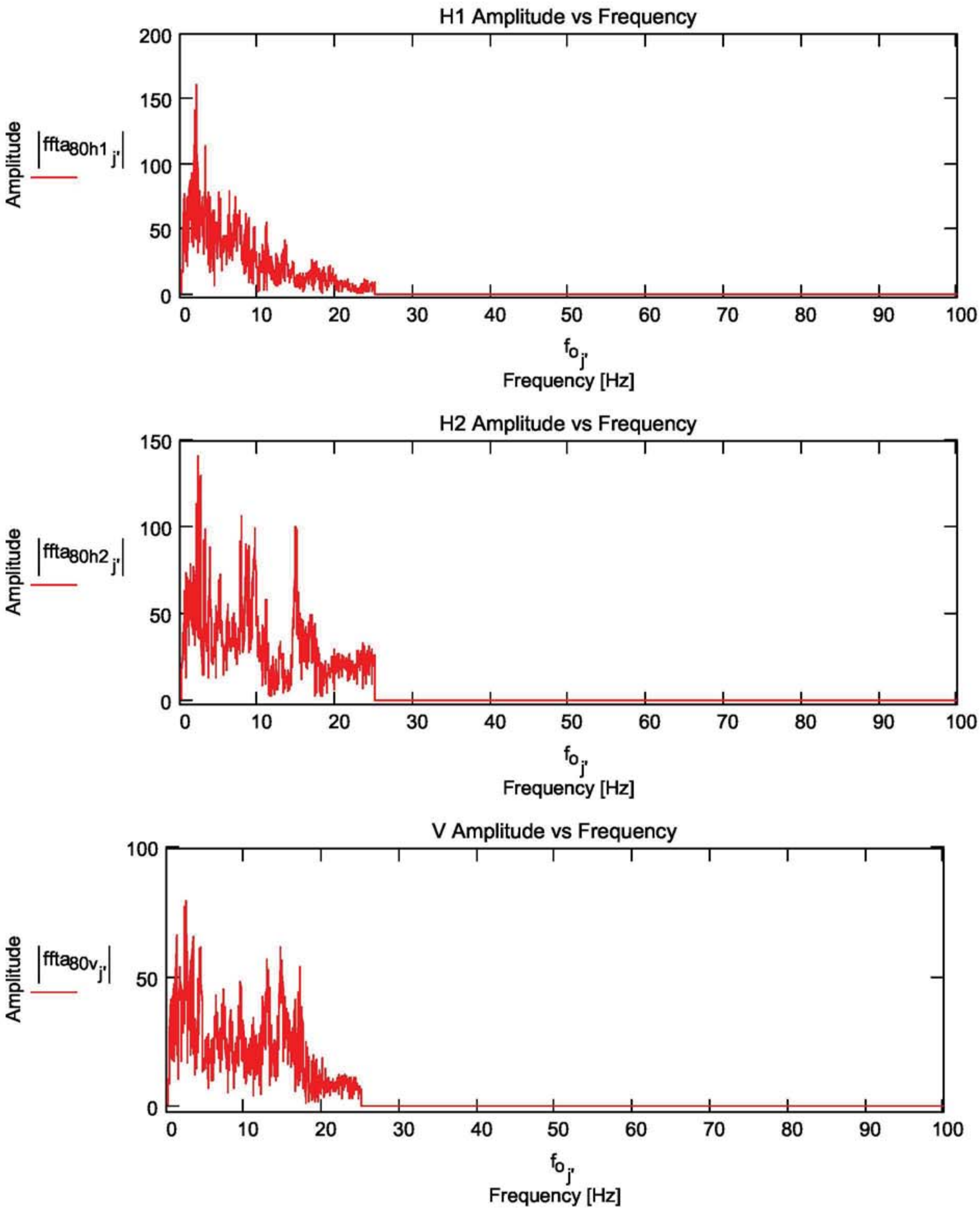

Fig. A.3.3.1-8 – Fast Fourier transform amplitudes for 80th percentile data.

The fourth step is to use the effective mass to establish the lower point where the Rayleigh damping curve crosses the 5% damping curve. This lower crossing frequency is defined as the frequency at or below where the cumulative effective mass percent reaches 5%. As shown in Fig. A.3.3.1-9, this occurs at 1.8 Hz.

The fifth step is to find Rayleigh damping constants that cause the Rayleigh damping curve to cross the 5% damping curve at the selected lower point and a reasonable upper point. Based on scoping analysis, the upper point is selected at 9.4 Hz. The derivation below shows the Rayleigh damping constants calculation and Fig. A.3.3.1-9 shows the resulting damping curve plotted with the desired damping curve.

$\omega_0 := 2\cdot\pi\cdot 1.8$ Lower end of the natural frequency range.

$\omega_1 := 2\cdot\pi\cdot 9.4$ Upper end of the natural frequency range.

$\xi := 0.05$ Desired damping value.

$$\xi = \frac{\alpha}{2\cdot\omega_0} + \frac{\beta\cdot\omega_0}{2} \qquad \xi = \frac{\alpha}{2\cdot\omega_1} + \frac{\beta\cdot\omega_1}{2}$$

$$\begin{pmatrix} \frac{1}{2\cdot\omega_0} & \frac{\omega_0}{2} \\ \frac{1}{2\cdot\omega_1} & \frac{\omega_1}{2} \end{pmatrix} \cdot \begin{pmatrix} \alpha \\ \beta \end{pmatrix} = \begin{pmatrix} \xi \\ \xi \end{pmatrix} \implies \begin{pmatrix} \alpha \\ \beta \end{pmatrix} = \begin{pmatrix} \frac{1}{2\cdot\omega_0} & \frac{\omega_0}{2} \\ \frac{1}{2\cdot\omega_1} & \frac{\omega_1}{2} \end{pmatrix}^{-1} \cdot \begin{pmatrix} \xi \\ \xi \end{pmatrix}$$

$$\alpha\beta := \begin{pmatrix} \frac{1}{2\cdot\omega_0} & \frac{\omega_0}{2} \\ \frac{1}{2\cdot\omega_1} & \frac{\omega_1}{2} \end{pmatrix}^{-1} \cdot \begin{pmatrix} \xi \\ \xi \end{pmatrix} = \begin{bmatrix} 2\cdot\omega_1\cdot\omega_0\cdot\frac{\xi}{(\omega_0+\omega_1)} \\ 2\cdot\frac{\xi}{(\omega_0+\omega_1)} \end{bmatrix}$$

$$\alpha\beta = \begin{pmatrix} 0.949 \\ 1.421\times 10^{-3} \end{pmatrix}$$ Constants definition.

$\alpha := \alpha\beta_0$ $\alpha = 0.949$

$\beta := \alpha\beta_1$ $\beta = 1.421\times 10^{-3}$

$\xi_g(\omega) := \frac{\alpha}{2\cdot\omega} + \frac{\beta\cdot\omega}{2}$ Definition for Rayleigh damping (for plotting).

$f_g := 0.01, 0.03 .. 100$ Graphing nature frequencies in Hertz (for plotting)

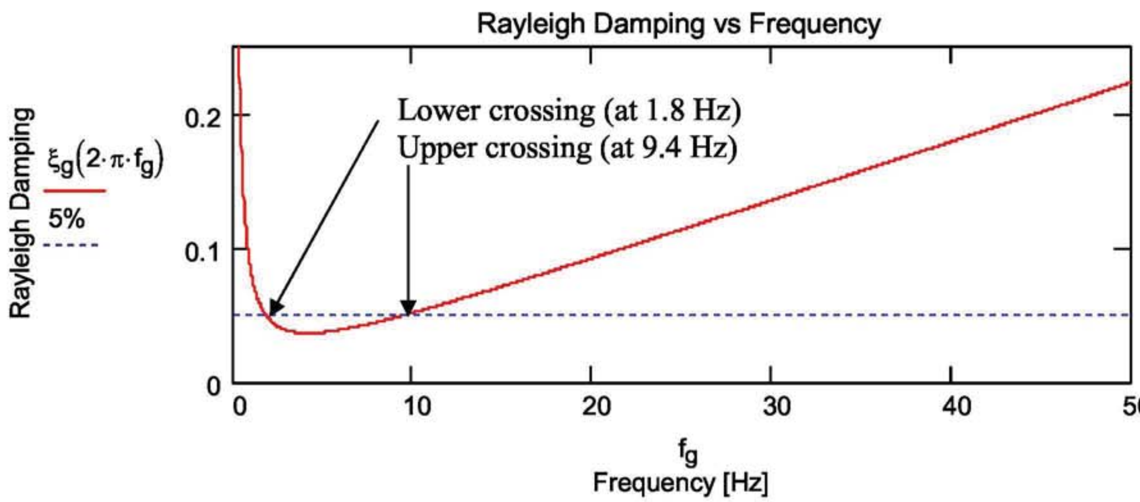

Fig. A.3.3.1-9 – Model 3 Rayleigh damping curve and desired damping curve versus frequency.

The Sixth step is to establish the Rayleigh damping response spectra for the 80th percentile time histories and the Rayleigh damping constants. This is performed with the ReSpect_vardamp (see Appendix A.3.4 for validation) program. This program is very similar to the ReSpect. The important difference between the two programs is that ReSpect_vardamp uses Rayleigh damping where ReSpect uses constant damping. The input file and the output file format are the same between the two programs.

Fig. A.3.3.1-10 shows a comparison of the response spectra for 5% damping and Rayleigh damping. Fig. A.3.3.1-11 shows the response spectra difference between Rayleigh damping and 5% damping.

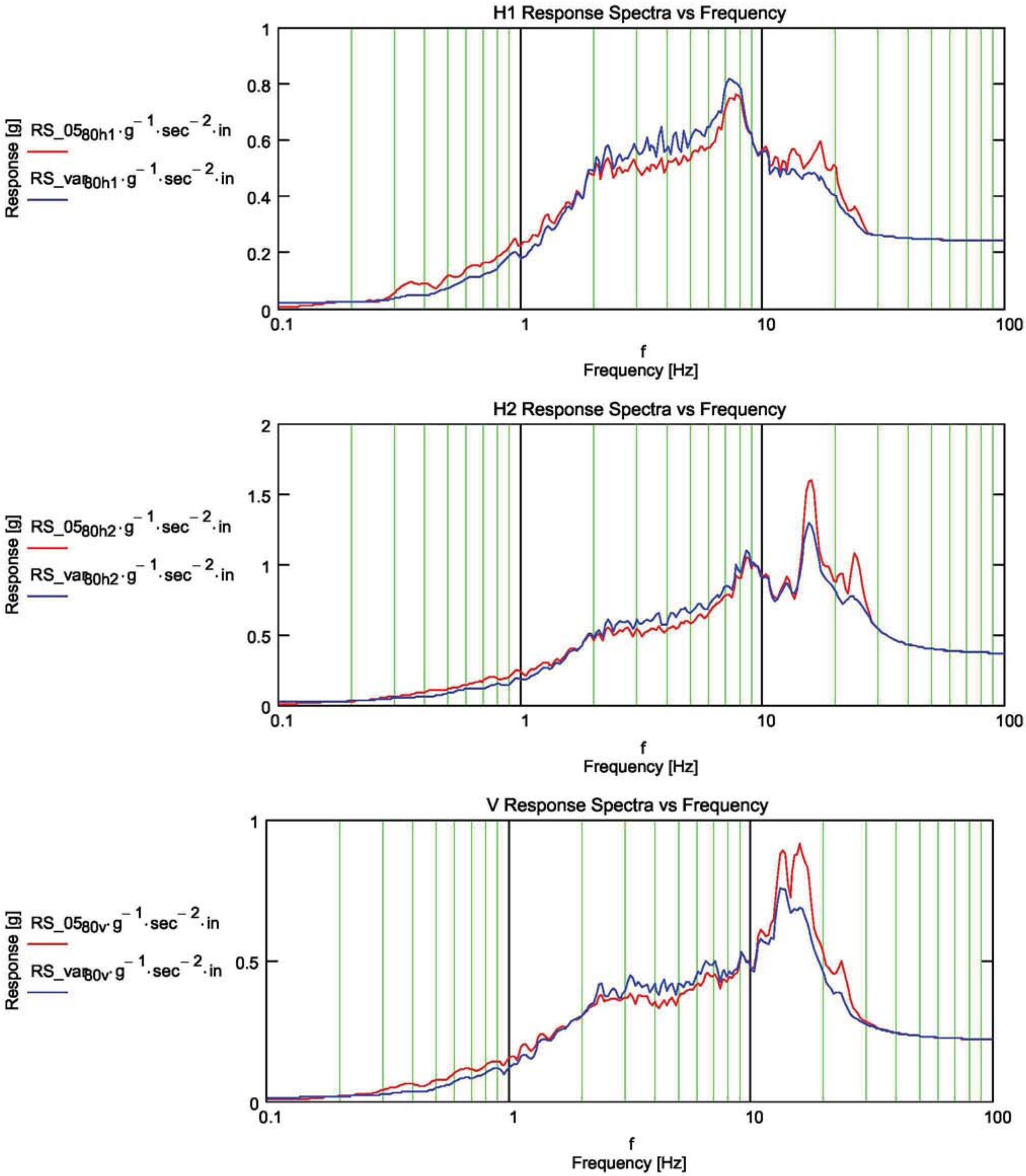

Fig. A.3.3.1-10 – Response spectra for 5% damping (red) and Rayleigh damping (blue).

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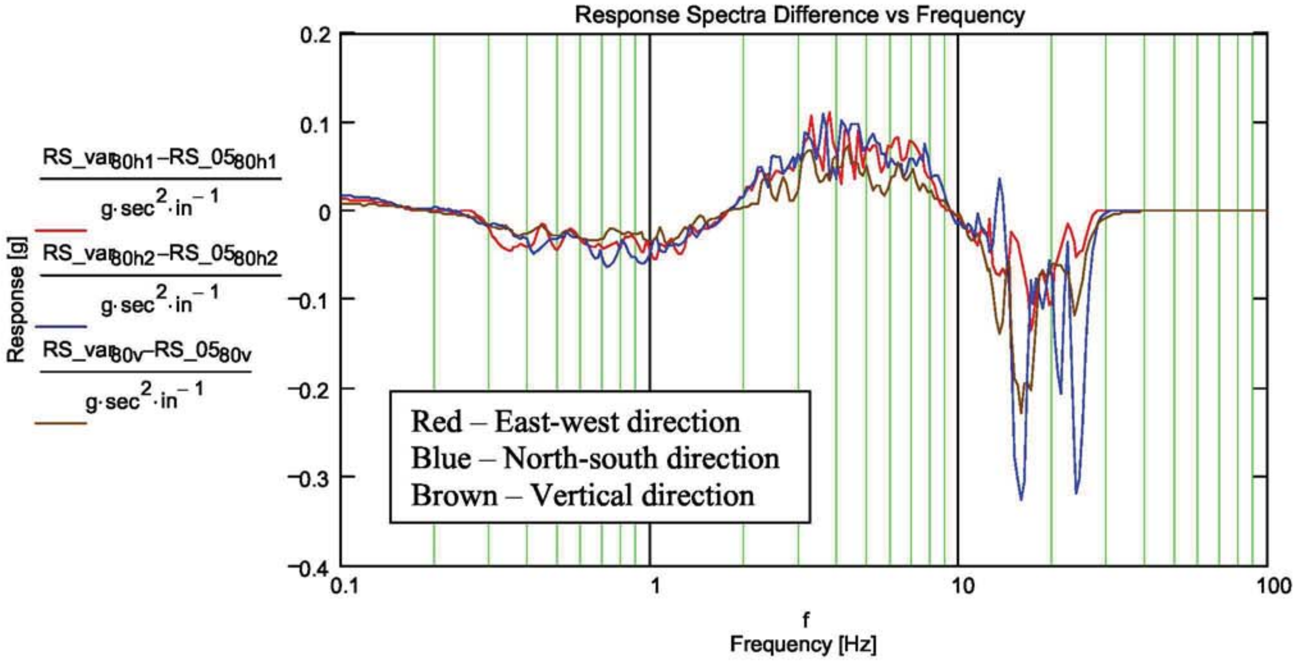

Fig. A.3.3.1-11 – Response spectra difference between Rayleigh damping and 5% damping.

The seventh step is to generate a cumulative weighted response curve. This uses the curve generated by subtracting the 5% damping response spectra from the Rayleigh damping response spectra (shown in Fig. A.3.3.1-11). The weighted response is then taken as the effective mass at each natural frequency multiplied by the difference in response spectra at that natural frequency (corresponding to the effective mass). These values are then summed for the significant effective mass values in all three directions. If the sum produced a small positive number, then the Rayleigh damping values are considered acceptable.

The subroutine "$Damp_{wt}$ is written to perform this task. It accepts response spectra difference, the response spectra frequencies, the effective mass, and the effective mass frequencies as input. The first "for loop is written to generate the base 10 logarithm values for the response spectra frequencies. Next, the "sum variable is set to zero. Then, a "for loop is performed that generates the cumulative effective mass multiplied by response versus effective mass frequency. Similar to the subroutine "P80wt, a log-linear interpolation is performed to establish response difference at a given effective mass frequency. The output for the subroutine is then the cumulative weighted response curve.

```
Damp_wt(ΔRS, f, m_e, f_e) := | for  i ∈ 0.. last(f)
                             |   f_log_i ← log(f_i)
                             | sum ← 0
                             | for  i ∈ 0.. last(f_e)
                             |   | out_i,0 ← f_e_i
                             |   | sum ← sum + m_e_i · linterp(f_log, ΔRS, log(f_e_i))
                             |   | out_i,1 ← sum
                             | out
```

The cumulative weighted response for each direction is calculated below. A plot of this summed for all three directions is shown in Fig. A.3.3.1-12.

$\Delta RS_{wt\_h1} := Damp_{wt}\left(RS\_var_{80h1} - RS\_05_{80h1}, f, m_{eh1}, freq\right)$ East-west cumulative weighted response.

$\Delta RS_{wt\_h2} := Damp_{wt}\left(RS\_var_{80h2} - RS\_05_{80h2}, f, m_{eh2}, freq\right)$ North-southcumulative weighted response.

$\Delta RS_{wt\_v} := Damp_{wt}\left(RS\_var_{80v} - RS\_05_{80v}, f, m_{ev}, freq\right)$ Vertical cumulative weighted response.

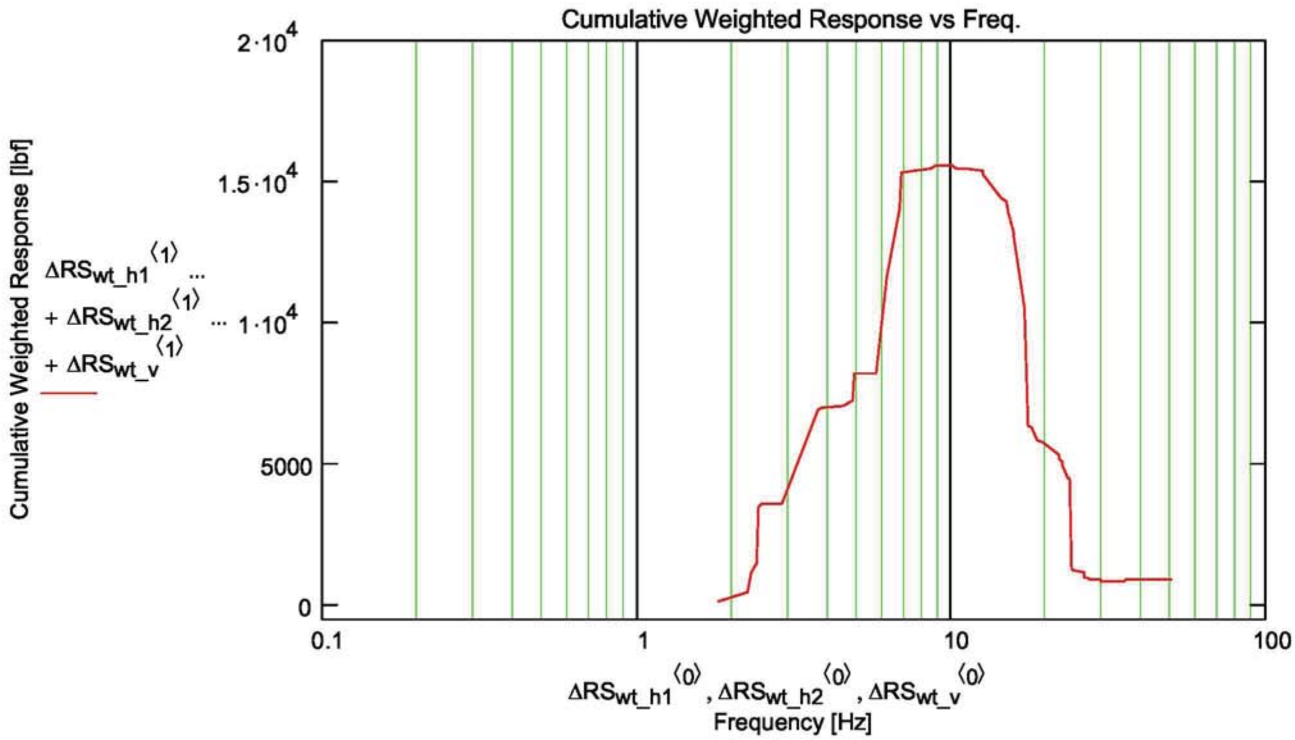

Fig. A.3.3.1-12 – Summed cumulative weighted response for Model 3.

The important feature of Fig. A.3.3.1-12 is that the last point has a value greater than zero. Because the last point value is greater than zero, the selected Rayleigh damping constants are acceptable relative to the code-specified 5% modal damping.

A.3.3.2 – Rayleigh Damping Constants for Model 265

Rayleigh damping constants for Model 265 are calculated in the same manner as those calculated in Model 3. See the Model 3 discussion in Section A.3.3.1 for the details of these calculations. The first step of the process, the calculation of a full set of 5% damping response spectra, was done for Model 3, with the results applied to the other two models.

For the second step, effective mass values for the Model 265 modes are needed. To accomplish this, a modal analysis is run with the input file "model265_fr_9-24-08.inp in ABAQUS (as shown in Fig. A.3.3.2-1) to find all natural frequencies occurring between 0 Hz and 50 Hz. Upon completion of the model runs, effective mass in all three directions versus frequency are gathered from the "model265_fr_9-24-08.dat file and read into the Mathcad variable "dat`. Results of this analysis are processed as was done for Model 3, and described in section A.3.3.1 above, with the results plotted in Fig. A.3.3.2-2. The figure shows the effect mass and cumulative effective mass percentage versus frequency for Model 265.

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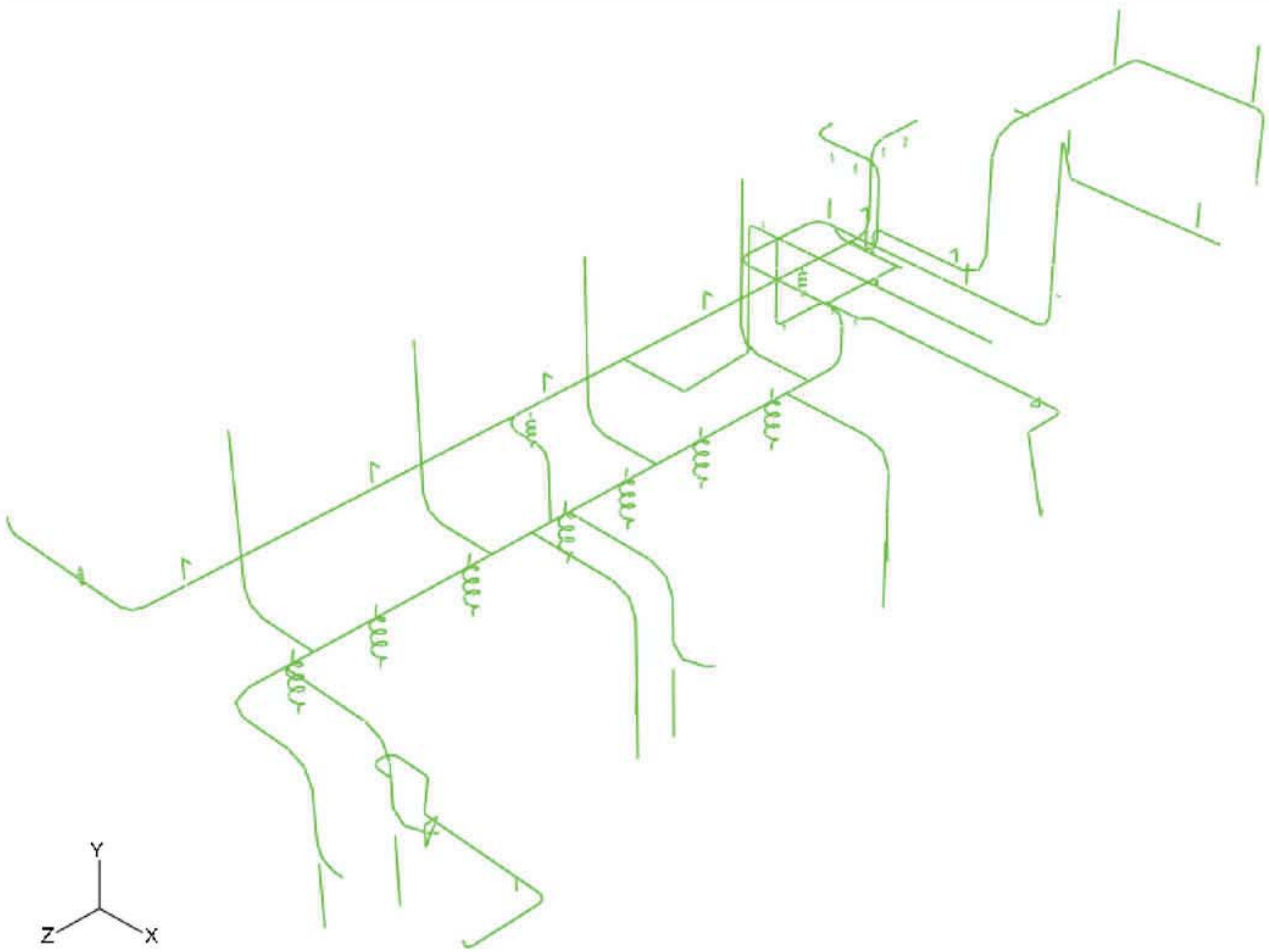

SDRC I-DEAS ABAQUS FILE TRANSLATOR 24-Sep-08 16:24:04
ODB: model265_fr_9-24-08.odb Abaqus/Standard Version 6.7-5 Wed Sep 24 17:03:27 MDT 2008

Step: Step-2
Mode 1: Value = 27.483 Freq = 0.83436 (cycles/time)

Fig. A.3.3.2-1 – Modal analysis for Model 265.

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Title:	ATR Primary Coolant System Seismic Evaluation				
Authors:	R. E. Spears	**Date:** 09/30/08	**Checker:** M. J. Russell	**Date:**	09/30/08

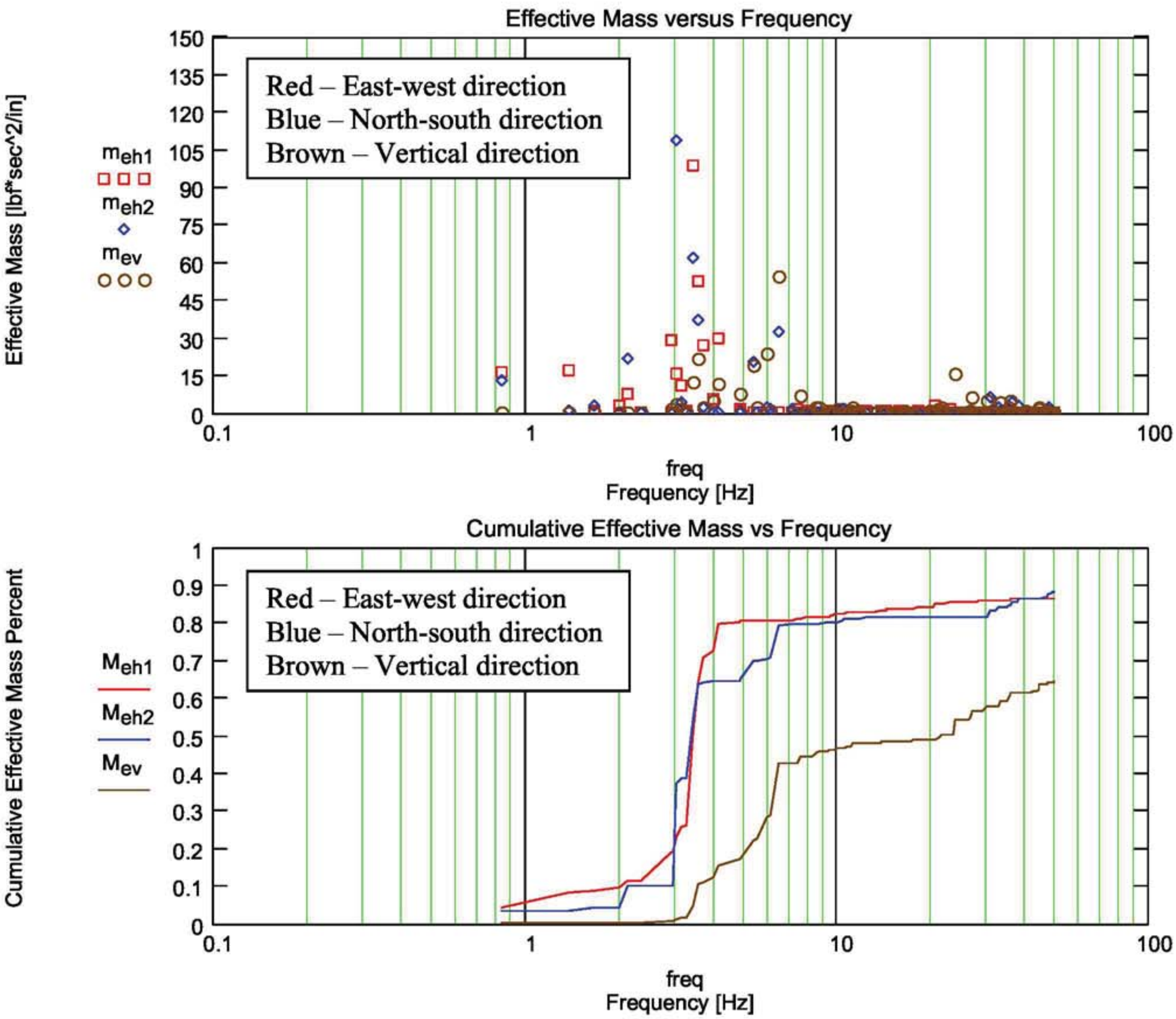

Fig. A.3.3.2-2 – Effect mass and cumulative effective mass percentage versus frequency.

The third step is to establish the 80th percentile response spectrum. Similar to Model 3, this is done with the subroutine "P80wt.

$P80_{H1} := P80wt(RS\_05_{H1}, freq, m_{eh1})_{round(32 \cdot 80 \cdot \%)-1, 0}$ Eightieth percentile realization for east-west motion.

$P80_{H1} = 17$

$P80_{H2} := P80wt(RS\_05_{H2}, freq, m_{eh2})_{round(32 \cdot 80 \cdot \%)-1, 0}$ Eightieth percentile realization for north-south motion.

$P80_{H2} = 11$

$P80_{V} := P80wt(RS\_05_{V}, freq, m_{ev})_{round(32 \cdot 80 \cdot \%)-1, 0}$ Eightieth percentile realization for vertical motion.

$P80_{V} = 22$

Fig. A.3.3.2-3 shows the response spectra data for all 32 realizations as data points. It also shows the response spectra realizations selected as 80th percentile.

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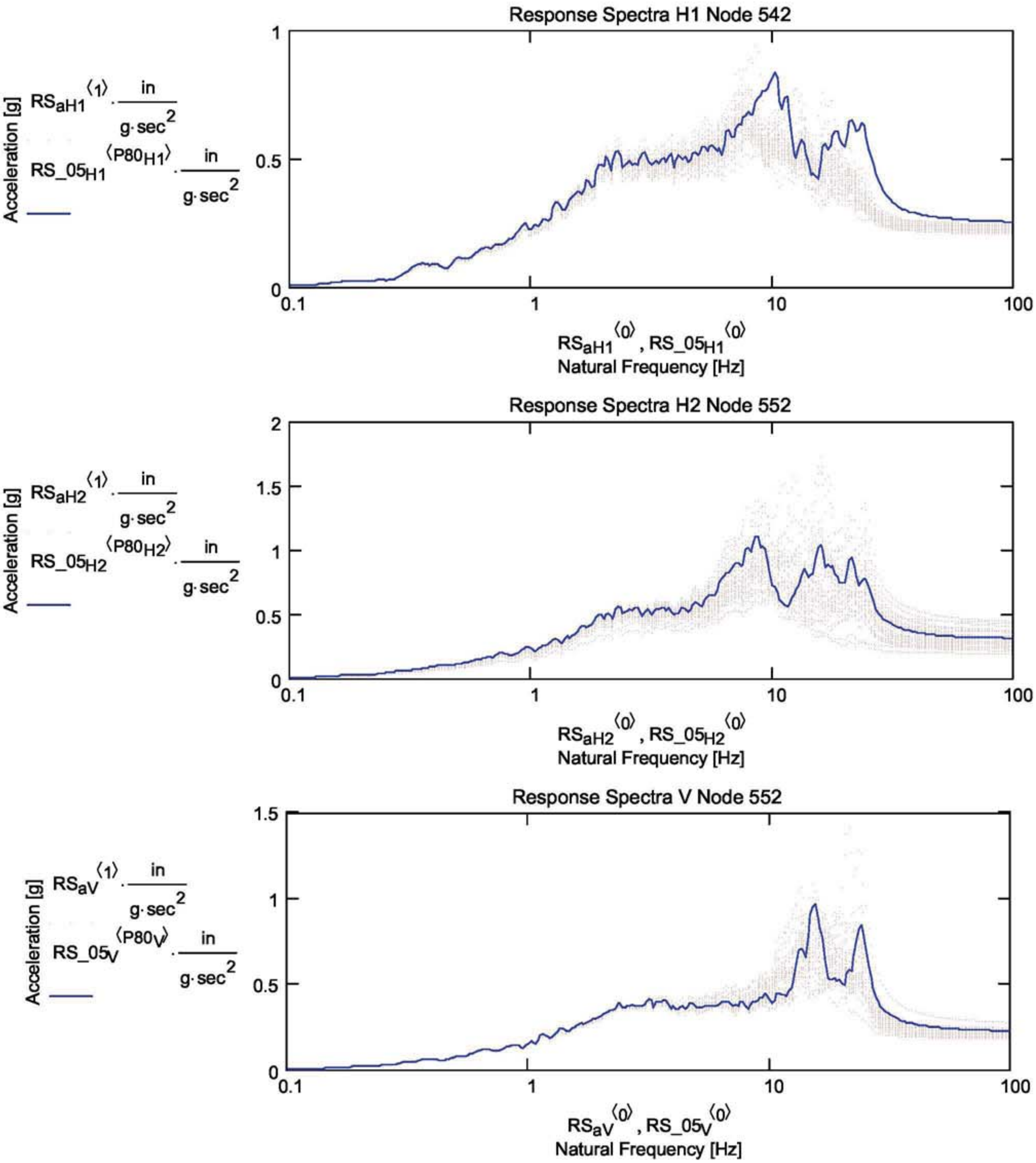

Fig. A.3.3.2-3 – All realizations (red) and 80th percentile (blue) 5% damping response spectra.

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The fourth step is to use the effective mass to establish the lower point where the Rayleigh damping curve crosses the 5% damping curve. This lower crossing frequency is defined as the frequency at or below where the cumulative effective mass percent reaches 5%. As shown in Fig. A.3.3.2-2, this occurs at 0.8 Hz.

The fifth step is to find Rayleigh damping constants that cause the Rayleigh damping curve to cross the 5% damping curve at the selected lower point and a reasonable upper point. Based on scoping analysis, the upper point is selected at 4.7 Hz. The derivation below shows the Rayleigh damping constants calculation and Fig. A.3.3.2-4 shows the resulting damping curve plotted with the desired damping curve for Model 265.

$\omega_0 := 2\cdot\pi\cdot 0.8$ Lower end of the natural frequency range.

$\omega_1 := 2\cdot\pi\cdot 4.7$ Upper end of the natural frequency range.

$\xi := 0.05$ Desired damping value.

$$\xi = \frac{\alpha}{2\cdot\omega_0} + \frac{\beta\cdot\omega_0}{2} \qquad \xi = \frac{\alpha}{2\cdot\omega_1} + \frac{\beta\cdot\omega_1}{2}$$

$$\begin{pmatrix} \frac{1}{2\cdot\omega_0} & \frac{\omega_0}{2} \\ \frac{1}{2\cdot\omega_1} & \frac{\omega_1}{2} \end{pmatrix} \cdot \begin{pmatrix} \alpha \\ \beta \end{pmatrix} = \begin{pmatrix} \xi \\ \xi \end{pmatrix} \quad ==> \quad \begin{pmatrix} \alpha \\ \beta \end{pmatrix} = \begin{pmatrix} \frac{1}{2\cdot\omega_0} & \frac{\omega_0}{2} \\ \frac{1}{2\cdot\omega_1} & \frac{\omega_1}{2} \end{pmatrix}^{-1} \cdot \begin{pmatrix} \xi \\ \xi \end{pmatrix}$$

$$\alpha\beta := \begin{pmatrix} \frac{1}{2\cdot\omega_0} & \frac{\omega_0}{2} \\ \frac{1}{2\cdot\omega_1} & \frac{\omega_1}{2} \end{pmatrix}^{-1} \cdot \begin{pmatrix} \xi \\ \xi \end{pmatrix} = \begin{bmatrix} 2\cdot\omega_1\cdot\omega_0\cdot\frac{\xi}{(\omega_0+\omega_1)} \\ 2\cdot\frac{\xi}{(\omega_0+\omega_1)} \end{bmatrix}$$

$$\alpha\beta = \begin{pmatrix} 0.43 \\ 2.894\times 10^{-3} \end{pmatrix}$$ Constants definition.

$\alpha := \alpha\beta_0$ $\alpha = 0.4295$

$\beta := \alpha\beta_1$ $\beta = 2.894\times 10^{-3}$

$\xi_g(\omega) := \frac{\alpha}{2\cdot\omega} + \frac{\beta\cdot\omega}{2}$ Definition for Rayleigh damping (for plotting).

$f_g := 0.01, 0.03 .. 100$ Graphing nature frequencies in Hertz (for plotting)

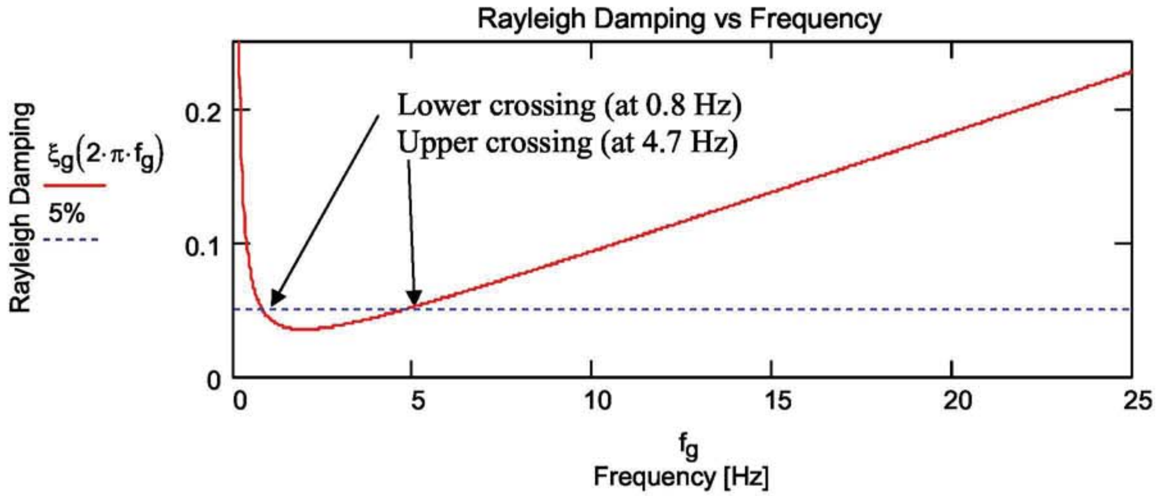

Fig. A.3.3.2-4 – Model 265 Rayleigh damping curve and desired damping curve versus frequency.

The Sixth step is to establish the Rayleigh damping response spectra for the 80th percentile time histories and the Rayleigh damping constants. This is done as described in Section A.3.3.1, with the results plotted in Fig. A.3.3.2-5. The figure shows a comparison of the response spectra for 5% damping and Rayleigh damping for Model 265. Fig. A.3.3.2-6 shows the response spectra difference between Rayleigh damping and 5% damping.

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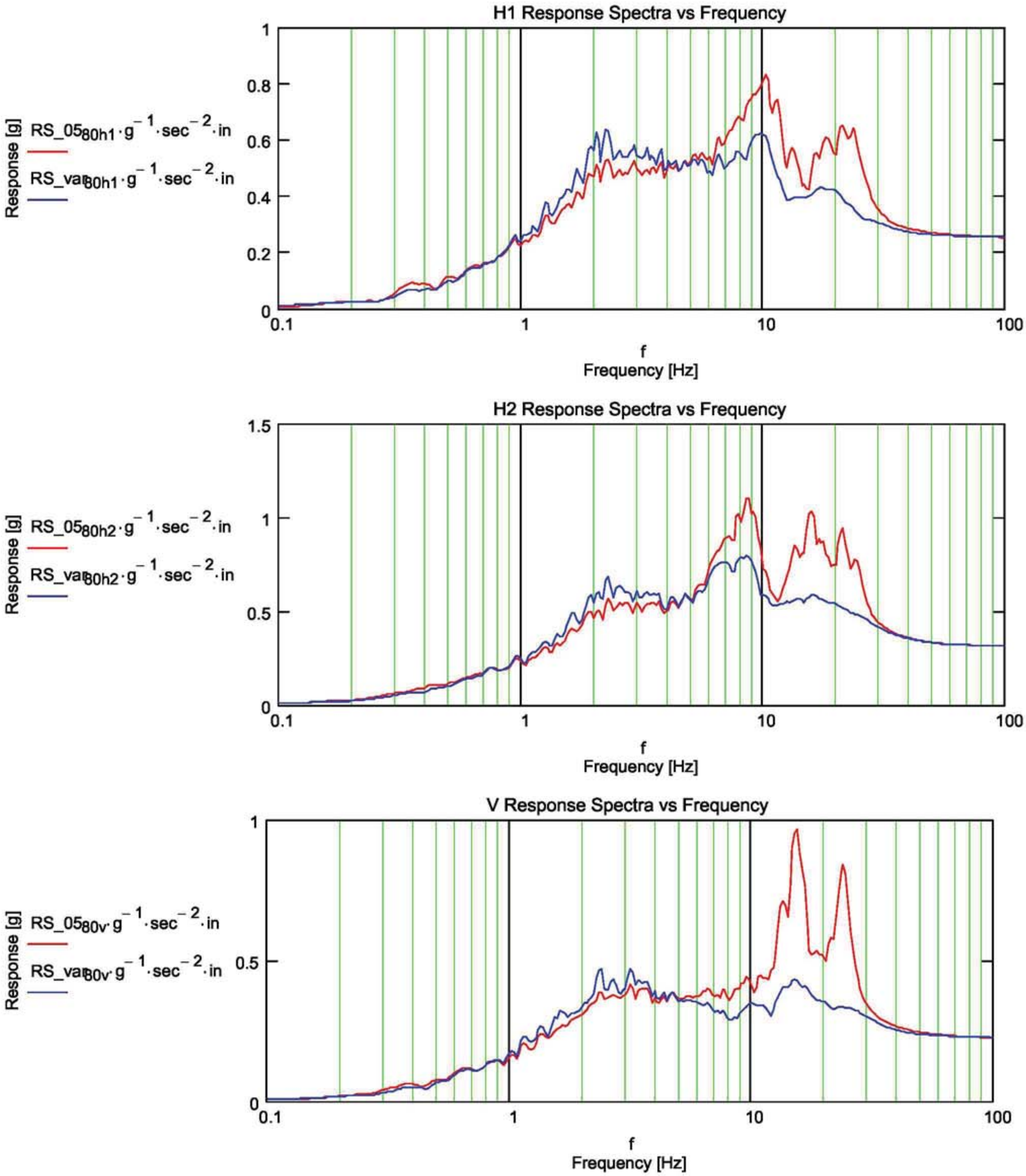

Fig. A.3.3.2-5 – Response spectra for 5% damping (red) and Rayleigh damping (blue).

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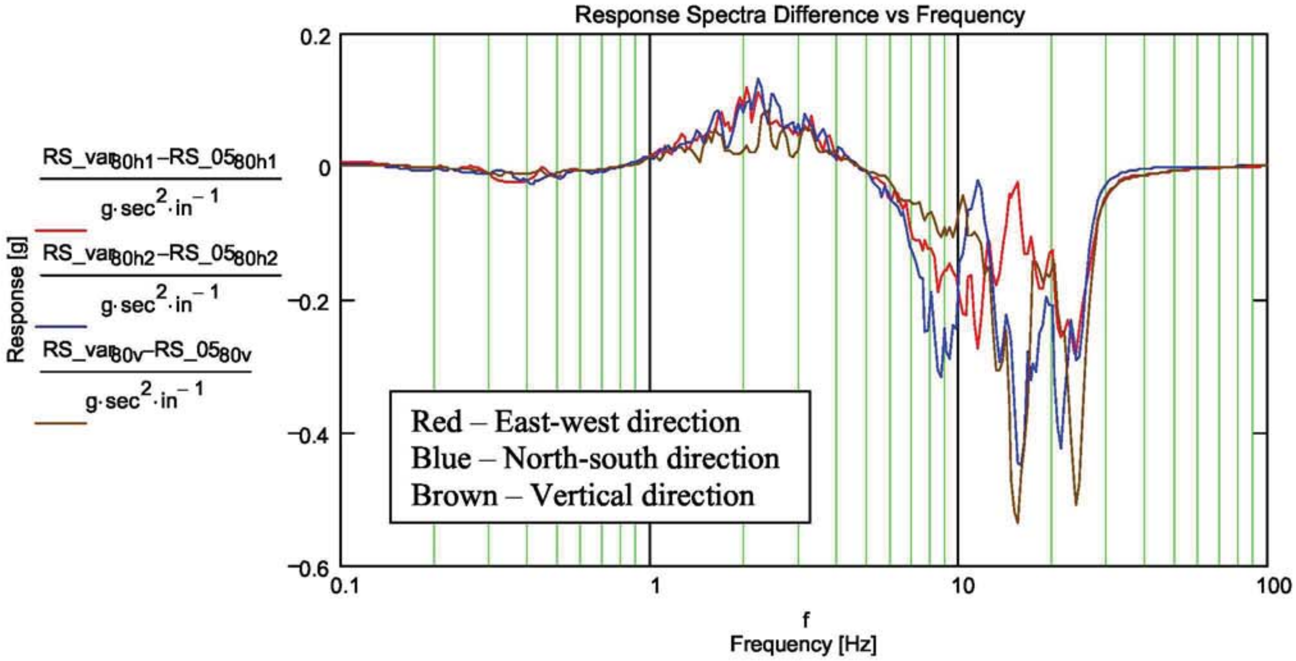

Fig. A.3.3.2-6 – Response spectra difference between Rayleigh damping and 5% damping.

The seventh step is to generate a cumulative weighted response curve. This is done as described in Section A.3.3.1, with the results plotted in Fig. A.3.3.2-6. The weighted response is then the effective mass at each natural frequency multiplied by the difference in response spectra at that natural frequency (corresponding to the effective mass). These values are then summed for the significant effective mass values in all three directions. If the sum produced a positive number, then the Rayleigh damping values are considered acceptable. The cumulative weighted response for each direction is calculated as described in Section A.3.3.1. A plot of this summed for all three directions is shown in Fig. A.3.3.2-7.

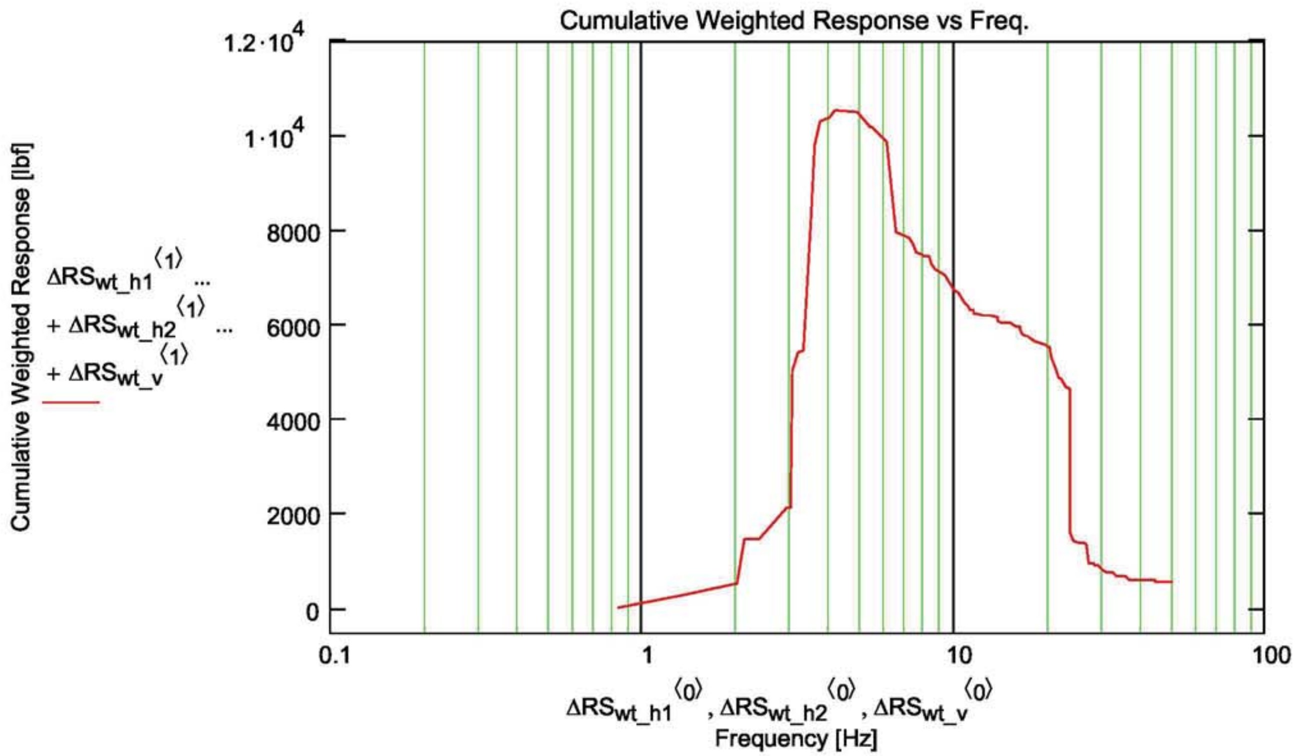

Fig. A.3.3.2-7 – Summed cumulative weighted response for Model 265.

The important feature of Fig. A.3.3.2-7 is that the last point has a value greater than zero. Because the last point value is greater than zero, the selected Rayleigh damping constants are acceptable relative to the code-specified 5% modal damping.

A.3.3.3 – Rayleigh Damping Constants for Model 14

Rayleigh damping constants for Model 14 are calculated in the same manner as those calculated for Model 3. See the Model 3 discussion in Section A.3.3.1 for the details of these calculations. The first step of the process, the calculation of a full set of 5% damping response spectra, was done for Model 3, with the results applied to the other two models.

For the second step, effective mass values for the Model 14 modes are needed. To accomplish this, a modal analysis is run with the input file "Base_M14_fr_9-24-08.inp in ABAQUS (as shown in Fig. A.3.3.3-1) to find all natural frequencies occurring between 0 Hz and 50 Hz. Upon completion of the model runs, effective mass in all three directions versus frequency are gathered from the "Base_M14_fr_9-24-08.dat file and read into the Mathcad variable "dat`. Results of this analysis are processed as was done for Model 3, and described in section A.3.3.1 above, with the results plotted in Fig. A.3.3.3-2. The figure shows the effect mass and cumulative effective mass percentage versus frequency for Model 14.

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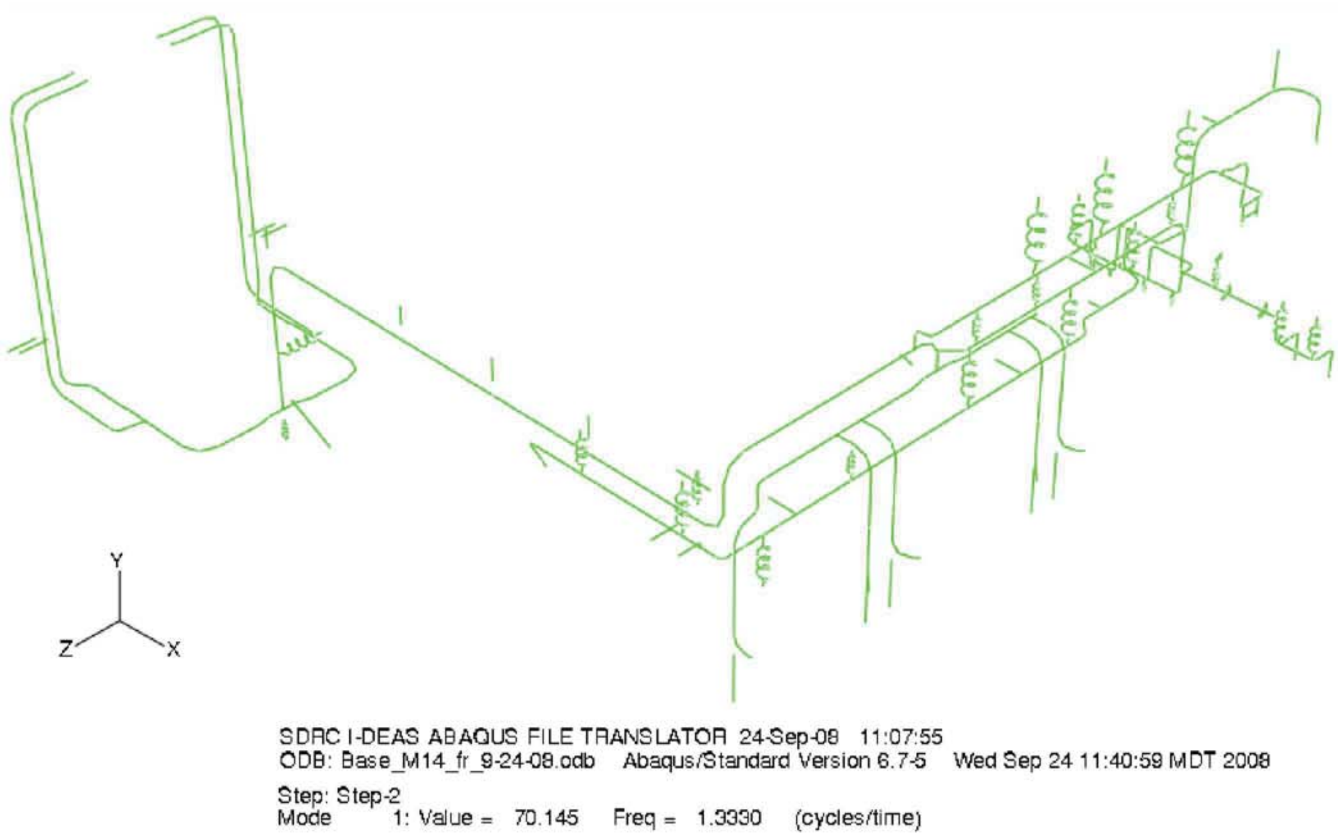

Fig. A.3.3.3-1 – Modal analysis for Model 14.

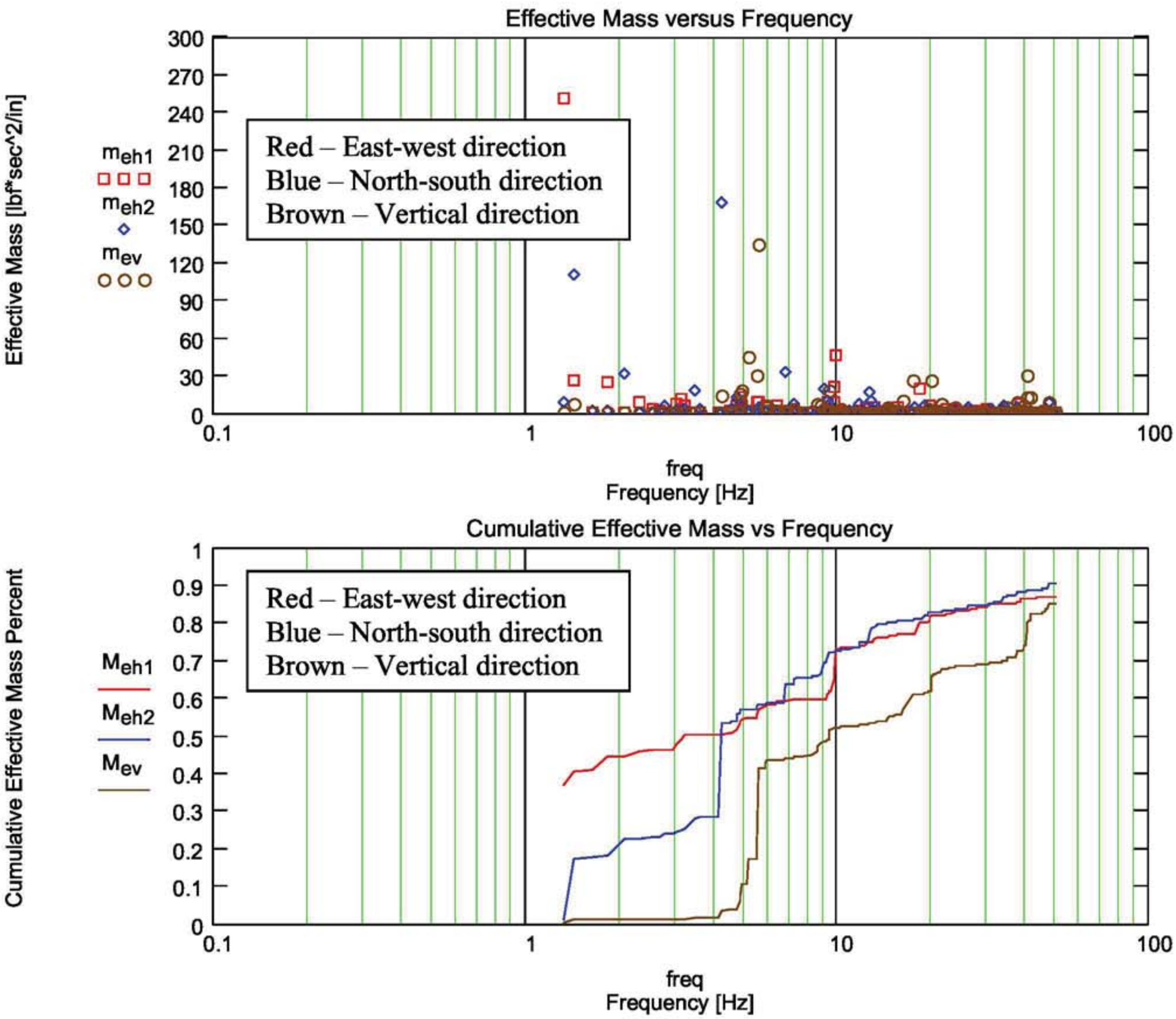

Fig. A.3.3.3-2 – Effect mass and cumulative effective mass percentage versus frequency.

The third step is to establish the 80th percentile response spectrum. Similar to Model 3, this is done with the subroutine "P80wt.

$P80_{H1} := P80wt\left(RS\_05_{H1}, freq, m_{eh1}\right)_{round(32 \cdot 80 \cdot \%)-1,\, 0}$ Eightieth percentile realization for east-west motion.

$P80_{H1} = 27$

$P80_{H2} := P80wt\left(RS\_05_{H2}, freq, m_{eh2}\right)_{round(32 \cdot 80 \cdot \%)-1,\, 0}$ Eightieth percentile realization for north-south motion.

$P80_{H2} = 22$

$P80_{V} := P80wt\left(RS\_05_{V}, freq, m_{ev}\right)_{round(32 \cdot 80 \cdot \%)-1,\, 0}$ Eightieth percentile realization for vertical motion.

$P80_{V} = 23$

Fig. A.3.3.3-3 shows the response spectra data for all 32 realizations as data points. It also shows the response spectra realizations selected as 80^{th} percentile.

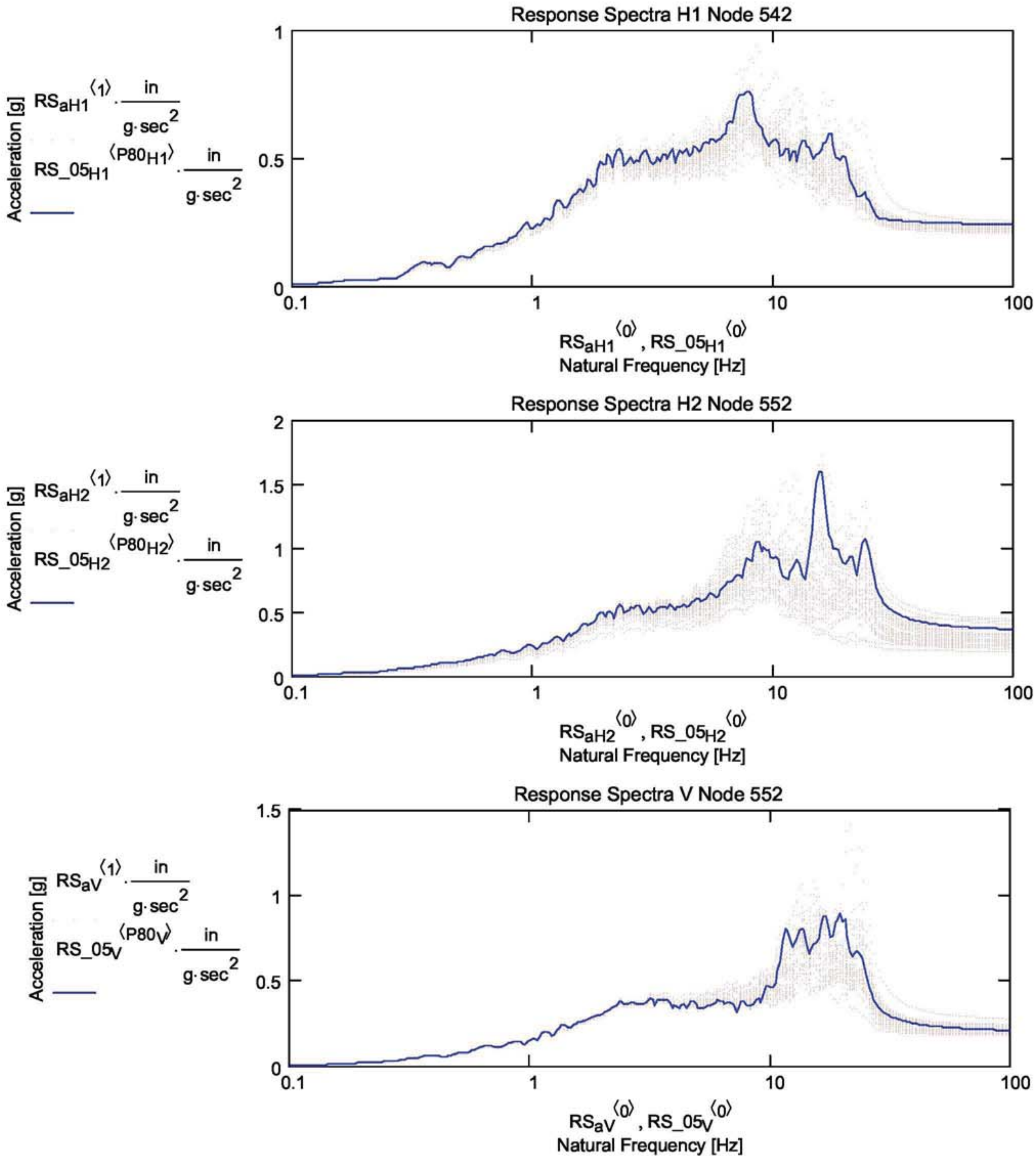

Fig. A.3.3.3-3 – All realizations (red) and 80th percentile (blue) 5% damping response spectra.

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The fourth step is to use the effective mass to establish the lower point where the Rayleigh damping curve crosses the 5% damping curve. This lower crossing frequency is defined as the frequency at or below where the cumulative effective mass percent reaches 5%. As shown in Fig. A.3.3.3-4, this occurs at 1.3 Hz.

The fifth step is to find Rayleigh damping constants that cause the Rayleigh damping curve to cross the 5% damping curve at the selected lower point and a reasonable upper point. Based on scoping analysis, the upper point is selected at 8.0 Hz. The derivation below shows the Rayleigh damping constants calculation and Fig. A.3.3.3-4 shows the resulting damping curve plotted with the desired damping curve.

$\omega_0 := 2\cdot\pi\cdot 1.3$ — Lower end of the natural frequency range.

$\omega_1 := 2\cdot\pi\cdot 8.0$ — Upper end of the natural frequency range.

$\xi := 0.05$ — Desired damping value.

$$\xi = \frac{\alpha}{2\cdot\omega_0} + \frac{\beta\cdot\omega_0}{2} \qquad \xi = \frac{\alpha}{2\cdot\omega_1} + \frac{\beta\cdot\omega_1}{2}$$

$$\begin{pmatrix} \frac{1}{2\cdot\omega_0} & \frac{\omega_0}{2} \\ \frac{1}{2\cdot\omega_1} & \frac{\omega_1}{2} \end{pmatrix} \cdot \begin{pmatrix} \alpha \\ \beta \end{pmatrix} = \begin{pmatrix} \xi \\ \xi \end{pmatrix} \quad ==> \quad \begin{pmatrix} \alpha \\ \beta \end{pmatrix} = \begin{pmatrix} \frac{1}{2\cdot\omega_0} & \frac{\omega_0}{2} \\ \frac{1}{2\cdot\omega_1} & \frac{\omega_1}{2} \end{pmatrix}^{-1} \cdot \begin{pmatrix} \xi \\ \xi \end{pmatrix}$$

$$\alpha\beta := \begin{pmatrix} \frac{1}{2\cdot\omega_0} & \frac{\omega_0}{2} \\ \frac{1}{2\cdot\omega_1} & \frac{\omega_1}{2} \end{pmatrix}^{-1} \cdot \begin{pmatrix} \xi \\ \xi \end{pmatrix} = \begin{bmatrix} 2\cdot\omega_1\cdot\omega_0\cdot\frac{\xi}{(\omega_0+\omega_1)} \\ 2\cdot\frac{\xi}{(\omega_0+\omega_1)} \end{bmatrix}$$

$$\alpha\beta = \begin{pmatrix} 0.703 \\ 1.711\times 10^{-3} \end{pmatrix}$$ Constants definition.

$\alpha := \alpha\beta_0$ — $\alpha = 0.703$

$\beta := \alpha\beta_1$ — $\beta = 1.711\times 10^{-3}$

$\xi_g(\omega) := \frac{\alpha}{2\cdot\omega} + \frac{\beta\cdot\omega}{2}$ — Definition for Rayleigh damping (for plotting).

$f_g := 0.01, 0.03 .. 100$ — Graphing nature frequencies in Hertz (for plotting)

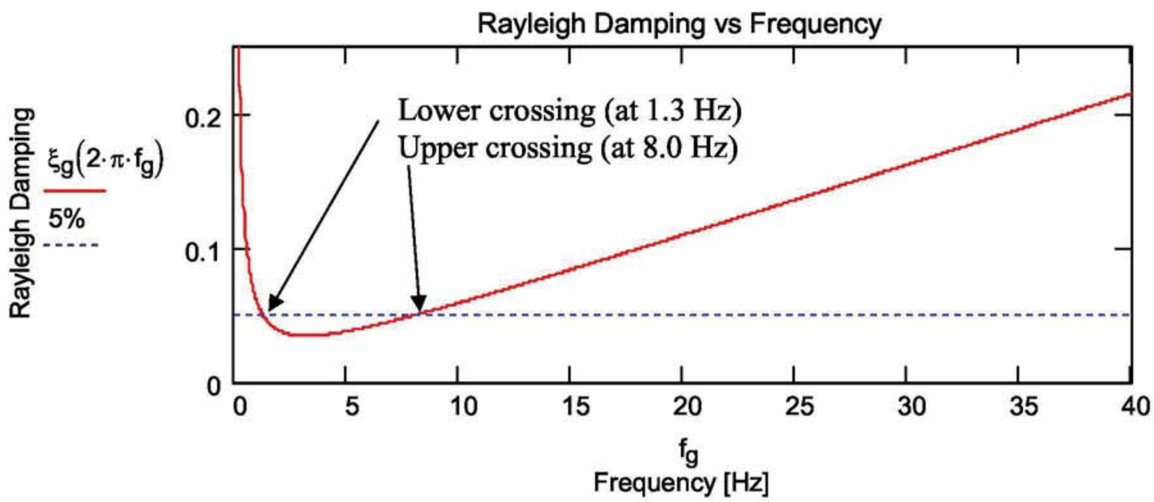


Fig. A.3.3.3-4 – Model 14 Rayleigh damping curve and desired damping curve versus frequency.

The Sixth step is to establish the Rayleigh damping response spectra for the 80th percentile time histories and the Rayleigh damping constants. This is done as described in Section A.3.3.1, with the results plotted in Fig. A.3.3.3-5. The figure shows a comparison of the response spectra for 5% damping and Rayleigh damping for Model 14. Fig. A.3.3.3-6 shows the response spectra difference between Rayleigh damping and 5% damping.

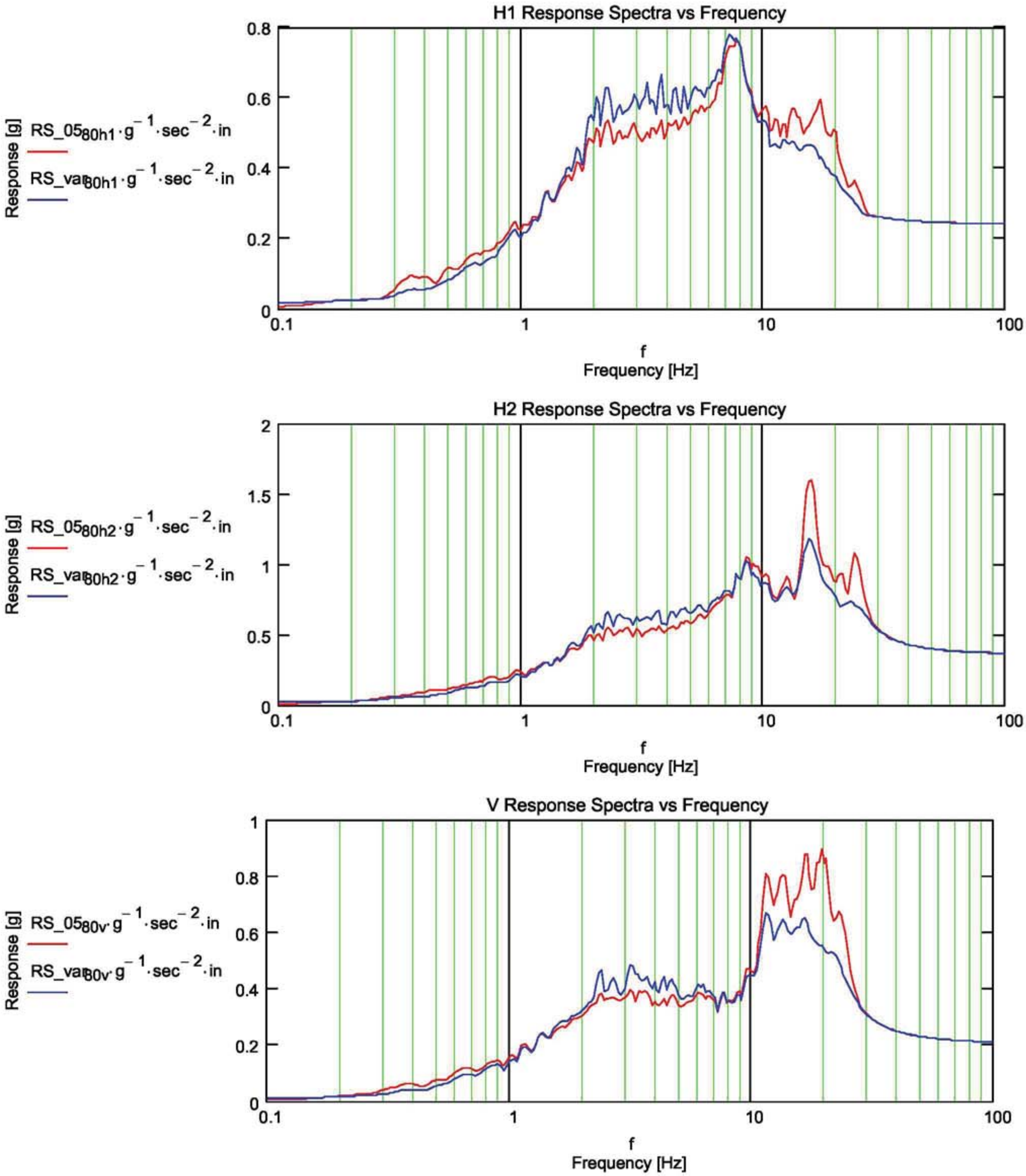


Fig. A.3.3.3-5 – Response spectra for 5% damping (red) and Rayleigh damping (blue).

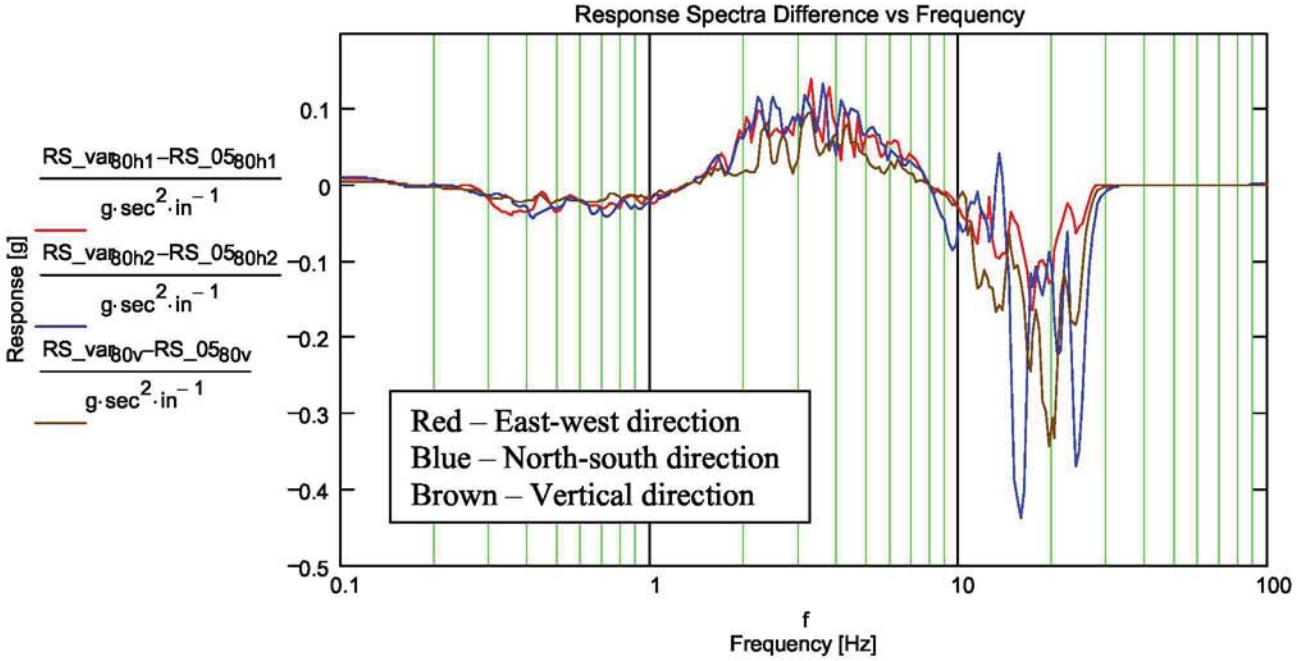


Fig. A.3.3.3-6 – Response spectra difference between Rayleigh damping and 5% damping.

The seventh step is to generate a cumulative weighted response curve. This is done as described in Section A.3.3.1, with the results plotted in Fig. A.3.3.3-6. The weighted response is then the effective mass at each natural frequency multiplied by the difference in response spectra at that natural frequency (corresponding to the effective mass). These values are then summed for the significant effective mass values in all three directions. If the sum produced a positive number, then the Rayleigh damping values are considered acceptable. The cumulative weighted response for each direction is calculated as described in Section A.3.3.1. A plot of this summed for all three directions is shown in Fig. A.3.3.3-7.

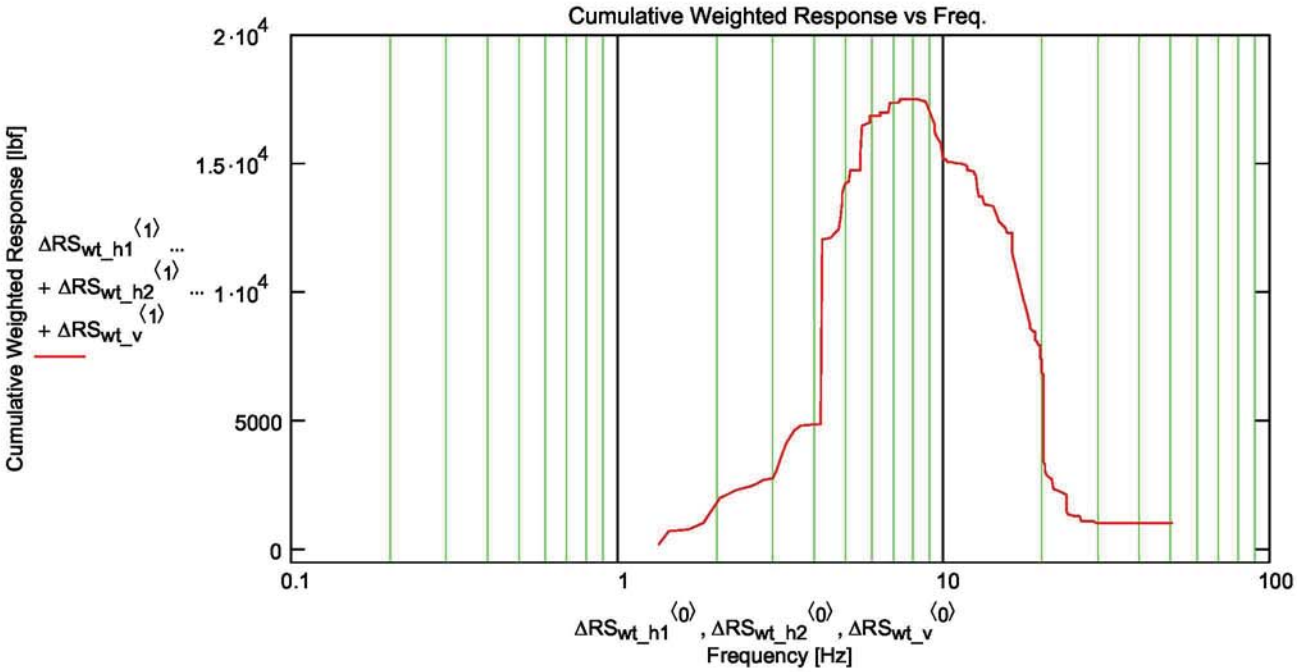


Fig. A.3.3.3-7 – Summed cumulative weighted response for Model 14.

The important feature of Fig. A.3.3.3-7 is that the last point has a value greater than zero. Because the last point value is greater than zero, the selected Rayleigh damping constants are acceptable relative to the code-specified 5% modal damping.

A.3.4 – Validation for Response Spectrum Programs

Two response spectrum programs are used in this appendix. The program ReSpect is used for constant damping response spectra and the program ReSpect_vardamp is used for Rayleigh damping response spectra. Both programs use the same input time histories file and have the same output file format.

The response spectrum programs use a superposition approach with the Duhamel integral

$$x = \frac{-1}{\omega \cdot \sqrt{1-\zeta^2}} \cdot \int_0^t x''_g(\tau) \cdot e^{-\zeta \cdot \omega \cdot (t-\tau)} \cdot \sin\left[\omega \cdot \sqrt{1-\zeta^2} \cdot (t-\tau)\right] d\tau \qquad \text{Duhamel integra}$$

where x is point mass position, ω is natural frequency, ζ is damping ratio, x''_g is the ground acceleration function, t is time and τ is the integration variable.

The earthquake time history is given in discrete points, ground acceleration “a_g versus time “t . Considering this, a linear interpolation is performed between each pair of discrete points (as shown in the left-hand plot of Fig. A.3.4-1). Over a step, the ground acceleration value is ramped and then held constant to the end of the solution. Using superposition, these steps can be summed to produce a complete solution (as in the right-hand plot of Fig. A.3.4-1).

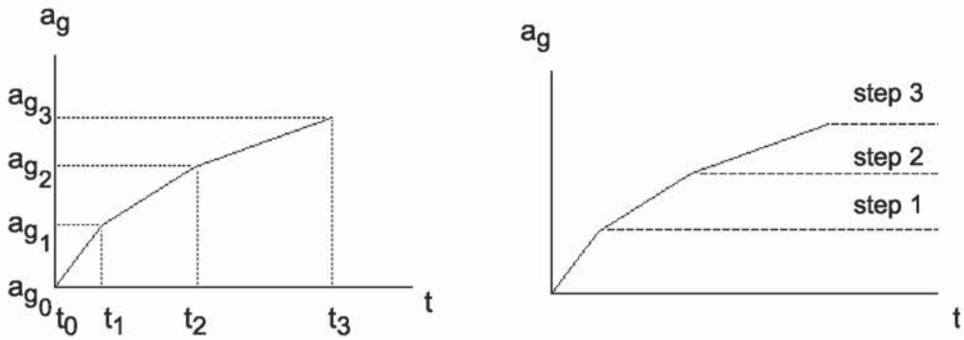
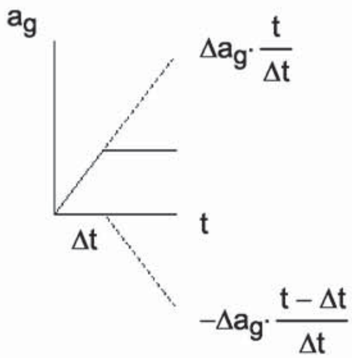


Fig. A.3.4-1 – Ground acceleration time history in a superposition approach.

An advantage of this approach is that an exact solution for the Duhamel integral can be found for each step. This allows a very stable complete solution using a summation of an exact solution. Below is the derivation for a single step based on the Fig. A.3.4-2 plot.



$$x''_g(\tau) = \begin{cases} \Delta a_g \cdot \dfrac{\tau}{\Delta t} & \text{for } 0 \le \tau < \Delta t \\ \Delta a_g \cdot \left(\dfrac{\tau}{\Delta t} - \dfrac{\tau - \Delta t}{\Delta t} \right) & \text{for } \Delta t \le \tau \end{cases}$$

Fig. A.3.4-2 – Single step derivation plot.

In Fig. A.3.4-2, the solid line represents the desired result. To achieve this, the initial slope is extended over the time step “Δt. Then an additional, equivalent slope is subtracted to make the curve remain constant. Because no output is needed between discrete points, the integral only needs to be solved for “t greater than or equal to “Δt as below

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$$x_{st} = \frac{-\Delta a_g}{\omega \cdot \sqrt{1-\zeta^2}} \cdot \left[\int_0^{\Delta t} \frac{\tau}{\Delta t} \cdot e^{-\zeta \cdot \omega \cdot (t-\tau)} \cdot \sin\left[\omega \cdot \sqrt{1-\zeta^2} \cdot (t-\tau)\right] d\tau \ldots + \int_{\Delta t}^{t} \left(\frac{\tau}{\Delta t} - \frac{\tau - \Delta t}{\Delta t}\right) \cdot e^{-\zeta \cdot \omega \cdot (t-\tau)} \cdot \sin\left[\omega \cdot \sqrt{1-\zeta^2} \cdot (t-\tau)\right] d\tau \right]$$

where "x_{st} is the position resulting from a step that has occurred. Solving and reducing the integral:

$$x_{st} = \frac{-\Delta a_g}{\omega \cdot \sqrt{1-\zeta^2}} \cdot \left[\frac{\sqrt{1-\zeta^2}}{\omega} \ldots + \left[\left(1 - e^{\zeta \cdot \omega \cdot \Delta t} \cdot \cos(\omega_d \cdot \Delta t)\right) \cdot \left(2 \cdot \zeta^2 - 1\right) \ldots + -2 \cdot e^{\zeta \cdot \omega \cdot \Delta t} \cdot \sqrt{1-\zeta^2} \cdot \zeta \cdot \sin(\omega_d \cdot \Delta t) \right] \cdot \frac{e^{-\zeta \cdot \omega \cdot t} \cdot \sin(\omega_d \cdot t)}{\omega^2 \cdot \Delta t} \ldots + \left[\left(1 - e^{\zeta \cdot \omega \cdot \Delta t} \cdot \cos(\omega_d \cdot \Delta t)\right) \cdot \left(2 \cdot \zeta \cdot \sqrt{1-\zeta^2}\right) \ldots + \left(2 \cdot \zeta^2 - 1\right) \cdot e^{\zeta \cdot \omega \cdot \Delta t} \cdot \sin(\omega_d \cdot \Delta t) \right] \cdot \frac{e^{-\zeta \cdot \omega \cdot t} \cdot \cos(\omega_d \cdot t)}{\omega^2 \cdot \Delta t} \right]$$

Defining: $C_0 = \frac{1}{\omega^2}$ $\qquad \omega_d = \omega \cdot \sqrt{1-\zeta^2}$

$$C_1 = \frac{1}{\omega_d \cdot \omega^2 \cdot \Delta t} \cdot \left[\left(1 - e^{\zeta \cdot \omega \cdot \Delta t} \cdot \cos(\omega_d \cdot \Delta t)\right) \cdot \left(2 \cdot \zeta^2 - 1\right) \ldots + -2 \cdot e^{\zeta \cdot \omega \cdot \Delta t} \cdot \sqrt{1-\zeta^2} \cdot \zeta \cdot \sin(\omega_d \cdot \Delta t) \right]$$

$$C_2 = \frac{1}{\omega_d \cdot \omega^2 \cdot \Delta t} \cdot \left[\left(1 - e^{\zeta \cdot \omega \cdot \Delta t} \cdot \cos(\omega_d \cdot \Delta t)\right) \cdot \left(2 \cdot \zeta \cdot \sqrt{1-\zeta^2}\right) \ldots + \left(2 \cdot \zeta^2 - 1\right) \cdot e^{\zeta \cdot \omega \cdot \Delta t} \cdot \sin(\omega_d \cdot \Delta t) \right]$$

$$x_{st} = \left(a_{g_{i-1}} - a_{g_i}\right) \cdot \left(C_0 + C_1 \cdot e^{-\zeta \cdot \omega \cdot t} \cdot \sin(\omega_d \cdot t) + C_2 \cdot e^{-\zeta \cdot \omega \cdot t} \cdot \cos(\omega_d \cdot t)\right)$$

From this, velocity "v_{st} and acceleration "a_{st} resulting from a step that has occurred can be derived.

Defining:

$$C_3 = -C_1\cdot\zeta\cdot\omega - C_2\cdot\omega_d \qquad C_4 = C_1\cdot\omega_d - C_2\cdot\zeta\cdot\omega$$

$$v_{st} = \left(a_{g_{i-1}} - a_{g_i}\right)\cdot\left(C_3\cdot e^{-\zeta\cdot\omega\cdot t}\cdot\sin\left(\omega_d\cdot t\right) + C_4\cdot e^{-\zeta\cdot\omega\cdot t}\cdot\cos\left(\omega_d\cdot t\right)\right)$$

Defining:

$$C_5 = -C_3\cdot\zeta\cdot\omega - C_4\cdot\omega_d \qquad C_6 = C_3\cdot\omega_d - C_4\cdot\zeta\cdot\omega$$

$$a_{st} = \left(a_{g_{i-1}} - a_{g_i}\right)\cdot\left(C_5\cdot e^{-\zeta\cdot\omega\cdot t}\cdot\sin\left(\omega_d\cdot t\right) + C_6\cdot e^{-\zeta\cdot\omega\cdot t}\cdot\cos\left(\omega_d\cdot t\right)\right)$$

This approach can be performed in a Mathcad subroutine as shown in subroutine "X_{lc} which is a function of a natural frequency (in Hz), a damping ratio, and a base acceleration time history (in in/sec^2). Subroutine "X_{lc} first establishes the constants defined above. Next, two vectors are established with values defined at each point in time. This is done for efficiency as these values are used multiple times in the last set of "for loops. Next, the output array "Out is filled with zeros. Finally, the superposition is performed by summing all of the steps required at each time step in the time history.

$$X_{lc}(f,\zeta,a) := \left|\begin{array}{l}
\omega \leftarrow 2\cdot\pi\cdot f \\
\omega_d \leftarrow \omega\cdot\sqrt{1-\zeta^2} \\
C_0 \leftarrow \omega^{-2} \\
C_1 \leftarrow \dfrac{1}{\omega_d\cdot\omega^2\cdot\Delta t}\cdot\left[\begin{array}{l}\left(1-e^{\zeta\cdot\omega\cdot\Delta t}\cdot\cos(\omega_d\cdot\Delta t)\right)\cdot\left(2\cdot\zeta^2-1\right)\ ...\\ +\ -2\cdot e^{\zeta\cdot\omega\cdot\Delta t}\cdot\sqrt{1-\zeta^2}\cdot\zeta\cdot\sin(\omega_d\cdot\Delta t)\end{array}\right] \\
C_2 \leftarrow \dfrac{1}{\omega_d\cdot\omega^2\cdot\Delta t}\cdot\left[\begin{array}{l}\left(1-e^{\zeta\cdot\omega\cdot\Delta t}\cdot\cos(\omega_d\cdot\Delta t)\right)\cdot\left(2\cdot\zeta\cdot\sqrt{1-\zeta^2}\right)\ ...\\ +\ \left(2\cdot\zeta^2-1\right)\cdot e^{\zeta\cdot\omega\cdot\Delta t}\cdot\sin(\omega_d\cdot\Delta t)\end{array}\right] \\
C_3 \leftarrow -C_1\cdot\zeta\cdot\omega - C_2\cdot\omega_d \\
C_4 \leftarrow C_1\cdot\omega_d - C_2\cdot\zeta\cdot\omega \\
C_5 \leftarrow -C_3\cdot\zeta\cdot\omega - C_4\cdot\omega_d \\
C_6 \leftarrow C_3\cdot\omega_d - C_4\cdot\zeta\cdot\omega \\
\text{for } i\in 0..\,\text{last}(t) \\
\quad \left|\begin{array}{l} esn_i \leftarrow e^{-\zeta\cdot\omega\cdot t_i}\cdot\sin(\omega_d\cdot t_i) \\ ecs_i \leftarrow e^{-\zeta\cdot\omega\cdot t_i}\cdot\cos(\omega_d\cdot t_i)\end{array}\right. \\
Out_{\text{last}(t),2} \leftarrow 0 \\
\text{for } j\in 1..\,\text{last}(t) \\
\quad \text{for } i\in j..\,\text{last}(t) \\
\quad\quad \left|\begin{array}{l} Out_{i,0} \leftarrow (a_{j-1}-a_j)\cdot(C_0 + C_1\cdot esn_{i-j+1} + C_2\cdot ecs_{i-j+1}) + Out_{i,0} \\ Out_{i,1} \leftarrow (a_{j-1}-a_j)\cdot(C_3\cdot esn_{i-j+1} + C_4\cdot ecs_{i-j+1}) + Out_{i,1} \\ Out_{i,2} \leftarrow (a_{j-1}-a_j)\cdot(C_5\cdot esn_{i-j+1} + C_6\cdot ecs_{i-j+1}) + Out_{i,2}\end{array}\right. \\
Out
\end{array}\right.$$

The file "Model_3_TH_mod.rpt contains a representative set of time histories that will be used for the validation of ReSpect and ReSpect_vardamp. This file is read into Mathcad under the variable "In. Considering the column order of the file, the following definitions can be made where "t is time, "a is acceleration, "v is velocity, and "x is displacement and the subscripts "h1 , "h2 , and "v imply east-west, north-south, and vertical respectively.

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Authors:	R. E. Spears	**Date:** 09/30/08	**Checker:** M. J. Russell	**Date:**	09/30/08

$t := \left(In^{\langle 0\rangle} - In_{0,0}\right)$ sec $\quad \Delta t := t_1 \quad \Delta t = 0.005$ sec

$a_{h1} := \left(In^{\langle 1\rangle} - In_{0,1}\right) \frac{in}{sec^2} \quad v_{h1} := \left(In^{\langle 7\rangle} - In_{0,7}\right) \frac{in}{sec} \quad x_{h1} := \left(In^{\langle 4\rangle} - In_{0,4}\right)$ in

$a_{h2} := \left(In^{\langle 3\rangle} - In_{0,1}\right) \frac{in}{sec^2} \quad v_{h2} := \left(In^{\langle 9\rangle} - In_{0,9}\right) \frac{in}{sec} \quad x_{h2} := \left(In^{\langle 6\rangle} - In_{0,6}\right)$ in

$a_v := \left(In^{\langle 2\rangle} - In_{0,2}\right) \frac{in}{sec^2} \quad v_v := \left(In^{\langle 8\rangle} - In_{0,8}\right) \frac{in}{sec} \quad x_v := \left(In^{\langle 5\rangle} - In_{0,5}\right)$ in

All of the variables above are defined relative to their initial value in the file. (This is useful if ABAQUS output is used and time and motion for the seismic event do not start at zero. This could occur in a multi-step run.) All of the variables are done this way just to be consistent with the programs ReSpect and ReSpect_vardamp.

Fig. A.3.4-3 – Fig. A.3.4-5 shows the acceleration, velocity, and displacement plots for the variables above.

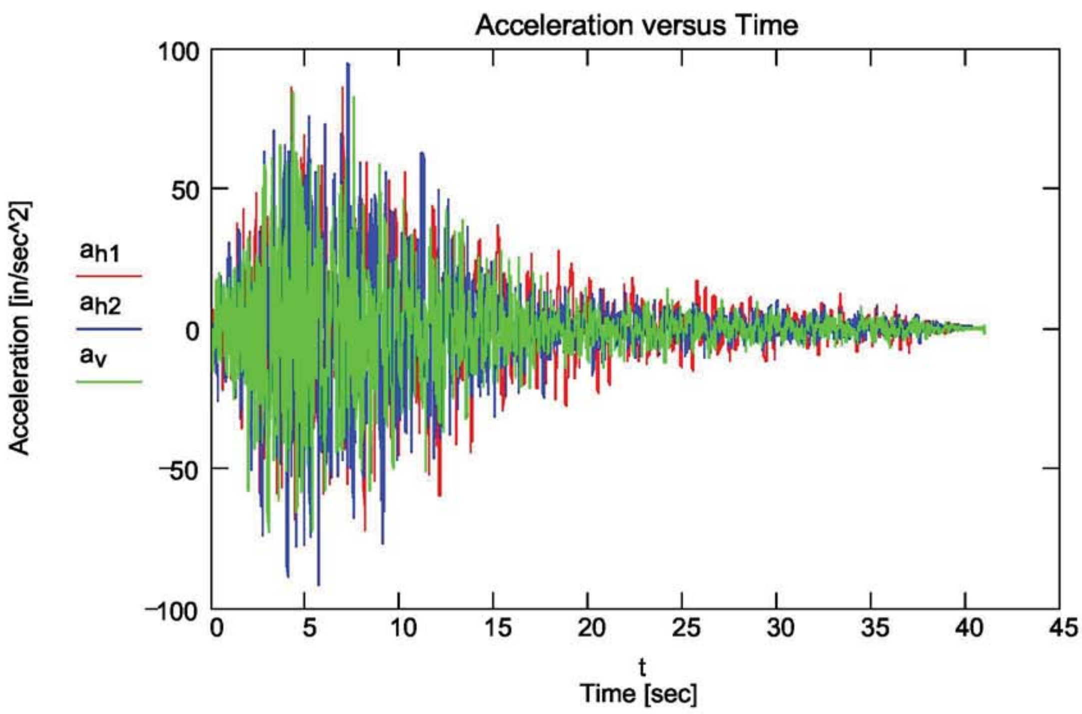

Fig. A.3.4-3 – Acceleration plot.

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Authors:	R. E. Spears	**Date:** 09/30/08	**Checker:** M. J. Russell	**Date:**	09/30/08

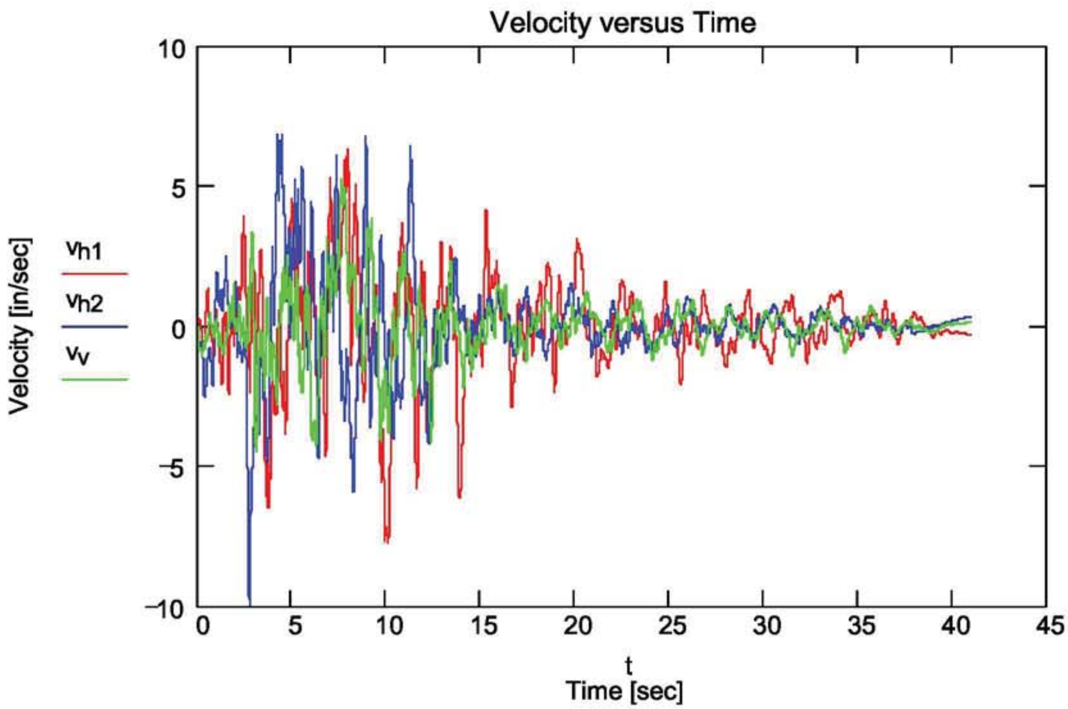

Fig. A.3.4-4 – Velocity plot.

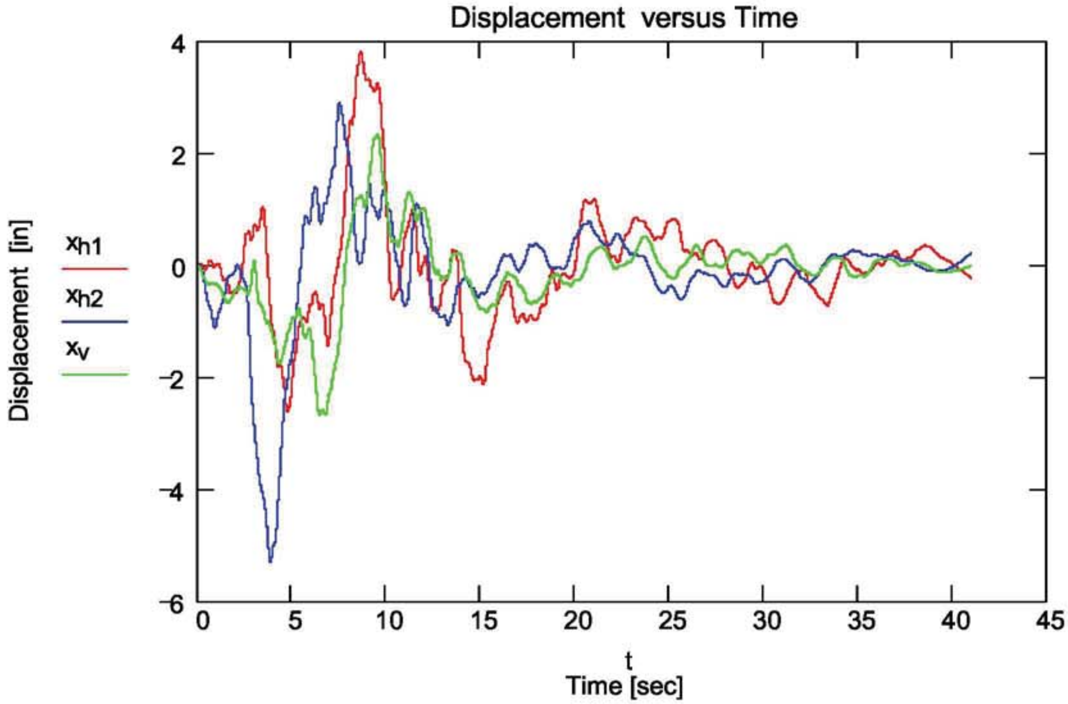

Fig. A.3.4-5 – Displacement plot.

As an example, the east-west acceleration data can be input into the subroutine "X_{lc} considering a point mass, spring, and damper having natural frequency of 1 Hz and a damping ratio of 0.05.

$out := X_{lc}(1, 0.05, a_{h1})$

$x_r := out^{\langle 0 \rangle}$ Relative displacement

$v_r := out^{\langle 1 \rangle}$ Relative velocity.

$a_r := out^{\langle 2 \rangle}$ Relative acceleration.

To generate total displacement, velocity, and acceleration values, the above variables can be added to the input variables as in Fig. A.3.4-6.

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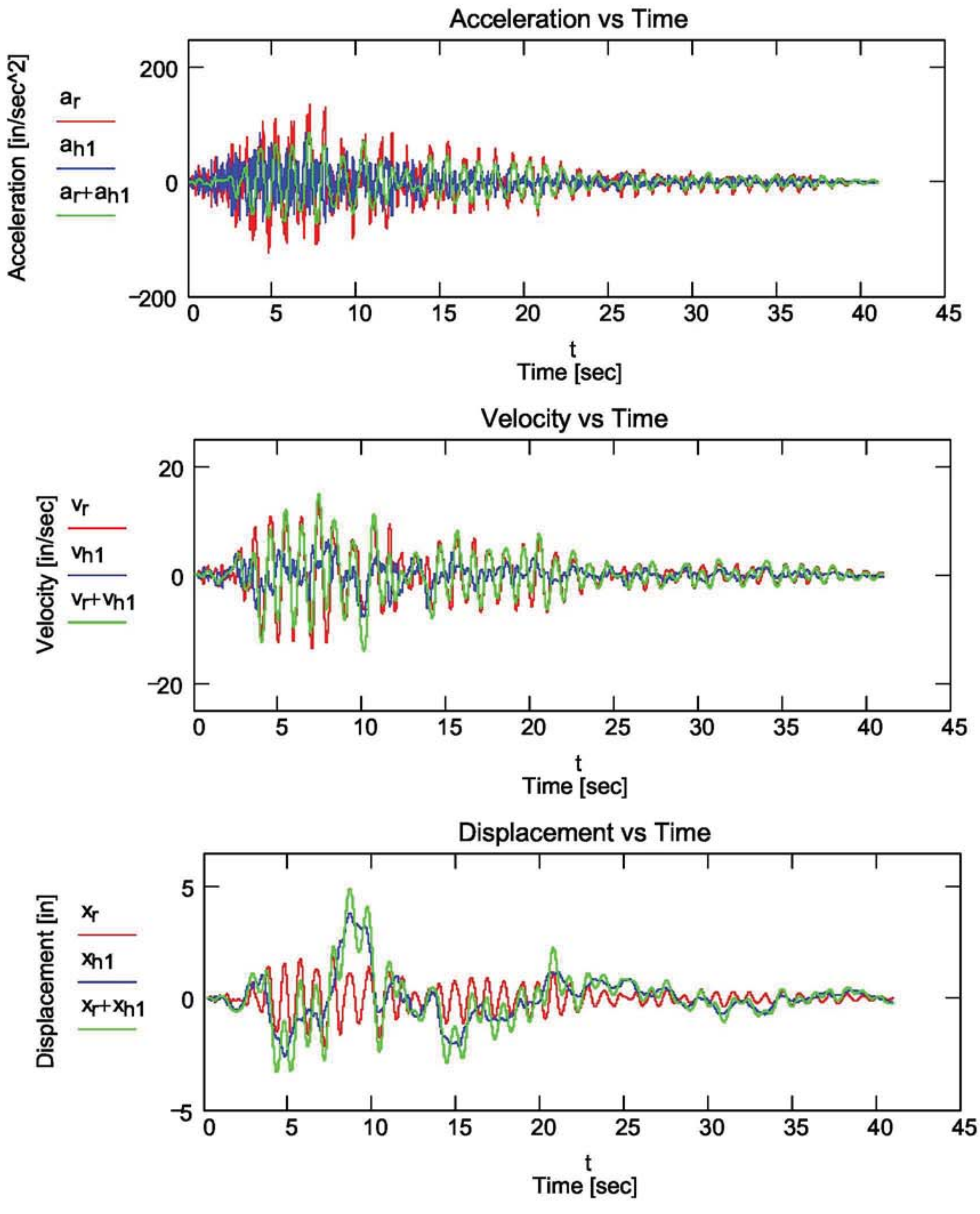

Fig. A.3.4-6 – Relative, input, and total east-west motion plots for a natural frequency of 1 Hz and a damping ratio of 0.05.

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Authors:	R. E. Spears	Date: 09/30/08	Checker: M. J. Russell	Date:	09/30/08

A.3.4.1 – ReSpect Validation

The program ReSpect accepts a text file containing acceleration, velocity, and displacement for x-, y-, and z-directions (similar to that exported by ABAQUS). It then performs relative and total response spectrum analysis on all of the variables for as many damping ratios as desired. For the validation problem, the arbitrary time history file is generated from PSSI node time histories. This file is made up of columns that are time, east-west acceleration, vertical acceleration, north-south acceleration, east-west displacement, vertical displacement, north-south displacement, east-west velocity, vertical velocity, and north-south velocity respectively. The units are seconds for time, inches for displacement, inches per second for velocity, and inches per second squared for acceleration.

To run the program ReSpect, an additional file is needed that defines how the response spectra evaluation is to be performed. For the validation problem, this file is "ReSpect.dat. The contents of this file are as follows:

```
# ReSpect.dat - data parameter input file for ReSpect program
# File format rules:
# All blank lines will be ignored
# All characters after # (pound sign) will be ignored
# All blanks are ignored

NumPoints 300  # Number of response spectra output points

LowFreq 0.1   # Lowest frequency for response spectra output points

HighFreq 100.0 # Highest frequency for response spectra output points

AddFreq 0     # Number of additional dominant modes natural frequencies (0 = no additional)

#   2.1989   # Frequencies of interest must follow AddFreq
#   4.8334
#   2.8091
#   5.7223
#   2.4087
#   3.4298

NumDamping 1 # Number of damping ratios to be used

#   0.02    # Damping ratios must follow NumDamping
#   0.03
  0.05
#   0.07
```

 # 0.10

NumSig 5 # number of significant figures in output files

InFile Model_3_TH_mod.rpt # ABAQUS rpt (or Mathcad) file with acceleration data (edited)

 # Note that the abaqus.rpt file must have the leading blank lines and header removed.

FileBase Model_3_RS_con # base name for output file (e.g. ???_02.prn)

OverSw 1 # Overwrite switch. If file exists 0 = exit; 1 = overwrite

#End of data file

Given the above "dat file the command line for running the code is:
directory path/ReSpect ReSpect .dat

The file above defines six things. First, each response spectrum is to be calculated over a frequency range of 0.1 Hz to 100 Hz with 300 evenly spaced points on a log plot. Second, no additional frequencies are being evaluated. Third, the only output damping ratio is set at 5%. Fourth, the output is to five significant figures. Fifth, the time histories are input with the file "Model_3_TH_mod.rpt and output response spectra are written to the file "Model_3_RS_con_05.prn. Sixth, if previous files of the same name exist, then they will be overwritten.

The ".prn files output from ReSpect are made up of columns that are natural frequency, relative east-west displacement, relative east-west velocity, relative east-west acceleration, relative north-south displacement, relative north-south velocity, relative north-south acceleration, relative vertical displacement, relative vertical velocity, relative vertical acceleration, total east-west displacement, total east-west velocity, total east-west acceleration, total north-south displacement, total north-south velocity, total north-south acceleration, total vertical displacement, total vertical velocity, and total vertical acceleration respectively. The units are Hertz for natural frequency, inches for displacement, inches per second for velocity, and inches per second squared for acceleration.

To establish the response spectra, the point furthest from zero on each of the relative and total curves must be found. This can be performed in a Mathcad subroutine as shown in subroutine "ResSp. The subroutine "ResSp calculates all the response spectra data given that the input acceleration, number of response spectrum output points, and lower and upper bound frequency values are defined in advance of the subroutine. To match the validation problem, the following definitions are made.

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Title:	ATR Primary Coolant System Seismic Evaluation				
Authors:	R. E. Spears	**Date:** 09/30/08	**Checker:** M. J. Russell	**Date:**	09/30/08

$n := 300$ Number of response spectra output points.

$f_{lo} := 0.1$ Lowest frequency for response spectra output points

$f_{hi} := 100$ Highest frequency for response spectra output point

Subroutine "ResSp is a "for loop where each loop generates an output row in the same column arrangement that is found in the ".prn files produced by the program ReSpect. Within the loop, the given natural frequency is first defined based on an even spacing for a log plot. Next, all of the relative values are calculated with subroutine "X_{lc} and augmented together. Input values are then augmented into the same order as the relative values. Then a counting variable is defined and the natural frequency value is put into its position in the output variable. Finally, a "for loop finds the point furthest from zero.

$$\text{ResSp}(\zeta) := \left| \begin{array}{l} \text{for } i \in 0..n \\ \quad \left| \begin{array}{l} f_{r'} \leftarrow 10^{\frac{(\log(f_{hi}) - \log(f_{lo}))\cdot i}{n} + \log(f_{lo})} \\ z_r \leftarrow \text{augment}\left(X_{lc}(f_{r'}, \zeta, a_{h1}), X_{lc}(f_{r'}, \zeta, a_{h2}), X_{lc}(f_{r'}, \zeta, a_v)\right) \\ z_g \leftarrow \text{augment}(x_{h1}, v_{h1}, a_{h1}, x_{h2}, v_{h2}, a_{h2}, x_v, v_v, a_v) \\ n_j \leftarrow \text{cols}(z_r) - 1 \\ out_{i,0} \leftarrow f_{r'} \\ \text{for } j \in 0..n_j \\ \quad \left| \begin{array}{l} out_{i,j+1} \leftarrow \max\left(\left(\max\left(z_r^{\langle j \rangle}\right) \ \left|\min\left(z_r^{\langle j \rangle}\right)\right|\right)\right) \\ out_{i,j+n_j+2} \leftarrow \max\left(\left(\max\left(z_r^{\langle j \rangle} + z_g^{\langle j \rangle}\right) \ \left|\min\left(z_r^{\langle j \rangle} + z_g^{\langle j \rangle}\right)\right|\right)\right) \end{array} \right. \end{array} \right. \\ out \end{array} \right.$$

Fig. A.3.4.1-1 – Fig. A.3.4.1-3 show the overlaid plots and the difference plots for some results from the program ReSpect and from Mathcad.

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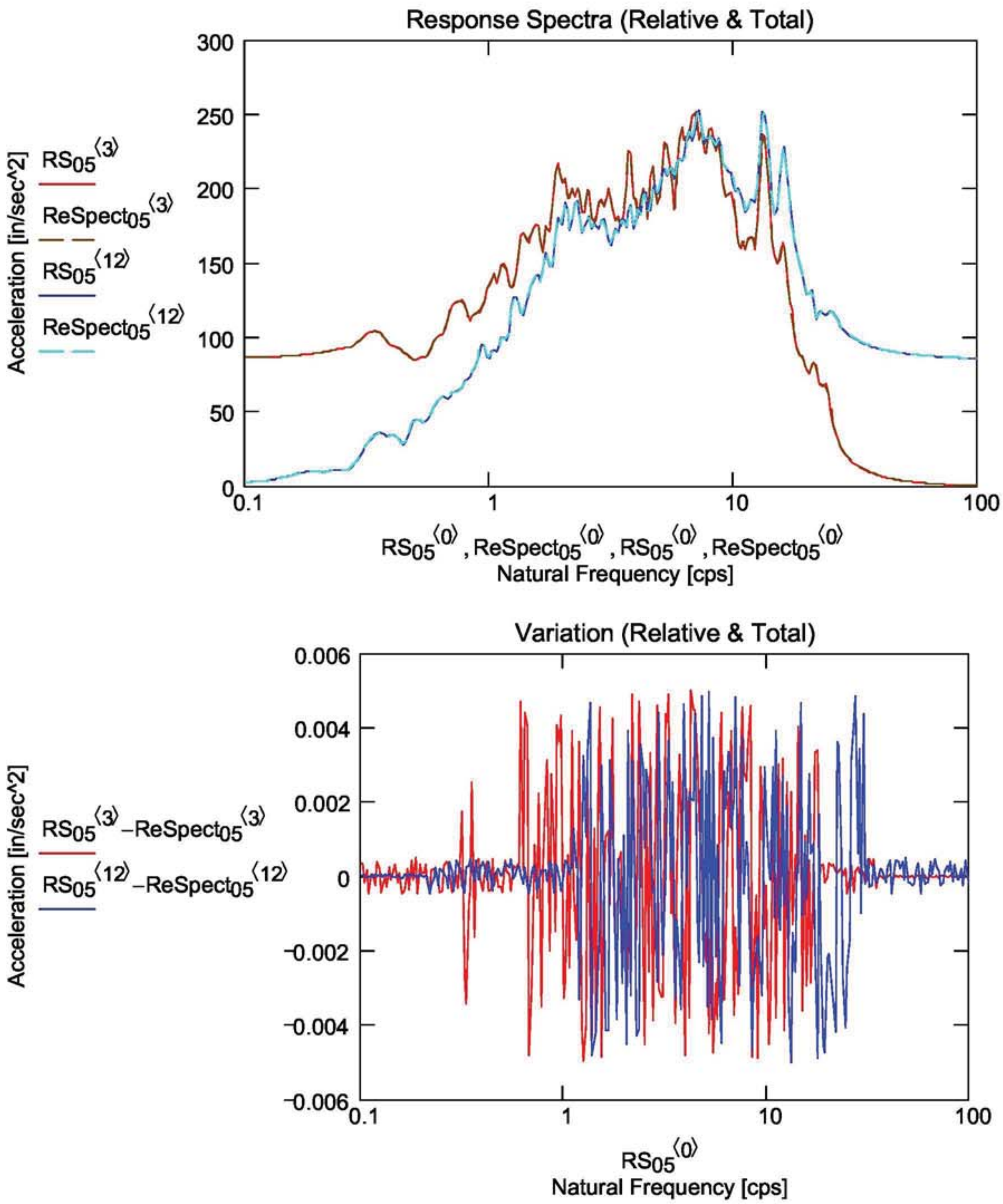

Fig. A.3.4.1-1 – East-west acceleration response spectra comparison.

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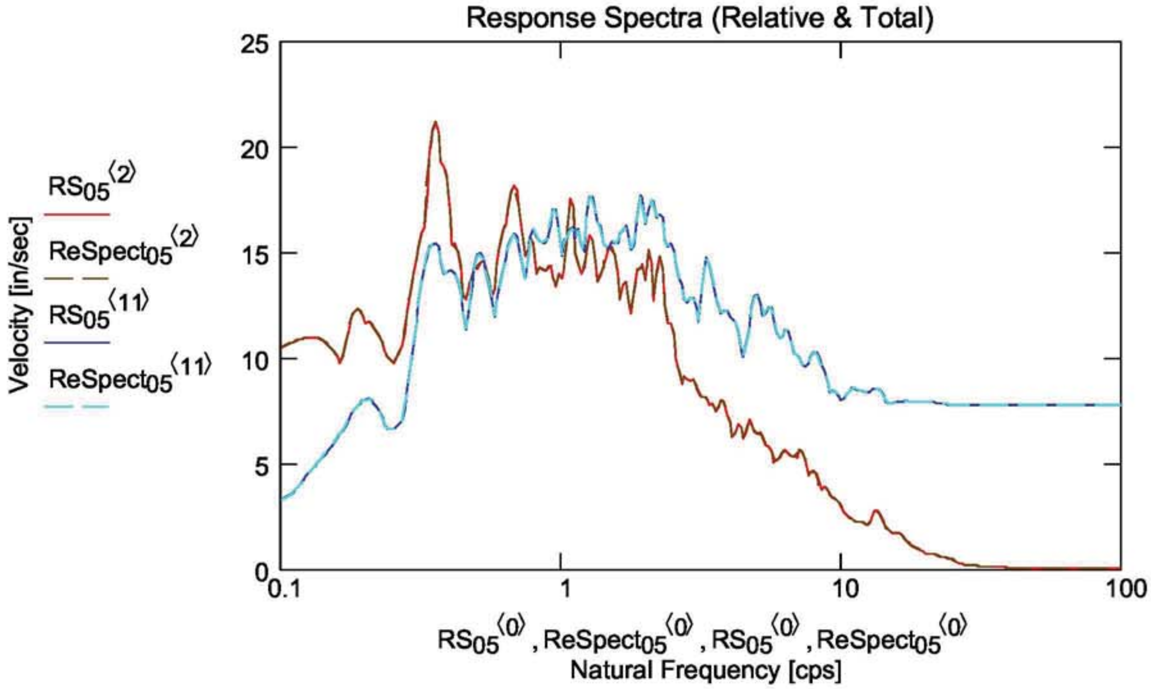
Authors:	R. E. Spears	Date: 09/30/08	Checker: M. J. Russell	Date:	09/30/08



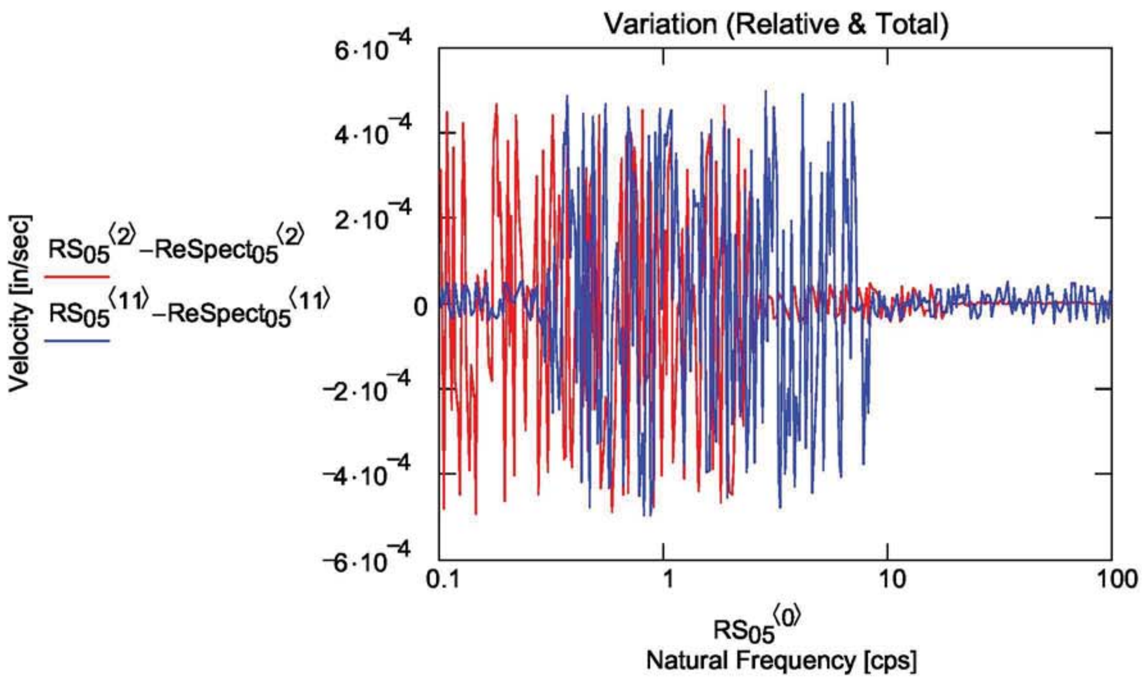


Fig. A.3.4.1-2– East-west velocity response spectra comparison.

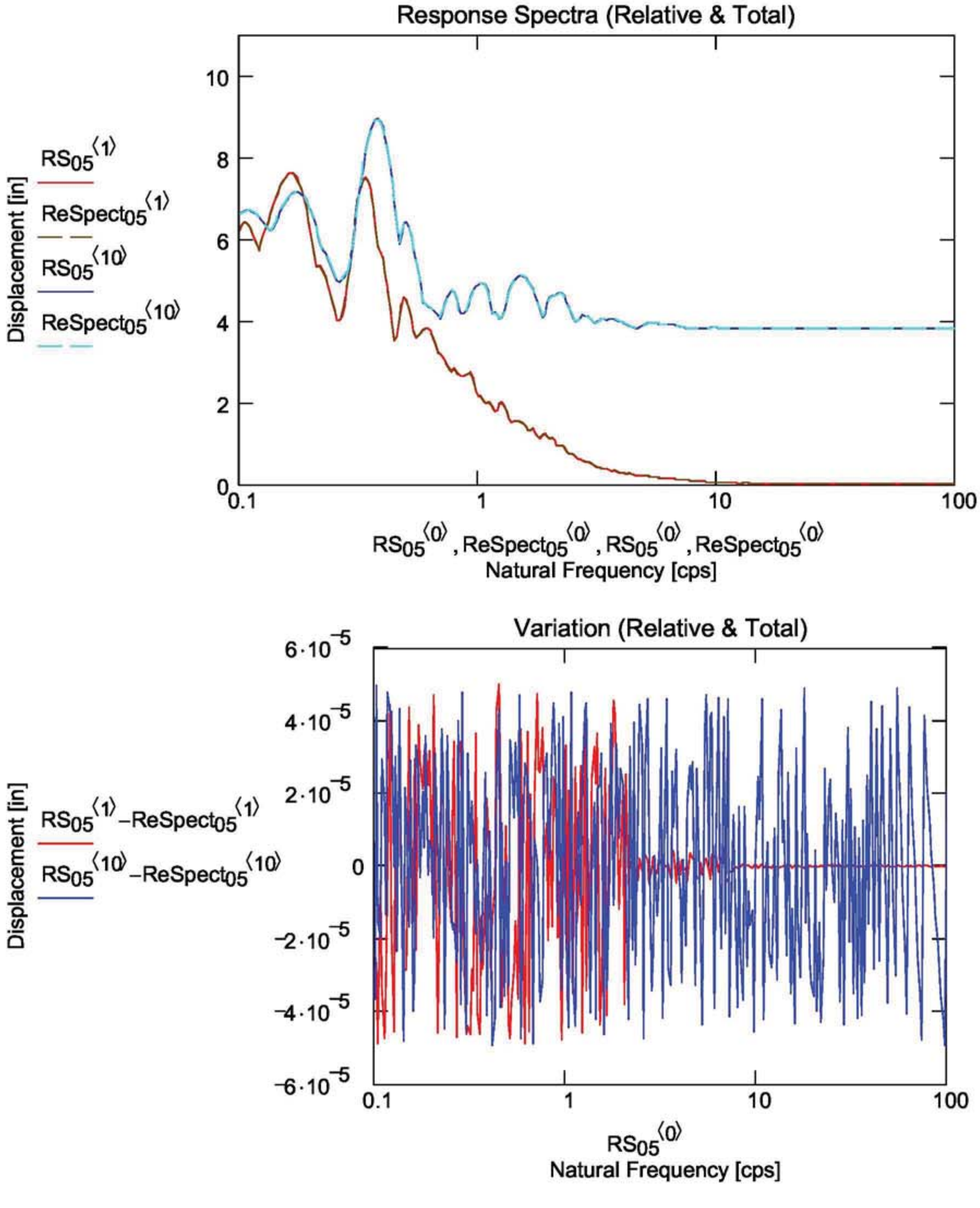


Fig. A.3.4.1-3 – East-west displacement response spectra comparison.

Fig. A.3.4.1-1 – Fig. A.3.4.1-3 show the east-west response spectra data. This provides a cross section of the data plots. As a measure for comparison, the percent change for each pair of curves will be calculated as the maximum difference divided by the maximum amplitude from the Mathcad curve. This is performed on all of the pairs of curves using subroutine “Δ% . Subroutine “Δ% is a “for loop that outputs a three column array. The first column is the maximum amplitude for the given Mathcad curve, the second column is the maximum difference between the Mathcad curve and the ReSpect_vardamp curve, and the third column is the percent change.

$$\Delta\% := \left| \begin{array}{l} \text{for } i \in 1 .. \text{cols}(RS_{var}) - 1 \\ \quad \left| \begin{array}{l} out_{i,0} \leftarrow \max\left(\left(\max\left(RS_{var}^{\langle i \rangle}\right) \;\; \left|\min\left(RS_{var}^{\langle i \rangle}\right)\right|\right)\right) \\ out_{i,1} \leftarrow \max\left(\left(\begin{array}{l} \max\left(RS_{var}^{\langle i \rangle} - ReSpect_{var}^{\langle i \rangle}\right) \\ \left|\min\left(RS_{var}^{\langle i \rangle} - ReSpect_{var}^{\langle i \rangle}\right)\right| \end{array}\right)\right) \\ out_{i,2} \leftarrow \dfrac{out_{i,1}}{out_{i,0}} \end{array} \right. \\ out \end{array} \right.$$

The output for subroutine “Δ% is given below.

Δ% =

	0	1	2
0	0	0	0
1	7.619	$5.01\cdot10^{-5}$	$6.575\cdot10^{-6}$
2	21.165	$4.925\cdot10^{-4}$	$2.327\cdot10^{-5}$
3	251.619	$4.995\cdot10^{-3}$	$1.985\cdot10^{-5}$
4	8.059	$4.995\cdot10^{-5}$	$6.198\cdot10^{-6}$
5	20.063	$4.963\cdot10^{-4}$	$2.474\cdot10^{-5}$
6	345.718	$4.997\cdot10^{-3}$	$1.445\cdot10^{-5}$
7	4.547	$4.985\cdot10^{-5}$	$1.096\cdot10^{-5}$
8	11.602	$4.881\cdot10^{-4}$	$4.207\cdot10^{-5}$
9	369.707	$4.963\cdot10^{-3}$	$1.342\cdot10^{-5}$
10	8.945	$4.97\cdot10^{-5}$	$5.556\cdot10^{-6}$
11	17.718	$4.959\cdot10^{-4}$	$2.799\cdot10^{-5}$
12	252.349	$5.012\cdot10^{-3}$	$1.986\cdot10^{-5}$
13	8.92	$4.942\cdot10^{-5}$	$5.541\cdot10^{-6}$
14	17.933	$4.942\cdot10^{-4}$	$2.756\cdot10^{-5}$
15	334.529	0.331	$9.897\cdot10^{-4}$
16	5.432	$4.999\cdot10^{-5}$	$9.203\cdot10^{-6}$
17	12.585	$4.996\cdot10^{-4}$	$3.97\cdot10^{-5}$
18	353.38	$4.963\cdot10^{-3}$	$1.404\cdot10^{-5}$

The maximum percent change is 0.099%. This represents an acceptably low percentage change.

A.3.4.2 – ReSpect_vardamp Validation

The program ReSpect_vardamp accepts a text file containing acceleration, velocity, and displacement for x-, y-, and z-directions (similar to that exported by ABAQUS). It then performs relative and total response spectrum analysis on all of the variables for Rayleigh damping defined by the Rayleigh damping "α and "β constants. For the validation problem, the arbitrary time history file is generated from PSSI node time histories. This file is made up of columns that are time, east-west acceleration, vertical acceleration, north-south acceleration, east-west displacement, vertical displacement, north-south displacement, east-west velocity, vertical velocity, and north-south velocity respectively. The units are seconds for time, inches for displacement, inches per second for velocity, and inches per second squared for acceleration.

To run the program ReSpect_vardamp, an additional file is needed that defines how the response spectra evaluation is to be performed. For the validation problem, this file is "ReSpect_vardamp.dat. The contents of this file are as follows:

```
# ReSpect_vardamp.dat - data parameter input file for ReSpect_vardamp program
# File format rules:
# All blank lines will be ignored
# All characters after # (pound sign) will be ignored
# All blanks are ignored

NumPoints 300  # Number of response spectra output points

LowFreq 0.1   # Lowest frequency for response spectra output points

HighFreq 100.0 # Highest frequency for response spectra output points

AddFreq 0     # Number of additional dominant modes natural frequencies (0 = no additional)

#   2.1989   # Frequencies of interest must follow AddFreq
#   4.8334
#   2.8091
#   5.7223
#   2.4087
#   3.4298

DampingAlpha 0.877 # Alpha value for Rayleigh damping (1.63Hz & 9.7Hz)
DampingBeta 0.001405 # Beta value for Rayleigh damping

NumSig 5  # number of significant figures in output files
```

InFile Model_3_TH_mod.rpt # ABAQUS rpt (or Mathcad) file with acceleration data (edited)

 # Note that the abaqus.rpt file must have the leading blank lines and header removed.

FileBase Model_3_RS_var # base name for output file (e.g. ???.prn)

OverSw 1 # Overwrite switch. If file exists 0 = exit; 1 = overwrite

#End of data file

Given the above "dat file the command line for running the code is:
directory path/ReSpect_vardamp ReSpect_vardamp.dat

The file above defines six things. First, each response spectrum is to be calculated over a frequency range of 0.1 Hz to 100 Hz with 300 evenly spaced points on a log plot. Second, no additional frequencies are being evaluated. Third, Rayleigh damping constants "α and "β are defined as 0.877 and 0.001405 respectively. Fourth, the output is to five significant figures. Fifth, the time histories are input with the file "Model_3_TH_mod.rpt and output response spectra are written to the file "Model_3_RS_var.prn. Sixth, if previous files of the same name exist, then they will be overwritten.

The ".prn files output from ReSpect_vardamp are made up of columns that are natural frequency, relative east-west displacement, relative east-west velocity, relative east-west acceleration, relative north-south displacement, relative north-south velocity, relative north-south acceleration, relative vertical displacement, relative vertical velocity, relative vertical acceleration, total east-west displacement, total east-west velocity, total east-west acceleration, total north-south displacement, total north-south velocity, total north-south acceleration, total vertical displacement, total vertical velocity, and total vertical acceleration respectively. The units are Hertz for natural frequency, inches for displacement, inches per second for velocity, and inches per second squared for acceleration.

For damping in the calculation of response spectra, the following example evaluation can be performed to establish the Rayleigh damping constants. Fig. A.3.4.2-1 shows the example Rayleigh damping curve along with the example desired damping curve for the calculated constants.

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$\xi_i = \frac{\alpha}{2\cdot\omega_i} + \frac{\beta\cdot\omega_i}{2}$ Modal damping as a function of the Rayleigh damping constant

$\omega_0 := 2\cdot\pi\cdot 1.63$ Lower end of the natural frequency range.

$\omega_1 := 2\cdot\pi\cdot 9.7$ Upper end of the natural frequency range.

$\xi := 0.05$ Desired damping value.

$\xi = \frac{\alpha}{2\cdot\omega_0} + \frac{\beta\cdot\omega_0}{2}$ $\quad\quad \xi = \frac{\alpha}{2\cdot\omega_1} + \frac{\beta\cdot\omega_1}{2}$

$$\begin{pmatrix} \frac{1}{2\cdot\omega_0} & \frac{\omega_0}{2} \\ \frac{1}{2\cdot\omega_1} & \frac{\omega_1}{2} \end{pmatrix} \cdot \begin{pmatrix} \alpha \\ \beta \end{pmatrix} = \begin{pmatrix} \xi \\ \xi \end{pmatrix} \implies \begin{pmatrix} \alpha \\ \beta \end{pmatrix} = \begin{pmatrix} \frac{1}{2\cdot\omega_0} & \frac{\omega_0}{2} \\ \frac{1}{2\cdot\omega_1} & \frac{\omega_1}{2} \end{pmatrix}^{-1} \cdot \begin{pmatrix} \xi \\ \xi \end{pmatrix}$$

$$\alpha\beta := \begin{pmatrix} \frac{1}{2\cdot\omega_0} & \frac{\omega_0}{2} \\ \frac{1}{2\cdot\omega_1} & \frac{\omega_1}{2} \end{pmatrix}^{-1} \cdot \begin{pmatrix} \xi \\ \xi \end{pmatrix} = \begin{bmatrix} 2\cdot\omega_1\cdot\omega_0\cdot\frac{\xi}{(\omega_0+\omega_1)} \\ 2\cdot\frac{\xi}{(\omega_0+\omega_1)} \end{bmatrix}$$

$\alpha\beta = \begin{pmatrix} 0.877 \\ 1.405\times 10^{-3} \end{pmatrix}$ Constants definition.

$\alpha := \alpha\beta_0$ $\quad\quad \alpha = 0.877$

$\beta := \alpha\beta_1$ $\quad\quad \beta = 1.405\times 10^{-3}$

$\xi_g(\omega) := \frac{\alpha}{2\cdot\omega} + \frac{\beta\cdot\omega}{2}$ Definition for Rayleigh damping (for plotting).

$f_g := 0.01, 0.03 .. 100$ Graphing nature frequencies in Hertz (for plotting).

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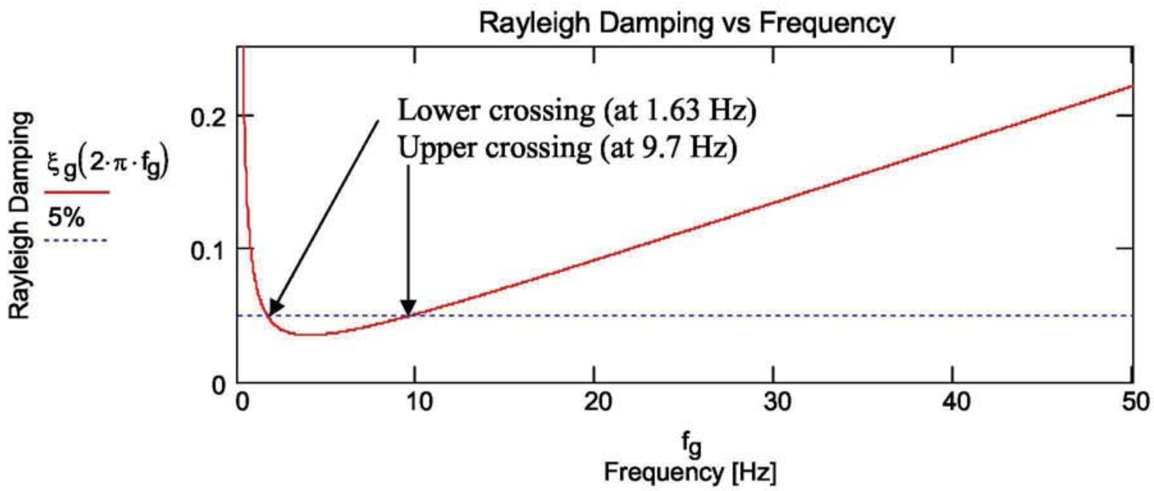

Fig. A.3.4.2-1 – Validation Rayleigh damping curve and desired damping curve versus frequency.

To establish the response spectra, the point furthest from zero on each of the relative and total curves must be found. This can be performed in a Mathcad subroutine as shown in subroutine "$ResSp_{var}$. The subroutine "$ResSp_{var}$ calculates all the response spectra data given that the input acceleration, number of response spectrum output points, and lower and upper bound frequency values are defined in advance of the subroutine. To match the validation problem, the following definitions are made.

$n := 300$	Number of response spectra output points.
$f_{lo} := 0.1$	Lowest frequency for response spectra output points
$f_{hi} := 100$	Highest frequency for response spectra output point

Subroutine "$ResSp_{var}$ is a "for loop where each loop generates an output row in the same column arrangement that is found in the ".prn files produced by the program ReSpect_vardamp. Within the loop, the given natural frequency is first defined based on an even spacing for a log plot. Next, all of the relative values are calculated with subroutine "X_{lc} and augmented together. Input values are then augmented into the same order as the relative values. Then a counting variable is defined and the natural frequency value is put into its position in the output variable. Finally, a "for loop finds the point furthest from zero.

```
ResSp_var := | for i ∈ 0.. n
             |   | f_r' ← 10^( (log(f_hi) − log(f_lo))·i / n + log(f_lo) )
             |   | ζ ← ξ_g(2·π·f_r')
             |   | z_r ← augment(X_lc(f_r', ζ , a_h1), X_lc(f_r', ζ , a_h2), X_lc(f_r', ζ , a_v))
             |   | z_g ← augment(x_h1, v_h1, a_h1, x_h2, v_h2, a_h2, x_v, v_v, a_v)
             |   | n_j ← cols(z_r) − 1
             |   | out_i,0 ← f_r'
             |   | for j ∈ 0.. n_j
             |   |   | out_i,j+1 ← max((max(z_r^<j>)  |min(z_r^<j>)| ))
             |   |   | out_i,j+nj+2 ← max((max(z_r^<j> + z_g^<j>)  |min(z_r^<j> + z_g^<j>)| ))
             | out
```

Fig. A.3.4.2-2 – Fig. A.3.4.2-4 show the overlaid plots and the difference plots for some results from the program ReSpect and from Mathcad.

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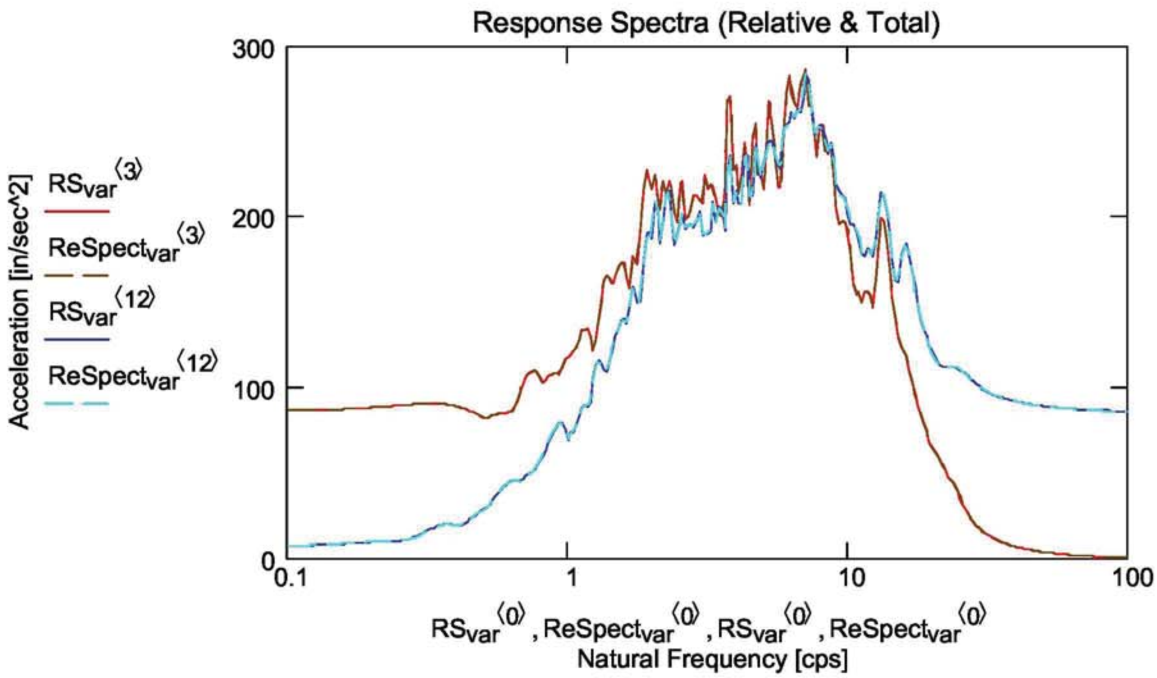
Title:	ATR Primary Coolant System Seismic Evaluation				
Authors:	R. E. Spears	**Date:** 09/30/08	**Checker:** M. J. Russell	**Date:**	09/30/08



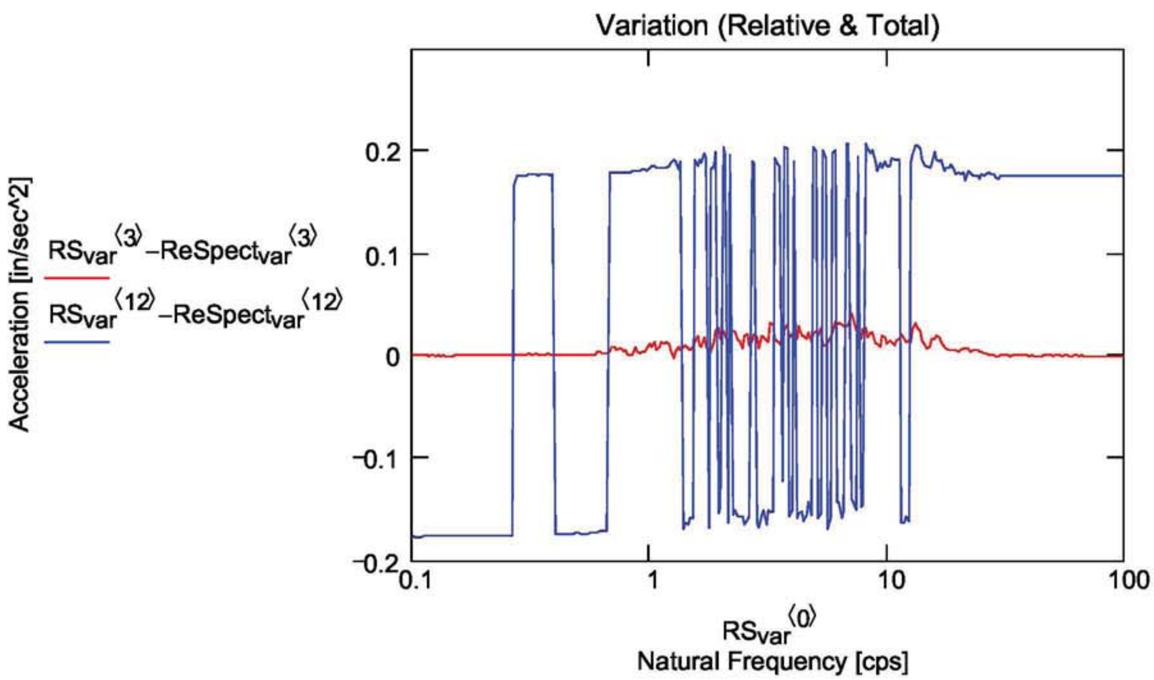
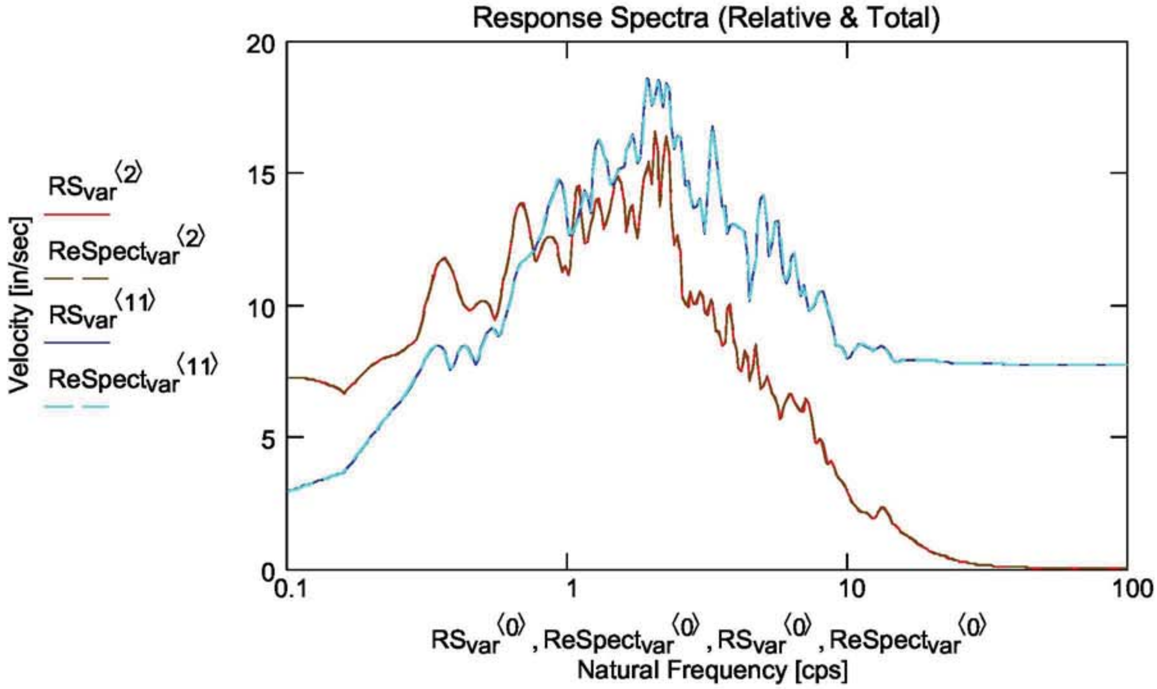


Fig. A.3.4.2-2 – East-west acceleration response spectra comparison.

Project:	ATR Life-Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Authors:	R. E. Spears **Date:** 09/30/08	**Checker:**	M. J. Russell	**Date:**	09/30/08



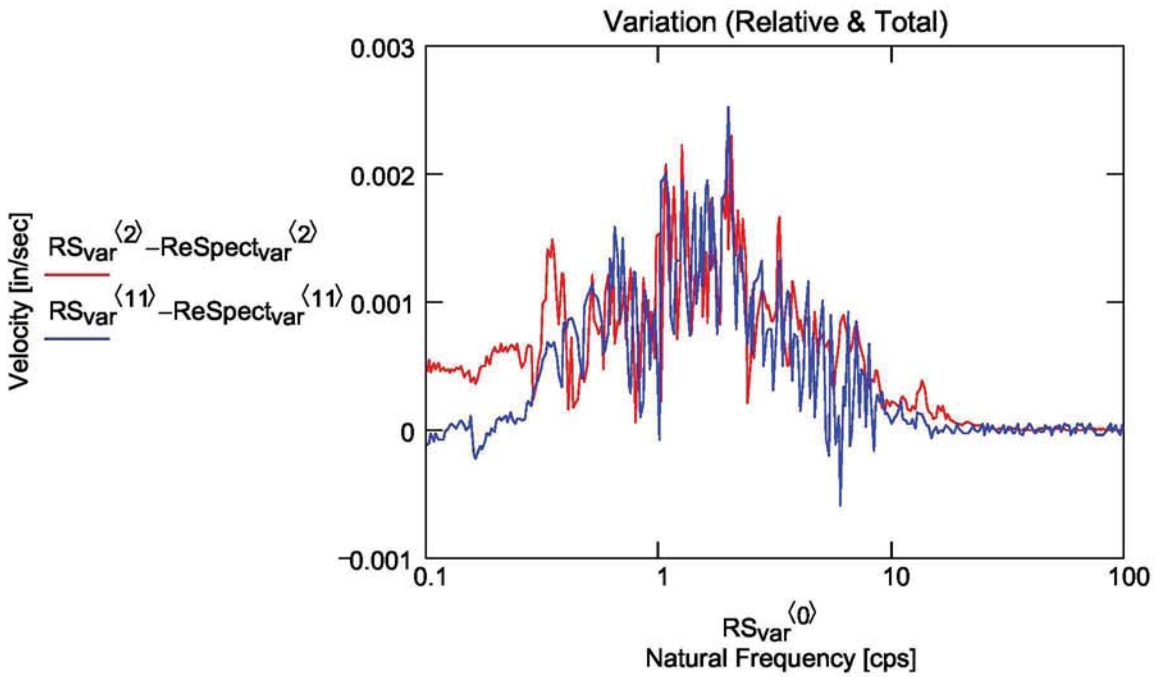
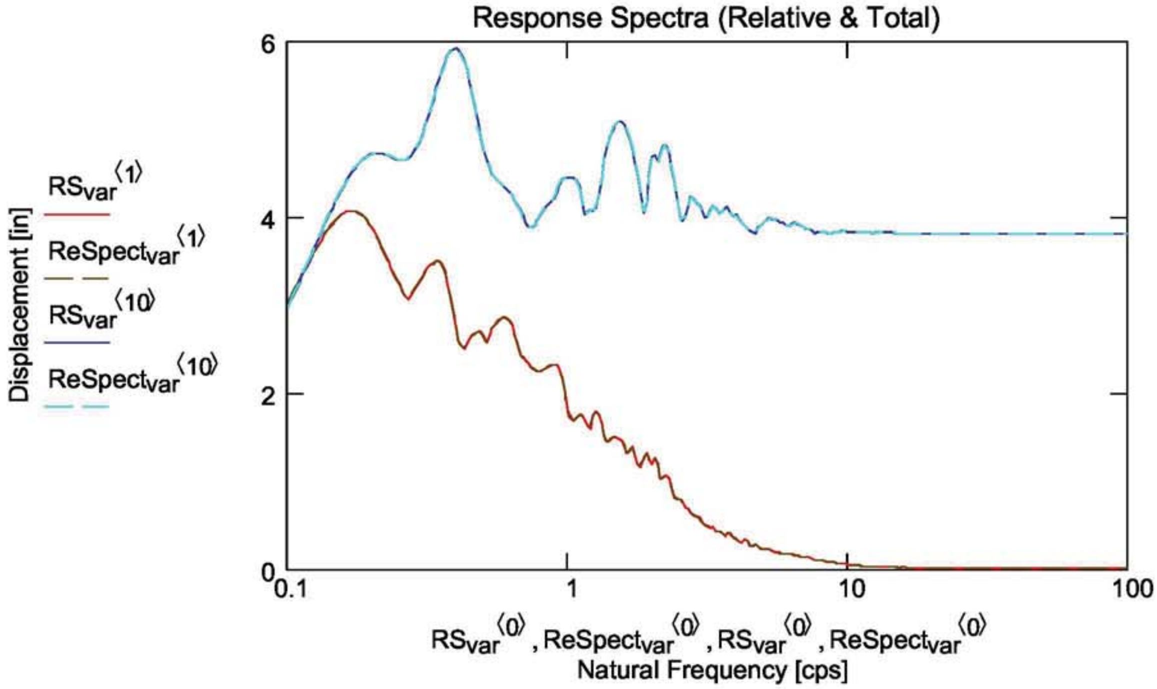


Fig. A.3.4.2-3 – East-west velocity response spectra comparison.

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Authors: R. E. Spears **Date:** 09/30/08 **Checker:** M. J. Russell **Date:** 09/30/08



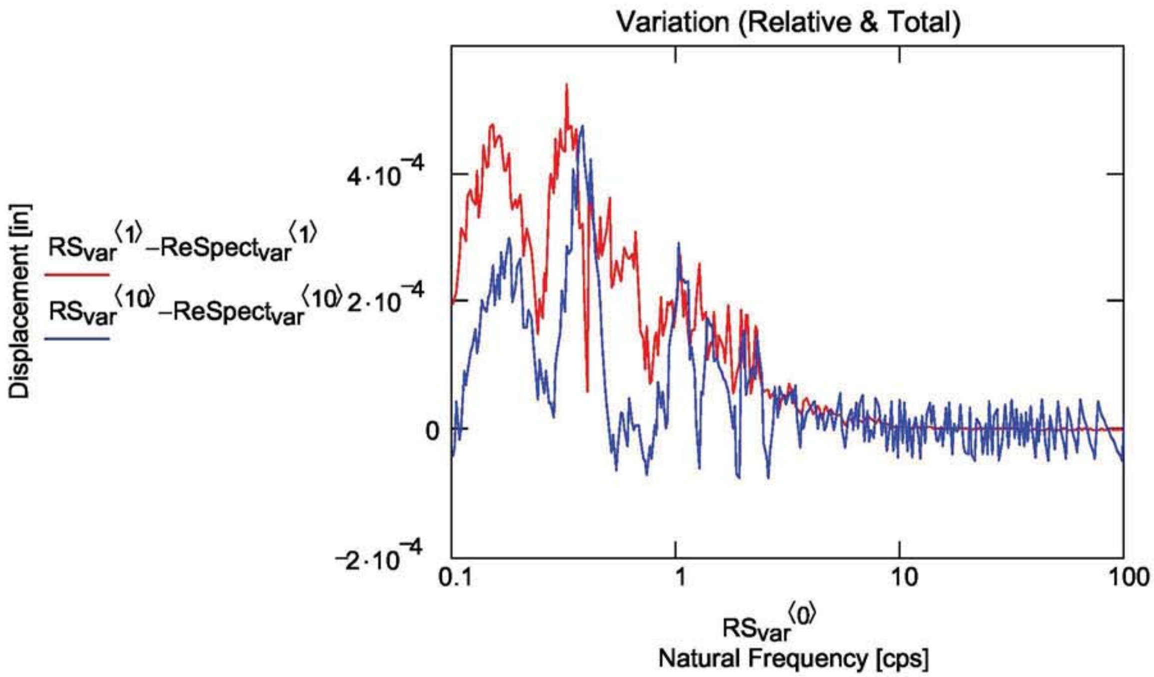


Fig. A.3.4.2-4 – East-west displacement response spectra comparison.

Fig. A.3.4.2-2 – Fig. A.3.4.2-4 show the east-west response spectra data. This provides a cross section of the data plots. As a measure for comparison, the subroutine "Δ% is used (as described for the ReSpect validation).

The output for subroutine "Δ% is given below.

Δ% =

	0	1	2
0	0	0	0
1	4.069	$5.386\cdot10^{-4}$	$1.324\cdot10^{-4}$
2	16.565	$2.294\cdot10^{-3}$	$1.385\cdot10^{-4}$
3	286.782	0.042	$1.458\cdot10^{-4}$
4	4.023	$4.918\cdot10^{-4}$	$1.223\cdot10^{-4}$
5	16.826	$2.433\cdot10^{-3}$	$1.446\cdot10^{-4}$
6	372.119	0.043	$1.164\cdot10^{-4}$
7	2.553	$3.396\cdot10^{-4}$	$1.33\cdot10^{-4}$
8	11.117	$1.646\cdot10^{-3}$	$1.481\cdot10^{-4}$
9	319.067	0.037	$1.171\cdot10^{-4}$
10	5.912	$4.747\cdot10^{-4}$	$8.029\cdot10^{-5}$
11	18.552	$2.525\cdot10^{-3}$	$1.361\cdot10^{-4}$
12	284.06	0.207	$7.302\cdot10^{-4}$
13	7.302	$3.297\cdot10^{-4}$	$4.514\cdot10^{-5}$
14	18.644	$2.359\cdot10^{-3}$	$1.265\cdot10^{-4}$
15	353.944	0.227	$6.417\cdot10^{-4}$
16	3.833	$3.409\cdot10^{-4}$	$8.893\cdot10^{-5}$
17	12.649	$1.605\cdot10^{-3}$	$1.269\cdot10^{-4}$
18	295.473	0.143	$4.834\cdot10^{-4}$

The maximum percent change is 0.073%. This represents an acceptably low percentage change.

A.3.5 – Abbreviated Input File Data

Input file names

1. model3_fr_9-24-08.inp
2. model265_fr_9-24-08.inp
3. Base_M14_fr_9-24-08.inp

The file "model3_R1fr_6-3-08.inp is the same as the file "model3_R1.inp (described in Appendix B.2) with the exception of the modifications to the second step (listed below) and having no time history data.

```
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
**% Note: Nodes vertical is possitive z
```

```
**%      Elements vertical is possitive y
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.01
 0.005,1.0,1.0E-08,1.0
**%  STATIC PLUS SEISMIC
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
        535,  1,,       0.00000E+00
        102,  1,,       0.00000E+00
        102,  3,,       0.00000E+00
BS000001,    1, 3,      0.00000E+00
BS000002,    1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
        531,    2, 3.9000E+03
        513,    2, 4.5000E+03
        169,    2, 4.6000E+03
        512,    2, 5.0000E+03
        533,    2, 5.0000E+03
        168,    2, 5.1500E+03
        505,    2, 5.2500E+03
         40,    2, 5.5000E+03
        504,    2, 5.5000E+03
         16,    2, 5.7500E+03
        199,    2, 6.0500E+03
        187,    2, 6.6000E+03
        516,    2, 6.6000E+03
        519,    2, 7.2000E+03
        542,    2, 7.2000E+03
        541,    2, 7.9000E+03
         68,    2, 9.3500E+03
        517,    2, 9.6000E+03
        518,    2, 1.2900E+04
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
**%OUTPUT, FIELD
**%NODE OUTPUT
**%ELEMENT OUTPUT
*OUTPUT, HISTORY,FREQUENCY=10000
**%ELEMENT OUTPUT
*NODE PRINT, TOTAL=YES
*MONITOR, NODE=69, DOF=1
*END STEP
**%
**% ====== EIGENSOLVER ======
**%
*STEP,INC=10
*FREQUENCY, EIGENSOLVER=LANCZOS, NORMALIZATION=DISPLACEMENT
,,50.,
*OUTPUT, FIELD
*NODE OUTPUT
 U
```

```
***ELEMENT OUTPUT
** E,S,SF
***NODE PRINT, MODE=1
** U
** RF
*END STEP
```

The file "model265_fr_9-24-08.inp is the same as the file "model265_R1.inp (described in Appendix B.2) with the exception of the modifications to the second step (listed below) and having no time history data.

```
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
**% Note: Nodes vertical is possitive z
**%       Elements vertical is possitive y
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.01
 0.005,1.0,1.0E-08,1.0
**%  STATIC PLUS SEISMIC
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
BS000001,     1, 3,      0.00000E+00
        837,  4, 6,      0.00000E+00
        836,  2,,        0.00000E+00
        836,  4, 6,      0.00000E+00
       1045,  2, 6,      0.00000E+00
       1047,  2, 6,      0.00000E+00
BS000002,     1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
        890,    2, 7.2000E+03
        889,    2, 7.8000E+03
        891,    2, 7.8000E+03
        892,    2, 7.8000E+03
        871,    2, 8.1000E+03
        883,    2, 8.4000E+03
        867,    2, 8.7000E+03
        874,    2, 8.9000E+03
        877,    2, 9.0000E+03
        887,    2, 9.6000E+03
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
**%OUTPUT, FIELD
**%NODE OUTPUT
**%ELEMENT OUTPUT
*OUTPUT, HISTORY,FREQUENCY=10000
**%ELEMENT OUTPUT
*NODE PRINT, TOTAL=YES
*MONITOR, NODE=1, DOF=1
*END STEP
```

```
**%
**% ====== EIGENSOLVER ======
**%
*STEP,INC=10
*FREQUENCY, EIGENSOLVER=LANCZOS, NORMALIZATION=DISPLACEMENT
,,50.,
*OUTPUT, FIELD
*NODE OUTPUT
 U
***ELEMENT OUTPUT
** E,S,SF
***NODE PRINT, MODE=1
** U
** RF
*END STEP
```

The file "Base_M14_fr_9-24-08.inp is the same as the file "model14_R1.inp (described in Appendix B.2) with the exception of the modifications to the second step (listed below) and having no time history data.

```
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
**% Note: Nodes vertical is possitive z
**%       Elements vertical is possitive y
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.01
 0.005,1.0,1.0E-08,1.0
**%  STATIC PLUS SEISMIC
**%  RESTRAINT SET 3
*BOUNDARY,OP=NEW
       1346,  1,,       0.00000E+00
       1347,  1,,       0.00000E+00
       1444,  1,,       0.00000E+00
       1431,  1,,       0.00000E+00
       1431,  3,,       0.00000E+00
       1432,  1,,       0.00000E+00
       1432,  3,,       0.00000E+00
       1446,  1,,       0.00000E+00
       1446,  3,,       0.00000E+00
       1445,  2, 3,      0.00000E+00
BS000001,    1, 3,      0.00000E+00
       1222,  1, 3,      0.00000E+00
       1222,  5,,       0.00000E+00
       1223,  1, 3,      0.00000E+00
       1223,  5,,       0.00000E+00
       1401,  1, 5,      0.00000E+00
       1348,  1, 2,      0.00000E+00
       1348,  5, 6,      0.00000E+00
       1391,  1, 3,      0.00000E+00
       1391,  5, 6,      0.00000E+00
```

```
       1355,  1, 2,       0.00000E+00
       1355,  4, 6,       0.00000E+00
       1406,  1,,        0.00000E+00
       1406,  3, 6,       0.00000E+00
BS000002,    1, 6,       0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
       1367,    2, 8.5000E+02
       1080,    2, 2.9000E+03
       1099,    2, 3.1000E+03
       1075,    2, 3.4500E+03
       1078,    2, 3.4500E+03
       1074,    2, 3.5000E+03
       1079,    2, 3.5000E+03
       1077,    2, 3.5500E+03
       1072,    2, 3.6000E+03
       1073,    2, 3.6000E+03
       1076,    2, 3.6000E+03
       1071,    2, 3.7000E+03
       1095,    2, 4.5000E+03
       1094,    2, 5.6000E+03
       1084,    2, 5.7000E+03
       1083,    2, 6.0000E+03
       1091,    2, 6.5000E+03
       1085,    2, 9.2000E+03
       1086,    2, 9.6000E+03
       1087,    2, 9.6000E+03
       1088,    2, 1.0100E+04
       1089,    2, 1.7100E+04
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
**%OUTPUT, FIELD
**%NODE OUTPUT
**%ELEMENT OUTPUT
*OUTPUT, HISTORY,FREQUENCY=10000
**%ELEMENT OUTPUT
*NODE PRINT, TOTAL=YES
*MONITOR, NODE=589, DOF=1
*END STEP
**%
**% ====== EIGENSOLVER ======
**%
*STEP,INC=10
*FREQUENCY, EIGENSOLVER=LANCZOS, NORMALIZATION=DISPLACEMENT
,,50.,
*OUTPUT, FIELD
*NODE OUTPUT
 U
***ELEMENT OUTPUT
** E,S,SF
***NODE PRINT, MODE=1
** U
** RF
```

```
*END STEP
```

Project:	ATR Life-Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Authors:	D. T. Clark	**Date:** 09/30/08	**Checker:** S. R. Jensen	**Date:**	09/30/08

Appendix A.4
ABAQUS Standard Validation.

ABAQUS Standard, Version 6.7-5, was the software used to produce all solution runs and post-processing results for all FE models. Figure A.4-1 shows a reprint of the title and signature page of the validation report [16].

TEM-10200-1
12/11/2007
Rev. 01

ENGINEERING CALCULATIONS AND ANALYSIS REPORT Page 1 of 4

ECAR No.: ECAR-202 ECAR Rev. No.: 0 Project File No.: 26276 Date: May 13, 2008

Title: Software Validation Report for ABAQUS/Standard and ABAQUS/Explicit Version 6.7-5

1. Index Codes
   Building/Type: SSC ID: Site Area:
2. Quality Level: 2
3. Objective/Purpose:
   The purposes of this report are to: (1) validate the software ABAQUS/Standard and ABAQUS/Explicit Version 6.7-5 on INL computers Snowsd, Aurora, Helios, and Icestorm, and (2) evaluate an automated script written to streamline the validation process. The automated script will then be used to validate ABAQUS/Standard and ABAQUS/Explicit Version 6.7-5 on selected INL workstation computers (see Appendix C).
4. Conclusions/Recommendations:
   This report shows that the specific features of ABAQUS/Explicit Version 6.7-5 listed in Section 6.1 are validated and approved for use on INL computers Snowsd, Aurora, Helios, and Icestorm. It also shows that specific features of ABAQUS/Standard Version 6.7-5 listed in Section 6.2 are validated and approved for use on the same INL computers. However, several ABAQUS/Standard elements listed in Section 6.2 are approved for limited use only (limitations discussed in detail in Appendix B).
   The automated validation script (instructions to load and run the script located at: http://hpcweb.inel.gov/home/Abaqus) has also been shown to adequately validate ABAQUS/Explicit and ABAQUS/Standard Version 6.7-5 for use in the following circumstances:
   - To initially validate ABAQUS/Explicit and ABAQUS/Standard Version 6.7-5 on other INL computers,
   - To re-validate ABAQUS/Explicit and ABAQUS/Standard Version 6.7-5 on INL computers previously validated after configuration changes (e.g., software patches are installed, operating system is updated, etc.).

   The automation script has been used to validate ABAQUS/Standard and ABAQUS/Explicit Version 6.7-5 on the following INL workstation computers: INL387944linux, INL388267, INL387426, INL386796 INL387945, INL410657, INL388264, BLANRK, BEA384437. Appendix C provides details on these workstation computer configurations.

   For INL computers not specifically approved herein, the output from the validation script must be included as part of the analysis report (e.g., an appendix) where the software is employed to document the validation. Any output results that differ by more than 3% from the baseline values must be evaluated and dispositioned.

   For the INL computers specifically approved herein, the output from the validation script (i.e., re-validation) may be documented as a memo to file (located in the Inel-nt network drive: '\\Fserob1\PROJECTS2\B160\ABAQUS Validation'), in lieu of a revision to this ECAR. Again, any output results that differ by more than 3% from the baseline values must be evaluated and dispositioned therein.

   The automated script version is "Rev. 8," and the last changed date is "2008-05-08 11:09:25". The instructions to verify this are also included in the above referenced web page.

5. Review (R) and Approval (A) and Acceptance (Ac):

		Typed Name/Organization	Signature/Date
Performer/Author		S. D. Snow / B160	SDSnow 13MAY 2008
Technical Checker	R	B. D. Hawkes / B160	Pages checked: All B.D. Hawkes 13May2008
Independent Peer Reviewer	R	N/A	N/A
Performer's Manager	A	C. C. O'Brien / B160	[signature] 5/16/08
Requester	Ac	S. S. Mascarenas / G600	[signature] 5/22/08

6. Additional Distribution: (Name and Mail Stop) Document Control: Kathryn Jenson - Kathryn Jenson 5.27.08

M.J. Russell, S.R. Novascone, R.E. Spears, D.T. Clark, K.D. Ellis, R.G. Kobbe, R.K. Blandford, V.J. Balls; MS-3760

Figure A.4-1 Reprint of ABAQUS Standard, Version 6.7-5, used to solve and produce results for all FE models

Appendix A.5

Demand to Capacity Calculation Details

Contents

Appendix A.5.1

Supports

SUPPORTS

Supports Strategy: *Search based on the node for which the support acts. If this node is a termination point there will only be one node to evaluate. If this node is in line with a section of pipe there will be two representations of the same node (one for each element on each side of the node) to combine and the difference between them is the force required of the support. The D/C ratio for each support will be found by dividing the the required force found above by the support capacity.*

SUPPORT OUTPUT: (DC, Loading, Time, Node, Indicy Associated With Node)

NOTE: Indicies in the MathCad program begin at 0

Demand/Capacity Calculation:

$$SupDC(P_r, P_c) := \frac{P_r}{P_c}$$

Function Definition: *The function's name is* ***SupDC*** *and the inputs required are* ***(P_r, P_c)***

$$SupDC(P_r, P_c) :=$$

P_r *is the force experienced by the support (supplied to eqn at each time step)*

P_c *is the capacity of the support whose directionality is consistent with that of P_r*

Equation Definition: *The equation is the ratio of the experienced force* ***(P_r)*** *divided by* ***(P_c)***

$$\frac{P_r}{P_c}$$

Data Extraction from Abaqus Results for Supports:

$$\mathrm{Support}(nf, nd, C_o, EL) := \begin{array}{|l} ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0\rangle}\right) \\ ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0\rangle}\right) \\ ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1\rangle}\right) \\ \text{for } i \in 1..\mathrm{last}(nd) \qquad\qquad \text{if } \mathrm{rows}(nd) > 1 \\ \quad ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1\rangle}\right)\right)\right] \\ \begin{pmatrix} Int_{1_4} & Int_{2_4} \end{pmatrix} \leftarrow (0 \;\; 0) \\ \text{for } i \in 0..ind_{nfo_0} - ind_{nfi_0} \\ \quad \begin{array}{|l} \text{for } j \in 0..\mathrm{last}(ind_{nd}) \\ \quad \begin{array}{|l} P_{rg_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}-1},\, ind_{nd_j}} \\ P_{r_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}-1+i},\, ind_{nd_j}} - P_{rg_j}\right) \cdot C_{o_{2,0}} + P_{rg_j} \end{array} \\ PR_i \leftarrow \sum_{n=0}^{j} P_{r_n} \\ \text{if } PR_i < Int_{1_1} \wedge C_{o_{0,0}} \neq 0 \\ \quad \begin{array}{|l} Int_1' \leftarrow \mathrm{SupDC}\left(\left|PR_i\right|, C_{o_{0,0}}\right) \\ Int_1 \leftarrow \mathrm{stack}\left(Int_1', PR_i, nf_{ind_{nfiC_{o_{0,1}}-1+i},\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd}\right) \end{array} \\ \text{if } PR_i > Int_{2_1} \wedge C_{o_{1,0}} \neq 0 \\ \quad \begin{array}{|l} Int_2' \leftarrow \mathrm{SupDC}\left(\left|PR_i\right|, C_{o_{1,0}}\right) \\ Int_2 \leftarrow \mathrm{stack}\left(Int_2', PR_i, nf_{ind_{nfiC_{o_{0,1}}-1+i},\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd}\right) \end{array} \end{array} \\ \left(Int_1 \;\; Int_2\right) \end{array}$$

Function Definition: *This function's name is* ***Support*** *and the inputs are* ***(nf, nd, C_o)***

$$\text{Support}(nf, nd, C_o, EL) :=$$

nf *is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of* ***nf*** *represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

nd *is a vector of defined nodes associated with the support in the finite element model. Typically only one node is included in vector.*

EL *is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of* ***nf.***

C_o *is a matrix (shown below) defining the* ***Direction*** *of support capacity in the global coordinate system (1-x, 2-y, 3-z), capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system* ***(P_1)***, *capacity of the support if the reaction force proved at the node of interest is in the negative direction of the global coordinate system* ***(P_2)***, *and the seismic scale factor* ***(F_a)***.

$$C_o := \begin{bmatrix} P_1 & (1,2,\text{or}3) \\ P_2 & 0 \\ F_a & 0 \end{bmatrix}$$

Equation Definition: *The equation gathers force infromation from the available data and outputs max D/C ratio, max applied force, time when max values occur, node(s) retrieved for calculations, and indicie of node(s)*

Line 1: *Identifies the row indicies in the time column of* ***nf*** *that match that of the specified initial time of the dynamic step and places them in a vector* ***(ind_{nfi})***.

$$ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$$

$t_{initial}$ *is the intial start point when the seimic input was applied to the model*

$nf^{<0>}$ *is the time column of the Abaqus output data*

Line 2: *Identifies the row indicies in the time column of **nf** that match that of the specified final time of the dynamic step and places them in a vector (**ind_{nfo}**).*

$$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right)$$

t_{final} *is the final time when the seimic input was stopped*

$nf^{<0>}$ *is the time column of the Abaqus output data*

Line 3: *Matches the indicy where the first specified node in the **nd** vector occurs in the second column of **EL** and defines it as the variable **ind_{nd}**.*

$$ind_{nd} \leftarrow match\left(nd_0, EL^{\langle 1 \rangle}\right)$$

nd_0 *is the first node specified in the **nd** vector*

EL *is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of **nf**.*

Line 4 - 5: *If the length of the **nd** vector is greater than 1 then the logic statement here identifies (matches) and appends the indicies of the remaining node one on top and converts the variable **ind_{nd}** into a vector. This logic statement is to add versitility to the function but is not typically used.*

$$\text{for } i \in 1..\text{last}(nd) \quad \text{if rows}(nd) > 1$$
$$\quad ind_{nd} \leftarrow stack\left[ind_{nd}, \left(match\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$$

for *is a looping function that iterates through the specified range of variables*

last(nd) *indicates the indicy of the last row of the **nd** vector*

if *only allows loop to calculate if the number of rows in **nd** is greater than 1*

nd_i *is the i^{th} node specified in the **nd** vector*

EL *is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of **nf**.*

stack *is a command that adds the newly matched indicy onto the current variable/vector of* $\boldsymbol{ind_{nd}}$ *to redefine* $\boldsymbol{ind_{nd}}$

Line 6: *Initiates the two row vectors* $\boldsymbol{Int_1}$ *and* $\boldsymbol{Int_2}$ *to null values (this is used later in the logic when comparing the force gathered from the Abaqus results at the designated support node to a baseline value)*

$$\begin{pmatrix} Int1_4 & Int2_4 \end{pmatrix} \leftarrow \begin{pmatrix} 0 & 0 \end{pmatrix}$$

Line 7: *Ranges variable* ***i*** *from 0 over the length of the time column specified by the difference between the final time* ($\boldsymbol{ind_{nfo0}}$) *and initial time* ($\boldsymbol{ind_{nfi0}}$) *indicies of the x-0 direction force. The length of final and initial time indicy difference is consistent for all forces and moment. Associated lines for which this loop applies includes 7 through 17.*

$$\text{for } i \in 0..\, ind_{nfo_0} - ind_{nfi_0}$$

for *is a looping function that iterates through the specified range of variables*

$\boldsymbol{ind_{nfo0}}$ *is the final time indicy for the x-0 direction force (See Line 2)*

$\boldsymbol{ind_{nfi0}}$ *is the initial time indicy for the x-0 direction force (See Line 1)*

Line 8: *Ranges variable* ***j*** *from 0 over the length of the indicies of the nodes matching those specified. Associated lined for which this loop applies includes 8 through 10.*

$$\text{for } j \in 0..\, last(ind_{nd})$$

for *is a looping function that iterates through the specified range of variables*

last($\boldsymbol{ind_{nd}}$***)*** *indicates the indicy of the last row of the* $\boldsymbol{ind_{nd}}$ *vector (See Line 3)*

Line 9: *Specifies the gravitational force* ($\boldsymbol{P_{rg}}$) *on the support by locating the initial force in the Abaqus results* ***(nf)*** *at the row corresponding to the initial dynamic time step* ($\boldsymbol{ind_{nfi}}$) *of the direction for which the support acts* ($\boldsymbol{Co_{0,1}}$ ***- 1)*** *and the associated column of the specified node at the* $\boldsymbol{j^{th}}$ *indicy of the specified node indicy vector* ($\boldsymbol{ind_{nd}}$) *(Note: -1 is included in the* ($\boldsymbol{Co_{0,1}}$ ***- 1)*** *expression to modify the output such that the specified direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (0-x, 1-y, 2-z)).*

$$P_{rg_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}-1},\, ind_{nd_j}}$$

nf *is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of* ***nf*** *represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

$\boldsymbol{ind_{nfi}}$ *is the initial time indicy for the force whose direction is specified by* $\boldsymbol{(Co_{0,1} - 1)}$ *(See next definition for* $\boldsymbol{(Co_{0,1} - 1)}$*)*

$\boldsymbol{Co_{0,1}}$ *indicates the direction for which the support acts (Note: -1 is included in the* $\boldsymbol{(Co_{0,1} - 1)}$ *expression to modify the output such that the specified direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (0-x, 1-y, 2-z)).*

$\boldsymbol{ind_{nd}}$ *is the vector of indicies corresponding to the locations of the specified nodes*

j *is the indicy in the vector* $\boldsymbol{ind_{nd}}$ *for which this line applies*

Line 10: *Specifies the force* $\boldsymbol{(P_r)}$ *on the support by first locating the total force in the Abaqus results* ***(nf)*** *at the row corresponding to the dynamic time step* $\boldsymbol{(ind_{nfi})}$ *at the* ***i***th *indicy of the time column of the direction for which the support acts* $\boldsymbol{(Co_{0,1} - 1)}$ *and the associated column of the specified node at the* ***j***th *indicy of the specified node indicy vector* $\boldsymbol{(ind_{nd})}$*. The gravitational force* $\boldsymbol{(P_{rg})}$ *specified immediately proprior on Line 9 and included in the same for loop as that specified in Line 8 is subtracted from the total force and the difference is multiplied by the seismic factor* $\boldsymbol{(F_a)}$ *identified in the Co matrix on the third row first column* $\boldsymbol{(Co_{2,0})}$*. The gravitational force* $\boldsymbol{(P_{rg})}$ *is then added back into the adjusted dynamic force. (Note: -1 is included in the* $\boldsymbol{(Co_{0,1} - 1)}$ *expression to modify the output such that the specified direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (0-x, 1-y, 2-z)).*

$$P_{r_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}-1}+i,\ ind_{nd_j}} - P_{rg_j}\right) \cdot C_{o_{2,0}} + P_{rg_j}$$

nf *is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of* ***nf*** *represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

$\boldsymbol{ind_{nfi}}$ *is the initial time indicy for the force whose direction is specified by* $\boldsymbol{(Co_{0,1} - 1)}$ *(See next definition for* $\boldsymbol{(Co_{0,1} - 1)}$*)*

$\boldsymbol{Co_{0,1}}$ *indicates the direction for which the support acts (Note: -1 is included in the* $\boldsymbol{(Co_{0,1} - 1)}$ *expression to modify the output such that the specified direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (0-x, 1-y, 2-z)).*

i *is the indicy of the for loop specifed in Line 7*

***ind**$_{nd}$ is the vector of indicies corresponding to the locations of the specified nodes*

j *is the indicy in the vector* ***ind**$_{nd}$ for which this line applies*

***P**$_{rg}$ is the gravitational force specified in Line 9*

***Co**$_{2,0}$ locates the seismic factor in the Co matrix provided to the function*

Line 11: *Combines the nodal force associated with each element meeting at the specified node. Typically there is only one element corresponding to the node of interest.*

$$PR_i \leftarrow \sum_{n=0}^{j} P_{r_n}$$

***P**$_r$ is the force(s) specified on Line 10.*

Line 12: *If statement that applies if the* ***PR*** *defined on Line 11 is less than the formerly least experienced force by the node of interest and the capacity in that direction is not equal to 0. (Note: As specified on Line 6 Int1$_1$ is initially 0, therefore* ***PR*** *must be at least less than 0 for this condition to apply)*

$$\text{if } PR_i < Int1_1 \wedge Co_{0,0} \neq 0$$

PR *is the combined forces at a node as specified on Line 11*

***Int1**$_1$ is the minimum force value experience by the node in the global coordinate system and the variable is redefined in the if loop if it meets the conditions of the statement*

***Co**$_{0,0}$ is the capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system*

^ *indicates an and condition*

Line 13: *Calls the function* ***SupDC*** *that calculates the Demand* ***(PR)*** *to Capacity* ***(Co**$_{0,0}$**)*** *ratio of the support given the loading applicable to the conditions of Line 12.*

$$Int1_{1'} \leftarrow SupDC\left(\left|PR_i\right|, Co_{0,0}\right)$$

***SupDC** is the function that calculates the Demand **(PR)** to Capacity **($Co_{0,0}$)** ratio of the support given the loading applicable to the conditions of Line 12.*

***PR** is the combined forces at a node as specified on Line 11 (Absolute value used for sorting purposes)*

***$Co_{0,0}$** is the capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system*

***Line 14:** Creats a vector of values of interest applicable for a specified node with loading that satisfies the conditions of Line 12*

$$Int_1 \leftarrow stack\left(Int_1', PR_i, nf_{ind_{nfiCo_{0,1}}-1+i,0}, EL_{ind_{nd_j},1}, ind_{nd}\right)$$

***stack** is a command that adds values in the parentheses into a vector form*

***Int_1'** is the demand to capacity ratio calculated in Line 13*

$nf_{ind_{nfiCo_{0,1}}-1+i,0}$ *is the time for which the associated values occur*

$EL_{ind_{nd_j},1}$ *is the node that is was specified. This form of acquiring the node is used to assist in checking the program*

***ind_{nd}** is the indicy for which node occurs*

***Line 15:** If statement that applies if the **PR** defined on Line 11 is greater than the formerly greatest experienced force by the node of interest and the capacity in that direction is not equal to 0. (Note: As specified on Line 6 $Int2_1$ is initially 0, therefore **PR** must be at least greater than 0 for this condition to apply)*

$$\text{if } PR_i > Int2_1 \wedge Co_{1,0} \neq 0$$

***PR** is the combined forces at a node as specified on Line 11*

***$Int2_1$** is the maximum force value experience by the node in the global coordinate system and the variable is redefined in the if loop if it meets the conditions of the statement*

***$Co_{1,0}$** is the capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system*

^ *indicates an and condition*

Line 16: *Calls the function* ***SupDC*** *that calculates the Demand* ***(PR)*** *to Capacity* ***($Co_{1,0}$)*** *ratio of the support given the loading applicable to the conditions of Line 15.*

$$\mathrm{Int}_{2'} \leftarrow \mathrm{SupDC}\left(\left|\mathrm{PR}_i\right|, \mathrm{C}_{o_{1,0}}\right)$$

SupDC *is the function that calculates the Demand* ***(PR)*** *to Capacity* ***($Co_{0,0}$)*** *ratio of the support given the loading applicable to the conditions of Line 15.*

PR *is the combined forces at a node as specified on Line 11 (Absolute value used for sorting purposes)*

$Co_{1,0}$ *is the capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system*

Line 17: *Creats a vector of values of interest applicable for a specified node with loading that satisfies the conditions of Line 15*

$$\mathrm{Int}_2 \leftarrow \mathrm{stack}\left(\mathrm{Int}_{2'}, \mathrm{PR}_i, \mathrm{nf}_{\mathrm{ind}_{\mathrm{nfiC}_{o_{0,1}}-1}+i,\,0}, \mathrm{nd}, \mathrm{ind}_{\mathrm{nd}}\right)$$

stack *is a command that adds values in the parentheses into a vector form*

$Int_{2'}$ *is the demand to capacity ratio calculated in Line 13*

$\mathrm{nf}_{\mathrm{ind}_{\mathrm{nfiC}_{o_{0,1}}-1}+i,\,0}$ *is the time for which the associated values occur*

$\mathrm{EL}_{\mathrm{ind}_{\mathrm{nd}_j},\,1}$ *is the node that is was specified. This form of acquiring the node is used to assist in checking the program*

ind_{nd} *is the indicy for which node occurs*

Line 18: *Prepares the output vectors* ***Int_1*** *and* ***Int_2*** *as the function outputs*

$$\left(\mathrm{Int}_1 \;\; \mathrm{Int}_2\right)$$

Int_1 *vector of values as specified in Line 14 provided that conditions of Line 12 were met. If conditions of Line 12 were not met then* ***Int_1*** *returns a null vector indicating that no loading was seen in the direction or there wasn't any capacity in that direction.*

Int_2 *vector of values as specified in Line 17 provided that conditions of Line 15 were met. If conditions of Line 15 were not met then* ***Int_2*** *returns a null vector indicating that no loading was seen in the direction or there wasn't any capacity in that direction.*

SUPPORT OUTPUT: (DC, Loading, Time, Node, Indicy Associated With Node)

Appendix A.5.2

Terminations

TERMINATION LOCATIONS

Termination Locations Strategy: *Search based on the node for which the termination location acts. The D/C ratio for each termination location will be found by dividing the the required force found above by the support capacity.* [18]

TERMINATION OUTPUT: (DC, SRSS Moment, Time, Node, Indicy Associated With Node, Mx, My, Mz)

Demand to Capacity Calculation:

$$\mathrm{TermDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

Function Definition: *This function's name is* ***TermDC*** *and inputs are* ***(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o)***

$$\mathrm{TermDC}(P, D_o, t, I, B_1, B_2, M, S)$$

P *is the pressure applied to the piping system at the termination node of interest*

D_o *is the outside diameter of the pipe at the termination node*

t *is the thickness of the pipe at the termination node*

I *is the moment of inertia of the pipe at the termination node*

B_1 *is the stress indicy associated with the pressure term in equation 9 of NB3600*

B_2 *is the stress indicy associated with the moment term in equation 9 of NB3600*

M *is the SSRS moment at the termination node*

S *is the allowable design stress intensity factor associated with the pipe at the termination node (min of 2*Sy and 3*Sm)*

Equation Definition: *The equation is the ratio of the experienced stess associated with pressure* ($B_1 \cdot \frac{P \cdot D_o}{2 \cdot t}$)*and applied moment* ($B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]$) *versus the of the pipe capacity* (S).

$$\frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

Data Extraction from Abaqus Results for Terminations:

$$\mathrm{Term}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(nd)$ if $\mathrm{rows}(nd) > 1$

  $ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$\left(M \;\; Int_0\right) \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \mathrm{last}(ind_{nd})$

    $M_{rxg} \leftarrow nf_{ind_{nfiC_{o_{0,1}}+2}, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfiC_{o_{1,1}}+2}, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfiC_{o_{2,1}}+2}, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}+2}+i, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}+2}+i, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}+2}+i, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow \mathrm{TermDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$

    if $Int'_j > Int_0$

      $Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfiC_{o_{0,1}}-1}+i, 0}, EL_{ind_{nd_j}, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M_{rz}\right)$

      $Result \leftarrow M'$

Int

Function Definition: *This function's name is **Term** and the inputs are **(P, D_o, t, I, B_1, B_2, S_m, nf, nd, C_o)***

$$\text{Term}\left(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL\right)$$

***P** is the pressure applied to the piping system at the termination node of interest*

***D_o** is the outside diameter of the pipe at the termination node*

***t** is the thickness of the pipe at the termination node*

***I** is the moment of inertia of the pipe at the termination node*

***B_1** is the stress indicy associated with the pressure term in equation 9 of NB3600*

***B_2** is the stress indicy associated with the moment term in equation 9 of NB3600*

***S** is the allowable design stress intensity factor associated with the pipe at the termination node (min of 2*Sy and 3*Sm)*

***nf** is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of **nf** represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

***nd** is a vector of defined nodes associated with the support in the finite element model. Typically only one node is included in vector.*

***EL** is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of **nf**.*

***C_o** is a matrix (shown below) defining the **Direction** termination moments in the global coordinate system (1-x, 2-y, 3-z), defines the seismic scale factor **(F_a)**, and represents **(M_{cx}, M_{cy}, and M_{cz})** as place holders in the matrix and aren't referenced for any calculations.*

$$C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Equation Definition: *The equation gathers moment infromation from the available data and outputs max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, indicie of element(s), and moments about the x, y, and z axes.*

Line 1: *Identifies (matches) the row indicies in the time column of **nf** that match that of the specified initial time of the dynamic step and places them in a vector* ($\boldsymbol{ind_{nfi}}$).

$$ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right)$$

$\boldsymbol{t_{initial}}$ *is the intial start point when the seimic input was applied to the model*

$\boldsymbol{nf^{<0>}}$ *is the time column of the Abaqus output data*

Line 2: *Identifies (matches) the row indicies in the time column of **nf** that match that of the specified final time of the dynamic step and places them in a vector* ($\boldsymbol{ind_{nfo}}$).

$$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right)$$

$\boldsymbol{t_{final}}$ *is the final time when the seimic input was stopped*

$\boldsymbol{nf^{<0>}}$ *is the time column of the Abaqus output data*

Line 3: *Matches the indicy where the first specified node in the **nd** vector occurs in the second column of **EL** and defines it as the variable* $\boldsymbol{ind_{nd}}$.

$$ind_{nd} \leftarrow match\left(nd_0, EL^{\langle 1 \rangle}\right)$$

$\boldsymbol{nd_0}$ *is the first node specified in the **nd** vector*

EL *is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of **nf**.*

Line 4 - 5: *If the length of the **nd** vector is greater than 1 then the logic statement here identifies (matches) and appends the indicies of the remaining node one on top and converts the variable* $\boldsymbol{ind_{nd}}$ *into a vector. This logic statement is to add versitility to the function but is not typically used.*

$$\begin{array}{ll} \text{for } i \in 1..\,last(nd) & \text{if } rows(nd) > 1 \\ \quad ind_{nd} \leftarrow stack\left[ind_{nd}, \left(match\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] & \end{array}$$

for *is a looping function that iterates through the specified range of variables*

last(nd) *indicates the indicy of the last row of the* ***nd*** *vector*

if *only allows loop to calculate if the number of rows in* ***nd*** *is greater than 1*

nd_i *is the* i^{th} *node specified in the* ***nd*** *vector*

EL *is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of* ***nf.***

stack *is a command that adds the newly matched indicy onto the current variable/vector of* ind_{nd} *to redefine* ind_{nd}

Line 6: *Initiates the two row vectors* ***M*** *and* Int_0 *to null values (this is used later in the logic when comparing the force gathered from the Abaqus results at the designated support node to a baseline value)*

$$\left(M \;\; Int_0\right) \leftarrow (0 \;\; 0)$$

Line 7: *Ranges variable* ***i*** *from 0 over the length of the time column specified by the difference between the final time* (ind_{nfo0}) *and initial time* (ind_{nfi0}) *indicies of the x-0 direction force. The length of final and initial time indicy difference is consistent for all forces and moment. Associated lines for which this loop applies includes 7 through 17.*

$$\text{for } i \in 0..\, ind_{nfo_0} - ind_{nfi_0}$$

for *is a looping function that iterates through the specified range of variables*

ind_{nfo0} *is the final time indicy for the x-0 direction force (See Line 2)*

ind_{nfi0} *is the initial time indicy for the x-0 direction force (See Line 1)*

Line 8: *Ranges variable* ***j*** *from 0 over the length of the indicies of the nodes matching those specified. Associated lined for which this loop applies includes 8 through 10.*

$$\text{for } j \in 0..\, \text{last}\left(ind_{nd}\right)$$

for *is a looping function that iterates through the specified range of variables*

last(ind_{nd}) *indicates the indicy of the last row of the* ind_{nd} *vector (See Line 3)*

Lines 9-11: *Specifies the gravitational moments* ***(M_{rxg}, M_{ryg}, and M_{rzg})*** *on the support by locating the initial moment in the Abaqus results* ***(nf)*** *at the row corresponding to the initial dynamic time step* ***(ind_{nfi})*** *about all three axes (x, y, and z)* ***($Co_{0,1}$+2, $Co_{1,1}$+2, and $Co_{2,1}$+2,)*** *and the associated column of the specified node at the j^{th} indicy of the specified node indicy vector* ***(ind_{nd})*** *(Note: +2 is included in the* ***($Co_{2,1}$+2)*** *expression to modify the output such that the specified moment axes direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

$$M_{rxg} \leftarrow nf_{ind_{nfiC_{o_{0,1}}+2},\, ind_{nd_j}}$$
$$M_{ryg} \leftarrow nf_{ind_{nfiC_{o_{1,1}}+2},\, ind_{nd_j}}$$
$$M_{rzg} \leftarrow nf_{ind_{nfiC_{o_{2,1}}+2},\, ind_{nd_j}}$$

nf *is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of* ***nf*** *represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

ind_{nfi} *is the initial time indicy for the force whose direction is specified by* ***($Co_{0,1}$+2, $Co_{1,1}$+2,*** *and* ***$Co_{2,1}$+2)*** *(See next definition for* ***($Co_{0,1}$+2, $Co_{1,1}$+2,*** *and* ***$Co_{2,1}$+2)*** *)*

($Co_{0,1}$+2, $Co_{1,1}$+2, *and* ***$Co_{2,1}$+2)*** *indicates the direction for which the support acts (Note: +2 is included in the expressions to modify the output such that the specified moment axes direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

ind_{nd} *is the vector of indicies corresponding to the locations of the specified nodes in* ***nd****.*

j *is the indicy in the vector* ***ind_{nd}*** *for which this line applies*

Line 12-14: *Specifies the moments* ***(M_{rx}, M_{ry}, and M_{rz})*** *on the support by first locating the total moment for each direction in the Abaqus results* ***(nf)*** *at the row corresponding to the dynamic time step* ***(ind_{nfi})*** *for all three axes (x, y, and z)* ***($Co_{0,1}$+2, $Co_{1,1}$+2, and $Co_{2,1}$+2,)*** *at the i^{th} indicy of the time column of the direction for which the support acts, and the associated column of the specified node at the j^{th} indicy of the specified node indicy vector* ***(ind_{nd})****. The gravitational moments* ***(M_{rxg}, M_{ryg}, and M_{rzg})*** *specified immediately proprior on Lines 9-11 and included in the same for loop as that specified in Line 8 is subtracted from the total force and the difference is multiplied by the seismic factor* ***(F_a)*** *identified in the Co matrix on the fourth row first column* ***($Co_{3,0}$)****. The gravitational moments* ***(M_{rxg}, M_{ryg}, and M_{rzg})*** *are then added back into the adjusted dynamic force. (Note: +2 is included in the* ***($Co_{0,1}$+2, $Co_{1,1}$+2, and $Co_{2,1}$+2,)*** *expression to modify the output such that the specified direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

$$M_{rx} \leftarrow \left(nf_{ind_{nfiCo_{0,1}+2}+i,\, ind_{nd_j}} - M_{rxg}\right) Co_{3,0} + M_{rxg}$$
$$M_{ry} \leftarrow \left(nf_{ind_{nfiCo_{1,1}+2}+i,\, ind_{nd_j}} - M_{ryg}\right) Co_{3,0} + M_{ryg}$$
$$M_{rz} \leftarrow \left(nf_{ind_{nfiCo_{2,1}+2}+i,\, ind_{nd_j}} - M_{rzg}\right) Co_{3,0} + M_{rzg}$$

***nf** is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of **nf** represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

***ind_{nfi}** is the initial time indicy for the force whose direction is specified by **($Co_{0,1}$+2, $Co_{1,1}$+2,** and **$Co_{2,1}$+2)** (See next definition for **($Co_{0,1}$+2, $Co_{1,1}$+2,** and **$Co_{2,1}$+2)**)*

***($Co_{0,1}$+2, $Co_{1,1}$+2,** and **$Co_{2,1}$+2)** indicates the direction for which the support acts (Note: +2 is included in the expressions to modify the output such that the specified moment axes direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

***ind_{nd}** is the vector of indicies corresponding to the locations of the specified nodes in **nd**.*

***($Co_{3,0}$)** is the seismic factor **(F_a)** identified in the Co matrix on the fourth row first column.*

***(M_{rxg}, M_{ryg},** and **M_{rzg})** are the gravitational moments defined in Lines 9 - 11.*

***j** is the indicy in the vector **ind_{nd}** for which this line applies*

***Line 15:** Specifies the total moment (SRSS Combination) associated with the j^{th} indicy*

$$M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$$

***M_{rx}, M_{ry},** and **M_{rz}** are the moments calculated in Lines 12 - 14.*

***Line 16:** Calls the function **TermDC** that calculates the Demand to Capacity ratio of the termination given the loading applicable to the conditions of Line 15.*

$$Int'_j \leftarrow TermDC\left(P, D_0, t, I, B_1, B_2, M'_j, S\right)$$

***P** is the pressure applied to the piping system at the termination node of interest*

***D_o** is the outside diameter of the pipe at the termination node*

***t** is the thickness of the pipe at the termination node*

***I** is the moment of inertia of the pipe at the termination node*

***B_1** is the stress indicy associated with the pressure term in equation 9 of NB3600*

***B_2** is the stress indicy associated with the moment term in equation 9 of NB3600*

***M** is the SSRS moment at the termination node*

***S** is the allowable design stress intensity factor associated with the pipe at the termination node (min of 2*Sy and 3*Sm)*

Line 17: *If statement that applies if the **Int`** defined on Line 16 is greater than the formerly greatest Demand to Capacity ratio by the node of interest. (Note: As specified on Line 6 Int_0 is initially 0)*

$\text{if } Int'_j > Int_0$

***Int_0** is the variable initially defined on Line 6 and redefined in loop if condition is satisifec*

***Int`** is the Demand to Capacity ratio of the termination*

Line 18: *Creats a vector of values of interest applicable for a specified node*

$$Int \leftarrow stack\left(Int'_j, M'_j, nf_{ind_{nfiC_{o_{0,1}}}-1+i,\,0}, EL_{ind_{nd_j},\,1}, ind_{nd_j}, M_{rx}, M_{ry}, M_{rz}\right)$$

***stack** is a command that adds values in the parentheses into a vector form*

***$Int`_j$** is the demand to capacity ratio calculated in Line 16*

$nf_{ind_{nfiC_{o_{0,1}}}-1+i,\,0}$ *is the time for which the associated values occur*

$EL_{ind_{nd_j},\,1}$ *is the node that is was specified. This form of acquiring the node is used to assist in checking the program*

***ind_{nd}** is the indicy for which node occurs*

***M_{rx}**, **M_{ry}**, and **M_{rz}** moments calculated in Lines 12 - 14 assisting in program checking*

Line 19: *Variable used in testing program*

$Result \leftarrow M'$

Line 20: *Prepares the output vector **Int** as the function output*

Int ***Int** is a vector of values specified in Line 18*

TERMINATION OUTPUT: (DC, SRSS Moment, Time, Node, Indicy Associated With Node, Mx, My, Mz)

Appendix A.5.3

Pipe Runs

PIPE RUNS

Pipe Runs Strategy: *Search based on the elements present in each run of pipe. Find the maximum moment combination among all of the nodes and apply to equation (9) of ASME III, Division I - NB - 3652. Use the goemetry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation.*

PIPE RUNS OUTPUT: (DC, SRSS Moment, Time, Element, Node, Indicy Associated With Element/ Node Combination, Mx, My, Mz)

Demand to Capacity Calculation:

$$\text{PipeRunDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S} \qquad [18]$$

Function Definition: *This function's name is **PipeRunC** and inputs are **(P, D_o, t, I, B_1, B_2, S_m, nf, nd, C_o)***

$\text{PipeRunDC}(P, D_o, t, I, B_1, B_2, M, S)$

P *is the pressure applied to the piping system at the termination node of interest*

D_o *is the outside diameter of the pipe at the termination node*

t *is the thickness of the pipe at the termination node*

I *is the moment of inertia of the pipe at the termination node*

B_1 *is the stress indicy associated with the pressure term in equation 9 of NB3600*

B_2 *is the stress indicy associated with the moment term in equation 9 of NB3600*

M *is the SSRS moment at the termination node*

S *is the allowable design stress intensity factor associated with the pipe at the termination node (min of 2*Sy and 3*Sm)*

Equation Definition: *The equation is the ratio of the experienced stess associated with pressure* ($B_1 \cdot \frac{P \cdot D_o}{2 \cdot t}$) *and applied moment* ($B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]$) *versus the of the pipe capacity* (S).

$$\frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

Data Extraction from Abaqus Results for Pipe Runs:

$PipeRun(P, D_o, t, I, B_1, B_2, S, nf, el, C_o, EL) :=$

$$\begin{aligned}
& ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
& ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
& ind_{el} \leftarrow match\left(el_0, EL^{\langle 0 \rangle}\right) \\
& \text{for } i \in 1..last(el) \quad \text{if } rows(el) > 1 \\
& \quad ind_{el} \leftarrow stack\left[ind_{el}, \left(match\left(el_i, EL^{\langle 0 \rangle}\right)\right)\right] \\
& \left(M \ \ Int_{5, last(ind_{el})}\right) \leftarrow (0 \ \ 0) \\
& \text{for } i \in 0..ind_{nfo_0} - ind_{nfi_0} \\
& \quad \text{for } j \in 0..last(ind_{el}) \\
& \qquad M_{rxg} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{el_j}} \\
& \qquad M_{ryg} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{el_j}} \\
& \qquad M_{rzg} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{el_j}} \\
& \qquad M_{rx_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{el_j}} - M_{rxg}\right) C_{o_{3,0}} + M_{rxg} \\
& \qquad M_{ry_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{el_j}} - M_{ryg}\right) C_{o_{3,0}} + M_{ryg} \\
& \qquad M_{rz_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{el_j}} - M_{rzg}\right) C_{o_{3,0}} + M_{rzg} \\
& \qquad M'_j \leftarrow \sqrt{\left(M_{rx_j}\right)^2 + \left(M_{ry_j}\right)^2 + \left(M_{rz_j}\right)^2} \\
& \qquad Int'_j \leftarrow PipeRunDC\left(P, D_o, t, I, B_1, B_2, M'_j, S\right) \\
& \qquad \text{if } Int'_j > Int_{0,j} \\
& \qquad \quad H \leftarrow \left(Int'_j \ \ M'_j \ \ nf_{ind_{nfiC_{o_{0,1}}}-1+i,\, 0} \ \ EL_{ind_{el_j},\, 0} \ \ EL_{ind_{el_j},\, 1} \ \ ind_{el_j} \ \ M_{rx_j} \ \ M_{ry_j} \ \ M_{rz_j}\right)^T \\
& \qquad \quad \text{for } k \in 0..5 \\
& \qquad \qquad Int_{k,j} \leftarrow H_k \\
& Int
\end{aligned}$$

Function Definition: *This function's name is* ***PipeRun*** *and inputs are* ***(P, D_o, t, I, B_1, B_2, S_m, nf, el, C_o)***

$$\text{Term}\left(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL\right)$$

P *is the pressure applied to the piping system at the termination node of interest*

D_o *is the outside diameter of the pipe at the termination node*

t *is the thickness of the pipe at the termination node*

I *is the moment of inertia of the pipe at the termination node*

B_1 *is the stress indicy associated with the pressure term in equation 9 of NB3600*

B_2 *is the stress indicy associated with the moment term in equation 9 of NB3600*

S *is the allowable design stress intensity factor associated with the pipe at the termination node (min of 2*Sy and 3*Sm)*

nf *is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of* ***nf*** *represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

nd *is a vector of defined nodes associated with the support in the finite element model.*

EL *is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of* ***nf.***

C_o *is a matrix (shown below) defining the* ***Direction*** *termination moments in the global coordinate system (1-x, 2-y, 3-z), defines the seismic scale factor* ***(F_a)****, and represents* ***(M_{cx}, M_{cy}, and M_{cz})*** *as place holders in the matrix and aren't referenced for any calculations.*

$$C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

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Performer: A. L. Crawford	**Date:** 09/30/2008	**Checker:** M. J. Russell	**Date:** 09/30/2008

Equation Definition: *The equation gathers moment infromation from the available data and outputs max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, indicie of element(s), and moments about the x, y, and z axes.*

Line 1: *Identifies (matches) the row indicies in the time column of **nf** that match that of the specified initial time of the dynamic step and places them in a vector* $(\mathbf{ind_{nfi}})$.

$$ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0\rangle}\right)$$

$t_{initial}$ *is the intial start point when the seimic input was applied to the model*

$nf^{<0>}$ *is the time column of the Abaqus output data*

Line 2: *Identifies (matches) the row indicies in the time column of **nf** that match that of the specified final time of the dynamic step and places them in a vector* $(\mathbf{ind_{nfo}})$.

$$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0\rangle}\right)$$

t_{final} *is the final time when the seimic input was stopped*

$nf^{<0>}$ *is the time column of the Abaqus output data*

Line 3: *Matches the indicy where the first specified element in the **el** vector occurs in the first column of **EL** and defines it as the variable* $\mathbf{ind_{el}}$.

$$ind_{el} \leftarrow match\left(el_0, EL^{\langle 0\rangle}\right)$$

el_0 *is the first element specified in the **el** vector*

EL *is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of **nf**.*

Line 4 - 5: *If the length of the **el** vector is greater than 1 then the logic statement here identifies (matches) and appends the indicies of the remaining node one on top and converts the variable* $\mathbf{ind_{el}}$ *into a vector. This logic statement is to add versitility to the function but is not typically used.*

$$\text{for } i \in 1..last(el) \qquad \text{if } rows(el) > 1$$
$$ind_{el} \leftarrow stack\left[ind_{el}, \left(match\left(el_i, EL^{\langle 0\rangle}\right)\right)\right]$$

***for** is a looping function that iterates through the specified range of variables*

***last(el)** indicates the indicy of the last row of the **el** vector*

***if** only allows loop to calculate if the number of rows in **el** is greater than 1*

el_i *is the* i^{th} *node specified in the **el** vector*

***EL** is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of **nf**.*

***stack** is a command that adds the newly matched indicy onto the current variable/vector of* ind_{el} *to redefine* ind_{el}

Line 6: *Initiates the vector **M** and matrix* $Int_{5,\,last(ind_{el})}$ *to null values (this is used later in the logic when comparing the force gathered from the Abaqus results at the designated support node to a baseline value). The subscripts of* $Int_{5,\,last(ind_{el})}$ *correlates to the number of outputs assigned to Int and the number of elements specified in input for which the output will include.*

$$\begin{pmatrix} M & Int_{5,\,last(ind_{el})} \end{pmatrix} \leftarrow (0 \;\; 0)$$

Line 7: *Ranges variable **i** from 0 over the length of the time column specified by the difference between the final time (*ind_{nfo0}*) and initial time (*ind_{nfi0}*) indicies of the x-0 direction force. The length of final and initial time indicy difference is consistent for all forces and moment. Associated lines for which this loop applies includes 7 through 17.*

$$\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$$

***for** is a looping function that iterates through the specified range of variables*

ind_{nfo0} *is the final time indicy for the x-0 direction force (See Line 2)*

ind_{nfi0} *is the initial time indicy for the x-0 direction force (See Line 1)*

Line 8: *Ranges variable **j** from 0 over the length of the indicies of the elements matching those specified.*

Associated lined for which this loop applies includes 8 through 10.

$$\text{for } j \in 0..\,\text{last}(ind_{el})$$

for *is a looping function that iterates through the specified range of variables*

last(ind$_{el}$) *indicates the indicy of the last row of the* ***ind$_{el}$*** *vector (See Line 3)*

Lines 9-11: *Specifies the gravitational moments* ***(M_{rxg}, M_{ryg},*** *and* ***M_{rzg})*** *on the support by locating the initial moment in the Abaqus results* ***(nf)*** *at the row corresponding to the initial dynamic time step* ***(ind_{nfi})*** *about all three axes (x, y, and z)* ***($Co_{0,1}$+2, $Co_{1,1}$+2,*** *and* ***$Co_{2,1}$+2,)*** *and the associated column of the specified node at the* ***j^{th}*** *indicy of the specified node indicy vector* ***(ind_{el})*** *(Note: +2 is included in the* ***($Co_{2,1}$+2)*** *expression to modify the output such that the specified moment axes direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

$$M_{rxg} \leftarrow nf_{ind_{nfiC_{o_{0,1}}+2},\, ind_{el_j}}$$
$$M_{ryg} \leftarrow nf_{ind_{nfiC_{o_{1,1}}+2},\, ind_{el_j}}$$
$$M_{rzg} \leftarrow nf_{ind_{nfiC_{o_{2,1}}+2},\, ind_{el_j}}$$

nf *is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of* ***nf*** *represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

ind_{nfi} *is the initial time indicy for the force whose direction is specified by* ***($Co_{0,1}$+2, $Co_{1,1}$+2,*** *and* ***$Co_{2,1}$+2)*** *(See next definition for* ***($Co_{0,1}$+2, $Co_{1,1}$+2,*** *and* ***$Co_{2,1}$+2)*** *)*

($Co_{0,1}$+2, $Co_{1,1}$+2, *and* ***$Co_{2,1}$+2)*** *indicates the direction for which the support acts (Note: +2 is included in the expressions to modify the output such that the specified moment axes direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

ind_{el} *is the vector of indicies corresponding to the locations of the specified elements in* ***el****.*

j *is the indicy in the vector* ***ind_{el}*** *for which this line applies*

Line 12-14: *Specifies the moments (**M_{rx}, M_{ry},** and **M_{rz}**) on the support by first locating the total moment for each direction in the Abaqus results (**nf**) at the row corresponding to the dynamic time step (**ind_{nfi}**) for all three axes (x, y, and z) (**$Co_{0,1}$+2, $Co_{1,1}$+2,** and **$Co_{2,1}$+2,**) at the i^{th} indicy of the time column of the direction for which the support acts, and the associated column of the specified node at the j^{th} indicy of the specified node indicy vector (**ind_{el}**). The gravitational forces (**M_{rxg}, M_{ryg},** and **M_{rzg}**) specified immediately proprior on Lines 9-11 and included in the same for loop as that specified in Line 8 is subtracted from the total force and the difference is multiplied by the seismic factor (**F_a**) identified in the Co matrix on the fourth row first column (**$Co_{3,0}$**). The gravitational moments (**M_{rxg}, M_{ryg},** and **M_{rzg}**) are then added back into the adjusted dynamic force. (Note: +2 is included in the (**$Co_{0,1}$+2, $Co_{1,1}$+2,** and **$Co_{2,1}$+2,**) expression to modify the output such that the specified direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

$$M_{rx} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}+2}+i,\, ind_{el_j}} - M_{rxg}\right) C_{o_{3,0}} + M_{rxg}$$
$$M_{ry} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}+2}+i,\, ind_{el_j}} - M_{ryg}\right) C_{o_{3,0}} + M_{ryg}$$
$$M_{rz} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}+2}+i,\, ind_{el_j}} - M_{rzg}\right) C_{o_{3,0}} + M_{rzg}$$

nf *is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of **nf** represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

ind_{nfi} *is the initial time indicy for the force whose direction is specified by (**$Co_{0,1}$+2, $Co_{1,1}$+2,** and **$Co_{2,1}$+2**) (See next definition for (**$Co_{0,1}$+2, $Co_{1,1}$+2,** and **$Co_{2,1}$+2**))*

*(**$Co_{0,1}$+2, $Co_{1,1}$+2,** and **$Co_{2,1}$+2**) indicates the direction for which the support acts (Note: +2 is included in the expressions to modify the output such that the specified moment axes direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

ind_{el} *is the vector of indicies corresponding to the locations of the specified elements in **el**.*

*(**$Co_{3,0}$**) is the seismic factor (**F_a**) identified in the Co matrix on the fourth row first column.*

*(**M_{rxg}, M_{ryg},** and **M_{rzg}**) are the gravitational moments defined in Lines 9 - 11.*

j *is the indicy in the vector **ind_{el}** for which this line applies*

Line 15: *Specifies the total moment (SRSS Combination) associated with the j^{th} indicy*

$$M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$$

***M_{rx}, M_{ry}, and M_{rz}** moments calculated in Lines 12 - 14*

Line 16: *Calls the function **TermDC** that calculates the Demand to Capacity ratio of the termination given the loading applicable to the conditions of Line 15.*

$$Int'_j \leftarrow PipeRunDC(P, D_o, t, I, B_1, B_2, M'_j, S)$$

***P** is the pressure applied to the piping system at the termination node of interest*

***D_o** is the outside diameter of the pipe at the termination node*

***t** is the thickness of the pipe at the termination node*

***I** is the moment of inertia of the pipe at the termination node*

***B_1** is the stress indicy associated with the pressure term in equation 9 of NB3600*

***B_2** is the stress indicy associated with the moment term in equation 9 of NB3600*

***M** is the SSRS moment at the termination node*

***S** is the allowable design stress intensity factor associated with the pipe at the termination node (min of 2*Sy and 3*Sm)*

Line 17: *If statement that applies if the **Int`** defined on Line 16 is greater than the formerly greatest Demand to Capacity ratio by the node of interest. (Note: As specified on Line 6 Int_0 is initially 0)*

$$\text{if } Int'_j > Int_{0,j}$$

***$Int_{0,j}$** is the variable initially defined on Line 6 and redefined in loop if condition is satisifed*

***Int`** is the Demand to Capacity ratio of the termination*

Line 18: *Creats a vector of values of interest applicable for a specified node*

$$H \leftarrow \left(Int'_j \quad M'_j \quad nf_{ind_{nfiC_{o_{0,1}}-1}+i,0} \quad EL_{ind_{el_j},0} \quad EL_{ind_{el_j},1} \quad ind_{el_j} \quad M_{rx_j} \quad M_{ry_j} \quad M_{rz_j} \right)^T$$

***$Int`_j$** is the demand to capacity ratio calculated in Line 16*

M`$_j$ *is the total moment experienced at the element corresponding to the indicies in* ind_{el} *at j*

$nf_{ind_{nfiC_{o_{0,1}}-1}+i,\,0}$ *is the time for which the associated values occur*

$EL_{ind_{nd_j},\,1}$ *is the node that is was specified. This form of acquiring the node is used to assist in checking the program*

ind$_{el}$ *is the indicy for which element(s) occur(s)*

***M$_{rx}$**, **M$_{ry}$**, and **M$_{rz}$** moments calculated in Lines 12 - 14 assisting in program checking*

Line 19-20: *For loop appending the first 6 rows of **H** into the first 6 rows of vector **Int** at the column corresponding to the **j**th indicy*

```
for k ∈ 0..5
  Int_k,j ← H_k
```

Line 21: *Prepares the output vector **Int** as the function output*

```
Int
```

***Int** is a vector of values specified in Line 20*

PIPE RUNS OUTPUT: (DC, SRSS Moment, Time, Element, Node, Indicy Associated With Element/ Node Combination, Mx, My, Mz)

Appendix A.5.4

Reducers

REDUCERS

Reducers Strategy: *Search based on the nodes compising either end of the reducers. SRSS combine the three moments of each of the four node representations (one for each element connected by the node in question). Find the maximum of the moment combinations for each element and apply to equation (9) of ASME III, Division I - NB - 3652. It is important to not combine the data from both nodes as the goemetry for each is different and (9) must be applied for each node. The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.* [18]

REDUCERS OUTPUT: (DC, SRSS Moment, Time, Node, Indicy Associated With Node, Mx, My, Mz)

Demand to Capacity Calculation:

$$\text{ReducerDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

Function Definition: *This function's name is* ***ReducerDC*** *with inputs* ***(P, D_o, t, I, B_1, B_2, S_m, nf, nd, C_o)***

$$\text{ReducerDC}(P, D_o, t, I, B_1, B_2, M, S)$$

P *is the pressure applied to the piping system at the termination node of interest*

D_o *is the outside diameter of the pipe at the termination node*

t *is the thickness of the pipe at the termination node*

I *is the moment of inertia of the pipe at the termination node*

B_1 *is the stress indicy associated with the pressure term in equation 9 of NB3600*

B_2 *is the stress indicy associated with the moment term in equation 9 of NB3600*

M *is the SSRS moment at the termination node*

S *is the allowable design stress intensity factor associated with the pipe at the termination node (min of 2*Sy and 3*Sm)*

Equation Definition: *The equation is the ratio of the experienced stess associated with pressure ($B_1 \cdot \frac{P \cdot D_o}{2 \cdot t}$) and applied moment ($B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]$) versus the of the pipe capacity (S).*

$$\frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

Data Extraction from Abaqus Results for Reducers:

$\text{Reducer}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \text{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

$\text{for } i \in 1..\text{last}(nd) \quad \text{if rows}(nd) > 1$

$\quad ind_{nd} \leftarrow \text{stack}\left[ind_{nd}, \left(\text{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$(M \;\; Int_0) \leftarrow (0 \;\; 0)$

$\text{for } i \in 0..ind_{nfo_0} - ind_{nfi_0}$

$\quad \text{for } j \in 0..\text{last}(ind_{nd})$

$\qquad M_{rxg} \leftarrow nf_{ind_{nfiC_{o_{0,1}}+2},\, ind_{nd_j}}$

$\qquad M_{ryg} \leftarrow nf_{ind_{nfiC_{o_{1,1}}+2},\, ind_{nd_j}}$

$\qquad M_{rzg} \leftarrow nf_{ind_{nfiC_{o_{2,1}}+2},\, ind_{nd_j}}$

$\qquad M_{rx} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}+2}+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

$\qquad M_{ry} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}+2}+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

$\qquad M_{rz} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}+2}+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

$\qquad M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

$\qquad Int'_j \leftarrow \text{ReducerDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$

$\qquad \text{if } Int'_j > Int_0$

$\qquad\quad Int \leftarrow \text{stack}\left(Int'_j, M'_j, nf_{ind_{nfiC_{o_{0,1}}-1}+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M_{rz}\right)$

$\qquad\quad Result \leftarrow M'$

Int

Function Definition: *This function's name is **Reducer** with inputs **(P, D_o, t, I, B_1, B_2, S_m, nf, nd, C_o)***

$$\text{Reducer}\left(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL\right)$$

***P** is the pressure applied to the piping system at the termination node of interest*

***D_o** is the outside diameter of the pipe at the termination node*

***t** is the thickness of the pipe at the termination node*

***I** is the moment of inertia of the pipe at the termination node*

***B_1** is the stress indicy associated with the pressure term in equation 9 of NB3600*

***B_2** is the stress indicy associated with the moment term in equation 9 of NB3600*

***S** is the allowable design stress intensity factor associated with the pipe at the termination node (min of 2*Sy and 3*Sm)*

***nf** is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of **nf** represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

***nd** is a vector of defined nodes associated with the support in the finite element model. Typically only one node is included in vector.*

***EL** is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of **nf**.*

***C_o** is a matrix (shown below) defining the **Direction** termination moments in the global coordinate system (1-x, 2-y, 3-z), defines the seismic scale factor **(F_a)**, and represents **(M_{cx}, M_{cy}, and M_{cz})** as place holders in the matrix and aren't referenced for any calculations.*

$$C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Equation Definition: *The equation gathers moment infromation from the available data and outputs max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, indicie of element(s), and moments about the x, y, and z axes.*

Line 1: *Identifies (matches) the row indicies in the time column of **nf** that match that of the specified initial time of the dynamic step and places them in a vector* $(\mathbf{ind_{nfi}})$.

$$ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right)$$

$t_{initial}$ *is the intial start point when the seimic input was applied to the model*

$nf^{<0>}$ *is the time column of the Abaqus output data*

Line 2: *Identifies (matches) the row indicies in the time column of **nf** that match that of the specified final time of the dynamic step and places them in a vector* $(\mathbf{ind_{nfo}})$.

$$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right)$$

t_{final} *is the final time when the seimic input was stopped*

$nf^{<0>}$ *is the time column of the Abaqus output data*

Line 3: *Matches the indicy where the first specified node in the **nd** vector occurs in the second column of **EL** and defines it as the variable* $\mathbf{ind_{nd}}$.

$$ind_{nd} \leftarrow match\left(nd_0, EL^{\langle 1 \rangle}\right)$$

nd_0 *is the first node specified in the **nd** vector*

EL *is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of **nf**.*

Line 4 - 5: *If the length of the **nd** vector is greater than 1 then the logic statement here identifies (matches) and appends the indicies of the remaining node one on top and converts the variable* $\mathbf{ind_{nd}}$ *into a vector. This logic statement is to add versitility to the function but is not typically used.*

$$\begin{array}{ll} \text{for } i \in 1..\text{last}(nd) & \text{if } rows(nd) > 1 \\ \quad ind_{nd} \leftarrow stack\left[ind_{nd}, \left(match\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] & \end{array}$$

***for** is a looping function that iterates through the specified range of variables*

***last(nd)** indicates the indicy of the last row of the **nd** vector*

***if** only allows loop to calculate if the number of rows in **nd** is greater than 1*

*nd_i is the i^{th} node specified in the **nd** vector*

***EL** is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of **nf**.*

***stack** is a command that adds the newly matched indicy onto the current variable/vector of ind_{nd} to redefine ind_{nd}*

***Line 6:** Initiates the two row vectors **M** and Int_0 to null values (this is used later in the logic when comparing the force gathered from the Abaqus results at the designated support node to a baseline value)*

$$\begin{pmatrix} M & Int_0 \end{pmatrix} \leftarrow \begin{pmatrix} 0 & 0 \end{pmatrix}$$

***Line 7:** Ranges variable **i** from 0 over the length of the time column specified by the difference between the final time (ind_{nfo0}) and initial time (ind_{nfi0}) indicies of the x-0 direction force. The length of final and initial time indicy difference is consistent for all forces and moment. Associated lines for which this loop applies includes 7 through 17.*

$$\text{for } i \in 0..\, ind_{nfo_0} - ind_{nfi_0}$$

***for** is a looping function that iterates through the specified range of variables*

ind_{nfo0} is the final time indicy for the x-0 direction force (See Line 2)

ind_{nfi0} is the initial time indicy for the x-0 direction force (See Line 1)

***Line 8:** Ranges variable **j** from 0 over the length of the indicies of the nodes matching those specified. Associated lined for which this loop applies includes 8 through 10.*

$$\text{for } j \in 0..\, \text{last}(ind_{nd})$$

***for** is a looping function that iterates through the specified range of variables*

***last(ind_{nd})** indicates the indicy of the last row of the ind_{nd} vector (See Line 3)*

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Lines 9-11: *Specifies the gravitational moments* ***(M_{rxg}, M_{ryg}, and M_{rzg})*** *on the support by locating the initial moment in the Abaqus results* ***(nf)*** *at the row corresponding to the initial dynamic time step* ***(ind_{nfi})*** *about all three axes (x, y, and z)* ***($Co_{0,1}$+2, $Co_{1,1}$+2, and $Co_{2,1}$+2)*** *and the associated column of the specified node at the j^{th} indicy of the specified node indicy vector* ***(ind_{nd})*** *(Note: +2 is included in the* ***($Co_{2,1}$+2)*** *expression to modify the output such that the specified moment axes direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

$$M_{rxg} \leftarrow nf_{ind_{nfiC_{o_{0,1}}+2},\, ind_{nd_j}}$$
$$M_{ryg} \leftarrow nf_{ind_{nfiC_{o_{1,1}}+2},\, ind_{nd_j}}$$
$$M_{rzg} \leftarrow nf_{ind_{nfiC_{o_{2,1}}+2},\, ind_{nd_j}}$$

nf *is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of* ***nf*** *represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

ind_{nfi} *is the initial time indicy for the force whose direction is specified by* ***($Co_{0,1}$+2, $Co_{1,1}$+2,*** *and* ***$Co_{2,1}$+2)*** *(See next definition for* ***($Co_{0,1}$+2, $Co_{1,1}$+2,*** *and* ***$Co_{2,1}$+2)*** *)*

($Co_{0,1}$+2, $Co_{1,1}$+2, *and* ***$Co_{2,1}$+2)*** *indicates the direction for which the support acts (Note: +2 is included in the expressions to modify the output such that the specified moment axes direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

ind_{nd} *is the vector of indicies corresponding to the locations of the specified nodes in* ***nd****.*

j *is the indicy in the vector* ***ind_{nd}*** *for which this line applies*

Line 12-14: *Specifies the moments* ***(M_{rx}, M_{ry}, and M_{rz})*** *on the support by first locating the total moment for each direction in the Abaqus results* ***(nf)*** *at the row corresponding to the dynamic time step* ***(ind_{nfi})*** *for all three axes (x, y, and z)* ***($Co_{0,1}$+2, $Co_{1,1}$+2, and $Co_{2,1}$+2,)*** *at the i^{th} indicy of the time column of the direction for which the support acts, and the associated column of the specified node at the j^{th} indicy of the specified node indicy vector* ***(ind_{nd})****. The gravitational forces* ***(M_{rxg}, M_{ryg}, and M_{rzg})*** *specified immediately proprior on Lines 9-11 and included in the same for loop as that specified in Line 8 is subtracted from the total force and the difference is multiplied by the seismic factor* ***(F_a)*** *identified in the Co matrix on the fourth row first column* ***($Co_{3,0}$)****. The gravitational moments* ***(M_{rxg}, M_{ryg}, and M_{rzg})*** *are then added back into the adjusted dynamic force. (Note: +2 is included in the* ***($Co_{0,1}$+2, $Co_{1,1}$+2,*** *and* ***$Co_{2,1}$+2,)*** *expression to modify the output such that the specified direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

$$M_{rx} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}+2}+i,\ ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$$
$$M_{ry} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}+2}+i,\ ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$$
$$M_{rz} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}+2}+i,\ ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$$

***nf** is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of **nf** represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

***ind_{nfi}** is the initial time indicy for the force whose direction is specified by **($Co_{0,1}$+2, $Co_{1,1}$+2,** and **$Co_{2,1}$+2)** (See next definition for **($Co_{0,1}$+2, $Co_{1,1}$+2,** and **$Co_{2,1}$+2)**)*

***($Co_{0,1}$+2, $Co_{1,1}$+2,** and **$Co_{2,1}$+2)** indicates the direction for which the support acts (Note: +2 is included in the expressions to modify the output such that the specified moment axes direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

***ind_{nd}** is the vector of indicies corresponding to the locations of the specified nodes in **nd**.*

***($Co_{3,0}$)** is the seismic factor **(F_a)** identified in the Co matrix on the fourth row first column.*

***(M_{rxg}, M_{ryg},** and **M_{rzg})** are the gravitational moments defined in Lines 9 - 11.*

***j** is the indicy in the vector **ind_{nd}** for which this line applies*

***Line 15:** Specifies the total moment (SRSS Combination) associated with the **j**th indicy*

$$M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$$

***M_{rx}, M_{ry},** and **M_{rz}** moments calculated in Lines 12 - 14*

***Line 16:** Calls the function **TermDC** that calculates the Demand to Capacity ratio of the termination given the loading applicable to the conditions of Line 15.*

$$Int'_j \leftarrow TermDC\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$$

***P** is the pressure applied to the piping system at the termination node of interest*

***D_o** is the outside diameter of the pipe at the termination node*

***t** is the thickness of the pipe at the termination node*

I *is the moment of inertia of the pipe at the termination node*

B_1 *is the stress indicy associated with the pressure term in equation 9 of NB3600*

B_2 *is the stress indicy associated with the moment term in equation 9 of NB3600*

M *is the SSRS moment at the termination node*

S *is the allowable design stress intensity factor associated with the pipe at the termination node (min of 2*Sy and 3*Sm)*

Line 17: *If statement that applies if the **Int`** defined on Line 16 is greater than the formerly greatest Demand to Capacity ratio by the node of interest. (Note: As specified on Line 6* Int_0 *is initially 0)*

$\text{if } Int'_j > Int_0$

Int_0 *is the variable initially defined on Line 6 and redefined in loop if condition is satisifed*

Int` *is the Demand to Capacity ratio of the termination*

Line 18: *Creats a vector of values of interest applicable for a specified node*

$$Int \leftarrow \text{stack}\left(Int'_j, M'_j, nf_{ind_{nfiC_{o_{0,1}}}-1+i,0}, EL_{ind_{nd_j},1}, ind_{nd_j}, M_{rx}, M_{ry}, M_{rz}\right)$$

stack *is a command that adds values in the parentheses into a vector form*

$Int`_j$ *is the demand to capacity ratio calculated in Line 16*

$nf_{ind_{nfiC_{o_{0,1}}}-1+i,0}$ *is the time for which the associated values occur*

$EL_{ind_{nd_j},1}$ *is the node that is was specified. This form of acquiring the node is used to assist in checking the program*

ind_{nd} *is the indicy for which node occurs*

M_{rx}, M_{ry}, *and* M_{rz} *moments calculated in Lines 12 - 14 assisting in program checking*

Line 19: *Variable used in testing program*

$Result \leftarrow M'$

Line 20: *Prepares the output vector **Int** as the function output*

Int ***Int*** *is a vector of values specified in Line 18*

REDUCERS OUTPUT: (DC, SRSS Moment, Time, Node, Indicy Associated With Node, Mx, My, Mz)

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Appendix A.5.5

Elbows

ELBOWS

Elbows Strategy: *Search based on the two nodes comprising the ends of each elbow. SRSS combine the three moments of each of the four node representations (one for each element connected by the nodes in question). Find the maximum of the four moment combinations and apply to equation (9) of ASME III, Division I - NB - 3652. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

ELBOWS OUTPUT: (DC, SRSS Moment , Time, Node, Indicy Associated With Node, Mx, My, Mz)

Demand to Capacity Calculation:

$$\mathrm{ElbowDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S} \qquad [18]$$

Function Definition: *This function's name is* ***ElbowDC*** *with inputs* ***(P, D_o, t, I, B_1, B_2, S_m, nf, nd, C_o)***

$$\mathrm{ElbowDC}(P, D_o, t, I, B_1, B_2, M, S)$$

P *is the pressure applied to the piping system at the termination node of interest*

D_o *is the outside diameter of the pipe at the termination node*

t *is the thickness of the pipe at the termination node*

I *is the moment of inertia of the pipe at the termination node*

B_1 *is the stress indicy associated with the pressure term in equation 9 of NB3600*

B_2 *is the stress indicy associated with the moment term in equation 9 of NB3600*

M *is the SSRS moment at the termination node*

S *is the allowable design stress intensity factor associated with the pipe at the termination node (min of 2*Sy and 3*Sm)*

Equation Definition: *The equation is the ratio of the experienced stess associated with pressure ($B_1 \cdot \frac{P \cdot D_o}{2 \cdot t}$) and applied moment ($B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]$) versus the of the pipe capacity (S).*

$$\frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

Data Extraction from Abaqus Results for Elbows:

$Elbow(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow match\left(nd_0, EL^{\langle 1 \rangle}\right)$

$\text{for } i \in 1..last(nd) \quad \text{if } rows(nd) > 1$

$\quad ind_{nd} \leftarrow stack\left[ind_{nd}, \left(match\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$(M \;\; Int_0) \leftarrow (0 \;\; 0)$

$\text{for } i \in 0..ind_{nfo_0} - ind_{nfi_0}$

$\quad \text{for } j \in 0..last(ind_{nd})$

$\quad\quad M_{rxg} \leftarrow nf_{ind_{nfiC_{o_{0,1}}+2}, ind_{nd_j}}$

$\quad\quad M_{ryg} \leftarrow nf_{ind_{nfiC_{o_{1,1}}+2}, ind_{nd_j}}$

$\quad\quad M_{rzg} \leftarrow nf_{ind_{nfiC_{o_{2,1}}+2}, ind_{nd_j}}$

$\quad\quad M_{rx} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}+2}+i, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

$\quad\quad M_{ry} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}+2}+i, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

$\quad\quad M_{rz} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}+2}+i, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

$\quad\quad M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

$\quad\quad Int'_j \leftarrow ElbowDC\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$

$\quad\quad \text{if } Int'_j > Int_0$

$\quad\quad\quad Int \leftarrow stack\left(Int'_j, M'_j, nf_{ind_{nfiC_{o_{0,1}}-1}+i, 0}, EL_{ind_{nd_j}, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M_{rz}\right)$

$\quad\quad\quad Result \leftarrow M'$

Int

Function Definition: *This function's name is* ***Elbow*** *with inputs* ***(P, D_o, t, I, B_1, B_2, S_m, nf, nd, C_o)***

$$\boxed{\text{Elbow}\left(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL\right)}$$

P *is the pressure applied to the piping system at the termination node of interest*

D_o *is the outside diameter of the pipe at the termination node*

t *is the thickness of the pipe at the termination node*

I *is the moment of inertia of the pipe at the termination node*

B_1 *is the stress indicy associated with the pressure term in equation 9 of NB3600*

B_2 *is the stress indicy associated with the moment term in equation 9 of NB3600*

S *is the allowable design stress intensity factor associated with the pipe at the termination node (min of 2*Sy and 3*Sm)*

nf *is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of* ***nf*** *represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

nd *is a vector of defined nodes associated with the support in the finite element model. Typically only one node is included in vector.*

EL *is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of* ***nf****.*

C_o *is a matrix (shown below) defining the* ***Direction*** *termination moments in the global coordinate system (1-x, 2-y, 3-z), defines the seismic scale factor* ***(F_a)****, and represents* ***(M_{cx}, M_{cy}, and M_{cz})*** *as place holders in the matrix and aren't referenced for any calculations.*

$$C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

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Equation Definition: *The equation gathers moment infromation from the available data and outputs max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, indicie of element(s), and moments about the x, y, and z axes.*

Line 1: *Identifies (matches) the row indicies in the time column of **nf** that match that of the specified initial time of the dynamic step and places them in a vector* (ind_{nfi}).

$$ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right)$$

$t_{initial}$ *is the intial start point when the seimic input was applied to the model*

$nf^{<0>}$ *is the time column of the Abaqus output data*

Line 2: *Identifies (matches) the row indicies in the time column of **nf** that match that of the specified final time of the dynamic step and places them in a vector* (ind_{nfo}).

$$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right)$$

t_{final} *is the final time when the seimic input was stopped*

$nf^{<0>}$ *is the time column of the Abaqus output data*

Line 3: *Matches the indicy where the first specified node in the **nd** vector occurs in the second column of **EL** and defines it as the variable* ind_{nd}.

$$ind_{nd} \leftarrow match\left(nd_0, EL^{\langle 1 \rangle}\right)$$

nd_0 *is the first node specified in the **nd** vector*

EL *is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of **nf**.*

Line 4 - 5: *If the length of the **nd** vector is greater than 1 then the logic statement here identifies (matches) and appends the indicies of the remaining node one on top and converts the variable* ind_{nd} *into a vector. This logic statement is to add versitility to the function but is not typically used.*

$$\begin{aligned} &\text{for } i \in 1..\,last(nd) \qquad\qquad \text{if } rows(nd) > 1 \\ &\quad ind_{nd} \leftarrow stack\left[ind_{nd}, \left(match\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \end{aligned}$$

for *is a looping function that iterates through the specified range of variables*

last(nd) *indicates the indicy of the last row of the* ***nd*** *vector*

if *only allows loop to calculate if the number of rows in* ***nd*** *is greater than 1*

nd_i *is the* i^{th} *node specified in the* ***nd*** *vector*

EL *is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of* ***nf.***

stack *is a command that adds the newly matched indicy onto the current variable/vector of* ind_{nd} *to redefine* ind_{nd}

Line 6: *Initiates the variable* ***M*** *and row vector* Int_0 *to null values (this is used later in the logic when comparing the force gathered from the Abaqus results at the designated support node to a baseline value)*

$$\left(M \;\; Int_0\right) \leftarrow (0 \;\; 0)$$

Line 7: *Ranges variable* ***i*** *from 0 over the length of the time column specified by the difference between the final time (*ind_{nfo0}*) and initial time (*ind_{nfi0}*) indicies of the x-0 direction force. The length of final and initial time indicy difference is consistent for all forces and moment. Associated lines for which this loop applies includes 7 through 17.*

$$\text{for } \; i \in 0..\, ind_{nfo_0} - ind_{nfi_0}$$

for *is a looping function that iterates through the specified range of variables*

ind_{nfo0} *is the final time indicy for the x-0 direction force (See Line 2)*

ind_{nfi0} *is the initial time indicy for the x-0 direction force (See Line 1)*

Line 8: *Ranges variable* ***j*** *from 0 over the length of the indicies of the nodes matching those specified. Associated lined for which this loop applies includes 8 through 10.*

$$\text{for } \; j \in 0..\, last\left(ind_{nd}\right)$$

for *is a looping function that iterates through the specified range of variables*

last(ind_{nd}***)*** *indicates the indicy of the last row of the* ind_{nd} *vector (See Line 3)*

Lines 9-11: *Specifies the gravitational moments (M_{rxg}, M_{ryg}, and M_{rzg}) on the support by locating the initial moment in the Abaqus results (**nf**) at the row corresponding to the initial dynamic time step (ind_{nfi}) about all three axes (x, y, and z) ($Co_{0,1}+2$, $Co_{1,1}+2$, and $Co_{2,1}+2$,) and the associated column of the specified node at the j^{th} indicy of the specified node indicy vector (ind_{nd}) (Note: +2 is included in the ($Co_{2,1}+2$) expression to modify the output such that the specified moment axes direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

$$M_{rxg} \leftarrow nf_{ind_{nfiC_{o_{0,1}}+2},\, ind_{nd_j}}$$
$$M_{ryg} \leftarrow nf_{ind_{nfiC_{o_{1,1}}+2},\, ind_{nd_j}}$$
$$M_{rzg} \leftarrow nf_{ind_{nfiC_{o_{2,1}}+2},\, ind_{nd_j}}$$

*__nf__ is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of **nf** represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

ind_{nfi} is the initial time indicy for the force whose direction is specified by ($Co_{0,1}+2$, $Co_{1,1}+2$, and $Co_{2,1}+2$) (See next definition for ($Co_{0,1}+2$, $Co_{1,1}+2$, and $Co_{2,1}+2$))

($Co_{0,1}+2$, $Co_{1,1}+2$, and $Co_{2,1}+2$) indicates the direction for which the support acts (Note: +2 is included in the expressions to modify the output such that the specified moment axes direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).

*ind_{nd} is the vector of indicies corresponding to the locations of th e specified nodes in **nd**.*

__j__ is the indicy in the vector ind_{nd} for which these lines apply.

Line 12-14: *Specifies the moments (M_{rx}, M_{ry}, and M_{rz}) on the support by first locating the total moment for each direction in the Abaqus results (**nf**) at the row corresponding to the dynamic time step (ind_{nfi}) for all three axes (x, y, and z) ($Co_{0,1}+2$, $Co_{1,1}+2$, and $Co_{2,1}+2$,) at the i^{th} indicy of the time column of the direction for which the support acts, and the associated column of the specified node at the j^{th} indicy of the specified node indicy vector (ind_{nd}). The gravitational forces (M_{rxg}, M_{ryg}, and M_{rzg}) specified immediately proprior on Lines 9-11 and included in the same for loop as that specified in Line 8 is subtracted from the total force and the difference is multiplied by the seismic factor (F_a) identified in the Co matrix on the fourth row first column ($Co_{3,0}$). The gravitational moments (M_{rxg}, M_{ryg}, and M_{rzg}) are then added back into the adjusted dynamic force. (Note: +2 is included in the ($Co_{0,1}+2$, $Co_{1,1}+2$, and $Co_{2,1}+2$,) expression to modify the output such that the specified direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

$$M_{rx} \leftarrow \left(nf_{ind_{nfiCo_{0,1}+2}+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot Co_{3,0} + M_{rxg}$$
$$M_{ry} \leftarrow \left(nf_{ind_{nfiCo_{1,1}+2}+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot Co_{3,0} + M_{ryg}$$
$$M_{rz} \leftarrow \left(nf_{ind_{nfiCo_{2,1}+2}+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot Co_{3,0} + M_{rzg}$$

nf *is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of* ***nf*** *represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

ind_{nfi} *is the initial time indicy for the force whose direction is specified by* **($Co_{0,1}$+2, $Co_{1,1}$+2,** *and* **$Co_{2,1}$+2)** *(See next definition for* **($Co_{0,1}$+2, $Co_{1,1}$+2,** *and* **$Co_{2,1}$+2)** *)*

($Co_{0,1}$+2, $Co_{1,1}$+2, *and* **$Co_{2,1}$+2)** *indicates the direction for which the support acts (Note: +2 is included in the expressions to modify the output such that the specified moment axes direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

ind_{nd} *is the vector of indicies corresponding to the locations of the specified nodes in* ***nd***.

($Co_{3,0}$) *is the seismic factor* **(F_a)** *identified in the Co matrix on the fourth row first column.*

(M_{rxg}, M_{ryg}, *and* **M_{rzg})** *are the gravitational moments defined in Lines 9 - 11.*

j *is the indicy in the vector* **ind_{nd}** *for which this line applies*

Line 15: *Specifies the total moment (SRSS Combination) associated with the* ***j***th *indicy*

$$M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$$

M_{rx}, M_{ry}, *and* **M_{rz}** *moments calculated in Lines 12 - 14*

Line 16: *Calls the function* ***TermDC*** *that calculates the Demand to Capacity ratio of the termination given the loading applicable to the conditions of Line 15.*

$$Int'_j \leftarrow TermDC\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$$

P *is the pressure applied to the piping system at the termination node of interest*

D_o *is the outside diameter of the pipe at the termination node*

t *is the thickness of the pipe at the termination node*

I *is the moment of inertia of the pipe at the termination node*

B_1 *is the stress indicy associated with the pressure term in equation 9 of NB3600*

B_2 *is the stress indicy associated with the moment term in equation 9 of NB3600*

M *is the SSRS moment at the termination node*

S *is the allowable design stress intensity factor associated with the pipe at the termination node (min of 2*Sy and 3*Sm)*

Line 17: *If statement that applies if the **Int`** defined on Line 16 is greater than the formerly greatest Demand to Capacity ratio by the node of interest. (Note: As specified on Line 6 Int_0 is initially 0)*

$\text{if } Int'_j > Int_0$

Int_0 *is the variable initially defined on Line 6 and redefined in loop if condition is satisifed*

Int` *is the Demand to Capacity ratio of the termination*

Line 18: *Creats a vector of values of interest applicable for a specified node*

$$Int \leftarrow \text{stack}\left(Int'_j, M'_j, nf_{ind_{nfiC_{o_{0,1}}}-1+i,\,0}, EL_{ind_{nd_j},\,1}, ind_{nd_j}, M_{rx}, M_{ry}, M_{rz}\right)$$

stack *is a command that adds values in the parentheses into a vector form*

$Int`_j$ *is the demand to capacity ratio calculated in Line 16*

$nf_{ind_{nfiC_{o_{0,1}}}-1+i,\,0}$ *is the time for which the associated values occur*

$EL_{ind_{nd_j},\,1}$ *is the node that is was specified. This form of acquiring the node is used to assist in checking the program*

ind_{nd} *is the indicy for which node occurs*

M_{rx}, M_{ry}, *and* ***M_{rz}*** *moments calculated in Lines 12 - 14 assisting in program checking*

Line 19: *Variable used in testing program*

$Result \leftarrow M'$

Line 20: *Prepares the output vector **Int** as the function output*

Int ***Int*** *is a vector of values specified in Line 18*

ELBOWS OUTPUT: (DC, SRSS Moment, Time, Node, Indicy Associated With Node, Mx, My, Mz)

Appendix A.5.6

Tees and Fabricated Branches

FORGED TEES AND FABRICATED BRANCH TEES

Tees Strategy: *Search based on the elements comprising the tee. The input identifies which elements are associated with the pipe run and which element is associated with the branch from the run. The indices for the defined common node for all three elements is identified and the associated SRSS moment is identified for each time step. The maximum moment for the elements comprising the pipe run is found and applied as M_r in equation (9) of ASME III, Division I - NB - 3652 which is modified to represent tees. The maximum moment for the branch element is found and applied as M_b in equation (9) of ASME III, Division I - NB - 3652. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

TEES OUTPUT: (DC, SRSS Moment of Pipe Run, SRSS Moment of Branch, Time, Node, Indicy Associated with Run Node, Indicy Associated with Branch Node)

Demand to Capacity Calculation:

$$\text{TeeDC}(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_b, M_r, Z_b, Z_r, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot T_r} + B_{2b} \cdot \left[\frac{M_b \cdot (1\,\text{lbf} \cdot \text{in})}{Z_b}\right] + B_{2r} \cdot \left[\frac{M_r \cdot (1\,\text{lbf} \cdot \text{in})}{Z_r}\right]}{S} \qquad [18]$$

Function Definition: *This function's name is* ***TeeDC*** *and the inputs are* ***(P, D_o, t, I, B_1, B_2, S_m, nf, nd, C_o)***

$\text{TeeDC}(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_b, M_r, Z_b, Z_r, S)$

- ***P*** *is the pressure applied to the piping system at the termination node of interest*
- ***D_o*** *is the outside diameter of the pipe at the termination node*
- ***T_r*** *is the thickness of the pipe run*
- ***B_1*** *is the stress indicy associated with the pressure term in equation 9 of NB-3600 modified in NB-3683.1*
- ***B_{2b}*** *is the stress indicy associated with the moment term for the branch in equation 9 of NB-3600 modified in NB-3683.1*
- ***B_{2r}*** *is the stress indicy associated with the moment term for the branch in equation 9 of NB-3600 modified in NB-3683.1*
- ***M_b*** *is the SSRS moment at the branche's specified node*
- ***M_r*** *is the SSRS moment at the pipe run's specified node*
- ***Z_b*** *is the approximate section modulus of attached branch pipe*
- ***Z_r*** *is the approximate section modulus of designated run pipe*
- ***S*** *is the allowable design stress intensity factor associated with the pipe at the termination node (min of 2*Sy and 3*Sm)*

Equation Definition: *The equation is the ratio of the experienced stess associated with pressure* ($B_1 \cdot \frac{P \cdot D_o}{2 \cdot T_r}$)*and applied moments on the branch* $B_{2b} \cdot \left[\frac{M_b \cdot (1\,lbf \cdot in)}{Z_b}\right]$ *& run* $B_{2r} \cdot \left[\frac{M_r \cdot (1\,lbf \cdot in)}{Z_r}\right]$ *versus the of the pipe capacity* (S).

$$\frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot T_r} + B_{2b} \cdot \left[\frac{M_b \cdot (1\,lbf \cdot in)}{Z_b}\right] + B_{2r} \cdot \left[\frac{M_r \cdot (1\,lbf \cdot in)}{Z_r}\right]}{S}$$

Data Extraction from Abaqus Results for Tees and Braches:

$$Tee\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S, nf, el_R, el_B, nd_R, nd_B, C_o, EL\right) :=$$

$$\begin{aligned}
& ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
& ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
& ind_{elR} \leftarrow match\left(el_{R_0}, EL^{\langle 0 \rangle}\right) \\
& \text{for } i \in 1..last(el_R) \quad \text{if } rows(el_R) > 1 \\
& \quad ind_{elR} \leftarrow stack\left[ind_{elR}, \left(match\left(el_{R_i}, EL^{\langle 0 \rangle}\right)\right)\right] \\
& EL'R_{last\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0 \\
& \text{for } i \in 0..last(ind_{elR}) \\
& \quad EL'R_{ind_{elR_i}} \leftarrow EL_{ind_{elR_i}, 1} \\
& ind_{ndR} \leftarrow match\left(nd_{R_0}, EL'R^{\langle 0 \rangle}\right) \\
& \text{for } i \in 1..last(nd_R) \quad \text{if } rows(nd_R) > 1 \\
& \quad ind_{ndR} \leftarrow stack\left[ind_{ndR}, \left(match\left(nd_{R_i}, EL'R^{\langle 0 \rangle}\right)\right)\right] \\
& ind_{elB} \leftarrow match\left(el_{B_0}, EL^{\langle 0 \rangle}\right) \\
& \text{for } i \in 1..last(el_B) \quad \text{if } rows(el_B) > 1 \\
& \quad ind_{elB} \leftarrow stack\left[ind_{elB}, \left(match\left(el_{B_i}, EL^{\langle 0 \rangle}\right)\right)\right] \\
& EL'B_{last\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0
\end{aligned}$$

for $i \in 0 .. last(ind_{elB})$

$EL'B_{ind_{elB_i}} \leftarrow EL_{ind_{elB_i}, 1}$

$ind_{ndB} \leftarrow match\left(nd_{B_0}, EL'B^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(nd_B)$ if $rows(nd_B) > 1$

$ind_{ndB} \leftarrow stack\left[ind_{ndB}, \left(match\left(nd_{B_i}, EL'B^{\langle 0 \rangle}\right)\right)\right]$

$\left(M_R \;\; M_B \;\; Int_0\right) \leftarrow (0 \;\; 0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

for $j \in 0 .. last(ind_{ndR})$

for $k \in 0 .. last(ind_{ndB})$

$M_{rxgR_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}+2}, ind_{ndR_j}}$

$M_{rygR_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}+2}, ind_{ndR_j}}$

$M_{rzgR_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}+2}, ind_{ndR_j}}$

$M_{rxR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}+2}+i, ind_{ndR_j}} - M_{rxgR_j}\right) \cdot C_{o_{3,0}} + M_{rxgR_j}$

$M_{ryR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}+2}+i, ind_{ndR_j}} - M_{rygR_j}\right) \cdot C_{o_{3,0}} + M_{rygR_j}$

$M_{rzR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}+2}+i, ind_{ndR_j}} - M_{rzgR_j}\right) \cdot C_{o_{3,0}} + M_{rzgR_j}$

$M_{R_j} \leftarrow \sqrt{\left(M_{rxR_j}\right)^2 + \left(M_{ryR_j}\right)^2 + \left(M_{rzR_j}\right)^2}$

$M_{rxgB_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}+2}, ind_{ndB_k}}$

$M_{rygB_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}+2}, ind_{ndB_k}}$

$M_{rzgB_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}+2}, ind_{ndB_k}}$

$M_{rxB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}+2}+i, ind_{ndB_k}} - M_{rxgB_j}\right) \cdot C_{o_{3,0}} + M_{rxgB_j}$

$M_{ryB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}+2}+i, ind_{ndB_k}} - M_{rygB_j}\right) \cdot C_{o_{3,0}} + M_{rygB_j}$

$M_{rzB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}+2}+i, ind_{ndB_k}} - M_{rzgB_j}\right) \cdot C_{o_{3,0}} + M_{rzgB_j}$

$$M_{B_j} \leftarrow \sqrt{\left(M_{rxB_j}\right)^2 + \left(M_{ryB_j}\right)^2 + \left(M_{rzB_j}\right)^2}$$

$$Int'_j \leftarrow TeeDC\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_{B_j}, M_{R_j}, Z_b, Z_r, S\right)$$

if $Int'_j > Int_0$

$$Int \leftarrow stack\left(Int'_j, M_{R_j}, M_{B_j}, nf_{ind_{nfiC_{o_{0,1}}-1}+i, 0}, EL_{ind_{ndR_j}, 1}, ind_{ndR}, ind_{ndB}\right)$$

$$Result \leftarrow stack\left(M_{R_j}, M_{B_j}, M_{rxR_j}, M_{ryR_j}, M_{rzR_j}, M_{rxB_j}, M_{ryB_j}, M_{rzB_j}\right)$$

$$M \leftarrow M_R$$

Int

Function Definition: Name is Tee with inputs ($P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_m, el_R, el_B, nd_R, nd_B, C_o$, EL)

$$Tee\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S, nf, el_R, el_B, nd_R, nd_B, C_o, EL\right)$$

***P** is the pressure applied to the piping system at the termination node of interest.*

***D_o** is the outside diameter of the pipe at the termination node.*

***T_r** is the thickness of the pipe run.*

***B_1** is the stress indicy associated with the pressure term in equation 9 of NB-3600 modified in NB-3683.1.*

***B_{2b}** is the stress indicy associated with the moment term for the branch in equation 9 of NB-3600 modified in NB-3683.1.*

***B_{2r}** is the stress indicy associated with the moment term for the branch in equation 9 of NB-3600 modified in NB-3683.1.*

***M_b** is the SSRS moment at the branche's specified node.*

***M_r** is the SSRS moment at the pipe run's specified node.*

***Z_b** is the approximate section modulus of attached branch pipe.*

***Z_r** is the approximate section modulus of designated run pipe.*

***S** is the allowable design stress intensity factor associated with the pipe at the termination node (min of 2*Sy and 3*Sm).*

***nf** is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of **nf** represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

el_R is a vector of defined elements associated with the run of pipe portion of the tee or branch.

el_B is the elements associated with the branch portion of the tee or branch.

nd_R is a vector of the defined node associated with the run of pipe for the tee or branch.

nd_B is a vector of the defined node associated with the branch for the tee or branch.

***EL** is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of **nf**.*

*C_o is a matrix (shown below) defining the **Direction** termination moments in the global coordinate system (1-x, 2-y, 3-z), defines the seismic scale factor **(F_a)**, and represents **(M_{cx}, M_{cy}, and M_{cz})** as place holders in the matrix and aren't referenced for any calculations.*

$$C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

***Equation Definition:** The equation gathers moment infromation from the available data and outputs max D/C ratio, applied pipe run moment when D/C ratio is highest, applied branch moment when D/C ratio is highest, time when max values occur, pipe run node retrieved for calculations, indicies of pipe run node, and indicies of branch node.*

***Line 1:** Identifies (matches) the row indicies in the time column of **nf** that match that of the specified initial time of the dynamic step and places them in a vector **(ind_{nfi})**.*

$$ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right)$$

$t_{initial}$ is the intial start point when the seimic input was applied to the model

$nf^{<0>}$ is the time column of the Abaqus output data

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Line 2: *Identifies (matches) the row indicies in the time column of **nf** that match that of the specified final time of the dynamic step and places them in a vector **(ind_{nfo})**.*

$$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right)$$

t_{final} is the final time when the seimic input was stopped

$nf^{<0>}$ is the time column of the Abaqus output data

Line 3: *Identifies (matches) the index location of the node specified in the el_{R0} vector in the first column of the **EL** vector and defines it as the variable ind_{elR}.*

$$ind_{elR} \leftarrow match\left(el_{R_0}, EL^{\langle 0 \rangle}\right)$$

el_{R0} is the first element specified in the el_R vector

***EL** is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of **nf**.*

Line 4 - 5: *If the length of the el_R vector is greater than 1 then the logic statement here identifies (matches) and appends the indicies of the remaining node(s) and converts the variable ind_{elR} into a vector.*

$$\text{for } i \in 1 .. last\left(el_R\right) \qquad \text{if } rows\left(el_R\right) > 1$$
$$ind_{elR} \leftarrow stack\left[ind_{elR}, \left(match\left(el_{R_i}, EL^{\langle 0 \rangle}\right)\right)\right]$$

***for** is a looping function that iterates through the specified range of variables*

***last(el_R)** indicates the indicy of the last row of the el_R vector*

***if** only allows loop to calculate if the number of rows in **nd** is greater than 1*

el_{Ri} is the i^{th} node specified in the el_R vector

***EL** is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of **nf**.*

***stack** is a command that adds the newly matched indicy onto the current variable/vector of* $\boldsymbol{ind_{elR}}$ *to redefine* $\boldsymbol{ind_{elR}}$

***Line 6:** Defines **EL`R** as a column of zeros as long as the first column of **EL** where the **last** command identifies the index corresponding to the last row of* $\boldsymbol{EL^{<0>}}$

$$EL'R_{last\left(EL^{\langle 0\rangle}\right)} \leftarrow 0$$

$\boldsymbol{last(EL^{<0>})}$ *indicates the indicy of the last row of the first column of the **EL** vector*

***EL** is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of **nf**.*

***Line 7 - 8:** Lines contain a for loop that iterates through the row indicies of the* $\boldsymbol{ind_{elR}}$ *vector. As the loop iterates through the row indicies of the* $\boldsymbol{ind_{elR}}$ *vector it locates the nodes in the second column of the **EL** matrix corresponding to the specified element indicies embeded in the* $\boldsymbol{ind_{elR}}$ *vector and assigns those values in the **EL`R** vector at the same row index location of the **EL** matrix.*

$$\begin{aligned}&\text{for } i \in 0 .. last\left(ind_{elR}\right)\\ &\quad EL'R_{ind_{elR_i}} \leftarrow EL_{ind_{elR_i},1}\end{aligned}$$

***for** is a looping function that iterates through the specified range of variables*

$\boldsymbol{last(ind_{elR})}$ *indicates the indicy of the last row of the* $\boldsymbol{ind_{elR}}$ *matrix*

$EL_{ind_{elR_i},1}$ *is the component in **EL** that corresponds to the* i^{th} *row value and second column value of the* $\boldsymbol{ind_{elR}}$ matrix

***EL** is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of **nf**.*

Line 9: *Identifies (matches) the index location of the node specified in the* $\boldsymbol{nd_{R0}}$ *vector in first column of the* ***EL`R****.*

$$ind_{ndR} \leftarrow match\left(nd_{R_0}, EL'R^{\langle 0\rangle}\right)$$

$\boldsymbol{nd_{R0}}$ *is the first element specified in the* $\boldsymbol{nd_R}$ *vector*

EL'R *is a vector of equivelent length to* ***EL*** *and has null values for every entry exept at the indicies where the specified elements defined in* ***elR****, where the corresponding node values to the defined elements is located.*

Line 10 - 11: *If the length of the* $\boldsymbol{nd_R}$ *vector is greater than 1 then the logic statement here identifies (matches) and appends the indicies of the remaining node(s) and converts the variable* $\boldsymbol{ind_{ndR}}$ *into a vector.*

$$\text{for } i \in 1..\text{last}(nd_R) \quad \text{if rows}(nd_R) > 1$$
$$ind_{ndR} \leftarrow stack\left[ind_{ndR}, \left(match\left(nd_{R_i}, EL'R^{\langle 0\rangle}\right)\right)\right]$$

for *is a looping function that iterates through the specified range of variables*

$\boldsymbol{last(nd_R)}$ *indicates the indicy of the last row of the* $\boldsymbol{nd_R}$ *vector*

if *only allows loop to calculate if the number of rows in* ***nd*** *is greater than 1*

$\boldsymbol{nd_{Ri}}$ *is the* i^{th} *node specified in the* $\boldsymbol{nd_R}$ *vector*

EL'R *is a vector of equivelent length to* ***EL*** *and has null values for every entry exept at the indicies where the specified elements defined in* ***elR****, where the corresponding node values to the defined elements is located.*

stack *is a command that adds the newly matched indicy onto the current variable/vector of* $\boldsymbol{ind_{ndR}}$ *to redefine* $\boldsymbol{ind_{ndR}}$

Line 12: *Identifies (matches) the index location of the node specified in the* $\boldsymbol{el_{B0}}$ *vector in the first column of the* ***EL*** *vector and defines it as the variable* $\boldsymbol{ind_{elB}}$*.*

$$ind_{elB} \leftarrow match\left(el_{B_0}, EL^{\langle 0\rangle}\right)$$

$\boldsymbol{el_{B0}}$ *is the first element specified in the* $\boldsymbol{el_B}$ *vector*

EL *is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of* ***nf****.*

Line 13 -14: *If the length of the* $\mathbf{el_B}$ *vector is greater than 1 then the logic statement here identifies (matches) and identifies (matches) and appends the indicies of the remaining node(s) and converts the variable* $\mathbf{ind_{elB}}$ *into a vector.*

$$\text{for } i \in 1 .. \text{last}(el_B) \qquad \text{if rows}(el_B) > 1$$
$$ind_{elB} \leftarrow \text{stack}\left[ind_{elB}, \left(\text{match}\left(el_{B_i}, EL^{\langle 0 \rangle}\right)\right)\right]$$

for *is a looping function that iterates through the specified range of variables*

last(el**_B_**) *indicates the indicy of the last row of the* $\mathbf{el_B}$ *vector*

if *only allows loop to calculate if the number of rows in* $\mathbf{el_B}$ *is greater than 1*

$\mathbf{el_{Bi}}$ *is the* i^{th} *node specified in the* $\mathbf{el_B}$ *vector*

EL *is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of* ***nf.***

stack *is a command that adds the newly matched indicy onto the current variable/vector of* $\mathbf{ind_{ndR}}$ *to redefine* $\mathbf{ind_{ndR}}$

Line 15: *Defines* ***EL`B*** *as a column of zeros as long as the first column of* ***EL*** *where the* ***last*** *command identifies the index corresponding to the last row of* $\mathbf{EL^{<0>}}$

$$EL'B_{\text{last}\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$$

last(EL**$^{<0>}$**) *indicates the indicy of the last row of the first column of the* ***EL*** *vector*

EL *is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of* ***nf.***

Lines 16 - 17: *Lines contain a for loop that iterates through the row indicies of the* $\mathbf{ind_{elB}}$ *vector. As the loop iterates through the row indicies of the* $\mathbf{ind_{elB}}$ *vector it locates the nodes in the second column of the* ***EL*** *matrix corresponding to the specified element indicies embeded in the* $\mathbf{ind_{elB}}$ *vector and assigns those values in the* ***EL`B*** *vector at the same row index location of the* ***EL*** *matrix.*

$$\begin{array}{l} \text{for } i \in 0..\text{last}(ind_{elB}) \\ \quad EL'B_{ind_{elB_i}} \leftarrow EL_{ind_{elB_i},1} \end{array}$$

for *is a looping function that iterates through the specified range of variables*

last(ind$_{elB}$) *indicates the indicy of the last row of the* ***ind$_{elB}$*** *matrix*

$EL_{ind_{elB_i},1}$ *is the component in* ***EL*** *that corresponds to the ith row value and second column value of the* ***ind$_{elB}$*** matrix

EL *is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of* ***nf****.*

Line 18: *Identifies (matches) the index location of the node specified in the* ***nd$_{B0}$*** *vector in first column of the* ***EL`B****.*

$$ind_{ndB} \leftarrow \text{match}\left(nd_{B_0}, EL'B^{\langle 0 \rangle}\right)$$

nd$_{B0}$ *is the first element specified in the* ***nd$_B$*** *vector*

EL`B *is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of* ***nf****.*

Lines 19 - 20: *If the length of the* ***nd$_B$*** *vector is greater than 1 then the logic statement here identifies (matches) and appends the indicies of the remaining node(s) and converts the variable* ***ind$_{ndB}$*** *into a vector.*

$$\begin{array}{l} \text{for } i \in 1..\text{last}(nd_B) \quad \text{if rows}(nd_B) > 1 \\ \quad ind_{ndB} \leftarrow \text{stack}\left[ind_{ndB}, \left(\text{match}\left(nd_{B_i}, EL'B^{\langle 0 \rangle}\right)\right)\right] \end{array}$$

for *is a looping function that iterates through the specified range of variables*

last(nd$_B$) *indicates the indicy of the last row of the* ***nd$_B$*** *vector*

if *only allows loop to calculate if the number of rows in* ***nd*** *is greater than 1*

nd_{Ri} *is the i* th *node specified in the* nd_R *vector*

EL'B *is a vector of equivelent length to* ***EL*** *and has null values for every entry exept at the indicies where the specified elements defined in* ***elB****, where the corresponding node values to the defined elements is located.*

stack *is a command that adds the newly matched indicy onto the current variable/vector of* ind_{ndB} *to redefine* ind_{ndB}

Line 21: *Initiates the values of* M_R *and* M_B *and vector of* ***Int*** *to null values. (this is used later in the logic when comparing the force gathered from the Abaqus results at the designated support node to a baseline value)*

$$\left(M_R \;\; M_B \;\; Int_0\right) \leftarrow (0 \;\; 0 \;\; 0)$$

Line 22: *Ranges variable* ***i*** *from 0 over the length of the time column specified by the difference between the final time (*ind_{nfo0}*) and initial time (*ind_{nfi0}*) indicies of the x-0 direction force. The length of final and initial time indicy difference is consistent for all forces and moment. Associated lines for which this loop applies includes 22 through 43.*

$$\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$$

for *is a looping function that iterates through the specified range of variables*

ind_{nfo0} *is the final time indicy for the x-0 direction force (See Line 2)*

ind_{nfi0} *is the initial time indicy for the x-0 direction force (See Line 1)*

Line 23: *Ranges variable* ***j*** *from 0 over the length of the indicies of the nodes matching those specified in* ind_{ndR}*. Associated lines for which this loop applies includes 23 through 43*

$$\text{for } j \in 0 .. \text{last}\left(ind_{ndR}\right)$$

for *is a looping function that iterates through the specified range of variables*

last(ind_{ndR}***)*** *indicates the indicy of the last row of the* ind_{ndR} *vector (See Line 3)*

Line 24: *Ranges variable* ***k*** *from 0 over the length of the indicies of the nodes matching those specified in* ind_{ndB}*. Associated lines for which this loop applies includes 24 through 43*

$$\text{for } k \in 0 .. \text{last}(ind_{ndB})$$

***for** is a looping function that iterates through the specified range of variables*

***last(ind**$_{ndB}$**)** indicates the indicy of the last row of the **ind**$_{ndB}$ vector (See Line 3)*

***Lines 25 - 27:** Specifies the gravitational moments (**M**$_{rxgR}$, **M**$_{rygR}$, and **M**$_{rzgR}$) on the support by locating the initial moment in the Abaqus results **(nf)** at the row corresponding to the initial dynamic time step (**ind**$_{nfi}$) about all three axes (x, y, and z) (**Co**$_{0,1}$**+2, Co**$_{1,1}$**+2,** and **Co**$_{2,1}$**+2,**) and the associated column of the specified node at the jth indicy of the specified node indicy vector (**ind**$_{ndR}$) (Note: +2 is included in the (**Co**$_{2,1}$**+2**) expression to modify the output such that the specified moment axes direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

$$M_{rxgR_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}+2},\ ind_{ndR_j}}$$
$$M_{rygR_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}+2},\ ind_{ndR_j}}$$
$$M_{rzgR_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}+2},\ ind_{ndR_j}}$$

***nf** is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of **nf** represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

***ind**$_{nfi}$ is the initial time indicy for the force whose direction is specified by (**Co**$_{0,1}$**+2, Co**$_{1,1}$**+2,** and **Co**$_{2,1}$**+2**) (See next definition for (**Co**$_{0,1}$**+2, Co**$_{1,1}$**+2,** and **Co**$_{2,1}$**+2**))*

*(**Co**$_{0,1}$**+2, Co**$_{1,1}$**+2,** and **Co**$_{2,1}$**+2**) indicates the direction for which the support acts (Note: +2 is included in the expressions to modify the output such that the specified moment axes direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

***ind**$_{ndR}$ is the vector of indicies corresponding to the locations of the specified nodes in the vector **ndR**.*

***j** is the indicy in the vector **ind**$_{ndR}$ for which these lines apply.*

***Line 28 - 31:** Specifies the moments (**M**$_{rx}$, **M**$_{ry}$, and **M**$_{rz}$) on the support by first locating the total moment for each direction in the Abaqus results **(nf)** at the row corresponding to the dynamic time step* *(**ind**$_{nfi}$) for all three axes (x, y, and z) (**Co**$_{0,1}$**+2, Co**$_{1,1}$**+2,** and **Co**$_{2,1}$**+2,**) at the **i**th indicy of the time column of the direction for which the support acts, and the associated column of the specified node at the **j**th indicy of the specified node indicy vector (**ind**$_{nd}$). The gravitational forces (**M**$_{rxg}$, **M**$_{ryg}$, and **M**$_{rzg}$) specified immediately proprior on Lines 9-11 and included in the same for loop as that specified in Line 8 is subtracted from the total force and the difference is multiplied by the seismic factor (**F**$_a$) identified in the Co matrix on the fourth row first column (**Co**$_{3,0}$). The gravitational moments (**M**$_{rxg}$, **M**$_{ryg}$, and **M**$_{rzg}$) are then added back into the adjusted dynamic force. (Note: +2 is included in the (**Co**$_{0,1}$**+2, Co**$_{1,1}$**+2,** and **Co**$_{2,1}$**+2,**) expression to modify the output such that the specified direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

$$M_{rxR_j} \leftarrow \left(nf_{ind_{nfi C_{o_{0,1}}+2}+i,\, ind_{ndR_j}} - M_{rxgR_j}\right) C_{o_{3,0}} + M_{rxgR_j}$$
$$M_{ryR_j} \leftarrow \left(nf_{ind_{nfi C_{o_{1,1}}+2}+i,\, ind_{ndR_j}} - M_{rygR_j}\right) C_{o_{3,0}} + M_{rygR_j}$$
$$M_{rzR_j} \leftarrow \left(nf_{ind_{nfi C_{o_{2,1}}+2}+i,\, ind_{ndR_j}} - M_{rzgR_j}\right) C_{o_{3,0}} + M_{rzgR_j}$$

***nf** is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of **nf** represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

***ind**$_{nfi}$ is the initial time indicy for the force whose direction is specified by (**Co**$_{0,1}$**+2, Co**$_{1,1}$**+2,** and **Co**$_{2,1}$**+2**) (See next definition for (**Co**$_{0,1}$**+2, Co**$_{1,1}$**+2,** and **Co**$_{2,1}$**+2**))*

*(**Co**$_{0,1}$**+2, Co**$_{1,1}$**+2,** and **Co**$_{2,1}$**+2**) indicates the direction for which the support acts (Note: +2 is included in the expressions to modify the output such that the specified moment axes direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

***ind**$_{ndR}$ is the vector of indicies corresponding to the locations of the specified nodes in **ndR**.*

*(**Co**$_{3,0}$) is the seismic factor (**F**$_a$) identified in the Co matrix on the fourth row first column.*

*(**M**$_{rxgR}$, **M**$_{rygR}$, and **M**$_{rzgR}$) are the gravitational moments defined in Lines 25 - 27.*

***j** is the indicy in the vector **ind**$_{ndR}$ for which this line applies*

***Line 32:** Specifies the total moment (SRSS Combination) of the moments applied to the run and associated with the **j**th indicy*

$$M_{R_j} \leftarrow \sqrt{\left(M_{rxR_j}\right)^2 + \left(M_{ryR_j}\right)^2 + \left(M_{rzR_j}\right)^2}$$

***M_{rxR}, M_{ryR},** and **M_{rzR}** are the pipe run moments calculated in Lines 28 - 31.*

***j** is the indicy in the vectors **(M_{rxR}, M_{ryR}, and M_{rzR})** for which this line applies*

***Lines 33 - 35:** Specifies the gravitational moments **(M_{rxgR}, M_{rygR},** and **M_{rzgR})** on the support by locating the initial moment in the Abaqus results **(nf)** at the row corresponding to the initial dynamic time step **(ind_{nfi})** about all three axes (x, y, and z) **($Co_{0,1}$+2, $Co_{1,1}$+2,** and **$Co_{2,1}$+2,)** and the associated column of the specified node at the j^{th} indicy of the specified node indicy vector **(ind_{ndR})** (Note: +2 is included in the **($Co_{2,1}$+2)** expression to modify the output such that the specified moment axes direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

$$M_{rxgB_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}+2},\, ind_{ndB_k}}$$
$$M_{rygB_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}+2},\, ind_{ndB_k}}$$
$$M_{rzgB_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}+2},\, ind_{ndB_k}}$$

***nf** is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of **nf** represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

***ind_{nfi}** is the initial time indicy for the force whose direction is specified by **($Co_{0,1}$+2, $Co_{1,1}$+2,** and **$Co_{2,1}$+2)** (See next definition for **($Co_{0,1}$+2, $Co_{1,1}$+2,** and **$Co_{2,1}$+2)**)*

***($Co_{0,1}$+2, $Co_{1,1}$+2,** and **$Co_{2,1}$+2)** indicates the direction for which the support acts (Note: +2 is included in the expressions to modify the output such that the specified moment axes direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

***ind_{ndB}** is the vector of indicies corresponding to the locations of the specified nodes in the vector **ndb**.*

***j** is the indicy in the vector **ind_{ndR}** for which these lines apply.*

***k** is the indicy in the vector **ind_{ndB}** for which these lines apply.*

Line 36 - 38: *Specifies the moments* $(M_{rx}$, M_{ry}, *and* $M_{rz})$ *on the support by first locating the total moment for each direction in the Abaqus results* ***(nf)*** *at the row corresponding to the dynamic time step* (ind_{nfi}) *for all three axes (x, y, and z)* $(Co_{0,1}+2$, $Co_{1,1}+2$, *and* $Co_{2,1}+2,)$ *at the* i^{th} *indicy of the time column of the direction for which the support acts, and the associated column of the specified node at the* j^{th} *indicy of the specified node indicy vector* (ind_{nd}). *The gravitational forces* $(M_{rxg}$, M_{ryg}, *and* $M_{rzg})$ *specified immediately proprior on Lines 9-11 and included in the same for loop as that specified in Line 8 is subtracted from the total force and the difference is multiplied by the seismic factor* (F_a) *identified in the Co matrix on the fourth row first column* $(Co_{3,0})$. *The gravitational moments* $(M_{rxg}$, M_{ryg}, *and* $M_{rzg})$ *are then added back into the adjusted dynamic force. (Note: +2 is included in the* $(Co_{0,1}+2$, $Co_{1,1}+2$, *and* $Co_{2,1}+2,)$ *expression to modify the output such that the specified direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

$$M_{rxB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}+2}+i,\, ind_{ndB_k}} - M_{rxgB_j}\right) C_{o_{3,0}} + M_{rxgB_j}$$
$$M_{ryB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}+2}+i,\, ind_{ndB_k}} - M_{rygB_j}\right) C_{o_{3,0}} + M_{rygB_j}$$
$$M_{rzB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}+2}+i,\, ind_{ndB_k}} - M_{rzgB_j}\right) C_{o_{3,0}} + M_{rzgB_j}$$

nf *is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of* ***nf*** *represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

ind_{nfi} *is the initial time indicy for the force whose direction is specified by* $(Co_{0,1}+2$, $Co_{1,1}+2$, *and* $Co_{2,1}+2)$ *(See next definition for* $(Co_{0,1}+2$, $Co_{1,1}+2$, *and* $Co_{2,1}+2)$ *)*

$(Co_{0,1}+2$, $Co_{1,1}+2$, *and* $Co_{2,1}+2)$ *indicates the direction for which the support acts (Note: +2 is included in the expressions to modify the output such that the specified moment axes direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

ind_{ndB} *is the vector of indicies corresponding to the locations of the specified nodes in* ***ndB****.*

$(Co_{3,0})$ *is the seismic factor* (F_a) *identified in the Co matrix on the fourth row first column.*

$(M_{rxgB}$, M_{rygB}, *and* $M_{rzgB})$ *are the gravitational moments for the branch defined in Lines 33 - 35.*

j *is the indicy in the vector* ind_{ndR} *for which these lines apply.*

k *is the indicy in the vector* ind_{ndB} *for which these lines apply.*

Line 39: *Specifies the total moment (SRSS Combination) of the moments applied to the branch and associated with the* ***j*** *th indicy*

$$M_{B_j} \leftarrow \sqrt{\left(M_{rxB_j}\right)^2 + \left(M_{ryB_j}\right)^2 + \left(M_{rzB_j}\right)^2}$$

M_{rxB}, M_{ryB}, *and* M_{rzB} *are the moments calculated in Lines 28 - 31.*

j *is the indicy in the vectors* (M_{rxB}, M_{ryB}, **and** M_{rzB}) *for which this line applies*

Line 40: *Calls the function* ***TeeDC*** *that calculates the Demand to Capacity ratio of the tee given the loading applicable to the conditions of Lines 32 and 39.*

$$Int'_j \leftarrow TeeDC\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_{B_j}, M_{R_j}, Z_b, Z_r, S\right)$$

P *is the pressure applied to the piping system at the termination node of interest*

D_o *is the outside diameter of the pipe at the termination node*

T_r *is the thickness of the pipe along the pipe run*

B_1 *is the stress indicy associated with the pressure term in equation 9 of NB3600*

B_{2b} *is the stress indicy associated with the moment term for the branch in equation 9 of NB3600*

B_{2r} *is the stress indicy associated with the moment term for the pipe run in equation 9 of NB3600*

M_B *is the SSRS moment on the branch*

M_R *is the SSRS moment on the pipe run*

Z_b *is the approximate section modulus of branch*

Z_r *is the approximate section modulus of the designated pipe run*

S *is the allowable design stress intensity factor associated with the pipe at the termination node (min of 2*Sy and 3*Sm)*

Line 41: *If statement that applies if the **Int`** defined on Line 16 is greater than the formerly greatest Demand to Capacity ratio by the node of interest. (Note: As specified on Line 6 Int_0 is initially 0)*

$$\text{if } Int'_j > Int_0$$

***Int_0** is the variable initially defined on Line 6 and redefined in loop if condition is satisifed*

***Int`** is the Demand to Capacity ratio of the termination*

Line 42: *Creats a vector of values of interest applicable for a specified node*

$$Int \leftarrow stack\left(Int'_j, M_{R_j}, M_{B_j}, nf_{ind_{nfiC_{o_{0,1}}}-1+i,0}, EL_{ind_{ndR_j},1}, ind_{ndR}, ind_{ndB}\right)$$

***stack** is a command that adds values in the parentheses into a vector form*

***$Int`_j$** is the demand to capacity ratio calculated in Line 40*

***M_R** is the SSRS moment on the pipe run*

***M_B** is the SSRS moment on the branch*

$nf_{ind_{nfiC_{o_{0,1}}}-1+i,0}$ *is the time for which the associated values occur*

$EL_{ind_{ndR_j},1}$ *is the node that is was specified for the pipe run in **ndR**. This form of acquiring the node is used to assist in checking the program*

***ind_{ndR}** is the indicy for which nodes of the pipe run occur in **ndR**.*

***ind_{ndB}** is the indicy for which node of the branch occur in **ndB**.*

***j** is the indicy associated with iteration.*

Line 43: *Creates a vector of moment values associated with the above calculations use primarily for checking purposes.*

$$Result \leftarrow stack\left(M_{R_j}, M_{B_j}, M_{rxR_j}, M_{ryR_j}, M_{rzR_j}, M_{rxB_j}, M_{ryB_j}, M_{rzB_j}\right)$$

***M_R** is the SSRS moment on the pipe run*

***M_B** is the SSRS moment on the branch*

***M_{rxR}**, **M_{ryR}**, and **M_{rzR}** are the pipe run moments calculated in Lines 28 - 31.*

(M_{rxgB}, M_{rygB}, and M_{rzgB}) are the gravitational moments for the branch defined in Lines 33 - 35.

j is the indicy associated with iteration.

Line 44: *Variable used in testing logic*

$M \leftarrow M_R$

Line 45: *Prepares the output vector **Int** as the function output .*

Int

TEES OUTPUT: (DC, SRSS Moment of Pipe Run, SRSS Moment of Branch, Time, Node, Indicy Associated with Run Node, Indicy Associated with Branch Node)

Appendix A.5.7

Flanges

FLANGES

Flange Strategy: *Search based on the nodes where flanges occur. Find the maximum moment combination for the node and apply to equation (9) of ASME III, Division I - NB - 3652. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

FLANGES OUTPUT: (DC, SRSS Moment, Time, Node, Indicy Associated with Node, Mx, My, Mz)

Demand to Capacity Calculation:

$$\mathrm{FlangeDC}\left(P, D_o, t, I, B_1, B_2, M, S\right) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\,\mathrm{lbf} \cdot \mathrm{in})]}{S} \qquad [18]$$

Function Definition: *This function's name is* ***FlangeDC*** *with inputs* ***(P, D_o, t, I, B_1, B_2, S_m, nf, nd, C_o)***

$\mathrm{FlangeDC}\left(P, D_o, t, I, B_1, B_2, M, S\right)$

P *is the pressure applied to the piping system at the termination node of interest*

D_o *is the outside diameter of the pipe at the termination node*

t *is the thickness of the pipe at the termination node*

I *is the moment of inertia of the pipe at the termination node*

B_1 *is the stress indicy associated with the pressure term in equation 9 of NB3600*

B_2 *is the stress indicy associated with the moment term in equation 9 of NB3600*

M *is the SSRS moment at the termination node*

S *is the allowable design stress intensity factor associated with the pipe at the termination node (min of 2*Sy and 3*Sm)*

Equation Definition: *The equation is the ratio of the experienced stess associated with pressure* $\left(B_1 \cdot \frac{P \cdot D_o}{2 \cdot t}\right)$ *and applied moment* $\left(B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\,\mathrm{lbf} \cdot \mathrm{in})]\right)$ *versus the of the pipe capacity* (S).

$$\frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\,\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

Data Extraction from Abaqus Results for Flanges:

$\text{Flange}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \text{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

$\text{for } i \in 1..\text{last}(nd)$ $\quad \text{if rows}(nd) > 1$

$\quad ind_{nd} \leftarrow \text{stack}\left[ind_{nd}, \left(\text{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$(M \;\; Int_0) \leftarrow (0 \;\; 0)$

$\text{for } i \in 0..ind_{nfo_0} - ind_{nfi_0}$

$\quad \text{for } j \in 0..\text{last}(ind_{nd})$

$\quad\quad M_{rxg} \leftarrow nf_{ind_{nfiC_{o_{0,1}}+2},\, ind_{nd_j}}$

$\quad\quad M_{ryg} \leftarrow nf_{ind_{nfiC_{o_{1,1}}+2},\, ind_{nd_j}}$

$\quad\quad M_{rzg} \leftarrow nf_{ind_{nfiC_{o_{2,1}}+2},\, ind_{nd_j}}$

$\quad\quad M_{rx} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}+2}+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

$\quad\quad M_{ry} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}+2}+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

$\quad\quad M_{rz} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}+2}+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

$\quad\quad M'_j \leftarrow \sqrt{M_{rx}^{\,2} + M_{ry}^{\,2} + M_{rz}^{\,2}}$

$\quad\quad Int'_j \leftarrow \text{FlangeDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$

$\quad\quad \text{if } Int'_j > Int_0$

$\quad\quad\quad Int \leftarrow \text{stack}\left(Int'_j, M'_j, nf_{ind_{nfiC_{o_{0,1}}-1}+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M_{rz}\right)$

$\quad\quad\quad Result \leftarrow M'$

Int

Function Definition: *This function's name is* ***Flange*** *with inputs* ***(P, D_o, t, I, B_1, B_2, S_m, nf, nd, C_o)***

$\text{Flange}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL)$

P *is the pressure applied to the piping system at the termination node of interest*

D_o *is the outside diameter of the pipe at the termination node*

t *is the thickness of the pipe at the termination node*

I *is the moment of inertia of the pipe at the termination node*

B_1 *is the stress indicy associated with the pressure term in equation 9 of NB3600*

B_2 *is the stress indicy associated with the moment term in equation 9 of NB3600*

S *is the allowable design stress intensity factor associated with the pipe at the termination node (min of 2*Sy and 3*Sm)*

nf *is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of* ***nf*** *represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

nd *is a vector of defined nodes associated with the support in the finite element model. Typically only one node is included in vector.*

EL *is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of* ***nf****.*

C_o *is a matrix (shown below) defining the* ***Direction*** *termination moments in the global coordinate system (1-x, 2-y, 3-z), defines the seismic scale factor* ***(F_a)****, and represents* ***(M_{cx}, M_{cy}, and M_{cz})*** *as place holders in the matrix and aren't referenced for any calculations.*

$$C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Equation Definition: *The equation gathers moment infromation from the available data and outputs max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, indicie of element(s), and moments about the x, y, and z axes.*

Line 1: *Identifies (matches) the row indicies in the time column of **nf** that match that of the specified initial time of the dynamic step and places them in a vector* ($\mathbf{ind_{nfi}}$).

$$ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right)$$

$t_{initial}$ *is the intial start point when the seimic input was applied to the model*

$nf^{<0>}$ *is the time column of the Abaqus output data*

Line 2: *Identifies (matches) the row indicies in the time column of **nf** that match that of the specified final time of the dynamic step and places them in a vector* ($\mathbf{ind_{nfo}}$).

$$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right)$$

t_{final} *is the final time when the seimic input was stopped*

$nf^{<0>}$ *is the time column of the Abaqus output data*

Line 3: *Matches the indicy where the first specified node in the **nd** vector occurs in the second column of **EL** and defines it as the variable* $\mathbf{ind_{nd}}$.

$$ind_{nd} \leftarrow match\left(nd_0, EL^{\langle 1 \rangle}\right)$$

nd_0 *is the first node specified in the **nd** vector*

EL *is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of **nf**.*

Line 4 - 5: *If the length of the **nd** vector is greater than 1 then the logic statement here identifies (matches) and appends the indicies of the remaining node one on top and converts the variable* $\mathbf{ind_{nd}}$ *into a vector. This logic statement is to add versitility to the function but is not typically used.*

$$\begin{array}{l} \text{for } i \in 1..\text{last}(nd) \\ \quad ind_{nd} \leftarrow stack\left[ind_{nd}, \left(match\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \end{array} \quad \text{if } rows(nd) > 1$$

for *is a looping function that iterates through the specified range of variables*

last(nd) *indicates the indicy of the last row of the* ***nd*** *vector*

if *only allows loop to calculate if the number of rows in* ***nd*** *is greater than 1*

nd_i *is the* i^{th} *node specified in the* ***nd*** *vector*

EL *is a matrix of two columns where the first column contains all the element numbers arranged in ascending order and the second column contains all the node numbers corresponding to the elements and arranged in ascending order at the local level for each element. An additional row is included at the top of the matrix to identify the element and node columns and also increase the indicy value for which each element node combination occurs by one in order to match the shifting effect caused by the initial time column of* ***nf***.

stack *is a command that adds the newly matched indicy onto the current variable/vector of* ind_{nd} *to redefine* ind_{nd}

Line 6: *Initiates the two row vectors* ***M*** *and* Int_0 *to null values (this is used later in the logic when comparing the force gathered from the Abaqus results at the designated support node to a baseline value)*

$$\begin{pmatrix} M & Int_0 \end{pmatrix} \leftarrow \begin{pmatrix} 0 & 0 \end{pmatrix}$$

Line 7: *Ranges variable* ***i*** *from 0 over the length of the time column specified by the difference between the final time* (ind_{nfo0}) *and initial time* (ind_{nfi0}) *indicies of the x-0 direction force. The length of final and initial time indicy difference is consistent for all forces and moment. Associated lines for which this loop applies includes 7 through 17.*

$$\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$$

for *is a looping function that iterates through the specified range of variables*

ind_{nfo0} *is the final time indicy for the x-0 direction force (See Line 2)*

ind_{nfi0} *is the initial time indicy for the x-0 direction force (See Line 1)*

Line 8: *Ranges variable* ***j*** *from 0 over the length of the indicies of the nodes matching those specified. Associated lined for which this loop applies includes 8 through 10.*

$$\text{for } j \in 0 .. \text{last}(ind_{nd})$$

for *is a looping function that iterates through the specified range of variables*

last(ind_{nd}***)*** *indicates the indicy of the last row of the* ind_{nd} *vector (See Line 3)*

Lines 9-11: *Specifies the gravitational moments **(M_{rxg}, M_{ryg}, and M_{rzg})** on the support by locating the initial moment in the Abaqus results **(nf)** at the row corresponding to the initial dynamic time step **(ind_{nfi})** about all three axes (x, y, and z) **($Co_{0,1}$+2, $Co_{1,1}$+2, and $Co_{2,1}$+2,)** and the associated column of the specified node at the j^{th} indicy of the specified node indicy vector **(ind_{nd})** (Note: +2 is included in the **($Co_{2,1}$+2)** expression to modify the output such that the specified moment axes direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

$$M_{rxg} \leftarrow nf_{ind_{nfiC_{o_{0,1}}+2},\, ind_{nd_j}}$$
$$M_{ryg} \leftarrow nf_{ind_{nfiC_{o_{1,1}}+2},\, ind_{nd_j}}$$
$$M_{rzg} \leftarrow nf_{ind_{nfiC_{o_{2,1}}+2},\, ind_{nd_j}}$$

nf *is the element/nodal force/moment output from Abaqus. The output is comprised of Force in the global X, Y, and Z directions and Moment about the global X, Y, and Z axes sequentially appended one on top of the other in this order and labeled as NFORC1 through NFORC6. The first column of **nf** represents the time progression of the dynamic step for each NFORC while the remaining columns are arranged across primarily by ascending element number and secondarily by ascending node number.*

ind_{nfi} *is the initial time indicy for the force whose direction is specified by **($Co_{0,1}$+2, $Co_{1,1}$+2,** and **$Co_{2,1}$+2)** (See next definition for **($Co_{0,1}$+2, $Co_{1,1}$+2,** and **$Co_{2,1}$+2)**)*

($Co_{0,1}$+2, $Co_{1,1}$+2,** and **$Co_{2,1}$+2) *indicates the direction for which the support acts (Note: +2 is included in the expressions to modify the output such that the specified moment axes direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

ind_{nd} *is the vector of indicies corresponding to the locations of the specified nodes*

j *is the indicy in the vector **ind_{nd}** for which this line applies*

Line 12-14: *Specifies the moments **(M_{rx}, M_{ry}, and M_{rz})** on the support by first locating the total moment for each direction in the Abaqus results **(nf)** at the row corresponding to the dynamic time step **(ind_{nfi})** for all three axes (x, y, and z) **($Co_{0,1}$+2, $Co_{1,1}$+2, and $Co_{2,1}$+2,)** at the i^{th} indicy of the time column of the direction for which the support acts, and the associated column of the specified node at the j^{th} indicy of the specified node indicy vector **(ind_{nd})**. The gravitational forces **(M_{rxg}, M_{ryg}, and M_{rzg})** specified immediately proprior on Lines 9-11 and included in the same for loop as that specified in Line 8 is subtracted from the total force and the difference is multiplied by the seismic factor **(F_a)** identified in the Co matrix on the fourth row first column **($Co_{3,0}$)**. The gravitational moments **(M_{rxg}, M_{ryg}, and M_{rzg})** are then added back into the adjusted dynamic force. (Note: +2 is included in the **($Co_{0,1}$+2, $Co_{1,1}$+2, and $Co_{2,1}$+2,)** expression to modify the output such that the specified direction (1-x,2-y, 3-z) corresponds to the appropriate indicies as specified by MathCad (3-x, 4-y, 5-z)).*

$$M_{rx} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}+2}+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$$
$$M_{ry} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}+2}+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$$
$$M_{rz} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}+2}+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$$

Line 15: *Specifies the total moment (SRSS Combination) associated with the* ***j****th* *indicy*

$$M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$$

M_{rx}, M_{ry}, *and* ***M_{rz}*** *moments calculated in Lines 12 - 14*

Line 16: *Calls the function* ***TermDC*** *that calculates the Demand to Capacity ratio of the termination given the loading applicable to the conditions of Line 15.*

$$Int'_j \leftarrow \mathrm{TermDC}\left(P, D_0, t, I, B_1, B_2, M'_j, S\right)$$

P *is the pressure applied to the piping system at the termination node of interest*

D_o *is the outside diameter of the pipe at the termination node*

t *is the thickness of the pipe at the termination node*

I *is the moment of inertia of the pipe at the termination node*

B_1 *is the stress indicy associated with the pressure term in equation 9 of NB3600*

B_2 *is the stress indicy associated with the moment term in equation 9 of NB3600*

M *is the SSRS moment at the termination node*

S *is the allowable design stress intensity factor associated with the pipe at the termination node (min of 2*S_y and 3*S_m)*

Line 17: *If statement that applies if the* ***Int`*** *defined on Line 16 is greater than the formerly greatest Demand to Capacity ratio by the node of interest. (Note: As specified on Line 6 Int_0 is initially 0)*

$$\text{if } Int'_j > Int_0$$

Int_0 *is the variable initially defined on Line 6 and redefined in loop if condition is satisifed*

Int` *is the Demand to Capacity ratio of the termination*

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Line 18: *Creats a vector of values of interest applicable for a specified node*

$$\text{Int} \leftarrow \text{stack}\left(\text{Int}'_j, M'_j, nf_{ind_{nfiCo_{0,1}}-1+i,\,0}, EL_{ind_{nd_j},\,1}, ind_{nd_j}, M_{rx}, M_{ry}, M_{rz}\right)$$

***stack** is a command that adds values in the parentheses into a vector form*

***Int`**$_j$ *is the demand to capacity ratio calculated in Line 16*

$nf_{ind_{nfiCo_{0,1}}-1+i,\,0}$ *is the time for which the associated values occur*

$EL_{ind_{nd_j},\,1}$ *is the node that is was specified. This form of acquiring the node is used to assist in checking the program*

ind_{nd} *is the indicy for which node occurs*

M_{rx}, M_{ry}, *and* M_{rz} *moments calculated in Lines 12 - 14 assisting in program checking*

Line 19: *Variable used in testing program*

$\text{Result} \leftarrow M'$

Line 20: *Prepares the output vector **Int** as the function output*

Int

***Int** is a vector of values specified in Line 18*

FLANGES OUTPUT: (DC, SRSS Moment, Time, Node, Indicy Associated with Node, Mx, My, Mz)

Appendix A.5.8

Determining 80th Percentile Results

LOGIC WITHIN COMPOLATION FILE THAT SORTS ALL 32 RUNS IN ASCENDING ORDER TO DETERMINE 80TH PERCENTILE

$$
\begin{aligned}
C\_S(v,R) := \; & \text{for } i \in 0..\text{cols}(v)-1 \\
& \quad \text{for } k \in 0..\text{rows}\left(v_{0,i}\right)-1 \\
& \quad\quad \text{for } j \in 0..\text{rows}(v)-1 \\
& \quad\quad\quad a_{0,j} \leftarrow \left[\left(\left(v_{j,i}\right)^{T}\right)^{\langle k\rangle}\right]^{T} \\
& \quad\quad\quad A \leftarrow a_{0,j} \;\text{ if } j = 0 \\
& \quad\quad\quad A \leftarrow \text{stack}\left(A, a_{0,j}\right) \;\text{ if } j > 0 \\
& \quad\quad b_{k,i} \leftarrow \text{stack}\left(A^{T}, R^{T}\right)^{T} \\
& \quad\quad \text{Sorted}_{k,i} \leftarrow \text{reverse}\left(\text{csort}\left(b_{k,i}, 0\right)\right) \\
& \text{Sorted}
\end{aligned}
$$

Function Definition: *This function's name is* ***C_S*** *with inputs* ***(v,R)***

C_S(v, R)

v *is a matrix of embedded matricies where each column corresponds to a particular component or set of components in the case of pipe runs. Each embedded matrix consists of 32 rows corresponding to each realization and a number of columns corresponding to the number of result terms delivered from the logic blocks defined above.*

R *is a vector ranging from 1 to 32 corresponding to all 32 realizations*

Equation Definition: *The equation sorts each component from one another (includinge the individual elements of a pipe run) and orders all 32 runs in accending order to determine the 80th percentile results for each.*

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Line 1: *Ranges variable **i** from 0 over the length of the columns associated with **v**. Associated lines for which this loop applies includes 1 through 8. (**-1** included to accomodate mathcad indicies starting at 0)*

$$\text{for } i \in 0 .. \text{cols}(v) - 1$$

__for__ is a looping function that iterates through the specified range of variables

cols(v) - 1 *indicates the indicy of the last column of the **v** matrix*

Line 2: *Ranges variable **k** from 0 over the length of rows associated with the submatrix $v_{0,i}$ (the first row of **v** is specified since each row in column **i** has the same number of rows. For this project there are 32 rows representing each realization but the logic was written to be robust enough to accomodate for an instance where this specification could be altered.) Associated lines for which this loop applies includes 2 through 8. (**-1** included to accomodate mathcad indicies starting at 0)*

$$\text{for } k \in 0 .. \text{rows}\left(v_{0,i}\right) - 1$$

__for__ is a looping function that iterates through the specified range of variables

rows($v_{0,i}$) - 1 *indicates the indicy of the last row of the $v_{0,i}$ submatrix*

Line 3: *Ranges variable **j** from 0 over the length of rows associated with the **v** matrix. Associated lines for which this loop applies includes 3 through 8. (**-1** included to accomodate mathcad indicies starting at 0)*

$$\text{for } j \in 0 .. \text{rows}(v) - 1$$

__for__ is a looping function that iterates through the specified range of variables

rows(v) - 1 *indicates the indicy of the last row of the $v_{0,i}$ submatrix*

Line 4: *Line takes the submatrix at the j^{th} row and i^{th} column of **v**, transposes it, selects the k^{th} column of the transposed submatrix, retransposes the selected column into row form and assigns it as a submatrix at the j^{th} column of the first row of the variable **a**. The two transpose commands applied to the matrix are nessacary since there isn't a command in MathCad to define an entire row vector, however, there is a command to define an entire column vector. Therefore by transposing the matrix such that the desired row becomes a column, then selecting that column and retransposing it back to a row performed the desired task.*

$$a_{0,j} \leftarrow \left[\left(\left(v_{j,i}\right)^{T}\right)^{\langle k\rangle}\right]^{T}$$

$\blacksquare^{T}$ *is a superscripted T that transposes the matrix in parentheses to its left for which it is superscripted on*

$\blacksquare^{\langle\blacksquare\rangle}$ *is a superscripted <> that selects the specific column of interest*

Line 5: *Defines or redefines the variable vector **A** as the vector $a_{0,j}$ defined previously in Line 4 if **j=0**. Command is beneficial in that for each iteration of **i** the same variable (**A**) gets redefined for the initial iteration of **j**.*

$$A \leftarrow a_{0,j} \;\text{ if } j = 0$$

Line 6: *Stacks $a_{0,j}$ onto **A** for each iteration of **j** if **j** is greater than 0.*

$$A \leftarrow \text{stack}\left(A, a_{0,j}\right) \;\text{ if } j > 0$$

Line 7: *Stacks the transpose of **A** onto the transpose of **R** and takes the transpose of the resulting matrix. The resulting matrix is then defined as a submatrix on the k^{th} row and i^{th} column of the matrix **b**.*

$$b_{k,i} \leftarrow \text{stack}\left(A^{T}, R^{T}\right)^{T}$$

Line 8: *Sorts the $b_{k,i}$ matrix defined on Line 7 into ascending order based on the terms in the first column using the **csort** command and using the **reverse** command to rearrange the results into decending order. The resulting matrix is then defined as a submatrix on the k^{th} row and i^{th} column of the matrix **Sorted**.*

$$\text{Sorted}_{k,i} \leftarrow \text{reverse}\left(\text{csort}\left(b_{k,i}, 0\right)\right)$$

csort(x,y) *sorts matrix **x** based on the terms contained in column **y** in ascending order*

reverse(z) *reverses the order of the rows of matrix **z***

Line 9: *Prepares the output vector **Sorted** as the function output*

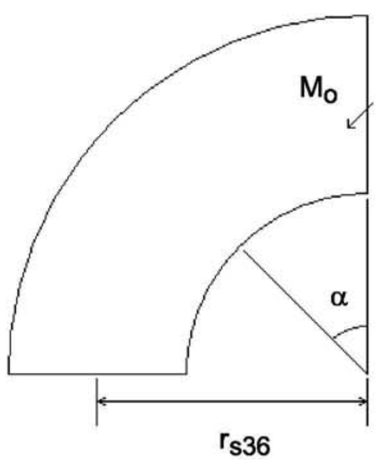
$$\text{Sorted}$$

Sorted *is the total matrix composed of submatricie sspecified in Line 8*

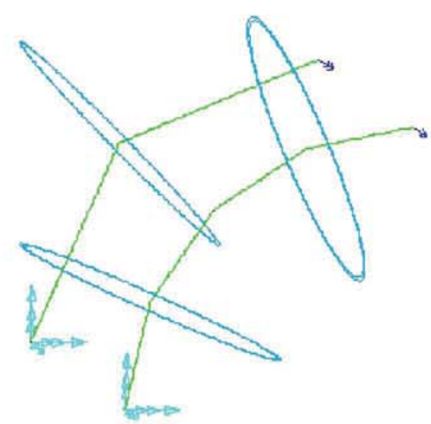
Appendix A.6
Elbow Element Sensitivity

There are many elbows in the piping system that must be addressed. For the piping models, these elbows are modeled with beam elements. Flexibility factors for the elbows are defined with the 2007 ASME Section III, Division 1, Subsection NB [18] definitions. These flexibility factors are used to modify the section properties of the elbow beam elements. For this to be an accurate approach the nominal angular displacement needs to match between the unmodified elbow beam elements and the ASME [18] nominal angular displacement definition. For efficiency, the proposed finite element model of an elbow is to use either one or two parabolic beam elements.

The purpose of this section in Appendix A is to ensure that the beam element modeling approach accurately matches the ASME [18] definitions for an elbow. The scope of this section in Appendix A includes providing an example comparison between the proposed finite element approach and the applicable ASME [18] definitions. The example geometry is a short radius, 36 inch stainless steel pipe with a ½ inch wall thickness (and no flexibility factor section modification). A one million inch-pound moment is applied to one end that tends to open the elbow and the other end is fixed. Fig. A.6-1 shows the example elbow and the one and two parabolic beam element meshes used to evaluate it.



Elbow with variables identified.



Two finite element models one consisting of a single parabolic element and one consisting of two parabolic elements.

Fig. A.6-1 – Example elbow evaluation.

Given this example model, the following definitions can be made.

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$E_s := 2.8 \cdot 10^7 \cdot psi$ — Modulus of elasticity.

$\nu_s := 0.3$ — Poisson's ratio.

$d_{36} := 36 \cdot in$ — Pipe outside diameter.

$t_{36} := 0.5 \cdot in$ — Pipe thickness.

$r_{s36} := d_{36}$ — Radius for short radius elbow.

$r_{s36} = 36\,in$

$I_{36} := \frac{\pi}{64} \cdot \left[d_{36}^{\ 4} - \left(d_{36} - 2 \cdot t_{36}\right)^4 \right]$ — Pipe area moment of inertia.

$I_{36} = 8786.20\,in^4$

$M_o := 10^6 \cdot in \cdot lbf$ — Applied moment.

The ASME [18, NB-3686.2] nominal angular displacement for the model shown in Fig. A.6-1 and the variables defined above is:

$$\theta_{nom} = \frac{r_{s36}}{E_s \cdot I_{36}} \cdot \int_0^{\frac{\pi}{2}} M_o \, d\alpha$$ Nominal rotation.

$$\theta_{nom} := \frac{M_o \cdot r_{s36}}{E_s \cdot I_{36}} \cdot \frac{\pi}{2}$$

$$\theta_{nom} = 2.2986 \times 10^{-4}$$

The ABAQUS input file for the model shown in Fig. A.6-1 is given in Ta Table A.6-1.

Table A.6-1 – Example model input file (elbow_sens1.inp).

```
**%   ==============================================================
**%
**%              I-DEAS 10 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\model3_springs.mf1
**%          INPUT FILE: C:\er2\work\TRA-670_piping\input\elbow_sens1.inp
**%            EXPORTED: AT 15:45:20 ON 21-May-08
**%                PART: test
**%                 FEM: Fem1
**%
```

```
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  21-May-08   15:45:20
**%=============================================
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**%=============================================
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         27,-2.5459874E+01, 2.5451813E+01, 2.0000000E+02
         28,-3.6000000E+01,-2.7187721E-14, 2.5000000E+02
         29, 2.2043642E-15, 3.6000000E+01, 2.5000000E+02
         30,-3.3259650E+01, 1.3776634E+01, 2.5000000E+02
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     23,     31,     32,     29
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 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_36
*ELASTIC,TYPE=ISOTROPIC
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*DENSITY
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*STEP,INC=10
*STATIC
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
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         28,  1, 6,      0.00000E+00
**%  LOAD SET 1
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        29,    6, 1.0000E+06
*OUTPUT, FIELD
*NODE OUTPUT
 U,RF
*ELEMENT OUTPUT
 SF,S,NFORC
*MONITOR, NODE=26, DOF=6
*END STEP
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The model shown in Table A.6-1 was run in ABAQUS version 6.7-5 and the angular displacement at the free end of the elbow was found. These were then compared to the ASME [18] nominal angular displacement values and a percent error was established.

$\theta_{1p} := 2.29445 \cdot 10^{-4}$ Finite element model rotation considering the one parabolic element.

$\theta_{2p} := 2.29876 \cdot 10^{-4}$ Finite element model rotation considering the two parabolic elements.

$\Delta\%_{1p} := \left| 1 - \frac{\theta_{1p}}{\theta_{nom}} \right|$ Error in the finite model element rotation considering the one parabolic element.

$\Delta\%_{1p} = 0.181\,\%$

$\Delta\%_{2p} := \left| 1 - \frac{\theta_{2p}}{\theta_{nom}} \right|$ Error in the finite element model rotation considering the two parabolic elements.

$\Delta\%_{2p} = 0.007\,\%$

This example shows an insignificant difference between the ASME [18] and finite element model nominal displacement. With the percent error being very low for either mesh, a single parabolic element is considered the minimum mesh required to model an elbow.

Project:	ATR Life-Time Extension Project	ECAR No.:	ECAR-194	Rev.:	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Authors:	D. T. Clark	Date: 09/30/08	Checker: M. J. Russell	Date:	09/30/08

Appendix A.7
Appendix References

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2. Carl J. Costantino and Associates, "Probabilistic Soil-Structure Interaction Analysis of TRA-670", CJC-INC-C-003, Revision 0, September 2007.
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7. ABAQUS Inc., ABAQUS Version 6.5-4, Tracking No. 198706.
8. INL Report INL/INT-07-12839,"ATR Primary Coolant System Walkdown Report", November 6, 2007.
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10. Parametric Technology Corporation, MATHCAD Version 14.0.0.163.
11. INL Laboratory Wide Procedure LWP-10200, "Calculations and Analysis", Revision 2, December 2007.
12. PR-T-78-003, "ATR Primary Coolant System Piping Design Specification for Modifications," Revision 6, May 1989.
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14. The Quadrex Corporation, "NUPIPE-II Piping Analysis Program User Manual", Version 1.8.1, Revision 0.
15. LWP-10200, "Calculations and Analysis," Laboratory-wide Manual 10A, Applied Engineering Management System
16. ECAR-202, "Software Validation "report for ABAQUS/Standard and ABAQUS/Explicit Version 6.7-5," Revision 0, May, 2008.

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19. Carl J. Costantino and Associates, “Additional Hazard Consistent In-Structure Response Spectra”, CJC-INL-C-004, Revision 0, February 2008.

20. INL drawing 120110, “Reactor Building Section A-A,” ATR-1075-MTR 670.A.B, Rev. B, Ebasco Services Incorporated, Oct. 10, 1961.

Document ID: ECAR-194
Revision ID: 0
Effective Date: 9/30/2008

Engineering Calculations and Analysis Report

ATR Primary Coolant System Piping Seismic Evaluation

D. T. Clark
A. L. Crawford
K. D. Ellis
R. E. Spears

Volume 2 of 5

Appendix B

Idaho National Laboratory

The INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance.

Appendix B

Calculations Associated with Model 3 Seismic Evaluation

Contents

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** M. J. Russell **Date:** 09/30/08

Appendix B.1

Identified Components Associated with Model 3

Project:	ATR Life-Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation				
Performer:	A. L. Crawford **Date:** 09/30/08	**Checker:**	M. J. Russell	**Date:**	09/30/08

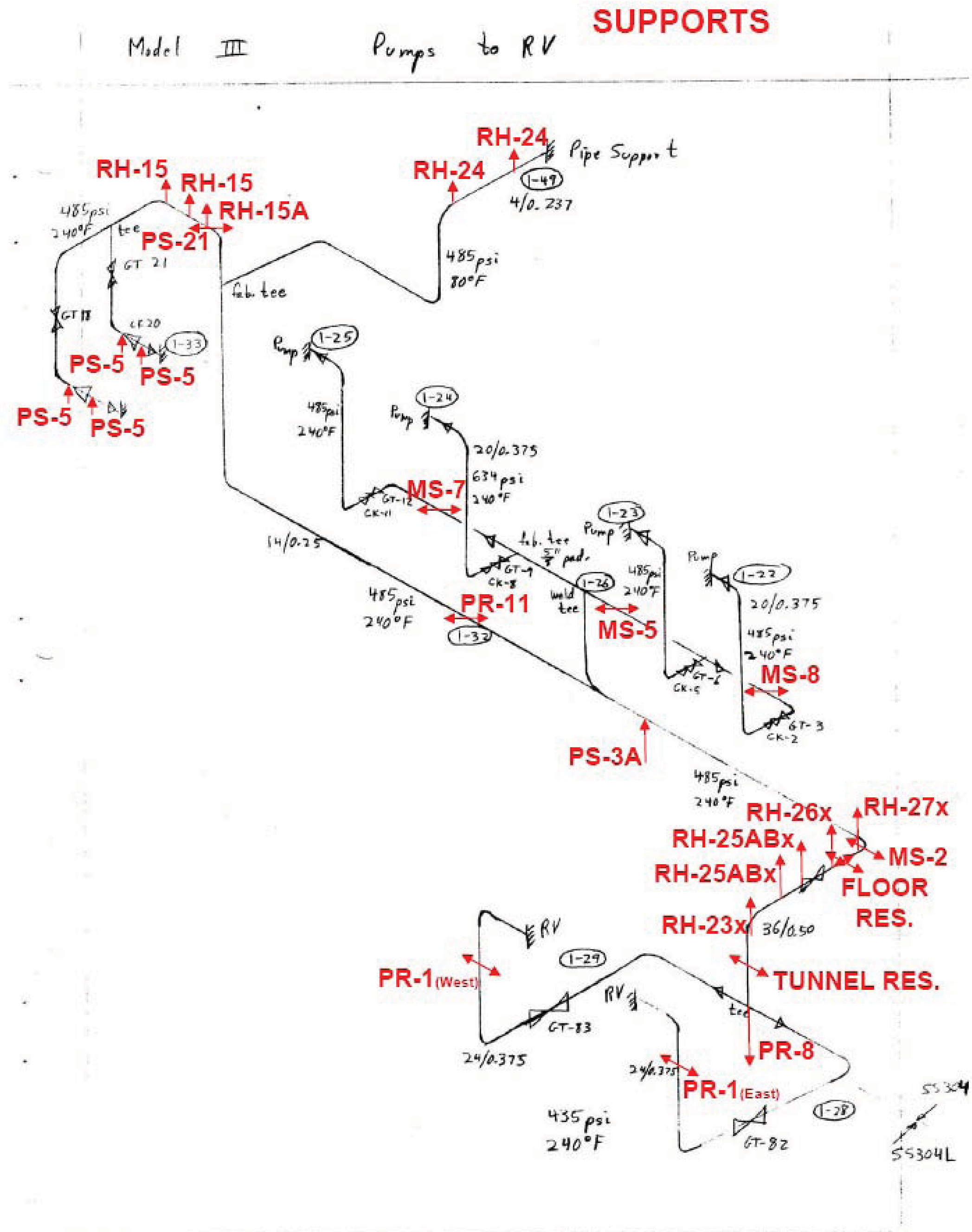

Figure B.1-1. Supports Associated with Model 3 [1]

Project:	ATR Life-Time Extension Project		**ECAR No.:**	ECAR-194		**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation						
Performer:	A. L. Crawford	**Date:** 09/30/08	**Checker:**	M. J. Russell		**Date:**	09/30/08

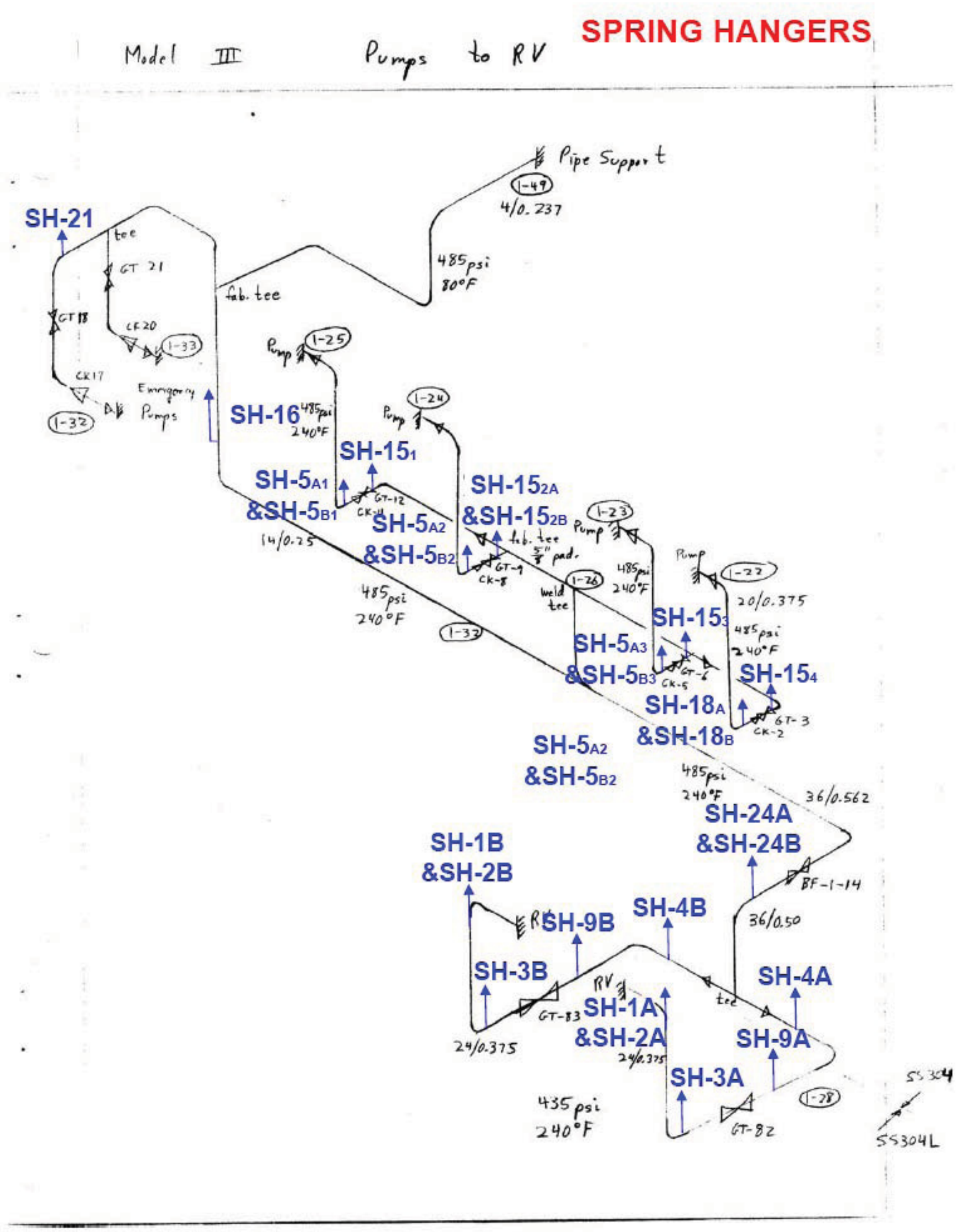

Figure B.1-2. Spring Hangers Associated with Model 3 [1]

Project:	ATR Life-Time Extension Project		**ECAR No.:**	ECAR-194		**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation						
Performer:	A. L. Crawford	**Date:** 09/30/08	**Checker:**	M. J. Russell		**Date:**	09/30/08

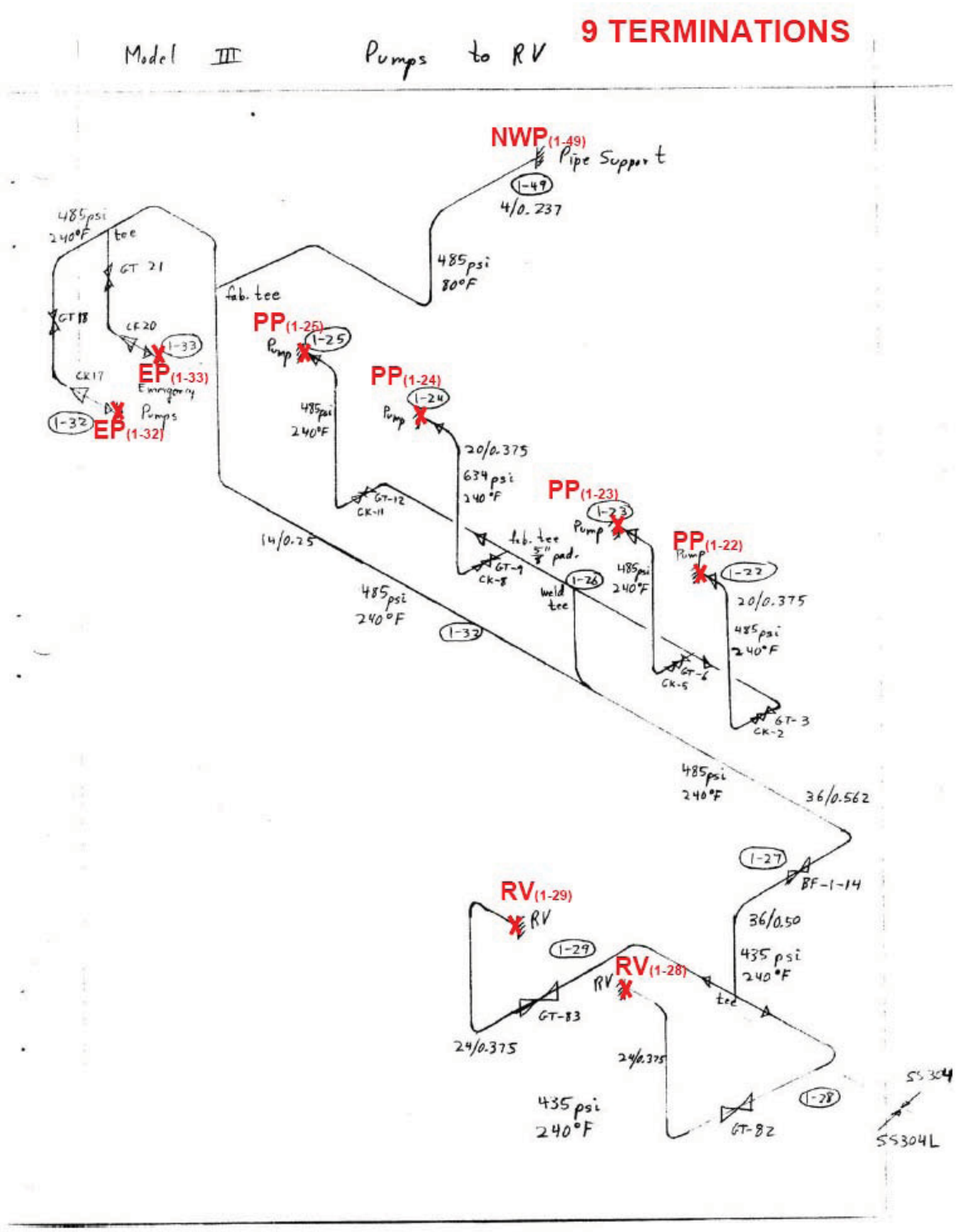

Figure B.1-3. Terminations Associated with Model 3 [1]

Project:	ATR Life-Time Extension Project			**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation						
Performer:	A. L. Crawford	**Date:**	09/30/08	**Checker:**	M. J. Russell	**Date:**	09/30/08

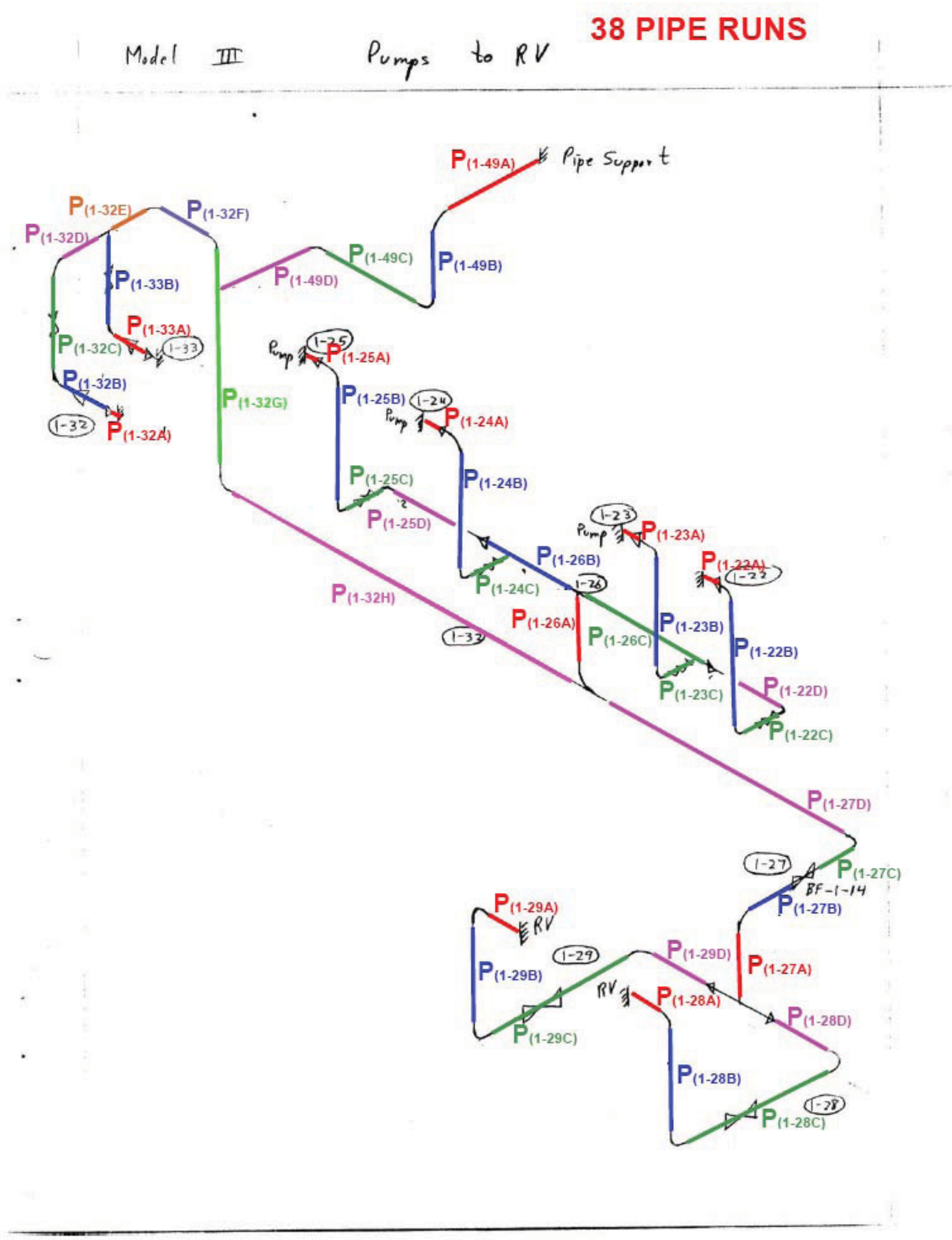

Figure B.1-4. Pipe Runs Associated with Model 3 [1]

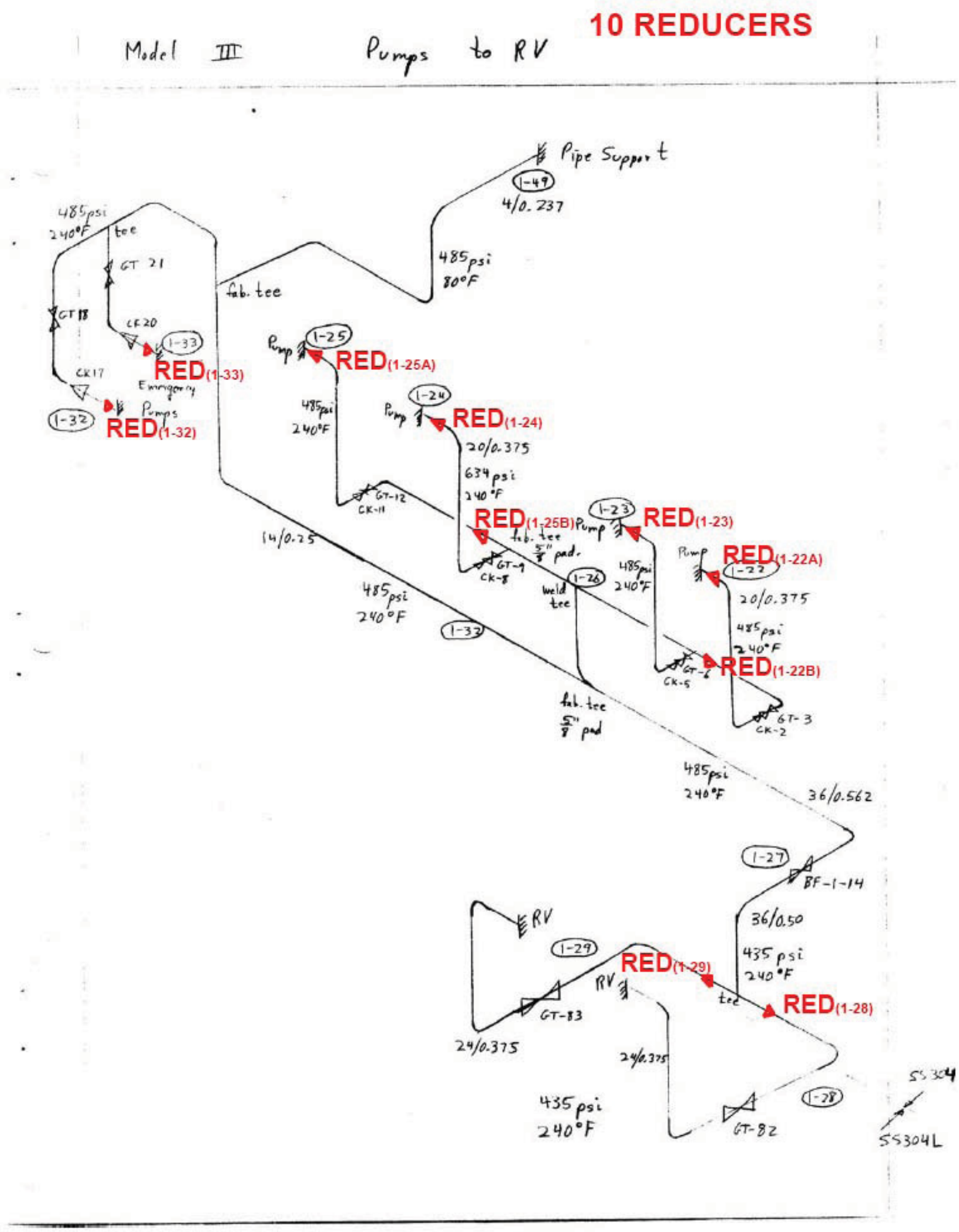

Figure B.1-5. Reducers Associated with Model 3 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** M. J. Russell **Date:** 09/30/08

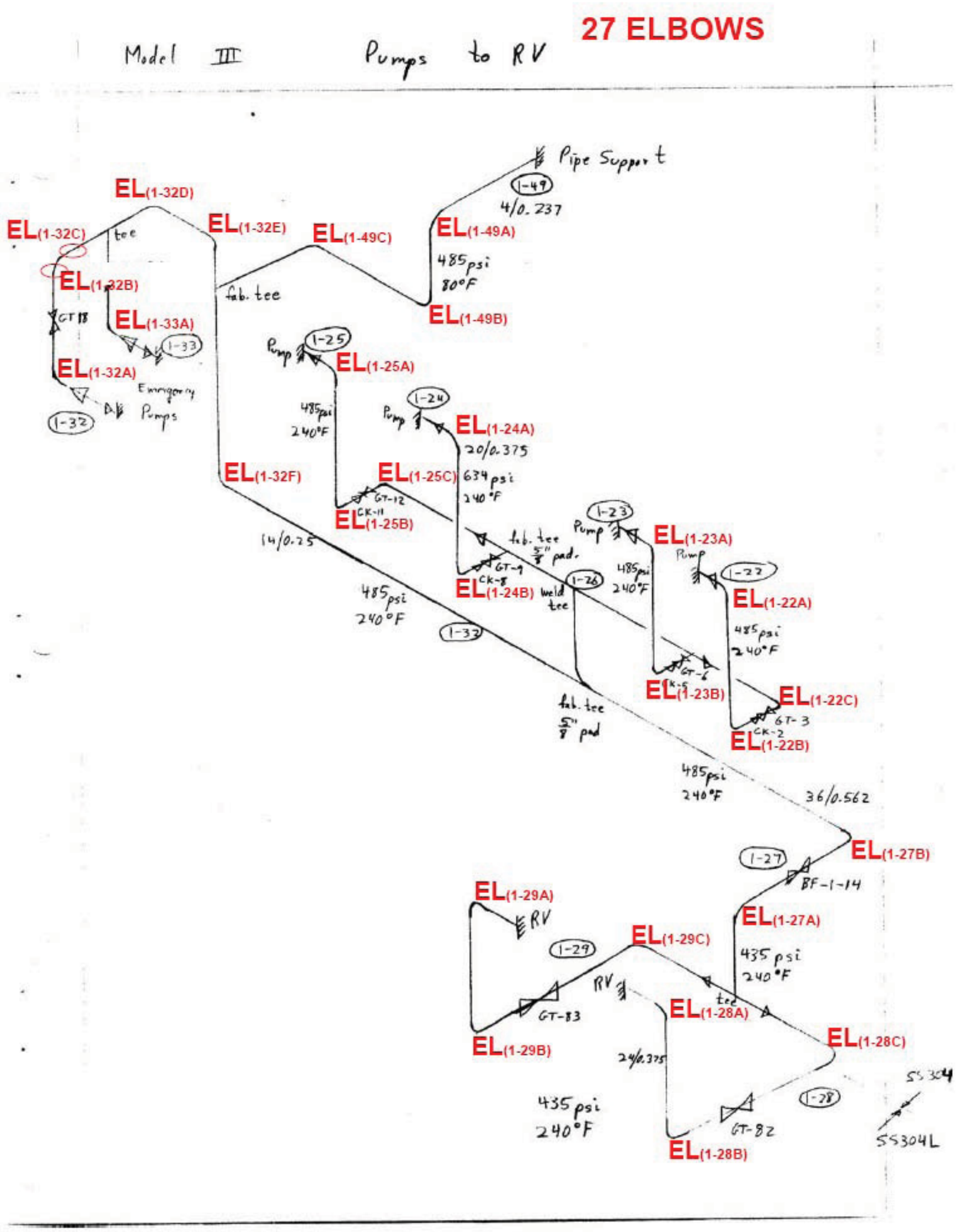

Figure B.1-6. Elbows Associated with Model 3 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** M. J. Russell **Date:** 09/30/08

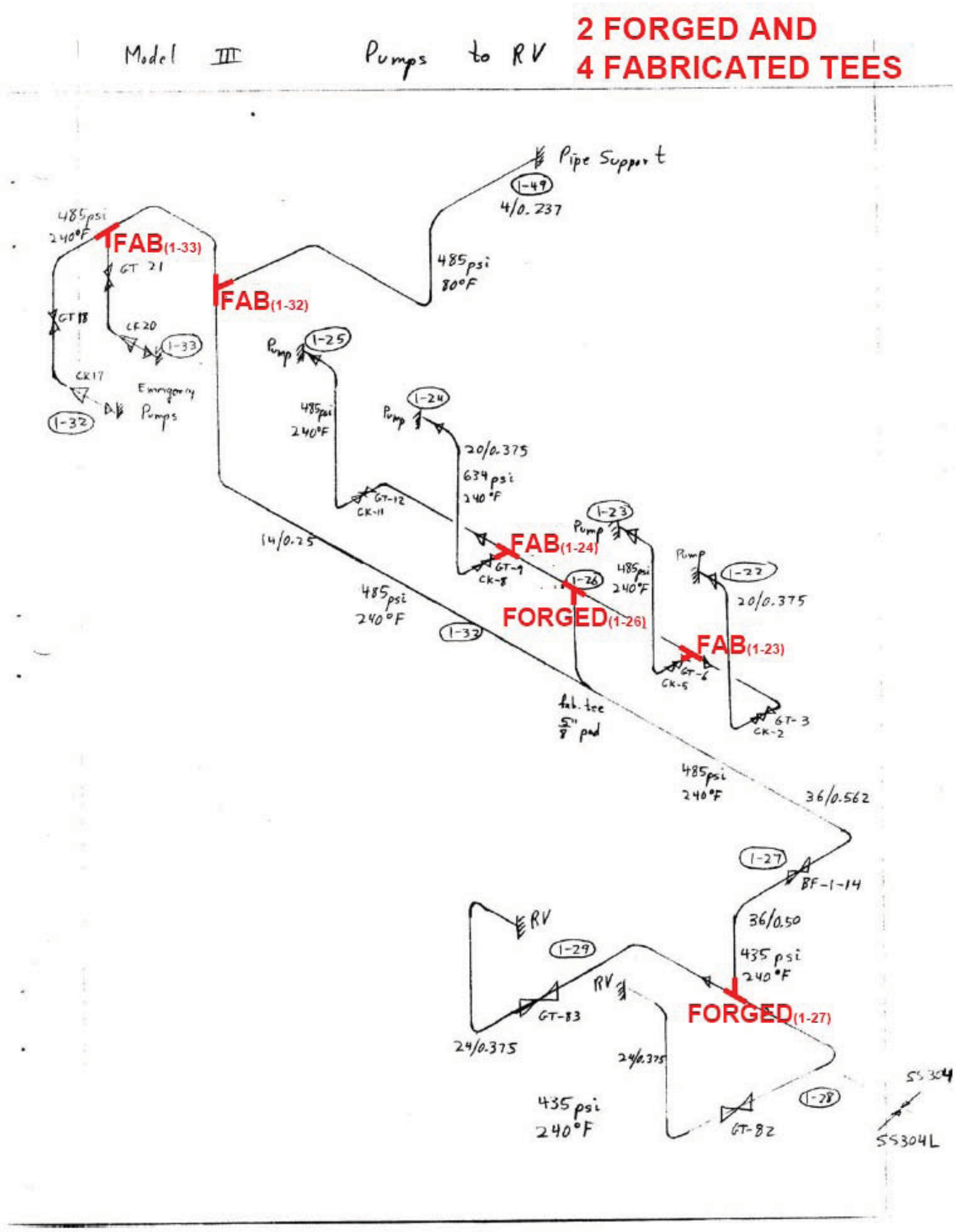

Figure B.1-7. Tees Associated with Model 3 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** M. J. Russell **Date:** 09/30/08

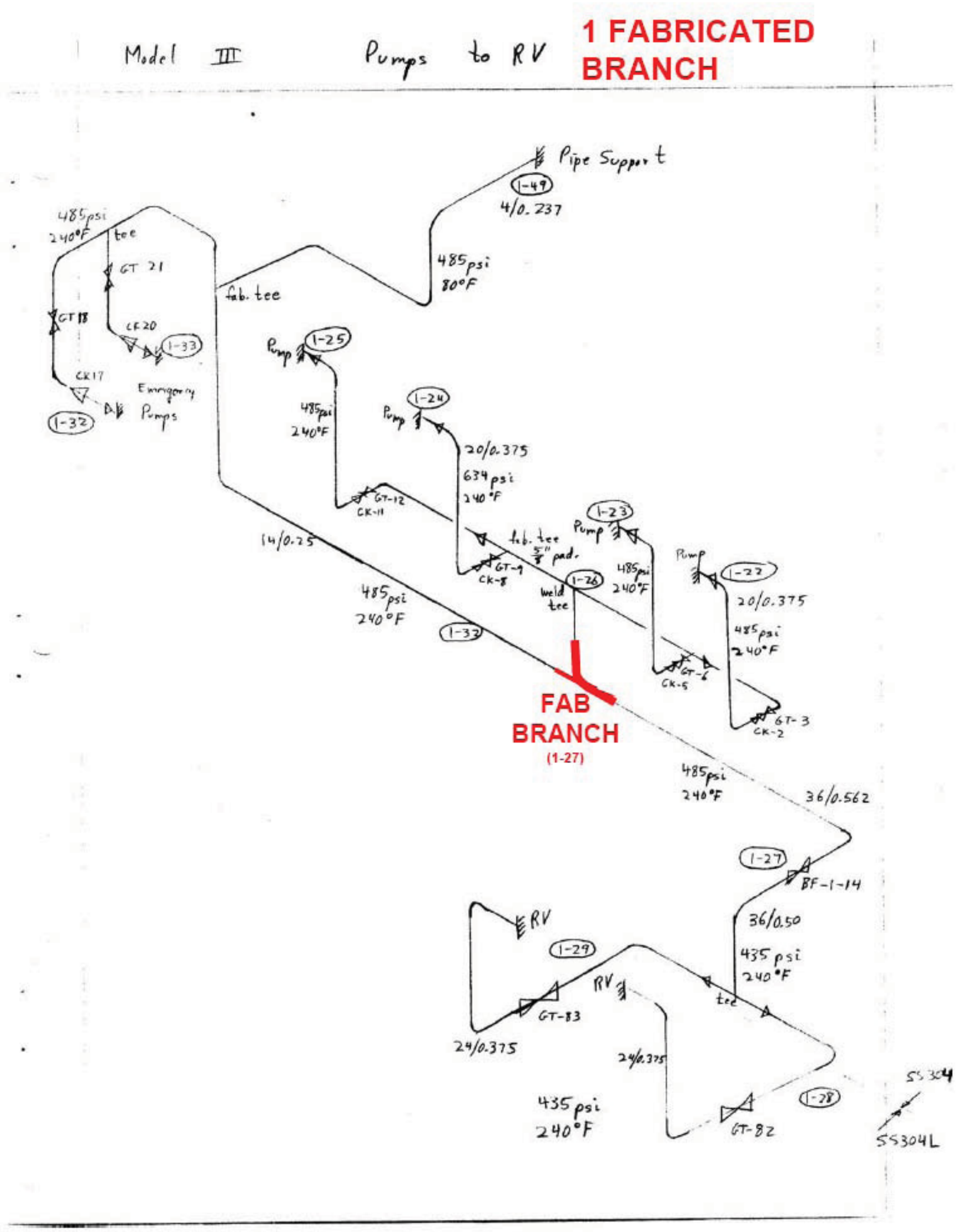

Figure B.1-8. Fabricated Branch Associated with Model 3 [1]

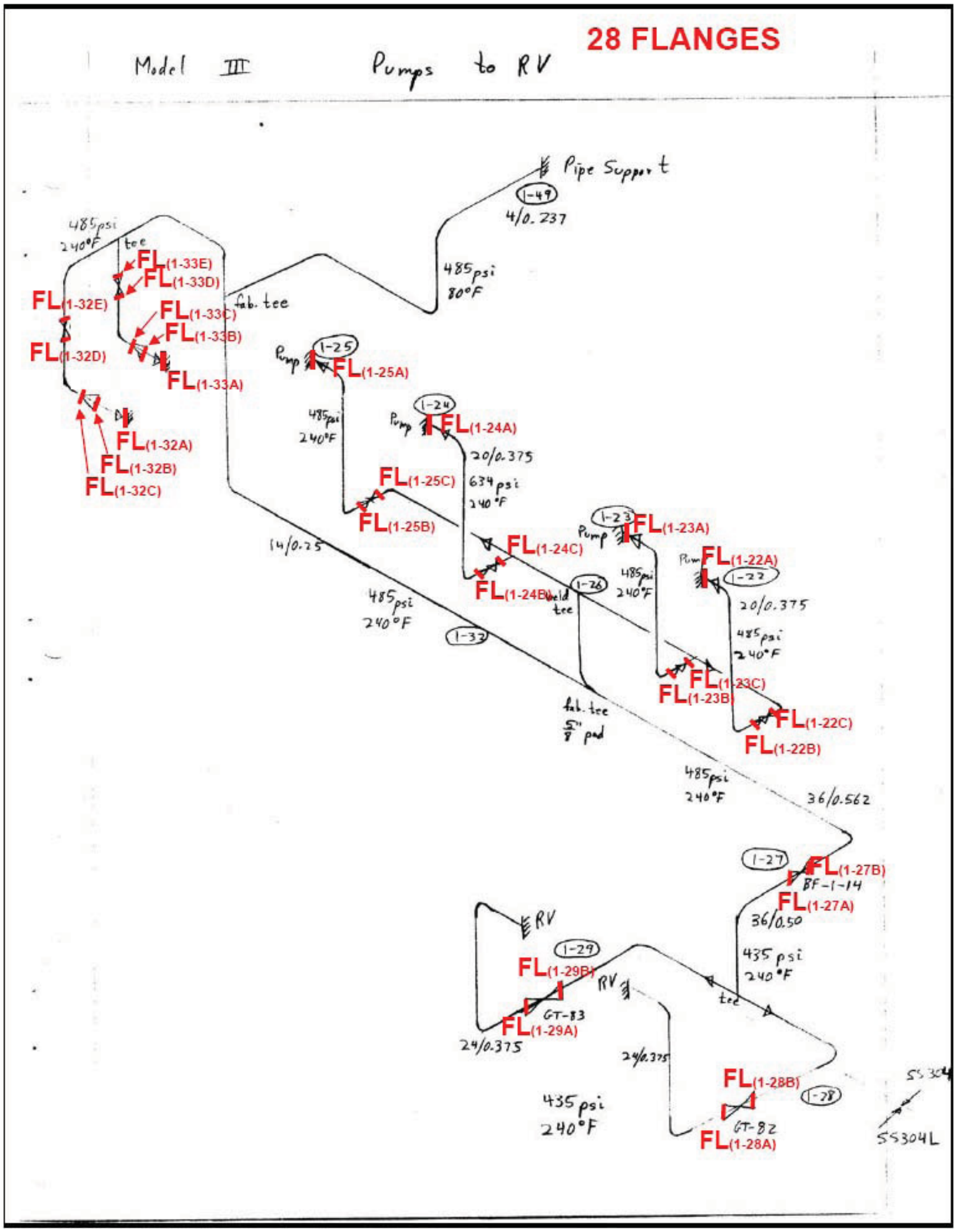

Figure B.1-9. Flanges Associated with Model 3 [1]

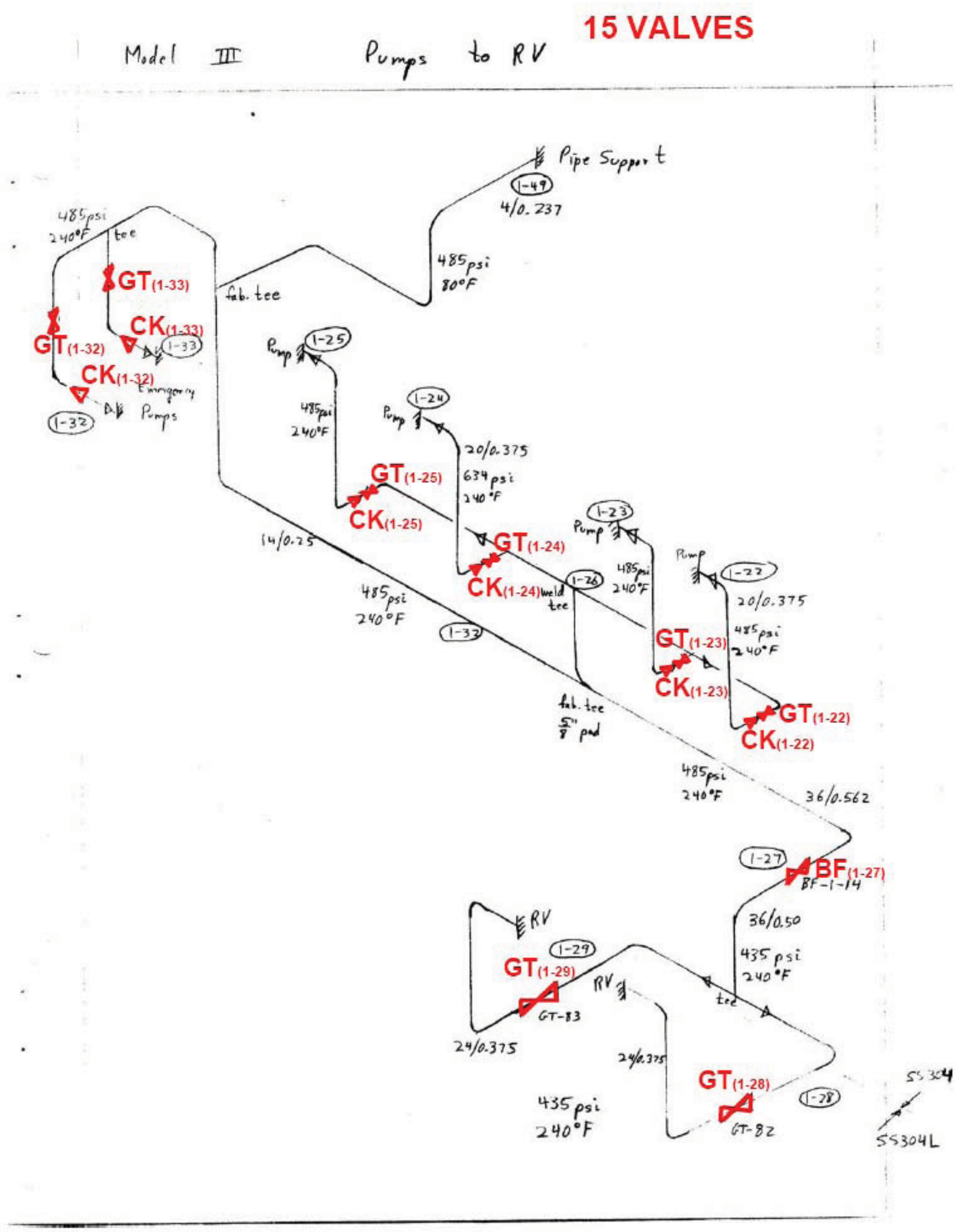

Figure B.1-10. Valves Associated with Model 3 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** M. J. Russell **Date:** 09/30/08

Appendix B.2

I-DEAS Model of Model 3

Project:	ATR Life-Time Extension Project			**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation						
Performer:	A. L. Crawford	**Date:**	09/30/08	**Checker:**	M. J. Russell	**Date:**	09/30/08

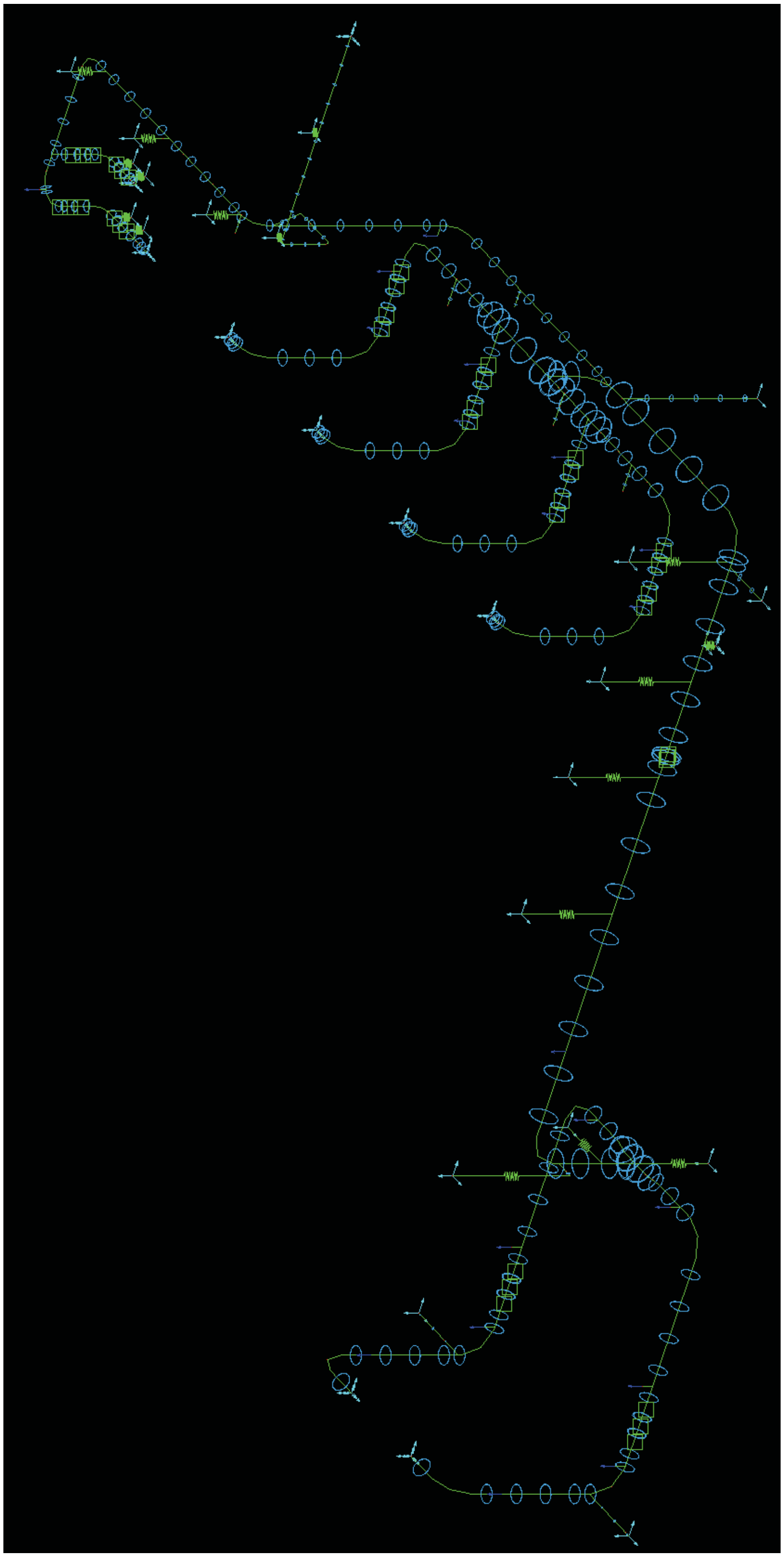

Figure B.2-1. Complete Model 3 Piping System

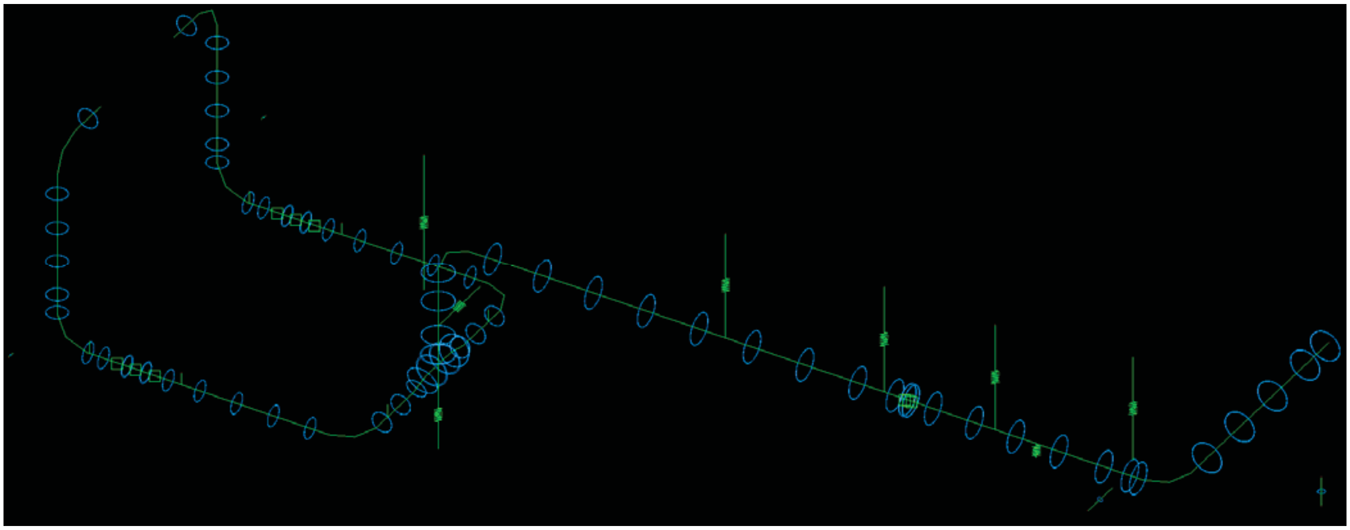

Figure B.2-2. Group of Components Associated with Lines 27-29 of Model 3

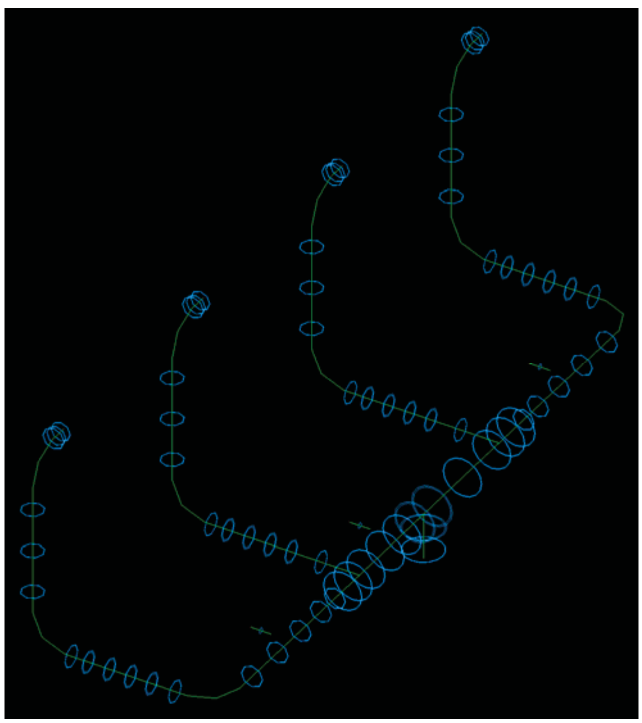

Figure B.2-3. Group of Components Associated with Lines 22-26 of Model 3

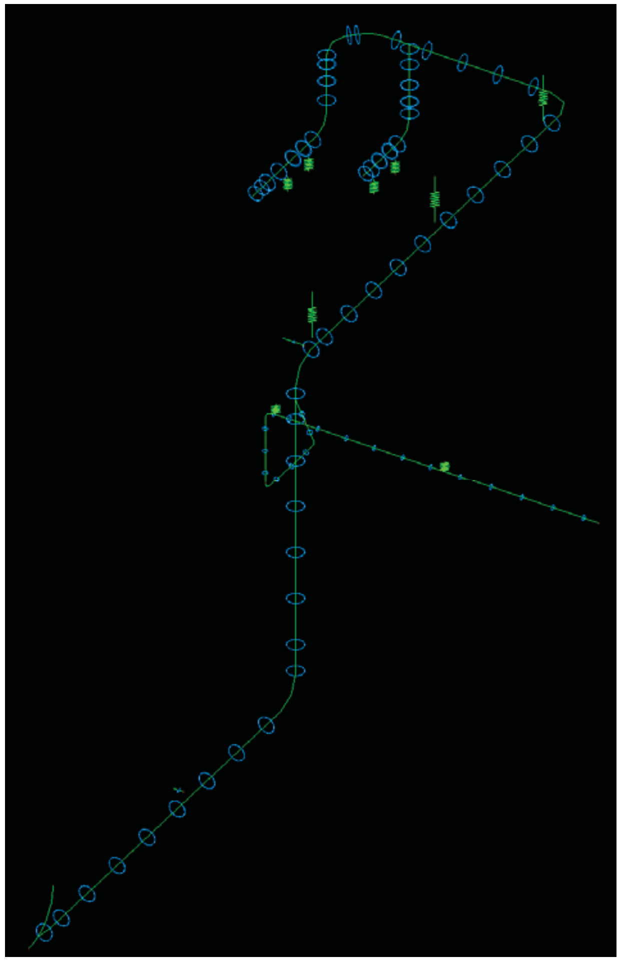

Figure B.2-4. Group of Components Associated with Lines 32, 33, and 49 of Model 3

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** M. J. Russell **Date:** 09/30/08

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**%                     ... TIME   : sec
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**%                     ... TEMPERATURE : deg Fahrenheit
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*ELEMENT, TYPE=B32      , ELSET=ELBOW_15
    341,     249,     141,     250
*ELEMENT, TYPE=B32      , ELSET=ELBOW_16
    338,     123,     124,     125
    343,     255,     145,     254
    344,     257,     137,     253
*ELEMENT, TYPE=B32      , ELSET=ELBOW_17
    339,     128,     134,     129
*ELEMENT, TYPE=B32      , ELSET=ELBOW_18
    340,     252,     132,     251
*ELEMENT, TYPE=B32      , ELSET=ELBOW_19
    349,     244,     153,     240
*ELEMENT, TYPE=B32      , ELSET=ELBOW_20
    348,     243,     152,     242
*ELEMENT, TYPE=B32      , ELSET=ELBOW_21
    347,     246,     151,     245
*ELEMENT, TYPE=B32      , ELSET=ELBOW_22
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    323,      32,     113,      33
    326,       8,     112,       9
*ELEMENT, TYPE=B32     , ELSET=ELBOW_23
    325,       4,     114,       5
*ELEMENT, TYPE=B32     , ELSET=ELBOW_24
    322,      26,     115,      29
*ELEMENT, TYPE=B32     , ELSET=ELBOW_25
    327,      13,     116,      14
*ELEMENT, TYPE=B32     , ELSET=ELBOW_26
    324,      37,     117,      38
*MPC
 BEAM,      80,      82
*MPC
 BEAM,      51,     350
*MPC
 BEAM,     378,     259
*MPC
 BEAM,     380,     258
*MPC
 BEAM,     382,     261
*MPC
 BEAM,     388,     139
*MPC
 BEAM,     390,     138
*MPC
 BEAM,     384,     147
*MPC
 BEAM,     386,     148
*MPC
 BEAM,     397,      49
*MPC
 BEAM,     401,      50
*MPC
 BEAM,     421,     419
*MPC
 BEAM,     439,      89
*MPC
 BEAM,     427,     103
*MPC
 BEAM,     433,     263
*MPC
 BEAM,     430,     264
*MPC
 BEAM,     265,     436
*MPC
 BEAM,     504,     502
*MPC
 BEAM,     505,     503
*MPC
 BEAM,     513,      24
*MPC
 BEAM,     512,      48
*MPC
 BEAM,     516,     186
*MPC
 BEAM,     517,     166
*MPC
 BEAM,     518,     167
*MPC
 BEAM,     519,     198
*MPC
 BEAM,     533,     532
*MPC
 BEAM,     534,     259
*MPC
 BEAM,     541,      19
*MPC
 BEAM,     542,      43
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*MPC
 BEAM,    590,    531
*ELEMENT, TYPE=SPRINGA , ELSET=PS5_SPRING
    531,    386,    371
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    534,    384,    372
*ELEMENT, TYPE=SPRINGA , ELSET=TIEBACK_SPRING
    555,    102,    463
*ELEMENT, TYPE=SPRINGA , ELSET=TUNNEL_RES_SPRING
    589,    485,     88
*ELEMENT, TYPE=SPRINGA , ELSET=PR8_SPRING
    590,    350,     59
*ELEMENT, TYPE=SPRINGA , ELSET=RH25X_SPRING
    651,     63,    537
    652,    536,     69
*ELEMENT, TYPE=SPRINGA , ELSET=RH26X_SPRING
    650,     84,    538
*ELEMENT, TYPE=SPRINGA , ELSET=RH23X_SPRING
    653,    440,    394
*ELEMENT, TYPE=SPRINGA , ELSET=RH27X_SPRING
    654,    539,    421
*ELEMENT, TYPE=SPRINGA , ELSET=RH29_SPRING
    655,    370,    369
    656,    368,    154
*ELEMENT, TYPE=SPRINGA , ELSET=RH15A_SPRING
    659,    365,    378
*ELEMENT, TYPE=SPRINGA , ELSET=RH15_SPRING
    657,    367,    382
    658,    366,    380
*ELEMENT, TYPE=MASS    , ELSET=LMASS36LAP
     70,     65
     71,     62
*ELEMENT, TYPE=MASS    , ELSET=LMASS36BF
     72,     64
*ELEMENT, TYPE=MASS    , ELSET=LMASS24GT
     17,     11
     52,     35
*ELEMENT, TYPE=MASS    , ELSET=LMASS24LAP
     15,     10
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     51,     36
*ELEMENT, TYPE=MASS    , ELSET=LMASS20LAP
    243,    186
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    262,    199
*ELEMENT, TYPE=MASS    , ELSET=LMASS14LAP
    314,    139
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    542,    136
*ELEMENT, TYPE=MASS    , ELSET=LMASS20GT
    244,    221
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    259,    230
*ELEMENT, TYPE=MASS    , ELSET=LMASS14GT
    537,    453
    538,    454
*ELEMENT, TYPE=MASS    , ELSET=LMASS20CK
    246,    220
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    261,    229
*ELEMENT, TYPE=MASS    , ELSET=LMASS14CK
    315,    267
    318,    268
**%
**% I-DEAS BEAM CROSS SECTION: PIPE8_625X0_322
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
```

```
 ELSET=BEAM,
 SECTION=PIPE
 0.43125E+01, 0.32200E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=A7_STEEL
*ELASTIC,TYPE=ISOTROPIC
 3.00000E+07,  2.90000E-01
*DENSITY
 7.31737E-04,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE2_5X5
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_1,
 SECTION=PIPE
 0.14400E+01, 0.20500E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: RECT1_5X6_0
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_2,
 SECTION=RECT
 0.15000E+01, 0.60000E+01
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: RECT3_0X10_0
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_3,
 SECTION=RECT
 0.30000E+01, 0.10000E+02
 0.00000E+00,-0.10000E+01, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: RECT3_0X7_0
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_4,
 SECTION=RECT
 0.30000E+01, 0.70000E+01
 0.00000E+00,-0.10000E+01, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: RECT3_0X7_0
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_5,
 SECTION=RECT
 0.30000E+01, 0.70000E+01
 0.00000E+00, 0.10000E+01, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: MS2
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_6,
 SECTION=CIRC
 0.30000E+01,
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: MS5,7,8
**%
*BEAM SECTION,
```

```
 MATERIAL=A7_STEEL,
 ELSET=BEAM_7,
 SECTION=CIRC
 0.25000E+01,
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PS21ANGLE
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_8,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.17495E+01, 0.40282E+00, 0.00000E+00, 0.15199E+01, 0.90268E-01, 0, 0.00000E+00
 0.00000E+00,-0.70710E+00,-0.70710E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00,-0.79709E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**%INFO: THE ABOVE CROSS SECTION CANNOT BE TRANSLATED TO AN
**%INFO: ABAQUS LIBRARY SECTION AND HENCE IS WRITTEN AS BEAM
**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
**%
**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5
**%
*BEAM SECTION,
 MATERIAL=SST304_36X05,
 ELSET=PIPE,
 SECTION=PIPE
 0.18000E+02, 0.50000E+00
 0.00000E+00,-0.97014E+00,-0.24253E+00
*MATERIAL,NAME=SST304_36X05
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.33600E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5
**%
*BEAM SECTION,
 MATERIAL=SST304_36X05,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.18000E+02, 0.50000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5
**%
*BEAM SECTION,
 MATERIAL=SST304_36X05,
 ELSET=PIPE_2,
 SECTION=PIPE
 0.18000E+02, 0.50000E+00
 0.00000E+00, 0.97014E+00,-0.24253E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304_20X0375,
 ELSET=PIPE_3,
 SECTION=PIPE
 0.10000E+02, 0.37500E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_20X0375
```

```
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.90100E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304_20X0375,
 ELSET=PIPE_4,
 SECTION=PIPE
 0.10000E+02, 0.37500E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5625
**%
*BEAM SECTION,
 MATERIAL=SST304_36X05625 ,
 ELSET=PIPE_5,
 SECTION=PIPE
 0.18000E+02, 0.56250E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_36X05625
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5625
**%
*BEAM SECTION,
 MATERIAL=SST304_36X05625 ,
 ELSET=PIPE_6,
 SECTION=PIPE
 0.18000E+02, 0.56250E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5625
**%
*BEAM SECTION,
 MATERIAL=SST304_36X05625 ,
 ELSET=PIPE_7,
 SECTION=PIPE
 0.18000E+02, 0.56250E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE18_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304_18X0375,
 ELSET=PIPE_8,
 SECTION=PIPE
 0.90000E+01, 0.37500E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_18X0375
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.80300E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE14_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_14X025 ,
 ELSET=PIPE_9,
```

```
 SECTION=PIPE
 0.70000E+01, 0.25000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_14X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.96300E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE14_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_14X025 ,
 ELSET=PIPE_10 ,
 SECTION=PIPE
 0.70000E+01, 0.25000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE14_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_14X025 ,
 ELSET=PIPE_11 ,
 SECTION=PIPE
 0.70000E+01, 0.25000E+00
 0.00000E+00, 0.10000E+01, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE14_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_14X025 ,
 ELSET=PIPE_12 ,
 SECTION=PIPE
 0.70000E+01, 0.25000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE4_5X0_237
**%
*BEAM SECTION,
 MATERIAL=SST304_4X0237 ,
 ELSET=PIPE_13 ,
 SECTION=PIPE
 0.22500E+01, 0.23700E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_4X0237
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.10000E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE4_5X0_237
**%
*BEAM SECTION,
 MATERIAL=SST304_4X0237 ,
 ELSET=PIPE_14 ,
 SECTION=PIPE
 0.22500E+01, 0.23700E+00
 0.50000E+00,-0.70710E+00,-0.50000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE4_5X0_237
**%
*BEAM SECTION,
 MATERIAL=SST304_4X0237 ,
 ELSET=PIPE_15 ,
 SECTION=PIPE
 0.22500E+01, 0.23700E+00
```

```
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE12_75X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_12X025 ,
 ELSET=PIPE_16 ,
 SECTION=PIPE
 0.63750E+01, 0.25000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_12X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.87300E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304L_24X0375 ,
 ELSET=PIPE_17 ,
 SECTION=PIPE
 0.12000E+02, 0.37500E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304L_24X0375
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304L_24X0375 ,
 ELSET=PIPE_18 ,
 SECTION=PIPE
 0.12000E+02, 0.37500E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304L_24X0375 ,
 ELSET=PIPE_19 ,
 SECTION=PIPE
 0.12000E+02, 0.37500E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304_24X0375,
 ELSET=PIPE_20 ,
 SECTION=PIPE
 0.12000E+02, 0.37500E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_24X0375
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_375
**%
*BEAM SECTION,
```

```
 MATERIAL=SST304_24X0375,
 ELSET=PIPE_21 ,
 SECTION=PIPE
 0.12000E+02, 0.37500E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_5
**%
*BEAM SECTION,
 MATERIAL=SST304_RED24X05 ,
 ELSET=PIPE_22 ,
 SECTION=PIPE
 0.12000E+02, 0.50000E+00
 0.00000E+00,-0.97014E+00,-0.24253E+00
*MATERIAL,NAME=SST304_RED24X05
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.77600E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_5
**%
*BEAM SECTION,
 MATERIAL=SST304_RED24X05 ,
 ELSET=PIPE_23 ,
 SECTION=PIPE
 0.12000E+02, 0.50000E+00
 0.00000E+00, 0.97014E+00,-0.24253E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_5625
**%
*BEAM SECTION,
 MATERIAL=SST304_RED20X05625,
 ELSET=PIPE_24 ,
 SECTION=PIPE
 0.10000E+02, 0.56250E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_RED20X05625
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.48600E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_5625
**%
*BEAM SECTION,
 MATERIAL=SST304_RED20X05625,
 ELSET=PIPE_25 ,
 SECTION=PIPE
 0.10000E+02, 0.56250E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5625
**%
*BEAM SECTION,
 MATERIAL=SST304_RED36X05625,
 ELSET=PIPE_26 ,
 SECTION=PIPE
 0.18000E+02, 0.56250E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_RED36X05625
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
```

```
**%
**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5625
**%
*BEAM SECTION,
 MATERIAL=SST304_RED36X05625,
 ELSET=PIPE_27 ,
 SECTION=PIPE
 0.18000E+02, 0.56250E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304_RED20X0375 ,
 ELSET=PIPE_28 ,
 SECTION=PIPE
 0.10000E+02, 0.37500E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_RED20X0375
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.90100E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304_RED20X0375 ,
 ELSET=PIPE_29 ,
 SECTION=PIPE
 0.10000E+02, 0.37500E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE18_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304_RED18X0375 ,
 ELSET=PIPE_30 ,
 SECTION=PIPE
 0.90000E+01, 0.37500E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_RED18X0375
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.77600E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE14_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_RED14X025,
 ELSET=PIPE_31 ,
 SECTION=PIPE
 0.70000E+01, 0.25000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_RED14X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.96300E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE12_75X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_RED12X025,
```

```
 ELSET=PIPE_32 ,
 SECTION=PIPE
 0.63750E+01, 0.25000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_RED12X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.84600E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: TEE37_75X1_375
**%
*BEAM SECTION,
 MATERIAL=SST304_T3775X1375 ,
 ELSET=PIPE_33 ,
 SECTION=PIPE
 0.18875E+02, 0.13750E+01
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_T3775X1375
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.29700E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: TEE37_75X1_375
**%
*BEAM SECTION,
 MATERIAL=SST304_T3775X1375 ,
 ELSET=PIPE_34 ,
 SECTION=PIPE
 0.18875E+02, 0.13750E+01
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: TEE37_75X1_375
**%
*BEAM SECTION,
 MATERIAL=SST304_T3775X1375 ,
 ELSET=PIPE_35 ,
 SECTION=PIPE
 0.18875E+02, 0.13750E+01
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE14_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_T14X025,
 ELSET=PIPE_36 ,
 SECTION=PIPE
 0.70000E+01, 0.25000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_T14X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.96300E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5625
**%
*BEAM SECTION,
 MATERIAL=SST304_B36X05625_R,
 ELSET=PIPE_37 ,
 SECTION=PIPE
 0.18000E+02, 0.56250E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_B36X05625_R
```

```
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5625
**%
*BEAM SECTION,
 MATERIAL=SST304_B36X05625_R,
 ELSET=PIPE_38 ,
 SECTION=PIPE
 0.18000E+02, 0.56250E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304_B20X0375_BR,
 ELSET=PIPE_39 ,
 SECTION=PIPE
 0.10000E+02, 0.37500E+00
 0.00000E+00, 0.10000E+01, 0.00000E+00
*MATERIAL,NAME=SST304_B20X0375_BR
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: BR_36X20BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_40 ,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.23120E+02, 0.50029E+02, 0.00000E+00, 0.22421E+03, 0.22270E+04, 0, 0.00000E+00
 0.00000E+00,-0.10000E+01, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE14_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_B14X05625_R,
 ELSET=PIPE_41 ,
 SECTION=PIPE
 0.70000E+01, 0.25000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_B14X05625_R
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.96300E-03,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: BR_14X4_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_42 ,
 DENSITY= 0.11000E-02,
 ZERO= 0.00000E+00
 0.31740E+01, 0.19450E+01, 0.00000E+00, 0.51470E+01, 0.14465E+02, 0, 0.00000E+00
 0.00000E+00, 0.10000E+01, 0.00000E+00
```

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 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: VALVE36X1_206
**%
*BEAM SECTION,
 MATERIAL=SST304_BV36 ,
 ELSET=PIPE_43 ,
 SECTION=PIPE
 0.18000E+02, 0.12060E+01
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_BV36
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 3.44500E-05,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: VALVE24X1_258
**%
*BEAM SECTION,
 MATERIAL=SST304_V24,
 ELSET=PIPE_44 ,
 SECTION=PIPE
 0.12000E+02, 0.12580E+01
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_V24
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.24600E-05,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: VALVE20X1_293
**%
*BEAM SECTION,
 MATERIAL=SST304_V20,
 ELSET=PIPE_45 ,
 SECTION=PIPE
 0.10000E+02, 0.12930E+01
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_V20
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.20700E-05,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: VALVE14X0_855
**%
*BEAM SECTION,
 MATERIAL=SST304_V14,
 ELSET=PIPE_46 ,
 SECTION=PIPE
 0.70000E+01, 0.85500E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_V14
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.37100E-05,
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: VALVE14X0_855
```

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**%
*BEAM SECTION,
 MATERIAL=SST304_V14,
 ELSET=PIPE_47 ,
 SECTION=PIPE
 0.70000E+01, 0.85500E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: VALVE14X0_855
**%
*BEAM SECTION,
 MATERIAL=SST304_V14,
 ELSET=PIPE_48 ,
 SECTION=PIPE
 0.70000E+01, 0.85500E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: IBEAM3X7_5
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW ,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.22486E+01, 0.66167E+00, 0.00000E+00, 0.29986E+01, 0.89192E-01, 0, 0.12846E+01
 0.00000E+00, 0.00000E+00,-0.10000E+01
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**%INFO: THE ABOVE CROSS SECTION CANNOT BE TRANSLATED TO AN
**%INFO: ABAQUS LIBRARY SECTION AND HENCE IS WRITTEN AS BEAM
**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
**%
**% I-DEAS BEAM CROSS SECTION: CIRC1_25
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=ELBOW_1 ,
 SECTION=CIRC
 0.62500E+00,
-0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: CIRC1_25
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=ELBOW_2 ,
 SECTION=CIRC
 0.62500E+00,
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE4_5X0_237
**%
*BEAM SECTION,
 MATERIAL=SST304_4X0237 ,
 ELSET=ELBOW_3 ,
 SECTION=PIPE
 0.22500E+01, 0.23700E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW36_0X0_5R36P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_4 ,
```

```
 DENSITY= 0.23360E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.43273E+03, 0.00000E+00, 0.43273E+03, 0.17572E+05, 0, 0.00000E+00
-0.70710E+00, 0.70710E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW20_0X0_375R30P485
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_5 ,
 DENSITY= 0.19010E-02,
 ZERO= 0.00000E+00
 0.23120E+02, 0.10359E+03, 0.00000E+00, 0.10359E+03, 0.22269E+04, 0, 0.00000E+00
 0.00000E+00, 0.70710E+00, 0.70710E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW20_0X0_375R30P400
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_6 ,
 DENSITY= 0.19010E-02,
 ZERO= 0.00000E+00
 0.23120E+02, 0.98786E+02, 0.00000E+00, 0.98786E+02, 0.22269E+04, 0, 0.00000E+00
-0.70710E+00,-0.70710E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW20_0X0_375R30P400
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_7 ,
 DENSITY= 0.19010E-02,
 ZERO= 0.00000E+00
 0.23120E+02, 0.98786E+02, 0.00000E+00, 0.98786E+02, 0.22269E+04, 0, 0.00000E+00
 0.00000E+00, 0.70710E+00, 0.70710E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW20_0X0_375R30P400
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_8 ,
 DENSITY= 0.19010E-02,
 ZERO= 0.00000E+00
 0.23120E+02, 0.98786E+02, 0.00000E+00, 0.98786E+02, 0.22269E+04, 0, 0.00000E+00
 0.70710E+00, 0.00000E+00,-0.70710E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
```

```
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW20_0X0_375R30P400
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_9 ,
 DENSITY= 0.19010E-02,
 ZERO= 0.00000E+00
 0.23120E+02, 0.98786E+02, 0.00000E+00, 0.98786E+02, 0.22269E+04, 0, 0.00000E+00
 0.70710E+00, 0.00000E+00, 0.70710E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW36_0X0_5625R36P400
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_10,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.62623E+02, 0.51514E+03, 0.00000E+00, 0.51514E+03, 0.19666E+05, 0, 0.00000E+00
 0.70710E+00, 0.00000E+00, 0.70710E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW36_0X0_5625R36P400_FAB
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_11,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.62623E+02, 0.51820E+03, 0.00000E+00, 0.51820E+03, 0.19666E+05, 0, 0.00000E+00
-0.20000E-04,-0.98078E+00,-0.19510E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW36_0X0_5625R36P400_FAB
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_12,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.62623E+02, 0.51820E+03, 0.00000E+00, 0.51820E+03, 0.19666E+05, 0, 0.00000E+00
 0.00000E+00,-0.38268E+00,-0.92387E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW36_0X0_5625R36P400_FAB
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_13,
 DENSITY= 0.21500E-02,
```

```
 ZERO= 0.00000E+00
 0.62623E+02, 0.51820E+03, 0.00000E+00, 0.51820E+03, 0.19666E+05, 0, 0.00000E+00
 0.00000E+00,-0.83146E+00,-0.55557E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW14_0X0_25SR14P400
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_14,
 DENSITY= 0.19630E-02,
 ZERO= 0.00000E+00
 0.10799E+02, 0.14299E+02, 0.00000E+00, 0.14299E+02, 0.51060E+03, 0, 0.00000E+00
 0.81649E+00,-0.57735E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW14_0X0_25LR21P400
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_15,
 DENSITY= 0.19630E-02,
 ZERO= 0.00000E+00
 0.10799E+02, 0.22065E+02, 0.00000E+00, 0.22065E+02, 0.51060E+03, 0, 0.00000E+00
-0.38268E+00, 0.00000E+00,-0.92387E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW14_0X0_25LR21P400
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_16,
 DENSITY= 0.19630E-02,
 ZERO= 0.00000E+00
 0.10799E+02, 0.22065E+02, 0.00000E+00, 0.22065E+02, 0.51060E+03, 0, 0.00000E+00
 0.00000E+00,-0.70710E+00,-0.70710E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW14_0X0_25LR21P400
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_17,
 DENSITY= 0.19630E-02,
 ZERO= 0.00000E+00
 0.10799E+02, 0.22065E+02, 0.00000E+00, 0.22065E+02, 0.51060E+03, 0, 0.00000E+00
 0.00000E+00, 0.70710E+00, 0.70710E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
```

```
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW14_0X0_25LR21P400
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_18,
 DENSITY= 0.19630E-02,
 ZERO= 0.00000E+00
 0.10799E+02, 0.22065E+02, 0.00000E+00, 0.22065E+02, 0.51060E+03, 0, 0.00000E+00
 0.70710E+00, 0.00000E+00,-0.70710E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW4_5X0_237R6P400
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_19,
 DENSITY= 0.11000E-02,
 ZERO= 0.00000E+00
 0.31741E+01, 0.13999E+01, 0.00000E+00, 0.13999E+01, 0.14465E+02, 0, 0.00000E+00
-0.70711E+00, 0.70709E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW4_5X0_237R6P400
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_20,
 DENSITY= 0.11000E-02,
 ZERO= 0.00000E+00
 0.31741E+01, 0.13999E+01, 0.00000E+00, 0.13999E+01, 0.14465E+02, 0, 0.00000E+00
 0.00000E+00,-0.70710E+00, 0.70710E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW4_5X0_237R6P400
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_21,
 DENSITY= 0.11000E-02,
 ZERO= 0.00000E+00
 0.31741E+01, 0.13999E+01, 0.00000E+00, 0.13999E+01, 0.14465E+02, 0, 0.00000E+00
 0.92387E+00, 0.00000E+00,-0.38269E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW24_0X0_375R36P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_22,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
```

```
 0.27832E+02, 0.15558E+03, 0.00000E+00, 0.15558E+03, 0.38846E+04, 0, 0.00000E+00
-0.70702E+00,-0.70718E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW24_0X0_375R36P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_23,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.15558E+03, 0.00000E+00, 0.15558E+03, 0.38846E+04, 0, 0.00000E+00
 0.00000E+00, 0.70710E+00,-0.70710E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW24_0X0_375R36P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_24,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.15558E+03, 0.00000E+00, 0.15558E+03, 0.38846E+04, 0, 0.00000E+00
 0.00000E+00, 0.70710E+00, 0.70710E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW24_0X0_375R36P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_25,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.15558E+03, 0.00000E+00, 0.15558E+03, 0.38846E+04, 0, 0.00000E+00
 0.70710E+00, 0.00000E+00,-0.70710E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW24_0X0_375R36P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_26,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.15558E+03, 0.00000E+00, 0.15558E+03, 0.38846E+04, 0, 0.00000E+00
 0.70710E+00, 0.00000E+00, 0.70710E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
```

```
*SPRING, ELSET=PS5_SPRING,NONLINEAR

  -1.0000E+6, -0.15093
   0.0000E+0, 0.0000E+0
*SPRING, ELSET=TIEBACK_SPRING,NONLINEAR

  -1.0000E+6, -0.7701149428
   0.0000E+0, -0.7500E+0
*SPRING, ELSET=TUNNEL_RES_SPRING,NONLINEAR

  -1.0000E+6, -0.2686968
   0.0000E+0, 0.0000E+0
   1.0000E+6, 0.6717423519
*SPRING, ELSET=PR8_SPRING

  1.0000E+01,
*SPRING, ELSET=RH25X_SPRING,NONLINEAR

   0.0000E+0, 0.0000E+0
   1.0000E+6, 1.60165
*SPRING, ELSET=RH26X_SPRING,NONLINEAR

   0.0000E+0, 0.0000E+0
   1.0000E+6, 1.60165
*SPRING, ELSET=RH23X_SPRING,NONLINEAR

  -1.0000E+6, -5.24244
   0.0000E+0, -0.4375
   0.0000E+0, 0.0000E+0
   1.0000E+6, 4.80494
*SPRING, ELSET=RH27X_SPRING,NONLINEAR

   0.0000E+0, 0.0000E+0
   1.0000E+6, 1.33947
*SPRING, ELSET=RH29_SPRING,NONLINEAR

  -1.0000E+6, -1.14803
   0.0000E+0, -0.625
   0.0000E+0, 0.0000E+0
   1.0000E+6, 0.52313
*SPRING, ELSET=RH15A_SPRING,NONLINEAR

  -1.0000E+6, -2.64553
   0.0000E+0, -0.8125
   0.0000E+0, 0.0000E+0
   1.0000E+6, 1.83303
*SPRING, ELSET=RH15_SPRING,NONLINEAR

  -1.0000E+6, -3.25871
   0.0000E+0, 0.0000E+0
   1.0000E+6, 3.25871
*MASS, ALPHA=0.9492,
 ELSET=LMASS36LAP
  2.82100E+00,
*MASS, ALPHA=0.9492,
 ELSET=LMASS36BF
  8.66100E+00,
*MASS, ALPHA=0.9492,
 ELSET=LMASS24GT
  1.54240E+01,
*MASS, ALPHA=0.9492,
 ELSET=LMASS24LAP
  1.23800E+00,
*MASS, ALPHA=0.9492,
 ELSET=LMASS20LAP
  8.29000E-01,
*MASS, ALPHA=0.9492,
 ELSET=LMASS14LAP
```

```
  4.30000E-01,
*MASS, ALPHA=0.9492,
 ELSET=LMASS20GT
  9.00100E+00,
*MASS, ALPHA=0.9492,
 ELSET=LMASS14GT
  4.66200E+00,
*MASS, ALPHA=0.9492,
 ELSET=LMASS20CK
  8.19800E+00,
*MASS, ALPHA=0.9492,
 ELSET=LMASS14CK
  2.92900E+00,
**%
*ELSET, ELSET=ALLELEMENTS
 BEAM,
 BEAM_1,
 BEAM_2,
 BEAM_3,
 BEAM_4,
 BEAM_5,
 BEAM_6,
 BEAM_7,
 BEAM_8,
 PIPE,
 PIPE_1,
 PIPE_2,
 PIPE_3,
 PIPE_4,
 PIPE_5,
 PIPE_6,
 PIPE_7,
 PIPE_8,
 PIPE_9,
 PIPE_10 ,
 PIPE_11 ,
 PIPE_12 ,
 PIPE_13 ,
 PIPE_14 ,
 PIPE_15 ,
 PIPE_16 ,
 PIPE_17 ,
 PIPE_18 ,
 PIPE_19 ,
 PIPE_20 ,
 PIPE_21 ,
 PIPE_22 ,
 PIPE_23 ,
 PIPE_24 ,
 PIPE_25 ,
 PIPE_26 ,
 PIPE_27 ,
 PIPE_28 ,
 PIPE_29 ,
 PIPE_30 ,
 PIPE_31 ,
 PIPE_32 ,
 PIPE_33 ,
 PIPE_34 ,
 PIPE_35 ,
 PIPE_36 ,
 PIPE_37 ,
 PIPE_38 ,
 PIPE_39 ,
 PIPE_40 ,
 PIPE_41 ,
 PIPE_42 ,
 PIPE_43 ,
```

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```
 PIPE_44 ,
 PIPE_45 ,
 PIPE_46 ,
 PIPE_47 ,
 PIPE_48 ,
 ELBOW ,
 ELBOW_1 ,
 ELBOW_2 ,
 ELBOW_3 ,
 ELBOW_4 ,
 ELBOW_5 ,
 ELBOW_6 ,
 ELBOW_7 ,
 ELBOW_8 ,
 ELBOW_9 ,
 ELBOW_10,
 ELBOW_11,
 ELBOW_12,
 ELBOW_13,
 ELBOW_14,
 ELBOW_15,
 ELBOW_16,
 ELBOW_17,
 ELBOW_18,
 ELBOW_19,
 ELBOW_20,
 ELBOW_21,
 ELBOW_22,
 ELBOW_23,
 ELBOW_24,
 ELBOW_25,
 ELBOW_26,
 LMASS36LAP,
 LMASS36BF ,
 LMASS24GT ,
 PS5_SPRING,
 LMASS24LAP,
 LMASS20LAP,
 LMASS14LAP,
 LMASS20GT ,
 LMASS14GT ,
 LMASS20CK ,
 LMASS14CK ,
 TIEBACK_SPRING,
 TUNNEL_RES_SPRING ,
 PR8_SPRING,
 RH25X_SPRING,
 RH26X_SPRING,
 RH23X_SPRING,
 RH27X_SPRING,
 RH29_SPRING ,
 RH15A_SPRING,
 RH15_SPRING ,
**%
*NSET,NSET=ALL, GENERATE
         1,         4,         3
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
       545,       610,         1
*NSET,NSET=SUP_ELB_TEE_RED_FABBR
       4,        5,        8,        9,       10,       11,       12,       13,       14,       15,       29
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     454,      463,      480,      481,      482,      484,      485
*NSET,NSET=ELBOWS
       4,        5,        8,        9,       13,       14,       29,       32,       33,       37,       38
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     255,      257,      272
*NSET,NSET=LINES27TO29
       1,        4,        5,        8,        9,       10,       11,       12,       13,       14,       15
```

```
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     561,      562,      563,      564,      565,      566,      567,      568,      569
*NSET,NSET=LINES22TO26, GENERATE
      79,      159,       80
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
       573,       584,         1
*NSET,NSET=LINES32_33_49
      78,       79,      120,      121,      122,      123,      124,      125,      128,      129,      132
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     609,      610
*NSET,NSET=MODEL4_INPUT
      63,
*NSET,NSET=BC_NS_X_N1372
     140,      149,      371,      372,      373,      374
*NSET,NSET=BC_NS_X_N552
      59,       81,      102,      183,      184,      196,      207,      365,      366,      367,      394
     400,      404,      429,      463,      485,      535,      536,      537,      538,      539
*NSET,NSET=BC_NS_X_N815
     266,      368,      370
*NSET,NSET=BC_V_Y_N1577
       1,       25,      394
*NSET,NSET=BC_V_Y_N552
      59,       81,      140,      149,      183,      184,      196,      207,      266,      365,      366
     367,      368,      370,      371,      372,      373,      374,      400,      404,      429,      463
     485,      536,      537,      538,      539
*NSET,NSET=BC_EW_Z_N1577
       1,       25,      394
*NSET,NSET=BC_EW_Z_N319
      59,       81,      102,      400,      404,      429,      463,      485
*NSET,NSET=BC_EW_Z_N552
     140,      149,      183,      184,      196,      207,      266,      365,      366,      367,      368
     370,      371,      372,      373,      374,      536,      537,      538,      539
*NSET,NSET=BC_NS_X_N1577
       1,       25
*ELSET,ELSET=ALL
       1,        5,        7,        9,       10,       11,       12,       14,       15,       16,       17
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     730,
*ELSET,ELSET=SUPPORT_RELEASE_1
     475,      478,      527
*ELSET,ELSET=SUP_ELB_TEE_RED_FABBR
      15,       16,       17,       50,       51,       52,       55,       56,       57,       58,       59
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     577,      578,      579,      580,      581,      583,      584,      589,      590
*ELSET,ELSET=ELBOWS, GENERATE
       320,       349,         1
*ELSET,ELSET=PIPE_RUNS
       1,        5,        7,        9,       10,       11,       12,       14,       25,       26,       27
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     403,      421,      422,      423,      443,      444,      469,      495,      496
*ELSET,ELSET=LINES27TO29
       1,        5,        7,        9,       10,       11,       12,       14,       15,       16,       17
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     684,      685,      686,      687
*ELSET,ELSET=LINES22TO26
     136,      137,      138,      140,      141,      143,      144,      145,      146,      147,      148
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     695,      696,      697,      698,      699,      700,      701,      702,      703
*ELSET,ELSET=LINES32_33_49
     206,      207,      212,      217,      218,      225,      230,      241,      242,      270,      272
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     729,      730
*ELSET,ELSET=MODEL4_INPUT
      67,
**%
<<--Replace Time History-->> (KEY PHRASE USED IN SCRIPTING PROCESS)
**%
*NSET,NSET=BS000001
```

```
59,81,365,366,367,368,370,371,372,373,374,394,400,404,429,485
536,537,538,539
*NSET,NSET=BS000002
1,25,140,149,183,184,196,207,266,463
*RELEASE
SUPPORT_RELEASE_1, S1, M1-M2
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
**% Note: Nodes vertical is possitive z
**%       Elements vertical is possitive y
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.01
 0.005,1.0,1.0E-08,1.0
**%  STATIC PLUS SEISMIC
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
        535,  1,,       0.00000E+00
        102,  1,,       0.00000E+00
        102,  3,,       0.00000E+00
BS000001,    1, 3,      0.00000E+00
BS000002,    1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
        531,    2, 3.9000E+03
        513,    2, 4.5000E+03
        169,    2, 4.6000E+03
        512,    2, 5.0000E+03
        533,    2, 5.0000E+03
        168,    2, 5.1500E+03
        505,    2, 5.2500E+03
         40,    2, 5.5000E+03
        504,    2, 5.5000E+03
         16,    2, 5.7500E+03
        199,    2, 6.0500E+03
        187,    2, 6.6000E+03
        516,    2, 6.6000E+03
        519,    2, 7.2000E+03
        542,    2, 7.2000E+03
        541,    2, 7.9000E+03
         68,    2, 9.3500E+03
        517,    2, 9.6000E+03
        518,    2, 1.2900E+04
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
**%OUTPUT, FIELD
**%NODE OUTPUT
**%ELEMENT OUTPUT
*OUTPUT, HISTORY,FREQUENCY=10000
**%ELEMENT OUTPUT
*NODE PRINT, TOTAL=YES
*MONITOR, NODE=69, DOF=1
*END STEP
**%
**% ====== SEISMIC WITH G-LOAD ======
**%
**% Note: Damping is address in the material properties
**%
*STEP,INC=10000000,NLGEOM
*DYNAMIC, DIRECT
 0.005,20.0,1.0E-08,0.005
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%
*BOUNDARY,OP=NEW
BS000002,    4, 6,      0.00000E+00
*<<--H2_X_N1372_TIME_HISTORY_INPUT-->>  (KEY PHRASE USED IN SCRIPTING PROCESS)
```

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```
BC_NS_X_N1372, 1,,     1.0000E+00
*<<--H2_X_N552_TIME_HISTORY_INPUT-->>  (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_NS_X_N552, 1,,              1.0000E+00
*<<--H2_X_N815_TIME_HISTORY_INPUT-->>  (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_NS_X_N815, 1,,              1.0000E+00
*<<--H2_X_N1577_TIME_HISTORY_INPUT-->>  (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_NS_X_N1577, 1,,     1.0000E+00
*<<--V_Y_N1577_TIME_HISTORY_INPUT-->>  (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_V_Y_N1577, 2,,              1.0000E+00
*<<--V_Y_N552_TIME_HISTORY_INPUT-->>  (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_V_Y_N552, 2,,               1.0000E+00
*<<--H1_Z_N1577_TIME_HISTORY_INPUT-->>  (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_EW_Z_N1577, 3,,             1.0000E+00
*<<--H1_Z_N319_TIME_HISTORY_INPUT-->>  (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_EW_Z_N319, 3,,              1.0000E+00
*<<--H1_Z_N552_TIME_HISTORY_INPUT-->>  (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_EW_Z_N552, 3,,              1.0000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
        531,    2, 3.9000E+03
        513,    2, 4.5000E+03
        169,    2, 4.6000E+03
        512,    2, 5.0000E+03
        533,    2, 5.0000E+03
        168,    2, 5.1500E+03
        505,    2, 5.2500E+03
         40,    2, 5.5000E+03
        504,    2, 5.5000E+03
         16,    2, 5.7500E+03
        199,    2, 6.0500E+03
        187,    2, 6.6000E+03
        516,    2, 6.6000E+03
        519,    2, 7.2000E+03
        542,    2, 7.2000E+03
        541,    2, 7.9000E+03
         68,    2, 9.3500E+03
        517,    2, 9.6000E+03
        518,    2, 1.2900E+04
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT
 NFORC,SF,S
*OUTPUT, HISTORY,FREQUENCY=1
***NODE OUTPUT, NSET=CRANEND
** U,V,A
***ELEMENT OUTPUT
** UC
*NODE PRINT
*MONITOR, NODE=69, DOF=1
*END STEP
```

Project:	ATR Life-Time Extension Project			**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation						
Performer:	A. L. Crawford	**Date:**	09/30/08	**Checker:**	M. J. Russell	**Date:**	09/30/08

Appendix B.3

Calculations Associated with Model 3 Seismic Evaluation

Contents

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

Appendix B.3.1

Demand to Capacity Ratio Calculations for Components Associated with Lines 22-26 of ATR PCS Model 3

(NOTE: Values represented here are shown for one realization (Nodal Force file = Lines22to26_test_R1.dat and Element/Nodal order file = EL_22to26.xls) and may or may not be consistent with the 80th percentile results contained in Appendix B.4)

Force Outputs from Abaqus

$NF_{ML} :=$ ...\Lines22to26.dat — (N)odal (F)orces for the (M)edium (L)ines of Model 3

Defined Elemental and Corresponding Nodal Order

$EL_{ML} :=$ ...\EL_22to26(9-22-08).xls — Element and corresponding nodal order for the (M)edium (L)ines of Model 3

Time Boundaries

$t_{initial} := 1$ — Initial time for which dynamic loading is applied

$t_{final} := 21$ — Final time for which dynamic loading stops

Seismic Scale Factor (F_a)

$F_a := 1$ — Seismic scale factor

Allowable Design Stress Intensity Factor (S_m): *S_m is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{m\_125} := 20\text{ksi}$ — For SS304 at 125°F [2, pg 316-318] [3, pg 23]

$S_{m\_125L} := 16.7\text{ksi}$ — For SS304L at 125°F [2, pg 316-318] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Yield Strength (S_y): *S_y is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{y\_125} := 28.35\text{ksi}$ — For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_125L} := 23.85\text{ksi}$ — For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Maximum Strength Applicable for Equation 9 (S): *S is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{125} := \min\left(3 \cdot S_{m\_125}, 2 \cdot S_{y\_125}\right)$ — Maximum allowable stress applied to SS304 piping [9, NB-3656]

$\boxed{S_{125} = 56.7\,\text{ksi}}$

$S_{125L} := \min\left(3 \cdot S_{m\_125L}, 2 \cdot S_{y\_125L}\right)$ — Maximum allowable stress applied to SS304L piping [9, NB-3656]

$\boxed{S_{125L} = 47.7\,\text{ksi}}$

SUPPORTS

Supports Strategy: *Search based on the node for which the support acts. If this node is a termination point there will only be one node to evaluate. If this node is in line with a section of pipe there will be two representations of the same node (one for each element on each side of the node) to combine and the difference between them is the force required of the support. The D/C ratio for each support will be found by dividing the the required force found above by the support capacity.*

$$SupDC\left(P_r, P_c\right) := \frac{P_r}{P_c}$$

$\mathrm{Support}\left(nf, nd, C_o, EL\right) :=$

$$ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right)$$

$$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right)$$

$$ind_{nd} \leftarrow match\left(nd_0, EL^{\langle 1 \rangle}\right)$$

$$\text{for } i \in 1 .. last(nd) \quad \text{if } rows(nd) > 1$$

$$\quad ind_{nd} \leftarrow stack\left[ind_{nd}, \left(match\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$$

$$\left(Int1_4 \quad Int2_4\right) \leftarrow (0 \quad 0)$$

$$\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$$

$$\quad \text{for } j \in 0 .. last\left(ind_{nd}\right)$$

$$\quad\quad P_{rg_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}} - 1, ind_{nd_j}}$$

$$\quad\quad P_{r_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}} - 1 + i, ind_{nd_j}} - P_{rg_j}\right) \cdot C_{o_{2,0}} + P_{rg_j}$$

$$\quad PR_i \leftarrow \sum_{n=0}^{j} P_{r_n}$$

$$\quad \text{if } PR_i < Int1_1 \wedge C_{o_{0,0}} \neq 0$$

$$\quad\quad Int1' \leftarrow SupDC\left(\left|PR_i\right|, C_{o_{0,0}}\right)$$

$$\quad\quad Int1 \leftarrow stack\left(Int1', PR_i, nf_{ind_{nfiC_{o_{0,1}}} - 1 + i, 0}, EL_{ind_{nd_j}, 1}, ind_{nd}\right)$$

$$\quad \text{if } PR_i > Int2_1 \wedge C_{o_{1,0}} \neq 0$$

$$\quad\quad Int2' \leftarrow SupDC\left(\left|PR_i\right|, C_{o_{1,0}}\right)$$

$$\quad\quad Int2 \leftarrow stack\left(Int2', PR_i, nf_{ind_{nfiC_{o_{0,1}}} - 1 + i, 0}, EL_{ind_{nd_j}, 1}, ind_{nd}\right)$$

$$\left(Int1 \quad Int2\right)$$

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MS-5 Support (1x)

$P_{1\_MS5} := \frac{6 \cdot kip}{lbf}$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$P_{2\_MS5} := \frac{6 \cdot kip}{lbf}$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$Sup\_C_{o\_MS5} := \begin{pmatrix} P_{1\_MS5} & 1 \\ P_{2\_MS5} & 0 \\ F_a & 0 \end{pmatrix}$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

MS-5 (Node 432)

MS-7 horizontally (N/S) supports the horizontal (E/W) PCS pipe on line 1-26.

$nd432_{MS5_0} := 432$ Node associated with support

$\left(AL1_{MS5\_nd432} \;\; AL2_{MS5\_nd432}\right) := Support\left(NF_{ML}, nd432_{MS5}, Sup\_C_{o\_MS5}, EL_{ML}\right)$

$AL1_{MS5\_nd432}^{T} = \left(3.391 \times 10^{-3} \;\; -20.345 \;\; 8.575 \;\; 432 \;\; 140\right)$

$AL2_{MS5\_nd432}^{T} = \left(3.182 \times 10^{-3} \;\; 19.093 \;\; 8.79 \;\; 432 \;\; 140\right)$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

MS-7 Support (1x)

$P_{1\_MS7} := \frac{6 \cdot kip}{lbf}$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$P_{2\_MS7} := \frac{6 \cdot kip}{lbf}$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$Sup\_C_{o\_MS7} := \begin{pmatrix} P_{1\_MS7} & 1 \\ P_{2\_MS7} & 0 \\ F_a & 0 \end{pmatrix}$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

MS-7 (Node 438)

MS-7 horizontally (N/S) supports the horizontal (E/W) PCS pipe on line 1-25.

$nd438_{MS7_0} := 438$ Node associated with support

$\left(AL1_{MS7\_nd438} \;\; AL2_{MS7\_nd438}\right) := Support\left(NF_{ML}, nd438_{MS7}, Sup\_C_{o\_MS7}, EL_{ML}\right)$

$AL1_{MS7\_nd438}^{T} = \left(4.34 \times 10^{-3} \;\; -26.043 \;\; 7.37 \;\; 438 \;\; 142\right)$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node

$AL2_{MS7\_nd438}^{T} = \left(3.778\times10^{-3}\ \ 22.668\ \ 7.625\ \ 438\ \ 142\right)$

being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

MS-8 Support (1x)

$P_{1\_MS8} := \frac{6\cdot kip}{lbf}$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$P_{2\_MS8} := \frac{6\cdot kip}{lbf}$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$$Sup\_C_{o\_MS8} := \begin{pmatrix} P_{1\_MS8} & 1 \\ P_{2\_MS8} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

MS-8 (Node 435)

MS-8 horizontally (N/S) supports the horizontal (E/W) PCS pipe on line 1-22.

$nd435_{MS8_0} := 435$ Node associated with support

$\left(AL1_{MS8\_nd435}\ \ AL2_{MS8\_nd435}\right) := Support\left(NF_{ML}, nd435_{MS8}, Sup\_C_{o\_MS8}, EL_{ML}\right)$

$AL1_{MS8\_nd435}^{T} = \left(4.285\times10^{-3}\ \ -25.709\ \ 8.575\ \ 435\ \ 138\right)$

$AL2_{MS8\_nd435}^{T} = \left(3.959\times10^{-3}\ \ 23.755\ \ 8.785\ \ 435\ \ 138\right)$

D/C,demand force, occurrence time, efined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

Writing Output Data for Supports Associated with Lines 22 to 26

$SA1 := AL1_{MS5\_nd432}^{T}$ MS-5 Compression

$SA2 := AL2_{MS5\_nd432}^{T}$ MS-5 Tension

$SB1 := AL1_{MS7\_nd438}^{T}$ MS-7 Compression

$SB2 := AL2_{MS7\_nd438}^{T}$ MS-7 Tension

$SC1 := AL1_{MS8\_nd435}^{T}$ MS-8 Compression

$SC2 := AL2_{MS8\_nd435}^{T}$ MS-8 Tension

SupportsLines22to26 := WRITEPRN["SupLines22to26.prn" , (SA1 SA2 SB1 SB2 SC1 SC2)]

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TERMINATION LOCATIONS

Termination Locations Strategy: *Search based on the node for which the termination location acts as well as the next node inward. The D/C ratio for each termination location will be found by dividing the the required force found above by the support capacity.*

$$\mathrm{TermDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$$\mathrm{Term}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$$

$$\begin{array}{l}
ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right) \\
\text{for } i \in 1 .. \mathrm{last}(nd) \quad \text{if } \mathrm{rows}(nd) > 1 \\
\quad ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \\
(M \quad Int_0) \leftarrow (0 \quad 0) \\
\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0} \\
\quad \text{for } j \in 0 .. \mathrm{last}(ind_{nd}) \\
\qquad M_{rxg} \leftarrow nf_{ind_{nfiC_{o_{0,1}}+2},\, ind_{nd_j}} \\
\qquad M_{ryg} \leftarrow nf_{ind_{nfiC_{o_{1,1}}+2},\, ind_{nd_j}} \\
\qquad M_{rzg} \leftarrow nf_{ind_{nfiC_{o_{2,1}}+2},\, ind_{nd_j}} \\
\qquad M_{rx} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}+2}+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg} \\
\qquad M_{ry} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}+2}+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg} \\
\qquad M_{rz} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}+2}+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg} \\
\qquad M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2} \\
\qquad Int'_j \leftarrow \mathrm{TermDC}(P, D_o, t, I, B_1, B_2, M'_j, S) \\
\qquad \text{if } Int'_j > Int_0 \\
\qquad\quad Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfiC_{o_{0,1}}-1}+i,0}, EL_{ind_{nd_j},1}, ind_{nd_j}, M_{rx}, M_{ry}, M_{r} \right. \\
\qquad\quad Result \leftarrow M' \\
Int
\end{array}$$

Conditions applicable to all terminations

$M_{cx} := 0$ $M_{cy} := 0$ $M_{cz} := 0$

Defining place holding variables

$$Term\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

Primary Coolant Pumps (4x)

Define pertinent pipe variables

$D_o := 18in$ — Outside Diameter [4] [5] [6] [7]

$t := \frac{5}{16}in$ — Thickness [4] [5] [6] [7]

$P := 400psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

$I = 679.274\ in^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$S := S_{125}$ — Allowable design stress intensity value

Define primary stress indices

$B_1 := 0.5$

$$B_2 := \begin{cases} 1.0 & \text{if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50: & T \leftarrow 125;\ X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \frac{D_o}{t}\right);\ Y \leftarrow 1;\ 1.0 \cdot \frac{1}{X \cdot Y} \end{cases}$$

$B_2 = 1.048$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

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Primary Pump 1-25 (Node 207)

$nd207_{PP125_0} := 207$

$AL_{PP125\_nd207} := Term(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd207_{PP125}, Term\_C_o, EL_{ML})$

$AL_{PP125\_nd207}^T = (0.336 \quad 9.554 \times 10^5 \quad 7.36 \quad 207 \quad 76 \quad 2.205 \times 10^5 \quad 1.324 \times 10^5 \quad 9.201 \times 10^5)$

Primary Pump 1-24 (Node 184)

$nd184_{PP124_0} := 184$

$AL_{PP124\_nd184} := Term(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd184_{PP124}, Term\_C_o, EL_{ML})$

$AL_{PP124\_nd184}^T = (0.289 \quad 7.667 \times 10^5 \quad 7.615 \quad 184 \quad 74 \quad -5.264 \times 10^4 \quad -6.39 \times 10^4 \quad -7.622 \times 10^5)$

Primary Pump 1-23 (Node 183)

$nd183_{PP123_0} := 183$

$AL_{PP123\_nd183} := Term(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd183_{PP123}, Term\_C_o, EL_{ML})$

$AL_{PP123\_nd183}^T = (0.251 \quad 6.088 \times 10^5 \quad 10.185 \quad 183 \quad 72 \quad 2.32 \times 10^5 \quad 5.558 \times 10^4 \quad 5.601 \times 10^5)$

Primary Pump 1-22 (Node 196)

$nd196_{PP122_0} := 196$

$AL_{PP122\_nd196} := Term(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd196_{PP122}, Term\_C_o, EL_{ML})$

$AL_{PP122\_nd196}^T = (0.262 \quad 6.56 \times 10^5 \quad 8.57 \quad 196 \quad 70 \quad -3.931 \times 10^4 \quad 2.167 \times 10^5 \quad 6.179 \times 10^5)$

Writing Output Data for Terminations Associated with Lines 22 to 26

$T1 := AL_{PP125\_nd207}^T$ Primary Pump 1-25 (Node 207)

$T2 := AL_{PP124\_nd184}^T$ Primary Pump 1-24 (Node 184)

$T3 := AL_{PP123\_nd183}^T$ Primary Pump 1-23 (Node 183)

$T4 := AL_{PP122\_nd196}^T$ Primary Pump 1-22 (Node 196)

TerminationsLines22to26 := WRITEPRN["TermLines22to26.prn" ,(T1 T2 T3 T4)]

PIPE RUNS

Pipe Runs Strategy: *Search based on the nodes present in each run of pipe. Find the maximum moment combination among all of the nodes and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{PipeRunDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{PipeRun}(P, D_o, t, I, B_1, B_2, S, nf, el, C_o, EL) :=$

$$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$$
$$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$$
$$ind_{el} \leftarrow \mathrm{match}\left(el_0, EL^{\langle 0 \rangle}\right)$$

for $i \in 1 .. \mathrm{last}(el)$ if $\mathrm{rows}(el) > 1$

$$ind_{el} \leftarrow \mathrm{stack}\left[ind_{el}, \left(\mathrm{match}\left(el_i, EL^{\langle 0 \rangle}\right)\right)\right]$$

$$\left(M \quad Int_{5, \mathrm{last}(ind_{el})}\right) \leftarrow (0 \quad 0)$$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

for $j \in 0 .. \mathrm{last}(ind_{el})$

$$M_{rxg} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}}+2,\, ind_{el_j}}$$
$$M_{ryg} \leftarrow nf_{ind_{nfi_{C_{o_{1,1}}}}+2,\, ind_{el_j}}$$
$$M_{rzg} \leftarrow nf_{ind_{nfi_{C_{o_{2,1}}}}+2,\, ind_{el_j}}$$
$$M_{rx_j} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}}+2+i,\, ind_{el_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$$
$$M_{ry_j} \leftarrow \left(nf_{ind_{nfi_{C_{o_{1,1}}}}+2+i,\, ind_{el_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$$
$$M_{rz_j} \leftarrow \left(nf_{ind_{nfi_{C_{o_{2,1}}}}+2+i,\, ind_{el_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$$
$$M'_j \leftarrow \sqrt{\left(M_{rx_j}\right)^2 + \left(M_{ry_j}\right)^2 + \left(M_{rz_j}\right)^2}$$
$$Int'_j \leftarrow \mathrm{PipeRunDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$$

if $Int'_j > Int_{0,j}$

$$H \leftarrow \left(Int'_j \quad M'_j \quad nf_{ind_{nfi_{C_{o_{0,1}}}}-1+i,\, 0} \quad EL_{ind_{el_j}, 0} \quad EL_{ind_{el_j}, 1} \quad ind_{el_j} \quad M_{r\cdot}\right.$$

for $k \in 0 .. 5$

$$Int_{k,j} \leftarrow H_k$$

Int

Conditions applicable to all pipe runs

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$

Defining place holding directional moment variables

$$PipeRun\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties for Line 1-26

Define pertinent pipe variables

$D_o := 36in$ — Outside Diameter [10]

$t := 0.5625in$ — Thickness [10]

$P := 400psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 9.833 \times 10^3\, in^4$$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \left| \begin{array}{l} 1.0 \ \text{ if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50 \\ \quad \left| \begin{array}{l} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \dfrac{D_o}{t}\right) \\ Y \leftarrow 1.033 - 0.00033 \cdot T \\ 1.0 \cdot \dfrac{1}{X \cdot Y} \end{array} \right. \end{array} \right.$$

$B_{2PR} = 1.101$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-26A (Element 136)

$el_{PR126A} := (136)^T$

$AL_{PR126A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{ML}, el_{PR126A}, PipeRun\_C_o, EL_{ML}\right)$

$$AL_{PR126A}^T = \begin{pmatrix} 0.149 & 1.023 \times 10^6 & 10.195 & 136 & 79 & 1 \\ 0.151 & 1.074 \times 10^6 & 10.2 & 136 & 215 & 2 \end{pmatrix}$$

Pipe Run 1-26B (Elements 353)

$el_{PR126B} := (353)^T$

$AL_{PR126B} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{ML}, el_{PR126B}, PipeRun\_C_o, EL_{ML}\right)$

$$AL_{PR126B}^T = \begin{pmatrix} 0.159 & 1.31 \times 10^6 & 7.895 & 353 & 216 & 117 \\ 0.143 & 8.393 \times 10^5 & 7.895 & 353 & 279 & 118 \end{pmatrix}$$

Pipe Run 1-26C (Elements 306 & 350)

$el_{PR126C} := (306 \quad 350)^T$

$AL_{PR126C} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{ML}, el_{PR126C}, PipeRun\_C_o, EL_{ML}\right)$

$$AL_{PR126C}^T = \begin{pmatrix} 0.163 & 1.408 \times 10^6 & 7.115 & 306 & 217 & 81 \\ 0.159 & 1.291 \times 10^6 & 7.115 & 306 & 264 & 82 \\ 0.159 & 1.29 \times 10^6 & 7.115 & 350 & 264 & 113 \\ 0.15 & 1.04 \times 10^6 & 7.2 & 350 & 276 & 114 \end{pmatrix}$$

Pipe Properties for Lines 1-25, 1-24, 1-23, and 1-22

Define pertinent pipe variables

$D_o := 20in$ Outside Diameter [4] [5] [6] [7]

$t := 0.375in$ Thickness [4] [5] [6] [7]

$P := 400psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^4 - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$ Moment of inertia [8, Table 17-27, pg 17-39]

$I = 1.113 \times 10^3 \, in^4$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{cases} 1.0 \text{ if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 \\ \quad T \leftarrow 125 \\ \quad X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \frac{D_o}{t}\right) \\ \quad Y \leftarrow 1.033 - 0.00033 \cdot T \\ \quad 1.0 \cdot \frac{1}{X \cdot Y} \end{cases}$$

$B_{2PR} = 1.029$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-25A (Element 205)

$el_{PR125A} := (205)^T$

$AL_{PR125A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{ML}, el_{PR125A}, PipeRun\_C_o, EL_{ML}\right)$

$$AL_{PR125A}^T = \begin{pmatrix} 0.247 & 9.38 \times 10^5 & 7.36 & 205 & 206 & 75 \\ 0.25 & 9.554 \times 10^5 & 7.36 & 205 & 207 & 76 \end{pmatrix}$$

Pipe Run 1-25B (Elements 699, 698, & 374)

$el_{PR125B} := (699 \;\; 698 \;\; 374)^T$

$AL_{PR125B} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{ML}, el_{PR125B}, PipeRun\_C_o, EL_{ML}\right)$

$$AL_{PR125B}^T = \begin{pmatrix} 0.211 & 7.198 \times 10^5 & 7.36 & 699 & 204 & 173 \\ 0.165 & 4.338 \times 10^5 & 7.355 & 699 & 580 & 174 \\ 0.141 & 2.858 \times 10^5 & 7.885 & 698 & 579 & 171 \\ 0.165 & 4.338 \times 10^5 & 7.355 & 698 & 580 & 172 \\ 0.164 & 4.302 \times 10^5 & 7.365 & 374 & 202 & 127 \\ 0.141 & 2.857 \times 10^5 & 7.885 & 374 & 579 & 128 \end{pmatrix}$$

Pipe Run 1-25C (Elements 192 & 187)

$el_{PR125C} := (192 \quad 187)^T$

$AL_{PR125C} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{ML}, el_{PR125C}, PipeRun\_C_o, EL_{ML})$

$$AL_{PR125C}^T = \begin{pmatrix} 0.184 & 5.506\times10^5 & 7.36 & 192 & 199 & 67 \\ 0.187 & 5.68\times10^5 & 7.36 & 192 & 201 & 68 \\ 0.152 & 3.541\times10^5 & 4.32 & 187 & 198 & 57 \\ 0.143 & 3.028\times10^5 & 4.325 & 187 & 212 & 58 \end{pmatrix}$$

Pipe Run 1-25D (Elements 703, 382, 702, & 303)

$el_{PR125D} := (703 \quad 382 \quad 702 \quad 303)^T$

$AL_{PR125D} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{ML}, el_{PR125D}, PipeRun\_C_o, EL_{ML})$

$$AL_{PR125D}^T = \begin{pmatrix} 0.147 & 3.239\times10^5 & 7.085 & 703 & 211 & 181 \\ 0.153 & 3.592\times10^5 & 7.07 & 703 & 584 & 182 \\ 0.158 & 3.93\times10^5 & 7.065 & 382 & 265 & 131 \\ 0.153 & 3.593\times10^5 & 7.07 & 382 & 584 & 132 \\ 0.158 & 3.931\times10^5 & 7.065 & 702 & 265 & 179 \\ 0.167 & 4.498\times10^5 & 7.895 & 702 & 583 & 180 \\ 0.181 & 5.338\times10^5 & 7.895 & 303 & 162 & 79 \\ 0.167 & 4.498\times10^5 & 7.895 & 303 & 583 & 80 \end{pmatrix}$$

Pipe Run 1-24A (Element 203)

$el_{PR124A} := (203)^T$

$AL_{PR124A} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{ML}, el_{PR124A}, PipeRun\_C_o, EL_{ML})$

$$AL_{PR124A}^T = \begin{pmatrix} 0.218 & 7.634\times10^5 & 7.615 & 203 & 182 & 73 \\ 0.219 & 7.667\times10^5 & 7.615 & 203 & 184 & 74 \end{pmatrix}$$

Pipe Run 1-24B (Elements 679, 696, & 369)

$el_{PR124B} := (697 \quad 696 \quad 369)^T$

$AL_{PR124B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{ML}, el_{PR124B}, PipeRun\_C_o, EL_{ML})$

$$AL_{PR124B}^T = \begin{pmatrix} 0.195 & 6.18\times10^5 & 7.61 & 697 & 214 & 169 \\ 0.159 & 4.001\times10^5 & 7.605 & 697 & 578 & 170 \\ 0.141 & 2.885\times10^5 & 7.605 & 696 & 577 & 167 \\ 0.159 & 4.001\times10^5 & 7.605 & 696 & 578 & 168 \\ 0.158 & 3.901\times10^5 & 7.625 & 369 & 176 & 125 \\ 0.141 & 2.885\times10^5 & 7.605 & 369 & 577 & 126 \end{pmatrix}$$

Pipe Run 1-24C (Element 181 & 666)

$el_{PR124C} := (181 \quad 666)^T$

$AL_{PR124C} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{ML}, el_{PR124C}, PipeRun\_C_o, EL_{ML})$

$$AL_{PR124C}^T = \begin{pmatrix} 0.169 & 4.603\times10^5 & 10.205 & 181 & 169 & 55 \\ 0.168 & 4.522\times10^5 & 7.35 & 181 & 175 & 56 \\ 0.182 & 5.419\times10^5 & 7.26 & 666 & 167 & 157 \\ 0.157 & 3.877\times10^5 & 7.08 & 666 & 547 & 158 \end{pmatrix}$$

Pipe Run 1-23A (Element 201)

$el_{PR123A} := (201)^T$

$AL_{PR123A} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{ML}, el_{PR123A}, PipeRun\_C_o, EL_{ML})$

$$AL_{PR123A}^T = \begin{pmatrix} 0.19 & 5.89\times10^5 & 8.56 & 201 & 181 & 71 \\ 0.193 & 6.088\times10^5 & 10.185 & 201 & 183 & 72 \end{pmatrix}$$

Pipe Run 1-23B (Elements 695, 694, & 364)

$$el_{PR123B} := (695 \quad 694 \quad 364)^T$$

$$AL_{PR123B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{ML}, el_{PR123B}, PipeRun\_C_o, EL_{ML})$$

$$AL_{PR123B}^T = \begin{pmatrix} 0.167 & 4.469\times10^5 & 10.19 & 695 & 213 & 165 \\ 0.141 & 2.886\times10^5 & 7.59 & 695 & 576 & 166 \\ 0.133 & 2.382\times10^5 & 7.595 & 694 & 575 & 163 \\ 0.141 & 2.886\times10^5 & 7.59 & 694 & 576 & 164 \\ 0.149 & 3.374\times10^5 & 7.59 & 364 & 174 & 123 \\ 0.133 & 2.382\times10^5 & 7.595 & 364 & 575 & 124 \end{pmatrix}$$

Pipe Run 1-23C (Element 171 & 665)

$$el_{PR123C} := (171 \quad 665)^T$$

$$AL_{PR123C} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{ML}, el_{PR123C}, PipeRun\_C_o, EL_{ML})$$

$$AL_{PR123C}^T = \begin{pmatrix} 0.162 & 4.167\times10^5 & 8.58 & 171 & 168 & 45 \\ 0.16 & 4.051\times10^5 & 8.575 & 171 & 218 & 46 \\ 0.164 & 4.316\times10^5 & 5.54 & 665 & 166 & 155 \\ 0.158 & 3.91\times10^5 & 7.085 & 665 & 546 & 156 \end{pmatrix}$$

Pipe Run 1-22A (Element 199)

$$el_{PR122A} := (199)^T$$

$$AL_{PR122A} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{ML}, el_{PR122A}, PipeRun\_C_o, EL_{ML})$$

$$AL_{PR122A}^T = \begin{pmatrix} 0.199 & 6.43\times10^5 & 8.565 & 199 & 194 & 69 \\ 0.201 & 6.56\times10^5 & 8.57 & 199 & 196 & 70 \end{pmatrix}$$

Pipe Run 1-22B (Elements 693, 692, & 359)

$el_{PR122B} := (693 \quad 692 \quad 359)^T$

$AL_{PR122B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{ML}, el_{PR122B}, PipeRun\_C_o, EL_{ML})$

$$AL_{PR122B}^T = \begin{pmatrix} 0.17 & 4.65\times10^5 & 8.565 & 693 & 192 & 161 \\ 0.132 & 2.3\times10^5 & 8.555 & 693 & 574 & 162 \\ 0.12 & 1.618\times10^5 & 6.775 & 692 & 573 & 159 \\ 0.132 & 2.299\times10^5 & 8.555 & 692 & 574 & 160 \\ 0.145 & 3.127\times10^5 & 7.255 & 359 & 190 & 121 \\ 0.12 & 1.618\times10^5 & 6.775 & 359 & 573 & 122 \end{pmatrix}$$

Pipe Run 1-22C (Elements 161 & 156)

$el_{PR122C} := (161 \quad 156)^T$

$AL_{PR122C} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{ML}, el_{PR122C}, PipeRun\_C_o, EL_{ML})$

$$AL_{PR122C}^T = \begin{pmatrix} 0.159 & 3.984\times10^5 & 8.565 & 161 & 187 & 35 \\ 0.16 & 4.054\times10^5 & 7.25 & 161 & 189 & 36 \\ 0.154 & 3.671\times10^5 & 6.77 & 156 & 186 & 25 \\ 0.14 & 2.826\times10^5 & 6.77 & 156 & 209 & 26 \end{pmatrix}$$

Pipe Run 1-22D (Elements 301, 700, 378, & 701)

$el_{PR122D} := (301 \quad 700 \quad 378 \quad 701)^T$

$AL_{PR122D} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{ML}, el_{PR122D}, PipeRun\_C_o, EL_{ML})$

$$AL_{PR122D}^T = \begin{pmatrix} 0.134 & 2.46\times10^5 & 10.92 & 301 & 210 & 77 \\ 0.152 & 3.58\times10^5 & 7.205 & 301 & 581 & 78 \\ 0.175 & 4.991\times10^5 & 7.2 & 700 & 263 & 175 \\ 0.152 & 3.581\times10^5 & 7.205 & 700 & 581 & 176 \\ 0.176 & 4.998\times10^5 & 7.2 & 378 & 263 & 129 \\ 0.192 & 5.996\times10^5 & 7.2 & 378 & 582 & 130 \\ 0.206 & 6.865\times10^5 & 7.2 & 701 & 165 & 177 \\ 0.192 & 5.996\times10^5 & 7.2 & 701 & 582 & 178 \end{pmatrix}$$

Writing Output Data for Pipe Runs Associated with Lines 22 to 26

$PR1 := AL_{PR126A}^{T}$ $PR7 := AL_{PR125D}^{T}$ $PR13 := AL_{PR123C}^{T}$

$PR2 := AL_{PR126B}^{T}$ $PR8 := AL_{PR124A}^{T}$ $PR14 := AL_{PR122A}^{T}$

$PR3 := AL_{PR126C}^{T}$ $PR9 := AL_{PR124B}^{T}$ $PR15 := AL_{PR122B}^{T}$

$PR4 := AL_{PR125A}^{T}$ $PR10 := AL_{PR124C}^{T}$ $PR16 := AL_{PR122C}^{T}$

$PR5 := AL_{PR125B}^{T}$ $PR11 := AL_{PR123A}^{T}$ $PR17 := AL_{PR122D}^{T}$

$PR6 := AL_{PR125C}^{T}$ $PR12 := AL_{PR123B}^{T}$

PipeRunsLines22to26 := WRITEPRN["PRLines22to26.prn" , (PR1 PR2 PR3 PR4 PR5 PR6 PR7 PR8 PR9 PR10 PR11 P

REDUCERS

Reducers Strategy: *Search based on the nodes comprising either end of the reducers. SRSS combine the three moments of each of the four node representations (one for each element connected by the node in question). Find the maximum of the moment combinations for each element and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. It is important to not combine the data from both nodes as the geometry for each is different and (9) must be applied for each node. The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\text{ReducerDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

$\text{Reducer}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \text{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

$\text{for } i \in 1 .. \text{last}(nd)$ $\quad$ if rows(nd) > 1

$\quad ind_{nd} \leftarrow \text{stack}\left[ind_{nd}, \left(\text{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$(M \;\; Int_0) \leftarrow (0 \;\; 0)$

$\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

$\quad \text{for } j \in 0 .. \text{last}(ind_{nd})$

$\quad\quad M_{rxg} \leftarrow nf_{ind_{nfi} C_{o_{0,1}} + 2, ind_{nd_j}}$

$\quad\quad M_{ryg} \leftarrow nf_{ind_{nfi} C_{o_{1,1}} + 2, ind_{nd_j}}$

$\quad\quad M_{rzg} \leftarrow nf_{ind_{nfi} C_{o_{2,1}} + 2, ind_{nd_j}}$

$\quad\quad M_{rx} \leftarrow \left(nf_{ind_{nfi} C_{o_{0,1}} + 2 + i, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

$\quad\quad M_{ry} \leftarrow \left(nf_{ind_{nfi} C_{o_{1,1}} + 2 + i, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

$\quad\quad M_{rz} \leftarrow \left(nf_{ind_{nfi} C_{o_{2,1}} + 2 + i, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

$\quad\quad M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

$\quad\quad Int'_j \leftarrow \text{ReducerDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$

$\quad\quad \text{if } Int'_j > Int_0$

$\quad\quad\quad Int \leftarrow \text{stack}\left(Int'_j, M'_j, nf_{ind_{nfi} C_{o_{0,1}} - 1 + i, 0}, EL_{ind_{nd_j}, 1}, ind_{nd_j}, M_{rx}, M_{ry}, \right.$

$\quad\quad\quad Result \leftarrow M'$

Int

Conditions applicable to all reducers

$M_{cx} := 0 \quad M_{cy} := 0 \quad M_{cz} := 0$

Defining place holding variables

$$Reducer\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

Reducer Properties for Top of Lines 1-22, 1-23, 1-24, 1-25

Define pertinent reducer variables

$D_o := (20in \quad 18in)^T$

Outside Diameter [4] [5] [6] [7]

$t := \left(\frac{3}{8}in \quad \frac{3}{8}in\right)^T$

Thickness [4] [5] [6] [7]

$P := (400psi \quad 400psi)^T$

Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

$$I = \begin{pmatrix} 1.113 \times 10^3 \\ 806.631 \end{pmatrix} in^4$$

Moment of inertia [8, Table 17-27, pg 17-39]

Define primary stress indices

$$\alpha := atan\left(\frac{1in}{9in}\right)$$

$\alpha = 6.34\,deg$

Angular slope of reducer

$$B_1 := \begin{vmatrix} 0.5 \text{ if } \alpha \le 30deg \\ 1.0 \text{ if } 30deg < \alpha \le 60deg \end{vmatrix}$$

$B_1 = 0.5$

B_1 primary stress Index [9, NB-3683.7]

$B_2 := 1.0$

B_2 primary stress Index [9, NB-3683.7]

Reducer 1-22A (Nodes 193 & 194)

$nd_{RD122A\_L} := (193)^T$

Node associated with Large end of reducer

$$AL_{RD122A\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF_{ML}, nd_{RD122A\_L}, Reducer\_C_o, EL_{ML}\right)$$

$$AL_{RD122A\_L}^{\,T} = \left(0.195 \quad 6.357 \times 10^5 \quad 8.565 \quad 193 \quad 153 \quad 1.05 \times 10^5 \quad -1.083 \times 10^5 \quad -6.175 \times 10^5\right)$$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

$nd_{RD122A\_S} := (194)^T$ Node associated with Small end of reducer

$AL_{RD122A\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF_{ML}, nd_{RD122A\_S}, Reducer\_C_o, EL_{ML}\right)$

$$AL_{RD122A\_S}{}^T = \begin{pmatrix} 0.211 & 6.43\times10^5 & 8.565 & 194 & 69 & 7.585\times10^4 & -1.624\times10^5 & -6.175\times10^5 \end{pmatrix}$$

Reducer 1-23 (Nodes 179 & 181)

$nd_{RD123\_L} := (179)^T$ Node associated with Large end of reducer

$AL_{RD123\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF_{ML}, nd_{RD123\_L}, Reducer\_C_o, EL_{ML}\right)$

$$AL_{RD123\_L}{}^T = \begin{pmatrix} 0.186 & 5.808\times10^5 & 8.56 & 179 & 151 & -2.822\times10^4 & -2.374\times10^4 & -5.796\times10^5 \end{pmatrix}$$

$nd_{RD123\_S} := (181)^T$ Node associated with Small end of reducer

$AL_{RD123\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF_{ML}, nd_{RD123\_S}, Reducer\_C_o, EL_{ML}\right)$

$$AL_{RD123\_S}{}^T = \begin{pmatrix} 0.201 & 5.89\times10^5 & 8.56 & 181 & 71 & -7.302\times10^4 & -7.509\times10^4 & -5.796\times10^5 \end{pmatrix}$$

Reducer 1-24 (Nodes 180 & 182)

$nd_{RD124\_L} := (180)^T$ Node associated with Large end of reducer

$AL_{RD124\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF_{ML}, nd_{RD124\_L}, Reducer\_C_o, EL_{ML}\right)$

$$AL_{RD124\_L}{}^T = \begin{pmatrix} 0.215 & 7.652\times10^5 & 7.615 & 180 & 149 & 3.04\times10^4 & -6.116\times10^4 & 7.622\times10^5 \end{pmatrix}$$

$nd_{RD124\_S} := (182)^T$ Node associated with Small end of reducer

$AL_{RD124\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF_{ML}, nd_{RD124\_S}, Reducer\_C_o, EL_{ML}\right)$

$$AL_{RD124\_S}{}^T = \begin{pmatrix} 0.235 & 7.634\times10^5 & 7.615 & 182 & 73 & 4.206\times10^4 & 1.323\times10^3 & 7.622\times10^5 \end{pmatrix}$$

Reducer 1-25A (Nodes 205 & 206)

$nd_{RD125A\_L} := (205)^T$ Node associated with Large end of reducer

$AL_{RD125A\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF_{ML}, nd_{RD125A\_L}, Reducer\_C_o, EL_{ML}\right)$

$$AL_{RD125A\_L}{}^T = \begin{pmatrix} 0.241 & 9.294\times10^5 & 7.36 & 205 & 135 & -1.289\times10^5 & 2.33\times10^4 & -9.201\times10^5 \end{pmatrix}$$

$nd_{RD125A\_S} := (206)^T$ Node associated with Small end of reducer

$AL_{RD125A\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF_{ML}, nd_{RD125A\_S}, Reducer\_C_o, EL_{ML}\right)$

$AL_{RD125A\_S}{}^T = \begin{pmatrix} 0.269 & 9.38\times10^5 & 7.36 & 206 & 75 & -1.741\times10^5 & -5.452\times10^4 & -9.201\times10^5 \end{pmatrix}$

Reducer Properties for Bottom of Line 1-22 and 1-25

Define pertinent reducer variables

$D_o := (36in \quad 20in)^T$ Outside Diameter [10]

$t := \left(\frac{9}{16}in \quad \frac{9}{16}in\right)^T$ Thickness [10]

$P := (400psi \quad 400psi)^T$ Internal Pressure [3, pg 23]

$I := \frac{\pi\cdot\left[D_o{}^4 - \left(D_o - 2\cdot t\right)^4\right]}{64}$ Moment of inertia [8, Table 17-27, pg 17-39]

$I = \begin{pmatrix} 9.833\times10^3 \\ 1.624\times10^3 \end{pmatrix} in^4$

Define primary stress indices

$\alpha := atan\left(\frac{8in}{24in}\right)$ Angle of reducer slope

$\alpha = 18.435\,deg$

$B_1 := \begin{cases} 0.5 & \text{if } \alpha \le 30deg \\ 1.0 & \text{if } 30deg < \alpha \le 60deg \end{cases}$

B_1 primary stress Index [9, NB-3683.7]

$B_1 = 0.5$

$B_2 := 1.0$ B_2 primary stress Index [9, NB-3683.7]

Reducer 1-22B (Nodes 164 & 165)

$nd_{RD122B\_L} := (164)^T$ Node associated with Large end of reducer

$AL_{RD122B\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF_{ML}, nd_{RD122B\_L}, Reducer\_C_o, EL_{ML}\right)$

$AL_{RD122B\_L}{}^T = \begin{pmatrix} 0.137 & 7.407\times10^5 & 7.2 & 164 & 12 & 7.079\times10^5 & -2.02\times10^5 & -8.117\times10^4 \end{pmatrix}$

$nd_{RD122B\_S} := (165)^T$ Node associated with Small end of reducer

$AL_{RD122B\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF_{ML}, nd_{RD122B\_S}, Reducer\_C_o, EL_{ML}\right)$

$AL_{RD122B\_S}{}^T = \begin{pmatrix} 0.137 & 6.865\times10^5 & 7.2 & 165 & 23 & 6.579\times10^5 & -1.786\times10^5 & -8.115\times10^4 \end{pmatrix}$

Reducer 1-25B (Nodes 161 & 162)

$nd_{RD125B\_L} := (161)^T$ Node associated with Large end of reducer

$AL_{RD125B\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF_{ML}, nd_{RD125B\_L}, Reducer\_C_o, EL_{ML}\right)$

$AL_{RD125B\_L}{}^T = \begin{pmatrix} 0.132 & 5.972\times10^5 & 7.615 & 161 & 8 & 3.279\times10^5 & 4.94\times10^5 & 7.176\times10^4 \end{pmatrix}$

$nd_{RD125B\_S} := (162)^T$ Node associated with Small end of reducer

$AL_{RD125B\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF_{ML}, nd_{RD125B\_S}, Reducer\_C_o, EL_{ML}\right)$

$AL_{RD125B\_S}{}^T = \begin{pmatrix} 0.121 & 5.338\times10^5 & 7.895 & 162 & 21 & -4.793\times10^5 & -2.293\times10^5 & -5.127\times10^4 \end{pmatrix}$

Writing Output Data for Reducers Associated with Lines 22 to 26

$RL1 := AL_{RD122A\_L}{}^T$ $RL4 := AL_{RD125A\_L}{}^T$

$RS1 := AL_{RD122A\_S}{}^T$ $RS4 := AL_{RD125A\_S}{}^T$

$RL2 := AL_{RD123\_L}{}^T$ $RL5 := AL_{RD122B\_L}{}^T$

$RS2 := AL_{RD123\_S}{}^T$ $RS5 := AL_{RD122B\_S}{}^T$

$RL3 := AL_{RD124\_L}{}^T$ $RL6 := AL_{RD125B\_L}{}^T$

$RS3 := AL_{RD124\_S}{}^T$ $RS6 := AL_{RD125B\_S}{}^T$

ReducersLines22to26 := WRITEPRN["RedLines22to26.prn" ,(RL1 RS1 RL2 RS2 RL3 RS3 RL4 RS4 RL5 RS5 RL6 RS

ELBOWS

Elbows Strategy: *Search based on the two nodes comprising the ends of each elbow. SRSS combine the three moments of each of the four node representations (one for each element connected by the nodes in question). Find the maximum of the four moment combinations and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{ElbowDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Elbow}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$$
\begin{aligned}
& ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
& ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
& ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right) \\
& \text{for } i \in 1 .. \mathrm{last}(nd) \quad \text{if } \mathrm{rows}(nd) > 1 \\
& \quad ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \\
& (M \;\; Int_0) \leftarrow (0 \;\; 0) \\
& \text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0} \\
& \quad \text{for } j \in 0 .. \mathrm{last}(ind_{nd}) \\
& \qquad M_{rxg} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}}+2,\, ind_{nd_j}} \\
& \qquad M_{ryg} \leftarrow nf_{ind_{nfi_{C_{o_{1,1}}}}+2,\, ind_{nd_j}} \\
& \qquad M_{rzg} \leftarrow nf_{ind_{nfi_{C_{o_{2,1}}}}+2,\, ind_{nd_j}} \\
& \qquad M_{rx} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg} \\
& \qquad M_{ry} \leftarrow \left(nf_{ind_{nfi_{C_{o_{1,1}}}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg} \\
& \qquad M_{rz} \leftarrow \left(nf_{ind_{nfi_{C_{o_{2,1}}}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg} \\
& \qquad M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2} \\
& \qquad Int'_j \leftarrow \mathrm{ElbowDC}(P, D_o, t, I, B_1, B_2, M'_j, S) \\
& \qquad \text{if } Int'_j > Int_0 \\
& \qquad \quad Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfi_{C_{o_{0,1}}}}-1+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M \right. \\
& \qquad \quad Result \leftarrow M' \\
& Int
\end{aligned}
$$

Conditions applicable to all elbows

$M_{cx} := 0 \quad M_{cy} := 0 \quad M_{cz} := 0$ — Defining place holding variables

$$Elb\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

Elbow Properties for Lines 1-22, 1-23, 1-24, and 1-25

Define pertinent elbow variables

$D_o := 20in$ — Outside Diameter [4] [5] [6] [7]

$t := 0.375in$ — Thickness [4] [5] [6] [7]

$P := 400psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - (D_o - 2\cdot t)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 1.113 \times 10^3\, in^4$$

$R := 1.5 \cdot D_o$ — Nominal bend radius of curved pipe or elbow

$r_m := \frac{D_o - t}{2}$ — Mean pipe radius

Define primary stress indices

$h := \frac{t \cdot R}{r_m^{\,2}}$ — $h = 0.117$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4\cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4\cdot h > 0.5 \\ -0.1 + 0.4\cdot h & \text{otherwise} \end{cases}$$

$B_1 = 0$ — B_1 primary stress Index [9, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \frac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \frac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 5.439$ — B_2 primary stress Index [9, NB-3683.7]

Elbow 1-22A (Nodes 193 & 192)

$nd_{EL122A\_1} := (193)^T$

$AL_{EL122A\_nd193} := \text{Elbow}(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{EL122A\_1}, Elb\_C_o, EL_{ML})$

$AL_{EL122A\_nd193}{}^T = \begin{pmatrix} 0.548 & 6.357\times10^5 & 8.565 & 193 & 153 & 1.05\times10^5 & -1.083\times10^5 & -6.175\times10^5 \end{pmatrix}$

$nd_{EL122A\_2} := (192)^T$

$AL_{EL122A\_nd192} := \text{Elbow}(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{EL122A\_2}, Elb\_C_o, EL_{ML})$

$AL_{EL122A\_nd192}{}^T = \begin{pmatrix} 0.401 & 4.651\times10^5 & 8.565 & 192 & 90 & 1.376\times10^5 & 7.168\times10^4 & -4.384\times10^5 \end{pmatrix}$

Elbow 1-22B (Nodes 190 & 189)

$nd_{EL122B\_1} := (190)^T$

$AL_{EL122B\_nd190} := \text{Elbow}(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{EL122B\_1}, Elb\_C_o, EL_{ML})$

$AL_{EL122B\_nd190}{}^T = \begin{pmatrix} 0.269 & 3.127\times10^5 & 7.255 & 190 & 88 & 7.973\times10^4 & -7.982\times10^4 & -2.917\times10^5 \end{pmatrix}$

$nd_{EL122B\_2} := (189)^T$

$AL_{EL122B\_nd189} := \text{Elbow}(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{EL122B\_2}, Elb\_C_o, EL_{ML})$

$AL_{EL122B\_nd189}{}^T = \begin{pmatrix} 0.349 & 4.054\times10^5 & 7.25 & 189 & 87 & -1.256\times10^5 & 3.048\times10^4 & 3.843\times10^5 \end{pmatrix}$

Elbow 1-22C (Nodes 209 & 210)

$nd_{EL122C\_1} := (209)^T$

$AL_{EL122C\_nd209} := \text{Elbow}(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{EL122C\_1}, Elb\_C_o, EL_{ML})$

$AL_{EL122C\_nd209}{}^T = \begin{pmatrix} 0.243 & 2.826\times10^5 & 6.77 & 209 & 84 & -1.117\times10^5 & -5.336\times10^3 & -2.595\times10^5 \end{pmatrix}$

$nd_{EL122C\_2} := (210)^T$

$AL_{EL122C\_nd210} := \text{Elbow}(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{EL122C\_2}, Elb\_C_o, EL_{ML})$

$AL_{EL122C\_nd210}{}^T = \begin{pmatrix} 0.212 & 2.46\times10^5 & 10.92 & 210 & 77 & 1.794\times10^5 & -1.562\times10^5 & -6.253\times10^4 \end{pmatrix}$

Elbow 1-25A (Nodes 205 & 204)

$nd_{EL125A\_1} := (205)^T$

$AL_{EL125A\_nd205} := \text{Elbow}(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{EL125A\_1}, Elb\_C_o, EL_{ML})$

$AL_{EL125A\_nd205}{}^T = (0.801 \quad 9.294 \times 10^5 \quad 7.36 \quad 205 \quad 135 \quad -1.289 \times 10^5 \quad 2.33 \times 10^4 \quad -9.201 \times 10^5)$

$nd_{EL125A\_2} := (204)^T$

$AL_{EL125A\_nd204} := \text{Elbow}(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{EL125A\_2}, Elb\_C_o, EL_{ML})$

$AL_{EL125A\_nd204}{}^T = (0.62 \quad 7.199 \times 10^5 \quad 7.36 \quad 204 \quad 111 \quad -5.139 \times 10^3 \quad 2.817 \times 10^5 \quad -6.624 \times 10^5)$

Elbow 1-25B (Nodes 202 & 201)

$nd_{EL125B\_1} := (202)^T$

$AL_{EL125B\_nd202} := \text{Elbow}(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{EL125B\_1}, Elb\_C_o, EL_{ML})$

$AL_{EL125B\_nd202}{}^T = (0.371 \quad 4.302 \times 10^5 \quad 7.365 \quad 202 \quad 109 \quad 7.17 \times 10^4 \quad -2.8 \times 10^5 \quad -3.187 \times 10^5)$

$nd_{EL125B\_2} := (201)^T$

$AL_{EL125B\_nd201} := \text{Elbow}(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{EL125B\_2}, Elb\_C_o, EL_{ML})$

$AL_{EL125B\_nd201}{}^T = (0.489 \quad 5.68 \times 10^5 \quad 7.36 \quad 201 \quad 108 \quad -1.006 \times 10^5 \quad 2.541 \times 10^5 \quad 4.979 \times 10^5)$

Elbow 1-25C (Nodes 212 & 211)

$nd_{EL125C\_1} := (212)^T$

$AL_{EL125C\_nd212} := \text{Elbow}(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{EL125C\_1}, Elb\_C_o, EL_{ML})$

$AL_{EL125C\_nd212}{}^T = (0.261 \quad 3.028 \times 10^5 \quad 4.325 \quad 212 \quad 106 \quad 1.743 \times 10^5 \quad -5.055 \times 10^4 \quad -2.424 \times 10^5)$

$nd_{EL125C\_2} := (211)^T$

$AL_{EL125C\_nd211} := \text{Elbow}(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{EL125C\_2}, Elb\_C_o, EL_{ML})$

$AL_{EL125C\_nd211}{}^T = (0.279 \quad 3.239 \times 10^5 \quad 7.085 \quad 211 \quad 181 \quad -2.352 \times 10^5 \quad 2.092 \times 10^5 \quad 7.631 \times 10^4)$

Elbow 1-23A (Node 179 & 213)

$nd_{EL123A\_1} := (179)^T$

$AL_{EL123A\_nd179} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{EL123A\_1}, Elb\_C_o, EL_{ML})$

$AL_{EL123A\_nd179}^T = \begin{pmatrix} 0.5 & 5.808\times10^5 & 8.56 & 179 & 151 & -2.822\times10^4 & -2.374\times10^4 & -5.796\times10^5 \end{pmatrix}$

$nd_{EL123A\_2} := (213)^T$

$AL_{EL123A\_nd213} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{EL123A\_2}, Elb\_C_o, EL_{ML})$

$AL_{EL123A\_nd213}^T = \begin{pmatrix} 0.385 & 4.47\times10^5 & 10.19 & 213 & 97 & 5.143\times10^3 & 2.002\times10^5 & -3.996\times10^5 \end{pmatrix}$

Elbow 1-23B (Node 174 & 218)

$nd_{EL123B\_1} := (174)^T$

$AL_{EL123B\_nd174} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{EL123B\_1}, Elb\_C_o, EL_{ML})$

$AL_{EL123B\_nd174}^T = \begin{pmatrix} 0.291 & 3.374\times10^5 & 7.59 & 174 & 123 & 4.05\times10^4 & -2.325\times10^5 & -2.412\times10^5 \end{pmatrix}$

$nd_{EL123B\_2} := (218)^T$

$AL_{EL123B\_nd218} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{EL123B\_2}, Elb\_C_o, EL_{ML})$

$AL_{EL123B\_nd218}^T = \begin{pmatrix} 0.349 & 4.051\times10^5 & 8.575 & 218 & 94 & -1.005\times10^5 & 1.124\times10^5 & 3.76\times10^5 \end{pmatrix}$

Elbow 1-24A (Nodes 180 & 214)

$nd_{EL124A\_1} := (180)^T$

$AL_{EL124A\_nd180} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{EL124A\_1}, Elb\_C_o, EL_{ML})$

$AL_{EL124A\_nd180}^T = \begin{pmatrix} 0.659 & 7.652\times10^5 & 7.615 & 180 & 149 & 3.04\times10^4 & -6.116\times10^4 & 7.622\times10^5 \end{pmatrix}$

$nd_{EL124A\_2} := (214)^T$

$AL_{EL124A\_nd214} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{EL124A\_2}, Elb\_C_o, EL_{ML})$

$AL_{EL124A\_nd214}^T = \begin{pmatrix} 0.532 & 6.18\times10^5 & 7.61 & 214 & 103 & 2.123\times10^4 & -2.694\times10^5 & 5.558\times10^5 \end{pmatrix}$

Elbow 1-24B (Node 176 & 175)

$nd_{EL124B\_1} := (176)^T$

$AL_{EL124B\_nd176} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{EL124B\_1}, Elb\_C_o, EL_{ML})$

$AL_{EL124B\_nd176}{}^T = (0.336 \quad 3.901 \times 10^5 \quad 7.625 \quad 176 \quad 100 \quad -1.444 \times 10^5 \quad 2.66 \times 10^5 \quad 2.462 \times 10^5)$

$nd_{EL124B\_2} := (175)^T$

$AL_{EL124B\_nd175} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{EL124B\_2}, Elb\_C_o, EL_{ML})$

$AL_{EL124B\_nd175}{}^T = (0.39 \quad 4.522 \times 10^5 \quad 7.35 \quad 175 \quad 56 \quad 8.084 \times 10^4 \quad -1.499 \times 10^5 \quad -4.189 \times 10^5)$

Writing Output Data for Elbows Associated with Lines 22 to 26

$EL1A := AL_{EL122A\_nd193}{}^T$ $EL6A := AL_{EL125C\_nd212}{}^T$

$EL1B := AL_{EL122A\_nd192}{}^T$ $EL6B := AL_{EL125C\_nd211}{}^T$

$EL2A := AL_{EL122B\_nd190}{}^T$ $EL7A := AL_{EL123A\_nd179}{}^T$

$EL2B := AL_{EL122B\_nd189}{}^T$ $EL7B := AL_{EL123A\_nd213}{}^T$

$EL3A := AL_{EL122C\_nd209}{}^T$ $EL8A := AL_{EL123B\_nd174}{}^T$

$EL3B := AL_{EL122C\_nd210}{}^T$ $EL8B := AL_{EL123B\_nd218}{}^T$

$EL4A := AL_{EL125A\_nd205}{}^T$ $EL9A := AL_{EL124A\_nd180}{}^T$

$EL4B := AL_{EL125A\_nd204}{}^T$ $EL9B := AL_{EL124A\_nd214}{}^T$

$EL5A := AL_{EL125B\_nd202}{}^T$ $EL10A := AL_{EL124B\_nd176}{}^T$

$EL5B := AL_{EL125B\_nd201}{}^T$ $EL10B := AL_{EL124B\_nd175}{}^T$

ElbowLines22to26 := WRITEPRN["ElbowLines22to26.prn" , (EL1A EL1B EL2A EL2B EL3A EL3B EL4A EL4B EL5A l

FORGED TEES AND FABRICATED BRANCH TEES

Tees Strategy: *Search based on the elements comprising the tee. The input identifies which elements are associated with the pipe run and which element is associated with the branch from the run. The indices for the defined common node for all three elements is identified and the associated SRSS moment is identified for each time step. The maximum moment for the elements comprising the pipe run is found and applied as* M_r *in equation (9) of ASME III, Division I - NB - 3652 which is modified to represent tees. The maximum moment for the branch element is found and applied as* M_b *in equation (9) of ASME III, Division I - NB - 3652 [9]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{TeeDC}(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_b, M_r, Z_b, Z_r, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot T_r} + B_{2b} \cdot \left[\frac{M_b \cdot (1\,\mathrm{lbf \cdot in})}{Z_b}\right] + B_{2r} \cdot \left[\frac{M_r \cdot (1\,\mathrm{lbf \cdot in})}{Z_r}\right]}{S}$$

$\mathrm{Tee}(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S, nf, el_R, el_B, nd_R, nd_B, C_o, EL) :=$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{elR} \leftarrow \mathrm{match}\left(el_{R_0}, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(el_R)$ if rows

  $ind_{elR} \leftarrow \mathrm{stack}\left[ind_{elR}, \left(\mathrm{match}\left(el_{R_i}, EL^{\langle 0 \rangle}\right)\right)\right]$

$EL'R_{\mathrm{last}\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$

for $i \in 0 .. \mathrm{last}(ind_{elR})$

  $EL'R_{ind_{elR_i}} \leftarrow EL_{ind_{elR_i}, 1}$

$ind_{ndR} \leftarrow \mathrm{match}\left(nd_{R_0}, EL'R^{\langle 0 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(nd_R)$ if r

  $ind_{ndR} \leftarrow \mathrm{stack}\left[ind_{ndR}, \left(\mathrm{match}\left(nd_{R_i}, EL'R^{\langle 0 \rangle}\right)\right)\right]$

$ind_{elB} \leftarrow \mathrm{match}\left(el_{B_0}, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(el_B)$ if rows

  $ind_{elB} \leftarrow \mathrm{stack}\left[ind_{elB}, \left(\mathrm{match}\left(el_{B_i}, EL^{\langle 0 \rangle}\right)\right)\right]$

$EL'B_{\mathrm{last}\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$

for $i \in 0 .. \mathrm{last}(ind_{elB})$

  $EL'B_{ind_{elB_i}} \leftarrow EL_{ind_{elB_i}, 1}$

$ind_{ndB} \leftarrow \mathrm{match}\left(nd_{B_0}, EL'B^{\langle 0 \rangle}\right)$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

$$\text{for } i \in 1..\text{last}(nd_B) \qquad \text{if } r$$

$$ind_{ndB} \leftarrow \text{stack}\left[ind_{ndB}, \left(\text{match}\left(nd_{B_i}, EL'B^{\langle 0\rangle}\right)\right)\right]$$

$$(M_R \;\; M_B \;\; Int_0) \leftarrow (0 \;\; 0 \;\; 0)$$

$$\text{for } i \in 0..ind_{nfo_0} - ind_{nfi_0}$$

$$\text{for } j \in 0..\text{last}(ind_{ndR})$$

$$\text{for } k \in 0..\text{last}(ind_{ndB})$$

$$M_{rxgR_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{ndR_j}}$$

$$M_{rygR_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{ndR_j}}$$

$$M_{rzgR_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{ndR_j}}$$

$$M_{rxR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{ndR_j}} - M_{rxgR_j}\right)\cdot C$$

$$M_{ryR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{ndR_j}} - M_{rygR_j}\right)\cdot C$$

$$M_{rzR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{ndR_j}} - M_{rzgR_j}\right)\cdot C$$

$$M_{R_j} \leftarrow \sqrt{\left(M_{rxR_j}\right)^2 + \left(M_{ryR_j}\right)^2 + \left(M_{rzR_j}\right)^2}$$

$$M_{rxgB_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{ndB_k}}$$

$$M_{rygB_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{ndB_k}}$$

$$M_{rzgB_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{ndB_k}}$$

$$M_{rxB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{ndB_k}} - M_{rxgB_j}\right)\cdot C$$

$$M_{ryB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{ndB_k}} - M_{rygB_j}\right)\cdot C$$

$$M_{rzB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{ndB_k}} - M_{rzgB_j}\right)\cdot C$$

$$M_{B_j} \leftarrow \sqrt{\left(M_{rxB_j}\right)^2 + \left(M_{ryB_j}\right)^2 + \left(M_{rzB_j}\right)^2}$$

$$Int'_j \leftarrow \text{TeeDC}\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_{B_j}, M_R\right.$$

$$\text{if } Int'_j > Int_0$$

$$Int \leftarrow \text{stack}\left(Int'_j, M_{R_j}, M_{B_j}, nf_{ind_{nfiC_{o_{0,1}}}-1+i}\right.$$

$\text{Result} \leftarrow \text{stack}\left(M_{R_j}, M_{B_j}, M_{rxR_j}, M_{ryR_j}, M\right.$

$M \leftarrow M_R$

Int

Conditions applicable to forged tee

$M_{cx} := 0 \quad M_{cy} := 0 \quad M_{cz} := 0$

Defining place holding directional moment variables

$$Tee\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

FORGED TEE (LINE 1-26)

Define pertinent tee variables

$P := 400\text{psi}$ — Internal Pressure [3, pg 23]

$D_o := 36\text{in}$ — Outside Diameter [10]

$d_o := 36\text{in}$ — Outside Diameter of branch [10]

$B_1 := 0.5$ — B_1 primary stress Index for tees and branches [9, NB-3683.9]

$T_r := 1.375\text{in}$ — Nominal wall thickness of designated run pipe [14]

$$R_m := \frac{D_o - T_r}{2}$$

Mean radius of designated run pipe [10]

$$Z_r := \pi \cdot R_m^{\,2} \cdot T_r$$

Approximate section modulus of designated run pipe [9, NB-3683.1(d)]

$$Z_r = 1.2947 \times 10^3\ \text{in}^3$$

$$B_{2b} := \begin{cases} 0.4 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} & \text{if } 0.4 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} > 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Index for tees and branches [9, NB-3683.9]

$$B_{2b} = 2.165$$

$T'_b := 1.375\text{in}$ — Nominal wall thickness of attached branch pipe [14]

$r'_m := \frac{d_o - T'_b}{2}$ Mean radius of attached branch pipe [10]

$Z_b := \pi \cdot {r'_m}^2 \cdot T'_b$ Approximate section modulus of attached branch pipe [9, NB-3683.1(d)]

$Z_b = 1.295 \times 10^3 \, in^3$

$$B_{2r} := \begin{cases} 0.5 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} & \text{if } 0.5 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} > 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Index for tees and branches [9, NB-3683.9]

$B_{2r} = 2.706$

Tee 1-26 (Node 159)

$elR_{Tee126} := (138 \quad 141)^T$ Elements associated with pipe run

$ndR_{Tee126} := (159)^T$ Node between pipe run elements

$elB_{Tee126} := (137)^T$ Element associated with branch

$ndB_{Tee126} := (159)^T$ Node where branch intersects pipe run

$AL_{Tee126} := Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF_{ML}, elR_{Tee126}, elB_{Tee126}, ndR_{Tee126}, ndB_{Tee126}, Te$

$AL_{Tee126}^T = (0.133 \quad 1.4 \times 10^6 \quad 1.196 \times 10^6 \quad 7.885 \quad 159 \quad 5 \quad 9 \quad 3)$

FABRICATED TEES (LINES 1-24 & 1-25)

Define pertinent tee variables

$P := 400psi$ Internal Pressure [3, pg 23]

$D_o := 36in$ Outside Diameter of pipe run [17]

$d_o := 20in$ Outside Diameter of branch [17]

$B_1 := 0.5$ B_1 primary stress Index for tees and branches [9, Table NB-3681(a)-1]]

$T_r := 0.5625in$ Nominal wall thickness of designated run pipe [17]

$R_m := \frac{D_o - T_r}{2}$ Mean radius of designated run pipe [17]

$Z_r := \pi \cdot R_m^{\,2} \cdot T_r$

Approximate section modulus of designated run pipe [9, NB-3683.1(d)]

$Z_r = 554.8027\ in^3$

$T'_b := 0.375in$

Nominal wall thickness of attached branch pipe [16]

$r'_m := \dfrac{d_o - T'_b}{2}$

Mean radius of attached branch pipe [16]

$Z_b := \pi \cdot r'^{\,2}_m \cdot T'_b$

Approximate section modulus of attached branch pipe [9, NB-3683.1(d)]

$Z_b = 113.433\ in^3$

C_{2b} Secondary stress Index [9,NB-3683.8]

$$C_{2b} := \begin{cases} 1.5 \cdot \left(\dfrac{R_m}{T_r}\right)^{\frac{2}{3}} \left(\dfrac{r'_m}{R_m}\right)^{\frac{1}{2}} \left(\dfrac{T'_b}{T_r}\right)\left(\dfrac{r'_m}{\frac{d_o}{2}}\right) & \text{if } 1.5 \cdot \left(\dfrac{R_m}{T_r}\right)^{\frac{2}{3}} \left(\dfrac{r'_m}{R_m}\right)^{\frac{1}{2}} \left(\dfrac{T'_b}{T_r}\right)\left(\dfrac{r'_m}{\frac{d_o}{2}}\right) \ge 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$C_{2b} = 7.283$

C_{2r} Secondary stress Index [9,NB-3683.8]

$t_n := T'_b$

Wall thickness of nozzle or branch connection reinforcement associated with [9, NB-3643.4(A)-1, sketch (d)]

$$C_{2r} := \begin{cases} 1.15 \cdot \left(\dfrac{r'_m}{t_n}\right)^{\frac{1}{4}} & \text{if } 1.15 \cdot \left(\dfrac{r'_m}{t_n}\right)^{\frac{1}{4}} \ge 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$C_{2r} = 2.601$

$$B_{2b} := \begin{cases} 0.5 \cdot C_{2b} & \text{if } 0.5 \cdot C_{2b} \ge 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Index for branches [9, NB-3683.8]

$B_{2b} = 3.642$

$$B_{2r} := \begin{cases} 0.75 \cdot C_{2r} & \text{if } 0.75 \cdot C_{2r} \ge 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Index for branches [9, NB-3683.8]

$B_{2r} = 1.951$

Fabricated Tee 1-24 (Node 160)

$elR_{Tee124} := (354 \quad 140)^T$ Elements associated with pipe run

$ndR_{Tee124} := (160)^T$ Node between pipe run elements

$elB_{Tee124} := (145)^T$ Element associated with branch

$ndB_{Tee124} := (160)^T$ Node where branch intersects pipe run

$AL_{Tee124} := Tee\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF_{ML}, elR_{Tee124}, elB_{Tee124}, ndR_{Tee124}, ndB_{Tee124}, Te\right.$

$$AL_{Tee124}^T = \left(0.404 \quad 6.358\times10^5 \quad 4.443\times10^5 \quad 7.08 \quad 160 \quad 7 \quad 119 \quad 15\right)$$

Fabricated Tee 1-23 (Node 163)

$elR_{Tee123} := (351 \quad 143)^T$ Elements associated with pipe run

$ndR_{Tee123} := (163)^T$ Node between pipe run elements

$elB_{Tee123} := (144)^T$ Element associated with branch

$ndB_{Tee123} := (163)^T$ Node where branch intersects pipe run

$AL_{Tee123} := Tee\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF_{ML}, elR_{Tee123}, elB_{Tee123}, ndR_{Tee123}, ndB_{Tee123}, Te\right.$

$$AL_{Tee123}^T = \left(0.38 \quad 6.971\times10^5 \quad 3.946\times10^5 \quad 7.085 \quad 163 \quad 11 \quad 115 \quad 13\right)$$

Writing Output Data for Tees Associated with Lines 22 to 26

$Tee1 := AL_{Tee126}^T$

$Tee2 := AL_{Tee124}^T$

$Tee3 := AL_{Tee123}^T$

TeeLines22to26 := WRITEPRN["TeeLines22to26.prn" , (Tee1 Tee2 Tee3)]

FLANGES

Flange Strategy: *Search based on the nodes where flanges occur. Find the maximum moment combination for the node and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\mathrm{FlangeDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1 \mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Flange}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(nd)$ if $\mathrm{rows}(nd) > 1$

  $ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$(M \;\; Int_0) \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \mathrm{last}(ind_{nd})$

    $M_{rxg} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}}+2,\, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi_{C_{o_{1,1}}}}+2,\, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi_{C_{o_{2,1}}}}+2,\, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi_{C_{o_{1,1}}}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi_{C_{o_{2,1}}}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow \mathrm{FlangeDC}(P, D_o, t, I, B_1, B_2, M'_j, S)$

    if $Int'_j > Int_0$

      $Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfi_{C_{o_{0,1}}}-1}+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M\right.$

      $Result \leftarrow M'$

Int

Conditions applicable to all flanges

$M_{ox} := 0 \quad M_{oy} := 0 \quad M_{oz} := 0$

Defining place holding variables

$$Flange\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties of Line 1-22, 1-23, 1-24, & 1-25

Define pertinent pipe variables

$D_o := 20in$ — Outside Diameter [4] [5] [6] [7]

$t := 0.375in$ — Thickness [4] [5] [6] [7]

$P := 400psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 1.113 \times 10^3\ in^4$

Define primary stress indices (Utilize girth weld characteristic associated with lap joint flanges in determining values)

$B_1 := 0.5$ — B_1 for a girth weld [9, Table NB-3681(a)-1, pg 130]

$B_2 := 1$ — B_2 for a girth weld [9, Table NB-3681(a)-1, pg 130]

Flange (Primary Pump) 1-25A (Node 207)

$nd_{FL125A} := (207)^T$

$AL_{FL125A} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{FL125A}, Flange\_C_o, EL_{ML}\right)$

$$AL_{FL125A}^{\,T} = \begin{pmatrix} 0.245 & 9.554 \times 10^5 & 7.36 & 207 & 76 & 2.205 \times 10^5 & 1.324 \times 10^5 & 9.201 \times 10^5 \end{pmatrix}$$

Flange (Check Valve) 1-25B (Node 199)

$nd_{FL125B} := (199)^T$

$AL_{FL125B} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{FL125B}, Flange\_C_o, EL_{ML}\right)$

$$AL_{FL125B}^{\,T} = \begin{pmatrix} 0.181 & 5.506 \times 10^5 & 7.36 & 199 & 67 & -1.006 \times 10^5 & 2.425 \times 10^5 & 4.839 \times 10^5 \end{pmatrix}$$

Flange (Gate Valve) 1-25C (Node 198)

$nd_{FL125C} := (198)^T$

$AL_{FL125C} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{FL125C}, Flange\_C_o, EL_{ML})$

$AL_{FL125C}{}^T = (0.15 \quad 3.544 \times 10^5 \quad 4.32 \quad 198 \quad 59 \quad -1.743 \times 10^5 \quad 2.934 \times 10^4 \quad 3.072 \times 10^5)$

Flange (Primary Pump) 1-24A (Node 184)

$nd_{FL124A} := (184)^T$

$AL_{FL124A} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{FL124A}, Flange\_C_o, EL_{ML})$

$AL_{FL124A}{}^T = (0.215 \quad 7.667 \times 10^5 \quad 7.615 \quad 184 \quad 74 \quad -5.264 \times 10^4 \quad -6.39 \times 10^4 \quad -7.622 \times 10^5)$

Flange (Check Valve) 1-24B (Node 169)

$nd_{FL124B} := (169)^T$

$AL_{FL124B} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{FL124B}, Flange\_C_o, EL_{ML})$

$AL_{FL124B}{}^T = (0.167 \quad 4.603 \times 10^5 \quad 10.205 \quad 169 \quad 55 \quad -8.222 \times 10^4 \quad 1.882 \times 10^5 \quad 4.12 \times 10^5)$

Flange (Gate Valve) 1-24C (Node 167)

$nd_{FL124C} := (167)^T$

$AL_{FL124C} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{FL124C}, Flange\_C_o, EL_{ML})$

$AL_{FL124C}{}^T = (0.18 \quad 5.419 \times 10^5 \quad 7.26 \quad 167 \quad 47 \quad -1.174 \times 10^5 \quad 4.813 \times 10^3 \quad 5.29 \times 10^5)$

Flange (Primary Pump) 1-23A (Node 183)

$nd_{FL123A} := (183)^T$

$AL_{FL123A} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{FL123A}, Flange\_C_o, EL_{ML})$

$AL_{FL123A}{}^T = (0.19 \quad 6.088 \times 10^5 \quad 10.185 \quad 183 \quad 72 \quad 2.32 \times 10^5 \quad 5.558 \times 10^4 \quad 5.601 \times 10^5)$

Flange (Check Valve)B 1-23B (Node 168)

$nd_{FL123B} := (168)^T$

$AL_{FL123B} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{FL123B}, Flange\_C_o, EL_{ML})$

$AL_{FL123B}{}^T = (0.16 \quad 4.167 \times 10^5 \quad 8.58 \quad 168 \quad 43 \quad 8.852 \times 10^4 \quad -1.032 \times 10^5 \quad -3.939 \times 10^5)$

Flange (Gate Valve)B 1-23C (Node 166)

$nd_{FL123C} := (166)^T$

$AL_{FL123C} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{FL123C}, Flange\_C_o, EL_{ML})$

$AL_{FL123C}^T = (0.162 \quad 4.316 \times 10^5 \quad 5.54 \quad 166 \quad 155 \quad -1.389 \times 10^5 \quad -2.183 \times 10^3 \quad -4.086 \times 10^5)$

Flange (Primary Pump) 1-22A (Node 196)

$nd_{FL122A} := (196)^T$

$AL_{FL122A} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{FL122A}, Flange\_C_o, EL_{ML})$

$AL_{FL122A}^T = (0.198 \quad 6.56 \times 10^5 \quad 8.57 \quad 196 \quad 70 \quad -3.931 \times 10^4 \quad 2.167 \times 10^5 \quad 6.179 \times 10^5)$

Flange (Check Valve) 1-22B (Node 187)

$nd_{FL122B} := (187)^T$

$AL_{FL122B} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{FL122B}, Flange\_C_o, EL_{ML})$

$AL_{FL122B}^T = (0.157 \quad 3.984 \times 10^5 \quad 8.565 \quad 187 \quad 35 \quad -9.458 \times 10^4 \quad 2.716 \times 10^4 \quad 3.861 \times 10^5)$

Flange (Gate Valve) 1-22C (Node 186)

$nd_{FL122C} := (186)^T$

$AL_{FL122C} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF_{ML}, nd_{FL122C}, Flange\_C_o, EL_{ML})$

$AL_{FL122C}^T = (0.152 \quad 3.673 \times 10^5 \quad 6.77 \quad 186 \quad 27 \quad 1.117 \times 10^5 \quad 2.789 \times 10^4 \quad 3.488 \times 10^5)$

Writing Output Data for Flanges Associated with Lines 22 to 26

$F1 := AL_{FL125A}^T$ $F7 := AL_{FL123A}^T$

$F2 := AL_{FL125B}^T$ $F8 := AL_{FL123B}^T$

$F3 := AL_{FL125C}^T$ $F9 := AL_{FL123C}^T$

$F4 := AL_{FL124A}^T$ $F10 := AL_{FL122A}^T$

$F5 := AL_{FL124B}^T$ $F11 := AL_{FL122B}^T$

$F6 := AL_{FL124C}^T$ $F12 := AL_{FL122C}^T$

FlangeLines22to26 := WRITEPRN["FlangeLines22to26.prn" , (F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F12)]

Appendix B.3.2

Demand to Capacity Ratio Calculations for Components Associated with Lines 27-29 of ATR PCS Model 3

(NOTE: Values represented here are shown for one realization (Nodal Force file = Lines27to29_test_R1.dat and Element/Nodal order file = EL_27to29.xls) and may or may not be consistent with the 80th percentile results contained in Appendix B.4)

Nodal Force Outputs from Abaqus

NF_{LL} := ...\Lines27to29.dat

(N)odal (F)orces for the (L)arge (L)ines of Model 3

Defined Elemental and Corresponding Nodal Order

EL_{LL} := ...\EL_27to29(9-22-08).xls

Element and corresponding nodal order for the (L)arge (L)ines of Model 3

Time Boundaries

$t_{initial} := 1$

Initial time for which dynamic loading is applied

$t_{final} := 21$

Final time for which dynamic loading stops

Seismic Scale Factor (F_a)

$F_a := 1$

Seismic scale factor

Allowable Design Stress Intensity Factor (S_m): *S_m is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{m\_125} := 20ksi$

For SS304 at 125°F [2, pg 316-318] [3, pg 23]

$S_{m\_125L} := 16.7ksi$

For SS304L at 125°F [2, pg 316-318] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Yield Strength (S_y): *S_y is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{y\_125} := 28.35ksi$

For SS304 at 125°F [2, pg 646-648] [3, pg 23]]

$S_{y\_125L} := 23.85ksi$

For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Maximum Strength Applicable for Equation 9 (S): *S is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{125} := \min\left(3 \cdot S_{m\_125}, 2 \cdot S_{y\_125}\right)$

$\boxed{S_{125} = 56.7\,ksi}$

Maximum allowable stress applied to SS304 piping [9, NB-3656]

$S_{125L} := \min\left(3 \cdot S_{m\_125L}, 2 \cdot S_{y\_125L}\right)$

$\boxed{S_{125L} = 47.7\,ksi}$

Maximum allowable stress applied to SS304L piping [9, NB-3656]

SUPPORTS

Supports Strategy: *Search based on the node for which the support acts. If this node is a termination point there will only be one node to evaluate. If this node is in line with a section of pipe there will be two representations of the same node (one for each element on each side of the node) to combine and the difference between them is the force required of the support. The D/C ratio for each support will be found by dividing the the required force found above by the support capacity.*

$$SupDC(P_r, P_c) := \frac{P_r}{P_c}$$

$$
\begin{array}{l}
Support(nf, nd, C_o, EL) := \\
\quad ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
\quad ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
\quad ind_{nd} \leftarrow match\left(nd_0, EL^{\langle 1 \rangle}\right) \\
\quad \text{for } i \in 1..last(nd) \qquad\qquad \text{if } rows(nd) > 1 \\
\qquad ind_{nd} \leftarrow stack\left[ind_{nd}, \left(match\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \\
\quad \begin{pmatrix} Int1_4 & Int2_4 \end{pmatrix} \leftarrow \begin{pmatrix} 0 & 0 \end{pmatrix} \\
\quad \text{for } i \in 0..ind_{nfo_0} - ind_{nfi_0} \\
\qquad \text{for } j \in 0..last(ind_{nd}) \\
\qquad\quad P_{rg_j} \leftarrow nf_{ind_{nfi}C_{o_{0,1}}-1,\, ind_{nd_j}} \\
\qquad\quad P_{r_j} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}}-1+i,\, ind_{nd_j}} - P_{rg_j}\right) \cdot C_{o_{2,0}} + P_{rg_j} \\
\qquad PR_i \leftarrow \sum_{n=0}^{j} P_{r_n} \\
\qquad \text{if } PR_i < Int1_1 \wedge C_{o_{0,0}} \neq 0 \\
\qquad\quad Int1' \leftarrow SupDC\left(\left|PR_i\right|, C_{o_{0,0}}\right) \\
\qquad\quad Int1 \leftarrow stack\left(Int1', PR_i, nf_{ind_{nfi}C_{o_{0,1}}-1+i,\,0}, EL_{ind_{nd_j},\,1}, ind_{nd}\right) \\
\qquad \text{if } PR_i > Int2_1 \wedge C_{o_{1,0}} \neq 0 \\
\qquad\quad Int2' \leftarrow SupDC\left(\left|PR_i\right|, C_{o_{1,0}}\right) \\
\qquad\quad Int2 \leftarrow stack\left(Int2', PR_i, nf_{ind_{nfi}C_{o_{0,1}}-1+i,\,0}, EL_{ind_{nd_j},\,1}, ind_{nd}\right) \\
\quad \begin{pmatrix} Int1 & Int2 \end{pmatrix}
\end{array}
$$

PS-3A Support (1x)

$P_{1\_PS3A} := \frac{154.855 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$P_{2\_PS3A} := \frac{0.1kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$$Sup\_C_{o\_PS3A} := \begin{pmatrix} P_{1\_PS3A} & 2 \\ P_{2\_PS3A} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

PS-3A (Node 81)

PS-3A vertically resists downward displacement of the horizontal (E/W) PCS pipe on line 1-27 prior to the fab with line 1-32 protrusion

$nd81_{PS3A_0} := 81$ Node associated with support

$$\left(AL1_{PS3A\_nd81} \quad AL2_{PS3A\_nd81}\right) := Support\left(NF_{LL}, nd81_{PS3A}, Sup\_C_{o\_PS3A}, EL_{LL}\right)$$

$$AL1_{PS3A\_nd81}{}^T = \left(0.336 \quad -5.208 \times 10^4 \quad 4.98 \quad 81 \quad 75\right)$$

$$AL2_{PS3A\_nd81}{}^T = \left(0 \quad 0 \quad 0 \quad 0 \quad 0\right)$$

(D/C,demand force, occurrence time, defined node, associated Index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-23x Support (1x)

$P_{1\_RH23x} := \frac{41.417 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$P_{2\_RH23x} := \frac{41.417kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$$Sup\_C_{o\_RH23x} := \begin{pmatrix} P_{1\_RH23x} & 2 \\ P_{2\_RH23x} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

RH-23x (Node 394)

RH-23x vertically supports the vertical PCS pipe on line 1-27 traveling up from the reactor vessel area and into the tunnel

$nd394_{RH23x_0} := 394$ Node associated with support

$$\left(AL1_{RH23x\_nd394}\ \ AL2_{RH23x\_nd394}\right) := Support\left(NF_{LL}, nd394_{RH23x}, Sup\_C_{o\_RH23x}, EL_{LL}\right)$$

$$AL1_{RH23x\_nd394}{}^{T} = \left(1.153\ \ -4.776\times10^{4}\ \ 8.745\ \ 394\ \ 139\right)$$

$$AL2_{RH23x\_nd394}{}^{T} = \left(0\ \ 0\ \ 0\ \ 0\ \ 0\right)$$

D/C,demand force, occurrence time, defined node, associated Index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-25ABx Support (2x)

$$P_{1\_RH25x} := \frac{56.28\cdot kip}{lbf}$$

Tension

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$$P_{2\_RH25x} := \frac{0\cdot kip}{lbf}$$

Uplift

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$$Sup\_C_{o\_RH25x} := \begin{pmatrix} P_{1\_RH25x} & 2 \\ P_{2\_RH25x} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

RH-25ABx (Node 536)

RH-25Ax vertically supports the horizontal (N/S) PCS pipe on line 1-27 just north of RH-23x in the tunnel

$$nd536_{RH25x_0} := 536$$

Node associated with support

$$\left(AL1_{RH25x\_nd536}\ \ AL2_{RH25x\_nd536}\right) := Support\left(NF_{LL}, nd536_{RH25x}, Sup\_C_{o\_RH25x}, EL_{LL}\right)$$

$$AL1_{RH25x\_nd536}{}^{T} = \left(0.571\ \ -3.211\times10^{4}\ \ 8.745\ \ 536\ \ 138\right)$$

$$AL2_{RH25x\_nd536}{}^{T} = \left(0\ \ 0\ \ 0\ \ 0\ \ 0\right)$$

D/C,demand force, occurrence time, defined node, associated Index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-25ABx (Node 537)

RH-25Bx vertically supports the horizontal (N/S) PCS pipe on line 1-27 just north of RH-25Ax in the tunnel

$$nd537_{RH25x_0} := 537$$

Node associated with support

$$\left(AL1_{RH25x\_nd537}\ \ AL2_{RH25x\_nd537}\right) := Support\left(NF_{LL}, nd537_{RH25x}, Sup\_C_{o\_RH25x}, EL_{LL}\right)$$

$$AL1_{RH25x\_nd537}{}^{T} = \left(0.342\ \ -1.923\times10^{4}\ \ 5.485\ \ 537\ \ 136\right)$$

$$AL2_{RH25x\_nd537}{}^{T} = \left(0\ \ 0\ \ 0\ \ 0\ \ 0\right)$$

D/C,demand force, occurrence time, defined node, associated Index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

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Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

RH-26x Support (1x)

$P_{1\_RH26x} := \frac{56.28 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$P_{2\_RH26x} := \frac{0 \cdot kip}{lbf}$ ***Uplift*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$$Sup\_C_{o\_RH26x} := \begin{pmatrix} P_{1\_RH26x} & 2 \\ P_{2\_RH26x} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

RH-26x (Node 538)

RH-26x vertically supports the horizontal (N/S) PCS pipe on line 1-27 just north of RH-25Bx in the tunnel, RH-26x also supports line 8-14 using one of its component legs.

$nd538_{RH26x_0} := 538$ Node associated with support

$$\left(AL1_{RH26x\_nd538} \;\; AL2_{RH26x\_nd538}\right) := Support\left(NF_{LL}, nd538_{RH26x}, Sup\_C_{o\_RH26x}, EL_{LL}\right)$$

$$AL1_{RH26x\_nd538}^{T} = \left(0.261 \;\; -1.471 \times 10^{4} \;\; 5.485 \;\; 538 \;\; 134\right)$$

$$AL2_{RH26x\_nd538}^{T} = \left(0 \;\; 0 \;\; 0 \;\; 0 \;\; 0\right)$$

D/C,demand force, occurrence time, defined node, associated Index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-27x Support (1x)

$P_{1\_RH27x} := \frac{27.8 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$P_{2\_RH27x} := \frac{0 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$$Sup\_C_{o\_RH27x} := \begin{pmatrix} P_{1\_RH27x} & 2 \\ P_{2\_RH27x} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

RH-27x (Node 539)

RH-27x vertically supports the horizontal (N/S) PCS pipe on line 1-27 just north of RH-26x in the tunnel.

$nd539_{RH27x_0} := 539$ Node associated with support

$$\left(AL1_{RH27x\_nd539}\ \ AL2_{RH27x\_nd539}\right) := \text{Support}\left(NF_{LL}, nd539_{RH27x}, Sup\_C_{o\_RH27x}, EL_{LL}\right)$$

$$AL1_{RH27x\_nd539}^{T} = \left(0.786\ \ -2.186\times 10^{4}\ \ 5.565\ \ 539\ \ 142\right)$$

$$AL2_{RH27x\_nd539}^{T} = \left(0\ \ 0\ \ 0\ \ 0\ \ 0\right)$$

,demand force, occurrence time, ed node, associated Index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PR-1 Supports (1x East Side of Reactor Vessel)

$$P_{1\_PR1\_E} := \frac{3.188\cdot kip}{lbf}$$

Tension

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$$P_{2\_PR1\_E} := \frac{13.929\cdot kip}{lbf}$$

Compression

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$$Sup\_C_{o\_PR1} := \begin{pmatrix} P_{1\_PR1\_E} & 3 \\ P_{2\_PR1\_E} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

PR-1 (Node 400)

PR-1 horizontally (E/W) supports the vertical PCS pipe on line 1-27 on the east side of the reactor vessel.

$$nd400_{PR1_0} := 400$$

Node associated with support

$$\left(AL1_{PR1\_nd400}\ \ AL2_{PR1\_nd400}\right) := \text{Support}\left(NF_{LL}, nd400_{PR1}, Sup\_C_{o\_PR1}, EL_{LL}\right)$$

$$AL1_{PR1\_nd400}^{T} = \left(1.894\ \ -6.037\times 10^{3}\ \ 5.7\ \ 400\ \ 114\right)$$

$$AL2_{PR1\_nd400}^{T} = \left(0.461\ \ 6.421\times 10^{3}\ \ 12.51\ \ 400\ \ 114\right)$$

(D/C,demand force, occurrence time, defined node, associated Index for the reaction force at the selected node eing in the positive (AL1) and negative AL2) directions of the global coordinate system)

PR-1 Supports (1x West Side of Reactor Vessel)

$$P_{1\_PR1\_W} := \frac{13.929\cdot kip}{lbf}$$

Compression

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$$P_{2\_PR1\_W} := \frac{3.188\cdot kip}{lbf}$$

Tension

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$$Sup\_C_{o\_PR1} := \begin{pmatrix} P_{1\_PR1\_W} & 3 \\ P_{2\_PR1\_W} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

PR-1 (Node 404)

PR-1 horizontally (E/W) supports the vertical PCS pipe on line 1-29 on the west side of the reactor vessel.

$nd404_{PR1_0} := 404$ Node associated with support

$\left(AL1_{PR1\_nd404} \quad AL2_{PR1\_nd404}\right) := Support\left(NF_{LL}, nd404_{PR1}, Sup\_C_{o\_PR1}, EL_{LL}\right)$

$AL1_{PR1\_nd404}{}^{T} = \left(0.353 \quad -4.913\times10^{3} \quad 4.885 \quad 404 \quad 116\right)$

$AL2_{PR1\_nd404}{}^{T} = \left(1.678 \quad 5.349\times10^{3} \quad 4.715 \quad 404 \quad 116\right)$

/C,demand force, occurrence time, fined node, associated Index for the reaction force at the selected node eing in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PR-8 Supports (1x)

$P_{1\_PR8} := \frac{2.374 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$P_{2\_PR8} := \frac{33.548 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$Sup\_C_{o\_PR8} := \begin{pmatrix} P_{1\_PR8} & 2 \\ P_{2\_PR8} & 0 \\ F_a & 0 \end{pmatrix}$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

PR-8 (Node 59)

PR-1 vertically supports the vertical PCS pipe on line 1-27 below the tee connecting lines 1-27 to 1-28 & 1-29.

$nd59_{PR8_0} := 59$ Node associated with support

$\left(AL1_{PR8\_nd59} \quad AL2_{PR8\_nd59}\right) := Support\left(NF_{LL}, nd59_{PR8}, Sup\_C_{o\_PR8}, EL_{LL}\right)$

$AL1_{PR8\_nd59}{}^{T} = \left(1.343\times10^{-3} \quad -3.187 \quad 8.745 \quad 59 \quad 127\right)$

$AL2_{PR8\_nd59}{}^{T} = \left(2.441\times10^{-5} \quad 0.819 \quad 8.67 \quad 59 \quad 127\right)$

)/C,demand force, occurrence time, efined node, associated Index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

MS-2 Support (1x)

$P_{1\_MS2} := \frac{34.229 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$P_{2\_MS2} := \frac{50 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$$Sup\_C_{o\_MS2} := \begin{pmatrix} P_{1\_MS2} & 3 \\ P_{2\_MS2} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

MS-2 (Node 429)

MS-2 horizontally (E/W) supports the horizontal (N/S) PCS pipe on line 1-27 just north of the tunnel.

$$nd429_{MS2_0} := 429$$

Node associated with support

$$\left(AL1_{MS2\_nd429} \;\; AL2_{MS2\_nd429}\right) := Support\left(NF_{LL}, nd429_{MS2}, Sup\_C_{o\_MS2}, EL_{LL}\right)$$

$$AL1_{MS2\_nd429}^{T} = \left(0.844 \;\; -2.888\times10^{4} \;\; 5.795 \;\; 429 \;\; 122\right)$$

$$AL2_{MS2\_nd429}^{T} = \left(0.736 \;\; 3.682\times10^{4} \;\; 9.1 \;\; 429 \;\; 122\right)$$

(C,demand force, occurrence time, fined node, associated Index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

Tunnel Restraint Support (1x)

$$P_{1\_TR127} := \frac{61.48 \cdot kip}{lbf}$$

Eastward Compression

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$$P_{2\_TR127} := \frac{85.842 \cdot kip}{lbf}$$

Westward Compression

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$$Sup\_C_{o\_TR127} := \begin{pmatrix} P_{1\_TR127} & 3 \\ P_{2\_TR127} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

Tunnel Restraint (Node 485)

Tunnel Restraint horizontally (E/W) restrains the vertical PCS pipe on line 1-27

$$nd485_{TR127_0} := 485$$

Node associated with support

$$\left(AL1_{TR127\_nd485} \;\; AL2_{TR127\_nd485}\right) := Support\left(NF_{LL}, nd485_{TR127}, Sup\_C_{o\_TR127}, EL_{LL}\right)$$

$$AL1_{TR127\_nd485}^{T} = \left(0.198 \;\; -1.217\times10^{4} \;\; 5.71 \;\; 485 \;\; 126\right)$$

$$AL2_{TR127\_nd485}^{T} = \left(0.146 \;\; 1.254\times10^{4} \;\; 12.495 \;\; 485 \;\; 126\right)$$

,demand force, occurrence time, ed node, associated Index for the reaction force at the selected node in the positive (AL1) and negative directions of the global coordinate system)

Floor Tieback Support (1x)

$$P_{1\_TieB\_EW} := \frac{67.488 \cdot kip}{lbf}$$

Eastward Compression

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$$P_{2\_TieB\_EW} := \frac{67.488 \cdot kip}{lbf}$$

Westward Compression

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$$Sup\_C_{o\_TieB\_EW} := \begin{pmatrix} P_{1\_TieB\_EW} & 3 \\ P_{2\_TieB\_EW} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

$$P_{1\_TieB\_NS} := \frac{101.12 \cdot kip}{lbf}$$

Northward Compression

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$$P_{2\_TieB\_NS} := \frac{101.12 \cdot kip}{lbf}$$

Southward Compression

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$$Sup\_C_{o\_TieB\_NS} := \begin{pmatrix} P_{1\_TieB\_NS} & 1 \\ P_{2\_TieB\_NS} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

$$P_{1\_TieB\_V} := \frac{291 \cdot kip}{lbf}$$

Compression

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$$P_{2\_TieB\_V} := \frac{0kip}{lbf}$$

Tension

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$$Sup\_C_{o\_TieB\_V} := \begin{pmatrix} P_{1\_TieB\_V} & 2 \\ P_{2\_TieB\_V} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

Tieback East/West (Node 102)

The floor Tieback vertically and horizontally supports the horizontal (N/S) PCS pipe on line 1-27 south of MS-2

$nd102_{TB\_EW_0} := 102$ Node associated with support

$(AL1_{TB\_EW\_nd102} \;\; AL2_{TB\_EW\_nd102}) := Support(NF_{LL}, nd102_{TB\_EW}, Sup\_C_{o\_TieB\_EW}, EL_{LL})$

$AL1_{TB\_EW\_nd102}{}^T = (0.394 \;\; -2.658 \times 10^4 \;\; 8.005 \;\; 102 \;\; 78 \;\; 83 \;\; 123)$

$AL2_{TB\_EW\_nd102}{}^T = (0.37 \;\; 2.497 \times 10^4 \;\; 8.09 \;\; 102 \;\; 78 \;\; 83 \;\; 123)$

nd force, occurrence time, e, associated Index for the reaction force at the selected node the positive (AL1) and (AL2) directions of the global coordinate system)

Tieback North/South (Node 102)

The floor Tieback vertically and horizontally supports the horizontal (N/S) PCS pipe on line 1-27 south of MS-2

$nd102_{TB\_NS_0} := 102$ Node associated with support

$(AL1_{TB\_NS\_nd102} \;\; AL2_{TB\_NS\_nd102}) := Support(NF_{LL}, nd102_{TB\_NS}, Sup\_C_{o\_TieB\_NS}, EL_{LL})$

$AL1_{TB\_NS\_nd102}{}^T = (0.295 \;\; -2.98 \times 10^4 \;\; 6.975 \;\; 102 \;\; 78 \;\; 83 \;\; 123)$

$AL2_{TB\_NS\_nd102}{}^T = (0.248 \;\; 2.506 \times 10^4 \;\; 8.51 \;\; 102 \;\; 78 \;\; 83 \;\; 123)$

hand force, occurrence time, node, associated Index for the reaction force at the selected eing in the positive (AL1) and e (AL2) directions of the global coordinate system)

Tieback Vertical (Node 463)

The floor Tieback vertically and horizontally supports the horizontal (N/S) PCS pipe on line 1-27 south of MS-2

$nd463_{TB\_V_0} := 463$ Node associated with support

$(AL1_{TB\_V\_nd463} \;\; AL2_{TB\_V\_nd463}) := Support(NF_{LL}, nd463_{TB\_V}, Sup\_C_{o\_TieB\_V}, EL_{LL})$

$AL1_{TB\_V\_nd463}{}^T = (0 \;\; 0 \;\; 0 \;\; 0 \;\; 0)$

$AL2_{TB\_V\_nd463}{}^T = (0 \;\; 0 \;\; 0 \;\; 0 \;\; 0)$

(D/C,demand force, occurrence time, defined node, associated Index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

Writing Output Data for Supports Associated with Lines 27 to 29

$SA1 := AL1_{PS3A\_nd81}^{T}$ $SH1 := AL1_{PR1\_nd404}^{T}$

$SA2 := AL2_{PS3A\_nd81}^{T}$ $SH2 := AL2_{PR1\_nd404}^{T}$

$SB1 := AL1_{RH23x\_nd394}^{T}$ $SI1 := AL1_{PR8\_nd59}^{T}$

$SB2 := AL2_{RH23x\_nd394}^{T}$ $SI2 := AL2_{PR8\_nd59}^{T}$

$SC1 := AL1_{RH25x\_nd536}^{T}$ $SJ1 := AL1_{MS2\_nd429}^{T}$

$SC2 := AL2_{RH25x\_nd536}^{T}$ $SJ2 := AL2_{MS2\_nd429}^{T}$

$SD1 := AL1_{RH25x\_nd537}^{T}$ $SK1 := AL1_{TR127\_nd485}^{T}$

$SD2 := AL2_{RH25x\_nd537}^{T}$ $SK2 := AL2_{TR127\_nd485}^{T}$

$SE1 := AL1_{RH26x\_nd538}^{T}$ $SL1 := AL1_{TB\_EW\_nd102}^{T}$

$SE2 := AL2_{RH26x\_nd538}^{T}$ $SL2 := AL2_{TB\_EW\_nd102}^{T}$

$SF1 := AL1_{RH27x\_nd539}^{T}$ $SM1 := AL1_{TB\_NS\_nd102}^{T}$

$SF2 := AL2_{RH27x\_nd539}^{T}$ $SM2 := AL2_{TB\_NS\_nd102}^{T}$

$SG1 := AL1_{PR1\_nd400}^{T}$ $SN1 := AL1_{TB\_V\_nd463}^{T}$

$SG2 := AL2_{PR1\_nd400}^{T}$ $SN2 := AL2_{TB\_V\_nd463}^{T}$

SupportsLines27to29 := WRITEPRN["SupLines27to29.prn" , (SA1 SA2 SB1 SB2 SC1 SC2 SD1 SD2 SE1 SE2 SF1 SF2

TERMINATION LOCATIONS

Termination Locations Strategy: *Search based on the node for which the termination location acts as well as the next node inward. The D/C ratio for each termination location will be found by dividing the the required force found above by the support capacity.*

$$\mathrm{TermDC}\left(P, D_o, t, I, B_1, B_2, M, S\right) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Term}\left(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL\right) :=$

$$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$$

$$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$$

$$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$$

$$\text{for } i \in 1 .. \mathrm{last}(nd) \quad \text{if } \mathrm{rows}(nd) > 1$$

$$\quad ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$$

$$\left(M \quad Int_0\right) \leftarrow (0 \quad 0)$$

$$\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$$

$$\quad \text{for } j \in 0 .. \mathrm{last}\left(ind_{nd}\right)$$

$$\quad\quad M_{rxg} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{nd_j}}$$

$$\quad\quad M_{ryg} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{nd_j}}$$

$$\quad\quad M_{rzg} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{nd_j}}$$

$$\quad\quad M_{rx} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$$

$$\quad\quad M_{ry} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$$

$$\quad\quad M_{rz} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$$

$$\quad\quad M'_j \leftarrow \sqrt{M_{rx}^{\;2} + M_{ry}^{\;2} + M_{rz}^{\;2}}$$

$$\quad\quad Int'_j \leftarrow \mathrm{TermDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$$

$$\quad\quad \text{if } Int'_j > Int_0$$

$$\quad\quad\quad Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfiC_{o_{0,1}}-1}+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M\right.$$

$$\quad\quad\quad Result \leftarrow M'$$

$$Int$$

Conditions applicable to all terminations

$M_{cx} := 0$ $M_{cy} := 0$ $M_{cz} := 0$

Defining place holding variables

$$Term\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

Reactor Vessel Terminations (2x)

Define pertinent pipe variables

$D_o := 24in$ Outside Diameter [11] [12]

$t := 0.375in$ Thickness [11] [12]

$P := 376psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\ 4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 1.942 \times 10^3\ in^4$$

Define primary stress indices

$B_1 := 0.5$

$$B_2 := \begin{array}{|l} 1.0 \ \text{ if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50 \\ \quad \begin{array}{|l} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \dfrac{D_o}{t}\right) \\ Y \leftarrow 1 \\ 1.0 \cdot \dfrac{1}{X \cdot Y} \end{array} \end{array}$$

$B_2 = 1.092$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Reactor Vessel 1-28 (Node 25)

$nd25_{RV128_0} := 25$

$AL_{RV128\_nd25} := Term(P, D_o, t, I, B_1, B_2, S_{125L}, NF_{LL}, nd25_{RV128}, Term\_C_o, EL_{LL})$

$AL_{RV128\_nd25}^{T} = \begin{pmatrix} 0.271 & 1.026 \times 10^{6} & 8.83 & 25 & 21 & -9.315 \times 10^{5} & -2.962 \times 10^{5} & -3.108 \times 10^{5} \end{pmatrix}$

Reactor Vessel 1-29 (Node 1)

$nd1_{RV129_0} := 1$

$AL_{RV129\_nd1} := Term(P, D_o, t, I, B_1, B_2, S_{125L}, NF_{LL}, nd1_{RV129}, Term\_C_o, EL_{LL})$

$AL_{RV129\_nd1}^{T} = \begin{pmatrix} 0.254 & 9.075 \times 10^{5} & 8.56 & 1 & 1 & -6.172 \times 10^{5} & -3.16 \times 10^{5} & 5.855 \times 10^{5} \end{pmatrix}$

Writing Output Data for Terminations Associated with Lines 27 to 29

$T1 := AL_{RV128\_nd25}^{T}$

$T2 := AL_{RV129\_nd1}^{T}$

TermLines27to29 := WRITEPRN["TermLines27to29.prn" , (T1 T2)]

PIPE RUNS

Pipe Runs Strategy: *Search based on the nodes present in each run of pipe. Find the maximum moment combination among all of the nodes and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{PipeRunDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1 \mathrm{lbf} \cdot \mathrm{in})]}{S}$$

```
PipeRun(P, D_o, t, I, B_1, B_2, S, nf, el, C_o, EL) :=
  ind_nfi ← match(t_initial, nf^<0>)
  ind_nfo ← match(t_final, nf^<0>)
  ind_el ← match(el_0, EL^<0>)
  for i ∈ 1 .. last(el)                                      if rows(el) > 1
    ind_el ← stack[ind_el, (match(el_i, EL^<0>))]
  (M  Int_{5, last(ind_el)}) ← (0  0)
  for i ∈ 0 .. ind_nfo_0 − ind_nfi_0
    for j ∈ 0 .. last(ind_el)
        M_rxg ← nf_{ind_nfi_{C_o 0,1}+2, ind_el_j}
        M_ryg ← nf_{ind_nfi_{C_o 1,1}+2, ind_el_j}
        M_rzg ← nf_{ind_nfi_{C_o 2,1}+2, ind_el_j}
        M_rx_j ← (nf_{ind_nfi_{C_o 0,1}+2+i, ind_el_j} − M_rxg)·C_o 3,0 + M_rxg
        M_ry_j ← (nf_{ind_nfi_{C_o 1,1}+2+i, ind_el_j} − M_ryg)·C_o 3,0 + M_ryg
        M_rz_j ← (nf_{ind_nfi_{C_o 2,1}+2+i, ind_el_j} − M_rzg)·C_o 3,0 + M_rzg
        M'_j ← sqrt((M_rx_j)^2 + (M_ry_j)^2 + (M_rz_j)^2)
        Int'_j ← PipeRunDC(P, D_o, t, I, B_1, B_2, M'_j, S)
        if Int'_j > Int_{0, j}
          H ← (Int'_j  M'_j  nf_{ind_nfi_{C_o 0,1}−1+i, 0}  EL_{ind_el_j, 0}  EL_{ind_el_j, 1}  ind_el_j  M_r
          for k ∈ 0 .. 5
            Int_{k, j} ← H_k
```

Int

Conditions applicable to all pipe runs

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$

Defining place holding directional moment variables

$$PipeRun\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties for Line 1-28 and 1-29

Define pertinent pipe variables

$D_o := 24in$ — Outside Diameter [11] [12]

$t := 0.375in$ — Thickness [11] [12]

$P := 376psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 1.942 \times 10^3\ in^4$$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{cases} 1.0 & \text{if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50 & \begin{aligned} & T \leftarrow 125 \\ & X \leftarrow \min\left(1, 1.3 - 0.006\cdot\frac{D_o}{t}\right) \\ & Y \leftarrow 1.033 - 0.00033\cdot T \\ & 1.0\cdot\frac{1}{X\cdot Y} \end{aligned} \end{cases}$$

$B_{2PR} = 1.101$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

Pipe Run 1-28A (Elements 27)

$$el_{PR128A} := (27)^T$$

$$AL_{PR128A} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125L}, NF_{LL}, el_{PR128A}, PipeRun\_C_o, EL_{LL})$$

$$AL_{PR128A}^{\ T} = \begin{pmatrix} 0.272 & 1.026\times10^{6} & 8.83 & 27 & 25 & 21 \\ 0.21 & 5.9\times10^{5} & 11.56 & 27 & 26 & 22 \end{pmatrix}$$

Pipe Run 1-28B (Elements 31, 36, 670, 671, & 53)

$$el_{PR128B} := (31 \quad 36 \quad 670 \quad 671 \quad 53)^T$$

$$AL_{PR128B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125L}, NF_{LL}, el_{PR128B}, PipeRun\_C_o, EL_{LL})$$

$AL_{PR128B}^{\ T} =$

	0	1	2	3	4	5
0	0.191	$4.559\cdot10^{5}$	11.57	31	29	23
1	0.167	$2.9\cdot10^{5}$	11.575	31	40	24
2	0.167	$2.899\cdot10^{5}$	11.575	36	40	25
3	0.155	$2.041\cdot10^{5}$	12.515	36	551	26
4	0.155	$2.04\cdot10^{5}$	12.515	670	551	147
5	0.169	$3.009\cdot10^{5}$	8.585	670	552	148
6	0.191	$4.522\cdot10^{5}$	8.585	671	49	149
7	0.169	$3.009\cdot10^{5}$	8.585	671	552	150
8	0.192	$4.624\cdot10^{5}$	8.585	53	32	41
9	0.191	$4.522\cdot10^{5}$	8.585	53	49	42

Pipe Run 1-28C (Elements 38, 608, 41, 46, 675, 676, & 677)

$$el_{PR128C} := (38 \quad 608 \quad 41 \quad 46 \quad 675 \quad 676 \quad 677)^T$$

$$Al_{PR128C} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125L}, NF_{LL}, el_{PR128C}, PipeRun\_C_o, EL_{LL})$$

$Al_{PR128C}^{\ T} =$

	0	1	2	3	4	5
0	0.179	$3.711\cdot10^{5}$	11.77	38	33	27
1	0.179	$3.717\cdot10^{5}$	11.77	38	503	28
2	0.203	$5.371\cdot10^{5}$	8.78	608	34	131
3	0.179	$3.717\cdot10^{5}$	11.77	608	503	132
4	0.207	$5.7\cdot10^{5}$	3.825	41	36	33
5	0.217	$6.408\cdot10^{5}$	9.585	41	43	34
6	0.217	$6.408\cdot10^{5}$	9.585	46	43	35
7	0.231	$7.351\cdot10^{5}$	8.585	46	556	36
8	0.231	$7.354\cdot10^{5}$	8.585	675	556	157
9	0.242	$8.151\cdot10^{5}$	8.585	675	557	158
10	0.242	$8.153\cdot10^{5}$	8.585	676	557	159
11	0.236	$7.686\cdot10^{5}$	8.585	676	558	160
12	0.212	$6.008\cdot10^{5}$	8.58	677	37	161
13	0.236	$7.685\cdot10^{5}$	8.585	677	558	162

Pipe Run 1-28D (Elements 48 & 49)

$$el_{PR128D} := (48 \quad 49)^{T}$$

$$AL_{PR128D} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{LL}, el_{PR128D}, PipeRun\_C_o, EL_{LL}\right)$$

$$AL_{PR128D}{}^{T} = \begin{pmatrix} 0.192 & 7.194 \times 10^{5} & 11.985 & 48 & 38 & 37 \\ 0.205 & 8.268 \times 10^{5} & 11.58 & 48 & 48 & 38 \\ 0.241 & 1.123 \times 10^{6} & 8.755 & 49 & 39 & 39 \\ 0.205 & 8.269 \times 10^{5} & 11.58 & 49 & 48 & 40 \end{pmatrix}$$

Pipe Run 1-29A (Elements 1)

$$el_{PR129A} := (1)^{T}$$

$$Al_{PR129A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125L}, NF_{LL}, el_{PR129A}, PipeRun\_C_o, EL_{LL}\right)$$

$$Al_{PR129A}{}^{T} = \begin{pmatrix} 0.256 & 9.075 \times 10^{5} & 8.56 & 1 & 1 & 1 \\ 0.212 & 6.051 \times 10^{5} & 8.56 & 1 & 4 & 2 \end{pmatrix}$$

Pipe Run 1-29B (Elements 5, 7, 668, 669, & 54)

$$el_{PR129B} := (5 \quad 7 \quad 668 \quad 669 \quad 54)^{T}$$

$$Al_{PR129B} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125L}, NF_{LL}, el_{PR129B}, PipeRun\_C_o, EL_{LL}\right)$$

$Al_{PR129B}{}^{T} =$

	0	1	2	3	4	5
0	0.189	4.404·105	8.555	5	5	3
1	0.164	2.634·105	11.995	5	16	4
2	0.164	2.633·105	11.995	7	16	5
3	0.155	2.059·105	12	7	549	6
4	0.155	2.059·105	12	668	549	143
5	0.165	2.731·105	8.565	668	550	144
6	0.187	4.241·105	8.565	669	50	145
7	0.165	2.734·105	8.565	669	550	146
8	0.188	4.347·105	8.565	54	8	43
9	0.187	4.244·105	8.565	54	50	44

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Pipe Run 1-29C (Elements 9, 607, 12, 25, 672, 673, & 674)

$el_{PR129C} := (9 \quad 607 \quad 12 \quad 25 \quad 672 \quad 673 \quad 674)^T$

$Al_{PR129C} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125L}, NF_{LL}, el_{PR129C}, PipeRun\_C_o, EL_{LL})$

$Al_{PR129C}{}^T =$

	0	1	2	3	4	5
0	0.183	3.981·105	11.355	9	9	7
1	0.183	3.968·105	11.76	9	502	8
2	0.178	3.63·105	8.775	607	10	129
3	0.183	3.97·105	11.76	607	502	130
4	0.178	3.625·105	9.965	12	12	13
5	0.193	4.707·105	8.84	12	19	14
6	0.193	4.709·105	8.84	25	19	17
7	0.18	3.789·105	8.575	25	553	18
8	0.18	3.79·105	8.575	672	553	151
9	0.202	5.357·105	8.58	672	554	152
10	0.203	5.358·105	8.58	673	554	153
11	0.213	6.111·105	8.58	673	555	154
12	0.215	6.216·105	11.355	674	13	155
13	0.213	6.111·105	8.58	674	555	156

Pipe Run 1-29D (Elements 14 & 26)

$el_{PR129D} := (14 \quad 26)^T$

$AL_{PR129D} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{LL}, el_{PR129D}, PipeRun\_C_o, EL_{LL})$

$$AL_{PR129D}{}^T = \begin{pmatrix} 0.19 & 6.981\times10^5 & 11.765 & 14 & 14 & 15 \\ 0.194 & 7.29\times10^5 & 11.765 & 14 & 24 & 16 \\ 0.217 & 9.226\times10^5 & 11.77 & 26 & 15 & 19 \\ 0.194 & 7.29\times10^5 & 11.765 & 26 & 24 & 20 \end{pmatrix}$$

Pipe Properties for Lower (Southern) Portion of Line 1-27

Define pertinent pipe variables

$D_o := 36in$ — Outside Diameter [13]

$t := 0.5in$ — Thickness [13]

$P := 376psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 8.786 \times 10^3\, in^4$$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{array}{l} 1.0 \ \text{ if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50 \\ \quad T \leftarrow 125 \\ \quad X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \dfrac{D_o}{t}\right) \\ \quad Y \leftarrow 1.033 - 0.00033 \cdot T \\ \quad 1.0 \cdot \dfrac{1}{X \cdot Y} \end{array}$$

$B_{2PR} = 1.162$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-27A (Elements 93, 94, & 469)

$$el_{PR127A} := (93 \;\; 94 \;\; 469)^T$$

$$AL_{PR127A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{LL}, el_{PR127A}, PipeRun\_C_o, EL_{LL}\right)$$

$$AL_{PR127A}^{\;T} = \begin{pmatrix} 0.168 & 1.17 \times 10^6 & 4.13 & 93 & 56 & 79 \\ 0.172 & 1.264 \times 10^6 & 3.825 & 93 & 88 & 80 \\ 0.172 & 1.264 \times 10^6 & 3.825 & 94 & 88 & 81 \\ 0.173 & 1.274 \times 10^6 & 8.75 & 94 & 89 & 82 \\ 0.157 & 8.914 \times 10^5 & 11.58 & 469 & 60 & 111 \\ 0.151 & 7.602 \times 10^5 & 12.01 & 469 & 89 & 112 \end{pmatrix}$$

Pipe Run 1-27B (Elements 66, 678, 75, 679, 680, 76, 681, 682, & 67)

$$el_{PR127B} := (66\ \ 678\ \ 75\ \ 679\ \ 680\ \ 76\ \ 681\ \ 682\ \ 67)^{T}$$

$$AL_{PR127B} := \mathrm{PipeRun}\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{LL}, el_{PR127B}, PipeRun\_C_o, EL_{LL}\right)$$

$AL_{PR127B}{}^{T} =$

	0	1	2	3	4	5
0	0.177	$1.377\cdot10^{6}$	11.57	66	61	59
1	0.161	$9.966\cdot10^{5}$	11.57	66	559	60
2	0.161	$9.826\cdot10^{5}$	11.755	678	68	163
3	0.161	$9.967\cdot10^{5}$	11.57	678	559	164
4	0.161	$9.826\cdot10^{5}$	11.755	75	68	67
5	0.159	$9.532\cdot10^{5}$	8.09	75	560	68
6	0.159	$9.537\cdot10^{5}$	8.09	679	560	165
7	0.164	$1.061\cdot10^{6}$	8.085	679	561	166
8	0.196	$1.821\cdot10^{6}$	8.745	680	69	167
9	0.164	$1.062\cdot10^{6}$	8.085	680	561	168
10	0.196	$1.822\cdot10^{6}$	8.745	76	69	69
11	0.165	$1.086\cdot10^{6}$	8.745	76	562	70
12	0.165	$1.086\cdot10^{6}$	8.745	681	562	169
13	0.151	$7.493\cdot10^{5}$	10.875	681	563	170
14	0.146	$6.414\cdot10^{5}$	11.695	682	63	171
15	0.151	$7.492\cdot10^{5}$	10.875	682	563	172

Pipe Properties for Upper (Northern) Portion of Line 1-27

Define pertinent pipe variables

$D_o := 36\,in$ — Outside Diameter [7]

$t := 0.5625\,in$ — Thickness [7]

$P := 400\,psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^{4}\right]}{64}$$ — Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 9.833\times10^{3}\,in^{4}$$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{cases} 1.0 \text{ if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50 \\ \quad T \leftarrow 125 \\ \quad X \leftarrow \min\left(1, 1.3 - 0.006\cdot\dfrac{D_o}{t}\right) \\ \quad Y \leftarrow 1.033 - 0.00033\cdot T \\ \quad 1.0\cdot\dfrac{1}{X\cdot Y} \end{cases}$$

$$B_{2PR} = 1.101$$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-27C (Elements 81, 683, 89, 108, 684, 495, & 496)

$$el_{PR127C} := (81\ \ 683\ \ 89\ \ 108\ \ 684\ \ 495\ \ 496)^T$$

$$AL_{PR127C} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{LL}, el_{PR127C}, PipeRun\_C_o, EL_{LL}\right)$$

$AL_{PR127C}{}^T =$

	0	1	2	3	4	5
0	0.137	$6.67\cdot10^{5}$	11.29	81	65	71
1	0.146	$9.2\cdot10^{5}$	7.87	81	564	72
2	0.162	$1.37\cdot10^{6}$	7.86	683	84	173
3	0.146	$9.198\cdot10^{5}$	7.87	683	564	174
4	0.162	$1.371\cdot10^{6}$	7.86	89	84	77
5	0.181	$1.906\cdot10^{6}$	7.855	89	102	78
6	0.181	$1.907\cdot10^{6}$	7.855	108	102	83
7	0.154	$1.169\cdot10^{6}$	11.265	108	565	84
8	0.165	$1.456\cdot10^{6}$	9.1	684	103	175
9	0.154	$1.169\cdot10^{6}$	11.265	684	565	176
10	0.165	$1.455\cdot10^{6}$	9.1	495	103	117
11	0.16	$1.315\cdot10^{6}$	9.095	495	419	118
12	0.15	$1.039\cdot10^{6}$	9.095	496	75	119
13	0.16	$1.315\cdot10^{6}$	9.095	496	419	120

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Pipe Run 1-27D (Elements 117, 685, 686, 687, & 84)

$el_{PR127D} := (117 \quad 685 \quad 686 \quad 687 \quad 84)^T$

$AL_{PR127D} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{LL}, el_{PR127D}, PipeRun\_C_o, EL_{LL})$

$AL_{PR127D}{}^T =$

	0	1	2	3	4	5
0	0.143	$8.369 \cdot 10^5$	7.85	117	76	85
1	0.146	$9.227 \cdot 10^5$	5.685	117	566	86
2	0.146	$9.228 \cdot 10^5$	5.685	685	566	177
3	0.146	$9.326 \cdot 10^5$	4.34	685	567	178
4	0.146	$9.321 \cdot 10^5$	4.34	686	567	179
5	0.144	$8.715 \cdot 10^5$	8.575	686	568	180
6	0.172	$1.663 \cdot 10^6$	4.98	687	80	181
7	0.144	$8.714 \cdot 10^5$	8.575	687	568	182
8	0.156	$1.218 \cdot 10^6$	8.575	84	78	73
9	0.172	$1.676 \cdot 10^6$	4.98	84	80	74

Writing Output Data for Pipe Runs Associated with Lines 27 to 29

$PR1 := AL_{PR128A}{}^T$ $PR7 := Al_{PR129C}{}^T$

$PR2 := AL_{PR128B}{}^T$ $PR8 := AL_{PR129D}{}^T$

$PR3 := Al_{PR128C}{}^T$ $PR9 := AL_{PR127A}{}^T$

$PR4 := AL_{PR128D}{}^T$ $PR10 := AL_{PR127B}{}^T$

$PR5 := Al_{PR129A}{}^T$ $PR11 := AL_{PR127C}{}^T$

$PR6 := Al_{PR129B}{}^T$ $PR12 := AL_{PR127D}{}^T$

PipeRunsLines27to29 := WRITEPRN["PRLines27to29.prn" , (PR1 PR2 PR3 PR4 PR5 PR6 PR7 PR8 PR9 PR10 PR11 P

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REDUCERS

Reducers Strategy: *Search based on the nodes comprising either end of the reducers. SRSS combine the three moments of each of the four node representations (one for each element connected by the node in question). Find the maximum of the moment combinations for each element and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. It is important to not combine the data from both nodes as the geometry for each is different and (9) must be applied for each node. The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\text{ReducerDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

$\text{Reducer}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \text{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. \text{last}(nd)$ if $\text{rows}(nd) > 1$

  $ind_{nd} \leftarrow \text{stack}\left[ind_{nd}, \left(\text{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$(M \ \ Int_0) \leftarrow (0 \ \ 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \text{last}(ind_{nd})$

    $M_{rxg} \leftarrow nf_{ind_{nfi}C_{o_{0,1}}+2, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi}C_{o_{1,1}}+2, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi}C_{o_{2,1}}+2, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}}+2+i, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi}C_{o_{1,1}}+2+i, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi}C_{o_{2,1}}+2+i, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow \text{ReducerDC}(P, D_o, t, I, B_1, B_2, M'_j, S)$

    if $Int'_j > Int_0$

      $Int \leftarrow \text{stack}\left(Int'_j, M'_j, nf_{ind_{nfi}C_{o_{0,1}}-1+i, 0}, EL_{ind_{nd_j}, 1}, ind_{nd_j}, M_{rx}, M_{ry},\right.$

      $\text{Result} \leftarrow M'$

Int

Conditions applicable to all reducers

$M_{cx} := 0 \quad M_{cy} := 0 \quad M_{cz} := 0$ — Defining place holding variables

$$Reducer\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

Reducer Properties for Bottom of Line 1-28 and 1-29

Define pertinent reducer variables

$D_o := (36in \quad 24in)^T$ — Outside Diameter [13]

$t := \left(\frac{1}{2}in \quad \frac{3}{8}in\right)^T$ — Thickness [14]

$P := (376psi \quad 376psi)^T$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

$$I = \begin{pmatrix} 8.786\times10^3 \\ 1.942\times10^3 \end{pmatrix} in^4$$

Moment of inertia [8, Table 17-27, pg 17-39]

Define primary stress indices

$$\alpha := atan\left(\frac{6in}{24in}\right)$$

Angular slope of reducer [14]

$$\alpha = 14.036\,deg$$

$$B_1 := \begin{cases} 0.5 & \text{if } \alpha \le 30deg \\ 1.0 & \text{if } 30deg < \alpha \le 60deg \end{cases}$$

$$B_1 = 0.5$$

B_1 primary stress Index [9, NB-3683.7]

$B_2 := 1.0$ — B_2 primary stress Index [9, NB-3683.7]

Reducer 1-28 (Nodes 53 & 39)

$nd_{RD128\_L} := (53)^T$ Node associated with Large end of reducer

$AL_{RD128\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF_{LL}, nd_{RD128\_L}, Reducer\_C_o, EL_{LL}\right)$

$AL_{RD128\_L}^T = \left(0.168 \quad 1.354\times10^6 \quad 8.755 \quad 53 \quad 49 \quad 1.192\times10^6 \quad -4.107\times10^5 \quad 4.934\times10^5\right)$

$nd_{RD128\_S} := (39)^T$ Node associated with Small end of reducer

$AL_{RD128\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF_{LL}, nd_{RD128\_S}, Reducer\_C_o, EL_{LL}\right)$

$AL_{RD128\_S}^T = \left(0.228 \quad 1.123\times10^6 \quad 8.755 \quad 39 \quad 39 \quad 9.401\times10^5 \quad -3.377\times10^5 \quad 5.122\times10^5\right)$

Reducer 1-29 (Nodes 52 & 15)

$nd_{RD129\_L} := (52)^T$ Node associated with Large end of reducer

$AL_{RD129\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF_{LL}, nd_{RD129\_L}, Reducer\_C_o, EL_{LL}\right)$

$AL_{RD129\_L}^T = \left(0.157 \quad 1.028\times10^6 \quad 11.775 \quad 52 \quad 51 \quad 5.176\times10^5 \quad -6.228\times10^5 \quad -6.333\times10^5\right)$

$nd_{RD129\_S} := (15)^T$ Node associated with Small end of reducer

$AL_{RD129\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF_{LL}, nd_{RD129\_S}, Reducer\_C_o, EL_{LL}\right)$

$AL_{RD129\_S}^T = \left(0.207 \quad 9.226\times10^5 \quad 11.77 \quad 15 \quad 19 \quad 3.926\times10^5 \quad -4.89\times10^5 \quad -6.767\times10^5\right)$

Writing Output Data for Reducers Associated with Lines 27 to 29

$RL1 := AL_{RD128\_L}^T$

$RS1 := AL_{RD128\_S}^T$

$RL2 := AL_{RD129\_L}^T$

$RS2 := AL_{RD129\_S}^T$

ReducersLines27to29 := WRITEPRN["RedLines27to29.prn" , (RL1 RS1 RL2 RS2)]

ELBOWS

Elbows Strategy: *Search based on the two nodes comprising the ends of each elbow. SRSS combine the three moments of each of the four node representations (one for each element connected by the nodes in question). Find the maximum of the four moment combinations and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{ElbowDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Elbow}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$$

$$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$$

$$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$$

$\text{for } i \in 1 .. \mathrm{last}(nd)$ $\quad$ if $\mathrm{rows}(nd) > 1$

$$\quad ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$$

$$(M \quad Int_0) \leftarrow (0 \quad 0)$$

$\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

$\quad \text{for } j \in 0 .. \mathrm{last}(ind_{nd})$

$$M_{rxg} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}}+2,\, ind_{nd_j}}$$

$$M_{ryg} \leftarrow nf_{ind_{nfi_{C_{o_{1,1}}}}+2,\, ind_{nd_j}}$$

$$M_{rzg} \leftarrow nf_{ind_{nfi_{C_{o_{2,1}}}}+2,\, ind_{nd_j}}$$

$$M_{rx} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$$

$$M_{ry} \leftarrow \left(nf_{ind_{nfi_{C_{o_{1,1}}}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$$

$$M_{rz} \leftarrow \left(nf_{ind_{nfi_{C_{o_{2,1}}}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$$

$$M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$$

$$Int'_j \leftarrow \mathrm{ElbowDC}(P, D_o, t, I, B_1, B_2, M'_j, S)$$

$\text{if } Int'_j > Int_0$

$$Int \leftarrow \mathrm{stack}\Big(Int'_j, M'_j, nf_{ind_{nfi_{C_{o_{0,1}}}}-1+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M$$

$$Result \leftarrow M'$$

Int

Conditions applicable to all elbows

$M_{cx} := 0 \quad M_{cy} := 0 \quad M_{cz} := 0$

Defining place holding variables

$$Elb\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

Elbow Properties for Lines 1-28 and 1-29

Define pertinent elbow variables

$D_o := 24in$ — Outside Diameter [11] [12]

$t := 0.375in$ — Thickness [11] [12]

$P := 376psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 1.942 \times 10^3\, in^4$$

$R := 1.5 \cdot D_o$ — Nominal bend radius of curved pipe or elbow

$r_m := \frac{D_o - t}{2}$ — Mean pipe radius

Define primary stress indices

$h := \frac{t \cdot R}{r_m^{\,2}}$ $\quad h = 0.097$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4\cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4\cdot h > 0.5 \\ -0.1 + 0.4\cdot h & \text{otherwise} \end{cases}$$

$B_1 = 0$ — B_1 primary stress Index [9, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 6.168$ — B_2 primary stress Index [9, NB-3683.7]

Elbow 1-28A (Nodes 26 & 29)

$nd_{EL128A\_1} := (26)^T$

$AL_{EL128A\_nd28} := Elbow(P, D_o, t, I, B_1, B_2, S_{125L}, NF_{LL}, nd_{EL128A\_1}, Elb\_C_o, EL_{LL})$

$AL_{EL128A\_nd28}{}^T = \begin{pmatrix} 0.471 & 5.9\times10^5 & 11.56 & 26 & 22 & 4.645\times10^4 & 2.707\times10^4 & 5.875\times10^5 \end{pmatrix}$

$nd_{EL128A\_2} := (29)^T$

$AL_{EL128A\_nd29} := Elbow(P, D_o, t, I, B_1, B_2, S_{125L}, NF_{LL}, nd_{EL128A\_2}, Elb\_C_o, EL_{LL})$

$AL_{EL128A\_nd29}{}^T = \begin{pmatrix} 0.364 & 4.56\times10^5 & 11.57 & 29 & 94 & -1.202\times10^4 & -1.345\times10^5 & 4.356\times10^5 \end{pmatrix}$

Elbow 1-28B (Nodes 32 & 33)

$nd_{EL128B\_1} := (32)^T$

$AL_{EL128B\_nd32} := Elbow(P, D_o, t, I, B_1, B_2, S_{125L}, NF_{LL}, nd_{EL128B\_1}, Elb\_C_o, EL_{LL})$

$AL_{EL128B\_nd32}{}^T = \begin{pmatrix} 0.369 & 4.624\times10^5 & 8.585 & 32 & 96 & 1.761\times10^4 & -1.378\times10^5 & -4.41\times10^5 \end{pmatrix}$

$nd_{EL128B\_2} := (33)^T$

$AL_{EL128B\_nd33} := Elbow(P, D_o, t, I, B_1, B_2, S_{125L}, NF_{LL}, nd_{EL128B\_2}, Elb\_C_o, EL_{LL})$

$AL_{EL128B\_nd33}{}^T = \begin{pmatrix} 0.296 & 3.711\times10^5 & 11.77 & 33 & 97 & 1.658\times10^5 & 9.142\times10^4 & 3.191\times10^5 \end{pmatrix}$

Elbow 1-28C (Nodes 37 & 38)

$nd_{EL128C\_1} := (37)^T$

$AL_{EL128C\_nd37} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{LL}, nd_{EL128C\_1}, Elb\_C_o, EL_{LL})$

$AL_{EL128C\_nd37}{}^T = \begin{pmatrix} 0.404 & 6.008\times10^5 & 8.58 & 37 & 161 & -1.625\times10^4 & -4.128\times10^4 & -5.991\times10^5 \end{pmatrix}$

$nd_{EL128C\_2} := (38)^T$

$AL_{EL128C\_nd38} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{LL}, nd_{EL128C\_2}, Elb\_C_o, EL_{LL})$

$AL_{EL128C\_nd38}{}^T = \begin{pmatrix} 0.484 & 7.195\times10^5 & 11.985 & 38 & 100 & 1.833\times10^5 & -5.585\times10^4 & 6.935\times10^5 \end{pmatrix}$

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Elbow 1-29A (Nodes 4 & 5)

$nd_{EL129A\_1} := (4)^T$

$AL_{EL129A\_nd4} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125L}, NF_{LL}, nd_{EL129A\_1}, Elb\_C_o, EL_{LL}\right)$

$AL_{EL129A\_nd4}{}^T = \begin{pmatrix} 0.483 & 6.051\times10^5 & 8.56 & 4 & 2 & 1.462\times10^5 & 4.421\times10^4 & -5.855\times10^5 \end{pmatrix}$

$nd_{EL129A\_2} := (5)^T$

$AL_{EL129A\_nd5} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125L}, NF_{LL}, nd_{EL129A\_2}, Elb\_C_o, EL_{LL}\right)$

$AL_{EL129A\_nd5}{}^T = \begin{pmatrix} 0.352 & 4.404\times10^5 & 8.555 & 5 & 103 & -1.109\times10^5 & -1.429\times10^5 & -4.015\times10^5 \end{pmatrix}$

Elbow 1-29B (Nodes 8 & 9)

$nd_{EL129B\_1} := (8)^T$

$AL_{EL129B\_nd8} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125L}, NF_{LL}, nd_{EL129B\_1}, Elb\_C_o, EL_{LL}\right)$

$AL_{EL129B\_nd8}{}^T = \begin{pmatrix} 0.347 & 4.347\times10^5 & 8.565 & 8 & 105 & 4.018\times10^4 & 1.456\times10^5 & -4.076\times10^5 \end{pmatrix}$

$nd_{EL129B\_2} := (9)^T$

$AL_{EL129B\_nd9} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125L}, NF_{LL}, nd_{EL129B\_2}, Elb\_C_o, EL_{LL}\right)$

$AL_{EL129B\_nd9}{}^T = \begin{pmatrix} 0.318 & 3.981\times10^5 & 11.355 & 9 & 106 & -1.089\times10^3 & -1.2\times10^5 & 3.796\times10^5 \end{pmatrix}$

Elbow 1-29C (Nodes 13 & 14)

$nd_{EL129C\_1} := (13)^T$

$AL_{EL129C\_nd13} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{LL}, nd_{EL129C\_1}, Elb\_C_o, EL_{LL}\right)$

$AL_{EL129C\_nd13}{}^T = \begin{pmatrix} 0.418 & 6.216\times10^5 & 11.355 & 13 & 108 & 794.257 & 1.011\times10^3 & 6.216\times10^5 \end{pmatrix}$

$nd_{EL129C\_2} := (14)^T$

$AL_{EL129C\_nd14} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{LL}, nd_{EL129C\_2}, Elb\_C_o, EL_{LL}\right)$

$AL_{EL129C\_nd14}{}^T = \begin{pmatrix} 0.469 & 6.981\times10^5 & 11.765 & 14 & 109 & 6.336\times10^4 & -1.308\times10^5 & -6.828\times10^5 \end{pmatrix}$

Elbow Properties for Lower (Southern) Portion of Line 1-27

Define pertinent elbow variables

$D_o := 36in$ — Outside Diameter [13]

$t := 0.5in$ — Thickness [13]

$P := 376psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\ 4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 8.786 \times 10^3\ in^4$$

$R := 1.5 \cdot D_o$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$

Mean pipe radius

Define primary stress indices

$$h := \frac{t \cdot R}{r_m^{\ 2}} \qquad h = 0.086$$

Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h > 0.5 \\ -0.1 + 0.4 \cdot h & \text{otherwise} \end{cases} \qquad B_1 = 0$$

B_1 primary stress Index [9, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases} \qquad B_2 = 6.688$$

B_2 primary stress Index [9, NB-3683.7]

Elbow 1-27A (Nodes 60 & 61)

$$nd_{EL127A\_1} := (60)^T$$

$$AL_{EL127A\_nd60} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{LL}, nd_{EL127A\_1}, Elb\_C_o, EL_{LL}\right)$$

$$AL_{EL127A\_nd60}^{\ T} = \begin{pmatrix} 0.215 & 8.916 \times 10^5 & 11.58 & 60 & 87 & 1.163 \times 10^5 & 2.215 \times 10^5 & 8.558 \times 10^5 \end{pmatrix}$$

$$nd_{EL127A\_2} := (61)^T$$

$$AL_{EL127A\_nd61} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{LL}, nd_{EL127A\_2}, Elb\_C_o, EL_{LL}\right)$$

$$AL_{EL127A\_nd61}^{\ T} = \begin{pmatrix} 0.333 & 1.377 \times 10^6 & 11.57 & 61 & 59 & 1.388 \times 10^5 & 1.363 \times 10^5 & 1.363 \times 10^6 \end{pmatrix}$$

Elbow Properties for Upper (Northern) Portion of Line 1-27

Define pertinent elbow variables

$D_o := 36in$ — Outside Diameter [7]

$t := 0.562in$ — Thickness [7]

$P := 400psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 9.825 \times 10^3\ in^4$$

$R := 1.5 \cdot D_o$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$

Mean pipe radius

Define primary stress indices

$$h := \frac{t \cdot R}{r_m^{\,2}} \qquad h = 0.097$$

Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h > 0.5 \\ -0.1 + 0.4 \cdot h & \text{otherwise} \end{cases} \qquad B_1 = 0$$

B_1 primary stress Index [9, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases} \qquad B_2 = 6.172$$

B_2 primary stress Index [9, NB-3683.7]

Elbow 1-27B (Nodes 75 & 76)

$$nd_{EL127B\_1} := (75)^T$$

$$AL_{EL127B\_nd75} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{LL}, nd_{EL127B\_1}, Elb\_C_o, EL_{LL}\right)$$

$$AL_{EL127B\_nd75}^{\ T} = \left(0.207 \quad 1.039 \times 10^6 \quad 9.095 \quad 75 \quad 119 \quad -1.403 \times 10^5 \quad 9.11 \times 10^5 \quad 4.788 \times 10^5\right)$$

$$nd_{EL127B\_2} := (76)^T$$

$$AL_{EL127B\_nd76} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{LL}, nd_{EL127B\_2}, Elb\_C_o, EL_{LL}\right)$$

$$AL_{EL127B\_nd76}^{\ T} = \left(0.167 \quad 8.371 \times 10^5 \quad 7.85 \quad 76 \quad 91 \quad -5.199 \times 10^5 \quad 6.388 \times 10^5 \quad 1.495 \times 10^5\right)$$

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Writing Output Data for Elbows Associated with Lines 27 to 29

$EL1A := AL_{EL128A\_nd28}^{T}$

$EL1B := AL_{EL128A\_nd29}^{T}$

$EL2A := AL_{EL128B\_nd32}^{T}$

$EL2B := AL_{EL128B\_nd33}^{T}$

$EL3A := AL_{EL128C\_nd37}^{T}$

$EL3B := AL_{EL128C\_nd38}^{T}$

$EL4A := AL_{EL129A\_nd4}^{T}$

$EL4B := AL_{EL129A\_nd5}^{T}$

$EL5A := AL_{EL129B\_nd8}^{T}$

$EL5B := AL_{EL129B\_nd9}^{T}$

$EL6A := AL_{EL129C\_nd13}^{T}$

$EL6B := AL_{EL129C\_nd14}^{T}$

$EL7A := AL_{EL127A\_nd60}^{T}$

$EL7B := AL_{EL127A\_nd61}^{T}$

$EL8A := AL_{EL127B\_nd75}^{T}$

$EL8B := AL_{EL127B\_nd76}^{T}$

ElbowLines27to29 := WRITEPRN["ElbowLines27to29.prn" , (EL1A EL1B EL2A EL2B EL3A EL3B EL4A EL4B EL5A l

FORGED TEES

Tees Strategy: *Search based on the elements comprising the tee. The input identifies which elements are associated with the pipe run and which element is associated with the branch from the run. The indices for the defined common node for all three elements is identified and the associated SRSS moment is identified for each time step. The maximum moment for the elements comprising the pipe run is found and applied as* M_r *in equation (9) of ASME III, Division I - NB - 3652 which is modified to represent tees. The maximum moment for the branch element is found and applied as* M_b *in equation (9) of ASME III, Division I - NB - 3652 [9]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$TeeDC(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_b, M_r, Z_b, Z_r, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot T_r} + B_{2b} \cdot \left[\frac{M_b \cdot (1lbf \cdot in)}{Z_b}\right] + B_{2r} \cdot \left[\frac{M_r \cdot (1lbf \cdot in)}{Z_r}\right]}{S}$$

$Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S, nf, el_R, el_B, nd_R, nd_B, C_o, EL) :=$

$ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{elR} \leftarrow match\left(el_{R_0}, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(el_R)$ if rows

    $ind_{elR} \leftarrow stack\left[ind_{elR}, \left(match\left(el_{R_i}, EL^{\langle 0 \rangle}\right)\right)\right]$

$EL'R_{last\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$

for $i \in 0 .. last(ind_{elR})$

    $EL'R_{ind_{elR_i}} \leftarrow EL_{ind_{elR_i}, 1}$

$ind_{ndR} \leftarrow match\left(nd_{R_0}, EL'R^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(nd_R)$ if r

    $ind_{ndR} \leftarrow stack\left[ind_{ndR}, \left(match\left(nd_{R_i}, EL'R^{\langle 0 \rangle}\right)\right)\right]$

$ind_{elB} \leftarrow match\left(el_{B_0}, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(el_B)$ if rows

    $ind_{elB} \leftarrow stack\left[ind_{elB}, \left(match\left(el_{B_i}, EL^{\langle 0 \rangle}\right)\right)\right]$

$EL'B_{last\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$

for $i \in 0 .. last(ind_{elB})$

    $EL'B_{ind_{elB_i}} \leftarrow EL_{ind_{elB_i}, 1}$

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$ind_{ndB} \leftarrow match\left(nd_{B_0}, EL'B^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(nd_B)$ if r

$ind_{ndB} \leftarrow stack\left[ind_{ndB}, \left(match\left(nd_{B_i}, EL'B^{\langle 0 \rangle}\right)\right)\right]$

$(M_R \;\; M_B \;\; Int_0) \leftarrow (0 \;\; 0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

for $j \in 0 .. last(ind_{ndR})$

for $k \in 0 .. last(ind_{ndB})$

$M_{rxgR_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{ndR_j}}$

$M_{rygR_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{ndR_j}}$

$M_{rzgR_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{ndR_j}}$

$M_{rxR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{ndR_j}} - M_{rxgR_j}\right) \cdot C$

$M_{ryR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{ndR_j}} - M_{rygR_j}\right) \cdot C$

$M_{rzR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{ndR_j}} - M_{rzgR_j}\right) \cdot C$

$M_{R_j} \leftarrow \sqrt{\left(M_{rxR_j}\right)^2 + \left(M_{ryR_j}\right)^2 + \left(M_{rzR_j}\right)^2}$

$M_{rxgB_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{ndB_k}}$

$M_{rygB_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{ndB_k}}$

$M_{rzgB_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{ndB_k}}$

$M_{rxB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{ndB_k}} - M_{rxgB_j}\right) \cdot C$

$M_{ryB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{ndB_k}} - M_{rygB_j}\right) \cdot C$

$M_{rzB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{ndB_k}} - M_{rzgB_j}\right) \cdot C$

$M_{B_j} \leftarrow \sqrt{\left(M_{rxB_j}\right)^2 + \left(M_{ryB_j}\right)^2 + \left(M_{rzB_j}\right)^2}$

$Int'_j \leftarrow TeeDC\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_{B_j}, M_R\right.$

if $Int'_j > Int_0$

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$Int \leftarrow stack\left(Int'_j, M_{R_j}, M_{B_j}, nf_{ind_{nfiC_{o_{0,1}}-1+i}}\right)$

$Result \leftarrow stack\left(M_{R_j}, M_{B_j}, M_{rxR_j}, M_{ryR_j}, M\right)$

$M \leftarrow M_R$

Int

Conditions applicable to forged tee

$M_{ox} := 0 \quad M_{oy} := 0 \quad M_{oz} := 0$

Defining place holding directional moment variables

$$Tee\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

FORGED TEES

Define pertinent tee variables

$P := 376psi$ — Internal Pressure [3, pg 23]

$D_o := 36in$ — Outside Diameter [13]

$d_o := 36in$ — Outside Diameter of branch [13]

$B_1 := 0.5$ — B_1 primary stress Index for tees and branches [9, NB-3683.9]

$T_r := 1.375in$ — Nominal wall thickness of designated run pipe [14]

$R_m := \frac{D_o - T_r}{2}$ — Mean radius of designated run pipe [127015]

$Z_r := \pi \cdot R_m^{\,2} \cdot T_r$ — Approximate section modulus of designated run pipe [9, NB-3683.1(d)]

$Z_r = 1.2947 \times 10^3\, in^3$

$$B_{2b} := \begin{cases} 0.4 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} & \text{if } 0.4 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} > 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Index for tees and branches [9, NB-3683.9]

$B_{2b} = 2.165$

$T'_b := 1.375in$ — Nominal wall thickness of attached branch pipe [14]

$r'_m := \frac{d_o - T'_b}{2}$ — Mean radius of attached branch pipe [13]

$Z_b := \pi \cdot {r'_m}^2 \cdot T'_b$ — Approximate section modulus of attached branch pipe [9, NB-3683.1(d)]

$Z_b = 1.295 \times 10^3\ in^3$

$$B_{2r} := \begin{cases} 0.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} & \text{if } 0.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} > 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Index for tees and branches [9, NB-3683.9]

$B_{2r} = 2.706$

Tee 1-27 (Node 51)

$elR_{Tee127} := (59\ \ 60)^T$ — Elements associated with pipe run

$ndR_{Tee127} := (51)^T$ — Node between pipe run elements

$elB_{Tee127} := (61)^T$ — Element associated with branch

$ndB_{Tee127} := (51)^T$ — Node where branch intersects pipe run

$AL_{Tee127} := Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF_{LL}, elR_{Tee127}, elB_{Tee127}, ndR_{Tee127}, ndB_{Tee127}, Tee$

$$AL_{Tee127}{}^T = \left(0.14\ \ 1.686\times10^6\ \ 1.16\times10^6\ \ 8.755\ \ 51\ \ 53\ \ 55\ \ 57\right)$$

Writing Output Data for Tees Associated with Lines 22 to 26

$Tee1 := AL_{Tee127}{}^T$

TeeLines27to29 := WRITEPRN["TeeLines27to29.prn" , (Tee1)]

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FLANGES

Flange Strategy: *Search based on the nodes where flanges occur. Find the maximum moment combination for the node and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\mathrm{FlangeDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1 \mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Flange}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

```
ind_nfi ← match(t_initial, nf^<0>)
ind_nfo ← match(t_final, nf^<0>)
ind_nd ← match(nd_0, EL^<1>)
for i ∈ 1 .. last(nd)                                   if rows(nd) > 1
   ind_nd ← stack[ind_nd, (match(nd_i, EL^<1>))]
(M  Int_0) ← (0  0)
for i ∈ 0 .. ind_nfo_0 − ind_nfi_0
   for j ∈ 0 .. last(ind_nd)
      M_rxg ← nf_{ind_nfi_{Co_{0,1}}+2, ind_nd_j}
      M_ryg ← nf_{ind_nfi_{Co_{1,1}}+2, ind_nd_j}
      M_rzg ← nf_{ind_nfi_{Co_{2,1}}+2, ind_nd_j}
      M_rx ← (nf_{ind_nfi_{Co_{0,1}}+2+i, ind_nd_j} − M_rxg)·Co_{3,0} + M_rxg
      M_ry ← (nf_{ind_nfi_{Co_{1,1}}+2+i, ind_nd_j} − M_ryg)·Co_{3,0} + M_ryg
      M_rz ← (nf_{ind_nfi_{Co_{2,1}}+2+i, ind_nd_j} − M_rzg)·Co_{3,0} + M_rzg
      M'_j ← sqrt(M_rx^2 + M_ry^2 + M_rz^2)
      Int'_j ← FlangeDC(P, D_o, t, I, B_1, B_2, M'_j, S)
      if Int'_j > Int_0
         Int ← stack(Int'_j, M'_j, nf_{ind_nfi_{Co_{0,1}}−1+i, 0}, EL_{ind_nd_j, 1}, ind_nd_j, M_rx, M_ry, M
         Result ← M'
Int
```

Conditions applicable to all flanges

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$ Defining place holding variables

$$Flange\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties for Lower (Southern) Portion of Line 1-27

Define pertinent pipe variables

$D_o := 36in$ Outside Diameter [13]

$t := 0.5in$ Thickness [13]

$P := 400psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 8.786 \times 10^3\ in^4$$

Define primary stress indices (Utilize girth weld characteristic associated with lap joint flanges in determining values)

$B_1 := 0.5$ B_1 for a girth weld [9, Table NB-3681(a)-1, pg 130]

$B_2 := 1$ B_2 for a girth weld [9, Table NB-3681(a)-1, pg 130]

Flange 1-27A (Butterfly Valve) (Node 62)

$$nd_{FL127A} := (62)^T$$

$$AL_{FL127A} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{LL}, nd_{FL127A}, Flange\_C_o, EL_{LL}\right)$$

$$AL_{FL127A}^{\,T} = \begin{pmatrix} 0.15 & 6.305 \times 10^5 & 11.695 & 62 & 61 & -3.808 \times 10^5 & -4.942 \times 10^5 & -9.112 \times 10^4 \end{pmatrix}$$

Pipe Properties for Upper (Northern) Portion of Line 1-27

Define pertinent pipe variables

$D_o := 36in$ Outside Diameter [7]

$t := 0.5625in$ Thickness [7]

$P := 400psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\ 4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$ Moment of inertia [8, Table 17-27, pg 17-39]

$I = 9.833 \times 10^3 \, in^4$

Define primary stress indices (Utilize girth weld characteristic associated with lap joint flanges in determining values)

$B_1 := 0.5$ B_1 for a girth weld [9, Table NB-3681(a)-1, pg 130]

$B_2 := 1$ B_2 for a girth weld [9, Table NB-3681(a)-1, pg 130]

Flange 1-27B (Butterfly Valve) (Node 65)

$nd_{FL127B} := (65)^T$

$AL_{EL127B} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{LL}, nd_{FL127B}, Flange\_C_o, EL_{LL}\right)$

$AL_{EL127B}^{\ T} = \left(0.134 \quad 6.67 \times 10^5 \quad 11.29 \quad 65 \quad 71 \quad 4.624 \times 10^5 \quad 4.558 \times 10^5 \quad 1.529 \times 10^5\right)$

Pipe Properties for Upper (Northern) Portion of Lines 1-28 & 1-29

Define pertinent pipe variables

$D_o := 24in$ Outside Diameter [11] [12]

$t := 0.375in$ Thickness [11] [12]

$P := 376psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\ 4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$ Moment of inertia [8, Table 17-27, pg 17-39]

$I = 1.942 \times 10^3 \, in^4$

Define primary stress indices (Utilize girth weld characteristic associated with lap joint flanges in determining values)

$B_1 := 0.5$ B_1 for a girth weld [9, Table NB-3681(a)-1, pg 130]

$B_2 := 1$ B_2 for a girth weld [9, Table NB-3681(a)-1, pg 130]

Flange 1-28A (Gate Valve) (Node 34)

$nd_{FL128A} := (34)^T$

$AL_{FL128A} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125L}, NF_{LL}, nd_{FL128A}, Elb\_C_o, EL_{LL}\right)$

$AL_{FL128A}{}^T = \left(0.196 \quad 5.371\times 10^5 \quad 8.78 \quad 34 \quad 131 \quad -2.731\times 10^4 \quad 1.886\times 10^4 \quad -5.361\times 10^5\right)$

Flange 1-28B (Gate Valve) (Node 36)

$nd_{FL128B} := (36)^T$

$AL_{FL128B} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125L}, NF_{LL}, nd_{FL128B}, Flange\_C_o, EL_{LL}\right)$

$AL_{FL128B}{}^T = \left(0.2 \quad 5.7\times 10^5 \quad 3.825 \quad 36 \quad 33 \quad 3.533\times 10^4 \quad -1.936\times 10^5 \quad 5.35\times 10^5\right)$

Flange 1-29A (Gate Valve) (Node 10)

$nd_{FL129A} := (10)^T$

$AL_{FL129A} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125L}, NF_{LL}, nd_{FL129A}, Flange\_C_o, EL_{LL}\right)$

$AL_{FL129A}{}^T = \left(0.173 \quad 3.631\times 10^5 \quad 8.775 \quad 10 \quad 9 \quad -2.175\times 10^5 \quad -2.077\times 10^5 \quad 2.033\times 10^5\right)$

Flange 1-29B (Gate Valve) (Node 12)

$nd_{FL129B} := (12)^T$

$AL_{FL129B} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125L}, NF_{LL}, nd_{FL129B}, Flange\_C_o, EL_{LL}\right)$

$AL_{FL129B}{}^T = \left(0.173 \quad 3.625\times 10^5 \quad 9.965 \quad 12 \quad 13 \quad -1.826\times 10^5 \quad 1.855\times 10^4 \quad 3.126\times 10^5\right)$

Writing Output Data for Flanges Associated with Lines 27 to 29

$F1 := AL_{FL127A}{}^T$ $F4 := AL_{FL128B}{}^T$

$F2 := AL_{EL127B}{}^T$ $F5 := AL_{FL129A}{}^T$

$F3 := AL_{FL128A}{}^T$ $F6 := AL_{FL129B}{}^T$

FlangeLines27to29 := WRITEPRN["FlangeLines27to29.prn" , (F1 F2 F3 F4 F5 F6)]

Appendix B.3.3

Demand to Capacity Ratio Calculations for Components Associated with Lines 32, 33, and 49 of ATR PCS Model 3

(NOTE: Values represented here are shown for one realization (Nodal Force file = Lines32_33_49_test_R1.dat and Element/Nodal order file = EL_32_33_49.xls) and may or may not be consistent with the 80th percentile results contained in Appendix B.4)

Nodal Force Outputs from Abaqus

$NF_{SL} :=$ ..\Lines32_33_49.dat

(N)odal (F)orces for the (S)mall (L)ines of Model 3

Defined Elemental and Corresponding Nodal Order

$EL_{SL} :=$ ..\EL_32_33_49(9-22-08).xls

Element and corresponding nodal order for the (S)mall (L)ines of Model 3

Time Boundaries

$t_{initial} := 1$

Initial time for which dynamic loading is applied

$t_{final} := 21$

Final time for which dynamic loading stops

Seismic Scale Factor (F_a)

$F_a := 1$

Seismic scale factor [56]

Allowable Design Stress Intensity Factor (S_m): *S_m is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{m\_125} := 20ksi$

For SS304 at 125°F [2, pg 316-318] [3, pg 23]

$S_{m\_125L} := 16.7ksi$

For SS304L at 125°F [2, pg 316-318] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Yield Strength (S_y): *S_y is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{y\_125} := 28.35ksi$

For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_125L} := 23.85ksi$

For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Maximum Strength Applicable for Equation 9 (S): *S is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{125} := \min\left(3 \cdot S_{m\_125}, 2 \cdot S_{y\_125}\right)$

$\boxed{S_{125} = 56.7\,ksi}$

Maximum allowable stress applied to SS304 piping [9, NB-3656]

$S_{125L} := \min\left(3 \cdot S_{m\_125L}, 2 \cdot S_{y\_125L}\right)$

$\boxed{S_{125L} = 47.7\,ksi}$

Maximum allowable stress applied to SS304L piping [9, NB-3656]

SUPPORTS

Supports Strategy: *Search based on the node for which the support acts. If this node is a termination point there will only be one node to evaluate. If this node is in line with a section of pipe there will be two representations of the same node (one for each element on each side of the node) to combine and the difference between them is the force required of the support. The D/C ratio for each support will be found by dividing the the required force found above by the support capacity.*

$$SupDC(P_r, P_c) := \frac{P_r}{P_c}$$

$Support(nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow match\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. last(nd)$ if $rows(nd) > 1$

  $ind_{nd} \leftarrow stack\left[ind_{nd}, \left(match\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$\left(Int1_4 \quad Int2_4\right) \leftarrow (0 \quad 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. last\left(ind_{nd}\right)$

    $P_{rg_j} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}} - 1, ind_{nd_j}}$

    $P_{r_j} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}} - 1 + i, ind_{nd_j}} - P_{rg_j}\right) \cdot C_{o_{2,0}} + P_{rg_j}$

  $PR_i \leftarrow \sum_{n=0}^{j} P_{r_n}$

  if $PR_i < Int1_1 \wedge C_{o_{0,0}} \neq 0$

    $Int1' \leftarrow SupDC\left(\left|PR_i\right|, C_{o_{0,0}}\right)$

    $Int1 \leftarrow stack\left(Int1', PR_i, nf_{ind_{nfi_{C_{o_{0,1}}}} - 1 + i, 0}, EL_{ind_{nd_j}, 1}, ind_{nd}\right)$

  if $PR_i > Int2_1 \wedge C_{o_{1,0}} \neq 0$

    $Int2' \leftarrow SupDC\left(\left|PR_i\right|, C_{o_{1,0}}\right)$

    $Int2 \leftarrow stack\left(Int2', PR_i, nf_{ind_{nfi_{C_{o_{0,1}}}} - 1 + i, 0}, EL_{ind_{nd_j}, 1}, ind_{nd}\right)$

$\left(Int1 \quad Int2\right)$

PS-5 Supports (4x)

$P_{1\_PS5} := \frac{87.894 \cdot kip}{lbf}$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$P_{2\_PS5} := \frac{0 kip}{lbf}$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$$Sup\_C_{o\_PS5} := \begin{pmatrix} P_{1\_PS5} & 2 \\ P_{2\_PS5} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

PS-5 (Node 371)

PS-5 vertically supports the horizontal (E/W) PCS pipe entering emergency pump on line 1-33 on east side of check valve

$nd371_{PS5_0} := 371$ Node associated with support

$$\left(AL1_{PS5\_nd371} \ \ AL2_{PS5\_nd371}\right) := Support\left(NF_{SL}, nd371_{PS5}, Sup\_C_{o\_PS5}, EL_{SL}\right)$$

$$AL1_{PS5\_nd371}^{T} = \left(0.029 \ \ -2.539 \times 10^{3} \ \ 4.405 \ \ 371 \ \ 123\right)$$

$$AL2_{PS5\_nd371}^{T} = \left(0 \ \ 0 \ \ 0 \ \ 0 \ \ 0\right)$$

D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PS-5 (Node 372)

PS-5 vertically supports the horizontal (E/W) PCS pipe entering emergency pump on line 1-33 on west side of check valve

$nd372_{PS5_0} := 372$ Node associated with support

$$\left(AL1_{PS5\_nd372} \ \ AL2_{PS5\_nd372}\right) := Support\left(NF_{SL}, nd372_{PS5}, Sup\_C_{o\_PS5}, EL_{SL}\right)$$

$$AL1_{PS5\_nd372}^{T} = \left(0.043 \ \ -3.777 \times 10^{3} \ \ 6.59 \ \ 372 \ \ 129\right)$$

$$AL2_{PS5\_nd372}^{T} = \left(0 \ \ 0 \ \ 0 \ \ 0 \ \ 0\right)$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PS-5 (Node 373)

PS-5 vertically supports the horizontal (E/W) PCS pipe entering emergency pump on line 1-32 on east side of check valve

$nd373_{PS5_0} := 373$ Node associated with support

$(AL1_{PS5\_nd373} \;\; AL2_{PS5\_nd373}) := Support(NF_{SL}, nd373_{PS5}, Sup\_C_{o\_PS5}, EL_{SL})$

$AL1_{PS5\_nd373}^{T} = (0.024 \;\; -2.081\times10^{3} \;\; 12.52 \;\; 373 \;\; 127)$

$AL2_{PS5\_nd373}^{T} = (0 \;\; 0 \;\; 0 \;\; 0 \;\; 0)$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PS-5 (Node 374)

PS-5 vertically supports the horizontal (E/W) PCS pipe entering emergency pump on line 1-32 on west side of check valve

$nd374_{PS5_0} := 374$ Node associated with support

$(AL1_{PS5\_nd374} \;\; AL2_{PS5\_nd374}) := Support(NF_{SL}, nd374_{PS5}, Sup\_C_{o\_PS5}, EL_{SL})$

$AL1_{PS5\_nd374}^{T} = (0.105 \;\; -9.221\times10^{3} \;\; 8.425 \;\; 374 \;\; 125)$

$AL2_{PS5\_nd374}^{T} = (0 \;\; 0 \;\; 0 \;\; 0 \;\; 0)$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PS-21 Supports (1 x Axial (NS), 1 x Lateral (EW), 1 x Vertical)

$P_{1\_PS21AX} := \frac{34.838\cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$P_{2\_PS21AX} := \frac{40.589\cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$$Sup\_C_{o\_PS21AX} := \begin{pmatrix} P_{1\_PS21AX} & 1 \\ P_{2\_PS21AX} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

$P_{1\_PS21L} := \frac{0.765\cdot kip}{lbf}$ ***Flexure*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$P_{2\_PS21L} := \frac{0.765\cdot kip}{lbf}$ ***Flexure*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$$Sup\_C_{o\_PS21L} := \begin{pmatrix} P_{1\_PS21L} & 3 \\ P_{2\_PS21L} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

$$P_{1\_PS21V} := \frac{0.765 \cdot kip}{lbf}$$

Flexure

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$$P_{2\_PS21V} := \frac{0.765 \cdot kip}{lbf}$$

Flexure

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$$Sup\_C_{o\_PS21V} := \begin{pmatrix} P_{1\_PS21V} & 2 \\ P_{2\_PS21V} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

PS-21 Axial (NS) (Node 535)

PS-21 horizontally (N/S), laterally (E/W), and vertically supports the horizontal(E/W) PCS pipe on line 1-32 on the north side of the emergency pump room.

$$nd535_{PS21AX_0} := 535$$

Node associated with support

$$\left(AL1_{PS21AX\_nd535} \;\; AL2_{PS21AX\_nd535}\right) := Support\left(NF_{SL}, nd535_{PS21AX}, Sup\_C_{o\_PS21AX}, EL_{SL}\right)$$

$$AL1_{PS21AX\_nd535}^{\;T} = \left(0.054 \;\; -1.867\times10^{3} \;\; 8.22 \;\; 535 \;\; 144\right)$$

$$AL2_{PS21AX\_nd535}^{\;T} = \left(0.064 \;\; 2.593\times10^{3} \;\; 7.92 \;\; 535 \;\; 144\right)$$

demand force, occurrence time, ed node, associated index for the reaction force at the selected node ng in the positive (AL1) and negative 2) directions of the global coordinate system)

PS-21 Lateral (EW) (Node 535)

PS-21 horizontally (N/S), laterally (E/W), and vertically supports the horizontal(E/W) PCS pipe on line 1-32 on the north side of the emergency pump room.

$$nd535_{PS21L_0} := 535$$

Node associated with support

$$\left(AL1_{PS21L\_nd535} \;\; AL2_{PS21L\_nd535}\right) := Support\left(NF_{SL}, nd535_{PS21L}, Sup\_C_{o\_PS21L}, EL_{SL}\right)$$

$$AL1_{PS21L\_nd535}^{\;T} = \left(3.563\times10^{-3} \;\; -2.726 \;\; 9.57 \;\; 535 \;\; 144\right)$$

$$AL2_{PS21L\_nd535}^{\;T} = \left(2.905\times10^{-3} \;\; 2.222 \;\; 9.29 \;\; 535 \;\; 144\right)$$

,demand force, occurrence time, ed node, associated index for the reaction force at the selected node ng in the positive (AL1) and negative 2) directions of the global coordinate system)

PS-21 Vertical (Node 535)

PS-21 horizontally (N/S), laterally (E/W), and vertically supports the horizontal(E/W) PCS pipe on line 1-32 or side of the emergency pump room.

$$nd535_{PS21V_0} := 535$$

Node associated with support

$$\left(AL1_{PS21V\_nd535}\ \ AL2_{PS21V\_nd535}\right) := \text{Support}\left(NF_{SL}, nd535_{PS21V}, Sup\_C_{o\_PS21V}, EL_{SL}\right)$$

$$AL1_{PS21V\_nd535}{}^{T} = (0\ \ 0\ \ 0\ \ 0\ \ 0)$$

$$AL2_{PS21V\_nd535}{}^{T} = (0.015\ \ 11.791\ \ 5.685\ \ 535\ \ 144)$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and [negative] (AL2) directions of the global coordinate system)

RH-15A Support (1x)

$$P_{1\_RH15A} := \frac{21.648 \cdot kip}{lbf}$$

Tension

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$$P_{2\_RH15A} := \frac{21.648kip}{lbf}$$

Compression

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$$Sup\_C_{o\_RH15A} := \begin{pmatrix} P_{1\_RH15A} & 2 \\ P_{2\_RH15A} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

RH-15A (Node 365)

RH-15A vertically supports the horizontal (E/W) PCS pipe on line 1-32 in conjunction with the horizontal supp

$$nd365_{RH15A_0} := 365$$

Node associated with support

$$\left(AL1_{RH15A\_nd365}\ \ AL2_{RH15A\_nd365}\right) := \text{Support}\left(NF_{SL}, nd365_{RH15A}, Sup\_C_{o\_RH15A}, EL_{SL}\right)$$

$$AL1_{RH15A\_nd365}{}^{T} = \left(0.183\ \ -3.965\times10^{3}\ \ 5.69\ \ 365\ \ 153\right)$$

$$AL2_{RH15A\_nd365}{}^{T} = (0\ \ 0\ \ 0\ \ 0\ \ 0)$$

[(D/C],demand force, occurrence time, [defi]ned node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-15 Supports (2x)

$$P_{1\_RH15} := \frac{14.91 \cdot kip}{lbf}$$

Tension

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$$P_{2\_RH15} := \frac{14.91kip}{lbf}$$

Compression

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$$Sup\_C_{o\_RH15} := \begin{pmatrix} P_{1\_RH15} & 2 \\ P_{2\_RH15} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

RH-15 (Node 366)

RH-15 vertically supports the horizontal (E/W) PCS pipe on line 1-32 just west of RH-15A

$nd366_{RH15_0} := 366$ Node associated with support

$\left(AL1_{RH15\_nd366}\ \ AL2_{RH15\_nd366}\right) := \text{Support}\left(NF_{SL}, nd366_{RH15}, Sup\_C_{o\_RH15}, EL_{SL}\right)$

$AL1_{RH15\_nd366}^{\ T} = \left(0.137\ \ -2.049\times10^{3}\ \ 5.755\ \ 366\ \ 151\right)$

$AL2_{RH15\_nd366}^{\ T} = \left(0\ \ 0\ \ 0\ \ 0\ \ 0\right)$

C,demand force, occurrence time, ned node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-15 (Node 367)

RH-15 vertically supports the horizontal (E/W) PCS pipe on line 1-32 west of both RH-15A and the other RH-15 support and just prior to line 1-32 penetrating the concrete wall and entering the emergency pump room.

$nd367_{RH15_0} := 367$ Node associated with support

$\left(AL1_{RH15\_nd367}\ \ AL2_{RH15\_nd367}\right) := \text{Support}\left(NF_{SL}, nd367_{RH15}, Sup\_C_{o\_RH15}, EL_{SL}\right)$

$AL1_{RH15\_nd367}^{\ T} = \left(0.239\ \ -3.556\times10^{3}\ \ 5.025\ \ 367\ \ 149\right)$

$AL2_{RH15\_nd367}^{\ T} = \left(7.768\times10^{-4}\ \ 11.582\ \ 10.21\ \ 367\ \ 149\right)$

C,demand force, occurrence time, ned node, associated index for the reaction force at the selected node in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PR-11 Supports (1 x Vertical, 1 x Horizontal (North/South)

$P_{1\_PR11V} := \frac{0.139\cdot kip}{lbf}$ ***Flexure*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$P_{2\_PR11V} := \frac{0.139\cdot kip}{lbf}$ ***Flexure*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$Sup\_C_{o\_PR11V} := \begin{pmatrix} P_{1\_PR11V} & 2 \\ P_{2\_PR11V} & 0 \\ F_a & 0 \end{pmatrix}$ Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

$P_{1\_PR11H} := \frac{51.337\cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$P_{2\_PR11H} := \frac{7.86\cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

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$$Sup\_C_{o\_PR11H} := \begin{pmatrix} P_{1\_PR11H} & 1 \\ P_{2\_PR11H} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

PR-11 Vertical (Node 377)

PR-11 vertically and horizontally (N/S) supports the horizontal(E/W) PCS pipe on line 1-32 west of the fabricated elbow from line 1-27.

$$nd377_{PR11V_0} := 377$$

Node associated with support

$$\begin{pmatrix} AL1_{PR11V\_nd377} & AL2_{PR11V\_nd377} \end{pmatrix} := Support\left(NF_{SL}, nd377_{PR11V}, Sup\_C_{o\_PR11V}, EL_{SL}\right)$$

$$AL1_{PR11V\_nd377}^{T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

$$AL2_{PR11V\_nd377}^{T} = \begin{pmatrix} 0.102 & 14.121 & 5.605 & 377 & 122 \end{pmatrix}$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PR-11 Horizontal (Node 377)

PR-11 vertically and horizontally (N/S) supports the horizontal(E/W) PCS pipe on line 1-32 west of the fabricated elbow from line 1-27.

$$nd377_{PR11H_0} := 377$$

Node associated with support

$$\begin{pmatrix} AL1_{PR11H\_nd377} & AL2_{PR11H\_nd377} \end{pmatrix} := Support\left(NF_{SL}, nd377_{PR11H}, Sup\_C_{o\_PR11H}, EL_{SL}\right)$$

$$AL1_{PR11H\_nd377}^{T} = \begin{pmatrix} 1.81\times 10^{-4} & -9.291 & 7.94 & 377 & 122 \end{pmatrix}$$

$$AL2_{PR11H\_nd377}^{T} = \begin{pmatrix} 1.237\times 10^{-3} & 9.722 & 7.69 & 377 & 122 \end{pmatrix}$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-24 Supports (2x)

$$P_{1\_RH24} := \frac{7.069 \cdot kip}{lbf}$$

Tension

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$$P_{2\_RH24} := \frac{0.1kip}{lbf}$$

Doesn't experience uplift

Compression

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. B.10.1]

$$Sup\_C_{o\_RH24} := \begin{pmatrix} P_{1\_RH24} & 2 \\ P_{2\_RH24} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

RH-24 (Node 368)

RH-24 vertically supports the horizontal (N/S) PCS pipe on line 1-49

$nd368_{RH24_0} := 368$ Node associated with support

$(AL1_{RH24\_nd368} \quad AL2_{RH24\_nd368}) := Support(NF_{SL}, nd368_{RH24}, Sup\_C_{o\_RH24}, EL_{SL})$

$AL1_{RH24\_nd368}{}^{T} = (0.048 \quad -342.315 \quad 7.65 \quad 368 \quad 148)$

$AL2_{RH24\_nd368}{}^{T} = (0 \quad 0 \quad 0 \quad 0 \quad 0)$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-24 (Node 370)

RH-24 vertically supports the horizontal (N/S) PCS pipe on line 1-49

$nd370_{RH24_0} := 370$ Node associated with support

$(AL1_{RH24\_nd370} \quad AL2_{RH24\_nd370}) := Support(NF_{SL}, nd370_{RH24}, Sup\_C_{o\_RH24}, EL_{SL})$

$AL1_{RH24\_nd370}{}^{T} = (0.067 \quad -477.087 \quad 8.19 \quad 370 \quad 146)$

$AL2_{RH24\_nd370}{}^{T} = (0 \quad 0 \quad 0 \quad 0 \quad 0)$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

Writing Output Data for Supports Associated with Lines 32, 33, & 49

$SA1 := AL1_{PS5\_nd371}{}^{T}$

$SA2 := AL2_{PS5\_nd371}{}^{T}$

$SB1 := AL1_{PS5\_nd372}{}^{T}$

$SB2 := AL2_{PS5\_nd372}{}^{T}$

$SC1 := AL1_{PS5\_nd373}{}^{T}$

$SC2 := AL2_{PS5\_nd373}{}^{T}$

$SD1 := AL1_{PS5\_nd374}{}^{T}$

$SD2 := AL2_{PS5\_nd374}{}^{T}$

$SE1 := AL1_{PS21AX\_nd535}{}^{T}$

$SE2 := AL2_{PS21AX\_nd535}{}^{T}$

$SF1 := AL1_{PS21L\_nd535}{}^{T}$

$SF2 := AL2_{PS21L\_nd535}{}^{T}$

$SG1 := AL1_{PS21V\_nd535}{}^{T}$

$SG2 := AL2_{PS21V\_nd535}{}^{T}$

$SH1 := AL1_{RH15A\_nd365}{}^{T}$

$SH2 := AL2_{RH15A\_nd365}{}^{T}$

$SI1 := AL1_{RH15\_nd366}{}^{T}$

$SI2 := AL2_{RH15\_nd366}{}^{T}$

$SJ1 := AL1_{RH15\_nd367}{}^{T}$

$SJ2 := AL2_{RH15\_nd367}{}^{T}$

$SK1 := AL1_{PR11V\_nd377}{}^{T}$

$SK2 := AL2_{PR11V\_nd377}{}^{T}$

$SL1 := AL1_{PR11H\_nd377}{}^{T}$

$SL2 := AL2_{PR11H\_nd377}{}^{T}$

$SM1 := AL1_{RH24\_nd368}{}^{T}$

$SM2 := AL2_{RH24\_nd368}{}^{T}$

$SN1 := AL1_{RH24\_nd370}{}^{T}$

$SN2 := AL2_{RH24\_nd370}{}^{T}$

SupportsLines32_33_49 := WRITEPRN["SupLines32_33_49.prn" , (SA1 SA2 SB1 SB2 SC1 SC2 SD1 SD2 SE1 SE2 SF1

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TERMINATION LOCATIONS

Termination Locations Strategy: *Search based on the node for which the termination location acts. The D/C ratio for each termination location will be found by dividing the the required force found above by the support capacity.*

$$\mathrm{TermDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$$\mathrm{Term}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(nd)$ if $\mathrm{rows}(nd) > 1$

  $ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$(M \;\; Int_0) \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \mathrm{last}(ind_{nd})$

    $M_{rxg} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}}+2,\, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi_{C_{o_{1,1}}}}+2,\, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi_{C_{o_{2,1}}}}+2,\, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi_{C_{o_{1,1}}}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi_{C_{o_{2,1}}}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow \mathrm{TermDC}(P, D_o, t, I, B_1, B_2, M'_j, S)$

    if $Int'_j > Int_0$

      $Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfi_{C_{o_{0,1}}}}-1+i,0}, EL_{ind_{nd_j},1}, ind_{nd_j}, M_{rx}, M_{ry}, M_{r}\right.$

      $Result \leftarrow M'$

Int

Conditions applicable to all terminations

$M_{cx} := 0$ $M_{cy} := 0$ $M_{cz} := 0$ — Defining place holding variables

$$Term\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

North Wall Termination (1x)

Define pertinent pipe variables

$D_o := 4.5in$ — Outside Diameter [16, 57]

$t := 0.237in$ — Thickness [16, 57]

$P := 400psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 7.233\ in^4$$

$S := S_{125}$ — Allowable design stress intensity value

Define primary stress indices

$B_1 := 0.5$

$$B_2 := \begin{cases} 1.0 \ \text{ if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50 \\ \quad T \leftarrow 125 \\ \quad X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \dfrac{D_o}{t}\right) \\ \quad Y \leftarrow 1 \\ \quad 1.0 \cdot \dfrac{1}{X \cdot Y} \end{cases}$$

$B_2 = 1$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

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North Wall Penetration 1-49 (Node 266)

$nd266_{NWP149_0} := 266$

$AL_{NWP149\_nd266} := Term(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd266_{NWP149}, Term\_C_o, EL_{SL})$

$$AL_{NWP149\_nd266}^T = (0.102 \quad 1.24 \times 10^4 \quad 9.375 \quad 266 \quad 214 \quad -1.132 \times 10^3 \quad -1.232 \times 10^4 \quad 863.363)$$

Emergency Pumps (2x)

Define pertinent pipe variables

$D_o := 12.75in$ — Outside Diameter [17, 57]

$t := 0.25in$ — Thickness [17, 57]

$P := 400psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - (D_o - 2 \cdot t)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 191.824\ in^4$

$S := S_{125}$ — Allowable design stress intensity value

Define primary stress indices

$B_1 := 0.5$

$$B_2 := \begin{cases} 1.0 & \text{if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 & \begin{array}{l} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \frac{D_o}{t}\right) \\ Y \leftarrow 1 \\ 1.0 \cdot \frac{1}{X \cdot Y} \end{array} \end{cases}$$

$B_2 = 1.006$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Emergency Pump 1-32 (Node 149)

$nd149_{EP132_0} := 149$

$AL_{EP132\_nd149} := Term(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd149_{EP132}, Term\_C_o, EL_{SL})$

$$AL_{EP132\_nd149}^T = (0.161 \quad 1.197 \times 10^5 \quad 6.205 \quad 149 \quad 15 \quad 1.968 \times 10^4 \quad -1.153 \times 10^5 \quad -2.545 \times 10^4)$$

Emergency Pump 1-33 (Node 140)

$nd140_{EP133_0} := 140$

$AL_{EP133\_nd140} := Term(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd140_{EP133}, Term\_C_o, EL_{SL})$

$AL_{EP133\_nd140}^T = (0.222 \quad 2.245 \times 10^5 \quad 9.34 \quad 140 \quad 157 \quad 8.17 \times 10^3 \quad 2.242 \times 10^5 \quad -7.003 \times 10^3)$

Writing Output Data for Terminations Associated with Lines 32, 33, & 49

$T1 := AL_{NWP149\_nd266}^T$

$T2 := AL_{EP132\_nd149}^T$

$T3 := AL_{EP133\_nd140}^T$

TerminationsLines32_33_49 := WRITEPRN["TermLines32_33_49.prn" , (T1 T2 T3)]

PIPE RUNS

Pipe Runs Strategy: *Search based on the elements present in each run of pipe. Find the maximum moment combination among all of the nodes and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{PipeRunDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\,\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{PipeRun}(P, D_o, t, I, B_1, B_2, S, nf, el, C_o, EL) :=$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{el} \leftarrow \mathrm{match}\left(el_0, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(el)$ if $\mathrm{rows}(el) > 1$

  $ind_{el} \leftarrow \mathrm{stack}\left[ind_{el}, \left(\mathrm{match}\left(el_i, EL^{\langle 0 \rangle}\right)\right)\right]$

$\left(M \quad Int_{5, \mathrm{last}(ind_{el})}\right) \leftarrow (0 \quad 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \mathrm{last}(ind_{el})$

    $M_{rxg} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2, ind_{el_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2, ind_{el_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2, ind_{el_j}}$

    $M_{rx_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i, ind_{el_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i, ind_{el_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i, ind_{el_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{\left(M_{rx_j}\right)^2 + \left(M_{ry_j}\right)^2 + \left(M_{rz_j}\right)^2}$

    $Int'_j \leftarrow \mathrm{PipeRunDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$

    if $Int'_j > Int_{0,j}$

      $H \leftarrow \left(Int'_j \quad M'_j \quad nf_{ind_{nfiC_{o_{0,1}}}-1+i, 0} \quad EL_{ind_{el_j}, 0} \quad EL_{ind_{el_j}, 1} \quad ind_{el_j} \quad M_{r}\right.$

      for $k \in 0 .. 5$

        $Int_{k,j} \leftarrow H_k$

| Int

Conditions applicable to all pipe runs

$M_{cx} := 0 \qquad M_{cy} := 0 \qquad M_{cz} := 0$

Defining place holding directional moment variables

$$PipeRun\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

PIPE PROPERTIES FOR LINE 1-32A

Pipe runs exist immediately after the discharge from the emergency coolant pumps

Define pertinent pipe variables

$D_o := 12.75\,in$ — Outside Diameter [17, 57]

$t := 0.25\,in$ — Thickness [17, 57]

$P := 400\,psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t \right)^4 \right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 191.824\, in^4$$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{array}{|l} 1.0 \ \text{ if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50 \\ \quad \begin{array}{|l} T \leftarrow 125 \\ X \leftarrow 1.3 - 0.006 \cdot \dfrac{D_o}{t} \\ Y \leftarrow 1.033 - 0.00033 \cdot T \\ 1.0 \cdot \dfrac{1}{X \cdot Y} \end{array} \end{array}$$

$B_2 = 1.006$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-32A (Element 241)

$$el_{PR132A} := (241)^T$$

$$AL_{PR132A} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{SL}, el_{PR132A}, PipeRun\_C_o, EL_{SL})$$

$$AL_{PR132A}^T = \begin{pmatrix} 0.161 & 1.197 \times 10^5 & 6.205 & 241 & 149 & 15 \\ 0.153 & 1.067 \times 10^5 & 6.205 & 241 & 237 & 16 \end{pmatrix}$$

PIPE PROPERTIES FOR LINES 14 " SECTIONS OF 1-32 AND 1-33

Define pertinent pipe variables

$D_o := 14in$ — Outside Diameter [17]

$t := 0.25in$ — Thickness [17]

$P := 400psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^4 - (D_o - 2 \cdot t)^4\right]}{64}$$ Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 255.3\ in^4$$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{cases} 1.0 & \text{if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50: & T \leftarrow 125;\ X \leftarrow 1.3 - 0.006 \cdot \dfrac{D_o}{t};\ Y \leftarrow 1.033 - 0.00033 \cdot T;\ 1.0 \cdot \dfrac{1}{X \cdot Y} \end{cases}$$

$B_{2PR} = 1.046$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-32B (Elements 242 & 294)

$el_{PR132B} := (242 \;\; 294)^T$

$AL_{PR132B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{SL}, el_{PR132B}, PipeRun\_C_o, EL_{SL})$

$$AL_{PR132B}^T = \begin{pmatrix} 0.131 & 6.314\times10^4 & 6.215 & 242 & 148 & 17 \\ 0.143 & 8.742\times10^4 & 6.205 & 242 & 238 & 18 \\ 0.126 & 5.459\times10^4 & 7.91 & 294 & 147 & 39 \\ 0.127 & 5.57\times10^4 & 8.49 & 294 & 254 & 40 \end{pmatrix}$$

Pipe Run 1-32C (Elements 291 & 282)

$el_{PR132C} := (291 \;\; 282)^T$

$AL_{PR132C} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{SL}, el_{PR132C}, PipeRun\_C_o, EL_{SL})$

$$AL_{PR132C}^T = \begin{pmatrix} 0.12 & 4.297\times10^4 & 9.58 & 291 & 144 & 37 \\ 0.123 & 4.749\times10^4 & 9.11 & 291 & 255 & 38 \\ 0.127 & 5.634\times10^4 & 9.16 & 282 & 143 & 29 \\ 0.128 & 5.712\times10^4 & 9.16 & 282 & 247 & 30 \end{pmatrix}$$

Pipe Run 1-32D (Elements 640 & 279)

$el_{PR132D} := (640 \;\; 279)^T$

$AL_{PR132D} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{SL}, el_{PR132D}, PipeRun\_C_o, EL_{SL})$

$$AL_{PR132D}^T = \begin{pmatrix} 0.133 & 6.863\times10^4 & 9.34 & 640 & 248 & 141 \\ 0.141 & 8.401\times10^4 & 9.34 & 640 & 532 & 142 \\ 0.138 & 7.736\times10^4 & 9.335 & 279 & 250 & 27 \\ 0.141 & 8.409\times10^4 & 9.34 & 279 & 532 & 28 \end{pmatrix}$$

Pipe Run 1-32E (Elements 421, 422, & 423)

$el_{PR132E} := (421 \quad 422 \quad 423)^T$

$AL_{PR132E} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{SL}, el_{PR132E}, PipeRun\_C_o, EL_{SL})$

$$AL_{PR132E}^T = \begin{pmatrix} 0.185 & 1.704\times10^5 & 9.555 & 421 & 346 & 111 \\ 0.159 & 1.197\times10^5 & 9.56 & 421 & 347 & 112 \\ 0.159 & 1.197\times10^5 & 9.56 & 422 & 347 & 113 \\ 0.169 & 1.385\times10^5 & 7.92 & 422 & 348 & 114 \\ 0.179 & 1.58\times10^5 & 7.92 & 423 & 251 & 115 \\ 0.169 & 1.385\times10^5 & 7.92 & 423 & 348 & 116 \end{pmatrix}$$

Pipe Run 1-32F (Elements 295, 296, 715, 716, 717, 718, 297, 719, 720, 721, & 298)

$el_{PR132F} := (295 \quad 296 \quad 715 \quad 716 \quad 717 \quad 718 \quad 297 \quad 719 \quad 720 \quad 721 \quad 298)^T$

$AL_{PR132F} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{SL}, el_{PR132F}, PipeRun\_C_o, EL_{SL})$

$AL_{PR132F}^T =$

	0	1	2	3	4	5
0	0.201	$2.014\cdot10^5$	8.175	295	129	41
1	0.199	$1.987\cdot10^5$	8.175	295	259	42
2	0.2	$1.993\cdot10^5$	8.175	296	259	43
3	0.2	$2.002\cdot10^5$	8.165	296	595	44
4	0.2	$2.003\cdot10^5$	8.165	715	595	184
5	0.202	$2.033\cdot10^5$	8.16	715	596	185
6	0.202	$2.034\cdot10^5$	8.16	716	596	186
7	0.203	$2.051\cdot10^5$	8.16	716	597	187
8	0.203	$2.052\cdot10^5$	8.16	717	597	188
9	0.202	$2.05\cdot10^5$	8.16	717	598	189
10	0.202	$2.039\cdot10^5$	8.16	718	258	190
11	0.202	$2.051\cdot10^5$	8.16	718	598	191
12	0.202	$2.039\cdot10^5$	8.16	297	258	45
13	0.2	$1.992\cdot10^5$	8.16	297	599	46
14	0.2	$1.992\cdot10^5$	8.16	719	599	192
15	0.197	$1.936\cdot10^5$	8.165	719	600	193

Pipe Run 1-32G (Elements 714, 713, 712, 711, 709, & 637)

$el_{PR132G} := (714\ \ 713\ \ 712\ \ 711\ \ 709\ \ 637)^T$

$AL_{PR132G} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{SL}, el_{PR132G}, PipeRun\_C_o, EL_{SL})$

$AL_{PR132G}^{T} =$

	0	1	2	3	4	5
0	0.186	$1.727\cdot10^5$	8.18	714	323	182
1	0.177	$1.543\cdot10^5$	8.185	714	594	183
2	0.19	$1.806\cdot10^5$	7.915	713	593	180
3	0.177	$1.543\cdot10^5$	8.185	713	594	181
4	0.208	$2.167\cdot10^5$	7.915	712	592	178
5	0.19	$1.806\cdot10^5$	7.915	712	593	179
6	0.22	$2.402\cdot10^5$	7.92	711	591	176
7	0.208	$2.168\cdot10^5$	7.915	711	592	177
8	0.223	$2.452\cdot10^5$	7.92	709	590	174
9	0.22	$2.402\cdot10^5$	7.92	709	591	175
10	0.212	$2.232\cdot10^5$	7.665	637	125	139
11	0.212	$2.247\cdot10^5$	7.665	637	590	140

Pipe Run 1-32H (Elements 708, 707, 391, 706, 705, 704, 388, & 207)

$el_{PR132H} := (708\ \ 707\ \ 391\ \ 706\ \ 705\ \ 704\ \ 388\ \ 207)^T$

$AL_{PR132H} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{SL}, el_{PR132H}, PipeRun\_C_o, EL_{SL})$

$AL_{PR132H}^{T} =$

	0	1	2	3	4	5
0	0.202	$2.034\cdot10^5$	7.665	708	123	172
1	0.191	$1.83\cdot10^5$	8.175	708	589	173
2	0.192	$1.849\cdot10^5$	8.175	707	588	170
3	0.191	$1.83\cdot10^5$	8.175	707	589	171
4	0.214	$2.286\cdot10^5$	8.175	391	122	97
5	0.192	$1.85\cdot10^5$	8.175	391	588	98
6	0.214	$2.285\cdot10^5$	8.175	706	122	168
7	0.258	$3.151\cdot10^5$	8.175	706	587	169
8	0.317	$4.315\cdot10^5$	8.175	705	586	166
9	0.258	$3.152\cdot10^5$	8.175	705	587	167
10	0.386	$5.674\cdot10^5$	8.17	704	585	164
11	0.317	$4.315\cdot10^5$	8.175	704	586	165
12	0.461	$7.154\cdot10^5$	8.17	388	308	95
13	0.386	$5.675\cdot10^5$	8.17	388	585	96
14	0.516	$8.255\cdot10^5$	8.17	207	121	3
15	0.461	$7.155\cdot10^5$	8.17	207	308	4

Pipe Run 1-33A (Element 287)

$el_{PR133A} := (287)^T$

$AL_{PR133A} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{SL}, el_{PR133A}, PipeRun\_C_o, EL_{SL})$

$$AL_{PR133A}^T = \begin{pmatrix} 0.203 & 2.055 \times 10^5 & 9.325 & 287 & 138 & 33 \\ 0.192 & 1.849 \times 10^5 & 9.33 & 287 & 253 & 34 \end{pmatrix}$$

Pipe Run 1-33B (Element 290 & 667)

$el_{PR133B} := (290 \quad 667)^T$

$AL_{PR133B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{SL}, el_{PR133B}, PipeRun\_C_o, EL_{SL})$

$$AL_{PR133B}^T = \begin{pmatrix} 0.174 & 1.478 \times 10^5 & 9.525 & 290 & 136 & 35 \\ 0.176 & 1.518 \times 10^5 & 9.525 & 290 & 257 & 36 \\ 0.174 & 1.492 \times 10^5 & 9.335 & 667 & 135 & 162 \\ 0.191 & 1.814 \times 10^5 & 9.335 & 667 & 548 & 163 \end{pmatrix}$$

Pipe Properties for Line 1-49

Define pertinent pipe variables

$D_o := 4.5in$ Outside Diameter [16, 57]

$t := 0.237in$ Thickness [16, 57]

$P := 400psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^4 - (D_o - 2 \cdot t)^4\right]}{64}$$ Moment of inertia [8, Table 17-27, pg 17-39]

$I = 7.233\ in^4$

Define primary stress indices

$B_{1PR} := 0.5$

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Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

$$B_{2PR} := \left| \begin{array}{l} 1.0 \text{ if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 \\ \quad \left| \begin{array}{l} T \leftarrow 125 \\ X \leftarrow 1.3 - 0.006 \cdot \frac{D_o}{t} \\ Y \leftarrow 1.033 - 0.00033 \cdot T \\ 1.0 \cdot \frac{1}{X \cdot Y} \end{array} \right. \end{array} \right.$$

$B_{2PR} = 1$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-49A (Elements 730, 729, 728, 727, 308, 726, 725, 724, 723, 722, 444, & 443)

$$el_{PR149A} := (730\ \ 729\ \ 728\ \ 727\ \ 308\ \ 726\ \ 725\ \ 724\ \ 723\ \ 722\ \ 444\ \ 443)^T$$

$$AL_{PR149A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{SL}, el_{PR149A}, PipeRun\_C_o, EL_{SL}\right)$$

$AL_{PR149A}^T =$

	0	1	2	3	4	5
0	0.102	$1.24 \cdot 10^4$	9.375	730	266	214
1	0.088	$9.972 \cdot 10^3$	9.38	730	610	215
2	0.075	$7.616 \cdot 10^3$	9.38	729	609	212
3	0.088	$9.972 \cdot 10^3$	9.38	729	610	213
4	0.063	$5.409 \cdot 10^3$	9.355	728	608	210
5	0.075	$7.616 \cdot 10^3$	9.38	728	609	211
6	0.061	$4.936 \cdot 10^3$	7.64	727	607	208
7	0.063	$5.409 \cdot 10^3$	9.355	727	608	209
8	0.07	$6.717 \cdot 10^3$	7.645	308	154	49
9	0.061	$4.935 \cdot 10^3$	7.64	308	607	50
10	0.07	$6.717 \cdot 10^3$	7.645	726	154	206
11	0.053	$3.539 \cdot 10^3$	8.2	726	606	207
12	0.057	$4.347 \cdot 10^3$	7.645	725	605	204
13	0.053	$3.539 \cdot 10^3$	8.2	725	606	205
14	0.071	$6.795 \cdot 10^3$	7.645	724	604	202
15	0.057	$4.347 \cdot 10^3$	7.645	724	605	203

Pipe Run 1-49B (Elements 403, 402, & 270)

$el_{PR149B} := (403 \quad 402 \quad 270)^T$

$AL_{PR149B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{SL}, el_{PR149B}, PipeRun\_C_o, EL_{SL})$

$$AL_{PR149B}^T = \begin{pmatrix} 0.106 & 1.327\times10^4 & 7.685 & 403 & 242 & 109 \\ 0.1 & 1.212\times10^4 & 7.68 & 403 & 328 & 110 \\ 0.098 & 1.182\times10^4 & 7.65 & 402 & 327 & 107 \\ 0.1 & 1.212\times10^4 & 7.68 & 402 & 328 & 108 \\ 0.104 & 1.283\times10^4 & 7.645 & 270 & 244 & 19 \\ 0.098 & 1.182\times10^4 & 7.65 & 270 & 327 & 20 \end{pmatrix}$$

Pipe Run 1-49C (Elements 401, 400, & 275)

$el_{PR149C} := (401 \quad 400 \quad 275)^T$

$AL_{PR149C} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{SL}, el_{PR149C}, PipeRun\_C_o, EL_{SL})$

$$AL_{PR149C}^T = \begin{pmatrix} 0.104 & 1.278\times10^4 & 7.69 & 401 & 243 & 105 \\ 0.101 & 1.227\times10^4 & 8.16 & 401 & 326 & 106 \\ 0.116 & 1.504\times10^4 & 8.17 & 400 & 325 & 103 \\ 0.101 & 1.227\times10^4 & 8.16 & 400 & 326 & 104 \\ 0.137 & 1.887\times10^4 & 8.17 & 275 & 245 & 23 \\ 0.116 & 1.504\times10^4 & 8.17 & 275 & 325 & 24 \end{pmatrix}$$

Pipe Run 1-49D (Elements 272 & 399)

$el_{PR149D} := (272 \quad 399)^T$

$AL_{PR149D} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF_{SL}, el_{PR149D}, PipeRun\_C_o, EL_{SL})$

$$AL_{PR149D}^T = \begin{pmatrix} 0.219 & 3.38\times10^4 & 7.935 & 272 & 150 & 21 \\ 0.175 & 2.586\times10^4 & 7.935 & 272 & 324 & 22 \\ 0.143 & 1.993\times10^4 & 8.17 & 399 & 246 & 101 \\ 0.175 & 2.586\times10^4 & 7.935 & 399 & 324 & 102 \end{pmatrix}$$

Writing Output Data for Pipe Runs Associated with Lines 22 to 26

$PR1 := AL_{PR132A}^{T}$ $PR8 := AL_{PR132H}^{T}$

$PR2 := AL_{PR132B}^{T}$ $PR9 := AL_{PR133A}^{T}$

$PR3 := AL_{PR132C}^{T}$ $PR10 := AL_{PR133B}^{T}$

$PR4 := AL_{PR132D}^{T}$ $PR11 := AL_{PR149A}^{T}$

$PR5 := AL_{PR132E}^{T}$ $PR12 := AL_{PR149B}^{T}$

$PR6 := AL_{PR132F}^{T}$ $PR13 := AL_{PR149C}^{T}$

$PR7 := AL_{PR132G}^{T}$ $PR14 := AL_{PR149D}^{T}$

PipeRunsLines32_33_49 := WRITEPRN["PRLines32_33_49.prn" , (PR1 PR2 PR3 PR4 PR5 PR6 PR7 PR8 PR9 PR10 PI

REDUCERS

Reducers Strategy: *Search based on the nodes comprising either end of the reducers. SRSS combine the three moments of each of the four node representations (one for each element connected by the node in question). Find the maximum of the moment combinations for each element and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. It is important to not combine the data from both nodes as the geometry for each is different and (9) must be applied for each node. The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\text{ReducerDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

$\text{Reducer}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$$\begin{aligned}
& ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
& ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
& ind_{nd} \leftarrow \text{match}\left(nd_0, EL^{\langle 1 \rangle}\right) \\
& \text{for } i \in 1 .. \text{last}(nd) \quad \text{if rows}(nd) > 1 \\
& \quad ind_{nd} \leftarrow \text{stack}\left[ind_{nd}, \left(\text{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \\
& (M \;\; Int_0) \leftarrow (0 \;\; 0) \\
& \text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0} \\
& \quad \text{for } j \in 0 .. \text{last}(ind_{nd}) \\
& \qquad M_{rxg} \leftarrow nf_{ind_{nfi}{}_{C_{o_{0,1}}+2},\, ind_{nd_j}} \\
& \qquad M_{ryg} \leftarrow nf_{ind_{nfi}{}_{C_{o_{1,1}}+2},\, ind_{nd_j}} \\
& \qquad M_{rzg} \leftarrow nf_{ind_{nfi}{}_{C_{o_{2,1}}+2},\, ind_{nd_j}} \\
& \qquad M_{rx} \leftarrow \left(nf_{ind_{nfi}{}_{C_{o_{0,1}}+2}+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg} \\
& \qquad M_{ry} \leftarrow \left(nf_{ind_{nfi}{}_{C_{o_{1,1}}+2}+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg} \\
& \qquad M_{rz} \leftarrow \left(nf_{ind_{nfi}{}_{C_{o_{2,1}}+2}+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg} \\
& \qquad M'_j \leftarrow \sqrt{M_{rx}{}^2 + M_{ry}{}^2 + M_{rz}{}^2} \\
& \qquad Int'_j \leftarrow \text{ReducerDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right) \\
& \qquad \text{if } Int'_j > Int_0 \\
& \qquad \quad Int \leftarrow \text{stack}\left(Int'_j, M'_j, nf_{ind_{nfi}{}_{C_{o_{0,1}}-1}+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd_j}, M_{rx}, M_{ry},\right. \\
& \qquad \quad Result \leftarrow M'
\end{aligned}$$

Int

Conditions applicable to all reducers

$M_{cx} := 0 \quad M_{cy} := 0 \quad M_{cz} := 0$ — Defining place holding variables

$$Reducer\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

Reducer Properties for Bottom of Lines 1-32 and 1-33

Define pertinent reducer variables

$D_o := (14in \quad 12.75in)^T$ — Outside Diameter [17, 57]

$t := \left(\frac{1}{4}in \quad \frac{1}{4}in\right)^T$ — Thickness [17, 57]

$P := (400psi \quad 400psi)^T$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - (D_o - 2 \cdot t)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = \begin{pmatrix} 255.3 \\ 191.824 \end{pmatrix} in^4$$

Define primary stress indices

$$\alpha := atan\left(\frac{0.625in}{15.75in}\right)$$

Angular slope of reducer

$$\alpha = 2.272\ deg$$

$$B_1 := \begin{vmatrix} 0.5 \text{ if } \alpha \le 30deg \\ 1.0 \text{ if } 30deg < \alpha \le 60deg \end{vmatrix}$$

B_1 primary stress Index [9, NB-3683.7]

$$B_1 = 0.5$$

$B_2 := 1.0$ — B_2 primary stress Index [9, NB-3683.7]

Reducer 1-32 (Nodes 238 & 237)

$nd_{RD132\_L} := (238)^T$ — Node associated with Large end of reducer

$$AL_{RD132\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF_{SL}, nd_{RD132\_L}, Reducer\_C_o, EL_{SL}\right)$$

$$AL_{RD132\_L}^{\ T} = \left(0.141 \quad 8.742\times10^4 \quad 6.205 \quad 238 \quad 137 \quad -2.733\times10^4 \quad 7.905\times10^4 \quad 2.545\times10^4\right)$$

$nd_{RD132\_S} := (237)^T$ Node associated with Small end of reducer

$AL_{RD132\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF_{SL}, nd_{RD132\_S}, Reducer\_C_o, EL_{SL}\right)$

$AL_{RD132\_S}^T = \begin{pmatrix} 0.152 & 1.067\times10^5 & 6.205 & 237 & 16 & -2.328\times10^4 & 1.01\times10^5 & 2.545\times10^4 \end{pmatrix}$

Reducer 1-33 (Nodes 139 & 140)

$nd_{RD133\_L} := (139)^T$ Node associated with Large end of reducer

$AL_{RD133\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF_{SL}, nd_{RD133\_L}, Reducer\_C_o, EL_{SL}\right)$

$AL_{RD133\_L}^T = \begin{pmatrix} 0.197 & 2.022\times10^5 & 9.34 & 139 & 155 & 3.092\times10^4 & -1.997\times10^5 & 6.991\times10^3 \end{pmatrix}$

$nd_{RD133\_S} := (140)^T$ Node associated with Small end of reducer

$AL_{RD133\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF_{SL}, nd_{RD133\_S}, Reducer\_C_o, EL_{SL}\right)$

$AL_{RD133\_S}^T = \begin{pmatrix} 0.222 & 2.245\times10^5 & 9.34 & 140 & 157 & 8.17\times10^3 & 2.242\times10^5 & -7.003\times10^3 \end{pmatrix}$

Writing Output Data for Reducers Associated with Lines 32, 33, & 49

$RL1 := AL_{RD132\_L}^T$

$RS1 := AL_{RD132\_S}^T$

$RL2 := AL_{RD133\_L}^T$

$RS2 := AL_{RD133\_S}^T$

ReducersLines32_33_49 := WRITEPRN["RedLines32_33_49.prn" , (RL1 RS1 RL2 RS2)]

ELBOWS

Elbows Strategy: *Search based on the two nodes comprising the ends of each elbow. SRSS combine the three moments of each of the four node representations (one for each element connected by the nodes in question). Find the maximum of the four moment combinations and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{ElbowDC}\left(P, D_o, t, I, B_1, B_2, M, S\right) := \frac{B_1 \cdot \dfrac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \dfrac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$$\mathrm{Elbow}\left(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL\right) :=$$

$$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$$

$$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$$

$$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$$

$$\text{for } i \in 1 .. \mathrm{last}(nd) \quad \text{if } \mathrm{rows}(nd) > 1$$

$$\quad ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$$

$$\left(M \quad Int_0\right) \leftarrow (0 \quad 0)$$

$$\text{for } i \in 0 .. {ind_{nfo}}_0 - {ind_{nfi}}_0$$

$$\quad \text{for } j \in 0 .. \mathrm{last}\left(ind_{nd}\right)$$

$$\quad\quad M_{rxg} \leftarrow nf_{{ind_{nfi}}_{{C_o}_{0,1}+2}, {ind_{nd}}_j}$$

$$\quad\quad M_{ryg} \leftarrow nf_{{ind_{nfi}}_{{C_o}_{1,1}+2}, {ind_{nd}}_j}$$

$$\quad\quad M_{rzg} \leftarrow nf_{{ind_{nfi}}_{{C_o}_{2,1}+2}, {ind_{nd}}_j}$$

$$\quad\quad M_{rx} \leftarrow \left(nf_{{ind_{nfi}}_{{C_o}_{0,1}+2}+i, {ind_{nd}}_j} - M_{rxg}\right) \cdot {C_o}_{3,0} + M_{rxg}$$

$$\quad\quad M_{ry} \leftarrow \left(nf_{{ind_{nfi}}_{{C_o}_{1,1}+2}+i, {ind_{nd}}_j} - M_{ryg}\right) \cdot {C_o}_{3,0} + M_{ryg}$$

$$\quad\quad M_{rz} \leftarrow \left(nf_{{ind_{nfi}}_{{C_o}_{2,1}+2}+i, {ind_{nd}}_j} - M_{rzg}\right) \cdot {C_o}_{3,0} + M_{rzg}$$

$$\quad\quad M'_j \leftarrow \sqrt{{M_{rx}}^2 + {M_{ry}}^2 + {M_{rz}}^2}$$

$$\quad\quad Int'_j \leftarrow \mathrm{ElbowDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$$

$$\quad\quad \text{if } Int'_j > Int_0$$

$$\quad\quad\quad Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{{ind_{nfi}}_{{C_o}_{0,1}-1}+i, 0}, EL_{{ind_{nd}}_j, 1}, {ind_{nd}}_j, M_{rx}, M_{ry}, M\right.$$

$$\quad\quad\quad Result \leftarrow M'$$

$$Int$$

Conditions applicable to all elbows

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$ — Defining place holding variables

$$Elb\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

Elbow Properties for Lines 1-32A,B and 1-33

Define pertinent elbow variables

$D_o := 14in$ — Outside Diameter [17]

$t := 0.25in$ — Thickness [17]

$P := 400psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

$I = 255.3\ in^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$R := 1 \cdot D_o$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$ — Mean pipe radius

Define primary stress indices

$$h := \frac{t \cdot R}{r_m^{\,2}}$$ $h = 0.074$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h > 0.5 \\ -0.1 + 0.4 \cdot h & \text{otherwise} \end{cases}$$

$B_1 = 0$ — B_1 primary stress Index [9, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 7.372$ B_2 primary stress Index [9, NB-3683.7]

Elbow 1-32A (Nodes 254 & 255)

$nd_{EL132A\_1} := (254)^T$

$AL_{EL132A\_nd254} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{EL132A\_1}, Elb\_C_o, EL_{SL})$

$AL_{EL132A\_nd254}^T = (0.199 \quad 5.57\times10^4 \quad 8.49 \quad 254 \quad 40 \quad -4.543\times10^4 \quad -2.468\times10^4 \quad 2.072\times10^4)$

$nd_{EL132A\_2} := (255)^T$

$AL_{EL132A\_nd255} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{EL132A\_2}, Elb\_C_o, EL_{SL})$

$AL_{EL132A\_nd255}^T = (0.169 \quad 4.75\times10^4 \quad 9.11 \quad 255 \quad 76 \quad -4.343\times10^4 \quad 1.665\times10^4 \quad 9.627\times10^3)$

Elbow 1-32B (Nodes 247 & 248)

$nd_{EL132B\_1} := (247)^T$

$AL_{EL132B\_nd247} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{EL132B\_1}, Elb\_C_o, EL_{SL})$

$AL_{EL132B\_nd247}^T = (0.204 \quad 5.712\times10^4 \quad 9.16 \quad 247 \quad 72 \quad 5.148\times10^4 \quad -2.442\times10^4 \quad 4.062\times10^3)$

$nd_{EL132B\_2} := (248)^T$

$AL_{EL132B\_nd248} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{EL132B\_2}, Elb\_C_o, EL_{SL})$

$AL_{EL132B\_nd248}^T = (0.245 \quad 6.863\times10^4 \quad 9.34 \quad 248 \quad 73 \quad 5.311\times10^4 \quad -4.255\times10^4 \quad 8.93\times10^3)$

Elbow 1-33 (Nodes 253 & 257)

$nd_{EL133A\_1} := (253)^T$

$AL_{EL133\_nd253} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{EL133A\_1}, Elb\_C_o, EL_{SL})$

$AL_{EL133\_nd253}^T = (0.659 \quad 1.849\times10^5 \quad 9.33 \quad 253 \quad 78 \quad -1.19\times10^5 \quad 1.413\times10^5 \quad -8.44\times10^3)$

$nd_{EL133A\_2} := (257)^T$

$AL_{EL133\_nd257} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{EL133A\_2}, Elb\_C_o, EL_{SL})$

$AL_{EL133\_nd257}^T = (0.541 \quad 1.518\times10^5 \quad 9.525 \quad 257 \quad 79 \quad -3.788\times10^4 \quad 1.424\times10^5 \quad -3.669\times10^4)$

Elbow Properties for Lines 1-32C through 1-32 F

Define pertinent elbow variables

$D_o := 14in$ Outside Diameter [17]

$t := 0.25in$ Thickness [17]

$P := 400psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\ 4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 255.3\ in^4$

$R := 1.5 \cdot D_o$ Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$ Mean pipe radius

Define primary stress indices

$$h := \frac{t \cdot R}{r_m^{\ 2}}$$ $h = 0.111$ Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h > 0.5 \\ -0.1 + 0.4 \cdot h & \text{otherwise} \end{cases}$$

$B_1 = 0$ B_1 primary stress Index [9, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 5.626$ B_2 primary stress Index [9, NB-3683.7]

Elbow 1-32C (Nodes 250 & 249)

$nd_{EL132C\_1} := (250)^T$

$AL_{EL132C\_nd250} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{EL132C\_1}, Elb\_C_o, EL_{SL}\right)$

$AL_{EL132C\_nd250}^{\ T} = \left(0.21 \quad 7.736 \times 10^4 \quad 9.335 \quad 250 \quad 27 \quad 5.963 \times 10^4 \quad -4.67 \times 10^4 \quad 1.574 \times 10^4\right)$

$nd_{EL132C\_2} := (249)^T$

$AL_{EL132C\_nd249} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{EL132C\_2}, Elb\_C_o, EL_{SL}\right)$

$AL_{EL132C\_nd249}^{\ T} = \left(0.193 \quad 7.094 \times 10^4 \quad 9.335 \quad 249 \quad 69 \quad 4.942 \times 10^4 \quad -5.022 \times 10^4 \quad -8.271 \times 10^3\right)$

Elbow 1-32D (Nodes 251 & 252)

$nd_{EL132D\_1} := (251)^T$

$AL_{EL132D\_nd251} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{EL132D\_1}, Elb\_C_o, EL_{SL})$

$AL_{EL132D\_nd251}{}^T = (0.43 \;\; 1.58 \times 10^5 \;\; 7.92 \;\; 251 \;\; 115 \;\; -3.665 \times 10^4 \;\; 4.275 \times 10^3 \;\; -1.537 \times 10^5)$

$nd_{EL132D\_2} := (252)^T$

$AL_{EL132D\_nd252} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{EL132D\_2}, Elb\_C_o, EL_{SL})$

$AL_{EL132D\_nd252}{}^T = (0.5 \;\; 1.838 \times 10^5 \;\; 8.18 \;\; 252 \;\; 67 \;\; 3.494 \times 10^4 \;\; -4.942 \times 10^4 \;\; 1.735 \times 10^5)$

Elbow 1-32E (Nodes 129 & 128)

$nd_{EL132E\_1} := (129)^T$

$AL_{EL132E\_129} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{EL132E\_1}, Elb\_C_o, EL_{SL})$

$AL_{EL132E\_129}{}^T = (0.548 \;\; 2.014 \times 10^5 \;\; 8.175 \;\; 129 \;\; 41 \;\; -1.57 \times 10^4 \;\; -1.013 \times 10^5 \;\; 1.733 \times 10^5)$

$nd_{EL132E\_2} := (128)^T$

$AL_{EL132E\_nd128} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{EL132E\_2}, Elb\_C_o, EL_{SL})$

$AL_{EL132E\_nd128}{}^T = (0.535 \;\; 1.967 \times 10^5 \;\; 8.175 \;\; 128 \;\; 62 \;\; -3.275 \times 10^4 \;\; -1.371 \times 10^5 \;\; 1.371 \times 10^5)$

Elbow 1-32F (Nodes 125 & 123)

$nd_{EL132F\_1} := (125)^T$

$AL_{EL132F\_nd125} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{EL132F\_1}, Elb\_C_o, EL_{SL})$

$AL_{EL132F\_nd125}{}^T = (0.607 \;\; 2.232 \times 10^5 \;\; 7.665 \;\; 125 \;\; 61 \;\; 3.005 \times 10^4 \;\; 1.399 \times 10^5 \;\; 1.714 \times 10^5)$

$nd_{EL132F\_2} := (123)^T$

$AL_{EL132F\_nd123} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{EL132F\_2}, Elb\_C_o, EL_{SL})$

$AL_{EL132F\_nd123}{}^T = (0.553 \;\; 2.034 \times 10^5 \;\; 7.665 \;\; 123 \;\; 172 \;\; 5.662 \times 10^3 \;\; 1.255 \times 10^5 \;\; 1.599 \times 10^5)$

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Elbow Properties for Lines 1-49

Define pertinent elbow variables

$D_o := 4.5in$ — Outside Diameter [16, 57]

$t := 0.237in$ — Thickness [16, 57]

$P := 400psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 7.233\ in^4$

$R := 1.5 \cdot D_o$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$

Mean pipe radius

Define primary stress indices

$$h := \frac{t \cdot R}{r_m^{\,2}} \qquad h = 0.352$$

Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h > 0.5 \\ -0.1 + 0.4 \cdot h & \text{otherwise} \end{cases} \qquad B_1 = 0.041$$

B_1 primary stress Index [9, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases} \qquad B_2 = 2.607$$

B_2 primary stress Index [9, NB-3683.7]

Elbow 1-49A (Nodes 240 & 244)

$nd_{EL149A\_1} := (240)^T$

$AL_{EL149A\_nd240} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{EL149A\_1}, Elb\_C_o, EL_{SL}\right)$

$AL_{EL149A\_nd240}^{\ T} = \left(0.172 \quad 1.18 \times 10^4 \quad 7.9 \quad 240 \quad 117 \quad -3.102 \times 10^3 \quad 506.915 \quad -1.138 \times 10^4\right)$

$nd_{EL149A\_2} := (244)^T$

$AL_{EL149A\_nd244} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{EL149A\_2}, Elb\_C_o, EL_{SL}\right)$

$AL_{EL149A\_nd244}^{\ T} = \left(0.186 \quad 1.283 \times 10^4 \quad 7.645 \quad 244 \quad 94 \quad 3.236 \times 10^3 \quad -1.724 \times 10^3 \quad 1.229 \times 10^4\right)$

Elbow 1-49B (Nodes 242 & 243)

$nd_{EL149B\_1} := (242)^T$

$AL_{EL149B\_nd242} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{EL149B\_1}, Elb\_C_o, EL_{SL})$

$AL_{EL149B\_nd242}{}^T = \left(0.192 \quad 1.327\times10^4 \quad 7.685 \quad 242 \quad 90 \quad -6.352\times10^3 \quad 2.76\times10^3 \quad -1.131\times10^4\right)$

$nd_{EL149B\_2} := (243)^T$

$AL_{EL149B\_nd243} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{EL149B\_2}, Elb\_C_o, EL_{SL})$

$AL_{EL149B\_nd243}{}^T = \left(0.186 \quad 1.278\times10^4 \quad 7.69 \quad 243 \quad 105 \quad -4.756\times10^3 \quad 2.9\times10^3 \quad -1.15\times10^4\right)$

Elbow 1-49C (Nodes 245 & 246)

$nd_{EL149C\_1} := (245)^T$

$AL_{EL149C\_nd245} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{EL149C\_1}, Elb\_C_o, EL_{SL})$

$AL_{EL149C\_nd245}{}^T = \left(0.273 \quad 1.887\times10^4 \quad 8.17 \quad 245 \quad 23 \quad -1.455\times10^4 \quad -2.919\times10^3 \quad 1.166\times10^4\right)$

$nd_{EL149C\_2} := (246)^T$

$AL_{EL149C\_nd246} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{EL149C\_2}, Elb\_C_o, EL_{SL})$

$AL_{EL149C\_nd246}{}^T = \left(0.288 \quad 1.993\times10^4 \quad 8.17 \quad 246 \quad 88 \quad -1.555\times10^4 \quad -3.115\times10^3 \quad 1.207\times10^4\right)$

Writing Output Data for Elbows Associated with Lines 32, 33, and 49

$EL1A := AL_{EL132A\_nd254}{}^T$

$EL1B := AL_{EL132A\_nd255}{}^T$

$EL2A := AL_{EL132B\_nd247}{}^T$

$EL2B := AL_{EL132B\_nd248}{}^T$

$EL3A := AL_{EL133\_nd253}{}^T$

$EL3B := AL_{EL133\_nd257}{}^T$

$EL4A := AL_{EL132C\_nd250}{}^T$

$EL4B := AL_{EL132C\_nd249}{}^T$

$EL5A := AL_{EL132D\_nd251}{}^T$

$EL5B := AL_{EL132D\_nd252}{}^T$

$EL6A := AL_{EL132E\_129}{}^T$

$EL6B := AL_{EL132E\_nd128}{}^T$

$EL7A := AL_{EL132F\_nd125}{}^T$

$EL7B := AL_{EL132F\_nd123}{}^T$

$EL8A := AL_{EL149A\_nd240}{}^T$

$EL8B := AL_{EL149A\_nd244}{}^T$

$EL9A := AL_{EL149B\_nd242}{}^T$

$EL9B := AL_{EL149B\_nd243}{}^T$

$EL10A := AL_{EL149C\_nd245}{}^T$

$EL10B := AL_{EL149C\_nd246}{}^T$

ElbowLines32_33_49 := WRITEPRN["ElbowLines32_33_49.prn" , (EL1A EL1B EL2A EL2B EL3A EL3B EL4A EL4B El

FABRICATED TEES

Tees Strategy: *Search based on the elements comprising the tee. The input identifies which elements are associated with the pipe run and which element is associated with the branch from the run. The indices for the defined common node for all three elements is identified and the associated SRSS moment is identified for each time step. The maximum moment for the elements comprising the pipe run is found and applied as M_r in equation (9) of ASME III, Division I - NB - 3652 [9] which is modified to represent tees. The maximum moment for the branch element is found and applied as M_b in equation (9) of ASME III, Division I - NB - 3652 [9]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$TeeDC(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_b, M_r, Z_b, Z_r, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot T_r} + B_{2b} \cdot \left[\frac{M_b \cdot (1lbf \cdot in)}{Z_b}\right] + B_{2r} \cdot \left[\frac{M_r \cdot (1lbf \cdot in)}{Z_r}\right]}{S}$$

$$Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S, nf, el_R, el_B, nd_R, nd_B, C_o, EL) :=$$

```
ind_nfi ← match(t_initial, nf^⟨0⟩)
ind_nfo ← match(t_final, nf^⟨0⟩)
ind_elR ← match(el_R_0, EL^⟨0⟩)
for i ∈ 1 .. last(el_R)                                          if rows
   ind_elR ← stack[ind_elR, (match(el_R_i, EL^⟨0⟩))]
EL'R_last(EL^⟨0⟩) ← 0
for i ∈ 0 .. last(ind_elR)
   EL'R_ind_elR_i ← EL_ind_elR_i, 1
ind_ndR ← match(nd_R_0, EL'R^⟨0⟩)
for i ∈ 1 .. last(nd_R)                                           if r
   ind_ndR ← stack[ind_ndR, (match(nd_R_i, EL'R^⟨0⟩))]
ind_elB ← match(el_B_0, EL^⟨0⟩)
for i ∈ 1 .. last(el_B)                                          if rows
   ind_elB ← stack[ind_elB, (match(el_B_i, EL^⟨0⟩))]
EL'B_last(EL^⟨0⟩) ← 0
for i ∈ 0 .. last(ind_elB)
   EL'B_ind_elB_i ← EL_ind_elB_i, 1
ind_ndB ← match(nd_B_0, EL'B^⟨0⟩)
```

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for $i \in 1 .. last(nd_B)$ if r

$ind_{ndB} \leftarrow stack\left[ind_{ndB}, \left(match\left(nd_{B_i}, EL'B^{\langle 0 \rangle}\right)\right)\right]$

$\left(M_R \ \ M_B \ \ Int_0\right) \leftarrow (0 \ \ 0 \ \ 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

for $j \in 0 .. last(ind_{ndR})$

for $k \in 0 .. last(ind_{ndB})$

$M_{rxgR_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2, ind_{ndR_j}}$

$M_{rygR_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2, ind_{ndR_j}}$

$M_{rzgR_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2, ind_{ndR_j}}$

$M_{rxR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i, ind_{ndR_j}} - M_{rxgR_j}\right) \cdot C$

$M_{ryR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i, ind_{ndR_j}} - M_{rygR_j}\right) \cdot C$

$M_{rzR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i, ind_{ndR_j}} - M_{rzgR_j}\right) \cdot C$

$M_{R_j} \leftarrow \sqrt{\left(M_{rxR_j}\right)^2 + \left(M_{ryR_j}\right)^2 + \left(M_{rzR_j}\right)^2}$

$M_{rxgB_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2, ind_{ndB_k}}$

$M_{rygB_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2, ind_{ndB_k}}$

$M_{rzgB_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2, ind_{ndB_k}}$

$M_{rxB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i, ind_{ndB_k}} - M_{rxgB_j}\right) \cdot C$

$M_{ryB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i, ind_{ndB_k}} - M_{rygB_j}\right) \cdot C$

$M_{rzB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i, ind_{ndB_k}} - M_{rzgB_j}\right) \cdot C$

$M_{B_j} \leftarrow \sqrt{\left(M_{rxB_j}\right)^2 + \left(M_{ryB_j}\right)^2 + \left(M_{rzB_j}\right)^2}$

$Int'_j \leftarrow TeeDC\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_{B_j}, M_R\right.$

if $Int'_j > Int_0$

$Int \leftarrow stack\left(Int'_j, M_{R_j}, M_{B_j}, nf_{ind_{nfiC_{o_{0,1}}}-1+i}\right.$

$Result \leftarrow stack\left(M_{R_j}, M_{B_j}, M_{rxR_j}, M_{ryR_j}, M\right.$

$M \leftarrow M_R$

Int

Conditions applicable to forged tee

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$

Defining place holding directional moment variables

$$Tee\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

FABRICATED TEE (LINE 1-49 & 1-32)

Define pertinent tee variables

$P := 400psi$ — Internal Pressure [3, pg 23]

$D_o := 14in$ — Outside Diameter of pipe run [17]

$d_o := 4.5in$ — Outside Diameter of branch [17, 57]

$B_1 := 0.5$ — B_1 primary stress Index for tees and branches [9, Table NB-3681(a)-1]]

$T_r := 0.25in$ — Nominal wall thickness of designated run pipe [17]

$R_m := \frac{D_o - T_r}{2}$ — Mean radius of designated run pipe [17]

$Z_r := \pi \cdot R_m^{\ 2} \cdot T_r$ — Approximate section modulus of designated run pipe [9, NB-3683.1(d)]

$Z_r = 37.1223\ in^3$

$T'_b := 0.237in$ — Nominal wall thickness of attached branch pipe [16]

$r'_m := \frac{d_o - T'_b}{2}$ — Mean radius of attached branch pipe [16]

$Z_b := \pi \cdot r'^{\ 2}_m \cdot T'_b$ — Approximate section modulus of attached branch pipe [9, NB-3683.1(d)]

$Z_b = 3.383\ in^3$

C_{2b} Secondary stress Index [9,NB-3683.8]

$$C_{2b} := \begin{cases} 1.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}}\left(\frac{r'_m}{R_m}\right)^{\frac{1}{2}}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{\frac{d_o}{2}}\right) & \text{if } 1.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}}\left(\frac{r'_m}{R_m}\right)^{\frac{1}{2}}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{\frac{d_o}{2}}\right) \ge 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$$C_{2b} = 6.834$$

C_{2r} Secondary stress Index [9,NB-3683.8]

$$t_n := T'_b$$

Wall thickness of nozzle or branch connection reinforcement associated with [9, NB-3643.4(A)-1, sketch (d)]

$$C_{2r} := \begin{cases} 1.15\cdot\left(\frac{r'_m}{t_n}\right)^{\frac{1}{4}} & \text{if } 1.15\cdot\left(\frac{r'_m}{t_n}\right)^{\frac{1}{4}} \ge 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$$C_{2r} = 1.992$$

$$B_{2b} := \begin{cases} 0.5\cdot C_{2b} & \text{if } 0.5\cdot C_{2b} \ge 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Index for branches [9, NB-3683.8]

$$B_{2b} = 3.417$$

$$B_{2r} := \begin{cases} 0.75\cdot C_{2r} & \text{if } 0.75\cdot C_{2r} \ge 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Index for branches [9, NB-3683.8]

$$B_{2r} = 1.494$$

Fabricated Tee 1-49 (Node 233)

$elR_{Tee149} := (212 \;\; 398)^T$ — Elements associated with pipe run

$ndR_{Tee149} := (233)^T$ — Node between pipe run elements

$elB_{Tee149} := (230)^T$ — Element associated with branch

$ndB_{Tee149} := (150)^T$ — Node where branch intersects pipe run

$$AL_{Tee149} := Tee\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF_{SL}, elR_{Tee149}, elB_{Tee149}, ndR_{Tee149}, ndB_{Tee149}, Tee\_C_o, EL_{SL}\right)$$

$$AL_{Tee149}^T = \left(0.829 \quad 1.798\times10^5 \quad 3.38\times10^4 \quad 7.935 \quad 233 \quad 6 \quad 99 \quad 13\right)$$

FABRICATED TEE (LINE 1-33 & 1-32)

Define pertinent tee variables

$P := 400\text{psi}$ — Internal Pressure [3, pg 23]

$D_o := 14\text{in}$ — Outside Diameter of pipe run [17]

$d_o := 14\text{in}$ — Outside Diameter of branch [17]

$B_1 := 0.5$ — B_1 primary stress Index for tees and branches [9, Table NB-3681(a)-1]]

$T_r := 0.25\text{in}$ — Nominal wall thickness of designated run pipe [17]

$R_m := \frac{D_o - T_r}{2}$ — Mean radius of designated run pipe [17]

$Z_r := \pi \cdot R_m^{\,2} \cdot T_r$ — Approximate section modulus of designated run pipe [9, NB-3683.1(d)]

$Z_r = 37.1223\ \text{in}^3$

$T'_b := 0.25\text{in}$ — Nominal wall thickness of attached branch pipe [16]

$r'_m := \frac{d_o - T'_b}{2}$ — Mean radius of attached branch pipe [16]

$Z_b := \pi \cdot r'^{\,2}_m \cdot T'_b$ — Approximate section modulus of attached branch pipe [9, NB-3683.1(d)]

$Z_b = 37.122\ \text{in}^3$

C_{2b} Secondary stress Index [9,NB-3683.8]

$$C_{2b} := \begin{cases} 1.5 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} \left(\frac{r'_m}{R_m}\right)^{\frac{1}{2}} \left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{\frac{d_o}{2}}\right) & \text{if } 1.5 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} \left(\frac{r'_m}{R_m}\right)^{\frac{1}{2}} \left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{\frac{d_o}{2}}\right) \geq 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$C_{2b} = 13.422$

C_{2r} Secondary stress Index [9,NB-3683.8]

$t_n := T'_b$ — Wall thickness of nozzle or branch connection reinforcement associated with [9, NB-3643.4(A)-1, sketch (d)]

$$C_{2r} := \begin{cases} 1.15\cdot\left(\dfrac{r'_m}{t_n}\right)^{\frac{1}{4}} & \text{if } 1.15\cdot\left(\dfrac{r'_m}{t_n}\right)^{\frac{1}{4}} \ge 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$$C_{2r} = 2.633$$

$$B_{2b} := \begin{cases} 0.5\cdot C_{2b} & \text{if } 0.5\cdot C_{2b} \ge 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Index for branches [9, NB-3683.8]

$$B_{2b} = 6.711$$

$$B_{2r} := \begin{cases} 0.75\cdot C_{2r} & \text{if } 0.75\cdot C_{2r} \ge 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Index for branches [9, NB-3683.8]

$$B_{2r} = 1.975$$

Fabricated Tee 1-33 (Node 133)

$elR_{Tee133} := (276\ \ 283)^T$ Elements associated with pipe run

$ndR_{Tee133} := (133)^T$ Node between pipe run elements

$elB_{Tee133} := (217)^T$ Element associated with branch

$ndB_{Tee133} := (133)^T$ Node where branch intersects pipe run

$$AL_{Tee133} := Tee\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF_{SL}, elR_{Tee133}, elB_{Tee133}, ndR_{Tee133}, ndB_{Tee133}, Tee\_C_o, EL_{SL}\right)$$

$$AL_{Tee133}^{\ T} = \left(0.899\ \ 1.946\times10^5\ \ 1.938\times10^5\ \ 9.335\ \ 133\ \ 25\ \ 31\ \ 7\right)$$

FABRICATED TEE (LINE 1-32, 1-26, & 1-27)

Define pertinent tee variables

$P := 400psi$ Internal Pressure [3, pg 23]

$D_o := 36in$ Outside Diameter [7]

$T_r := 0.5625in$ Nominal wall thickness of designated run pipe [7]

$R_m := 18in$ Mean radius of designated run pipe [7]

$Z_r := \pi \cdot R_m^{\,2} \cdot T_r$ Approximate section modulus of designated run pipe [9, NB-3683.1(d)]

$Z_r = 572.5553\ in^3$

$T'_b := 0.25in$ Nominal wall thickness of attached branch pipe [7]

$r'_m := 7in$ Mean radius of attached branch pipe [9, NB-3683.1(d)]

$Z_b := \pi \cdot r'^{\,2}_m \cdot T'_b$ Approximate section modulus of attached branch pipe [9, NB-3683.1(d)]

$Z_b = 38.485\ in^3$

$B_1 := 4.678$

$B_{2r} := 26.755$

$B_{2b} := 2.0265$

Primary stress indices for unlisted component. Refer to the unlisted component analysis (Appendix F) of this report for the derivation of these values.

Fabricated Branch 1-32,1-26,1-27 (Node 120)

$elR_{Tee132} := (345\ \ 664)^T$

$ndR_{Tee132} := (120)^T$

$elB_{Tee132} := (206)^T$

$ndB_{Tee132} := (121)^T$

$AL_{Tee132} := Tee\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF_{SL}, elR_{Tee132}, elB_{Tee132}, ndR_{Tee132}, ndB_{Tee132}, Tee\_C_o, EL_{SL}\right)$

$AL_{Tee132}^{\ T} = \left(2.526\ \ 8.534\times10^5\ \ 8.255\times10^5\ \ 8.17\ \ 120\ \ 81\ \ 159\ \ 2\right)$

Writing Output Data for Tees Associated with Lines 32, 33, and 49

$Tee1 := AL_{Tee149}^{\ T}$

$Tee2 := AL_{Tee133}^{\ T}$

$Tee3 := AL_{Tee132}^{\ T}$

TeeLines32_33_49 := WRITEPRN["TeeLines32_33_49.prn" , (Tee1 Tee2 Tee3)]

FLANGES

Flange Strategy: *Search based on the nodes where flanges occur. Find the maximum moment combination for the node and apply to equation (9) of ASME III, Division I - NB - 3652 [9] Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\text{FlangeDC}\left(P, D_o, t, I, B_1, B_2, M, S\right) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

$$\text{Flange}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$$

$ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0\rangle}\right)$

$ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0\rangle}\right)$

$ind_{nd} \leftarrow \text{match}\left(nd_0, EL^{\langle 1\rangle}\right)$

for $i \in 1 .. \text{last}(nd)$ if $\text{rows}(nd) > 1$

  $ind_{nd} \leftarrow \text{stack}\left[ind_{nd}, \left(\text{match}\left(nd_i, EL^{\langle 1\rangle}\right)\right)\right]$

$(M \;\; Int_0) \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \text{last}(ind_{nd})$

    $M_{rxg} \leftarrow nf_{ind_{nfi} C_{o_{0,1}} + 2, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi} C_{o_{1,1}} + 2, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi} C_{o_{2,1}} + 2, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi} C_{o_{0,1}} + 2 + i, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi} C_{o_{1,1}} + 2 + i, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi} C_{o_{2,1}} + 2 + i, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow \text{FlangeDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$

    if $Int'_j > Int_0$

      $Int \leftarrow \text{stack}\left(Int'_j, M'_j, nf_{ind_{nfi} C_{o_{0,1}} - 1 + i, 0}, EL_{ind_{nd_j}, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M\right.$

      $Result \leftarrow M'$

Int

Conditions applicable to all flanges

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$

Defining place holding variables

$$\text{Flange\_C}_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties of Line 1-32 & 1-33

Define pertinent pipe variables

$D_o := 14in$ Outside Diameter [17]

$t := 0.25in$ Thickness [17]

$P := 400psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$ Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 255.3\ in^4$$

Define primary stress indices (Utilize girth weld characteristic associated with lap joint flanges in determining values)

$B_1 := 0.5$ B_1 for a girth weld [9, Table NB-3681(a)-1, pg 130]

$B_2 := 1$ B_2 for a girth weld [9, Table NB-3681(a)-1, pg 130]

Flange (Emergency Pump) 1-32A (Node 149)

$$nd_{FL132A} := (149)^T$$

$$AL_{EL132A} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{FL132A}, Flange\_C_o, EL_{SL}\right)$$

$$AL_{EL132A}^{\ T} = \left(0.157\quad 1.197\times10^5\quad 6.205\quad 149\quad 15\quad 1.968\times10^4\quad -1.153\times10^5\quad -2.545\times10^4\right)$$

Flange (Check Valve) 1-32B (Node 148)

$$nd_{FL132B} := (148)^T$$

$$AL_{EL132B} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{FL132B}, Flange\_C_o, EL_{SL}\right)$$

$$AL_{EL132B}^{\ T} = \left(0.129\quad 6.314\times10^4\quad 6.215\quad 148\quad 17\quad -3.803\times10^4\quad 3.926\times10^4\quad 3.161\times10^4\right)$$

Flange (Check Valve) 1-32C (Node 147)

$$nd_{FL132C} := (147)^T$$

$AL_{EL132C} := \text{Flange}\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{FL132C}, \text{Flange\_C}_o, EL_{SL}\right)$

$AL_{EL132C}^{T} = \begin{pmatrix} 0.125 & 5.46\times10^{4} & 7.91 & 147 & 55 & -4.583\times10^{4} & -9.214\times10^{3} & 2.821\times10^{4} \end{pmatrix}$

Flange (Gate Valve) 1-32D (Node 144)

$nd_{FL132D} := (144)^{T}$

$AL_{EL132D} := \text{Flange}\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{FL132D}, \text{Flange\_C}_o, EL_{SL}\right)$

$AL_{EL132D}^{T} = \begin{pmatrix} 0.12 & 4.297\times10^{4} & 9.58 & 144 & 37 & -3.429\times10^{4} & 2.56\times10^{4} & 3.855\times10^{3} \end{pmatrix}$

Flange (Gate Valve) 1-32E (Node 143)

$nd_{FL132E} := (143)^{T}$

$AL_{EL132E} := \text{Flange}\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{FL132E}, \text{Flange\_C}_o, EL_{SL}\right)$

$AL_{EL132E}^{T} = \begin{pmatrix} 0.126 & 5.634\times10^{4} & 9.16 & 143 & 29 & 5.063\times10^{4} & -2.442\times10^{4} & 3.916\times10^{3} \end{pmatrix}$

Flange (Emergency Pump) 1-33A (Node 140)

$nd_{FL133A} := (140)^{T}$

$AL_{EL133A} := \text{Flange}\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{FL133A}, \text{Flange\_C}_o, EL_{SL}\right)$

$AL_{EL133A}^{T} = \begin{pmatrix} 0.207 & 2.245\times10^{5} & 9.34 & 140 & 157 & 8.17\times10^{3} & 2.242\times10^{5} & -7.003\times10^{3} \end{pmatrix}$

Flange (Check Valve) 1-33B (Node 139)

$nd_{FL133B} := (139)^{T}$

$AL_{EL133B} := \text{Flange}\left(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{FL133B}, \text{Flange\_C}_o, EL_{SL}\right)$

$AL_{EL133B}^{T} = \begin{pmatrix} 0.197 & 2.022\times10^{5} & 9.34 & 139 & 155 & 3.092\times10^{4} & -1.997\times10^{5} & 6.991\times10^{3} \end{pmatrix}$

Flange (Check Valve) 1-33C (Node 138)

$nd_{FL133C} := (138)^{T}$

$AL_{EL133C} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{FL133C}, Flange\_C_o, EL_{SL})$

$AL_{EL133C}{}^T = (0.198 \quad 2.056\times10^5 \quad 9.325 \quad 138 \quad 53 \quad 1.411\times10^5 \quad -1.492\times10^5 \quad 9.515\times10^3)$

Flange (Gate Valve) 1-32D (Node 136)

$nd_{FL133D} := (136)^T$

$AL_{EL133D} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{FL133D}, Flange\_C_o, EL_{SL})$

$AL_{EL133D}{}^T = (0.17 \quad 1.478\times10^5 \quad 9.525 \quad 136 \quad 35 \quad -2.409\times10^4 \quad 1.424\times10^5 \quad -3.166\times10^4)$

Flange (Gate Valve) 1-32E (Node 135)

$nd_{FL133E} := (135)^T$

$AL_{EL133E} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF_{SL}, nd_{FL133E}, Flange\_C_o, EL_{SL})$

$AL_{EL133E}{}^T = (0.171 \quad 1.492\times10^5 \quad 9.335 \quad 135 \quad 9 \quad -3.456\times10^4 \quad -1.216\times10^5 \quad 7.919\times10^4)$

Writing Output Data for Flanges Associated with Lines 32, 33, and 49

$F1 := AL_{EL132A}{}^T$ $F6 := AL_{EL133A}{}^T$

$F2 := AL_{EL132B}{}^T$ $F7 := AL_{EL133B}{}^T$

$F3 := AL_{EL132C}{}^T$ $F8 := AL_{EL133C}{}^T$

$F4 := AL_{EL132D}{}^T$ $F9 := AL_{EL133D}{}^T$

$F5 := AL_{EL132E}{}^T$ $F10 := AL_{EL133E}{}^T$

FlangeLines32_33_49 := WRITEPRN["FlangeLines32_33_49.prn" , (F1 F2 F3 F4 F5 F6 F7 F8 F9 F10)]

Appendix B.4

80th Percentile Results of All 32 Realizations

LOGIC USED TO GATHER DATA FROM ALL 32 REALIZATIONS

a := "Y:\PCS2\Automated_Evaluation\Model_3\Real"

ReadData(b) := for k ∈ 1 .. 32

$d_{k-1} \leftarrow \text{READPRN}(\text{concat}(a, \text{num2str}(k), b))$

for j ∈ 0 .. $\text{length}\left(\left(d_{k-1}\right)^T\right) - 1$

$D_{k-1,j} \leftarrow \left(d_{k-1}\right)_{0,j}$

R := stack(1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32)

LOGIC USED TO SORT DATA BASED ON D/C RATIOS OF ALL 32 REALIZATIONS

C_S(v,R) := for i ∈ 0 .. cols(v) − 1

for k ∈ 0 .. $\text{rows}\left(v_{0,i}\right) - 1$

for j ∈ 0 .. rows(v) − 1

$a_{0,j} \leftarrow \left[\left(\left(v_{j,i}\right)^T\right)^{\langle k\rangle}\right]^T$

$A \leftarrow a_{0,j}$ if j = 0

$A \leftarrow \text{stack}\left(A, a_{0,j}\right)$ if j > 0

$b_{k,i} \leftarrow \text{stack}\left(A^T, R^T\right)^T$

$\text{Sorted}_{k,i} \leftarrow \text{reverse}\left(\text{csort}\left(b_{k,i}, 0\right)\right)$

Sorted

LOGIC USED TO JOIN RESULTS FROM EITHER END OF REDUCERS AND ELBOWS INTO ONE MATRIX

$\text{RED\_EL}_{80th}(RE) :=$ $k \leftarrow 0$

for i ∈ 0 .. $\dfrac{\text{cols}(RE) - 1}{2}$

$j \leftarrow 2 \cdot i$

$RE80TH_{i,k} \leftarrow \text{stack}\left(\left(\left(RE_{0,j}\right)^T\right)^{\langle 6\rangle T}, \left(\left(RE_{0,j+1}\right)^T\right)^{\langle 6\rangle T}\right)$

LOGIC USED TO CONCATENATE 80TH PERCENTILE RESULTS OF PIPE RUNS INTO ONE MATRIX

$PR_{80th}(PM) :=$ for $i \in 0 .. \text{cols}(PM) - 1$

- $k_i \leftarrow 0$
- for $j \in 0 .. \text{rows}\left(PM^{\langle i \rangle}\right) - 1$
  - $k_i \leftarrow k_i + 1$ if $PM_{j,i} \neq 0$
- for $m \in 0 .. k_i - 1$
  - $PM80th_{m,i} \leftarrow \left(PM_{m,i}{}^{T}\right)^{\langle 6 \rangle T}$
- $pm80th_{0,i} \leftarrow PM80th_{0,i}$
- for $n \in 1 .. k_i - 1$
  - $pm80th_{0,i} \leftarrow \text{stack}\left(pm80th_{0,i}, PM80th_{n,i}\right)$

LOGIC USED TO DETERMINE 80TH PERCENTILE RESULTS OF SUPPORTS & TEES

$T_{80th}(T) :=$ for $i \in 0 .. \text{cols}(T) - 1$

- $T80th_{0,i} \leftarrow \left(T_{0,i}{}^{T}\right)^{\langle 6 \rangle T}$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

SUPPORTS

Support output is ordered as (D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being collinear (AL1) and apposing (AL2) the positive directionality of the global coordinate system, and realization number)

EVALUATION OF SUPPORTS ON LINES 22 TO 26 FOR ALL 32 REALIZATIONS

$VSM := ReadData(\text{"\textbackslash SupLines22to26.prn"})$

$SM := C\_S(VSM, R)$

MS-5 Support (1x)

MS-5 (Node 432)

MS-7 horizontally (N/S) supports the horizontal (E/W) PCS pipe on line 1-26.

Compression $\left(SM_{0,0}{}^{T}\right)^{\langle 6 \rangle T} = \left(3.602 \times 10^{-3} \quad -21.61 \quad 8.57 \quad 432 \quad 140 \quad 19\right)$

Tension $\left(SM_{0,1}{}^{T}\right)^{\langle 6 \rangle T} = \left(3.244 \times 10^{-3} \quad 19.46 \quad 8.795 \quad 432 \quad 140 \quad 25\right)$

MS-7 Support (1x)

MS-7 (Node 438)

MS-7 horizontally (N/S) supports the horizontal (E/W) PCS pipe on line 1-25.

Compression $\left(SM_{0,2}{}^{T}\right)^{\langle 6 \rangle T} = \left(4.497 \times 10^{-3} \quad -26.98 \quad 7.365 \quad 438 \quad 142 \quad 16\right)$

Tension $\left(SM_{0,3}{}^{T}\right)^{\langle 6 \rangle T} = \left(3.864 \times 10^{-3} \quad 23.19 \quad 7.625 \quad 438 \quad 142 \quad 9\right)$

MS-8 Support (1x)

MS-8 (Node 435)

MS-8 horizontally (N/S) supports the horizontal (E/W) PCS pipe on line 1-22.

Compression $\left(SM_{0,4}{}^{T}\right)^{\langle 6 \rangle T} = \left(4.631 \times 10^{-3} \quad -27.78 \quad 8.57 \quad 435 \quad 138 \quad 11\right)$

Tension $\left(SM_{0,5}{}^{T}\right)^{\langle 6 \rangle T} = \left(3.831 \times 10^{-3} \quad 22.99 \quad 8.775 \quad 435 \quad 138 \quad 29\right)$

EVALUATION OF SUPPORTS ON LINES 27 TO 29 FOR ALL 32 REALIZATIONS

VSL := ReadData("\SupLines27to29.prn")

SL := C_S(VSL, R)

PS-3A Support (1x)

PS-3A (Node 81)

PS-3A vertically resists downward displacement of the horizontal (E/W) PCS pipe on line 1-27 prior to the fabricated elbow with line 1-32 protrusion

Compression $\left(SL_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(0.323 \quad -5.001\times 10^{4} \quad 4.975 \quad 81 \quad 75 \quad 8\right)$

Tension $\left(SL_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

RH-23x Support (1x)

RH-23x (Node 394)

RH-23x vertically supports the vertical PCS pipe on line 1-27 traveling up from the reactor vessel area and into the tunnel

Tension $\left(SL_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \left(0.993 \quad -4.113\times 10^{4} \quad 8.74 \quad 394 \quad 139 \quad 28\right)$

This challenged support will be evaluated using a ductility factor approach. The supporting calculations for this treatment are included in Appendix E.7 for all supports for which this approach is applicable. Below function writes this information to the Appendix E.7 file.

Duc_{RH23x} := WRITEPRN("Y:\PCS2\PCS Documentation\App_E\E7 DUCTILITY CALCS\RH23x.prn", $\left(SL_{0,2}{}^{T}\right)^{\langle 6\rangle T}$)

Compression $\left(SL_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

RH-25ABx Support (2x)

RH-25ABx (Node 536)

RH-25Ax vertically supports the horizontal (N/S) PCS pipe on line 1-27 just north of RH-23x in the tunnel

Tension $\left(SL_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \left(0.57 \quad -3.21\times 10^{4} \quad 5.82 \quad 536 \quad 138 \quad 25\right)$

Uplift $\left(SL_{0,5}{}^{T}\right)^{\langle 6\rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

RH-25ABx (Node 537)

RH-25Bx vertically supports the horizontal (N/S) PCS pipe on line 1-27 just north of RH-25Ax in the tunnel

Tension $\left(SL_{0,6}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.453 & -2.547\times 10^{4} & 4.605 & 537 & 136 & 11 \end{pmatrix}$

Uplift $\left(SL_{0,7}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 27 \end{pmatrix}$

RH-26x Support (1x)

RH-26x (Node 538)

RH-26x vertically supports the horizontal (N/S) PCS pipe on line 1-27 just north of RH-25Bx in the tunnel, RH-26x also supports line 8-14 using one of its component legs.

Tension $\left(SL_{0,8}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.344 & -1.937\times 10^{4} & 4.6 & 538 & 134 & 27 \end{pmatrix}$

This support will be evaluated in combination with RH-21x supporting line 1-7 and 8-14 which utilizes one of RH-26x legs to support its load. The supporting calculations for this treatment are included in Appendix E.8 for all supports for which this approach is applicable. Below function writes this information to the Appendix E.8 file.

$SRSS_{RH26x127} := WRITEPRN\Big($"Y:\PCS2\PCS Documentation\App_E\E8 Common Anchorage Combinations\RH-26x127.p

Uplift $\left(SL_{0,9}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 27 \end{pmatrix}$

RH-27x Support (1x)

RH-27x (Node 539)

RH-27x vertically supports the horizontal (N/S) PCS pipe on line 1-27 just north of RH-26x in the tunnel.

Tension $\left(SL_{0,10}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.786 & -2.186\times 10^{4} & 5.565 & 539 & 142 & 1 \end{pmatrix}$

This support will be evaluated in combination with RH-22x supporting line 1-7. The supporting calculations for this treatment are included in Appendix E.8 for all supports for which this approach is applicable. Below function writes this information to the Appendix E.8 file.

$SRSS_{RH27x} := WRITEPRN\Big($"Y:\PCS2\PCS Documentation\App_E\E8 Common Anchorage Combinations\RH-27x.prn" ,(S

Compression $\left(SL_{0,11}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 27 \end{pmatrix}$

PR-1 Supports (1x East Side of Reactor Vessel)

PR-1 (Node 400)

PR-1 horizontally (E/W) supports the vertical PCS pipe on line 1-27 on the east side of the reactor vessel.

Tension $\left(\left(SL_{0,12}\right)^{T}\right)^{\langle 6\rangle T} = \left(2.049 \quad -6.532\times 10^{3} \quad 8.755 \quad 400 \quad 114 \quad 10\right)$

This challenged support will be evaluated in a breakout analysis in Appendix E.4 where its loading will be applied simultaneously with that of the appropriate PR-2 support for which it shares a common anchorage structure. The below function writes this information to the Appendix E.4 file.

PR1_E_T := WRITEPRN("Y:\PCS2\Automated_Evaluation\PR-1&2_Combo_Evaluation\PR1_E_Tension.prn" , $SL_{0,12}$)

PR1_E_C := WRITEPRN("Y:\PCS2\Automated_Evaluation\PR-1&2_Combo_Evaluation\PR1_E_Compression.prn" , $SL_{0,13}$

Compression $\left(\left(SL_{0,13}\right)^{T}\right)^{\langle 6\rangle T} = \left(0.45 \quad 6.264\times 10^{3} \quad 12.52 \quad 400 \quad 114 \quad 24\right)$

PR-1 Supports (1x West Side of Reactor Vessel)

PR-1 (Node 404)

PR-1 horizontally (E/W) supports the vertical PCS pipe on line 1-29 on the west side of the reactor vessel.

Compression $\left(\left(SL_{0,14}\right)^{T}\right)^{\langle 6\rangle T} = \left(0.353 \quad -4.913\times 10^{3} \quad 4.885 \quad 404 \quad 116 \quad 1\right)$

Tension $\left(\left(SL_{0,15}\right)^{T}\right)^{\langle 6\rangle T} = \left(1.569 \quad 5.001\times 10^{3} \quad 4.72 \quad 404 \quad 116 \quad 21\right)$

This challenged support will be evaluated in a breakout analysis in Appendix E.4 where its loading will be applied simultaneously with that of the appropriate PR-2 support for which it shares a common anchorage structure. The below function writes this information to the Appendix E.4 file.

PR1_W_C := WRITEPRN("Y:\PCS2\Automated_Evaluation\PR-1&2_Combo_Evaluation\PR1_W_Compression.prn" , $SL_{0,}$

PR1_W_T := WRITEPRN("Y:\PCS2\Automated_Evaluation\PR-1&2_Combo_Evaluation\PR1_W_Tension.prn" , $SL_{0,15}$)

PR-8 Supports (1x)

PR-8 (Node 59)

PR-1 vertically supports the vertical PCS pipe on line 1-27 below the tee connecting lines 1-27 to 1-28 and 1-29.

Compression $\left(\left(SL_{0,16}\right)^{T}\right)^{\langle 6\rangle T} = \left(1.363\times 10^{-3} \quad -3.236 \quad 8.735 \quad 59 \quad 127 \quad 5\right)$

Tension $\left(\left(SL_{0,17}\right)^{T}\right)^{\langle 6\rangle T} = \left(2.441\times 10^{-5} \quad 0.819 \quad 8.67 \quad 59 \quad 127 \quad 1\right)$

MS-2 Support (1x)

MS-2 (Node 429)

MS-2 horizontally (E/W) supports the horizontal (N/S) PCS pipe on line 1-27 just north of the tunnel.

Tension $\left(SL_{0,18}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0.844 & -2.888 \times 10^{4} & 5.795 & 429 & 122 & 1 \end{pmatrix}$

Compression $\left(SL_{0,19}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0.701 & 3.507 \times 10^{4} & 9.1 & 429 & 122 & 8 \end{pmatrix}$

Tunnel Restraint Support (1x)

Tunnel Restraint (Node 485)

Tunnel Restraint horizontally (E/W) restrains the vertical PCS pipe on line 1-27

Eastward Compression $\left(SL_{0,20}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0.19 & -1.17 \times 10^{4} & 7.85 & 485 & 126 & 21 \end{pmatrix}$

Westward Compression $\left(SL_{0,21}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0.142 & 1.217 \times 10^{4} & 13.1 & 485 & 126 & 2 \end{pmatrix}$

Tieback Support (1x)

Tieback East/West (Node 102)

The floor Tieback vertically and horizontally supports the horizontal (N/S) PCS pipe on line 1-27 south of MS-2

Eastward Compression $\left(SL_{0,22}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0.368 & -2.484 \times 10^{4} & 8.325 & 102 & 78 & 83 & 123 & 2 \end{pmatrix}$

Westward Compression $\left(SL_{0,23}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0.349 & 2.353 \times 10^{4} & 8.09 & 102 & 78 & 83 & 123 & 2 \end{pmatrix}$

Tieback North/South (Node 102)

The floor Tieback vertically and horizontally supports the horizontal (N/S) PCS pipe on line 1-27 south of MS-2

Northward Compression $\left(SL_{0,24}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0.333 & -3.367 \times 10^{4} & 6.96 & 102 & 78 & 83 & 123 & 4 \end{pmatrix}$

Southward Compression $\left(SL_{0,25}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0.33 & 3.337 \times 10^{4} & 5.475 & 102 & 78 & 83 & 123 & 10 \end{pmatrix}$

Tieback Vertical (Node 463)

The floor Tieback vertically and horizontally supports the horizontal (N/S) PCS pipe on line 1-27 south of MS-2

Compression $\left(SL_{0,26}{}^{T}\right)^{\langle 6\rangle T} = (0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27)$

Tension $\left(SL_{0,27}{}^{T}\right)^{\langle 6\rangle T} = (0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27)$

EVALUATION OF SUPPORTS ON LINES 32, 33, AND 49 FOR ALL 32 REALIZATIONS

$VSS := ReadData(\text{"\\SupLines32\_33\_49.prn"})$

$SS := C\_S(VSS, R)$

PS-5 Supports (4x)

PS-5 (Node 371)

PS-5 vertically supports the horizontal (E/W) PCS pipe entering emergency pump on line 1-33 on east side of check valve

Compression $\left(SS_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(0.031\ \ -2.685\times 10^{3}\ \ 6.245\ \ 371\ \ 123\ \ 13\right)$

Tension $\left(SS_{0,1}{}^{T}\right)^{\langle 6\rangle T} = (0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27)$

PS-5 (Node 372)

PS-5 vertically supports the horizontal (E/W) PCS pipe entering emergency pump on line 1-33 on west side of check valve

Compression $\left(SS_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \left(0.061\ \ -5.32\times 10^{3}\ \ 3.95\ \ 372\ \ 129\ \ 10\right)$

Tension $\left(SS_{0,3}{}^{T}\right)^{\langle 6\rangle T} = (0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27)$

PS-5 (Node 373)

PS-5 vertically supports the horizontal (E/W) PCS pipe entering emergency pump on line 1-32 on east side of check valve

Compression $\left(SS_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \left(0.025\ \ -2.189\times 10^{3}\ \ 12.52\ \ 373\ \ 127\ \ 10\right)$

Tension $\left(SS_{0,5}{}^{T}\right)^{\langle 6\rangle T} = (0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27)$

PS-5 (Node 374)

PS-5 vertically supports the horizontal (E/W) PCS pipe entering emergency pump on line 1-32 on west side of check valve

Compression $\left(SS_{0,6}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.106 \quad -9.322 \times 10^{3} \quad 8.42 \quad 374 \quad 125 \quad 20\right)$

Tension $\left(SS_{0,7}{}^{T}\right)^{\langle 6 \rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

PS-21 Supports (1 x Axial (NS), 1 x Lateral (EW), 1 x Vertical)

PS-21 Axial (NS) (Node 535)

PR-21 horizontally (N/S), laterally (E/W), and vertically supports the horizontal(E/W) PCS pipe on line 1-32 on the north side of the emergency pump room.

Compression $\left(SS_{0,8}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.058 \quad -2.011 \times 10^{3} \quad 8.215 \quad 535 \quad 144 \quad 4\right)$

Tension $\left(SS_{0,9}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.065 \quad 2.629 \times 10^{3} \quad 7.93 \quad 535 \quad 144 \quad 14\right)$

PS-21 Lateral (EW) (Node 535)

PR-21 horizontally (N/S), laterally (E/W), and vertically supports the horizontal(E/W) PCS pipe on line 1-32 on the north side of the emergency pump room.

Flexure $\left(SS_{0,10}{}^{T}\right)^{\langle 6 \rangle T} = \left(3.876 \times 10^{-3} \quad -2.965 \quad 9.53 \quad 535 \quad 144 \quad 25\right)$

Flexure $\left(SS_{0,11}{}^{T}\right)^{\langle 6 \rangle T} = \left(3.153 \times 10^{-3} \quad 2.412 \quad 9.29 \quad 535 \quad 144 \quad 28\right)$

PS-21 Vertical (Node 535)

PR-21 horizontally (N/S), laterally (E/W), and vertically supports the horizontal(E/W) PCS pipe on line 1-32 on the north side of the emergency pump room.

Flexure $\left(SS_{0,12}{}^{T}\right)^{\langle 6 \rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

Flexure $\left(SS_{0,13}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.014 \quad 11.09 \quad 4.13 \quad 535 \quad 144 \quad 16\right)$

RH-15A Support (1x)

RH-15A (Node 365)

RH-15A vertically supports the horizontal (E/W) PCS pipe on line 1-32 in conjunction with the horizontal support of PS-21

Tension $\left(SS_{0,14}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.179 \quad -3.878\times 10^{3} \quad 4.135 \quad 365 \quad 153 \quad 17\right)$

Compression $\left(SS_{0,15}{}^{T}\right)^{\langle 6 \rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

RH-15 Supports (2x)

RH-15 (Node 366)

RH-15 vertically supports the horizontal (E/W) PCS pipe on line 1-32 just west of RH-15A

Tension $\left(SS_{0,16}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.142 \quad -2.113\times 10^{3} \quad 4.64 \quad 366 \quad 151 \quad 3\right)$

Compression $\left(SS_{0,17}{}^{T}\right)^{\langle 6 \rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

RH-15 (Node 367)

RH-15 vertically supports the horizontal (E/W) PCS pipe on line 1-32 west of both RH-15A and the other RH-15 support and just prior to line 1-32 penetrating the concrete wall and entering the emergency pump room.

Tension $\left(SS_{0,18}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.244 \quad -3.633\times 10^{3} \quad 5.025 \quad 367 \quad 149 \quad 15\right)$

Compression $\left(SS_{0,19}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.014 \quad 202.1 \quad 4.3 \quad 367 \quad 149 \quad 28\right)$

PR-11 Supports (1 x Vertical, 1 x Horizontal (North/South)

PR-11 Vertical (Node 377)

PR-11 vertically and horizontally (N/S) supports the horizontal(E/W) PCS pipe on line 1-32 west of the fabricated elbow from line 1-27.

Flexure $\left(SS_{0,20}{}^{T}\right)^{\langle 6 \rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

Flexure $\left(SS_{0,21}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.11 \quad 15.22 \quad 5.455 \quad 377 \quad 122 \quad 11\right)$

PR-11 Horizontal (Node 377)

PR-11 vertically and horizontally (N/S) supports the horizontal(E/W) PCS pipe on line 1-32 west of the fabricated elbow from line 1-27.

Compression $$\left(SS_{0,22}{}^{T}\right)^{\langle 6\rangle T} = \left(2.029 \times 10^{-4} \quad -10.42 \quad 7.94 \quad 377 \quad 122 \quad 27\right)$$

Tension $$\left(SS_{0,23}{}^{T}\right)^{\langle 6\rangle T} = \left(1.332 \times 10^{-3} \quad 10.47 \quad 8.175 \quad 377 \quad 122 \quad 28\right)$$

RH-24 Supports (2x)

RH-24 (Node 368)

RH-24 vertically supports the horizontal (N/S) PCS pipe on line 1-49

Tension $$\left(SS_{0,24}{}^{T}\right)^{\langle 6\rangle T} = (0.05 \quad -353 \quad 7.645 \quad 368 \quad 148 \quad 13)$$

Compression $$\left(SS_{0,25}{}^{T}\right)^{\langle 6\rangle T} = (0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27)$$

RH-24 (Node 370)

RH-24 vertically supports the horizontal (N/S) PCS pipe on line 1-49

Tension $$\left(SS_{0,26}{}^{T}\right)^{\langle 6\rangle T} = (0.07 \quad -496.6 \quad 8.145 \quad 370 \quad 146 \quad 12)$$

Compression $$\left(SS_{0,27}{}^{T}\right)^{\langle 6\rangle T} = (0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27)$$

TERMINATIONS

Termination output is ordered as (max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, Index of element(s), moments about the x, y, and z axes, and realization number)

EVALUATION OF TERMINATIONS ON LINES 22 TO 26 FOR ALL 32 REALIZATIONS

VTM := ReadData("\TermLines22to26.prn")

TM := C_S(VTM,R)

Primary Coolant Pumps (4x)

Primary Pump 1-25 (Node 207)

$$\left(TM_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.344 & 9.902\times 10^{5} & 7.37 & 207 & 76 & 2.715\times 10^{5} & 1.293\times 10^{5} & 9.434\times 10^{5} & 24 \end{pmatrix}$$

Primary Pump 1-24 (Node 184)

$$\left(TM_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.297 & 7.988\times 10^{5} & 7.615 & 184 & 74 & -4.998\times 10^{4} & -9.157\times 10^{4} & -7.92\times 10^{5} & 11 \end{pmatrix}$$

Primary Pump 1-23 (Node 183)

$$\left(TM_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.257 & 6.326\times 10^{5} & 10.19 & 183 & 72 & 2.27\times 10^{5} & 5.973\times 10^{4} & 5.874\times 10^{5} & 28 \end{pmatrix}$$

Primary Pump 1-22 (Node 196)

$$\left(TM_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.27 & 6.859\times 10^{5} & 8.565 & 196 & 70 & -3.016\times 10^{4} & 2.181\times 10^{5} & 6.496\times 10^{5} & 28 \end{pmatrix}$$

EVALUATION OF TERMINATIONS ON LINES 27 TO 29 FOR ALL 32 REALIZATIONS

VTL := ReadData("\TermLines27to29.prn")

TL := C_S(VTL,R)

Reactor Vessel Terminations (2x)

Reactor Vessel 1-28 (Node 25)

$$\left(TL_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.265 & 9.785\times 10^{5} & 8.595 & 25 & 21 & 7.904\times 10^{5} & 3.052\times 10^{5} & 4.895\times 10^{5} & 26 \end{pmatrix}$$

Reactor Vessel 1-29 (Node 1)

$$\left(TL_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.254 & 9.054\times 10^{5} & 8.56 & 1 & 1 & -6.039\times 10^{5} & -3.211\times 10^{5} & 5.933\times 10^{5} & 21 \end{pmatrix}$$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

EVALUATION OF TERMINATIONS ON LINES 32, 33, AND 49 FOR ALL 32 REALIZATIONS

$VTS := \text{ReadData}(\text{"\textbackslash TermLines32\_33\_49.prn"})$

$TS := C\_S(VTS, R)$

North Wall Termination (1x)

North Wall Penetration 1-49 (Node 266)

$$\left(TS_{0,0}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0.106 & 1.314 \times 10^{4} & 9.37 & 266 & 214 & -1.214 \times 10^{3} & -1.307 \times 10^{4} & 709.4 & 25 \end{pmatrix}$$

Emergency Pumps (2x)

Emergency Pump 1-32 (Node 149)

$$\left(TS_{0,1}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0.167 & 1.313 \times 10^{5} & 6.2 & 149 & 15 & 2.134 \times 10^{4} & -1.274 \times 10^{5} & -2.366 \times 10^{4} & 15 \end{pmatrix}$$

Emergency Pump 1-33 (Node 140)

$$\left(TS_{0,2}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0.234 & 2.447 \times 10^{5} & 9.355 & 140 & 157 & 6.816 \times 10^{3} & 2.446 \times 10^{5} & -1.079 \times 10^{3} & 26 \end{pmatrix}$$

PIPE RUNS

Pipe Run output is ordered as (max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, indices of element(s), and realization number)

EVALUATION OF PIPE RUNS ON LINES 22 TO 26 FOR ALL 32 REALIZATIONS

$VPM := \text{ReadData}(\text{"\textbackslash PRLines22to26.prn"})$

$PM := C\_S(VPM, R)$

$PM_{80TH} := PR_{80th}(PM)$

Pipe Properties for Line 1-26

Pipe Run 1-26A (Element 136)

$$PM_{80TH_{0,0}} = \begin{pmatrix} 0.151 & 1.074 \times 10^{6} & 10.19 & 136 & 79 & 1 & 28 \\ 0.152 & 1.102 \times 10^{6} & 10.19 & 136 & 215 & 2 & 25 \end{pmatrix}$$

Pipe Run 1-26B (Elements 353)

$$PM_{80TH_{0,1}} = \begin{pmatrix} 0.161 & 1.348 \times 10^{6} & 7.895 & 353 & 216 & 117 & 27 \\ 0.144 & 8.828 \times 10^{5} & 7.895 & 353 & 279 & 118 & 12 \end{pmatrix}$$

Pipe Run 1-26C (Elements 306 & 350)

$$PM80TH_{0,2} = \begin{pmatrix} 0.16 & 1.329\times10^{6} & 7.21 & 306 & 217 & 81 & 26 \\ 0.156 & 1.225\times10^{6} & 7.115 & 306 & 264 & 82 & 3 \\ 0.156 & 1.224\times10^{6} & 7.115 & 350 & 264 & 113 & 3 \\ 0.148 & 9.931\times10^{5} & 7.2 & 350 & 276 & 114 & 9 \end{pmatrix}$$

Pipe Properties for Lines 1-25, 1-24, 1-23, and 1-22

Pipe Run 1-25A (Element 205)

$$PM80TH_{0,3} = \begin{pmatrix} 0.252 & 9.699\times10^{5} & 7.36 & 205 & 206 & 75 & 22 \\ 0.255 & 9.902\times10^{5} & 7.37 & 205 & 207 & 76 & 24 \end{pmatrix}$$

Pipe Run 1-25B (Elements 699, 698, & 374)

$$PM80TH_{0,4} = \begin{pmatrix} 0.216 & 7.487\times10^{5} & 7.355 & 699 & 204 & 173 & 28 \\ 0.168 & 4.557\times10^{5} & 7.355 & 699 & 580 & 174 & 27 \\ 0.143 & 3.012\times10^{5} & 7.36 & 698 & 579 & 171 & 28 \\ 0.168 & 4.556\times10^{5} & 7.355 & 698 & 580 & 172 & 28 \\ 0.167 & 4.455\times10^{5} & 7.365 & 374 & 202 & 127 & 28 \\ 0.143 & 3.013\times10^{5} & 7.36 & 374 & 579 & 128 & 28 \end{pmatrix}$$

Pipe Run 1-25C (Elements 192 & 187)

$$PM80TH_{0,5} = \begin{pmatrix} 0.186 & 5.662\times10^{5} & 7.355 & 192 & 199 & 67 & 28 \\ 0.189 & 5.821\times10^{5} & 7.355 & 192 & 201 & 68 & 27 \\ 0.153 & 3.629\times10^{5} & 7.305 & 187 & 198 & 57 & 23 \\ 0.143 & 3.03\times10^{5} & 4.325 & 187 & 212 & 58 & 12 \end{pmatrix}$$

Pipe Run 1-25D (Elements 703, 382, 702, & 303)

$$PM80TH_{0,6} = \begin{pmatrix} 0.149 & 3.382 \times 10^5 & 7.09 & 703 & 211 & 181 & 28 \\ 0.153 & 3.641 \times 10^5 & 7.07 & 703 & 584 & 182 & 27 \\ 0.158 & 3.944 \times 10^5 & 7.065 & 382 & 265 & 131 & 10 \\ 0.153 & 3.642 \times 10^5 & 7.07 & 382 & 584 & 132 & 27 \\ 0.158 & 3.945 \times 10^5 & 7.065 & 702 & 265 & 179 & 10 \\ 0.173 & 4.877 \times 10^5 & 7.9 & 702 & 583 & 180 & 10 \\ 0.189 & 5.849 \times 10^5 & 7.905 & 303 & 162 & 79 & 10 \\ 0.173 & 4.877 \times 10^5 & 7.9 & 303 & 583 & 80 & 10 \end{pmatrix}$$

Pipe Run 1-24A (Element 203)

$$PM80TH_{0,7} = \begin{pmatrix} 0.223 & 7.931 \times 10^5 & 7.615 & 203 & 182 & 73 & 11 \\ 0.224 & 7.988 \times 10^5 & 7.615 & 203 & 184 & 74 & 11 \end{pmatrix}$$

Pipe Run 1-24B (Elements 679, 696, & 369)

$$PM80TH_{0,8} = \begin{pmatrix} 0.198 & 6.391 \times 10^5 & 7.605 & 697 & 214 & 169 & 22 \\ 0.161 & 4.104 \times 10^5 & 7.6 & 697 & 578 & 170 & 22 \\ 0.142 & 2.961 \times 10^5 & 7.605 & 696 & 577 & 167 & 28 \\ 0.161 & 4.104 \times 10^5 & 7.6 & 696 & 578 & 168 & 22 \\ 0.16 & 4.026 \times 10^5 & 7.625 & 369 & 176 & 125 & 11 \\ 0.142 & 2.961 \times 10^5 & 7.605 & 369 & 577 & 126 & 28 \end{pmatrix}$$

Pipe Run 1-24C (Element 181 and 666)

$$PM80TH_{0,9} = \begin{pmatrix} 0.172 & 4.789 \times 10^5 & 10.21 & 181 & 169 & 55 & 19 \\ 0.17 & 4.655 \times 10^5 & 7.33 & 181 & 175 & 56 & 25 \\ 0.189 & 5.808 \times 10^5 & 7.26 & 666 & 167 & 157 & 4 \\ 0.158 & 3.948 \times 10^5 & 7.085 & 666 & 547 & 158 & 27 \end{pmatrix}$$

Pipe Run 1-23A (Element 201)

$$PM80TH_{0,10} = \begin{pmatrix} 0.195 & 6.173 \times 10^{5} & 10.19 & 201 & 181 & 71 & 3 \\ 0.197 & 6.326 \times 10^{5} & 10.19 & 201 & 183 & 72 & 28 \end{pmatrix}$$

Pipe Run 1-23B (Elements 695, 694, & 364)

$$PM80TH_{0,11} = \begin{pmatrix} 0.171 & 4.698 \times 10^{5} & 10.19 & 695 & 213 & 165 & 27 \\ 0.142 & 2.918 \times 10^{5} & 7.59 & 695 & 576 & 166 & 27 \\ 0.133 & 2.404 \times 10^{5} & 7.6 & 694 & 575 & 163 & 25 \\ 0.142 & 2.918 \times 10^{5} & 7.59 & 694 & 576 & 164 & 27 \\ 0.151 & 3.472 \times 10^{5} & 7.08 & 364 & 174 & 123 & 24 \\ 0.133 & 2.404 \times 10^{5} & 7.6 & 364 & 575 & 124 & 25 \end{pmatrix}$$

Pipe Run 1-23C (Element 171 & 665)

$$PM80TH_{0,12} = \begin{pmatrix} 0.163 & 4.24 \times 10^{5} & 8.565 & 171 & 168 & 45 & 27 \\ 0.163 & 4.206 \times 10^{5} & 8.565 & 171 & 218 & 46 & 19 \\ 0.165 & 4.334 \times 10^{5} & 5.54 & 665 & 166 & 155 & 25 \\ 0.162 & 4.163 \times 10^{5} & 7.085 & 665 & 546 & 156 & 10 \end{pmatrix}$$

Pipe Run 1-22A (Element 199)

$$PM80TH_{0,13} = \begin{pmatrix} 0.204 & 6.723 \times 10^{5} & 8.565 & 199 & 194 & 69 & 28 \\ 0.206 & 6.859 \times 10^{5} & 8.565 & 199 & 196 & 70 & 28 \end{pmatrix}$$

Pipe Run 1-22B (Elements 693, 692, & 359)

$$PM80TH_{0,14} = \begin{pmatrix} 0.175 & 4.967\times10^{5} & 8.565 & 693 & 192 & 161 & 19 \\ 0.136 & 2.586\times10^{5} & 8.555 & 693 & 574 & 162 & 19 \\ 0.119 & 1.525\times10^{5} & 6.77 & 692 & 573 & 159 & 21 \\ 0.136 & 2.585\times10^{5} & 8.555 & 692 & 574 & 160 & 19 \\ 0.144 & 3.082\times10^{5} & 7.255 & 359 & 190 & 121 & 25 \\ 0.119 & 1.525\times10^{5} & 6.77 & 359 & 573 & 122 & 21 \end{pmatrix}$$

Pipe Run 1-22C (Elements 161 & 156)

$$PM80TH_{0,15} = \begin{pmatrix} 0.16 & 4.04\times10^{5} & 7.235 & 161 & 187 & 35 & 19 \\ 0.161 & 4.1\times10^{5} & 7.24 & 161 & 189 & 36 & 25 \\ 0.153 & 3.598\times10^{5} & 6.775 & 156 & 186 & 25 & 25 \\ 0.139 & 2.758\times10^{5} & 6.77 & 156 & 209 & 26 & 25 \end{pmatrix}$$

Pipe Run 1-22D (Elements 301, 700, 378, & 701)

$$PM80TH_{0,16} = \begin{pmatrix} 0.137 & 2.629\times10^{5} & 10.92 & 301 & 210 & 77 & 12 \\ 0.153 & 3.597\times10^{5} & 8.62 & 301 & 581 & 78 & 6 \\ 0.172 & 4.787\times10^{5} & 7.215 & 700 & 263 & 175 & 28 \\ 0.153 & 3.597\times10^{5} & 8.62 & 700 & 581 & 176 & 6 \\ 0.172 & 4.794\times10^{5} & 7.215 & 378 & 263 & 129 & 28 \\ 0.186 & 5.624\times10^{5} & 7.2 & 378 & 582 & 130 & 14 \\ 0.199 & 6.462\times10^{5} & 7.2 & 701 & 165 & 177 & 14 \\ 0.186 & 5.624\times10^{5} & 7.2 & 701 & 582 & 178 & 14 \end{pmatrix}$$

EVALUATION OF PIPE RUNS ON LINES 27 TO 29 FOR ALL 32 REALIZATIONS

VPL := ReadData("\PRLines27to29.prn")

PL := C_S(VPL, R)

$PL_{80TH} := PR_{80th}(PL)$

Pipe Properties for Line 1-28 and 1-29

Pipe Run 1-28A (Elements 27)

$$PL_{80TH_{0,0}} = \begin{pmatrix} 0.266 & 9.785 \times 10^5 & 8.595 & 27 & 25 & 21 & 26 \\ 0.219 & 6.548 \times 10^5 & 11.96 & 27 & 26 & 22 & 17 \end{pmatrix}$$

Pipe Run 1-28B (Elements 31, 36, 670, 671, & 53)

$PL_{80TH_{0,1}} =$

	0	1	2	3	4	5	6
0	0.198	$5.011 \cdot 10^5$	11.57	31	29	23	28
1	0.171	$3.152 \cdot 10^5$	11.57	31	40	24	25
2	0.171	$3.145 \cdot 10^5$	11.77	36	40	25	19
3	0.157	$2.189 \cdot 10^5$	8.57	36	551	26	19
4	0.157	$2.188 \cdot 10^5$	8.57	670	551	147	19
5	0.17	$3.074 \cdot 10^5$	8.575	670	552	148	20
6	0.192	$4.604 \cdot 10^5$	8.575	671	49	149	28
7	0.17	$3.073 \cdot 10^5$	8.575	671	552	150	20
8	0.193	$4.711 \cdot 10^5$	8.575	53	32	41	28
9	0.192	$4.606 \cdot 10^5$	8.575	53	49	42	28

Pipe Run 1-28C (Elements 38, 608, 41, 46, 675, 676, & 677)

$PL_{80TH_{0,2}} =$

	0	1	2	3	4	5	6
0	0.184	$4.039 \cdot 10^5$	11.36	38	33	27	9
1	0.184	$4.03 \cdot 10^5$	11.36	38	503	28	9
2	0.197	$4.984 \cdot 10^5$	5.27	608	34	131	7
3	0.184	$4.031 \cdot 10^5$	11.36	608	503	132	9
4	0.206	$5.608 \cdot 10^5$	8.58	41	36	33	23
5	0.21	$5.885 \cdot 10^5$	8.655	41	43	34	25
6	0.21	$5.885 \cdot 10^5$	8.655	46	43	35	25
7	0.226	$7.027 \cdot 10^5$	8.58	46	556	36	28
8	0.226	$7.03 \cdot 10^5$	8.58	675	556	157	28
9	0.24	$7.958 \cdot 10^5$	8.575	675	557	158	16
10	0.24	$7.958 \cdot 10^5$	8.575	676	557	159	16
11	0.234	$7.6 \cdot 10^5$	8.58	676	558	160	27
12	0.213	$6.092 \cdot 10^5$	8.57	677	37	161	16
13	0.234	$7.599 \cdot 10^5$	8.58	677	558	162	27

Pipe Run 1-28D (Elements 48 & 49)

$$PL80TH_{0,3} = \begin{pmatrix} 0.197 & 7.552\times 10^{5} & 11.98 & 48 & 38 & 37 & 11 \\ 0.209 & 8.578\times 10^{5} & 11.58 & 48 & 48 & 38 & 11 \\ 0.242 & 1.132\times 10^{6} & 11.58 & 49 & 39 & 39 & 27 \\ 0.209 & 8.578\times 10^{5} & 11.58 & 49 & 48 & 40 & 11 \end{pmatrix}$$

Pipe Run 1-29A (Element 1)

$$PL80TH_{0,4} = \begin{pmatrix} 0.255 & 9.054\times 10^{5} & 8.56 & 1 & 1 & 1 & 21 \\ 0.217 & 6.411\times 10^{5} & 8.55 & 1 & 4 & 2 & 29 \end{pmatrix}$$

Pipe Run 1-29B (Elements 5, 7, 668, 669, & 54)

$PL80TH_{0,5} =$

	0	1	2	3	4	5	6
0	0.193	$4.714\cdot 10^{5}$	8.545	5	5	3	17
1	0.168	$2.904\cdot 10^{5}$	11.99	5	16	4	11
2	0.168	$2.903\cdot 10^{5}$	11.99	7	16	5	11
3	0.158	$2.232\cdot 10^{5}$	12	7	549	6	9
4	0.158	$2.232\cdot 10^{5}$	12	668	549	143	9
5	0.166	$2.766\cdot 10^{5}$	8.555	668	550	144	17
6	0.188	$4.348\cdot 10^{5}$	8.565	669	50	145	28
7	0.166	$2.768\cdot 10^{5}$	8.555	669	550	146	17
8	0.19	$4.453\cdot 10^{5}$	8.565	54	8	43	28
9	0.188	$4.352\cdot 10^{5}$	8.565	54	50	44	28

Pipe Run 1-29C (Elements 9, 607, 12, 25, 672, 673, & 674)

$PL80TH_{0,6} =$

	0	1	2	3	4	5	6
0	0.188	$4.318\cdot 10^{5}$	11.76	9	9	7	28
1	0.187	$4.29\cdot 10^{5}$	11.75	9	502	8	25
2	0.184	$4.055\cdot 10^{5}$	8.75	607	10	129	19
3	0.187	$4.292\cdot 10^{5}$	11.35	607	502	130	24
4	0.184	$4.042\cdot 10^{5}$	4.305	12	12	13	10
5	0.192	$4.607\cdot 10^{5}$	3.925	12	19	14	10
6	0.192	$4.61\cdot 10^{5}$	3.925	25	19	17	10
7	0.181	$3.871\cdot 10^{5}$	6.925	25	553	18	6
8	0.181	$3.871\cdot 10^{5}$	6.925	672	553	151	6
9	0.202	$5.32\cdot 10^{5}$	8.57	672	554	152	26
10	0.202	$5.321\cdot 10^{5}$	8.57	673	554	153	26
11	0.213	$6.111\cdot 10^{5}$	8.58	673	555	154	1
12	0.222	$6.721\cdot 10^{5}$	11.35	674	13	155	27
13	0.213	$6.111\cdot 10^{5}$	8.58	674	555	156	1

Pipe Run 1-29D (Elements 14 & 26)

$$PL_{80TH_{0,7}} = \begin{pmatrix} 0.198 & 7.648 \times 10^{5} & 11.76 & 14 & 14 & 15 & 27 \\ 0.202 & 7.979 \times 10^{5} & 11.76 & 14 & 24 & 16 & 27 \\ 0.225 & 9.943 \times 10^{5} & 11.77 & 26 & 15 & 19 & 19 \\ 0.202 & 7.979 \times 10^{5} & 11.76 & 26 & 24 & 20 & 27 \end{pmatrix}$$

Pipe Properties for Lower (Southern) Portion of Line 1-27

Pipe Run 1-27A (Elements 93, 94, & 469)

$$PL_{80TH_{0,8}} = \begin{pmatrix} 0.165 & 1.095 \times 10^{6} & 4.12 & 93 & 56 & 79 & 7 \\ 0.169 & 1.177 \times 10^{6} & 4.12 & 93 & 88 & 80 & 7 \\ 0.169 & 1.178 \times 10^{6} & 4.12 & 94 & 88 & 81 & 7 \\ 0.166 & 1.117 \times 10^{6} & 8.74 & 94 & 89 & 82 & 28 \\ 0.16 & 9.757 \times 10^{5} & 11.57 & 469 & 60 & 111 & 27 \\ 0.154 & 8.209 \times 10^{5} & 11.57 & 469 & 89 & 112 & 25 \end{pmatrix}$$

Pipe Run 1-27B (Elements 66, 678, 75, 679, 680, 76, 681, 682, & 67)

$PL_{80TH_{0,9}} =$

	0	1	2	3	4	5	6
0	0.182	$1.487\cdot10^{6}$	11.57	66	61	59	11
1	0.166	$1.099\cdot10^{6}$	11.56	66	559	60	27
2	0.164	$1.052\cdot10^{6}$	11.74	678	68	163	24
3	0.166	$1.1\cdot10^{6}$	11.56	678	559	164	27
4	0.164	$1.053\cdot10^{6}$	11.74	75	68	67	24
5	0.162	$1.007\cdot10^{6}$	10.7	75	560	68	9
6	0.162	$1.007\cdot10^{6}$	10.7	679	560	165	9
7	0.17	$1.2\cdot10^{6}$	5.71	679	561	166	9
8	0.196	$1.821\cdot10^{6}$	8.745	680	69	167	1
9	0.17	$1.2\cdot10^{6}$	5.71	680	561	168	9
10	0.196	$1.822\cdot10^{6}$	8.745	76	69	69	1
11	0.166	$1.108\cdot10^{6}$	8.75	76	562	70	2
12	0.166	$1.108\cdot10^{6}$	8.75	681	562	169	2
13	0.154	$8.212\cdot10^{5}$	10.87	681	563	170	23
14	0.148	$6.826\cdot10^{5}$	10.87	682	63	171	26
15	0.154	$8.2\cdot10^{5}$	10.87	682	563	172	23
16	0.148	$6.724\cdot10^{5}$	11.68	67	62	61	12
17	0.148	$6.819\cdot10^{5}$	10.87	67	63	62	26

Pipe Properties for Upper (Northern) Portion of Line 1-27

Pipe Run 1-27C (Elements 81, 683, 89, 108, 684, 495, & 496)

$PL_{80TH_{0,10}} =$

	0	1	2	3	4	5	6
0	0.137	$6.894\cdot 10^{5}$	11.27	81	65	71	17
1	0.147	$9.59\cdot 10^{5}$	11.28	81	564	72	32
2	0.16	$1.336\cdot 10^{6}$	11.26	683	84	173	24
3	0.147	$9.595\cdot 10^{5}$	11.28	683	564	174	32
4	0.16	$1.337\cdot 10^{6}$	12.1	89	84	77	17
5	0.176	$1.77\cdot 10^{6}$	7.855	89	102	78	21
6	0.176	$1.771\cdot 10^{6}$	7.855	108	102	83	21
7	0.157	$1.234\cdot 10^{6}$	11.26	108	565	84	19
8	0.161	$1.339\cdot 10^{6}$	9.095	684	103	175	8
9	0.157	$1.234\cdot 10^{6}$	11.26	684	565	176	19
10	0.16	$1.338\cdot 10^{6}$	9.095	495	103	117	8
11	0.156	$1.216\cdot 10^{6}$	9.09	495	419	118	22
12	0.148	$1\cdot 10^{6}$	9.095	496	75	119	21
13	0.156	$1.216\cdot 10^{6}$	9.09	496	419	120	22

Pipe Run 1-27D (Elements 117, 685, 686, 687, & 84)

$PL_{80TH_{0,11}} =$

	0	1	2	3	4	5	6
0	0.143	$8.542\cdot 10^{5}$	7.87	117	76	85	19
1	0.146	$9.376\cdot 10^{5}$	4.34	117	566	86	6
2	0.146	$9.38\cdot 10^{5}$	4.34	685	566	177	6
3	0.147	$9.672\cdot 10^{5}$	4.34	685	567	178	11
4	0.147	$9.668\cdot 10^{5}$	4.34	686	567	179	11
5	0.146	$9.264\cdot 10^{5}$	8.57	686	568	180	26
6	0.171	$1.644\cdot 10^{6}$	4.975	687	80	181	8
7	0.146	$9.259\cdot 10^{5}$	8.57	687	568	182	26
8	0.159	$1.29\cdot 10^{6}$	8.575	84	78	73	7
9	0.172	$1.656\cdot 10^{6}$	4.975	84	80	74	8

EVALUATION OF PIPE RUNS ON LINES 32, 33, AND 49 FOR ALL 32 REALIZATIONS

VPS := ReadData("\PRLines32_33_49.prn")

$PS := C\_S(VPS, R)$

$PS_{80TH} := PR_{80th}(PS)$

PIPE PROPERTIES FOR LINE 1-32A

Pipe Run 1-32A (Element 241)

$$PS_{80TH_{0,0}} = \begin{pmatrix} 0.168 & 1.313\times 10^{5} & 6.2 & 241 & 149 & 15 & 15 \\ 0.159 & 1.168\times 10^{5} & 6.205 & 241 & 237 & 16 & 15 \end{pmatrix}$$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

PIPE PROPERTIES FOR LINES 14 " SECTIONS OF 1-32 AND 1-33

Pipe Run 1-32B (Elements 242 & 294)

$$PS80TH_{0,1} = \begin{pmatrix} 0.133 & 6.679 \times 10^{4} & 6.22 & 242 & 148 & 17 & 11 \\ 0.146 & 9.345 \times 10^{4} & 6.205 & 242 & 238 & 18 & 13 \\ 0.129 & 6.027 \times 10^{4} & 5.51 & 294 & 147 & 39 & 12 \\ 0.129 & 5.948 \times 10^{4} & 9.11 & 294 & 254 & 40 & 6 \end{pmatrix}$$

Pipe Run 1-32C (Elements 291 & 282)

$$PS80TH_{0,2} = \begin{pmatrix} 0.123 & 4.76 \times 10^{4} & 9.545 & 291 & 144 & 37 & 12 \\ 0.126 & 5.386 \times 10^{4} & 9.115 & 291 & 255 & 38 & 28 \\ 0.129 & 5.919 \times 10^{4} & 9.16 & 282 & 143 & 29 & 17 \\ 0.129 & 5.995 \times 10^{4} & 9.16 & 282 & 247 & 30 & 17 \end{pmatrix}$$

Pipe Run 1-32D (Elements 640 & 279)

$$PS80TH_{0,3} = \begin{pmatrix} 0.136 & 7.295 \times 10^{4} & 9.34 & 640 & 248 & 141 & 13 \\ 0.143 & 8.791 \times 10^{4} & 9.335 & 640 & 532 & 142 & 17 \\ 0.14 & 8.137 \times 10^{4} & 9.33 & 279 & 250 & 27 & 25 \\ 0.143 & 8.799 \times 10^{4} & 9.335 & 279 & 532 & 28 & 17 \end{pmatrix}$$

Pipe Run 1-32E (Elements 421, 422, & 423)

$$PS80TH_{0,4} = \begin{pmatrix} 0.191 & 1.828 \times 10^{5} & 9.535 & 421 & 346 & 111 & 17 \\ 0.163 & 1.271 \times 10^{5} & 7.935 & 421 & 347 & 112 & 10 \\ 0.163 & 1.271 \times 10^{5} & 7.935 & 422 & 347 & 113 & 10 \\ 0.171 & 1.436 \times 10^{5} & 7.92 & 422 & 348 & 114 & 11 \\ 0.183 & 1.655 \times 10^{5} & 7.92 & 423 & 251 & 115 & 11 \\ 0.171 & 1.436 \times 10^{5} & 7.92 & 423 & 348 & 116 & 11 \end{pmatrix}$$

Pipe Run 1-32F (Elements 295, 296, 715, 716, 717, 718, 297, 719, 720, 721, & 298)

$PS80TH_{0,5} =$

	0	1	2	3	4	5	6
0	0.205	$2.101 \cdot 10^5$	8.17	295	129	41	19
1	0.204	$2.074 \cdot 10^5$	8.17	295	259	42	19
2	0.204	$2.08 \cdot 10^5$	8.17	296	259	43	19
3	0.205	$2.096 \cdot 10^5$	8.16	296	595	44	7
4	0.205	$2.098 \cdot 10^5$	8.16	715	595	184	7
5	0.207	$2.135 \cdot 10^5$	8.16	715	596	185	3
6	0.207	$2.136 \cdot 10^5$	8.16	716	596	186	3
7	0.208	$2.168 \cdot 10^5$	8.16	716	597	187	3
8	0.209	$2.169 \cdot 10^5$	8.16	717	597	188	3
9	0.209	$2.177 \cdot 10^5$	8.155	717	598	189	7
10	0.208	$2.165 \cdot 10^5$	8.155	718	258	190	7
11	0.209	$2.177 \cdot 10^5$	8.155	718	598	191	7
12	0.208	$2.165 \cdot 10^5$	8.16	297	258	45	7
13	0.206	$2.116 \cdot 10^5$	8.16	297	599	46	7
14	0.206	$2.116 \cdot 10^5$	8.16	719	599	192	7
15	0.202	$2.05 \cdot 10^5$	8.16	719	600	193	6
16	0.203	$2.05 \cdot 10^5$	8.16	720	600	194	6
17	0.199	$1.98 \cdot 10^5$	8.165	720	601	195	6
18	0.197	$1.935 \cdot 10^5$	8.17	721	261	196	19
19	0.199	$1.981 \cdot 10^5$	8.165	721	601	197	6
20	0.196	$1.924 \cdot 10^5$	8.175	298	252	47	19
21	0.197	$1.935 \cdot 10^5$	8.17	298	261	48	28

Pipe Run 1-32G (Elements 714, 713, 712, 711, 709, & 637)

$PS80TH_{0,6} =$

	0	1	2	3	4	5	6
0	0.19	$1.802 \cdot 10^5$	8.18	714	323	182	22
1	0.181	$1.63 \cdot 10^5$	8.185	714	594	183	12
2	0.194	$1.885 \cdot 10^5$	7.92	713	593	180	10
3	0.181	$1.63 \cdot 10^5$	8.185	713	594	181	12
4	0.214	$2.272 \cdot 10^5$	7.92	712	592	178	10
5	0.194	$1.885 \cdot 10^5$	7.92	712	593	179	10
6	0.226	$2.519 \cdot 10^5$	7.915	711	591	176	22
7	0.214	$2.272 \cdot 10^5$	7.92	711	592	177	10
8	0.229	$2.581 \cdot 10^5$	7.92	709	590	174	24
9	0.226	$2.519 \cdot 10^5$	7.915	709	591	175	22
10	0.217	$2.331 \cdot 10^5$	7.665	637	125	139	19
11	0.217	$2.348 \cdot 10^5$	7.665	637	590	140	19

Pipe Run 1-32H (Elements 708, 707, 391, 706, 705, 704, 388, & 207)

$PS80TH_{0,7} =$

	0	1	2	3	4	5	6
0	0.206	2.128·10^5	7.66	708	123	172	11
1	0.196	1.927·10^5	8.175	708	589	173	25
2	0.197	1.937·10^5	8.17	707	588	170	30
3	0.196	1.927·10^5	8.175	707	589	171	25
4	0.219	2.375·10^5	8.19	391	122	97	24
5	0.197	1.938·10^5	8.17	391	588	98	30
6	0.219	2.374·10^5	8.19	706	122	168	24
7	0.263	3.248·10^5	8.155	706	587	169	11
8	0.325	4.471·10^5	8.16	705	586	166	11
9	0.263	3.248·10^5	8.155	705	587	167	11
10	0.397	5.896·10^5	8.17	704	585	164	11
11	0.325	4.472·10^5	8.16	704	586	165	11
12	0.478	7.505·10^5	8.17	388	308	95	11
13	0.397	5.896·10^5	8.17	388	585	96	11
14	0.539	8.697·10^5	8.17	207	121	3	28
15	0.478	7.505·10^5	8.17	207	308	4	11

Pipe Run 1-33A (Element 287)

$$PS80TH_{0,8} = \begin{pmatrix} 0.208 & 2.167 \times 10^5 & 9.325 & 287 & 138 & 33 & 13 \\ 0.198 & 1.963 \times 10^5 & 9.33 & 287 & 253 & 34 & 22 \end{pmatrix}$$

Pipe Run 1-33B (Element 290 & 667)

$$PS80TH_{0,9} = \begin{pmatrix} 0.182 & 1.648 \times 10^5 & 9.52 & 290 & 136 & 35 & 25 \\ 0.184 & 1.688 \times 10^5 & 9.52 & 290 & 257 & 36 & 25 \\ 0.182 & 1.649 \times 10^5 & 9.52 & 667 & 135 & 162 & 25 \\ 0.196 & 1.929 \times 10^5 & 9.335 & 667 & 548 & 163 & 17 \end{pmatrix}$$

Pipe Properties for Line 1-49

Pipe Run 1-49A (Elements 730, 729, 728, 727, 308, 726, 725, 724, 723, 722, 444, & 443)

$PS_{80TH_{0,10}} =$

	0	1	2	3	4	5	6
0	0.106	$1.314\cdot10^{4}$	9.37	730	266	214	25
1	0.091	$1.055\cdot10^{4}$	9.37	730	610	215	22
2	0.078	$8.092\cdot10^{3}$	9.375	729	609	212	13
3	0.091	$1.055\cdot10^{4}$	9.37	729	610	213	22
4	0.066	$5.905\cdot10^{3}$	9.39	728	608	210	20
5	0.078	$8.092\cdot10^{3}$	9.375	728	609	211	13
6	0.062	$5.123\cdot10^{3}$	9.15	727	607	208	6
7	0.066	$5.905\cdot10^{3}$	9.39	727	608	209	20
8	0.072	$6.973\cdot10^{3}$	7.645	308	154	49	13
9	0.062	$5.123\cdot10^{3}$	9.15	308	607	50	6
10	0.072	$6.973\cdot10^{3}$	7.645	726	154	206	13
11	0.054	$3.772\cdot10^{3}$	8.21	726	606	207	12
12	0.059	$4.576\cdot10^{3}$	7.64	725	605	204	13
13	0.054	$3.772\cdot10^{3}$	8.21	725	606	205	12
14	0.073	$7.152\cdot10^{3}$	7.64	724	604	202	13
15	0.059	$4.576\cdot10^{3}$	7.64	724	605	203	13
16	0.084	$9.249\cdot10^{3}$	7.63	723	603	200	17
17	0.073	$7.151\cdot10^{3}$	7.64	723	604	201	13
18	0.091	$1.046\cdot10^{4}$	7.645	722	602	198	22
19	0.084	$9.249\cdot10^{3}$	7.63	722	603	199	17
20	0.101	$1.227\cdot10^{4}$	7.905	444	369	119	11
21	0.091	$1.046\cdot10^{4}$	7.645	444	602	120	22
22	0.103	$1.269\cdot10^{4}$	7.905	443	240	117	22
23	0.101	$1.227\cdot10^{4}$	7.905	443	369	118	11

Pipe Run 1-49B (Elements 403, 402, & 270)

$$PS_{80TH_{0,11}} = \begin{pmatrix} 0.11 & 1.39\times10^{4} & 7.685 & 403 & 242 & 109 & 22 \\ 0.102 & 1.253\times10^{4} & 7.675 & 403 & 328 & 110 & 17 \\ 0.102 & 1.244\times10^{4} & 7.65 & 402 & 327 & 107 & 28 \\ 0.102 & 1.252\times10^{4} & 7.675 & 402 & 328 & 108 & 17 \\ 0.109 & 1.367\times10^{4} & 7.65 & 270 & 244 & 19 & 11 \\ 0.102 & 1.244\times10^{4} & 7.65 & 270 & 327 & 20 & 28 \end{pmatrix}$$

Pipe Run 1-49C (Elements 401, 400, & 275)

$$PS80TH_{0,12} = \begin{pmatrix} 0.107 & 1.345\times10^{4} & 7.685 & 401 & 243 & 105 & 22 \\ 0.106 & 1.327\times10^{4} & 7.69 & 401 & 326 & 106 & 28 \\ 0.12 & 1.579\times10^{4} & 8.17 & 400 & 325 & 103 & 27 \\ 0.106 & 1.327\times10^{4} & 7.69 & 400 & 326 & 104 & 28 \\ 0.142 & 1.971\times10^{4} & 8.165 & 275 & 245 & 23 & 27 \\ 0.12 & 1.578\times10^{4} & 8.17 & 275 & 325 & 24 & 27 \end{pmatrix}$$

Pipe Run 1-49D (Elements 272 & 399)

$$PS80TH_{0,13} = \begin{pmatrix} 0.23 & 3.574\times10^{4} & 7.94 & 272 & 150 & 21 & 28 \\ 0.184 & 2.735\times10^{4} & 7.93 & 272 & 324 & 22 & 19 \\ 0.148 & 2.08\times10^{4} & 8.165 & 399 & 246 & 101 & 19 \\ 0.184 & 2.735\times10^{4} & 7.93 & 399 & 324 & 102 & 19 \end{pmatrix}$$

REDUCERS

Reducer output is ordered as (max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, indicia of element(s), moments about the x, y, and z axes, and realization number)

EVALUATION OF REDUCERS ON LINES 22 TO 26 FOR ALL 32 REALIZATIONS

VRM := ReadData("\RedLines22to26.prn")

RM := C_S(VRM, R)

$RM_{80TH} := RED\_EL_{80th}(RM)$

Reducer Properties for Top of Lines 1-22, 1-23, 1-24, 1-25

Reducer 1-22A (Nodes 193 & 194)

$$RM80TH_{0} = \begin{pmatrix} 0.199 & 6.648\times10^{5} & 8.565 & 193 & 153 & 9.597\times10^{4} & -1.037\times10^{5} & -6.496\times10^{5} & 28 \\ 0.217 & 6.723\times10^{5} & 8.565 & 194 & 69 & 6.369\times10^{4} & -1.608\times10^{5} & -6.496\times10^{5} & 28 \end{pmatrix}$$

Reducer 1-23 (Nodes 179 & 181)

$$RM_{80TH_1} = \begin{pmatrix} 0.191 & 6.107\times10^5 & 8.56 & 179 & 151 & -1.46\times10^4 & -1.061\times10^4 & -6.105\times10^5 & 11 \\ 0.206 & 6.173\times10^5 & 10.19 & 181 & 71 & -1.934\times10^5 & -1.711\times10^4 & -5.86\times10^5 & 3 \end{pmatrix}$$

Reducer 1-24 (Nodes 180 & 182)

$$RM_{80TH_2} = \begin{pmatrix} 0.22 & 7.942\times10^5 & 7.605 & 180 & 102 & -4.519\times10^4 & 6.181\times10^4 & -7.905\times10^5 & 22 \\ 0.241 & 7.931\times10^5 & 7.615 & 182 & 73 & 3.543\times10^4 & 2.517\times10^4 & 7.92\times10^5 & 11 \end{pmatrix}$$

Reducer 1-25A (Nodes 205 & 206)

$$RM_{80TH_3} = \begin{pmatrix} 0.246 & 9.598\times10^5 & 7.36 & 205 & 135 & -1.521\times10^5 & 3.138\times10^4 & -9.471\times10^5 & 22 \\ 0.276 & 9.699\times10^5 & 7.36 & 206 & 75 & -2.03\times10^5 & -4.838\times10^4 & -9.472\times10^5 & 22 \end{pmatrix}$$

Reducer Properties for Bottom of Line 1-22 and 1-25

Reducer 1-22B (Nodes 164 & 165)

$$RM_{80TH_4} = \begin{pmatrix} 0.135 & 6.944\times10^5 & 7.21 & 164 & 17 & -6.73\times10^5 & 1.71\times10^5 & 9.191\times10^3 & 2 \\ 0.133 & 6.463\times10^5 & 7.2 & 165 & 23 & 6.248\times10^5 & -1.332\times10^5 & -9.795\times10^4 & 14 \end{pmatrix}$$

Reducer 1-25B (Nodes 161 & 162)

$$RM_{80TH_5} = \begin{pmatrix} 0.134 & 6.531\times10^5 & 7.62 & 161 & 8 & 4.11\times10^5 & 5.027\times10^5 & 7.07\times10^4 & 19 \\ 0.126 & 5.849\times10^5 & 7.905 & 162 & 21 & -5.248\times10^5 & -2.512\times10^5 & -5.973\times10^4 & 10 \end{pmatrix}$$

EVALUATION OF REDUCERS ON LINES 27 TO 29 FOR ALL 32 REALIZATIONS

VRL := ReadData("\RedLines27to29.prn")

RL := C_S(VRL, R)

$RL_{80TH} := RED\_EL_{80th}(RL)$

Reducer Properties for Bottom of Line 1-28 and 1-29

Reducer 1-28 (Nodes 53 & 39)

$$RL_{80TH_0} = \begin{pmatrix} 0.167 & 1.319\times10^6 & 5.275 & 53 & 49 & 1.008\times10^6 & -6.198\times10^5 & 5.832\times10^5 & 11 \\ 0.229 & 1.132\times10^6 & 11.58 & 39 & 39 & 6.002\times10^5 & -6.305\times10^5 & 7.23\times10^5 & 27 \end{pmatrix}$$

Reducer 1-29 (Nodes 52 & 15)

$$RL_{80TH_1} = \begin{pmatrix} 0.159 & 1.099\times10^{6} & 11.77 & 52 & 51 & 5.126\times10^{5} & -6.682\times10^{5} & -7.064\times10^{5} & 19 \\ 0.214 & 9.943\times10^{5} & 11.77 & 15 & 19 & 3.968\times10^{5} & -5.291\times10^{5} & -7.424\times10^{5} & 19 \end{pmatrix}$$

EVALUATION OF REDUCERS ON LINES 32, 33, & 49 TO 29 FOR ALL 32 REALIZATIONS

VRS := ReadData("\RedLines32_33_49.prn")

RS := C_S(VRS,R)

$RS_{80TH} := RED\_EL_{80th}(RS)$

Reducer Properties for Bottom of Lines 1-32 and 1-33

Reducer 1-32 (Nodes 238 & 237)

$$RS_{80TH_0} = \begin{pmatrix} 0.144 & 9.346\times10^{4} & 6.205 & 238 & 137 & -2.684\times10^{4} & 8.505\times10^{4} & 2.794\times10^{4} & 13 \\ 0.158 & 1.168\times10^{5} & 6.205 & 237 & 16 & -3.055\times10^{4} & 1.093\times10^{5} & 2.752\times10^{4} & 15 \end{pmatrix}$$

Reducer 1-33 (Nodes 139 & 140)

$$RS_{80TH_1} = \begin{pmatrix} 0.204 & 2.171\times10^{5} & 9.345 & 139 & 155 & 2.966\times10^{4} & -2.149\times10^{5} & 8.839\times10^{3} & 18 \\ 0.233 & 2.447\times10^{5} & 9.355 & 140 & 157 & 6.816\times10^{3} & 2.446\times10^{5} & -1.079\times10^{3} & 26 \end{pmatrix}$$

ELBOWS

Elbow output is ordered as (max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, indicia of element(s), moments about the x, y, and z axes, and realization number)

EVALUATION OF ELBOWS ON LINES 22 TO 26 FOR ALL 32 REALIZATIONS

VEM := ReadData("\ElbowLines22to26.prn")

EM := C_S(VEM,R)

$EM_{80TH} := RED\_EL_{80th}(EM)$

Elbow Properties for Lines 1-22, 1-23, 1-24, and 1-25

Elbow 1-22A (Nodes 193 & 192)

$$EM_{80TH_0} = \begin{pmatrix} 0.573 & 6.648\times10^{5} & 8.565 & 193 & 153 & 9.597\times10^{4} & -1.037\times10^{5} & -6.496\times10^{5} & 28 \\ 0.428 & 4.968\times10^{5} & 8.565 & 192 & 90 & 1.322\times10^{5} & 9.265\times10^{4} & -4.698\times10^{5} & 19 \end{pmatrix}$$

Elbow 1-22B (Nodes 190 & 189)

$$EM_{80TH_1} = \begin{pmatrix} 0.266 & 3.082\times10^5 & 7.255 & 190 & 88 & 7.39\times10^4 & -7.782\times10^4 & -2.889\times10^5 & 25 \\ 0.353 & 4.1\times10^5 & 7.24 & 189 & 87 & -1.18\times10^5 & 1.859\times10^4 & 3.922\times10^5 & 25 \end{pmatrix}$$

Elbow 1-22C (Nodes 209 & 210)

$$EM_{80TH_2} = \begin{pmatrix} 0.238 & 2.759\times10^5 & 6.77 & 209 & 84 & -9.067\times10^4 & -1.764\times10^4 & -2.6\times10^5 & 25 \\ 0.227 & 2.629\times10^5 & 10.92 & 210 & 77 & 1.868\times10^5 & -1.686\times10^5 & -7.626\times10^4 & 12 \end{pmatrix}$$

Elbow 1-25A (Nodes 205 & 204)

$$EM_{80TH_3} = \begin{pmatrix} 0.827 & 9.6\times10^5 & 7.365 & 205 & 135 & -1.476\times10^5 & 3.657\times10^4 & -9.479\times10^5 & 24 \\ 0.645 & 7.487\times10^5 & 7.355 & 204 & 111 & -1.251\times10^4 & 2.971\times10^5 & -6.871\times10^5 & 28 \end{pmatrix}$$

Elbow 1-25B (Nodes 202 & 201)

$$EM_{80TH_4} = \begin{pmatrix} 0.384 & 4.455\times10^5 & 7.365 & 202 & 109 & 6.444\times10^4 & -2.971\times10^5 & -3.256\times10^5 & 28 \\ 0.501 & 5.821\times10^5 & 7.355 & 201 & 108 & -1.003\times10^5 & 2.695\times10^5 & 5.061\times10^5 & 27 \end{pmatrix}$$

Elbow 1-25C (Nodes 212 & 211)

$$EM_{80TH_5} = \begin{pmatrix} 0.261 & 3.031\times10^5 & 4.325 & 212 & 106 & 1.803\times10^5 & -6.066\times10^4 & -2.36\times10^5 & 12 \\ 0.291 & 3.382\times10^5 & 7.09 & 211 & 105 & 2.434\times10^5 & -2.163\times10^5 & -9.132\times10^4 & 28 \end{pmatrix}$$

Elbow 1-23A (Node 179 & 213)

$$EM_{80TH_6} = \begin{pmatrix} 0.526 & 6.107\times10^5 & 8.56 & 179 & 151 & -1.46\times10^4 & -1.061\times10^4 & -6.105\times10^5 & 11 \\ 0.405 & 4.698\times10^5 & 10.19 & 213 & 97 & 2.369\times10^3 & 2.058\times10^5 & -4.223\times10^5 & 27 \end{pmatrix}$$

Elbow 1-23B (Node 174 & 218)

$$EM_{80TH_7} = \begin{pmatrix} 0.299 & 3.473\times10^5 & 7.08 & 174 & 93 & -2.317\times10^5 & 1.209\times10^5 & 2.286\times10^5 & 24 \\ 0.362 & 4.206\times10^5 & 8.565 & 218 & 94 & -1.016\times10^5 & 1.293\times10^5 & 3.871\times10^5 & 19 \end{pmatrix}$$

Elbow 1-24A (Nodes 180 & 214)

$$EM_{80TH_8} = \begin{pmatrix} 0.684 & 7.942\times10^5 & 7.605 & 180 & 102 & -4.519\times10^4 & 6.181\times10^4 & -7.905\times10^5 & 22 \\ 0.551 & 6.391\times10^5 & 7.605 & 214 & 103 & 2.258\times10^4 & -2.787\times10^5 & 5.747\times10^5 & 22 \end{pmatrix}$$

Elbow 1-24B (Node 176 & 175)

$$EM80TH_9 = \begin{pmatrix} 0.347 & 4.028\times10^5 & 7.625 & 176 & 100 & -1.489\times10^5 & 2.747\times10^5 & 2.541\times10^5 & 24 \\ 0.401 & 4.655\times10^5 & 7.33 & 175 & 56 & 1.085\times10^5 & -1.665\times10^5 & -4.209\times10^5 & 25 \end{pmatrix}$$

EVALUATION OF ELBOWS ON LINES 27 TO 29 FOR ALL 32 REALIZATIONS

VEL := ReadData("\ElbowLines27to29.prn")

EL := C_S(VEL,R)

EL_{80TH} := RED_EL_{80th}(EL)

Elbow Properties for Lines 1-28 and 1-29

Elbow 1-28A (Nodes 28 & 29)

$$EL80TH_0 = \begin{pmatrix} 0.523 & 6.548\times10^5 & 11.96 & 26 & 22 & 4.793\times10^4 & 3.987\times10^4 & 6.519\times10^5 & 17 \\ 0.4 & 5.012\times10^5 & 11.57 & 29 & 94 & -1.949\times10^4 & -1.518\times10^5 & 4.772\times10^5 & 28 \end{pmatrix}$$

Elbow 1-28B (Nodes 32 & 33)

$$EL80TH_1 = \begin{pmatrix} 0.376 & 4.711\times10^5 & 8.575 & 32 & 96 & -2.85\times10^4 & -1.554\times10^5 & -4.438\times10^5 & 28 \\ 0.323 & 4.042\times10^5 & 11.76 & 33 & 97 & 1.8\times10^5 & 1.047\times10^5 & 3.464\times10^5 & 27 \end{pmatrix}$$

Elbow 1-28C (Nodes 37 & 38)

$$EL80TH_2 = \begin{pmatrix} 0.409 & 6.092\times10^5 & 8.57 & 37 & 161 & -1.945\times10^4 & -3.439\times10^4 & -6.079\times10^5 & 16 \\ 0.508 & 7.553\times10^5 & 11.98 & 38 & 100 & 1.737\times10^5 & -3.601\times10^4 & 7.342\times10^5 & 11 \end{pmatrix}$$

Elbow 1-29A (Nodes 4 & 5)

$$EL80TH_3 = \begin{pmatrix} 0.512 & 6.411\times10^5 & 8.55 & 4 & 2 & 1.694\times10^5 & 3.928\times10^4 & -6.171\times10^5 & 29 \\ 0.377 & 4.715\times10^5 & 8.545 & 5 & 103 & -7.635\times10^4 & -1.595\times10^5 & -4.371\times10^5 & 17 \end{pmatrix}$$

Elbow 1-29B (Nodes 8 & 9)

$$EL80TH_4 = \begin{pmatrix} 0.356 & 4.453\times10^5 & 8.565 & 8 & 105 & 5.335\times10^4 & 1.538\times10^5 & -4.145\times10^5 & 28 \\ 0.345 & 4.318\times10^5 & 11.76 & 9 & 7 & 1.304\times10^4 & 8.588\times10^4 & -4.229\times10^5 & 28 \end{pmatrix}$$

Elbow 1-29C (Nodes 13 & 14)

$$EL80TH_5 = \begin{pmatrix} 0.452 & 6.721\times10^5 & 11.35 & 13 & 108 & -8.519\times10^3 & -5.648\times10^3 & 6.72\times10^5 & 27 \\ 0.514 & 7.65\times10^5 & 11.76 & 14 & 109 & 5.944\times10^4 & -1.406\times10^5 & -7.496\times10^5 & 27 \end{pmatrix}$$

Elbow Properties for Lines 1-27

Elbow 1-27A (Nodes 60 & 61)

$$EL80TH_6 = \begin{pmatrix} 0.236 & 9.758\times10^5 & 11.57 & 60 & 87 & 1.295\times10^5 & 1.924\times10^5 & 9.479\times10^5 & 27 \\ 0.359 & 1.487\times10^6 & 11.57 & 61 & 59 & 1.481\times10^5 & 1.749\times10^5 & 1.469\times10^6 & 11 \end{pmatrix}$$

Elbow 1-27B (Nodes 75 & 76)

$$EL80TH_7 = \begin{pmatrix} 0.2 & 1\times10^6 & 9.095 & 75 & 119 & -1.469\times10^5 & 8.789\times10^5 & 4.544\times10^5 & 21 \\ 0.17 & 8.542\times10^5 & 7.87 & 76 & 91 & -5.381\times10^5 & 6.579\times10^5 & 8.6\times10^4 & 19 \end{pmatrix}$$

EVALUATION OF ELBOWS ON LINES 32, 33, & 49 FOR ALL 32 REALIZATIONS

VES := ReadData("\ElbowLines32_33_49.prn")

ES := C_S(VES, R)

ES_{80TH} := RED_EL$_{80th}$(ES)

Elbow Properties for Lines 1-32A,B and 1-33

Elbow 1-32A (Nodes 254 & 255)

$$ES80TH_0 = \begin{pmatrix} 0.212 & 5.942\times10^4 & 9.105 & 254 & 40 & -5.469\times10^4 & 1.981\times10^4 & 1.212\times10^4 & 10 \\ 0.192 & 5.387\times10^4 & 9.115 & 255 & 76 & -4.965\times10^4 & 1.891\times10^4 & 8.926\times10^3 & 28 \end{pmatrix}$$

Elbow 1-32B (Nodes 247 & 248)

$$ES80TH_1 = \begin{pmatrix} 0.214 & 5.995\times10^4 & 9.16 & 247 & 72 & 5.377\times10^4 & -2.588\times10^4 & 5.768\times10^3 & 17 \\ 0.26 & 7.295\times10^4 & 9.34 & 248 & 73 & 5.644\times10^4 & -4.55\times10^4 & 8.085\times10^3 & 13 \end{pmatrix}$$

Elbow 1-33 (Nodes 137 & 136)

$$ES80TH_2 = \begin{pmatrix} 0.7 & 1.964\times10^5 & 9.325 & 253 & 34 & 1.273\times10^5 & -1.491\times10^5 & 1.274\times10^4 & 13 \\ 0.602 & 1.689\times10^5 & 9.52 & 257 & 79 & -3.954\times10^4 & 1.587\times10^5 & -4.184\times10^4 & 25 \end{pmatrix}$$

Elbow 1-32C (Nodes 250 & 249)

$$ES_{80TH_3} = \begin{pmatrix} 0.221 & 8.137\times10^4 & 9.33 & 250 & 27 & 6.215\times10^4 & -5.01\times10^4 & 1.576\times10^4 & 25 \\ 0.208 & 7.636\times10^4 & 9.325 & 249 & 69 & 5.111\times10^4 & -5.539\times10^4 & -1.23\times10^4 & 12 \end{pmatrix}$$

Elbow 1-32D (Nodes 251 & 252)

$$ES_{80TH_4} = \begin{pmatrix} 0.45 & 1.655\times10^5 & 7.92 & 251 & 115 & -4.04\times10^4 & 6.393\times10^3 & -1.603\times10^5 & 11 \\ 0.523 & 1.924\times10^5 & 8.175 & 252 & 67 & 3.659\times10^4 & -5.149\times10^4 & 1.817\times10^5 & 19 \end{pmatrix}$$

Elbow 1-32E (Nodes 129 & 128)

$$ES_{80TH_5} = \begin{pmatrix} 0.571 & 2.101\times10^5 & 8.17 & 129 & 41 & -1.783\times10^4 & -1.046\times10^5 & 1.813\times10^5 & 19 \\ 0.556 & 2.043\times10^5 & 8.17 & 128 & 62 & -3.139\times10^4 & -1.422\times10^5 & 1.433\times10^5 & 19 \end{pmatrix}$$

Elbow 1-32F (Nodes 125 & 123)

$$ES_{80TH_6} = \begin{pmatrix} 0.634 & 2.331\times10^5 & 7.665 & 125 & 139 & -2.681\times10^4 & -1.469\times10^5 & -1.79\times10^5 & 19 \\ 0.579 & 2.128\times10^5 & 7.66 & 123 & 172 & 7.26\times10^3 & 1.326\times10^5 & 1.663\times10^5 & 11 \end{pmatrix}$$

Elbow Properties for Lines 1-49

Elbow 1-49A (Nodes 240 & 244)

$$ES_{80TH_7} = \begin{pmatrix} 0.184 & 1.269\times10^4 & 7.905 & 240 & 117 & -3.455\times10^3 & 77.28 & -1.221\times10^4 & 22 \\ 0.198 & 1.367\times10^4 & 7.65 & 244 & 94 & 3.292\times10^3 & -1.56\times10^3 & 1.317\times10^4 & 11 \end{pmatrix}$$

Elbow 1-49B (Nodes 242 & 243)

$$ES_{80TH_8} = \begin{pmatrix} 0.202 & 1.39\times10^4 & 7.685 & 242 & 90 & -6.65\times10^3 & 2.677\times10^3 & -1.191\times10^4 & 22 \\ 0.195 & 1.345\times10^4 & 7.685 & 243 & 105 & -5.038\times10^3 & 2.875\times10^3 & -1.214\times10^4 & 22 \end{pmatrix}$$

Elbow 1-49C (Nodes 245 & 246)

$$ES_{80TH_9} = \begin{pmatrix} 0.285 & 1.971\times10^4 & 8.165 & 245 & 23 & -1.505\times10^4 & -2.947\times10^3 & 1.238\times10^4 & 27 \\ 0.3 & 2.08\times10^4 & 8.165 & 246 & 88 & -1.615\times10^4 & -3.087\times10^3 & 1.274\times10^4 & 19 \end{pmatrix}$$

TEES

Tees output is ordered as (max D/C ratio, applied pipe run moment when D/C ratio is highest, applied branch moment when D/C ratio is highest, time when max values occur, pipe run node retrieved for calculations, indices of pipe run nodes, Index of branch node, and realization number)

EVALUATION OF TEES ON LINES 22 TO 26 FOR ALL 32 REALIZATIONS

VTEM := ReadData("\TeeLines22to26.prn")

TEM := C_S(VTEM, R)

FORGED TEE (LINE 1-26)

Tee 1-26 (Node 159)

$$\left(TEM_{0,0}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0.134 & 1.413 \times 10^{6} & 1.219 \times 10^{6} & 11.61 & 159 & 5 & 9 & 3 & 26 \end{pmatrix}$$

FABRICATED TEES (LINES 1-24 & 1-25)

Fabricated Tee 1-24 (Node 160)

$$\left(TEM_{0,1}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0.404 & 6.358 \times 10^{5} & 4.443 \times 10^{5} & 7.08 & 160 & 7 & 119 & 15 & 1 \end{pmatrix}$$

Fabricated Tee 1-23 (Node 163)

$$\left(TEM_{0,2}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0.395 & 6.524 \times 10^{5} & 4.267 \times 10^{5} & 7.08 & 163 & 11 & 115 & 13 & 25 \end{pmatrix}$$

EVALUATION OF TEES ON LINES 27 TO 29 FOR ALL 32 REALIZATIONS

VTEL := ReadData("\TeeLines27to29.prn")

TEL := C_S(VTEL, R)

FORGED TEES

Tee 1-27 (Node 51)

$$\left(TEL_{0,0}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0.14 & 1.541 \times 10^{6} & 1.335 \times 10^{6} & 11.57 & 51 & 53 & 55 & 57 & 9 \end{pmatrix}$$

EVALUATION OF TEES ON LINES 32, 33, & 49 FOR ALL 32 REALIZATIONS

VTES := ReadData("\TeeLines32_33_49.prn")

TES := C_S(VTES,R)

FABRICATED TEE (LINE 1-49 & 1-32)

Fabricated Tee 1-49 (Node 233)

$$\left(TES_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(0.868 \quad 1.87\times 10^{5} \quad 3.574\times 10^{4} \quad 7.94 \quad 233 \quad 6 \quad 99 \quad 13 \quad 28\right)$$

FABRICATED TEE (LINE 1-33 & 1-32)

Fabricated Tee 1-33 (Node 133)

$$\left(TES_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \left(0.957 \quad 2.493\times 10^{5} \quad 1.959\times 10^{5} \quad 9.535 \quad 133 \quad 25 \quad 31 \quad 7 \quad 26\right)$$

FABRICATED TEE (LINE 1-32, 1-26, & 1-27)

Fabricated Branch 1-32,1-26,1-27 (Node 120)

$$\left(TES_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \left(2.598 \quad 8.876\times 10^{5} \quad 8.725\times 10^{5} \quad 8.17 \quad 120 \quad 81 \quad 159 \quad 2 \quad 27\right)$$

Evaluation of this fabricated branch is addressed in the main body of the report and Appendix F.

FLANGES

Flange output is ordered as (max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, index of element(s), moments about the x, y, and z axes, and realization number)

EVALUATION OF FLANGES ON LINES 22 TO 26 FOR ALL 32 REALIZATIONS

VFM := ReadData("\FlangeLines22to26.prn")

FM := C_S(VFM,R)

Pipe Properties of Line 1-22, 1-23, 1-24, & 1-25

Flange (Primary Pump) 1-25A (Node 207)

$$\left(FM_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(0.251 \quad 9.902\times 10^{5} \quad 7.37 \quad 207 \quad 76 \quad 2.715\times 10^{5} \quad 1.293\times 10^{5} \quad 9.434\times 10^{5} \quad 24\right)$$

Flange (Check Valve) 1-25B (Node 199)

$$\left(FM_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \left(0.184 \quad 5.662\times 10^{5} \quad 7.355 \quad 199 \quad 67 \quad -1.004\times 10^{5} \quad 2.58\times 10^{5} \quad 4.939\times 10^{5} \quad 28\right)$$

Flange (Gate Valve) 1-25C (Node 198)

$$\left(FM_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.152 & 3.631\times10^{5} & 7.305 & 198 & 59 & -1.699\times10^{5} & 4.83\times10^{4} & 3.172\times10^{5} & 23 \end{pmatrix}$$

Flange (Primary Pump) 1-24A (Node 184)

$$\left(FM_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.221 & 7.988\times10^{5} & 7.615 & 184 & 74 & -4.998\times10^{4} & -9.157\times10^{4} & -7.92\times10^{5} & 11 \end{pmatrix}$$

Flange (Check Valve) 1-24B (Node 169)

$$\left(FM_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.17 & 4.789\times10^{5} & 10.21 & 169 & 55 & -8.439\times10^{4} & 1.916\times10^{5} & 4.308\times10^{5} & 19 \end{pmatrix}$$

Flange (Gate Valve) 1-24C (Node 167)

$$\left(FM_{0,5}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.186 & 5.809\times10^{5} & 7.26 & 167 & 47 & -1.069\times10^{5} & 3.664\times10^{4} & 5.698\times10^{5} & 4 \end{pmatrix}$$

Flange (Primary Pump) 1-23A (Node 183)

$$\left(FM_{0,6}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.194 & 6.326\times10^{5} & 10.19 & 183 & 72 & 2.27\times10^{5} & 5.973\times10^{4} & 5.874\times10^{5} & 28 \end{pmatrix}$$

Flange (Check Valve)B 1-23B (Node 168)

$$\left(FM_{0,7}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.161 & 4.24\times10^{5} & 8.565 & 168 & 45 & -1.034\times10^{5} & 1.099\times10^{5} & 3.963\times10^{5} & 27 \end{pmatrix}$$

Flange (Gate Valve)B 1-23C (Node 166)

$$\left(FM_{0,8}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.163 & 4.334\times10^{5} & 5.54 & 166 & 37 & 1.587\times10^{5} & 267.4 & 4.033\times10^{5} & 25 \end{pmatrix}$$

Flange (Primary Pump) 1-22A (Node 196)

$$\left(FM_{0,9}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.203 & 6.859\times10^{5} & 8.565 & 196 & 70 & -3.016\times10^{4} & 2.181\times10^{5} & 6.496\times10^{5} & 28 \end{pmatrix}$$

Flange (Check Valve) 1-22B (Node 187)

$$\left(FM_{0,10}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.158 & 4.04\times10^{5} & 7.235 & 187 & 35 & -1.068\times10^{5} & -3.789\times10^{3} & 3.896\times10^{5} & 19 \end{pmatrix}$$

Flange (Gate Valve) 1-22C (Node 186)

$$\left(FM_{0,11}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.151 & 3.6\times10^{5} & 6.775 & 186 & 27 & 9.623\times10^{4} & 4.033\times10^{4} & 3.445\times10^{5} & 25 \end{pmatrix}$$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

EVALUATION OF FLANGES ON LINES 27 TO 29 FOR ALL 32 REALIZATIONS

VFL := ReadData("\FlangeLines27to29.prn")

FL := C_S(VFL, R)

Pipe Properties for Lower (Southern) Portion of Line 1-27

Flange 1-27A (Butterfly Valve) (Node 62)

$$\left(FL_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.151 & 6.724\times10^{5} & 11.68 & 62 & 61 & -4.048\times10^{5} & -5.162\times10^{5} & -1.477\times10^{5} & 12 \end{pmatrix}$$

Pipe Properties for Upper (Northern) Portion of Line 1-27

Flange 1-27B (Butterfly Valve) (Node 65)

$$\left(FL_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.135 & 6.894\times10^{5} & 11.27 & 65 & 71 & 4.777\times10^{5} & 4.548\times10^{5} & 2.006\times10^{5} & 17 \end{pmatrix}$$

Pipe Properties for Upper (Northern) Portion of Lines 1-28 & 1-29

Flange 1-28A (Gate Valve) (Node 34)

$$\left(FL_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.191 & 4.985\times10^{5} & 5.275 & 34 & 29 & 1.191\times10^{5} & 7.736\times10^{3} & 4.84\times10^{5} & 7 \end{pmatrix}$$

Flange 1-28B (Gate Valve) (Node 36)

$$\left(FL_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.199 & 5.608\times10^{5} & 8.58 & 36 & 33 & 2.462\times10^{4} & -9.779\times10^{4} & 5.516\times10^{5} & 23 \end{pmatrix}$$

Flange 1-29A (Gate Valve) (Node 10)

$$\left(FL_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.179 & 4.056\times10^{5} & 8.75 & 10 & 9 & -2.298\times10^{5} & -1.943\times10^{5} & 2.72\times10^{5} & 19 \end{pmatrix}$$

Flange 1-29B (Gate Valve) (Node 12)

$$\left(FL_{0,5}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.179 & 4.042\times10^{5} & 4.305 & 12 & 13 & -2.099\times10^{5} & -2.943\times10^{4} & 3.442\times10^{5} & 10 \end{pmatrix}$$

EVALUATION OF FLANGES ON LINES 32, 33, & 49 FOR ALL 32 REALIZATIONS

VFS := ReadData("\FlangeLines32_33_49.prn")

FS := C_S(VFS, R)

Pipe Properties of Line 1-32 & 1-33

Flange (Emergency Pump) 1-32A (Node 149)

$$\left(FS_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.162 & 1.313\times10^{5} & 6.2 & 149 & 15 & 2.134\times10^{4} & -1.274\times10^{5} & -2.366\times10^{4} & 15 \end{pmatrix}$$

Flange (Check Valve) 1-32B (Node 148)

$$\left(FS_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.131 & 6.679\times10^{4} & 6.22 & 148 & 17 & -4.357\times10^{4} & 3.623\times10^{4} & 3.536\times10^{4} & 11 \end{pmatrix}$$

Flange (Check Valve) 1-32C (Node 147)

$$\left(FS_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.128 & 6.029\times10^{4} & 5.51 & 147 & 55 & 5.427\times10^{4} & 2.477\times10^{4} & -8.675\times10^{3} & 12 \end{pmatrix}$$

Flange (Gate Valve) 1-32D (Node 144)

$$\left(FS_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.122 & 4.76\times10^{4} & 9.545 & 144 & 37 & -3.07\times10^{4} & 3.638\times10^{4} & -92.69 & 12 \end{pmatrix}$$

Flange (Gate Valve) 1-32E (Node 143)

$$\left(FS_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.127 & 5.919\times10^{4} & 9.16 & 143 & 29 & 5.292\times10^{4} & -2.588\times10^{4} & 5.739\times10^{3} & 17 \end{pmatrix}$$

Flange (Emergency Pump) 1-33A (Node 140)

$$\left(FS_{0,5}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.217 & 2.447\times10^{5} & 9.355 & 140 & 157 & 6.816\times10^{3} & 2.446\times10^{5} & -1.079\times10^{3} & 26 \end{pmatrix}$$

Flange (Check Valve) 1-33B (Node 139)

$$\left(FS_{0,6}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.204 & 2.171\times10^{5} & 9.345 & 139 & 155 & 2.966\times10^{4} & -2.149\times10^{5} & 8.839\times10^{3} & 18 \end{pmatrix}$$

Flange (Check Valve) 1-33C (Node 138)

$$\left(FS_{0,7}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.204 & 2.168\times10^{5} & 9.325 & 138 & 53 & 1.474\times10^{5} & -1.584\times10^{5} & 1.291\times10^{4} & 13 \end{pmatrix}$$

Flange (Gate Valve) 1-32D (Node 136)

$$\left(FS_{0,8}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.178 & 1.648\times10^{5} & 9.52 & 136 & 35 & -2.57\times10^{4} & 1.587\times10^{5} & -3.594\times10^{4} & 25 \end{pmatrix}$$

Flange (Gate Valve) 1-32E (Node 135)

$$\left(FS_{0,9}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.179 & 1.649\times10^{5} & 9.52 & 135 & 9 & 4.337\times10^{4} & 1.586\times10^{5} & -1.209\times10^{4} & 25 \end{pmatrix}$$

Appendix B.5

Spring Profiles for Supports Exhibiting Nonlinear Behavior

SPRING STIFFNESS CALCULATIONS FOR SUPPORTS THAT EXHIBIT NONLINEAR BEHAVIOR (UPLIFT, GAPS, AND DIRECTIONALLY VARYING STIFFNESSES)

$E := 29000ksi$ — Modulus of Elasticity for supports (A7 steel)

Note: Photos referenced in calculations are included at the ends of the support section.

PR-8 (Large Gap at Base)

PR-8 Stiffness

$D_{PR8} := 1\frac{1}{8}in$ — Diameter of rods comprising PR-8 [18]

$A_{PR8} := \frac{\pi \cdot D_{PR8}^{2}}{4}$ — Cross Sectional area of rods comprising PR-8

$A_{PR8} = 0.994\ in^{2}$

$L_{PR8} := 94in$ — Length between PR-8 connections [19, (H6)] [20, (Det 52)]

$K_{PR8} := \frac{A_{PR8} \cdot E}{L_{PR8}}$ — Stiffness of PR-8

$K_{PR8} = 3.067 \times 10^{5}\ \frac{lbf}{in}$

PR-8 Stiffness Profile

$G_{PR8} := 4in$ — PR-8 gap conservatively assumed to be 4" as indicated by [20] [M3-1-27-N150-FSUA-DSCN2877 (see below)]

$F_{PR8} := \left(-10^{6}\ \ 0\ \ 0\ \ 10^{6}\right)lbf^{T}$ — Force profile applied

(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$$Dis_{PR8} := \left[\left(\frac{F_{PR8_0}}{K_{PR8}} - G_{PR8}\right)\ \ -G_{PR8}\ \ 0in\ \ \frac{F_{PR8_3}}{K_{PR8}}\right]^{T}$$

Corresponding Displacement profile to applied Force profile

$Dis_{PR8}^{T} = (-7.26088\ \ -4\ \ 0\ \ 3.26088)\ in$

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Resulting Force Displacement profile for PR-8

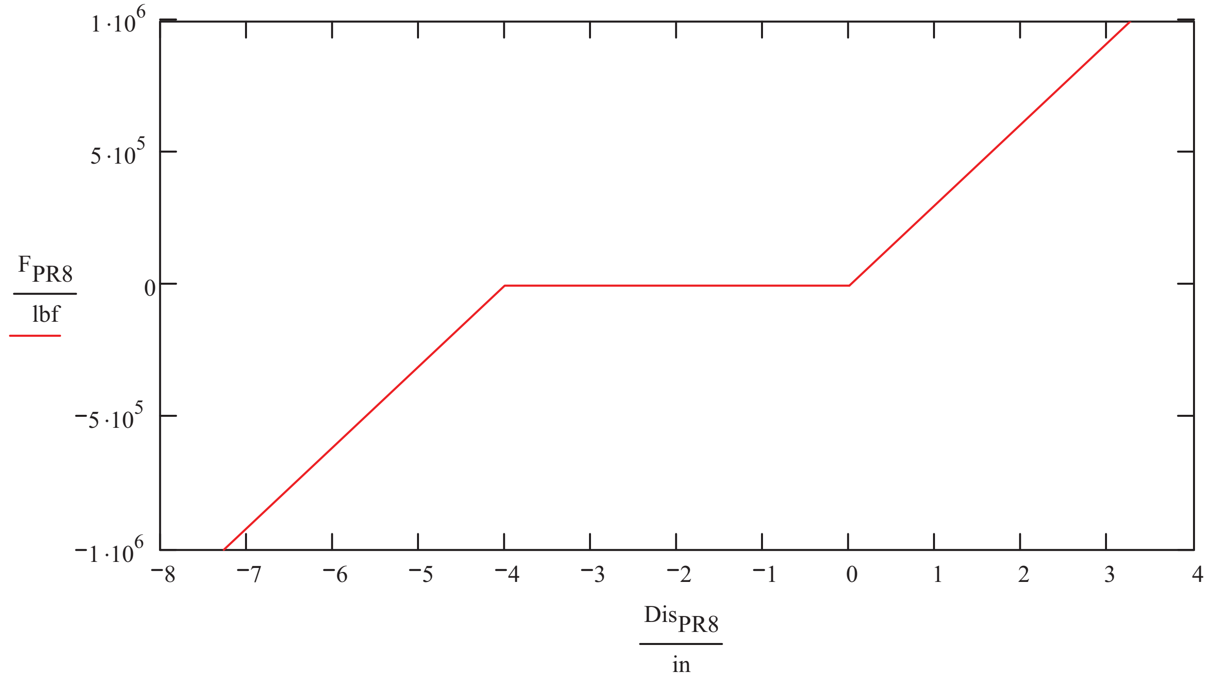

Photo [M3-1-27-N150-FSUA-DSCN2877]

Tunnel Restraint *(Varying stiffness dependant upon direction of loading (East or West))*

Tunnel Restraint Stiffness

$A_{TR} := 3.08in^2$ — Cross Sectional Tunnel Restraint sections [8, Table 1-5 pg 1-34]

$L_{TR\_E} := 24in$ — Length of east side of Tunnel Restraint support [21, (Det 28)]

$L_{TR\_W} := 60in$ — Length of west side Tunnel Restraint support [21, (Det 28)]

$$K_{TR\_E} := \frac{A_{TR} \cdot E}{L_{TR\_E}}$$

Stiffness of east side of Tunnel Restraint support

$$K_{TR\_E} = 3.722 \times 10^6 \frac{lbf}{in}$$

$$K_{TR\_W} := \frac{A_{TR} \cdot E}{L_{TR\_W}}$$

Stiffness of west side of Tunnel Restraint support

$$K_{TR\_W} = 1.489 \times 10^6 \frac{lbf}{in}$$

Tunnel Restraint Stiffness Profile

$G_{TR} := 0in$ — The Tunnel Restraint was observed to possess little if any gap at its interface with the pipe [M3-1-27-N300-WBUI-DSCN3044 & M3-1-27-N300-WBUI-DSCN2922 (see below)]

$F_{TR} := \left(-10^6 \quad 0 \quad 0 \quad 10^6\right) lbf^T$ — Force profile applied

(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$$Dis_{TR} := \left[\frac{F_{TR_0}}{K_{TR\_E}} \quad 0in \quad G_{TR} \quad \left(\frac{F_{TR_3}}{K_{TR\_W}} + G_{TR}\right)\right]^T$$

Corresponding Displacement profile to applied Force profile

$$Dis_{TR}^T = \left(-0.2687 \quad 0 \quad 0 \quad 0.67174\right) in$$

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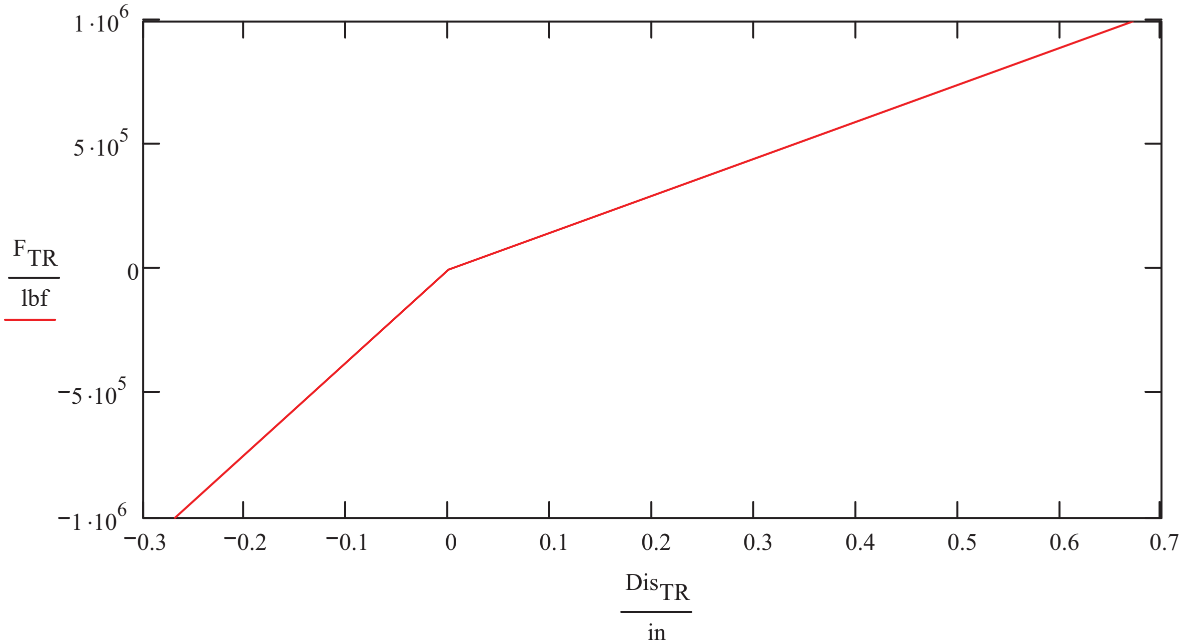
Resulting Force Displacement profile for the Tunnel Restraint where one nonlinear spring is utilized to represent the entire profile below.



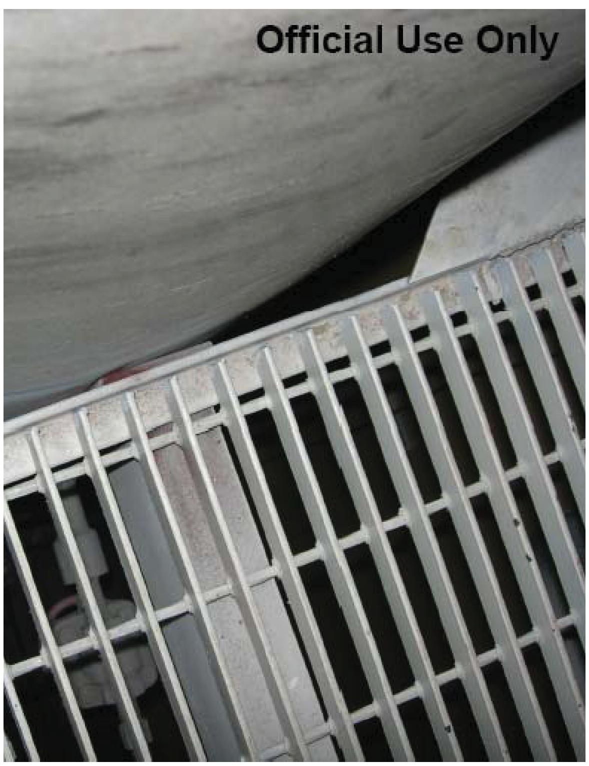


Photo [M3-1-27-N300-WBUI-DSCN3044]

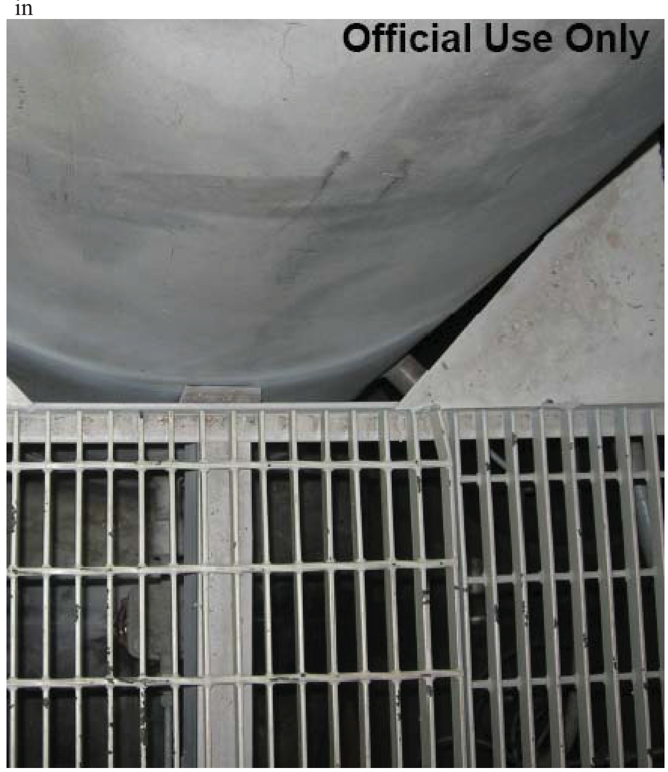


Photo [M3-1-27-N300-WBUI-DSCN2922]

RH-23x *(Gap in the top eye bolt where upward movement will cause lift off causing the top of the eye bolt to interface with the top interior of the welded beam attachment)*

RH-23x Stiffness

$D_{RH23x} := 1\frac{1}{4}in$ — Diameter of rods comprising RH-23x [18]

$A_{RH23x} := \frac{\pi \cdot D_{RH23x}^2}{4}$ — Cross Sectional area of rods comprising RH-23x

$A_{RH23x} = 1.227\ in^2$

$L_{RH23x} := 171in$ — Length between RH-23x's lower connection and area ceiling [19, (E6)] [15, (p19)] [M3-1-27-N310-CSUPC-DSC00143 (see below)]

$K_{RH23x} := \frac{A_{RH23x} \cdot E}{L_{RH23x}}$ — Stiffness of RH-23x

$K_{RH23x} = 2.081 \times 10^5 \frac{lbf}{in}$

RH-23x Stiffness Profile

Properties of welded beam attachment designed to accommodate 1.25" eye rod

$E'_{wba1.25} := 3in$ — Distance between top of welded beam attachment and center of bolt hole [22, ph-33]

$T_{wba1.25} := \frac{5}{8}in$ — Thickness of welded beam attachment [22, ph-33]

$H_{wba1.25} := 1\frac{3}{8}in$ — Diameter of welded beam attachment hole [22, ph-33]

$G_{RH23x} := E'_{wba1.25} - T_{wba1.25} - \frac{H_{wba1.25}}{2} - D_{RH23x}$ — RH-23x gap between top of welded beam attachment interior and top of eye rod in initial hanging state

$G_{RH23x} = 0.437\ in$

$F_{RH23x} := \begin{pmatrix} -10^6 & 0 & 0 & 10^6 \end{pmatrix} lbf^T$ — Force profile applied

(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$Dis_{RH23x} := \left[\left(\frac{F_{RH23x_0}}{K_{RH23x}} - G_{RH23x} \right) \quad -G_{RH23x} \quad 0in \quad \frac{F_{RH23x_3}}{K_{RH23x}} \right]^T$ — Corresponding Displacement profile to applied Force profile

$Dis_{RH23x}^T = \begin{pmatrix} -5.24244 & -0.4375 & 0 & 4.80494 \end{pmatrix} in$

Resulting Force Displacement profile for RH-23x

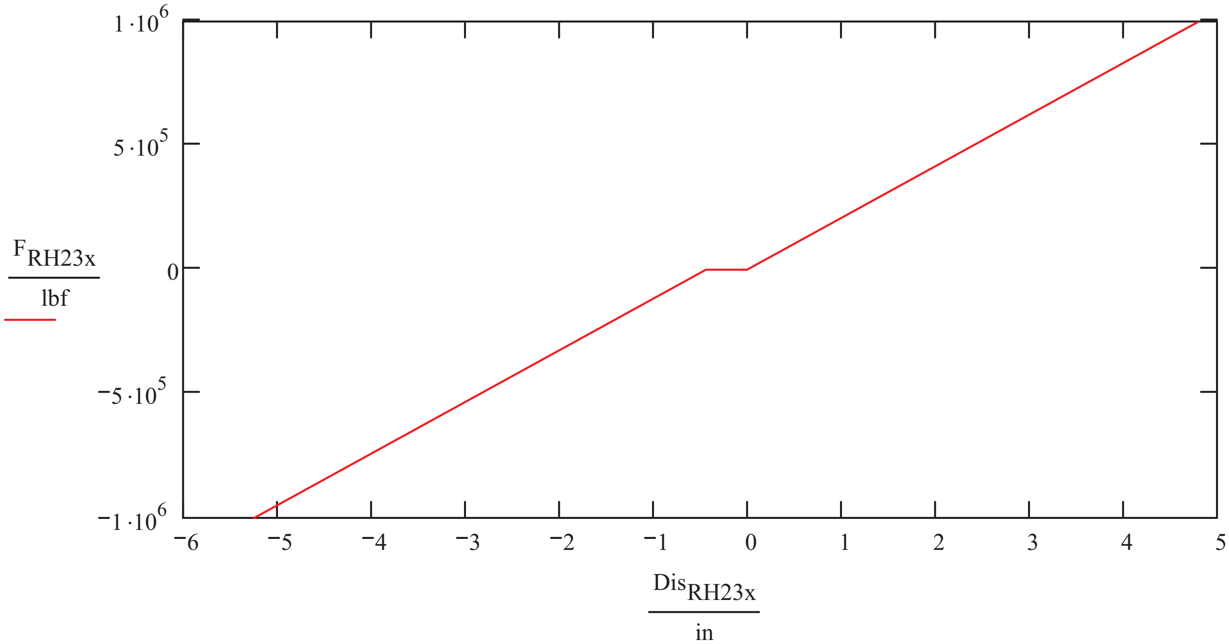


Photo of [M3-1-27-N310-CSUPC-DSC00143]

RH-25x *(Any upward movement causes uplift for this support)*

RH-25x Stiffness

$D_{RH25Ax} := 1\frac{1}{4}in$

Diameter of rods comprising RH-25x [18]

$A_{RH25Ax} := \frac{\pi \cdot D_{RH25Ax}^{2}}{4}$

Cross Sectional area of rods comprising RH-25x

$A_{RH25Ax} = 1.227\ in^{2}$

$L_{RH25Ax} := 114in$

Length between RH-25x's lower connections and area ceiling (the lower connection is assumed to be even with the top of the line 1-27 pipe [19, (E8)] [21, (Det 26)]

$K_{RH25Ax} := \frac{A_{RH25Ax} \cdot E}{L_{RH25Ax}}$

Stiffness of one leg of RH-25x

$K_{RH25Ax} = 3.122 \times 10^{5}\ \frac{lbf}{in}$

$K_{RH25ABx} := K_{RH25Ax} + K_{RH25Ax}$

$K_{RH25ABx} = 6.244 \times 10^{5}\ \frac{lbf}{in}$

Stiffness of entire support (NOTE: Springs add in parallel)

RH-25x Stiffness Profile

$F_{RH25ABx} := \begin{pmatrix} 0 & 0 & 10^{6} \end{pmatrix} lbf^{T}$

Force profile applied

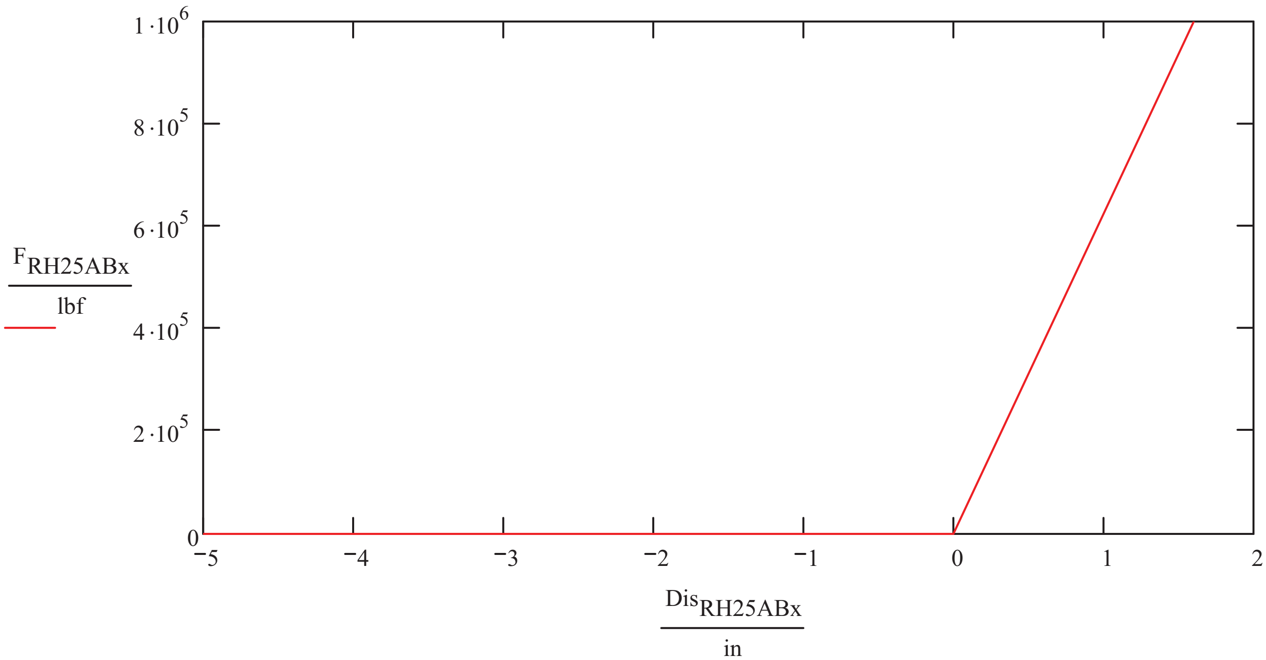
(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$Dis_{RH25ABx} := \begin{pmatrix} -5in & 0in & \frac{F_{RH25ABx_2}}{K_{RH25ABx}} \end{pmatrix}^{T}$

Corresponding Displacement profile to applied Force profile where 5in. is used to represent the uplift displacement response trend for upward force

$Dis_{RH25ABx}^{T} = \begin{pmatrix} -5 & 0 & 1.60165 \end{pmatrix} in$

Resulting Force Displacement profile for RH-25x



RH-26x *(Any upward movement causes uplift for this support)*

RH-26x Stiffness

$$D_{RH26Ax} := 1\frac{1}{4}\text{in}$$

Diameter of rods comprising RH-26x (though one leg of RH-26x is modified and its top portion consists of two 1" rods (increased cross section) it also has to accommodate another line of pipe (8-14) and assuming the more robust leg to be the same as that of the constant 1.25" leg is the technique applied to determine this supports stiffness [18]

$$A_{RH26Ax} := \frac{\pi \cdot D_{RH26Ax}^{2}}{4}$$

Cross Sectional area of rods comprising RH-26x

$$A_{RH26Ax} = 1.227\ \text{in}^2$$

$$L_{RH26Ax} := 114\text{in}$$

Length between RH-26x's lower connections and area ceiling [19, (E10)] (the lower connection is assumed to be even with the top of the line 1-27 pipe as approximated by [21, (Det 26)] & [M3-1-27-N340-CSUG-DSCN2934 (see below)]

$$K_{RH26Ax} := \frac{A_{RH26Ax} \cdot E}{L_{RH26Ax}}$$

Stiffness of one leg of RH-26x

$$K_{RH26Ax} = 3.122 \times 10^5 \frac{\text{lbf}}{\text{in}}$$

$$K_{RH26ABx} := K_{RH26Ax} + K_{RH26Ax}$$

$$K_{RH26ABx} = 6.244 \times 10^5 \frac{\text{lbf}}{\text{in}}$$

Stiffness of entire support (NOTE: Springs add in parallel)

RH-26x Stiffness Profile

$$F_{RH26ABx} := \begin{pmatrix} 0 & 0 & 10^6 \end{pmatrix}\text{lbf}^{T}$$

Force profile applied

$$Dis_{RH26ABx} := \begin{pmatrix} -5\text{in} & 0\text{in} & \dfrac{F_{RH26ABx_2}}{K_{RH26ABx}} \end{pmatrix}^{T}$$

Corresponding Displacement profile to applied Force profile where 5in. is used to represent the uplift displacement response trend for upward force

$$Dis_{RH26ABx}^{T} = \begin{pmatrix} -5 & 0 & 1.60165 \end{pmatrix}\text{in}$$

Resulting Force Displacement profile for RH-26x

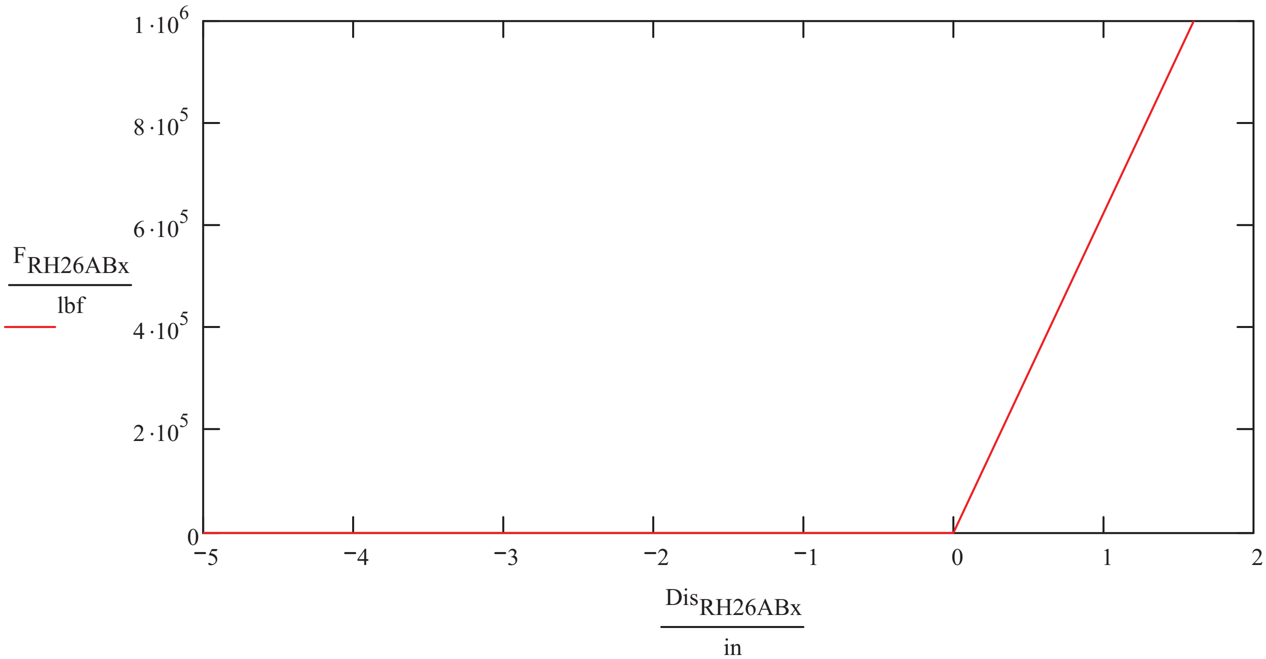


Photo of [M3-1-27-N340-CSUG-DSCN2934]

Tie Back *(Any upward movement causes uplift for this support)*

Tie Back Stiffness

$$W_{TB} := 8in$$

Width of Tie Back section interfacing with lower steel structure of support [21, (Det 7)] [23]

$$T_{TB} := \frac{3}{4}in$$

Thickness of Tie Back section interfacing with lower steel structure of support [21, (Det 7)] [23]

$$A_{TB} := W_{TB} \cdot T_{TB}$$

$$A_{TB} = 6\,in^2$$

Cross Sectional area of Tie Back section interfacing with lower steel structure of support

$$L_{TB} := 3\frac{1}{2}in$$

Length of Tie Back section interfacing with lower steel structure of support [21, (Det 7)] [23]

$$K_{TB} := \frac{A_{TB} \cdot E}{L_{TB}}$$

Stiffness of Tie Back

$$K_{TB} = 4.971 \times 10^7 \frac{lbf}{in}$$

Tie Back Stiffness Profile

$$F_{TB} := \begin{pmatrix} -10^6 & 0 & 0 \end{pmatrix} lbf^T$$

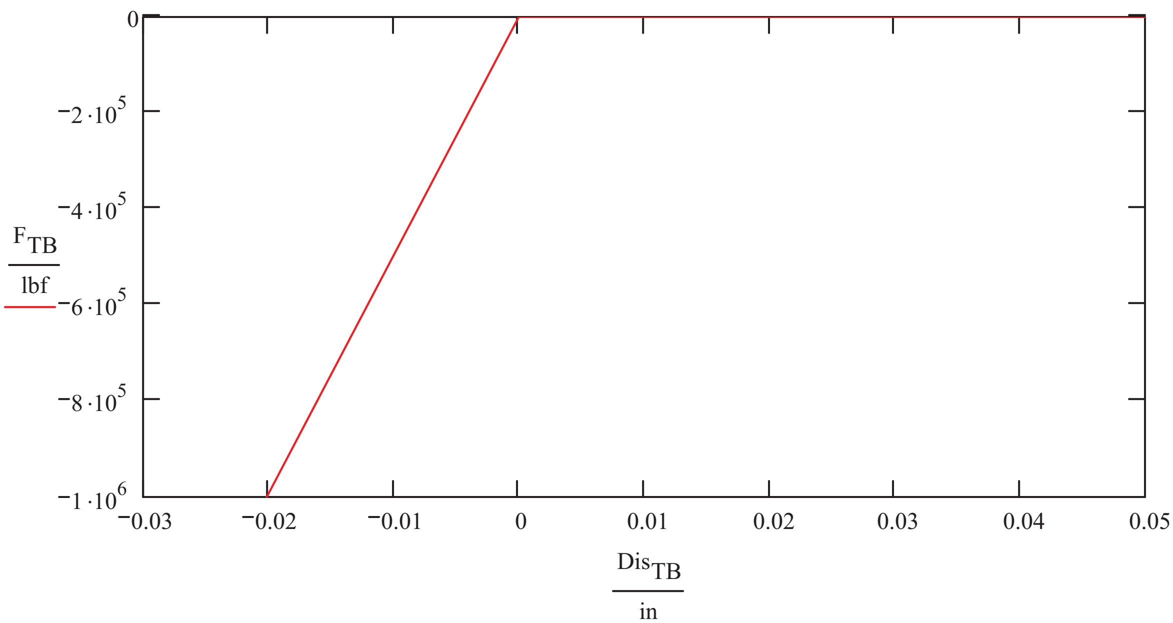
Force profile applied

$$Dis_{TB} := \begin{pmatrix} \frac{F_{TB_0}}{K_{TB}} & 0in & 0.05in \end{pmatrix}^T$$

Corresponding Displacement profile to applied Force profile where 0.05in. is used to represent the uplift displacement response trend for upward force

$$Dis_{TB}^T = \begin{pmatrix} -0.02011 & 0 & 0.05 \end{pmatrix} in$$

Resulting Force Displacement profile for Tie Back



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RH-27x *(This support behaves like a chain where any upward movement causes the chain to collapse)*

RH-27x Stiffness

Only the rods are considered in determining the stiffness of this support

$$D_{RH27Ax} := 1\frac{1}{4}in$$

Diameter of rods comprising RH-27x [18]

$$A_{RH27Ax} := \frac{\pi \cdot D_{RH27Ax}^2}{4}$$

Cross Sectional area of rods comprising RH-27x

$$A_{RH27Ax} = 1.227\ in^2$$

$$L_{RH27Ax} := 98.63\,in$$

Length between RH-27Ax's (east side leg's) lower connection and area ceiling [19, (E12)] [20, (Det 54)]

$$L_{RH27Bx} := 92.26\,in$$

Length between RH-27Bx's (west side leg's) lower connection and area ceiling [19, (E12)] [20, (Det 54)] [8] [22]

$$K_{RH27Ax} := \frac{A_{RH27Ax} \cdot E}{L_{RH27Ax}}$$

Stiffness of RH-27Ax (east leg)

$$K_{RH27Ax} = 3.608 \times 10^5\ \frac{lbf}{in}$$

$$K_{RH27Bx} := \frac{A_{RH27Ax} \cdot E}{L_{RH27Bx}}$$

Stiffness of RH-27Bx (east leg)

$$K_{RH27Bx} = 3.857 \times 10^5\ \frac{lbf}{in}$$

$$K_{RH27ABx} := K_{RH27Ax} + K_{RH27Bx}$$

Stiffness of entire support (NOTE: Springs add in parallel)

$$K_{RH27ABx} = 7.466 \times 10^5\ \frac{lbf}{in}$$

RH-27x Stiffness Profile

$$F_{RH27ABx} := \begin{pmatrix} 0 & 0 & 10^6 \end{pmatrix} lbf^T$$

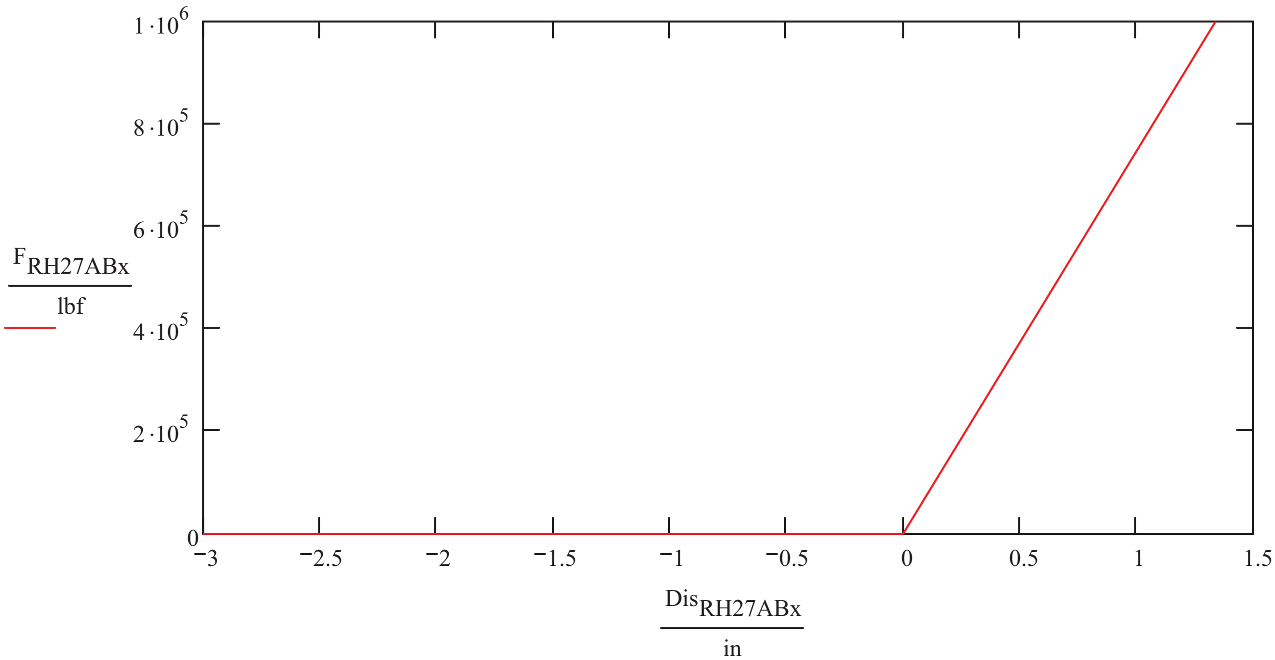
Force profile applied

$$Dis_{RH27ABx} := \begin{pmatrix} -3in & 0in & \dfrac{F_{RH27ABx_2}}{K_{RH27ABx}} \end{pmatrix}^T$$

Corresponding Displacement profile to applied Force profile where 5in. is used to represent the uplift displacement response trend for upward force

$$Dis_{RH27ABx}^T = \begin{pmatrix} -3 & 0 & 1.339 \end{pmatrix} in$$

Resulting Force Displacement profile for RH-27x



RH-24 *(Pipe allowed to slide up the threaded rod to a certain point given upward loading*

RH-24 Stiffness (Note: Support is not documented incorrectly in detail documentation. Subsequent dimensions are derived from the field photo shown below.)

Welded Beam Attachment section

$W_{RH29\_wba} := 2in$

Width of RH-24's welded beam attachment section [22, ph-33] [M3-1-47-N49-CSUG-DSCN2775 (see below]

$T_{RH29\_wba} := \frac{1}{2}in$

Thickness of both legs of RH-24's welded beam attachment section [22, ph-33] [M3-1-47-N49-CSUG-DSCN2775 (see below)]

$A_{RH29\_wba} := W_{RH29\_wba} \cdot T_{RH29\_wba}$

$A_{RH29\_wba} = 1\ in^2$

Cross sectional area of welded beam attachment

$L_{RH29\_wba} := 2in$

Length of welded beam attachment section [22, ph-33] scaled from [M3-1-47-N49-CSUG-DSCN2775 (see below)]

$K_{RH29\_wba} := \frac{A_{RH29\_wba} \cdot E}{L_{RH29\_wba}}$

Stiffness of welded beam attachment portion of RH-24

$K_{RH29\_wba} = 1.45 \times 10^7 \frac{lbf}{in}$

Rod section

$D_{RH29\_rod} := \frac{5}{8}in$

Diameter of rod comprising RH-24 [18]

$A_{RH29\_rod} := \frac{\pi \cdot D_{RH29\_rod}^2}{4}$

Cross Sectional area of rod comprising RH-24

$A_{RH29\_rod} = 0.307\ in^2$

$L_{RH29\_rod} := 1\frac{3}{4}in$

Length of rod section scaled from [M3-1-47-N49-CSUG-DSCN2775 (see below)]

$K_{RH29\_rod} := \frac{A_{RH29\_rod} \cdot E}{L_{RH29\_rod}}$

Stiffness of rod portion of RH-24

$K_{RH29\_rod} = 5.084 \times 10^6 \frac{lbf}{in}$

Adjustable Clevis section (will apply smaller cross section of the lower and upper portions of the clevis and use the distance from the pipe to where the clamp mates with the rod as the length of this cross section)

$$W_{RH29\_AC} := 1\frac{1}{4}in$$

Width of the lower section of RH-24's adjustable clevis [22, ph-12]

$$T_{RH29\_AC} := \frac{3}{16}in$$

Thickness of lower section of RH-24's adjustable clevis [22, ph-12]

$$A_{RH29\_AC} := W_{RH29\_AC} \cdot T_{RH29\_AC}$$

Cross sectional area of welded beam attachment

$$A_{RH29\_AC} = 0.234\ in^2$$

$$L_{RH29\_AC} := 1\frac{3}{4}in$$

Length of adjustable clevis section [22, ph-12]

$$K_{RH29\_AC} := \frac{A_{RH29\_AC} \cdot E}{L_{RH29\_AC}}$$

Stiffness of adjustable clevis portion of RH-24

$$K_{RH29\_AC} = 3.884 \times 10^6 \frac{lbf}{in}$$

Combined stiffness of support (NOTE: springs in series combine as reciprocals)

$$K_{RH29} := \frac{1}{\frac{1}{K_{RH29\_wba}} + \frac{1}{K_{RH29\_rod}} + \frac{1}{K_{RH29\_AC}}}$$

$$K_{RH29} = 1.912 \times 10^6 \frac{lbf}{in}$$

RH-24 Stiffness Profile

$$G_{RH29} := \frac{5}{8}in$$

RH-24 gap scaled from [M3-1-47-N49-CSUG-DSCN2775 (see below)]

$$F_{RH29} := \left(-10^6 \quad 0 \quad 0 \quad 10^6\right) lbf^T$$

Force profile applied

(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$$Dis_{RH29} := \left[\left(\frac{F_{RH29_0}}{K_{RH29}} - G_{RH29}\right) \quad -G_{RH29} \quad 0in \quad \frac{F_{RH29_3}}{K_{RH29}}\right]^T$$

Corresponding Displacement profile to applied Force profile

$$Dis_{RH29}^T = (-1.14813 \quad -0.625 \quad 0 \quad 0.52313)\ in$$

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Resulting Force Displacement profile for RH-24

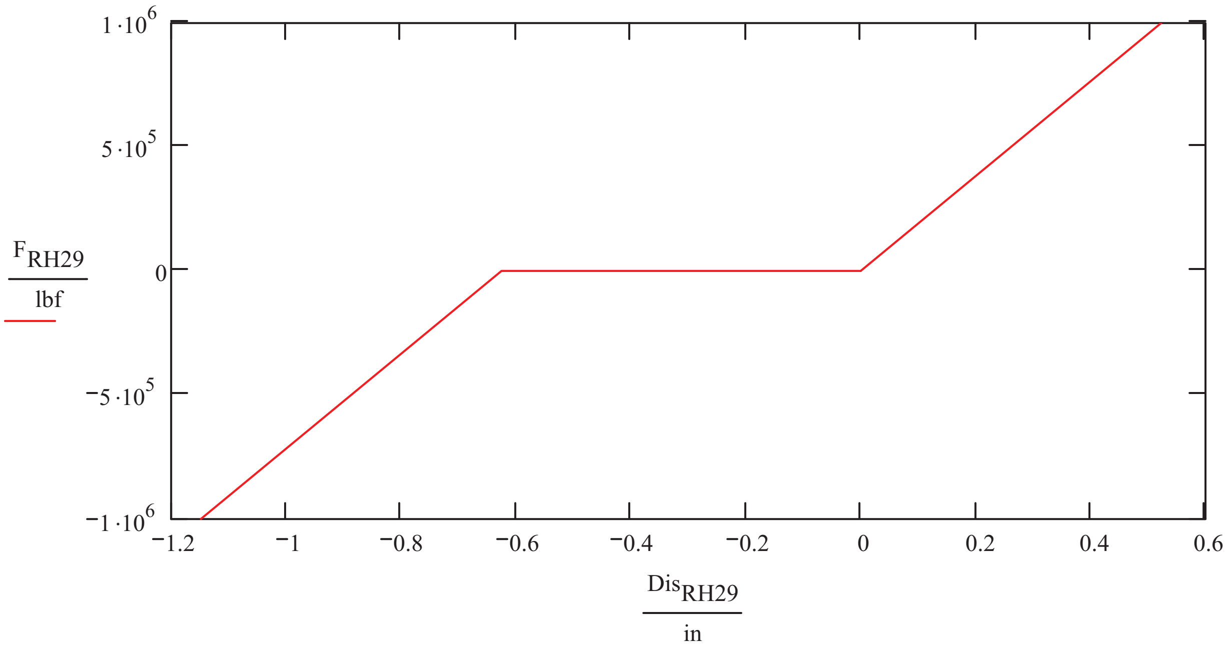

Photo [M3-1-47-N49-CSUG-DSCN2775]

RH-15A *(Large eye rod opening at pipe connection)*

RH-15A Stiffness

$D_{RH15A} := 1in$ — Diameter of rod comprising RH-15A [24]

$A_{RH15A} := \frac{\pi \cdot D_{RH15A}^2}{4}$ — Cross Sectional area of rods comprising RH-15A

$A_{RH15A} = 0.785\ in^2$

$L_{RH15A} := 41\frac{3}{4}in$ — Length between RH-15A connections [19, (H6)] [20, (Det 52)]

$K_{RH15A} := \frac{A_{RH15A} \cdot E}{L_{RH15A}}$ — Stiffness of RH-15A

$K_{RH15A} = 5.455 \times 10^5 \frac{lbf}{in}$

RH-15A Stiffness Profile

Properties of pipe clamp designed to accommodate 1" eye rod

$E_{clmp14} := 9\frac{1}{4}in$ — Distance between center of pipe and center of bolt hole [22, ph-33]

$F_{clmp14} := \frac{7}{8}in$ — Diameter of bolt [22, ph-33]

$D_{pipe14} := 14in$ — Diameter of line 1-32 that RH-15A is supporting

$G_{RH15A} := E_{clmp14} - \frac{F_{clmp14}}{2} - D_{RH15A} - \frac{D_{pipe14}}{2}$ — Gap between bottom of RH-15A eye rod and pipe on line 1-32

$G_{RH15A} = 0.813\ in$

$F_{RH15A} := \left(-10^6\ \ 0\ \ 0\ \ 10^6\right) lbf^T$ — Force profile applied

(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$Dis_{RH15A} := \left[\left(\frac{F_{RH15A_0}}{K_{RH15A}} - G_{RH15A}\right)\ \ -G_{RH15A}\ \ 0in\ \ \frac{F_{RH15A_3}}{K_{RH15A}}\right]^T$ — Corresponding Displacement profile to applied Force profile

$Dis_{RH15A}^T = (-2.64553\ \ -0.8125\ \ 0\ \ 1.83303)\ in$

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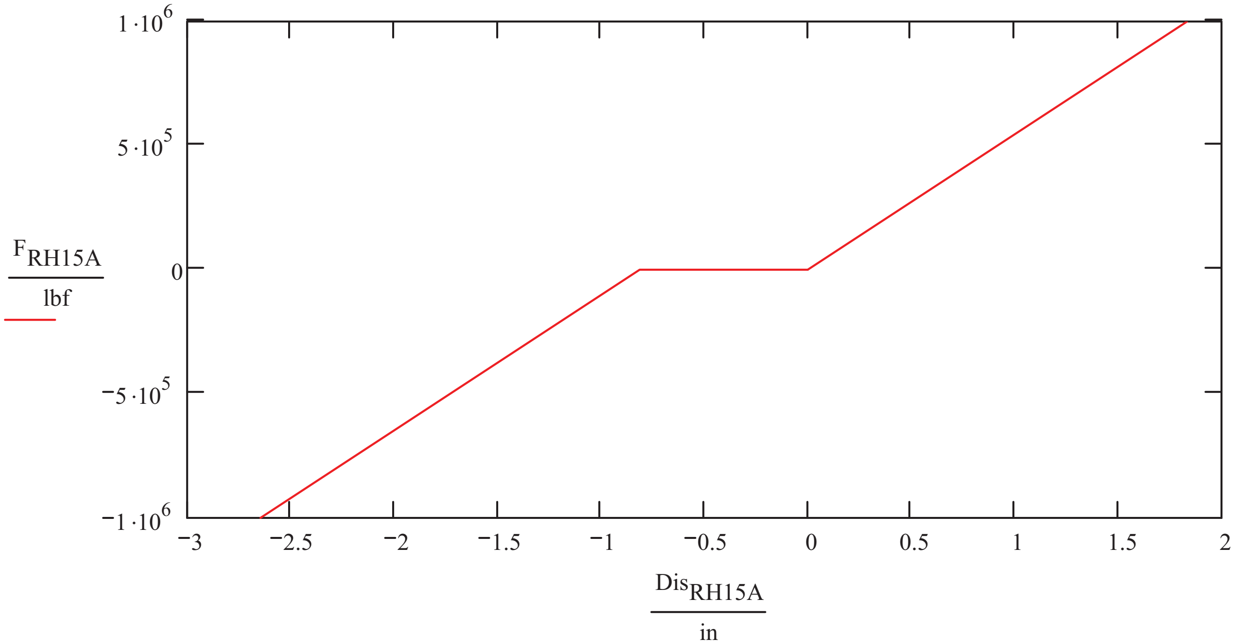
Resulting Force Displacement profile for RH-15A



RH-15 *(Connection appears to be tight enough to treat as a linear spring)*

RH-15 Stiffness

$D_{RH15} := 0.75in$ — Diameter of rod comprising RH-15 [18]

$A_{RH15} := \frac{\pi \cdot D_{RH15}^2}{4}$ — Cross Sectional area of rods comprising RH-15

$A_{RH15} = 0.442\ in^2$

$L_{RH15} := 41\frac{3}{4}in$ — Length between RH-15 connections [19, (H6)] [20, (Det 52)]

$K_{RH15} := \frac{A_{RH15} \cdot E}{L_{RH15}}$ — Stiffness of RH-15

$K_{RH15} = 3.069 \times 10^5 \frac{lbf}{in}$

RH-15 Stiffness Profile

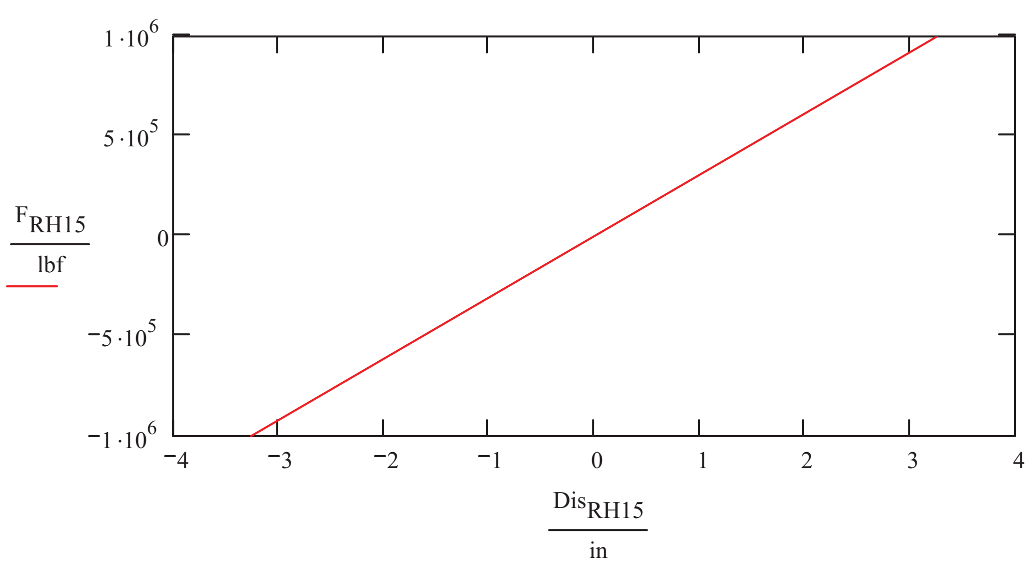
$F_{RH15} := \left(-10^6\ \ 10^6\right)^T lbf$ — Force profile applied

(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$Dis_{RH15} := \left(\frac{F_{RH15_0}}{K_{RH15}}\ \ \frac{F_{RH15_1}}{K_{RH15}}\right)^T$ — Corresponding Displacement profile to applied Force profile

$Dis_{RH15}^T = (-3.25871\ \ 3.25871)\ in$

Resulting Force Displacement profile for RH-15A



PS-5 *(Doesn't resist any uplift)*

PS-5 (Doesn't resist any uplift because the pipe flange only sits on the u-shaped interface)

PS-5 Stiffness

$A_{PS5} := 2.97in^2$ — Cross sectional area of PS-5 support [18] [8, Table 1-14 pg 1-99]

$L_{PS5} := 13in$ — Length of PS-5 support [18]

$$K_{PS5} := \frac{A_{PS5} \cdot E}{L_{PS5}}$$ Stiffness of PS-5

$$K_{PS5} = 6.625 \times 10^6 \frac{lbf}{in}$$

PS-5 Stiffness Profile

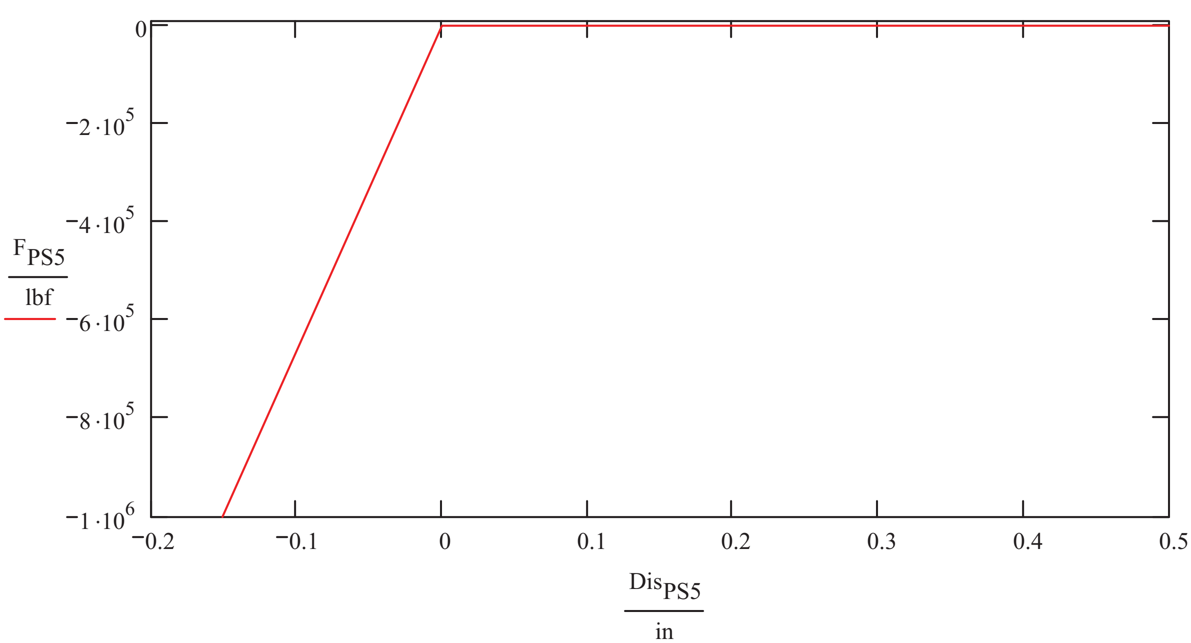
$F_{PS5} := \begin{pmatrix} -10^6 & 0 & 0 \end{pmatrix} lbf^T$ — Force profile applied

$$Dis_{PS5} := \begin{pmatrix} \frac{F_{PS5_0}}{K_{PS5}} & 0in & 0.5in \end{pmatrix}^T$$

Corresponding Displacement profile to applied Force profile where 5in. is used to represent the uplift displacement response trend for upward force

$$Dis_{PS5}^T = (-0.15093 \quad 0 \quad 0.5)\,in$$

Resulting Force Displacement profile for PS-5



Appendix B.6

Dimensions Associated with Supports, Spring Hangers, Terminations, Reducers, Elbows, Tees, Fabricated Branch, Flanges, and Valves of Model 3

(NOTE: Photos referenced in tables are included shortly after reference.)

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Table 1. Dimensions Associated with Supports on Line 1-22 of Model 3

Supports (1-22)	***Dimensions***		***Reference***
MS-8	Length of clamp cantilever	7.75"	[25]
	Size of cantilever	2 sections of (1.5" x 7")	M3-1-27-N470-WSNG-DSCN2963
	Length connection to anchorage	19"	[25]
	Distance from (Reference)	15' - 2*6.75" = 166.5" east of MS-5 located on West side of column [26, CD9]	[26, CD6-9],[27, L7-12],[28,EF7-12]

Table 2. Dimensions Associated with Supports on Line 1-25 of Model 3

Supports (1-25)	***Dimensions***		***Reference***
MS-7	Length of clamp cantilever	7.75"	[25]
	Size of cantilever	2 sections of (1.5" x 7")	M3-1-27-N470-WSNG-DSCN2963
	Length connection to anchorage	19"	[25]
	Distance from (Reference)	15' +2*3' + 2*6.75" = 265.5" west of MS-5 located on West side of column [26, CD7]	[26, CD6-9],[27, L7-12],[28,EF7-12]

Table 3. Dimensions Associated with Supports on Line 1-26 of Model 3

Supports (1-26)	***Dimensions***		***Reference***
MS-5	Length of clamp cantilever	7.75"	[25]
	Size of cantilever	2 sections of (1.5" x 7")	M3-1-27-N470-WSNG-DSCN2963
	Length connection to anchorage	19"	[25]
	Distance from (Reference)	13.25" from FORGED(1-26) located on East side of column [26, CD8]	M3-1-27-N470-WSNG-DSCN2963

Figure 1. Photo M3-1-27-N470-WSNG-DSCN2963

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Table 4. Dimensions Associated with Supports on Line 1-27 of Model 3

Supports (1-27)	***Dimensions***		***Reference***
PR-8	Length	86.5"	[19, H6], [28, Det 52]
	Nonlinear spring profile	See Appendix B.5	
Tunnel Restraint	Length	84" *	
	Distance from (Reference)	48" to FORGED(1-27) center	[19], M3-1-27-N300-WBUG-DSCN3050
	Nonlinear spring profile	See Appendix B.5	
RH-23x	Length of clamp cantilever	11"	M3-1-27-N310-CSUPC-DSC00143
	Size of cantilever	2 sections of (3/4" x 6")	[18]
	Distance from (Reference)	9" from EL(1-27A)	[19, G6], M3-1-27-N310-CSUPC-DSC00143
	Length connection to ceiling	171"	[19, E6]
	Nonlinear spring profile	See Appendix B.5	
RH-25ABx (South)	Length pipe center to ceiling	132"	[19, E8]
	Distance from (Reference)	29' - EL(1-27A) = 312"	[19, E6-8]
	Nonlinear spring profile	See Appendix B.5	
RH-25ABx (North)	Length pipe center to ceiling	132"	[19, E8,9]
	Distance from (Reference)	45' - EL(1-27A) = 504"	[19, E6-9]
	Nonlinear spring profile	See Appendix B.5	
RH-26x	Length pipe center to ceiling	132" (ceiling height different than drawing)	[19, E10], M3-1-27-N370-CSUA-DSCN3028
	Distance from (Reference)	100" north of BF(1-27)	M3-1-27-N370-CSUG-DSCN2941
	Nonlinear spring profile	See Appendix B.5	
Floor Restraint	Distance from (Reference)	150" north of BF(1-27)	[19, GH14,15]
	Nonlinear spring profile	See Appendix B.5	
MS-2	Length of clamp cantilever	11.125"	[29]
	Size of cantilever	2 sections of (1.5" x 10")	[29], M3-1-27-N390-CSNG-DSCN2950
	Diameter of Snubber	6" (Used to approximate extremely stiff member)	
	Distance from (Reference)	20" from EL(1-27B)	M3-1-27-N390-CSNG-DSCN2950
RH-27x	Length pipe center to ceiling	150"	[19, E12]
	Distance from (Reference)	12" from EL(1-27B)	M3-1-27-N390-CSNG-DSCN2950
	Nonlinear spring profile	See Appendix B.5	
PS-3A	Length bottom of pipe to floor	178"	[21, Det 21]
	Size of pipe	8" std (8.625" x 0.322")	[21, Det 21]
	Distance from (Reference)	15" from FAB BRANCH(1-26)	M3-1-27-N430-FSUPC-DSC00081

*Length was assumed to be long enough so that the system acted as if the pipe could slide across the face of the support in the NS direction (Small angle approximation theory)

Figure 2. Photo M3-1-27-N300-WBUG-DSCN3050

Figure 3. Photo M3-1-27-N310-CSUPC-DSC00143

Figure 4. Photo M3-1-27-N370-CSUA-DSCN3028

Figure 5. Photo M3-1-27-N370-CSUG-DSCN2941

Figure 6. Photo M3-1-27-N430-FSUPC-DSC00081

Table 5. Dimensions Associated with Supports on Line 1-28 of Model 3

Supports (1-28)	*Dimensions*		*Reference*
PR-1 (East)	Length pipe run to attachment	9"	M3-1-28-N50-WSUPC-DSCN2864
	Length of bolt connection rods	8.5" with 9.5" engagement	M3-1-28-N50-WSUPC-DSCN2864
	Size of bolt connection rods	1.25" diameter	[30]
	Length of intermediate pipe	54"	[30]
	Size of intermediate pipe	2.5" x 5 (2.88"D x 0.205"T)	[30]
	Distance from (Reference)	3" from EL(1-28B)	M3-1-28-N50-WSUPC-DSCN2864

Table 6. Dimensions Associated with Supports on Line 1-29 of Model 3

Supports (1-29)	*Dimensions*		*Reference*
PR-1 (West)	Length of clamp cantilever	9"	M3-1-28-N50-WSUPC-DSCN2864
	Length of bolt connection rods	8.5" with 9.5" engagement	M3-1-28-N50-WSUPC-DSCN2864
	Size of bolt connection rods	1.25" diameter	[30]
	Length of intermediate pipe	54"	[30]
	Size of intermediate pipe	2.5" x 5 (2.88"D x 0.205"T)	[30]
	Distance from (Reference)	3" from EL(1-29B)	M3-1-28-N50-WSUPC-DSCN2864

Figure 7. Photo M3-1-28-N50-WSUPC-DSCN2864

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Table 7. Dimensions Associated with Supports on Line 1-32 of Model 3

Supports (1-32)	*Dimensions*		*Reference*
PR-11	Length pipe edge to anchorage	17"	[20, Det 48]
	Size of cantilever	3I x 7.5	[20, Det 48]
	Distance from (Reference)	(1'-6") + 6.75" = 24.75" east of MS-7 located on center of column	[26, CD7]
PS-21	Length pipe edge to anchorage	18.5"	[24]
	Size of angle iron section	2.5" x 2.5" x 3/8"	[24]
	Distance from (Reference)	3" from EL(1-32E)	M3-1-32-N970-WSUG-DSC00068
RH-15A	Length from clamp to ceiling	41.75"	[27, J2-3]
	Distance from (Reference)	3" from EL(1-32E)	M3-1-32-N970-WSUG-DSC00068
	Nonlinear spring profile	See Appendix B.5	
RH-15	Length from clamp to ceiling	41.75"	[27, J2-3]
	Distance from (Reference)	(7'-3") + (6'-4") + (2'-0")/2 + (12") + (18") - (2") - EL(1-32E) = 182" from EL(1-32E)	[28, E2-4]
	Nonlinear spring profile	See Appendix B.5	
RH-15	Length from clamp to ceiling	41.75"	[27, J2-3]
	Distance from (Reference)	25.625" from EL(1-32D)	M3-1-32-N990-WPG-DSC00055
	Nonlinear spring profile	See Appendix B.5	
PS-5	Length from flange to floor	13"	[18]
	Distance from (Reference)	At FL(1-32C)	[28, G2-3]
	Nonlinear spring profile	See Appendix B.5	
PS-5	Length from flange to floor	13"	[18]
	Distance from (Reference)	At FL(1-32B)	[28, G2-3]
	Nonlinear spring profile	See Appendix B.5	

Figure 8. Photo M3-1-32-N970-WSUG-DSC00068

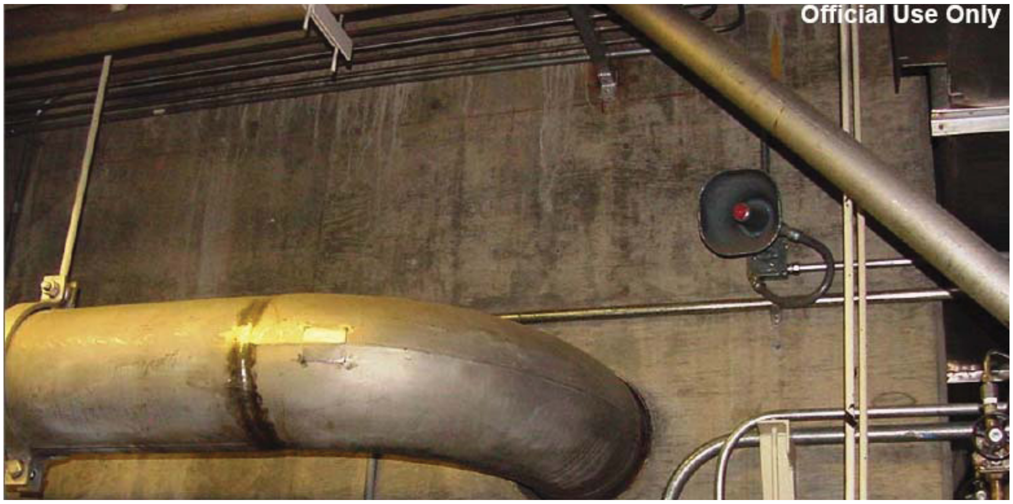

Figure 9. Photo M3-1-32-N990-WPG-DSC00055

Table 8. Dimensions Associated with Supports on Line 1-33 of Model 3

Supports (1-33)	***Dimensions***		***Reference***
PS-5	Length from flange to floor	13"	[18]
	Distance from (Reference)	At FL(1-33C)	[28, G2-3]
	Nonlinear spring profile	See Appendix B.5	

PS-5	Length from flange to floor	13"	[18]
	Distance from (Reference)	At FL(1-33B)	[28, G2-3]
	Nonlinear spring profile	See Appendix B.5	

Table 9. Dimensions Associated with Supports on Line 1-49 of Model 3

Supports (1-49)	***Dimensions***		***Reference***
RH-24	Length pipe center to ceiling	9.375"	M3-1-47-N49-CSUG-DSCN2775
	Distance from (Reference)	(6'-6")+(6'-0") = 150" from EL(1-49A)	[28, CD7]
	Nonlinear spring profile	See Appendix B.5	

RH-24	Length pipe center to ceiling	9.375"	M3-1-47-N49-CSUG-DSCN2775
	Distance from (Reference)	3" from EL(1-49A)	[28, D7]
	Nonlinear spring profile	See Appendix B.5	

Figure 10. Photo M3-1-47-N49-CSUG-DSCN2775

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Table 10. Dimensions Associated with Spring Hangers on Line 1-22 of Model 3

Spring Hangers (1-22)	*Dimensions*		*Reference*
SH-154	Location	Line 1-22C	[28, EF13]
	Dist from Ref	on FL(1-22C) *	M3-1-25-N870-CSPG-DSC00108
	Load	6600 lbf	[18]
SH-18A & SH-18B	Location	Line 1-22C	[28, FG13]
	Dist from Ref	on FL(1-22C)	M3-1-25-N850-CSPPC-DSC00103
	Load	3400 lbf + 3200 lbf = 6600 lbf	[18]

Table 11. Dimensions Associated with Spring Hangers on Line 1-23 of Model 3

Spring Hangers (1-23)	*Dimensions*		*Reference*
SH-153	Location	Line 1-23C	[28, EF10-11]
	Dist from Ref	on FL(1-23C) *	M3-1-25-N870-CSPG-DSC00108
	Load	9600 lbf	[18]
SH-5A3 & SH-5B3	Location	Line 1-23C	[28, FG10-11]
	Dist from Ref	on FL(1-23C)	M3-1-25-N850-CSPPC-DSC00103
	Load	2600 lbf + 2550 lbf = 5150 lbf	[18]

Table 12. Dimensions Associated with Spring Hangers on Line 1-24 of Model 3

Spring Hangers (1-24)	*Dimensions*		*Reference*
SH-152A & SH-152B	Location	Line 1-24C	[28, EF8-9]
	Dist from Ref	on FL(1-24C) *	M3-1-25-N870-CSPG-DSC00108
	Load	6300 lbf + 6600 lbf = 12900 lbf	[18]
SH-5A2 & SH-5B2	Location	Line 1-24C	[28, FG8-9]
	Dist from Ref	on FL(1-24C)	M3-1-25-N850-CSPPC-DSC00103
	Load	2400 lbf + 2200 lbf = 4600 lbf	[18]

Table 13. Dimensions Associated with Spring Hangers on Line 1-25 of Model 3

Spring Hangers (1-25)	*Dimensions*		*Reference*
SH-151	Location	Line 1-25C	[28, EF7]
	Dist from Ref	on FL(1-25C) *	M3-1-25-N870-CSPG-DSC00108
	Load	7200 lbf	[18]
SH-5A1 & SH-5B1	Location	Line 1-25C	[28, FG6]
	Dist from Ref	on FL(1-25C)	M3-1-25-N850-CSPPC-DSC00103
	Load	3050 lbf + 3000 lbf = 6050 lbf	[18]

* Though photo M3-1-25-N870-CSPG-DSC00108 indicates that the spring hanger is attached to the pipe approximately 5" away from the valve and flange joint the spring hanger load is applied at the joint to conserve nodal quantity in model

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Figure 11. Photo M3-1-25-N870-CSPG-DSC00108

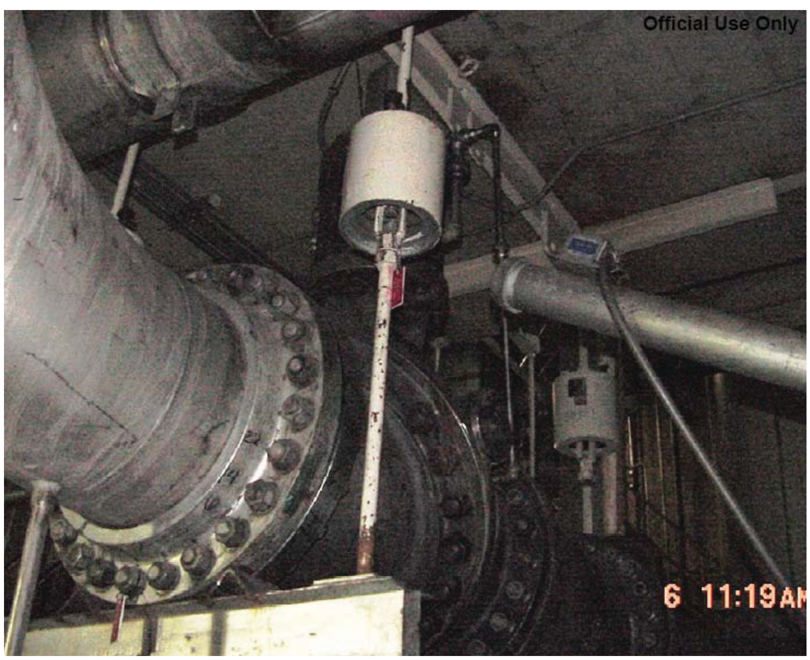

Figure 12. Photo M3-1-25-N850-CSPPC-DSC00103

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Table 14. Dimensions Associated with Spring Hangers on Line 1-27 of Model 3

Spring Hangers (1-27)	*Dimensions*		*Reference*
SH-24A & SH-24B	Location	Line 1-27B	[28, F7]
	Dist from Ref	(13'-0") - EL(1-27A) = 120"	[19, EF]
	Load	4700 lbf + 4650 lbf = 9350 lbf	[18]

Table 15. Dimensions Associated with Spring Hangers on Line 1-28 of Model 3

Spring Hangers (1-28)	*Dimensions*		*Reference*
SH-1A & SH-2A	Location	Line 1-28B	[19, E2], [28, N15]
	Dist from Ref	44" from EL(1-28A)	M3-1-28-N40-CSPG-DSCN2891
	Load	2750 lbf + 2750 lbf = 5500 lbf	[18]
SH-3A	Location	Line 1-28C	[28, M15]
	Dist from Ref	3" from EL(1-28B)	M3-1-28-N60-CSPG-DSCN2866
	Load	5250 lbf	[18]
SH-9A	Location	Line 1-28C	[19, G4], [28, L15]
	Dist from Ref	32" from GT(1-28) toward EL(1-28C)	M3-1-29-N210-CSPG-DSCN2871
	Load	7200 lbf	[18]
SH-4A	Location	Line 1-28D	[19, G6], [28, J15]
	Dist from Ref	24" from EL(1-28C)	M3-1-28-N120-CSUA-DSCN2875
	Load	5000 lbf	[18]

Table 16. Dimensions Associated with Spring Hangers on Line 1-29 of Model 3

Spring Hangers (1-29)	*Dimensions*		*Reference*
SH-1B & SH-2B	Location	Line 1-29B	[28, N12]
	Dist from Ref	44" from EL(1-29A)	M3-1-28-N40-CSPG-DSCN2891
	Load	2850 lbf + 2900 lbf = 5750 lbf	[18]
SH-3B	Location	Line 1-29C	[28, M12]
	Dist from Ref	3" from EL(1-29B)	M3-1-28-N60-CSPG-DSCN2866
	Load	5500 lbf	[18]
SH-9B	Location	Line 1-29C	[28, L12]
	Dist from Ref	32" from GT(1-29) toward EL(1-29C)	M3-1-29-N210-CSPG-DSCN2871
	Load	7900 lbf	[18]
SH-4B	Location	Line 1-29D	[28, J12]
	Dist from Ref	24" from EL(1-29C)	M3-1-28-N120-CSUA-DSCN2875
	Load	4500 lbf	[18]

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Figure 13. Photo M3-1-28-N40-CSPG-DSCN2891

Figure 14. Photo M3-1-28-N60-CSPG-DSCN2866

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Figure 15. Photo M3-1-29-N210-CSPG-DSCN2871

Figure 16. Photo M3-1-28-N120-CSUA-DSCN2875

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Table 17. Dimensions Associated with Spring Hangers on Line 1-2 of Model 3

Spring Hangers (1-32)	*Dimensions*		*Reference*
SH-16	Location	Line 1-32G	[27, L6]
	Dist from Ref	6" from EL(1-32F)	M3-1-32-N930-CSUPC-DSC00075
	Load	3900 lbf	[18]
SH-21	Location	Line 1-32D	[27, B2]
	Dist from Ref	6.3" from EL(1-32B) & EL(1-32C)	M3-1-32-N1110-CSPG-DSC00047
	Load	5000 lbf	[18]

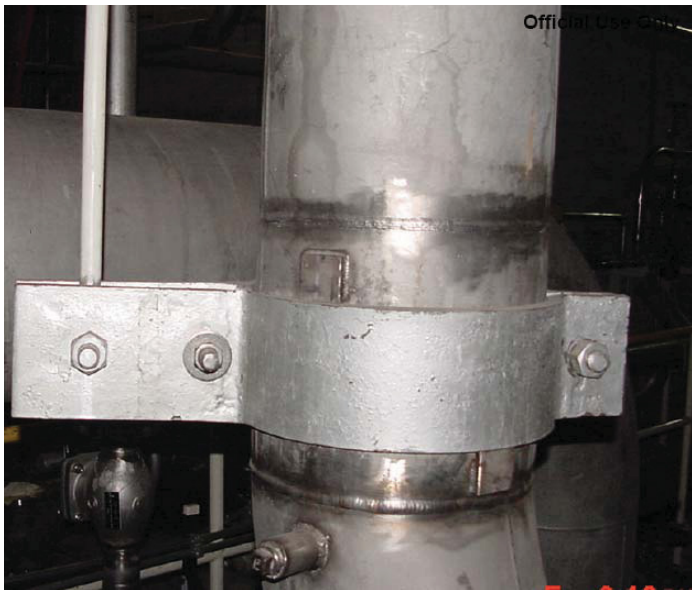

Figure 17. Photo M3-1-32-N930-CSUPC-DSC00075

Figure 18. Photo M3-1-32-N1110-CSPG-DSC00047

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Table 18. Location Associated with Termination on Line 1-22 of Model 3

Termination (1-22)	*Dimensions*		*Reference*
PP(1-22)	Location	Where line 1-22 connects to primary pump	[4]

Table 19. Location Associated with Termination on Line 1-23 of Model 3

Termination (1-23)	*Dimensions*		*Reference*
PP(1-23)	Location	Where line 1-23 connects to primary pump	[5]

Table 20. Location Associated with Termination on Line 1-24 of Model 3

Termination (1-24)	*Dimensions*		*Reference*
PP(1-24)	Location	Where line 1-24 connects to primary pump	[5]

Table 21. Location Associated with Termination on Line 1-25 of Model 3

Termination (1-25)	*Dimensions*		*Reference*
PP(1-25)	Location	Where line 1-25 connects to primary pump	[6]

Table 22. Location Associated with Termination on Line 1-28 of Model 3

Termination (1-28)	*Dimensions*		*Reference*
RV(1-28)	Location	Where line 1-28 connects to reactor vessel	[11]

Table 23. Location Associated with Termination on Line 1-29 of Model 3

Termination (1-29)	*Dimensions*		*Reference*
RV(1-29)	Location	Where line 1-29 connects to reactor vessel	[12]

Table 24. Location Associated with Termination on Line 1-32 of Model 3

Termination (1-32)	*Dimensions*		*Reference*
EP(1-32)	Location	Where line 1-32 connects to emergency pump	[17]

Table 25. Location Associated with Termination on Line 1-33 of Model 3

Termination (1-33)	*Dimensions*		*Reference*
EP(1-33)	Location	Where line 1-33 connects to emergency pump	[17]

Table 26. Location Associated with Termination on Line 1-49 of Model 3

Termination (1-49)	*Dimensions*		*Reference*
NWP(1-49)	Location	Where line 1-49 penetrates north wall	[17]

Table 27. Dimensions Associated with Pipe Runs on Line 1-22 of Model 3

Pipe Run (1-22)	***Dimensions***		***Reference***
P (1-22A)	Pipe Diameter	18"	[4]
	Pipe Thickness	0.3125"	[4]
	Pipe Material	SS304	[4]
	Length between nozzel and RED(1-22A)	(4') - EL(1-22A) - RED(1-22A) = 9"	[4]
P (1-22B)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.375"	[4]
	Pipe Material	SS304	[4]
	Length between EL(1-22A) and EL(1-22B)	(14'-10") - EL(1-22A) - EL(1-22B) = 118"	[4]
P (1-22C)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.375"	[4]
	Pipe Material	SS304	[4]
	Length between EL(1-22B) and CK(1-22)	(3'-6") - EL(1-22B) = 12"	[4]
	Length between GT(1-22) and EL(1-22C)	(4'-5.625") - EL(1-22C) = 23.625"	[4]
P (1-22D)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.375"	[4]
	Pipe Material	SS304	[4]
	Length between EL(1-22C) and RED(1-22B)	(14'-4") - EL(1-22B) = 142"	[4]

Table 28. Dimensions Associated with Pipe Runs on Line 1-23 of Model 3

Pipe Run (1-23)	***Dimensions***		***Reference***
P (1-23A)	Pipe Diameter	18"	[5]
	Pipe Thickness	0.3125"	[5]
	Pipe Material	SS304	[5]
	Length between nozzel and RED(1-23A)	(4') - EL(1-23A) - RED(1-23A) = 9"	[5]
P (1-23B)	Pipe Diameter	20"	[5]
	Pipe Thickness	0.375"	[5]
	Pipe Material	SS304	[5]
	Length between EL(1-23A) and EL(1-23B)	(14'-10") - EL(1-23A) - EL(1-23B) = 118"	[5]
P (1-23C)	Pipe Diameter	20"	[5]
	Pipe Thickness	0.375"	[5]
	Pipe Material	SS304	[5]
	Length between EL(1-23B) and CK(1-23)	(3'-6") - EL(1-23B) = 12"	[5]

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Table 29. . Dimensions Associated with Pipe Runs on Line 1-24 of Model 3

Pipe Run (1-24)	*Dimensions*		*Reference*
P (1-24A)	Pipe Diameter	18"	[5]
	Pipe Thickness	0.3125"	[5]
	Pipe Material	SS304	[5]
	Length between nozzel and RED(1-24A)	(4') - EL(1-24A) - RED(1-24A) = 9"	[5]
P (1-24B)	Pipe Diameter	20"	[5]
	Pipe Thickness	0.375"	[5]
	Pipe Material	SS304	[5]
	Length between EL(1-24A) and EL(1-24B)	(14'-10") - EL(1-24A) - EL(1-24B) = 118"	[5]
P (1-24C)	Pipe Diameter	20"	[5]
	Pipe Thickness	0.375"	[5]
	Pipe Material	SS304	[5]
	Length between EL(1-24B) and CK(1-24)	(3'-6") - EL(1-24B) = 12"	[5]

Table 30. Dimensions Associated with Pipe Runs on Line 1-25 of Model 3

Pipe Run (1-25)	*Dimensions*		*Reference*
P (1-25A)	Pipe Diameter	18"	[6]
	Pipe Thickness	0.3125"	[6]
	Pipe Material	SS304	[6]
	Length between nozzel and RED(1-25A)	(4') - EL(1-25A) - RED(1-25A) = 9"	[6]
P (1-25B)	Pipe Diameter	20"	[6]
	Pipe Thickness	0.375"	[6]
	Pipe Material	SS304	[6]
	Length between EL(1-25A) and EL(1-25B)	(14'-10") - EL(1-25A) - EL(1-25B) = 118"	[6]
P (1-25C)	Pipe Diameter	20"	[6]
	Pipe Thickness	0.375"	[6]
	Pipe Material	SS304	[6]
	Length between EL(1-25B) and CK(1-25)	(3'-6") - EL(1-25B) = 12"	[6]
	Length between GT(1-25) and EL(1-25C)	(4'-5.625") - EL(1-25C) = 23.625"	[6]
P (1-25D)	Pipe Diameter	20"	[6]
	Pipe Thickness	0.375"	[6]
	Pipe Material	SS304	[6]
	Length between EL(1-25C) and RED(1-25B)	(14'-4") - EL(1-25B) = 142"	[6]

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Table 31. Dimensions Associated with Pipe Runs on Line 1-26 of Model 3

Pipe Run (1-26)	*Dimensions*		*Reference*
P (1-26A)	Pipe Diameter	36"	[10]
	Pipe Thickness	0.5625"	[10]
	Pipe Material	SS304	[10]
	Length between FAB BRANCH(1-27) and	(3'-6") - FAB BRANCH(1-26)(br) = 16.5"	[10]
P (1-26B)	Pipe Diameter	36"	[10]
	Pipe Thickness	0.5625"	[10]
	Pipe Material	SS304	[10]
	Length between FORGED(1-26) and FAB(1-24)	(9'-9") - FAB(1-24)(L1) - FORGED(1-26)(L2) = 67.875"	[10]
P (1-26C)	Pipe Diameter	36"	[10]
	Pipe Thickness	0.5625"	[10]
	Pipe Material	SS304	[10]
	Length between FORGED(1-26) and FAB(1-23)	(9'-9") - FAB(1-23)(L1) - FORGED(1-26)(L2) = 52.75"	[10]

Table 32. Dimensions Associated with Pipe Runs on Line 1-27 of Model 3

Pipe Run (1-27)	*Dimensions*		*Reference*
P (1-27A)	Pipe Diameter	36"	[13]
	Pipe Thickness	0.5	[13]
	Pipe Material	SS304	[13]
	Length between FORGED(1-27) and EL(1-27A)	(33'-0") - FORGED(1-27)(br) - EL(1-27A) = 94.5"	[13]
P (1-27B)	Pipe Diameter	36"	[13]
	Pipe Thickness	0.5	[13]
	Pipe Material	SS304	[13]
	Length between EL(1-27A) and BF(1-27)	(47'-2.125") - EL(1-27A) = 530.125"	[13]
P (1-27C)	Pipe Diameter	36"	[7]
	Pipe Thickness	0.5625"	[7]
	Pipe Material	SS304	[7]
	Length between BF(1-27) and EL(1-27B)	(26'-3.125") - EL(1-27B) = 279.125"	[7]
P (1-27D)	Pipe Diameter	36"	[7]
	Pipe Thickness	0.5625"	[7]
	Pipe Material	SS304	[7]
	Length between EL(1-27B) and FAB BRANCH(1-27)	(29'-3") - EL(1-27B) - FAB BRANCH(1-27) = 279"	[7]

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Table 33. Dimensions Associated with Pipe Runs on Line 1-28 of Model 3

Pipe Run (1-28)	***Dimensions***		***Reference***
P (1-28A)	Pipe Diameter	24"	[11]
	Pipe Thickness	0.375"	[11]
	Pipe Material	SS304L	[11]
	Length between Reactor Vessel and EL(1-28A)	(7'-4") - EL(1-28A) = 52"	[11]
P (1-28B)	Pipe Diameter	24"	[11]
	Pipe Thickness	0.375"	[11]
	Pipe Material	SS304L	[11]
	Length between EL(1-28A) and EL(1-28B)	(20'-**6**")* - EL(1-28A) - EL(1-28B) = 174"	[11]
P (1-28C)	Pipe Diameter	24"	[11]
	Pipe Thickness	0.375"	[11]
	Pipe Material	SS304L	[11]
	Length between EL(1-28B) and GT(1-28)	(6'-1.375") - EL(1-28B) = 37.375"	[11]
	Length between GT(1-28) and EL(1-28C)	(20'-5.875") - EL(1-28C) = 209.875"	[11]
P (1-28D)	Pipe Diameter	24"	[11]
	Pipe Thickness	0.375"	[11]
	Pipe Material	SS304	[11]
	Length between EL(1-28C) and RED(1-28)	(9'-3.5") - EL(1-28C) = 75.5"	[11]

* The length of 20'-6" was used instead of 20'-7" because the spool piece drawing indicates that the distance from the horizontal section of the top elbow to the horizontal section of the bottom elbow is (20’-7”), however if this is the case and the rest

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Table 34. Dimensions Associated with Pipe Runs on Line 1-29 of Model 3

Pipe Run (1-29)	***Dimensions***		***Reference***
P (1-29A)	Pipe Diameter	24"	[12]
	Pipe Thickness	0.375"	[12]
	Pipe Material	SS304L	[12]
	Length between Reactor Vessel and EL(1-29A)	(7'-4") - EL(1-29A) = 52"	[12]
P (1-29B)	Pipe Diameter	24"	[12]
	Pipe Thickness	0.375"	[12]
	Pipe Material	SS304L	[12]
	Length between EL(1-29A) and EL(1-29B)	(20'-**6**")* - EL(1-29A) - EL(1-29B) = 174"	[12]
P (1-29C)	Pipe Diameter	24"	[12]
	Pipe Thickness	0.375"	[12]
	Pipe Material	SS304L	[12]
	Length between EL(1-29B) and GT(1-29)	(6'-1.375") - EL(1-29B) = 37.375"	[12]
	Length between GT(1-29) and EL(1-29C)	(20'-5.875") - EL(1-29C) = 209.875"	[12]
P (1-29D)	Pipe Diameter	24"	[12]
	Pipe Thickness	0.375"	[12]
	Pipe Material	SS304	[12]
	Length between EL(1-29C) and RED(1-29)	(9'-3.5") - EL(1-29C) = 75.5"	[12]

* The length of 20'-6" was used instead of 20'-7" because the spool piece drawing indicates that the distance from the horizontal section of the top elbow to the horizontal section of the bottom elbow is (20’-7”), however if this is the case and the rest

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Table 35. Dimensions Associated with Pipe Runs on Line 1-32 of Model 3

Pipe Run (1-32)	*Dimensions*		*Reference*
P (1-32A)	Pipe Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Pipe Material	SS304	[17]
	Length between Emergency Pump and RED(1-32)	(1'-6.125") - RED(1-32)/2 = 10.25"	[17]
P (1-32B)	Pipe Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Pipe Material	SS304	[17]
	Length between RED(1-32) and CK(1-32)	(4'-3.875") - RED(1-32) -P(1-32A) = 25.875"	[17]
	Length between CK(1-32) and EL(1-32A)	(2'-2") - EL(1-32A) = 12"	[17]
P (1-32C)	Pipe Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Pipe Material	SS304	[17]
	Length between EL(1-32A) and GT(1-32)	(2'-9.6875") - EL(1-32A) = 19.6875"	[17]
	Length between GT(1-32) and EL(1-32B)	(1'-3.5625) - EL(1-32B) = 1.5625"	[17]
P (1-32D)	Pipe Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Pipe Material	SS304	[17]
	Length of EL(1-32B) and EL(1-32C)	(2'-11.355") - EL(1-32B) - EL(1-32C) = 12.605"	[17]
P (1-32E)	Pipe Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Pipe Material	SS304	[17]
	Length between EL(1-32C) and EL(1-32D)	(14'-8") - EL(1-32C) - EL(1-32D) - FAB(1-33)(L1&L2) = 92.25"	[17]
P (1-32F)	Pipe Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Pipe Material	SS304	[17]
	Length between EL(1-32D) and EL(1-32E)	(25'-11.5625") + (0.5") + (7'-9") - EL(1-32D) - EL(1-32E) = 363.0625"	[17]
P (1-32G)	Pipe Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Pipe Material	SS304	[17]
	Length between FAB(1-32)(L2) and EL(1-32F)	(22'-6") - FAB(1-32)(L2) - EL(1-32F) = 217.875"	[17]
P (1-32H)	Pipe Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Pipe Material	SS304	[17]
	Length between EL(1-32F) and FAB BRANCH(1-27)	(26'-11.9375") - EL(1-32F) = 302.9375"	[17], [7]

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Table 36. Dimensions Associated with Pipe Runs on Line 1-33 of Model 3

Pipe Run (1-33)	***Dimensions***		***Reference***
P (1-33A)	Pipe Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Pipe Material	SS304	[17]
	Length between CK(1-33) and EL(1-33A)	(1'-9.125") - EL(1-33A) = 7.125"	[17]

Table 37. Dimensions Associated with Pipe Runs on Line 1-49 of Model 3

Pipe Run (1-49)	***Dimensions***		***Reference***
P (1-49A)	Pipe Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Pipe Material	SS304	[17]
	Length between North Wall Termination and EL(1-49A)	(24'-2") - EL(1-49A) = 284"	[17]
P (1-49B)	Pipe Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Pipe Material	SS304	[17]
	Length between EL(1-49A) and EL(1-49B)	(6'-0") - EL(1-49A) - EL(1-49B) = 60"	[17]
P (1-49C)	Pipe Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Pipe Material	SS304	[17]
	Length between EL(1-49A) and EL(1-49B)	(5'-11.9375") - EL(1-49B) - EL(1-49C) = 63.4375"	[17]
P (1-49D)	Pipe Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Pipe Material	SS304	[17]
	Length between EL(1-49A) and FAB(1-32)	(3'-10.375") + (1'-1") - EL(1-49C) - FAB(1-32) = 49.875"	[17]

Table 38. Dimensions Associated with Reducers on Line 1-22 of Model 3

Reducers (1-22)	***Dimensions***		***Reference***
RED(1-22A)	Small Diameter	18"	[4]
	Large Diameter	20"	[4]
	Length	9"	[4]
	Thickness	3/8"	[4]
	Eccentric Offset	0"	[4]
RED(1-22B)	Small Diameter	20"	[10]
	Large Diameter	36"	[10]
	Length	24"	[10]
	Thickness	9/16"	[10]
	Eccentric Offset	0"	[10]

Table 39. Dimensions Associated with Reducers on Line 1-23 of Model 3

Reducers (1-23)	***Dimensions***		***Reference***
RED(1-23)	Small Diameter	18"	[5]
	Large Diameter	20"	[5]
	Length	9"	[5]
	Thickness	3/8"	[5]
	Eccentric Offset	0"	[5]

Table 40. Dimensions Associated with Reducers on Line 1-24 of Model 3

Reducers (1-24)	***Dimensions***		***Reference***
RED(1-24)	Small Diameter	18"	[5]
	Large Diameter	20"	[5]
	Length	9"	[5]
	Thickness	3/8"	[5]
	Eccentric Offset	0"	[5]

Table 41. Dimensions Associated with Reducers on Line 1-25 of Model 3

Reducers (1-25)	***Dimensions***		***Reference***
RED(1-25A)	Small Diameter	18"	[6]
	Large Diameter	20"	[6]
	Length	9"	[6]
	Thickness	3/8"	[6]
	Eccentric Offset	0"	[6]
RED(1-25B)	Small Diameter	20"	[10]
	Large Diameter	36"	[10]
	Length	24"	[10]
	Thickness	9/16"	[10]
	Eccentric Offset	0"	[10]

Table 42. Dimensions Associated with Reducers on Line 1-28 of Model 3

Reducers (1-28)	***Dimensions***		***Reference***
RED(1-28)	Small Diameter	24"	[14]
	Large Diameter	36"	[14]
	Length	24"	[14]
	Thickness	0.5"	[14]
	Eccentric Offset	6"	[14]

Table 43. Dimensions Associated with Reducers on Line 1-29 of Model 3

Reducers (1-29)	***Dimensions***		***Reference***
RED(1-29)	Small Diameter	24"	[14]
	Large Diameter	36"	[14]
	Length	24"	[14]
	Thickness	0.5"	[14]
	Eccentric Offset	6"	[14]

Table 44. Dimensions Associated with Reducers on Line 1-32 of Model 3

Reducers (1-32)	***Dimensions***		***Reference***
RED(1-32)	Small Diameter	12"	[17]
	Large Diameter	14"	[17]
	Length	15.75"	[17]
	Thickness	0.25"	[17]
	Eccentric Offset	0"	[17]

Table 45. Dimensions Associated with Reducers on Line 1-33 of Model 3

Reducers (1-33)	***Dimensions***		***Reference***
RED(1-33)	Small Diameter	12"	[17]
	Large Diameter	14"	[17]
	Length	15.75"	[17]
	Thickness	0.25"	[17]
	Eccentric Offset	0"	[17]

Table 46. Dimensions Associated with Elbows on Line 1-22 of Model 3

Elbows (1-22)	***Dimensions***		***Reference***
EL (1-22A)	Pipe Diameter	20"	[4]
	Pipe Thickness	3/8"	[4]
	Elbow Type	90º Long Radius	[4]
	Elbow Leg Lengths	30"	[15, pg 9]
EL (1-22B)	Pipe Diameter	20"	[4]
	Pipe Thickness	3/8"	[4]
	Elbow Type	90º Long Radius	[4]
	Elbow Leg Lengths	30"	[15, pg 9]
EL (1-22C)	Pipe Diameter	20"	[4]
	Pipe Thickness	3/8"	[4]
	Elbow Type	90º Long Radius	[4]
	Elbow Leg Lengths	30"	[15, pg 9]

Table 47. Dimensions Associated with Elbows on Line 1-23 of Model 3

Elbows (1-23)	Dimensions		Reference
EL (1-23A)	Pipe Diameter	20"	[5]
	Pipe Thickness	3/8"	[5]
	Elbow Type	90º Long Radius	[5]
	Elbow Leg Lengths	30"	[15, pg 9]
EL (1-23B)	Pipe Diameter	20"	[5]
	Pipe Thickness	3/8"	[5]
	Elbow Type	90º Long Radius	[5]
	Elbow Leg Lengths	30"	[15, pg 9]

Table 48. . Dimensions Associated with Elbows on Line 1-24 of Model 3

Elbows (1-24)	Dimensions		Reference
EL (1-24A)	Pipe Diameter	20"	[5]
	Pipe Thickness	3/8"	[5]
	Elbow Type	90º Long Radius	[5]
	Elbow Leg Lengths	30"	[15, pg 9]
EL (1-24B)	Pipe Diameter	20"	[5]
	Pipe Thickness	3/8"	[5]
	Elbow Type	90º Long Radius	[5]
	Elbow Leg Lengths	30"	[15, pg 9]

Table 49. Dimensions Associated with Elbows on Line 1-25 of Model 3

Elbows (1-25)	Dimensions		Reference
EL (1-25A)	Pipe Diameter	20"	[6]
	Pipe Thickness	3/8"	[6]
	Elbow Type	90º Long Radius	[6]
	Elbow Leg Lengths	30"	[15, pg 9]
EL (1-25B)	Pipe Diameter	20"	[6]
	Pipe Thickness	3/8"	[6]
	Elbow Type	90º Long Radius	[6]
	Elbow Leg Lengths	30"	[15, pg 9]
EL (1-25C)	Pipe Diameter	20"	[6]
	Pipe Thickness	3/8"	[6]
	Elbow Type	90º Long Radius	[6]
	Elbow Leg Lengths	30"	[15, pg 9]

Table 50. Dimensions Associated with Elbows on Line 1-27 of Model 3

Elbows (1-27)	***Dimensions***		***Reference***
EL (1-27A)	Pipe Diameter	36"	[13]
	Pipe Thickness	1/2"	[13]
	Elbow Type	90º Short Radius	[13]
	Elbow Leg Lengths	36"	[15, pg 9]
EL (1-27B)	Pipe Diameter	36"	[7]
	Pipe Thickness	9/16"	[7]
	Elbow Type	90º Short Radius	[7]
	Elbow Leg Lengths	36"	[15, pg 9]

Table 51. Dimensions Associated with Elbows on Line 1-28 of Model 3

Elbows (1-28)	***Dimensions***		***Reference***
EL (1-28A)	Pipe Diameter	24"	[11]
	Pipe Thickness	3/8"	[11]
	Elbow Type	90º Long Radius	[11]
	Elbow Leg Lengths	36"	[15, pg 9]
EL (1-28B)	Pipe Diameter	24"	[11]
	Pipe Thickness	3/8"	[11]
	Elbow Type	90º Long Radius	[11]
	Elbow Leg Lengths	36"	[15, pg 9]
EL (1-28C)	Pipe Diameter	24"	[11]
	Pipe Thickness	3/8"	[11]
	Elbow Type	90º Long Radius	[11]
	Elbow Leg Lengths	36"	[15, pg 9]

Table 52. Dimensions Associated with Elbows on Line 1-29 of Model 3

Elbows (1-29)	***Dimensions***		***Reference***
EL (1-29A)	Pipe Diameter	24"	[12]
	Pipe Thickness	3/8"	[12]
	Elbow Type	90º Long Radius	[12]
	Elbow Leg Lengths	36"	[15, pg 9]
EL (1-29B)	Pipe Diameter	24"	[12]
	Pipe Thickness	3/8"	[12]
	Elbow Type	90º Long Radius	[12]
	Elbow Leg Lengths	36"	[15, pg 9]
EL (1-29C)	Pipe Diameter	24"	[12]
	Pipe Thickness	3/8"	[12]
	Elbow Type	90º Long Radius	[12]
	Elbow Leg Lengths	36"	[15, pg 9]

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Table 53. Dimensions Associated with Elbows on Line 1-32 of Model 3

Elbows (1-32)	*Dimensions*		*Reference*
EL (1-32A)	Pipe Diameter	14"	[17]
	Pipe Thickness	1/4"	[17]
	Elbow Type	90º Short Radius	[17]
	Elbow Leg Lengths	14"	[15, pg 9]
EL (1-32B)	Pipe Diameter	14"	[17]
	Pipe Thickness	1/4"	[17]
	Elbow Type	90º Short Radius	[17]
	Elbow Leg Lengths	14"	[15, pg 9]
EL (1-32C)	Pipe Diameter	14"	[17]
	Pipe Thickness	1/4"	[17]
	Elbow Type	45º Long Radius	[17]
	Elbow Leg Lengths	8.75"	[15, pg 23]
EL (1-32D)	Pipe Diameter	14"	[17]
	Pipe Thickness	1/4"	[17]
	Elbow Type	90º Long Radius	[17]
	Elbow Leg Lengths	21"	[15, pg 9]
EL (1-32E)	Pipe Diameter	14"	[17]
	Pipe Thickness	1/4"	[17]
	Elbow Type	90º Long Radius	[17]
	Elbow Leg Lengths	21"	[15, pg 9]
EL (1-32F)	Pipe Diameter	14"	[17]
	Pipe Thickness	1/4"	[17]
	Elbow Type	90º Long Radius	[17]
	Elbow Leg Lengths	21"	[15, pg 9]

Table 54. Dimensions Associated with Elbows on Line 1-33 of Model 3

Elbows (1-33)	*Dimensions*		*Reference*
EL (1-33A)	Pipe Diameter	14"	[17]
	Pipe Thickness	1/4"	[17]
	Elbow Type	90º Short Radius	[17]
	Elbow Leg Lengths	14"	[15, pg 9]

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Table 55. Dimensions Associated with Elbows on Line 1-49 of Model 3

Elbows (1-49)	*Dimensions*		*Reference*
EL (1-49A)	Pipe Diameter	4"	[17]
	Pipe Thickness	0.237"	[17]
	Elbow Type	90º Long Radius	[17]
	Elbow Leg Lengths	6"	[15, pg 9]
EL (1-49B)	Pipe Diameter	4"	[17]
	Pipe Thickness	0.237"	[17]
	Elbow Type	90º Long Radius	[17]
	Elbow Leg Lengths	6"	[15, pg 9]
EL (1-49C)	Pipe Diameter	4.5"	[17]
	Pipe Thickness	0.237"	[17]
	Elbow Type	45º Long Radius	[17]
	Elbow Leg Lengths	2.5"	[15, pg 23]

Table 56. Dimensions Associated with Tees on Line 1-23 of Model 3

Fabricated Tees	*Dimensions*		*Reference*
FAB(1-23)	Run Diameter	36"	[10]
	Run Thickness	9/16"	[10]
	Run Leg1 Length	20"	Result of FE Modeling
	Run Leg2 Length	22.625"	Result of FE Modeling
	Branch Diameter	20"	[10]
	Branch Length	53.625"	[10]
	Branch Thickness	3/8"	[10]

Table 57. Dimensions Associated with Tees on Line 1-24 of Model 3

Fabricated Tees	*Dimensions*		*Reference*
FAB(1-24)	Run Diameter	36"	[10]
	Run Thickness	9/16"	[10]
	Run Leg1 Length	20"	Result of FE Modeling
	Run Leg2 Length	22.625"	Result of FE Modeling
	Branch Diameter	20"	[10]
	Branch Length	53.625"	[10]
	Branch Thickness	3/8"	[10]

Table 58. Dimensions Associated with Tees on Line 1-26 of Model 3

Forged Tees	*Dimensions*		*Reference*
FORGED(1-26)*	Run Diameter	36"	[14]
	Run Length	52"	[14]
	Run Thickness	1.375"	[14]
	Branch Diameter	36"	[14]
	Branch Length	25.5"	[14]
	Branch Thickness	1.375"	[14]

*Assumed to be the same as FORGED(1-27)

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Table 59. Dimensions Associated with Tees on Line 1-27 of Model 3

Forged Tees	*Dimensions*		*Reference*
FORGED(1-27)	Run Diameter	36"	[14]
	Run Length	52"	[14]
	Run Thickness	1.375"	[14]
	Branch Diameter	36"	[14]
	Branch Length	25.5"	[14]
	Branch Thickness	1.375"	[14]

Table 60. Dimensions Associated with Tees on Line 1-32 of Model 3

Fabricated Tees	*Dimensions*		*Reference*
FAB(1-32)	Run Diameter	14"	[17]
	Run Thickness	1/4"	[17]
	Run Leg1 Length	12"	Result of FE Modeling
	Run Leg2 Length	31.125"	Result of FE Modeling
	Branch Diameter	4.5"	[16], [8, Table 1-14]
	Branch Length	7" *	[17]
	Branch Thickness	0.237"	[16], [8, Table 1-14]

Table 61. Dimensions Associated with Tees on Line 1-33 of Model 3

Fabricated Tees	*Dimensions*		*Reference*
FAB(1-33)	Run Diameter	14"	[17]
	Run Thickness	1/4"	[17]
	Run Leg1 Length	30.75"	Result of FE Modeling
	Run Leg2 Length	20"	Result of FE Modeling
	Branch Diameter	14"	[17]
	Branch Length	28.875"	[17]
	Branch Thickness	1/4"	[17]

Table 62. Dimensions Associated with Fabricated Branch Connecting Lines 1-26, 1-27 & 1-32 of Model 3

Fabricated Branch	*Dimensions*		*Reference*
FAB BRANCH (1-26, 1-27, 1-32)	Pipe Diameter	36"	[7]
	Pipe Thickness	9/16"	[7]
	Elbow Type	Short Radius	[7]
	Elbow Leg Lengths	36"	[15, pg 9]
	Branch Diameter	14"	[7]
	Branch Length from Centerline of Upper Elbow Leg	27"	[7]
	Branch Thickness	1/4"	[7]

Table 63. Dimensions Associated with Flanges on Line 1-22 of Model 3

Flanges (1-22)	*Dimensions*		*Reference*
FL (1-22A)	Location	At primary pump nozzel	
	Mass	Neglected due to fixation of nozzels	
FL (1-22B)	Location	At point where P(1-22C) and CK(1-22) meet	
	Mass	320 lbm = 0.829 lbf.s^2/in	[15, pg 99]
FL (1-22C)	Location	At point where P(1-22C) and GT(1-22) meet	
	Mass	320 lbm = 0.829 lbf.s^2/in	[15, pg 99]

Table 64. Dimensions Associated with Flanges on Line 1-23 of Model 3

Flanges (1-23)	*Dimensions*		*Reference*
FL (1-23A)	Location	At primary pump nozzel	
	Mass	Neglected due to fixation of nozzels	
FL (1-23B)	Location	At point where P(1-23C) and CK(1-23) meet	
	Mass	320 lbm = 0.829 lbf.s^2/in	[15, pg 99]
FL (1-23C)	Location	At point where P(1-23C) and GT(1-23) meet	
	Mass	320 lbm = 0.829 lbf.s^2/in	[15, pg 99]

Table 65. Dimensions Associated with Flanges on Line 1-24 of Model 3

Flanges (1-24)	*Dimensions*		*Reference*
FL (1-24A)	Location	At primary pump nozzel	
	Mass	Neglected due to fixation of nozzels	
FL (1-24B)	Location	At point where P(1-24C) and CK(1-24) meet	
	Mass	320 lbm = 0.829 lbf.s^2/in	[15, pg 99]
FL (1-24C)	Location	At point where P(1-24C) and GT(1-24) meet	
	Mass	320 lbm = 0.829 lbf.s^2/in	[15, pg 99]

Table 66. Dimensions Associated with Flanges on Line 1-25 of Model 3

Flanges (1-25)	*Dimensions*		*Reference*
FL (1-25A)	Location	At primary pump nozzel	
	Mass	Neglected due to fixation of nozzels	
FL (1-25B)	Location	At point where P(1-25C) and CK(1-25) meet	
	Mass	320 lbm = 0.829 lbf.s^2/in	[15, pg 99]
FL (1-25C)	Location	At point where P(1-25C) and GT(1-25) meet	
	Mass	320 lbm = 0.829 lbf.s^2/in	[15, pg 99]

Table 67. Dimensions Associated with Flanges on Line 1-27 of Model 3

Flanges (1-27)	*Dimensions*		*Reference*
FL (1-27A)	Location	At point where P(1-27B) and BF(1-27) meet	
	Mass	1090lbm = 2.821 lbf.s^2/in	Appendix B.8
FL (1-27B)	Location	At point where P(1-27C) and BF(1-27) meet	
	Mass	1090lbm = 2.821 lbf.s^2/in	Appendix B.8

Table 68. Dimensions Associated with Flanges on Line 1-28 of Model 3

Flanges (1-28)	*Dimensions*		*Reference*
FL (1-28A)	Location	At point where the southern side of P(1-28C) meets GT(1-28)	
	Mass	478 lbm = 1.238 lbf.s^2/in	[15, pg 99]
FL (1-28B)	Location	At point where the northern side of P(1-28C) meets GT(1-28)	
	Mass	478 lbm = 1.238 lbf.s^2/in	[15, pg 99]

Table 69. Dimensions Associated with Flanges on Line 1-29 of Model 3

Flanges (1-29)	*Dimensions*		*Reference*
FL (1-29A)	Location	At point where the southern side of P(1-29C) meets GT(1-29)	
	Mass	478 lbm = 1.238 lbf.s^2/in	[15, pg 99]
FL (1-29B)	Location	At point where the northern side of P(1-29C) meets GT(1-29)	
	Mass	478 lbm = 1.238 lbf.s^2/in	[15, pg 99]

Table 70. Dimensions Associated with Flanges on Line 1-32 of Model 3

Flanges (1-32)	*Dimensions*		*Reference*
FL (1-32A)	Location	At emergency pump nozzel	
	Mass	Neglected due to fixation of nozzels	
FL (1-32B)	Location	At point where P(1-32A) and CK(1-32)	
	Mass	166 lbm = 0.43 lbf.s^2/in	[15, pg 99]
FL (1-32C)	Location	At point where P(1-32B) and CK(1-32)	
	Mass	166 lbm = 0.43 lbf.s^2/in	[15, pg 99]
FL (1-32D)	Location	At point where the lower side of P(1-32C) meets GT(1-32)	
	Mass	166 lbm = 0.43 lbf.s^2/in	[15, pg 99]
FL (1-32E)	Location	At point where the upper side of P(1-32C) meets GT(1-32)	
	Mass	166 lbm = 0.43 lbf.s^2/in	[15, pg 99]

Table 71. Dimensions Associated with Flanges on Line 1-33 of Model 3

Flanges (1-33)	*Dimensions*		*Reference*
FL (1-33A)	Location	At emergency pump nozzel	
	Mass	Neglected due to fixation of nozzels	
FL (1-33B)	Location	At point where P(1-33A) and CK(1-33)	
	Mass	166 lbm = 0.43 lbf.s^2/in	[15, pg 99]
FL (1-33C)	Location	At point where P(1-33B) and CK(1-33)	
	Mass	166 lbm = 0.43 lbf.s^2/in	[15, pg 99]
FL (1-33D)	Location	At point where the lower side of P(1-33C) meets GT(1-33)	
	Mass	166 lbm = 0.43 lbf.s^2/in	[15, pg 99]
FL (1-33E)	Location	At point where the upper side of P(1-33C) meets GT(1-33)	
	Mass	166 lbm = 0.43 lbf.s^2/in	[15, pg 99]

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Table 72. Dimensions Associated with Valves on Line 1-22 of Model 3

Valves (1-22)	*Dimensions*		*Reference*
GT (1-22)	Pipe/Valve Diameter	20"	[4]
	Pipe Thickness	0.375"	[4]
	Equiv Valve Thickness	1.293"	App B.3.5
	Valve Lengths	3' - 3.1875"	[4]
	Valve Name	GT-A-1-3	[4]
	Valve Mass	3475 lb = 9.001 lbf*s^2/in	[3, pg B-2]
CK (1-22)	Pipe/Valve Diameter	20"	[4]
	Pipe Thickness	0.375"	[4]
	Equiv Valve Thickness	1.293"	App B.3.5
	Valve Lengths	3' - 3.1875"	[4]
	Valve Name	CK-A-1-2	[4]
	Valve Mass	3165 lb = 8.198 lbf*s^2/in	[3, pg B-2]

Table 73. Dimensions Associated with Valves on Line 1-23 of Model 3

Valves (1-23)	*Dimensions*		*Reference*
GT (1-23)	Pipe/Valve Diameter	20"	[5]
	Pipe Thickness	0.375"	[5]
	Equiv Valve Thickness	1.293"	App B.3.5
	Valve Lengths	3' - 3.1875"	[5]
	Valve Name	GT-A-1-6	[5]
	Valve Mass	3475 lb = 9.001 lbf*s^2/in	[3, pg B-2]
CK (1-23)	Pipe/Valve Diameter	20"	[5]
	Pipe Thickness	0.375"	[5]
	Equiv Valve Thickness	1.293"	App B.3.5
	Valve Lengths	3' - 3.1875"	[5]
	Valve Name	CK-A-1-6	[5]
	Valve Mass	3165 lb = 8.198 lbf*s^2/in	[3, pg B-2]

Table 74. Dimensions Associated with Valves on Line 1-24 of Model 3

Valves (1-24)	*Dimensions*		*Reference*
GT (1-24)	Pipe/Valve Diameter	20"	[5]
	Pipe Thickness	0.375"	[5]
	Equiv Valve Thickness	1.293"	App B.3.5
	Valve Lengths	3' - 3.1875"	[5]
	Valve Name	GT-A-1-9	[5]
	Valve Mass	3475 lb = 9.001 lbf*s^2/in	[3, pg B-2]
CK (1-24)	Pipe/Valve Diameter	20"	[5]
	Pipe Thickness	0.375"	[5]
	Equiv Valve Thickness	1.293"	App B.7
	Valve Lengths	3' - 3.1875"	[5]
	Valve Name	CK-A-1-9	[5]
	Valve Mass	3165 lb = 8.198 lbf*s^2/in	[3, pg B-2]

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Table 75. Dimensions Associated with Valves on Line 1-25 of Model 3

Valves (1-25)	***Dimensions***		***Reference***
GT (1-25)	Pipe/Valve Diameter	20"	[6]
	Pipe Thickness	0.375"	[6]
	Equiv Valve Thickness	1.293"	App B.7
	Valve Lengths	3' - 3.1875"	[6]
	Valve Name	GT-A-1-12	[6]
	Valve Mass	3475 lb = 9.001 lbf*s^2/in	[3, pg B-2]

CK (1-25)	Pipe/Valve Diameter	20"	[6]
	Pipe Thickness	0.375"	[6]
	Equiv Valve Thickness	1.293"	App B.7
	Valve Lengths	3' - 3.1875"	[6]
	Valve Name	CK-A-1-11	[6]
	Valve Mass	3165 lb = 8.198 lbf*s^2/in	[3, pg B-2]

Table 76. Dimensions Associated with Valves on Line 1-27 of Model 3

Valves (1-27)	***Dimensions***		***Reference***
BF (1-27)	Pipe/Valve Diameter	36"	[17]
	Pipe Thickness	0.5"/0.5625"	[17]
	Equiv Valve Thickness	1.206"	App B.7
	Valve Lengths	8.5"	[17]
	Valve Name	BF-A-1-14	[17]
	Valve Mass	3344 lb = 8.661 lbf*s^2/in	[3, pg B-2]

Table 77. Dimensions Associated with Valves on Line 1-28 of Model 3

Valves (1-28)	***Dimensions***		***Reference***
GT (1-28)	Pipe/Valve Diameter	24"	[11]
	Pipe Thickness	0.375"	[11]
	Equiv Valve Thickness	1.258"	App B.7
	Valve Lengths	3' - 9.25"	[11]
	Valve Name	GT-I-1-82	[11]
	Valve Mass	5955 lbf = 15.424 lbf*s^2/in	[3, pg B-3]

Table 78. Dimensions Associated with Valves on Line 1-29 of Model 3

Valves (1-29)	***Dimensions***		***Reference***
GT (1-29)	Pipe/Valve Diameter	24"	[12]
	Pipe Thickness	0.375"	[12]
	Equiv Valve Thickness	1.258"	App B.7
	Valve Lengths	3' - 9.25"	[12]
	Valve Name	GT-I-1-83	[12]
	Valve Mass	5955 lbf = 15.424 lbf*s^2/in	[3, pg B-3]

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Table 79. Dimensions Associated with Valves on Line 1-32 of Model 3

Valves (1-32)	*Dimensions*		*Reference*
GT (1-32)	Pipe/Valve Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Equiv Valve Thickness	0.855"	App B.7
	Valve Lengths	2' - 6.25"	[17]
	Valve Name	GT-B-1-18	[17]
	Valve Mass	1800 lb = 4.662 lbf*s^2/in	[3, pg B-3]
CK (1-32)	Pipe/Valve Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Equiv Valve Thickness	0.855"	App B.7
	Valve Lengths	2' - 6.25"	[17]
	Valve Name	CK-A-1-17	[17]
	Valve Mass	1131 lb = 2.929 lbf*s^2/in	[3, pg B-3]

Table 80. Dimensions Associated with Valves on Line 1-33 of Model 3

Valves (1-33)	*Dimensions*		*Reference*
GT (1-33)	Pipe/Valve Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Equiv Valve Thickness	0.855"	App B.7
	Valve Lengths	2' - 6.25"	[17]
	Valve Name	GT-B-1-21	[17]
	Valve Mass	1800 lb = 4.662 lbf*s^2/in	[3, pg B-3]
CK (1-33)	Pipe/Valve Diameter	16"	[17]
	Pipe Thickness	0.25"	[17]
	Equiv Valve Thickness	0.855"	App B.7
	Valve Lengths	2' - 6.25"	[17]
	Valve Name	CK-A-1-20	[17]
	Valve Mass	1131 lb = 2.929 lbf*s^2/in	[3, pg B-3]

Appendix B.7

Calculations of Pipe Thickness to Mimic Valve Behavior in Model

Valve Thickness Calculations

According to Nu-Pipe the moment of inertia of the pipe valves is to be three times that of the pipe for which it is attached to. [31, 2-21]

GATE AND CHECK VALVES ASSOCIATED WITH LINES 1-22 THROUGH 1-25

$GT_{1\text{-}22}$, $GT_{1\text{-}23}$, $GT_{1\text{-}24}$, $GT_{1\text{-}25}$, $CK_{1\text{-}22}$, $CK_{1\text{-}23}$, $CK_{1\text{-}24}$, and $CK_{1\text{-}25}$

The above four gate and four check valves are located two elbows below the discharge of each of the four primary coolant pumps.

$t_{PP} := 0.375in$ — Thickness of PCS pipe below primary coolant pumps [4]

$od_{PP} := 20in$ — Outer diameter of PCS pipe below primary coolant pumps [4]

$id_{PP} := od_{PP} - 2 \cdot t_{PP}$ — Inner diameter of PCS pipe below primary coolant pumps

$id_{PP} = 19.25\ in$

$$I_{PP} := \frac{\pi \cdot \left(od_{PP}^{\ 4} - id_{PP}^{\ 4}\right)}{4}$$

Moment of inertia of PCS pipe below primary coolant pumps [8, Table 17-27, pg 17-39]

$I_{PP} = 1.782 \times 10^{4}\ in^{4}$

$$T_{PP\_GT} := \left[\frac{\left[-\frac{4\cdot(3\cdot I_{PP})}{\pi} + od_{PP}^{\ 4}\right]^{0.25} - od_{PP}}{-2}\right]$$

Thickness of pipe representing valve if outer diameter is to remain consistent with attached pipe where equation is modification of moment of inertia equation for a pipe thickness as the output and the moment of inertia for the valve represented by 3 times the value of the moment of inertia of the pipe [8, Table 17-27, pg 17-39]

$\boxed{T_{PP\_GT} = 1.293\ in}$

GATE VALVES ASSOCIATED WITH LINES 1-28 THROUGH 1-29

$GT_{1\text{-}28}$ and $GT_{1\text{-}29}$

The above two gate valves are located two elbows below the inlet locations of the PCS system into the reactor.

$t_{RV} := 0.375in$ — Thickness of PCS pipe below primary coolant pumps [11]

$od_{RV} := 24in$ — Outer diameter of PCS pipe below primary coolant pumps [11]

$id_{RV} := od_{RV} - 2 \cdot t_{RV}$ — Inner diameter of PCS pipe below primary coolant pumps

$id_{RV} = 23.25\ in$

$$I_{RV} := \frac{\pi \cdot \left(od_{RV}^4 - id_{RV}^4\right)}{4}$$

$$I_{RV} = 3.108 \times 10^4\ in^4$$

Moment of inertia of PCS pipe below primary coolant pumps [8, Table 17-27, pg 17-39]

$$T_{RV\_GT} := \left[\frac{\left[-\frac{4\cdot(3\cdot I_{RV})}{\pi} + od_{RV}^4\right]^{0.25} - od_{RV}}{-2}\right]$$

$$\boxed{T_{RV\_GT} = 1.258\ in}$$

Thickness of pipe representing valve if outer diameter is to remain consistent with attached pipe where equation is modification of moment of inertia equation for a pipe thickness as the output and the moment of inertia for the valve represented by 3 times the value of the moment of inertia of the pipe [8, Table 17-27, pg 17-39]

GATE AND CHECK VALVES ASSOCIATED WITH LINES 1-32 THROUGH 1-33

$GT_{1\text{-}32}$, $GT_{1\text{-}33}$, $CK_{1\text{-}32}$, and $CK_{1\text{-}33}$

The above two gate valves are located one elbow beyond the emergency pumps and the above two check valves are located directly after the emergency pumps.

$$t_{EP} := 0.25in$$

Thickness of PCS pipe below primary coolant pumps [11]

$$od_{EP} := 14in$$

Outer diameter of PCS pipe below primary coolant pumps [11]

$$id_{EP} := od_{EP} - 2\cdot t_{EP}$$

$$id_{EP} = 13.5\ in$$

Inner diameter of PCS pipe below primary coolant pumps

$$I_{EP} := \frac{\pi \cdot \left(od_{EP}^4 - id_{EP}^4\right)}{4}$$

$$I_{EP} = 4.085 \times 10^3\ in^4$$

Moment of inertia of PCS pipe below primary coolant pumps [8, Table 17-27, pg 17-39]

$$T_{EP\_GT} := \left[\frac{\left[-\frac{4\cdot(3\cdot I_{EP})}{\pi} + od_{EP}^4\right]^{0.25} - od_{EP}}{-2}\right]$$

$$\boxed{T_{EP\_GT} = 0.855\ in}$$

Thickness of pipe representing valve if outer diameter is to remain consistent with attached pipe where equation is modification of moment of inertia equation for a pipe thickness as the output and the moment of inertia for the valve represented by 3 times the value of the moment of inertia of the pipe [8, Table 17-27, pg 17-39]

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Appendix B.8

Mass of BF-A-1-14 Lap Joint Flanges Calculation

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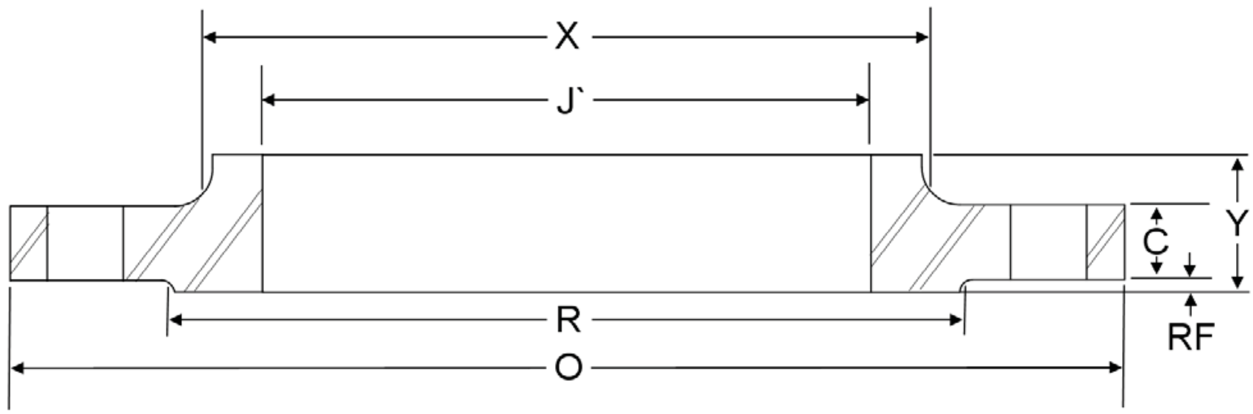
Flange Weights for BF-A-1-14 Butterfly Valve Calculations

According to [15, pg 126] the class 300 slip on flanges (equivalent in dimensions to lap joint flanges at 36") are fabricated out of A105 carbon steel. Since the table for the 36" slip on flanges in [15, pg 126] does not include the associated weight, the dimensions that are included in the table will be used to determine the approximate volume of the flanges. The volume in conjunction with the density of A105 steel will be implemented to determine the mass of each flange.

APPROXIMATE MASS OF BF-A-1-14 FLANGES



Volume of Interface

$R := 40.25in$ — Diameter of flange face

$RF := 0.06in$ — Raised face on flange interface

$$V_{interface} := \frac{\pi \cdot R^2}{4} \cdot RF$$

Volume of interface

$$V_{interface} = 76.344\ in^3$$

Volume of Flange

$C := 4.12in$ — Flange thickness

$O := 50in$ — Flange outside diameter

$$V_{flange} := \frac{\pi \cdot O^2}{4} \cdot C$$

Volume of flange (note:bolt holes were neglected as the bolts themselves will fill them and the weight of the rest of the bolts were neglected as their influence relative to the weight of the entire flange was assumed to be negligible)

$$V_{flange} = 8.09 \times 10^3\ in^3$$

Volume of Hub

$Y := 6.06\text{in}$ — Flange length

$X := 41\text{in}$ — Hub diameter

$$V_{hub} := \frac{\pi \cdot X^2}{4} \cdot (Y - C - RF)$$ — Volume of hub

$$\boxed{V_{hub} = 2.482 \times 10^3\ \text{in}^3}$$

Volume of Flange Bore

$J' := 36.25\text{in}$ — Flange Bore

$$V_{bore} := \frac{\pi \cdot J'^2}{4} \cdot Y$$ — Volume of bore

$$\boxed{V_{bore} = 6.254 \times 10^3\ \text{in}^3}$$

Total Volume

$$V_{total} := V_{interface} + V_{hub} + V_{flange} - V_{bore}$$ — Total Volume

$$\boxed{V_{total} = 4.394 \times 10^3\ \text{in}^3}$$

Total Mass

$$\rho_{A105} := 0.248\ \frac{\text{lb}}{\text{in}^3}$$ — Density of A105 steel

$$M_{flange} := \rho_{A105} \cdot V_{total}$$

$$\boxed{M_{flange} = 1090\ \text{lb}}$$ — Mass of each BF-A-1-14 flange

Appendix B.9

Elbow Stiffness and Water Filled Pipe Density Calculations

MATERIAL PROPERTIES USED IN ELBOW STIFFNESS CALCULATIONS

Stainless Steel Material Properties

The material properties below represent reasonable values that could be used in an analysis.

$E_s := 2.8 \cdot 10^7 \cdot psi$ — Modulus of elasticity for SS304 at 125 degrees Fahrenheit [53, Table TM]

$\nu_s := 0.30$ — Poisson's ratio [9, NB-3683.1(b)]

$$G_s := \frac{E_s}{2 \cdot (1 + \nu_s)}$$

Shear modulus [54, Eq 2-19]

$$G_s = 1.077 \times 10^7 \, psi$$

$\rho_s := 0.28 \frac{lb}{in^3}$ — Mass density [54]

Steel Material Properties

The material properties below represent reasonable values that could be used in an analysis.

$E_c := 3.0 \cdot 10^7 \cdot psi$ — Modulus of elasticity [54, Table A-5]

$\nu_c := 0.29$ — Poisson's ratio [54]

$\rho_c := 0.282 \frac{lb}{in^3}$ — Mass density [54]

Water Material Properties

The material properties below represent reasonable values that could be used in an analysis.

$\rho_w := 62.3 \cdot \frac{lb}{ft^3}$ — Mass density [55, Table A]

$$\rho_w = 0.0361 \frac{lb}{in^3}$$

FLEXIBILITY FACTOR FUNCTION AND CALCULATIONS APPROACH

Flexibility Factor

(a) R/r is not less than 1.7 [9, NB-3686.2]

(b) center line length Rα is greater than 2r [9, NB-3686.2]

(c) there are no flanges or other similar stiffeners within a distance r from either end of the curved section of pipe or from the ends of welding elbows. [9, NB-3686.2]

$$k(d_o, t, P, R) := \begin{array}{|l} d_i \leftarrow d_o - 2 \cdot t \\ r \leftarrow \frac{1}{4} \cdot (d_o + d_i) \\ h \leftarrow t \cdot R \cdot r^{-2} \\ X_k \leftarrow 6 \cdot \left(\frac{r}{t}\right)^{\frac{4}{3}} \cdot \left(\frac{R}{r}\right)^{\frac{1}{3}} \\ k_o \leftarrow 0 \\ k_o \leftarrow \frac{1.65}{h} \cdot \frac{1}{1 + \left(\frac{P \cdot r}{t \cdot E_s}\right) \cdot X_k} \quad \text{if } \frac{R}{r} \ge 1.7 \\ k_o \leftarrow 1 \quad \text{if } k_o \le 1 \end{array}$$

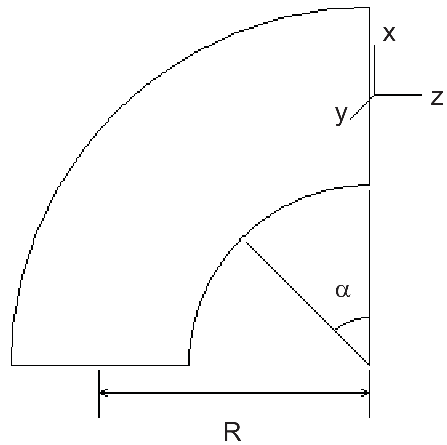
[9, NB-3686.2]

$$\theta_{nom1} = \frac{R}{E \cdot I} \cdot \int_0^{\theta} M_1 \, d\alpha \qquad \theta_{ab1} = k \cdot \theta_{nom1} = \frac{k \cdot R}{E \cdot I} \cdot \int_0^{\theta} M_1 \, d\alpha$$

$$\theta_{nom2} = \frac{R}{E \cdot I} \cdot \int_0^{\theta} M_2 \, d\alpha \qquad \theta_{ab2} = k \cdot \theta_{nom2} = \frac{k \cdot R}{E \cdot I} \cdot \int_0^{\theta} M_2 \, d\alpha$$

$$\theta_{nom3} = \frac{R}{G \cdot J} \cdot \int_0^{\theta} M_3 \, d\alpha \qquad \theta_{ab3} = \theta_{nom3} = \frac{R}{G \cdot J} \cdot \int_0^{\theta} M_3 \, d\alpha$$

To address the flexibility factor in the finite element model, an effective area moment of inertia will be established:



$$I_e = \frac{I}{k}$$

Therefore:

$$\theta_{ab1} = \frac{R}{E \cdot I_e} \cdot \int_0^{\theta} M_1 \, d\alpha$$

$$\theta_{ab2} = \frac{R}{E \cdot I_e} \cdot \int_0^{\theta} M_2 \, d\alpha$$

$$\theta_{ab3} = \frac{R}{G \cdot J} \cdot \int_0^{\theta} M_3 \, d\alpha$$

FLEXIBILITY FACTOR AND MOMENT OF INERTIA CALCULATIONS FOR MODEL 3

Pipe 36 Inch Diameter and 1/2 Thickness (Downstream of Valve BF-A-14)

$d_{36} := 36 \cdot in$ — Pipe outside diameter.

$t_{36} := 0.5 \cdot in$ — Pipe thickness.

$p_{376} := 376 \cdot psi$ — Internal pressure downstream of valve BF-A-14. [3]

$r_{s36} := d_{36}$ — Radius for short radius elbow.

$r_{s36} = 36\,in$

$r_{l36} := 1.5 \cdot r_{s36}$ — Radius for long radius elbow.

$r_{l36} = 54\,in$

$A_{36} := \frac{\pi}{4} \cdot \left[d_{36}^{\,2} - \left(d_{36} - 2 \cdot t_{36} \right)^2 \right]$ — Pipe cross section area.

$A_{36} = 55.7633\,in^2$

$A_{i36} := \frac{\pi}{4} \cdot \left(d_{36} - 2 \cdot t_{36} \right)^2$ — Pipe internal area.

$A_{i36} = 962.1\,in^2$

$$\rho_{sw36} := \frac{A_{36}\cdot\rho_s + A_{i36}\cdot\rho_w}{A_{36}}$$

Mass density for the pipe with water.

$$\rho_{sw36} = 2.336\times 10^{-3}\,\frac{\text{lbf}\cdot\text{sec}^2}{\text{in}^4}$$

$$I_{36} := \frac{\pi}{64}\cdot\left[d_{36}^{\,4} - \left(d_{36} - 2\cdot t_{36}\right)^4\right]$$

Pipe area moment of inertia.

$$I_{36} = 8786.20\,\text{in}^4$$

$$J_{36} := \frac{\pi}{32}\cdot\left[d_{36}^{\,4} - \left(d_{36} - 2\cdot t_{36}\right)^4\right]$$

Pipe polar moment of inertia.

$$J_{36} = 17572.4\,\text{in}^4$$

$$k_{s36} := k\left(d_{36}, t_{36}, p_{376}, r_{s36}\right)$$

Flexibility factor for short radius.

$$k_{s36} = 20.304$$

$$I_{es36} := \frac{I_{36}}{k_{s36}}$$

Effective moment of inertia for short radius.

$$\boxed{I_{es36} = 432.735\,\text{in}^4}$$

$$k_{l36} := k\left(d_{36}, t_{36}, p_{376}, r_{l36}\right)$$

Flexibility factor for long radius.

$$k_{l36} = 12.978$$

$$I_{el36} := \frac{I_{36}}{k_{l36}}$$

Effective moment of inertia for long radius.

$$\boxed{I_{el36} = 676.999\,\text{in}^4}$$

Pipe 36 Inch Diameter and 9/16 Thickness (Upstream of Valve BF-A-14)

$d_{36} = 36\,\text{in}$ Pipe outside diameter.

$t_{36a} := 0.5625\cdot\text{in}$ Pipe thickness.

$p_{400} := 400 \cdot psi$ — Internal pressure upstream of valve BF-A-14. [3]

$r_{s36} = 36\,in$ — Radius for short radius elbow.

$r_{l36} = 54\,in$ — Radius for long radius elbow.

$$A_{36a} := \frac{\pi}{4} \cdot \left[{d_{36}}^2 - \left(d_{36} - 2 \cdot t_{36a} \right)^2 \right]$$

Pipe cross section area.

$$A_{36a} = 62.6232\,in^2$$

$$A_{i36a} := \frac{\pi}{4} \cdot \left(d_{36} - 2 \cdot t_{36a} \right)^2$$

Pipe internal area.

$$A_{i36a} = 955.3\,in^2$$

$$\rho_{sw36a} := \frac{A_{36a} \cdot \rho_s + A_{i36a} \cdot \rho_w}{A_{36a}}$$

Mass density for the pipe with water.

$$\rho_{sw36a} = 2.15 \times 10^{-3} \frac{lbf \cdot sec^2}{in^4}$$

$$I_{36a} := \frac{\pi}{64} \cdot \left[{d_{36}}^4 - \left(d_{36} - 2 \cdot t_{36a} \right)^4 \right]$$

Pipe area moment of inertia.

$$I_{36a} = 9832.9\,in^4$$

$$J_{36a} := \frac{\pi}{32} \cdot \left[{d_{36}}^4 - \left(d_{36} - 2 \cdot t_{36a} \right)^4 \right]$$

Pipe polar moment of inertia.

$$J_{36a} = 19665.8\,in^4$$

$$k_{s36a} := k\left(d_{36}, t_{36a}, p_{400}, r_{s36} \right)$$

Flexibility factor for short radius.

$$k_{s36a} = 19.088$$

$$I_{es36a} := \frac{I_{36a}}{k_{s36a}}$$

Effective moment of inertia for short radius.

$$\boxed{I_{es36a} = 515.14\,in^4}$$

$k_{l36a} := k(d_{36}, t_{36a}, p_{400}, r_{l36})$

Flexibility factor for long radius.

$k_{l36a} = 12.274$

$I_{el36a} := \frac{I_{36a}}{k_{l36a}}$

Effective moment of inertia for long radius.

$\boxed{I_{el36a} = 801.096\,in^4}$

Pipe 24 Inch Diameter and 3/8 Thickness (Downstream of Valve BF-A-14)

$d_{24} := 24 \cdot in$ — Pipe outside diameter.

$t_{24} := 0.375 \cdot in$ — Pipe thickness.

$p_{376} = 376\,psi$ — Internal pressure downstream of valve BF-A-14. [3]

$r_{s24} := d_{24}$

Radius for short radius elbow.

$r_{s24} = 24\,in$

$r_{l24} := 1.5 \cdot r_{s24}$

Radius for long radius elbow.

$r_{l24} = 36\,in$

$A_{24} := \frac{\pi}{4} \cdot \left[d_{24}^{\;2} - (d_{24} - 2 \cdot t_{24})^2\right]$

Pipe cross section area.

$A_{24} = 27.8325\,in^2$

$A_{i24} := \frac{\pi}{4} \cdot (d_{24} - 2 \cdot t_{24})^2$

Pipe internal area.

$A_{i24} = 424.6\,in^2$

$\rho_{sw24} := \frac{A_{24} \cdot \rho_s + A_{i24} \cdot \rho_w}{A_{24}}$

Mass density for the pipe with water.

$\rho_{sw24} = 2.15 \times 10^{-3}\,\frac{lbf \cdot sec^2}{in^4}$

$I_{24} := \frac{\pi}{64} \cdot \left[d_{24}{}^4 - \left(d_{24} - 2 \cdot t_{24} \right)^4 \right]$

Pipe area moment of inertia.

$I_{24} = 1942.3\,in^4$

$J_{24} := \frac{\pi}{32} \cdot \left[d_{24}{}^4 - \left(d_{24} - 2 \cdot t_{24} \right)^4 \right]$

Pipe polar moment of inertia.

$J_{24} = 3884.60\,in^4$

$k_{s24} := k\left(d_{24}, t_{24}, p_{376}, r_{s24}\right)$

Flexibility factor for short radius.

$k_{s24} = 19.383$

$I_{es24} := \frac{I_{24}}{k_{s24}}$

Effective moment of inertia for short radius.

$\boxed{I_{es24} = 100.206\,in^4}$

$k_{l24} := k\left(d_{24}, t_{24}, p_{376}, r_{l24}\right)$

Flexibility factor for long radius.

$k_{l24} = 12.484$

$I_{el24} := \frac{I_{24}}{k_{l24}}$

Effective moment of inertia for long radius.

$\boxed{I_{el24} = 155.58\,in^4}$

Pipe 20 Inch Diameter and 3/8 Thickness (Upstream of Valve BF-A-14)

$d_{20} := 20 \cdot in$ — Pipe outside diameter.

$t_{20} := 0.375 \cdot in$ — Pipe thickness.

$p_{400} = 400\,psi$ — Internal pressure stream of valve BF-A-14. [3]

$r_{s20} := d_{20}$

Radius for short radius elbow.

$r_{s20} = 20\,in$

$r_{l20} := 1.5 \cdot r_{s20}$

Radius for long radius elbow.

$r_{l20} = 30\,in$

$$A_{20} := \frac{\pi}{4} \cdot \left[d_{20}{}^2 - \left(d_{20} - 2 \cdot t_{20} \right)^2 \right]$$

Pipe cross section area.

$$A_{20} = 23.1202\, in^2$$

$$A_{i20} := \frac{\pi}{4} \cdot \left(d_{20} - 2 \cdot t_{20} \right)^2$$

Pipe internal area.

$$A_{i20} = 291\, in^2$$

$$\rho_{sw20} := \frac{A_{20} \cdot \rho_s + A_{i20} \cdot \rho_w}{A_{20}}$$

Mass density for the pipe with water.

$$\rho_{sw20} = 1.901 \times 10^{-3} \frac{lbf \cdot sec^2}{in^4}$$

$$I_{20} := \frac{\pi}{64} \cdot \left[d_{20}{}^4 - \left(d_{20} - 2 \cdot t_{20} \right)^4 \right]$$

Pipe area moment of inertia.

$$I_{20} = 1113.5\, in^4$$

$$J_{20} := \frac{\pi}{32} \cdot \left[d_{20}{}^4 - \left(d_{20} - 2 \cdot t_{20} \right)^4 \right]$$

Pipe polar moment of inertia.

$$J_{20} = 2226.94\, in^4$$

$$k_{s20} := k\left(d_{20}, t_{20}, p_{400}, r_{s20} \right)$$

Flexibility factor for short radius.

$$k_{s20} = 17.35$$

$$I_{es20} := \frac{I_{20}}{k_{s20}}$$

Effective moment of inertia for short radius.

$$\boxed{I_{es20} = 64.177\, in^4}$$

$$k_{l20} := k\left(d_{20}, t_{20}, p_{400}, r_{l20} \right)$$

Flexibility factor for long radius.

$$k_{l20} = 11.271$$

$$I_{el20} := \frac{I_{20}}{k_{l20}}$$

Effective moment of inertia for long radius.

$$\boxed{I_{el20} = 98.786\,in^4}$$

Pipe 18 Inch Diameter and 3/8 Thickness (Upstream of Valve BF-A-14)

$d_{18} := 18 \cdot in$ — Pipe outside diameter.

$t_{18} := 0.375 \cdot in$ — Pipe thickness.

$p_{400} = 400\,psi$ — Internal pressure upstream of valve BF-A-14. [3]

$r_{s18} := d_{18}$

Radius for short radius elbow.

$r_{s18} = 18\,in$

$r_{l18} := 1.5 \cdot r_{s18}$

Radius for long radius elbow.

$r_{l18} = 27\,in$

$$A_{18} := \frac{\pi}{4} \cdot \left[{d_{18}}^2 - \left(d_{18} - 2 \cdot t_{18} \right)^2 \right]$$

Pipe cross section area.

$$A_{18} = 20.8\,in^2$$

$$A_{i18} := \frac{\pi}{4} \cdot \left(d_{18} - 2 \cdot t_{18} \right)^2$$

Pipe internal area.

$$A_{i18} = 233.7\,in^2$$

$$\rho_{sw18} := \frac{A_{18} \cdot \rho_s + A_{i18} \cdot \rho_w}{A_{18}}$$

Mass density for the pipe with water.

$$\rho_{sw18} = 1.776 \times 10^{-3}\,\frac{lbf \cdot sec^2}{in^4}$$

$$I_{18} := \frac{\pi}{64} \cdot \left[{d_{18}}^4 - \left(d_{18} - 2 \cdot t_{18} \right)^4 \right]$$

Pipe area moment of inertia.

$$I_{18} = 806.6\,in^4$$

$J_{18} := \frac{\pi}{32} \cdot \left[d_{18}^{\ 4} - \left(d_{18} - 2 \cdot t_{18} \right)^4 \right]$ — Pipe polar moment of inertia.

$J_{18} = 1613.3 \, in^4$

$k_{s18} := k\left(d_{18}, t_{18}, p_{400}, r_{s18}\right)$ — Flexibility factor for short radius.

$k_{s18} = 16.197$

$I_{es18} := \frac{I_{18}}{k_{s18}}$ — Effective moment of inertia for short radius.

$\boxed{I_{es18} = 49.801 \, in^4}$

$k_{l18} := k\left(d_{18}, t_{18}, p_{400}, r_{l18}\right)$ — Flexibility factor for long radius.

$k_{l18} = 10.574$

$I_{el18} := \frac{I_{18}}{k_{l18}}$ — Effective moment of inertia for long radius.

$\boxed{I_{el18} = 76.288 \, in^4}$

Pipe 14 Inch Diameter and 1/4 Thickness (Upstream of Valve BF-A-14)

$d_{14} := 14 \cdot in$ — Pipe outside diameter.

$t_{14} := 0.25 \cdot in$ — Pipe thickness.

$p_{400} = 400 \, psi$ — Internal pressure upstream of valve BF-A-14. [3]

$r_{s14} := d_{14}$ — Radius for short radius elbow.

$r_{s14} = 14 \, in$

$r_{l14} := 1.5 \cdot r_{s14}$ — Radius for long radius elbow.

$r_{l14} = 21 \, in$

$A_{14} := \frac{\pi}{4} \cdot \left[d_{14}^{\ 2} - \left(d_{14} - 2 \cdot t_{14} \right)^2 \right]$ — Pipe cross section area.

$A_{14} = 10.7992 \, in^2$

$$A_{i14} := \frac{\pi}{4} \cdot (d_{14} - 2 \cdot t_{14})^2$$

Pipe internal area.

$$A_{i14} = 143.1\,in^2$$

$$\rho_{sw14} := \frac{A_{14} \cdot \rho_s + A_{i14} \cdot \rho_w}{A_{14}}$$

Mass density for the pipe with water.

$$\rho_{sw14} = 1.963 \times 10^{-3} \frac{lbf \cdot sec^2}{in^4}$$

$$I_{14} := \frac{\pi}{64} \cdot \left[d_{14}{}^4 - (d_{14} - 2 \cdot t_{14})^4 \right]$$

Pipe area moment of inertia.

$$I_{14} = 255.3\,in^4$$

$$J_{14} := \frac{\pi}{32} \cdot \left[d_{14}{}^4 - (d_{14} - 2 \cdot t_{14})^4 \right]$$

Pipe polar moment of inertia.

$$J_{14} = 510.6\,in^4$$

$$k_{s14} := k(d_{14}, t_{14}, p_{400}, r_{s14})$$

Flexibility factor for short radius.

$$k_{s14} = 17.854$$

$$I_{es14} := \frac{I_{14}}{k_{s14}}$$

Effective moment of inertia for short radius.

$$\boxed{I_{es14} = 14.2989\,in^4}$$

$$k_{l14} := k(d_{14}, t_{14}, p_{400}, r_{l14})$$

Flexibility factor for long radius.

$$k_{l14} = 11.57$$

$$I_{el14} := \frac{I_{14}}{k_{l14}}$$

Effective moment of inertia for long radius.

$$\boxed{I_{el14} = 22.0652\,in^4}$$

Pipe 12.75 Inch Diameter and 1/4 Thickness (Upstream of Valve BF-A-14)

$d_{12} := 12.75 \cdot in$ — Pipe outside diameter.

$t_{12} := 0.25 \cdot in$ — Pipe thickness.

$p_{400} = 400\,psi$ — Internal pressure upstream of valve BF-A-14. [3]

$r_{s12} := 12in$ — Radius for short radius elbow.

$r_{s12} = 12\,in$

$r_{l12} := 1.5 \cdot r_{s12}$ — Radius for long radius elbow.

$r_{l12} = 18\,in$

$$A_{12} := \frac{\pi}{4} \cdot \left[{d_{12}}^2 - \left(d_{12} - 2 \cdot t_{12}\right)^2 \right]$$

Pipe cross section area.

$A_{12} = 9.8\,in^2$

$$A_{i12} := \frac{\pi}{4} \cdot \left(d_{12} - 2 \cdot t_{12}\right)^2$$

Pipe internal area.

$A_{i12} = 117.9\,in^2$

$$\rho_{sw12} := \frac{A_{12} \cdot \rho_s + A_{i12} \cdot \rho_w}{A_{12}}$$

Mass density for the pipe with water.

$$\rho_{sw12} = 1.846 \times 10^{-3} \frac{lbf \cdot sec^2}{in^4}$$

$$I_{12} := \frac{\pi}{64} \cdot \left[{d_{12}}^4 - \left(d_{12} - 2 \cdot t_{12}\right)^4 \right]$$

Pipe area moment of inertia.

$I_{12} = 191.8\,in^4$

$$J_{12} := \frac{\pi}{32} \cdot \left[{d_{12}}^4 - \left(d_{12} - 2 \cdot t_{12}\right)^4 \right]$$

Pipe polar moment of inertia.

$J_{12} = 383.6\,in^4$

$k_{s12} := k\left(d_{12}, t_{12}, p_{400}, r_{s12}\right)$ — Flexibility factor for short radius.

$k_{s12} = 17.983$

$I_{es12} := \frac{I_{12}}{k_{s12}}$

Effective moment of inertia for short radius.

$I_{es12} = 10.667\,in^4$

$k_{l12} := k(d_{12}, t_{12}, p_{400}, r_{l12})$

Flexibility factor for long radius.

$k_{l12} = 11.713$

$I_{el12} := \frac{I_{12}}{k_{l12}}$

Effective moment of inertia for long radius.

$I_{el12} = 16.378\,in^4$

Pipe 4.5 Inch Diameter and 0.237 Thickness (Upstream of Valve BF-A-14)

$d_4 := 4.5 \cdot in$

Pipe outside diameter.

$t_4 := 0.237 \cdot in$

Pipe thickness.

$p_{400} = 400\,psi$

Internal pressure upstream of valve BF-A-14. [3]

$r_{s4} := 4 \cdot in$

Radius for short radius elbow.

$r_{l4} := 1.5 \cdot r_{s4}$

Radius for long radius elbow.

$r_{l4} = 6\,in$

$A_4 := \frac{\pi}{4} \cdot \left[d_4^2 - (d_4 - 2 \cdot t_4)^2\right]$

Pipe cross section area.

$A_4 = 3.17405\,in^2$

$A_{i4} := \frac{\pi}{4} \cdot (d_4 - 2 \cdot t_4)^2$

Pipe internal area.

$A_{i4} = 12.7\,in^2$

$\rho_{sw4} := \frac{A_4 \cdot \rho_s + A_{i4} \cdot \rho_w}{A_4}$

Mass density for the pipe with water.

$\rho_{sw4} = 1.1 \times 10^{-3} \frac{lbf \cdot sec^2}{in^4}$

$$I_4 := \frac{\pi}{64}\cdot\left[d_4^{\;4} - \left(d_4 - 2\cdot t_4\right)^4\right]$$

Pipe area moment of inertia.

$$I_4 = 7.2\,in^4$$

$$J_4 := \frac{\pi}{32}\cdot\left[d_4^{\;4} - \left(d_4 - 2\cdot t_4\right)^4\right]$$

Pipe polar moment of inertia.

$$J_4 = 14.4652\,in^4$$

$$k_{s4} := k\left(d_4, t_4, p_{400}, r_{s4}\right)$$

Flexibility factor for short radius.

$$k_{s4} = 7.769$$

$$I_{es4} := \frac{I_4}{k_{s4}}$$

Effective moment of inertia for short radius.

$$\boxed{I_{es4} = 0.931\,in^4}$$

$$k_{l4} := k\left(d_4, t_4, p_{400}, r_{l4}\right)$$

Flexibility factor for long radius.

$$k_{l4} = 5.167$$

$$I_{el4} := \frac{I_4}{k_{l4}}$$

Effective moment of inertia for long radius.

$$\boxed{I_{el4} = 1.39988\,in^4}$$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: Spears/Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

SUMMARY OF ELBOW FLEXIBILITY RESULTS

Pipe 36 Inch Diameter and 1/2 Thickness (Downstream of Valve BF-A-14)

$k_{s36} = 20.304$ Flexibility factor for short radius.

$I_{es36} = 432.735\,in^4$ Effective moment of inertia for short radius.

$k_{l36} = 12.978$ Flexibility factor for long radius.

$I_{el36} = 676.999\,in^4$ Effective moment of inertia for long radius.

Pipe 36 Inch Diameter and 9/16 Thickness (Upstream of Valve BF-A-14)

$k_{s36a} = 19.088$ Flexibility factor for short radius.

$I_{es36a} = 515.14\,in^4$ Effective moment of inertia for short radius.

$k_{l36a} = 12.274$ Flexibility factor for long radius.

$I_{el36a} = 801.096\,in^4$ Effective moment of inertia for long radius.

Pipe 24 Inch Diameter and 3/8 Thickness (Downstream of Valve BF-A-14)

$k_{s24} = 19.383$ Flexibility factor for short radius.

$I_{es24} = 100.206\,in^4$ Effective moment of inertia for short radius.

$k_{l24} = 12.484$ Flexibility factor for long radius.

$I_{el24} = 155.58\,in^4$ Effective moment of inertia for long radius.

Pipe 20 Inch Diameter and 3/8 Thickness (Upstream of Valve BF-A-14)

$k_{s20} = 17.35$ Flexibility factor for short radius.

$I_{es20} = 64.177\,in^4$ Effective moment of inertia for short radius.

$k_{l20} = 11.271$ Flexibility factor for long radius.

$I_{el20} = 98.786\,in^4$ Effective moment of inertia for long radius.

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Pipe 18 Inch Diameter and 3/8 Thickness (Upstream of Valve BF-A-14)

$k_{s18} = 16.197$	Flexibility factor for short radius.
$I_{es18} = 49.801\,in^4$	Effective moment of inertia for short radius.
$k_{l18} = 10.574$	Flexibility factor for long radius.
$I_{el18} = 76.288\,in^4$	Effective moment of inertia for long radius.

Pipe 14 Inch Diameter and 1/4 Thickness (Upstream of Valve BF-A-14)

$k_{s14} = 17.854$	Flexibility factor for short radius.
$I_{es14} = 14.2989\,in^4$	Effective moment of inertia for short radius.
$k_{l14} = 11.57$	Flexibility factor for long radius.
$I_{el14} = 22.0652\,in^4$	Effective moment of inertia for long radius.

Pipe 12.75 Inch Diameter and 1/4 Thickness (Upstream of Valve BF-A-14)

$k_{s12} = 17.983$	Flexibility factor for short radius.
$I_{es12} = 10.667\,in^4$	Effective moment of inertia for short radius.
$k_{l12} = 11.713$	Flexibility factor for long radius.
$I_{el12} = 16.378\,in^4$	Effective moment of inertia for long radius.

Pipe 4.5 Inch Diameter and 0.237 Thickness (Upstream of Valve BF-A-14)

$k_{s4} = 7.769$	Flexibility factor for short radius.
$I_{es4} = 0.931\,in^4$	Effective moment of inertia for short radius.
$k_{l4} = 5.167$	Flexibility factor for long radius.
$I_{el4} = 1.39988\,in^4$	Effective moment of inertia for long radius.

WATER FILLED PIPE DENSITY CALCULATIONS

$$\rho_s = 0.28 \frac{lb}{in^3}$$ Mass density of Stainless Steel [54]

$$\rho_w = 0.0361 \frac{lb}{in^3}$$ Mass density of Water [55, Table A]

Pipe Sections

The density of the pipe sections will be calculated by taking the density associated with the steel and the water and multiplying the value by the cross sectional area that each will have as well as a common length variable (L). The resulting weight will be divided by the cross sectional area of the pipe section and the L multiplier. The L multiplier will cancel from the top and bottom of the equation and the result will be the density that the pipe would need to be to represent the weight of the steel and water simultaneously in the beam model.

$i := 1..8$

$j := 0..7$

Ranges used to iterate through data

$$Pipe_{Dt} := \begin{pmatrix} \text{"Diameter"} & \text{"Thickness"} \\ 36 & 0.5625 \\ 36 & 0.5 \\ 24 & 0.375 \\ 20 & 0.375 \\ 18 & 0.375 \\ 14 & 0.25 \\ 12.75 & 0.25 \\ 4.5 & 0.237 \end{pmatrix}$$

$$Di\_p_{i-1} := \left(Pipe_{Dt_{i,0}} - 2 \cdot Pipe_{Dt_{i,1}}\right) in$$

$$Di\_p^T = (34.875 \quad 35 \quad 23.25 \quad 19.25 \quad 17.25 \quad 13.5 \quad 12.25 \quad 4.026)\ in$$

$$A_{w\_p_j} := \frac{\pi \cdot \left(Di\_p_j\right)^2}{4}$$

$$A_{w\_p}^T = (955.253 \quad 962.113 \quad 424.557 \quad 291.039 \quad 233.705 \quad 143.139 \quad 117.859 \quad 12.73)\ in^2$$

$$A_{s\_p_{i-1}} := \left[\frac{\pi \cdot \left(Pipe_{Dt_{i,0}} \cdot in\right)^2}{4} - A_{w\_p_{i-1}}\right]$$

$$A_{s\_p}{}^T = (62.623 \quad 55.763 \quad 27.833 \quad 23.12 \quad 20.764 \quad 10.799 \quad 9.817 \quad 3.174)\, in^2$$

$$Eq\_\rho\_p_{j,1} := \frac{\rho_s \cdot A_{s\_p_j} + \rho_w \cdot A_{w\_p_j}}{A_{s\_p_j}}$$

$$Eq\_\rho\_p^{\langle 0 \rangle} := \begin{pmatrix} \text{"36 x 0.5625"} \\ \text{"36 x 0.5"} \\ \text{"24 x 0.375"} \\ \text{"20 x 0.375"} \\ \text{"18 x 0.375"} \\ \text{"14 x 0.25"} \\ \text{"12.75 x 0.25"} \\ \text{"4.5 x 0.237"} \end{pmatrix} \qquad Eq\_\rho\_p = \begin{pmatrix} \text{"36 x 0.5625"} & 2.15 \times 10^{-3} \\ \text{"36 x 0.5"} & 2.336 \times 10^{-3} \\ \text{"24 x 0.375"} & 2.15 \times 10^{-3} \\ \text{"20 x 0.375"} & 1.901 \times 10^{-3} \\ \text{"18 x 0.375"} & 1.776 \times 10^{-3} \\ \text{"14 x 0.25"} & 1.963 \times 10^{-3} \\ \text{"12.75 x 0.25"} & 1.846 \times 10^{-3} \\ \text{"4.5 x 0.237"} & 1.1 \times 10^{-3} \end{pmatrix} \frac{lbf \cdot s^2}{in^4}$$

Reducers

The density of the reducers will be calculated by first considering the reducer to be two beams connected in the middle of the reducer where one beam has dimensions associated with the large open end and the other beam has dimensions associated with the small open end. The method used to determine the density of each section will be the same as that for the pipe sections described above.

$i := 1 .. 8$

$j := 0 .. 7$

Ranges used to iterate through data

$$Red_{Dt} := \begin{pmatrix} \text{"Diameter"} & \text{"Thickness"} \\ 36 & 0.5 \\ 24 & 0.5 \\ 36 & 0.5625 \\ 20 & 0.5625 \\ 20 & 0.375 \\ 18 & 0.375 \\ 14 & 0.25 \\ 12.75 & 0.25 \end{pmatrix}$$

$$Di\_r_{i-1} := \left(Red_{Dt_{i,0}} - 2 \cdot Red_{Dt_{i,1}}\right) in$$

$$Di\_r^T = (35 \quad 23 \quad 34.875 \quad 18.875 \quad 19.25 \quad 17.25 \quad 13.5 \quad 12.25)\ in$$

$$A_{w\_r_j} := \frac{\pi \cdot \left(Di\_r_j\right)^2}{4}$$

$$A_{w\_r}^T = (962.113 \quad 415.476 \quad 955.253 \quad 279.81 \quad 291.039 \quad 233.705 \quad 143.139 \quad 117.859)\ in^2$$

$$A_{s\_r_{i-1}} := \left[\frac{\pi \cdot \left(Red_{Dt_{i,0}} \cdot in\right)^2}{4} - A_{w\_r_{i-1}}\right]$$

$$A_{s\_r}^T = (55.763 \quad 36.914 \quad 62.623 \quad 34.349 \quad 23.12 \quad 20.764 \quad 10.799 \quad 9.817)\ in^2$$

$$Eq\_\rho\_r_{j,1} := \frac{\rho_s \cdot A_{s\_r_j} + \rho_w \cdot A_{w\_r_j}}{A_{s\_r_j}}$$

$$Eq\_\rho\_r^{\langle 0 \rangle} := \begin{pmatrix} \text{"36x24 lg"} \\ \text{"36x24 sm"} \\ \text{"36x20 lg"} \\ \text{"36x20 sm"} \\ \text{"20x18 lg"} \\ \text{"20x18 sm"} \\ \text{"14x12 lg"} \\ \text{"14x12 sm"} \end{pmatrix} \qquad Eq\_\rho\_r = \begin{pmatrix} \text{"36x24 lg"} & 2.336 \times 10^{-3} \\ \text{"36x24 sm"} & 1.776 \times 10^{-3} \\ \text{"36x20 lg"} & 2.15 \times 10^{-3} \\ \text{"36x20 sm"} & 1.486 \times 10^{-3} \\ \text{"20x18 lg"} & 1.901 \times 10^{-3} \\ \text{"20x18 sm"} & 1.776 \times 10^{-3} \\ \text{"14x12 lg"} & 1.963 \times 10^{-3} \\ \text{"14x12 sm"} & 1.846 \times 10^{-3} \end{pmatrix} \frac{lbf \cdot s^2}{in^4}$$

Elbows

The density of the Elbows will be considered to be the same as that of the pipe with the same dimensions as an relatively close approximation.

Tees and Branches

The density of the Tees will be calculated by observing that the run and branch are both comprised of the same pipe type and one density will be associated with that pipe type. The Branches will be calculated by considering the run and branch as two separate components and a density for each will be calculated. The method used to determine the density of each section will be the same as that for the pipe sections described above.

$i := 1..6$

$j := 0..5$

Ranges used to iterate through data

$$T\_Br_{Dt} := \begin{pmatrix} \text{"Diameter"} & \text{"Thickness"} \\ 37.75 & 1.375 \\ 14 & 0.25 \\ 36 & 0.5625 \\ 20 & 0.375 \\ 14 & 0.25 \\ 4.5 & 0.237 \end{pmatrix}$$

$$Di\_TB_{i-1} := \left(T\_Br_{Dt_{i,0}} - 2 \cdot T\_Br_{Dt_{i,1}}\right) in$$

$$Di\_TB^T = (35 \quad 13.5 \quad 34.875 \quad 19.25 \quad 13.5 \quad 4.026)\ in$$

$$A_{w\_TB_j} := \frac{\pi \cdot \left(Di\_TB_j\right)^2}{4}$$

$$A_{w\_TB}^T = (962.113 \quad 143.139 \quad 955.253 \quad 291.039 \quad 143.139 \quad 12.73)\ in^2$$

$$A_{s\_TB_{i-1}} := \left[\frac{\pi \cdot \left(T\_Br_{Dt_{i,0}} \cdot in\right)^2}{4} - A_{w\_TB_{i-1}}\right]$$

$$A_{s\_TB}^T = (157.129 \quad 10.799 \quad 62.623 \quad 23.12 \quad 10.799 \quad 3.174)\ in^2$$

$$Eq\_\rho\_TB_{j,1} := \frac{\rho_s \cdot A_{s\_TB_j} + \rho_w \cdot A_{w\_TB_j}}{A_{s\_TB_j}}$$

$$Eq\_\rho\_TB^{\langle 0 \rangle} := \begin{pmatrix} \text{"T 37.75"} \\ \text{"T 14"} \\ \text{"Br 36x20\_r"} \\ \text{"Br 36x20\_br"} \\ \text{"Br 14x4\_r"} \\ \text{"Br 14x4\_br"} \end{pmatrix} \qquad Eq\_\rho\_TB = \begin{pmatrix} \text{"T 37.75"} & 1.297 \times 10^{-3} \\ \text{"T 14"} & 1.963 \times 10^{-3} \\ \text{"Br 36x20\_r"} & 2.15 \times 10^{-3} \\ \text{"Br 36x20\_br"} & 1.901 \times 10^{-3} \\ \text{"Br 14x4\_r"} & 1.963 \times 10^{-3} \\ \text{"Br 14x4\_br"} & 1.1 \times 10^{-3} \end{pmatrix} \frac{lbf \cdot s^2}{in^4}$$

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Valves

The density of the Valves will be calculated by observing that the approach adopted by this project was to approximate the valves influence by increasing the thickness of the pipe until the moment of inertia was increased to 3 times that of the connecting pipe. However, since a lump mass representing the mass of the valve was included in the model the density of the valves will be adjusted such that it is only 10% of the mass of the pipe run that the valve intermediates.

$i := 1..4$

$j := 0..3$

Ranges used to iterate through data

$$PR_{Dt} := \begin{pmatrix} \text{"Pipe Diameter"} & \text{"Pipe Thickness"} \\ 36in & 0.5625in \\ 24in & 0.375in \\ 20in & 0.375in \\ 14in & 0.855in \end{pmatrix} \qquad Valve_{Dt} := \begin{pmatrix} \text{"Valve Diameter"} & \text{"Valve Thickness"} \\ 36in & 1.206in \\ 24in & 1.258in \\ 20in & 1.293in \\ 14in & 0.25in \end{pmatrix}$$

$$A_{s\_PR_{i-1}} := \left[\frac{\pi\cdot\left(PR_{Dt_{i,0}}\right)^2}{4} - \frac{\pi\cdot\left(PR_{Dt_{i,0}} - 2\cdot PR_{Dt_{i,1}}\right)^2}{4}\right]$$

$$A_{s\_PR}^{T} = (62.623 \quad 27.833 \quad 23.12 \quad 35.308)\,in^2$$

$$A_{s\_V_{i-1}} := \left[\frac{\pi\cdot\left(Valve_{Dt_{i,0}}\right)^2}{4} - \frac{\pi\cdot\left(Valve_{Dt_{i,0}} - 2\cdot Valve_{Dt_{i,1}}\right)^2}{4}\right]$$

$$A_{s\_V}^{T} = (131.826 \quad 89.879 \quad 75.989 \quad 10.799)\,in^2$$

$$Eq\_\rho\_V_{j,1} := \frac{0.1\cdot\rho_s\cdot A_{s\_PR_j}}{A_{s\_V_j}}$$

$$Eq\_\rho\_V^{\langle 0\rangle} := \begin{pmatrix} \text{"36in Pipe Run"} \\ \text{"24in Pipe Run"} \\ \text{"20in Pipe Run"} \\ \text{"14in Pipe Run"} \end{pmatrix} \qquad Eq\_\rho\_V = \begin{pmatrix} \text{"36in Pipe Run"} & 3.445\times10^{-5} \\ \text{"24in Pipe Run"} & 2.246\times10^{-5} \\ \text{"20in Pipe Run"} & 2.207\times10^{-5} \\ \text{"14in Pipe Run"} & 2.371\times10^{-4} \end{pmatrix}\frac{lbf\cdot s^2}{in^4}$$

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Appendix B.10

Support / Anchorage Capacities

Note: Limiting capacities for each appendix are highlighted yellow in their respective summary sections

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Appendix B.10.1

Capacity Table for Supports / Anchorage Associated with Model 3

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PCS Support/Anchorage Capacities for Model 3

Support	Line #	Direction	Capacity Type	Calculated Anchorage Capacity (kips)	Anchorage Reference	Calculated Support Capacity (kips)	Support Reference
MS-5	1-26	NS (X)	TEN/COM	>Support	App B.10.11	6	[32, App D8-5]
MS-7	1-26	NS (X)	TEN/COM	>Support	App B.10.11	6	[32, App D8-5]
MS-8	1-26	NS (X)	TEN/COM	>Support	App B.10.11	6	[32, App D8-5]
PS-3A	1-27	V (Y)	COM	NA	[32, App E6]	154.855	[32, App D3-4]
RH-23x or 23A	1-27	V (Y)	TEN	56.28	[32, App E5]	41.417	App B.10.7
RH-25Ax or Bx	1-27	V (Y)	TEN	56.28	[32, App E5]	82.835	App B.10.8
RH-25Ax or Bx	1-27	V (Y)	TEN	56.28	[32, App E5]	82.835	App B.10.8
RH-26x A&B	1-27	V (Y)	TEN	Combined (28.14)	[32, App E5]	82.835	App B.10.9
RH-27x	1-27	V (Y)	TEN	Combined (28.14)	[32, App E5]	27.8	[32, App E5]
PR-1 (West) +	1-28	E (+Z)	TEN	3.188	[32, App E7]	41.417	App B.10.4
	1-28	W (-Z)	COM	NA		13.929	App B.10.4
PR-1 (East) +	1-29	E (+Z)	TEN	3.188	[32, App E7]	41.417	App B.10.4
	1-29	W (-Z)	COM	NA		13.929	App B.10.4
PR-8	1-27	V (+Y)	TEN	0	App B.10.11	33.548	App B.10.5
	1-27	V (-Y)	COM	NA		2.374	App B.10.5
MS-2	1-27	E (+Z)	COM	NA	[32, App E7]	50	App B.10.3
	1-27	W (-Z)	TEN	34.229	[32, App E7]	50	App B.10.3
Tunnel Restraint	1-27	W (-Y)	COM	NA	[32, App E6]	85.842	[32, App D22B-9]
	1-27	E (+Y)	COM	NA	[32, App E6]	61.48	[32, App D22B-9]
Floor Tieback	1-27	NS (X)	LATERAL	NA	[32, App C]	101.12	[32, App C]
	1-27	EW (Y)	LATERAL	NA	[32, App C]	67.488	[32, App C]
PS-5	1-32	V (-Y)	COM	NA	[32, App E6]	87.894	[32, App D3-4]
PS-5	1-33	V (-Y)	COM	NA	[32, App E6]	87.894	D3-4
PS-5	1-33	V (-Y)	COM	NA	[32, App E6]	87.894	D3-4
PS-5	1-33	V (-Y)	COM	NA	[32, App E6]	87.894	D3-4
PS-21	1-32	N (+X)	TEN	>1.25*Support	App B.10.11	40.589	[32, App D2-16]
	1-32	S (-X)	COM	NA		34.838	[32, App D2-16]
	1-32	EW (Y)	LATERAL	NA		0.765	[32, App D2-16]
	1-32	V (Y)	LATERAL	NA		0.765	[32, App D2-16]
RH-15A	1-32	V (-Y)	TEN	46.9	[32, App E5]	21.648	[32, App D7-12]
RH-15	1-32	V (-Y)	TEN	46.9	[32, App E5]	14.91	D7-12
RH-15	1-32	V (-Y)	TEN	46.9	[32, App E5]	14.91	D7-12
PR-11	1-32	V (Y)	LATERAL	0.139	[32, App E5]	0.162	[32, App D23-14]
	1-32	N (+X)	TEN	11.25	[32, App E5]	7.86	[32, App D23-13]
	1-32	S (-X)	COM	NA		51.337	[32, App D23-13]
RH-24	1-49	V (-Y)	TEN	11.25*	[32, App E5]	7.069	App B.10.10
RH-24	1-49	V (-Y)	TEN	11.25*	[32, App E5]	7.069	App B.10.10
PS-3	1-22	V (-Y)	COM	NA		87.05	App B.10.6
PS-3	1-23	V (-Y)	COM	NA		87.05	App B.10.6
PS-3	1-24	V (-Y)	COM	NA		87.05	App B.10.6
PS-3	1-25	V (-Y)	COM	NA		87.05	App B.10.6

* Assumed same as RH-16 [32, D4-15]

+ PR-1's are further evaluated in combination with PR-2's in appendix E

Combined (28.14) - Indicates that the support shares a common anchorage with another support and the stated value is a place holder and the extended evaluation is shown in App E.8

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Appendix B.10.2

Photos Associated with Following Supports

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Figure B.10.2-1. Photo DSCN2885 (also labeled as M3-1-27-N200-WSUPC-DSCN2885)

Figure B.10.2-2. Photo DSCN2864 (also labeled as M3-1-28-N50-WSUPC-DSCN2864)

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Figure B.10.2-3. Photo Dsc00079

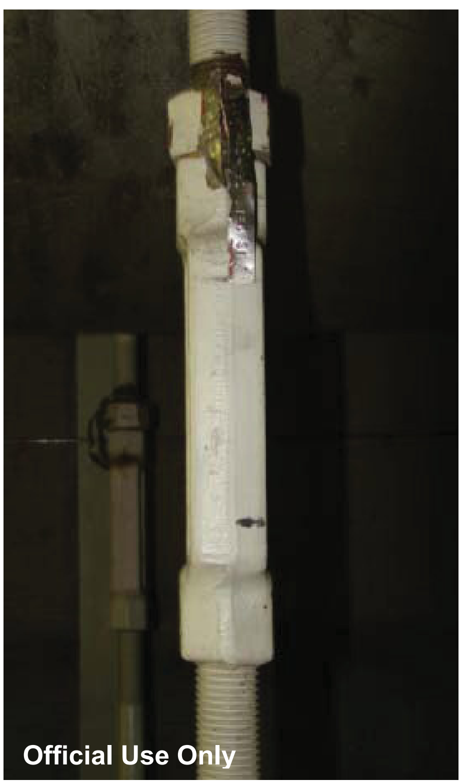

Figure B.10.2-4. Photo Dcn00080

Figure B.10.2-5. Photo DSCN2934
(also labeled as M3-1-27-N340-CSUG-DSCN2934)

Figure B.10.2-6. Photo DSC00143 (also labeled as M3-1-27-N310-CSUPC-DSC00143)

Figure B.10.2-7. Photo DSCN2917 (also labeled as M3-1-27-N310-CSUPC-DSCN2917)

Figure B.10.2-8. Photo Dsc00034

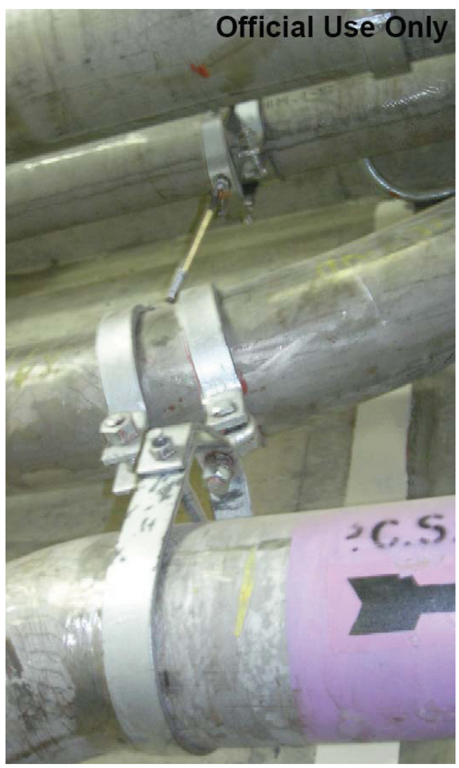

Figure B.10.2-9. Photo DSCN2683 (also labeled as M4-1-40-N64-PSUG-DSCN2683)

Appendix B.10.3

Capacity of MS-2 Support

MS-2 CAPACITY

MS-2 restricts seismic motion in the east/west direction of the horizontally oriented PCS piping traveling in the north/south direction. MS-2 is comprised of the PSA-35 mechanical snubber, base plate bolted to the wall, and clamp attaching the support to the 36" PSC pipe. The snubber is connected to the clamp and base plate by a pin and the clamp is secured to the pipe by two large threaded rods on either side. . The anchorage assembly capacities and the associated capacities of the wall embedment are found in the anchorage and embedment portions of [32, App E] while the capacities for the remainder of the previously mentioned components are calculated below.

Component Capacity Overview:

- Eastward/Westward Loading:
- Shear capacity of mechanical snubber's pins
- Tension/Compression capacity of snubber
- Tension/Compression capacity of clamp

Procedures from SEI/ASCE 8-02 (Applying LRFD)

References contained in Appendix B.11 of this Report

Note:

SEI/ASCE 8-02 was applied for these supports instead of AISC 13th Edition because the vendor data capacities for the mechanical snubbers and their associated clamps were available, however, the stainless steel pins implemented were associated with a drawing given specific material properties and dimensions of the stainless steel.

$i := 0$

Assigned indices corresponding to number of support types associated with these calculations

Support =	0
	(MS-2)

Relationship between support and corresponding indices

Geometric and Material Properties of Support Components

MECHANICAL SNUBBER PINS (Mechanical Snubber Pin Detail [45])

Material Properties of Mechanical Snubber Pins as Defined in the [45] and [47]:

$F_{y\_pin} := 115ksi$ — Yield Strength for SA-564, Tp 630, Cond 1100

$F_{u\_pin} := 140ksi$ — Ultimate Strength for SA-564, Tp 630, Cond 1100

Geometric Properties of Mechanical Snubber Pins:

$d_{pin} := (1.4970in)^T$ — Diameter of mechanical snubber pins [29], [45]

$L_{pin} := (7in)^T$ — Length of mechanical snubber pins [29], [45]

MECHANICAL SNUBBER (PSA Mechanical Snubber [29])

Rated Capacity of Mechanical Snubbers:

$Capacity_{MS} := (50kip)^T$ — Rated capacity of mechanical snubbers [48, pg 171]

CLAMP (Pipe Clamp [159776])

Rated Capacity of Mechanical Snubbers' Pipe Clamp:

$Capacity_{cl} := (55kip)^T$ — Rated capacity of pipe clamp connecting mechanical snubber [43]

Applicability of applying SEI/ASCE 8-02

MECHANICAL SNUBBER PINS

1.3.3 Ductility

This code does not list SA-564 as an applicable stainless steel unless it meets the following criteria

Ratio of tensile strength to yield strength must not be less than 1.08

$$\frac{F_{u\_pin}}{F_{y\_pin}} = 1.217$$

Since this value is greater than the 1.08 specification SA-564 meets this requirement

Total elongation shall not be less than 10% for a two-in. gage length standard specimen

Elongation = 14% [47, pg 1092]

Since this value is greater than the 10% requirement SA-564 meets this requirement as well

Capacities For Eastward/Westward Loading

MECHANICAL SNUBBER PINS

Shear, capacity of mechanical snubber anchorage and clamp pins [46, Ch. 5 pg 24 thru 25]

5. Connections and Joints

5.3.4. Shear and Tension in Stainless Steel Bolts

$\phi := 0.65$ [46, Table 6 pg 25]

$A_{pin_i} := \pi \cdot \left(\frac{d_{pin_i}}{2}\right)^2$ Gross cross sectional area of pin

$A_{pin\_ds_i} := 2 \cdot A_{pin_i}$ Applicable area for this case since the bolt is in double shear

$F_{nv\_cl\_bolt} := 0.5 \cdot F_{y\_pin}$ Since F_{nv} is not provided for SA-564 type 630 stainless steel in SEI/ASCE 8-02 it is observed from [46, Table A1] that the shear yield strength of the represented materials is no less than 0.51 of the yield strength, thus to be conservative it has been estimated to be 0.5 of the yield strength

$R_{nv\_cl\_bolt_i} := F_{nv\_cl\_bolt} \cdot A_{pin\_ds_i}$ Nominal strength (R_n) (5.3.4-1)

$\phi R_{nv\_cl\_bolt_i} := \phi \cdot R_{nv\_cl\_bolt_i}$

$\phi R_{nv\_cl\_bolt}^T = (131.566)\ kip$ Design shear strength

It appears that even with the conservative assumptions that these values are much greater than that of the snubber and clamp capacities, thus this treatment is adequate in determining if these components will govern this support

Compression/Tension, capacity of mechanical snubber

MECHANICAL SNUBBER

$P_{MS} := Capacity_{MS}$

$P_{MS}^T = (50)\ kip$ Supplied mechanical snubber strength

Compression/Tension, capacity of clamp

CLAMP

$P_{cl} := Capacity_{cl}$

$P_{cl}^T = (55)\ kip$ Supplied clamp strength

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Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

SUMMARY OF RESULTS

Capacities For Eastward/Westward Loading

MECHANICAL SNUBBER PINS

Shear, capacity of mechanical snubber anchorage and clamp pins [46 , Ch 5 pg 24 thru 25]

5. Connections and Joints

5.3.4. Shear and Tension in Stainless Steel Bolts

$\phi R_{nv\_cl\_bolt}^{T} = (131.566)\ kip$ Design shear strength

It appears that even with the conservative assumptions that these values are much greater than that of the snubber and clamp capacities, thus this treatment is adequate in determining if these components will govern this support

Compression/Tension, capacity of mechanical snubber

MECHANICAL SNUBBER

$P_{MS}^{T} = (50)\ kip$ Supplied mechanical snubber strength

Compression/Tension, capacity of clamp

CLAMP

$P_{cl}^{T} = (55)\ kip$ Supplied clamp strength

Appendix B.10.4

Capacity of PR-1 Support

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

PR-1 CAPACITY

PR-1 restricts seismic motion in the east/west direction of the vertically oriented PCS piping which it is attached. PR-1 is comprised of a 24" pipe clamp, a bolt connecting the pipe clamp to a plate welded to a threaded rod, a pipe tapped to accommodate the threaded rod, another threaded rod welded to a plate, another bolt attaching the second threaded rod and plate to the welded beam attachment. The anchorage assembly capacities and the associated capacities of the wall embedment are found in the anchorage and embedment portions of [32, App E] while the capacities for the remainder of the previously mentioned components are calculated below.

Component Capacity Overview:

- Eastward Loading:
- Compression capacity of pipe clamp
- Shear capacity of pipe clamp's bolt
- Compression capacity of threaded rods
- Compression capacity of support pipe
- Shear capacity of welded beam attachment bolt

- **Westward Loading:**
- Tension capacity of clamp
- Shear capacity of pipe clamp's bolt
- Tension capacity of plates welded to threaded rods
- Tension capacity of weld between plates and rods
- Tension capacity of threaded rods
- Tension capacity of support pipe
- Shear capacity of welded beam attachment bolt
- Tension capacity of welded beam attachment

Procedures from AISC 13th Edition (Applying LRFD)

References contained in Appendix B.11 of this Report

$i := 0$

Assigned indices corresponding to number of support types associated with these calculations

Support =	0
	(PR-1)

Relationship between support and corresponding indices

Geometric and Material Properties of Support Components

PIPE CLAMP

Material Properties of Clamp as Defined in the Material Section of Report [32]:

$F_{y\_cl} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{u\_cl} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E_{cl} := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Clamp:

$t_{cl} := \left(\frac{3}{4}in\right)^T$ — Thickness of plates forming the cantilever portion of the clamp [DSCN2885]

$w_{cl} := \left(5\frac{1}{2}in\right)^T$ — Width of plates forming the clamp [DSCN2864], [30]

$A_{cl_i} := \left(2\,t_{cl_i}\right)\cdot w_{cl_i}$ — Total cross sectional area of both sides of clamp

$A_{cl}^T = (8.25)\,in^2$

$d_{cl\_bolt} := \left(1\frac{3}{8}in\right)^T$ — Bolt diameter, in. of all three bolts based on allowable provided by rod [18], [22, Fig 66 ph-33]

$d_{cl\_hole} := \left(1\frac{1}{2}in\right)^T$ — Nominal bolt hole diameter as estimated from welded beam attachment dimensions estimated from [22, Fig 66 ph-33]

$a_{parrallel\_cl} := (1in)^T$ — Shortest distance from edge of the pin hole to the edge of the member measured parallel to the direction of the force from top of bolt hole to top of clamp bracket, in. (mm) conservatively estimated from [DSCN2864]

$a_{normal\_cl} := (2in)^T$ — Shortest distance from edge of pin hole to the edge of the member measured normal to the direction of the force, in. scaled from photo [DSCN2864]

$L_{cl\_cantilever} := (9in)^T$ — Length of cantilever section from pipe to connection bolt conservatively scaled from photo [DSCN2864]

$r_{gyrationH} := \frac{w_{cl}}{\sqrt{12}}$ — Radius of gyration about horizontal axis [8, Table 17-27]

$r_{gyrationH} = (1.588)\,in$

$$r_{gyrationV} := \frac{t_{cl}}{\sqrt{12}}$$

Radius of gyration about vertical axis [8, Table 17-27]

$$r_{gyrationV} = (0.217)\,in$$

PLATES WELDED TO THREADED RODS

Material Properties of Plate as Defined in the Material Section of Report [32]:

$F_{y\_pl\_tr} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{u\_pl\_tr} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E_{pl\_tr} := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Plate:

$$t_{pl\_tr} := \left(\frac{3}{4}in\right)^T$$

Thickness of plates forming the cantilever portion of the clamp [30]

$$w_{pl\_tr} := (3in)^T$$

Width of plates forming the clam [30]

$$A_{pl\_tr_i} := t_{pl\_tr_i} \cdot w_{pl\_tr_i}$$

Total cross sectional area of each side clamp, in.^{2} (mm^2)

$$A_{pl\_tr}{}^T = (2.25)\,in^2$$

$$d_{pl\_tr\_hole} := \left(1\frac{1}{2}in\right)^T$$

Nominal bolt hole diameter as estimated from welded beam attachment dimensions estimated from [22, Fig 66 ph-33]

$$a_{parrallel\_pl\_tr} := (1in)^T$$

Shortest distance from edge of the pin hole to the edge of the member measured parallel to the direction of the force from top of bolt hole to top of clamp bracket, in. (mm) conservatively estimated from [DSCN2864]

$$a_{normal\_pl\_tr} := \left(\frac{3}{4}in\right)^T$$

Shortest distance from edge of pin hole to the edge of the member measured normal to the direction of the force, in. scaled from photo [DSCN2864]

$$d_{tr} := \left(1\frac{1}{4}in\right)^T$$

Threaded rod diameter [30]

$$A_{tr\_minor} := \left[\pi \cdot \left(\frac{1.0644in}{2}\right)^2\right]^T$$

Minor area of treaded rods with welded plate [Machine Design, Table 14-1 pg 881]

$$A_{tr\_minor} = (0.89)\,in^2$$

$L_{pl\_tr} := (18in)^T$ — Conservative estimate of rod length from pin hole to support pipe connection [30]

$r_{gyration\_pl\_tr_i} := \frac{d_{tr_i}}{4}$ — Radius of gyration for threaded portion [8, Table 17-27, pg 17-39]

$r_{gyration\_pl\_tr} = (0.313)\,in$

$F_{EXX} := 60ksi$ — E6013 weld material ultimate strength [50, pg I-9], [51]

$\theta_{transverse} := \frac{\pi}{2}$ — Angle between loading and traverse welds

$F_{w\_transverse} := 0.60 \cdot F_{EXX} \cdot \left(1.0 + 0.5 \cdot \sin\left(\theta_{transverse}\right)^{1.5}\right)$ (J2-5)

$F_{w\_transverse} = 54\,ksi$ — Nominal Shear Strength of transverse welds

$\theta_{longitudinal} := 0$ — Angle between loading and traverse welds

$F_{w\_longitudinal} := 0.60 \cdot F_{EXX} \cdot \left(1.0 + 0.5 \cdot \sin\left(\theta_{longitudinal}\right)^{1.5}\right)$ (J2-5)

$F_{w\_longitudinal} = 36\,ksi$ — Nominal Shear Strength of longitudinal welds

$\omega := \left(\frac{1}{4}in\right)^T$ — Minimum size of fillet given that thinner joined part (plate) = 3/4" [8, Table J2.4, pg 16.1-96] [30]

$L_{w\_traverse} := \left(3\frac{1}{2}in\right)^T$ — Traverse length of weld [30]

$L_{w\_longitudinal} := (8in)^T$ — Longitudal length of weld [30]

$A_{w\_traverse_i} := L_{w\_traverse_i} \cdot 0.707\,\omega_i$ — Effective area of weld throat of traverse welds

$A_{w\_traverse} = (0.619)\,in^2$

$A_{w\_longitudinal_i} := L_{w\_longitudinal_i} \cdot 0.707\,\omega_i$ — Effective area of weld throat of traverse welds

$A_{w\_longitudinal} = (1.414)\,in^2$

SUPPORT PIPE (defined as 2-1/2" x 5)

Material Properties of Support Pipe as Defined in the Material Section of Report [32]:

$F_{y\_sp} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{u\_sp} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E_{sp} := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Support Pipe:

$d_{sp\_od} := (2.88in)^T$ — Outside diameter of support pipe [8, Table 1-14]

$d_{sp\_id} := (2.47in)^T$ — Inside diameter of support pipe [8, Table 1-14]

$t_{sp} := (0.276in)^T$ — Thickness of support pipe [8, Table 1-14]

$A_{sp} := \left(1.59in^2\right)^T$ — Cross sectional are of support pipe [8, Table 1-14]

$L_{sp} := (90in)^T$ — Conservatively estimated length between pins connecting support pipe to PCS pipe and anchorage [30]

$r_{gyration\_sp} := (0.952in)^T$ — Radius of gyration for support pipe [8, Table 1-14]

WELDED BEAM ATTACHMENT (Welded Beam Attachment FIG 66 1-1/4" Rod [120925, Sheet 2])

Material Properties of Welded Beam Attachment as Defined in the Material Section of Report [32]:

$F_{y\_wba} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{u\_wba} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E_{wba} := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Welded Beam Attachment:

$t_{wba} := \left[2 \cdot \left(\frac{5}{8}in\right)\right]^T$ — Combined thickness of welded beam attachment [22, Fig 66 ph-33]

$w_{wba} := (4in)^T$ — Width of welded beam attachment [22, Fig 66 ph-33]

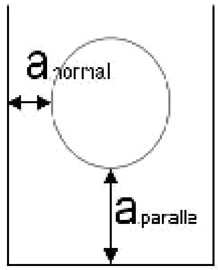
$A_{wba_i} := t_{wba_i} \cdot w_{wba_i}$

$A_{wba} = (5)\ in^2$ — Cross sectional area of welded beam attachment

$d_{wba\_bolt} := \left(1\frac{3}{8}in\right)^T$ — Diameter of welded beam attachment bolt [22, Fig 66 ph-33]

$$d_{wba\_hole} := \left(1\frac{1}{2}in\right)^T$$

Diameter of welded beam attachment bolt hole [22, Fig 66 ph-33], [8, Table J3.3 pg 16.1-105]



$$a_{parrallel\_wba} := \left(1\frac{1}{4}in\right)^T$$

Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force from bottom of bolt hole to the bottom of the welded beam attachment, in. (mm) hand calculated from d_{wba_hole} and [22, Fig 66 ph-33] data

$$a_{normal\_wba_i} := \frac{w_{wba_i} - d_{wba\_hole_i}}{2}$$

$$a_{normal\_wba}^T = (1.25)\ in$$

Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force, in. (mm) [22, Fig 66 ph-33]

Capacities For Outward Loading

PIPE CLAMP

Compression, capacity of clamp's cantilever section [8, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

$$\phi_c := 0.9$$

Resistance factor for compression

E2. Slenderness Limitations and Effective Length

$$K := 2.1$$

Effective length in accordance with C2.1b, [8, comm.C2 (Table C-C2.2 case e) pg 16.1-240], conservatively chosen as the behavior will actually be something between case c and case e.

The slenderness ratio (KL/r) should preferably not exceed 200

$$r_{gyration\_gov_i} := \min\left(r_{gyrationH_i}, r_{gyrationV_i}\right)$$

Governing radius of gyration

$$KLr_i := \left(\frac{K \cdot L_{cl\_cantilever_i}}{r_{gyration\_gov_i}}\right)$$

The below KLr values verify that all supports do not exceed the 200 recommended limitation

$$KLr^T = (87.295)$$

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified by classification)

$$F_{e_i} := \frac{\pi^2 E_{cl}}{\left(KLr_i\right)^2}$$

F_e is the elastic critical buckling stress (E3-4)

$$F_e^T = (37.559)\,ksi$$

Calculating the variables Limit, Op1, and Op2 to be utilized in logic to determine flexural buckling stress.

$$Limit := 4.71 \cdot \sqrt{\frac{E_{cl}}{F_{y\_cl}}}$$

$$Limit = 139.625$$

$$Op1_i := \left(0.658^{\frac{F_{y\_cl}}{F_{e_i}}}\right) F_{y\_cl}$$

$$Op2_i := 0.877 \cdot F_{e_i}$$

Calculating the flexural buckling stress

$$F_{cr_i} := \begin{cases} Op1_i & \text{if } KLr_i \le Limit \\ Op2_i & \text{if } KLr_i > Limit \end{cases}$$

(E3-2)

(E3-3)

$$F_{cr}^T = (22.846)\,ksi$$

Results:

$$\phi P_{n\_SL_i} := 2 \cdot \phi_c \cdot F_{cr_i} \cdot A_{cl_i}$$

2 is included to account for both sides of clamp

$$\boxed{\phi P_{n\_SL}^T = (339.259)\,kip}$$

Design compressive strength

Shear, capacity of clamp's bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$A_{cl\_bolt_i} := \pi \cdot \left(\frac{d_{cl\_bolt_i}}{2}\right)^2$$

Nominal unthreaded body area

$$A_{cl\_bolt\_ds_i} := 2 \cdot A_{cl\_bolt_i}$$

Applicable area for this case since the bolt is in double shear

$$F_{nv\_cl\_bolt} := 24ksi$$

Nominal shear stress in bearing type connections (A307) [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment and includes an allowance for threads in the shear plane

$$R_{nv\_cl\_bolt_i} := F_{nv\_cl\_bolt} \cdot A_{cl\_bolt\_ds_i}$$

Nominal strength (R_n) (J3-1)

$$\phi_{b\_sr} := 0.75$$

Resistance factor

$$\phi R_{nv\_cl\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_cl\_bolt_i}$$

$$\phi R_{nv\_cl\_bolt}^{T} = (53.456)\,kip$$

Design shear strength

PLATES WELDED TO THREADED RODS

Compression, capacity of threaded rods [8, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

$$\phi_c := 0.9$$

Resistance factor for compression

E2. Slenderness Limitations and Effective Length

$$K_{pl\_tr} := 2.0$$

Effective length in accordance with C2.b1, [8, comm.C2 (Table C-C2.2) (case e) pg 16.1-240] Case e was chosen because the support was conservatively allowed to rotate at its base and translate at its top without rotation.

The Slenderness ratio KL/r should preferably not exceed 200

$$KLr_{pl\_tr_i} := \left(\frac{K_{pl\_tr} \cdot L_{pl\_tr_i}}{r_{gyration\_pl\_tr_i}}\right)$$

The below KLr values verify that all supports do not exceed the 200 recommended limitation

$$KLr_{pl\_tr}^{T} = (115.2)$$

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified by classification)

$$F_{e\_pl\_tr_i} := \frac{\pi^2 E_{pl\_tr}}{\left(KLr_{pl\_tr_i}\right)^2}$$

F_e is the elastic critical buckling stress (E3-4)

$$F_{e\_pl\_tr}^{T} = (21.567)\,ksi$$

Calculating the variables Limit, Op1, and Op2 to be utilized in logic to determine flexural buckling stress.

$$Limit := 4.71 \cdot \sqrt{\frac{E_{pl\_tr}}{F_{y\_pl\_tr}}} \qquad Op1_i := \left(0.658^{\frac{F_{y\_pl\_tr}}{F_{e\_pl\_tr_i}}}\right) F_{y\_pl\_tr} \qquad Op2_i := 0.877 \cdot F_{e\_pl\_tr_i}$$

$$Limit = 139.625 \qquad Op1 = (17.393)\,ksi \qquad Op2 = (18.914)\,ksi$$

Calculating the flexural buckling stress

$$F_{cr\_pl\_tr_i} := \begin{cases} Op1_i & \text{if } KLr_{pl\_tr_i} \le Limit \quad \text{(E3-2)} \\ Op2_i & \text{if } KLr_{pl\_tr_i} > Limit \quad \text{(E3-3)} \end{cases}$$

$$F_{cr\_pl\_tr}^{T} = (17.393)\,ksi$$

$\phi P_{n\_pl\_tr_i} := \phi_c \cdot F_{cr\_pl\_tr_i} \cdot A_{tr\_minor_i}$

$\phi P_{n\_pl\_tr}{}^T = (13.929)\ kip$

Design compressive strength

SUPPORT PIPE

Determine if support pipe is ***compact (1)***, ***non-compact (2)***, or ***slender (3)*** as defined in first paragraph of B4

B4. Classification of sections for local buckling (Table B4.1 Case 15)

$$D2t_{sp_i} := \frac{d_{sp\_od_i}}{t_{sp_i}} \qquad D2t_{sp}{}^T = (10.435)$$

Definition of λ_p and λ_r from Table B4.1 Case 15 (Circular hollow sections in uniform compression) to be applied in classification logic. λ_p is the separation point between a compact and non compact member. λ_r is separation point between a non compact and slender member. However, Table B4.1 Case 15 defines λ_p = NA because the only thing of concern is if the support is slender or non-slender, thus only if the classification is 3 do we apply slenderness considerations, otherwise we treat the member as not having slender elements.

$$\lambda_p := 0 \qquad \lambda_r := 0.11 \frac{E_{sp}}{F_{y\_sp}}$$

$$Classification_{sp_i} := \begin{cases} 1 & \text{if } D2t_{sp_i} \le \lambda_p \\ 2 & \text{if } \lambda_p < D2t_{sp_i} \le \lambda_r \\ 3 & \text{if } \lambda_r < D2t_{sp_i} \end{cases}$$

$$Classification_{sp}{}^T = (2)$$

Compression, capacity in pipe [8, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

$\phi_c := 0.9$

Resistance factor for compression

E2. Slenderness Limitations and Effective Length

$K_{sp} := 1.0$

Effective length in accordance with C2.b1, [8, comm.C2 (Table C-C2.2) (case d) pg 16.1-240] Case d was chosen because the support was allowed to rotate on both ends.

The Slenderness ratio KL/r should preferably not exceed 200

$$KLr_{sp_i} := \left(\frac{K_{sp} \cdot L_{sp_i}}{r_{gyration\_sp_i}} \right)$$

The below KLr values verify that all supports do not exceed the 200 recommended limitation

$KLr_{sp}^{T} = (94.538)$

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified by classification)

$$F_{e\_sp_i} := \frac{\pi^2 E_{sp}}{\left(KLr_{sp_i}\right)^2}$$

F_e is the elastic critical buckling stress (E3-4)

$F_{e\_sp}^{T} = (32.025)\ ksi$

Calculating the variables Limit, Op1, and Op2 to be utilized in logic to determine flexural buckling stress.

$$Limit := 4.71 \cdot \sqrt{\frac{E_{sp}}{F_{y\_sp}}} \qquad Op1_i := \left(0.658^{\frac{F_{y\_sp}}{F_{e\_sp_i}}}\right) F_{y\_sp} \qquad Op2_i := 0.877 \cdot F_{e\_sp_i}$$

$Limit = 139.625$

Calculating the flexural buckling stress

$$F_{cr\_sp_i} := \begin{cases} Op1_i & \text{if } KLr_{sp_i} \le Limit \quad \text{(E3-2)} \\ Op2_i & \text{if } KLr_{sp_i} > Limit \quad \text{(E3-3)} \end{cases}$$

$F_{cr\_sp}^{T} = (21.439)\ ksi$

$\phi P_{n\_sp_i} := \phi_c \cdot F_{cr\_sp_i} \cdot A_{sp_i}$ Design compressive strength

$\boxed{\phi P_{n\_sp}^{T} = (30.679)\ kip}$

WELDED BEAM ATTACHMENT

Shear, capacity of welded beam attachment bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$A_{wba\_bolt_i} := \pi \cdot \left(\frac{d_{wba\_bolt_i}}{2}\right)^2$$

Nominal unthreaded body area

$$A_{wba\_bolt\_ds_i} := 2 \cdot A_{wba\_bolt_i}$$

Applicable area for this case since the bolt is in double shear

$F_{nv\_wba\_bolt} := 24ksi$

Nominal shear stress in bearing type connections (A307) [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment and includes an allowance for threads in the shear plane

$R_{nv\_wba\_bolt_i} := F_{nv\_wba\_bolt} \cdot A_{wba\_bolt\_ds_i}$

Nominal strength (R_n) (J3-1)

$\phi_{b\_sr} = 0.75$

Resistance factor

$\phi R_{nv\_wba\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_wba\_bolt_i}$

$\boxed{\phi R_{nv\_wba\_bolt}^{T} = (53.456)\ kip}$

Design shear strength

Capacities For Inward Loading

PIPE CLAMP

Tension, capacity of clamp [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$b_{cl_i} := 2\,t_{cl_i} + 0.63in$

$b_{cl}^{T} = (2.13)\ in$

$b_{eff\_cl_i} := \min\left(b_{cl_i}, a_{normal\_cl_i}\right)$

$b_{eff\_cl}^{T} = (2)\ in$

b_{eff} is an effective length (2t+0.63in) which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$P_{n\_cl\_trp_i} := 2 \cdot \left(2\,t_{cl_i}\right) \cdot b_{eff\_cl_i} \cdot F_{u\_cl}$

Nominal axial strength (P_n) (D5-1)

$\phi_{n\_trp} := 0.75$

Resistance factor for tension (ϕ_t)

$\phi P_{n\_cl\_trp_i} := \phi_{n\_trp} \cdot P_{n\_cl\_trp_i}$

$\boxed{\phi P_{n\_cl\_trp}^{T} = (270)\ kip}$

Design tensile strength

(b) For shear rupture on the effective area:

$A_{sf\_cl_i} := 2 \cdot \left(2\,t_{cl_i}\right) \cdot \left(a_{parrallel\_cl_i} + \frac{d_{cl\_bolt_i}}{2}\right)$

$A_{sf\_cl}^{T} = (5.062)\ in^2$ — Effective area

$P_{n\_cl\_srp_i} := 0.6 \cdot F_{u\_cl} \cdot A_{sf\_cl_i}$ — Nominal axial strength (P_n) (D5-2)

$\phi_{n\_srp} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_cl\_srp_i} := \phi_{n\_srp} \cdot P_{n\_cl\_srp_i}$

$\phi P_{n\_cl\_srp}^{T} = (136.687)\ kip$ — Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_cl_i} := d_{cl\_bolt_i} \cdot \left(2\, t_{cl_i}\right)$ — Projected bearing area in.^{2} (mm^2)

$R_{n\_cl\_bs_i} := 1.8 \cdot F_{y\_cl} \cdot A_{pd\_cl_i}$ — Nominal bearing strength (J7-1)

$\phi := 0.75$ — Resistance factor

$\phi R_{n\_cl\_bs_i} := \phi \cdot R_{n\_cl\_bs_i}$

$\phi R_{n\_cl\_bs}^{T} = (91.884)\ kip$ — Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_cl_i} := A_{cl_i}$ — Gross area

(a) For tensile yielding in the gross section:

$P_{n\_cl\_ty_i} := F_{y\_cl} \cdot A_{g\_cl_i}$ — Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_cl\_ty_i} := \phi_{t\_ty} \cdot P_{n\_cl\_ty_i}$

$\phi P_{n\_cl\_ty}^{T} = (245.025)\ kip$ — Design tensile strength

Shear, capacity of pipe clamp's bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$A_{cl\_bolt_i} := \pi \cdot \left(\frac{d_{cl\_bolt_i}}{2}\right)^2$$

Nominal unthreaded body area

$$A_{cl\_bolt\_ds_i} := 2 \cdot A_{cl\_bolt_i}$$

Applicable area for this case since the bolt is in double shear

$$F_{nv\_cl\_bolt} := 24ksi$$

Nominal shear stress in bearing type connections (A307) [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment and includes an allowance for threads in the shear plane

$$R_{nv\_cl\_bolt_i} := F_{nv\_cl\_bolt} \cdot A_{cl\_bolt\_ds_i}$$

Nominal strength (R_n) (J3-1)

$$\phi_{b\_sr} := 0.75$$

Resistance factor

$$\phi R_{nv\_cl\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_cl\_bolt_i}$$

$$\boxed{\phi R_{nv\_cl\_bolt}^{T} = (53.456)\ kip}$$

Design shear strength

PLATES WELDED TO THREADED RODS

Tension, capacity of plates welded to threaded rods [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$b_{pl\_tr_i} := 2\,t_{pl\_tr_i} + 0.63in$$

$$b_{pl\_tr}^{T} = (2.13)\ in$$

$$b_{eff\_pl\_tr_i} := \min\left(b_{pl\_tr_i}, a_{normal\_pl\_tr_i}\right)$$

$$b_{eff\_pl\_tr}^{T} = (0.75)\ in$$

b_{eff} is an effective length calculated as (2t + 0.63in) which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$$P_{n\_pl\_tr\_trp_i} := 2 \cdot t_{pl\_tr_i} \cdot b_{eff\_pl\_tr_i} \cdot F_{u\_pl\_tr}$$

Nominal axial strength (P_n) (D5-1)

$$\phi_{n\_trp} := 0.75$$

Resistance factor for tension (ϕ_t)

$\phi P_{n\_pl\_tr\_trp_i} := \phi_{n\_trp} \cdot P_{n\_pl\_tr\_trp_i}$

$\phi P_{n\_pl\_tr\_trp}{}^T = (50.625)\ \text{kip}$ Design tensile strength

(b) For shear rupture on the effective area:

$$A_{sf\_pl\_tr_i} := 2 \cdot t_{pl\_tr_i} \cdot \left(a_{parrallel\_pl\_tr_i} + \frac{d_{tr_i}}{2} \right)$$

$A_{sf\_pl\_tr}{}^T = (2.438)\ \text{in}^2$ Effective area

$P_{n\_pl\_tr\_srp_i} := 0.6 \cdot F_{u\_pl\_tr} \cdot A_{sf\_pl\_tr_i}$ Nominal axial strength (P_n) (D5-2)

$\phi_{n\_srp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_pl\_tr\_srp_i} := \phi_{n\_srp} \cdot P_{n\_pl\_tr\_srp_i}$

$\phi P_{n\_pl\_tr\_srp}{}^T = (65.813)\ \text{kip}$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_pl\_tr_i} := d_{tr_i} \cdot t_{pl\_tr_i}$ Projected bearing area in.^{2} (mm^2)

$R_{n\_pl\_tr\_bs_i} := 1.8 \cdot F_{y\_pl\_tr} \cdot A_{pd\_pl\_tr_i}$ Nominal bearing strength (J7-1)

$\phi := 0.75$ Resistance factor

$\phi R_{n\_pl\_tr\_bs_i} := \phi \cdot R_{n\_pl\_tr\_bs_i}$

$\phi R_{n\_pl\_tr\_bs}{}^T = (41.766)\ \text{kip}$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_pl\_tr_i} := A_{pl\_tr_i}$ Gross area

(a) For tensile yielding in the gross section:

$P_{n\_pl\_tr\_ty_i} := F_{y\_pl\_tr} \cdot A_{g\_pl\_tr_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_pl\_tr\_ty_i} := \phi_{t\_ty} \cdot P_{n\_pl\_tr\_ty_i}$

$\boxed{\phi P_{n\_pl\_tr\_ty}^{T} = (66.825)\,kip}$ Design tensile strength

Shear, capacity of weld between plates and threaded rods [8, Ch. J pg 16.1-90 thru 121]

J2. Welds

4. Strength

$\phi_{weld} := 0.75$ Resistance factor of weld

$$R_{n\_weld_i} := \phi_{weld} \cdot \left(F_{w\_transverse} \cdot A_{w\_traverse_i} + F_{w\_longitudinal} \cdot A_{w\_longitudinal_i}\right) \qquad \text{(J2-4)}$$

$\boxed{R_{n\_weld} = (63.232)\,kip}$ Nominal shear strength of weld

Tension, capacity of threaded rods [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$A_{b\_tr_i} := \pi \cdot \left(\frac{d_{tr_i}}{2}\right)^2$ Nominal unthreaded body area

$F_{nt\_tr} := 45ksi$ Nominal tensile stress (A307) [8, Table J3.2] [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment

$R_{nt\_tr_i} := F_{nt\_tr} \cdot A_{b\_tr_i}$ Nominal strength (R_n) (J3-1)

$\phi_{b\_tr} := 0.75$ Resistance factor

$\phi R_{nt\_tr_i} := \phi_{b\_tr} \cdot R_{nt\_tr_i}$

$\boxed{\phi R_{nt\_tr}^{T} = (41.417)\,kip}$ Design tension strength

SUPPORT PIPE

Tension, capacity of support pipe [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

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D3. Area Determination

1. Gross Area

$A_{g\_sp_i} := A_{sp_i}$ Gross area

2. Net Area

$A_{net\_sp_i} := A_{sp_i}$ Net area

3. Effective Net Area

$U_{sp} := 1.0$ Shear Lag Factor [8, Table D3.1]

$A_{e\_sp_i} := A_{net\_sp_i} \cdot U_{sp}$ Effective net area

(a) For tensile yielding in the gross section:

$P_{n\_sp\_ty_i} := F_{y\_sp} \cdot A_{g\_sp_i}$ Nominal axial strength (P_n)

$\phi_{ty} := 0.9$ Resistance factor for tension yielding (ϕ_{ty})

$\phi P_{n\_sp\_ty_i} := \phi_{ty} \cdot P_{n\_sp\_ty_i}$

$\boxed{\phi P_{n\_sp\_ty} = (47.223)\,kip}$ Design tensile yielding strength

(b) For tensile rupture in net section:

$P_{n\_sp\_tr_i} := F_{u\_sp} \cdot A_{e\_sp_i}$ Nominal axial strength (P_n)

$\phi_{tr} := 0.75$ Resistance factor for tension rupture (ϕ_{tr})

$\phi P_{n\_sp\_tr_i} := \phi_{tr} \cdot P_{n\_sp\_tr_i}$

$\boxed{\phi P_{n\_sp\_tr} = (71.55)\,kip}$ Design tensile rupture strength

WELDED BEAM ATTACHMENT

Tension, capacity of welded beam attachment [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$b_i := 2\,t_{wba_i} + 0.63in$

$b^T = (3.13)\ in$

$b_{eff_i} := \min\left(b_i, a_{normal\_wba_i}\right)$

$b_{eff}^T = (1.25)\ in$

b_{eff} is an effective length calculated as (2t + 0.63in) which can not be larger than the actual distance from the edge of the hole in the direction normal to the applied force

$P_{n\_wba\_trp_i} := 2 \cdot t_{wba_i} \cdot b_{eff_i} \cdot F_{u\_wba}$ Nominal axial strength (P_n) (D5-1)

$\phi_{n\_trp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_wba\_trp_i} := \phi_{n\_trp} \cdot P_{n\_wba\_trp_i}$

$\boxed{\phi P_{n\_wba\_trp}^T = (140.625)\ kip}$ Design tensile strength

(b) For shear rupture on the effective area:

$A_{sf\_wba_i} := 2 \cdot t_{wba_i} \cdot \left(a_{parrallel\_wba_i} + \frac{d_{wba\_bolt_i}}{2}\right)$

$A_{sf\_wba}^T = (4.844)\ in^2$ Effective area

$P_{n\_wba\_srp_i} := 0.6 \cdot F_{u\_wba} \cdot A_{sf\_wba_i}$ Nominal axial strength (P_n) (D5-2)

$\phi_{n\_srp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_wba\_srp_i} := \phi_{n\_srp} \cdot P_{n\_wba\_srp_i}$

$\boxed{\phi P_{n\_wba\_srp}^T = (130.781)\ kip}$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_wba_i} := d_{wba\_bolt_i} \cdot t_{wba_i}$ Projected bearing area in.^{2} (mm^2)

$R_{n\_wba\_bs_i} := 1.8 \cdot F_{y\_wba} \cdot A_{pd\_wba_i}$ Nominal bearing strength (J7-1)

$\phi := 0.75$ Resistance factor

$\phi R_{n\_wba\_bs_i} := \phi \cdot R_{n\_wba\_bs_i}$

$\boxed{\phi R_{n\_wba\_bs}^T = (76.57)\ kip}$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_wba_i} := A_{wba_i}$ Gross area

(a) For tensile yielding in the gross section:

$P_{n\_wba\_ty_i} := F_{y\_wba} \cdot A_{g\_wba_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_wba\_ty_i} := \phi_{t\_ty} \cdot P_{n\_wba\_ty_i}$

$\phi P_{n\_wba\_ty}{}^T = (148.5)\,\text{kip}$ Design tensile strength

Shear, capacity of welded beam attachment bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$A_{wba\_bolt_i} := \pi \cdot \left(\frac{d_{wba\_bolt_i}}{2}\right)^2$ Nominal unthreaded body area

$A_{wba\_bolt\_ds_i} := 2 \cdot A_{wba\_bolt_i}$ Applicable area for this case since the bolt is in double shear

$F_{nv\_wba\_bolt} := 24\text{ksi}$ Nominal shear stress in bearing type connections (A307) [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment and includes an allowance for threads in the shear plane

$R_{nv\_wba\_bolt_i} := F_{nv\_wba\_bolt} \cdot A_{wba\_bolt\_ds_i}$ Nominal strength (R_n) (J3-1)

$\phi_{b\_sr} = 0.75$ Resistance factor

$\phi R_{nv\_wba\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_wba\_bolt_i}$

$\phi R_{nv\_wba\_bolt}{}^T = (53.456)\,\text{kip}$ Design shear strength

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SUMMARY OF RESULTS

Capacities For Outward Loading

PIPE CLAMP

Compression, capacity of clamp's cantilever section [8, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

E2. Slenderness Limitations and Effective Length

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified by classification)

$$\phi P_{n\_SL}{}^{T} = (339.259)\ kip$$

Design compressive strength

Shear, capacity of clamp's bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$\phi R_{nv\_cl\_bolt}{}^{T} = (53.456)\ kip$$

Design shear strength

PLATES WELDED TO THREADED RODS

Compression, capacity of threaded rods [8, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

E2. Slenderness Limitations and Effective Length

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified by classification)

$$\phi P_{n\_pl\_tr}{}^{T} = (13.929)\ kip$$

SUPPORT PIPE

Compression, capacity in pipe [8, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

E2. Slenderness Limitations and Effective Length

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified by classification)

$$\phi P_{n\_sp}{}^{T} = (30.679)\ kip$$

WELDED BEAM ATTACHMENT

Shear, capacity of welded beam attachment bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$\phi R_{nv\_wba\_bolt}{}^{T} = (53.456)\ kip$$

Design shear strength

Capacities For Inward Loading

PIPE CLAMP

Tension, capacity of clamp [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_cl\_trp}^{T} = (270)\ kip$$ Design tensile strength

(b) For shear rupture on the effective area:

$$\phi P_{n\_cl\_srp}^{T} = (136.687)\ kip$$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\phi R_{n\_cl\_bs}^{T} = (91.884)\ kip$$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_cl\_ty}^{T} = (245.025)\ kip$$ Design tensile strength

Shear, capacity of pipe clamp's bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$\phi R_{nv\_cl\_bolt}^{T} = (53.456)\ kip$$ Design shear strength

PLATES WELDED TO THREADED RODS

Tension, capacity of plates welded to threaded rods [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_pl\_tr\_trp}^{T} = (50.625)\ kip$$ Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_pl\_tr\_srp}^{T} = (65.813)\ kip$ — Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_pl\_tr\_bs}^{T} = (41.766)\ kip$ — Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_pl\_tr\_ty}^{T} = (66.825)\ kip$ — Design tensile strength

Tension, capacity of weld between plates and threaded rods [8, Ch. J pg 16.1-90 thru 121]

J3. Welds

4. Strength

$R_{n\_weld} = (63.232)\ kip$ — Nominal shear strength of weld

Tension, capacity of threaded rods [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$\phi R_{nt\_tr}^{T} = (41.417)\ kip$ — Design tension strength

SUPPORT PIPE

Tension, capacity of support pipe [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_sp\_ty} = (47.223)\ kip$ — Design tensile yielding strength

(b) For tensile rupture in net section:

$\phi P_{n\_sp\_tr} = (71.55)\ kip$ — Design tensile rupture strength

WELDED BEAM ATTACHMENT

Tension, capacity of welded beam attachment [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_wba\_trp}^{T} = (140.625)\,kip$$ Design tensile strength

(b) For shear rupture on the effective area:

$$\phi P_{n\_wba\_srp}^{T} = (130.781)\,kip$$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\phi R_{n\_wba\_bs}^{T} = (76.57)\,kip$$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_wba\_ty}^{T} = (148.5)\,kip$$ Design tensile strength

Shear, capacity of welded beam attachment bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$\phi R_{nv\_wba\_bolt}^{T} = (53.456)\,kip$$ Design shear strength

Appendix B.10.5

Capacity of PR-8 Support

PR-8 CAPACITY

The PR-8 support is composed of tee ears welded to the bottom of the forged tee joining lines 1-28 and 1-29 to 1-27. A bolt attaches the tee ears to an eye rod. A turnbuckle connects the downward traveling eye rod to the lower rod. The lower rod is attached to a welded box structure that is fixed to the ground by four bolts and grout pad. The capacities for these components are calculated below, however, the capacity for the bolt fixating the box structure to the floor is found in the anchorage and embedment portions of [32, App E].

Component Capacity Overview:

- Downward Loading:
  - Shear capacity of tee ears welds
  - Tension capacity of tee ears
  - Shear capacity of tee ears' upper bolt
  - Tension capacity of upper eye rod
  - Tension capacity of turnbuckle
  - Tension capacity of lower rod
  - Flexure capacity of welded box structure's upper section
  - Shear capacity of welded box structure's upper section
  - Shear capacity of welded box structure's upper welds
  - Tension capacity of welded box structure's side sections

(**Procedures from AISC 13th Edition (Applying LRFD)**)

References contained in Appendix B.11 of this Report

$i := 0$

Assigned indices corresponding to number of support types associated with these calculations

Support =	0
	(PR-8)

Relationship between support and corresponding indices

Geometric and Material Properties of Support Components

TEE EARS ([20])

Material Properties of Tee Ears as Defined in the Material Section of Report [32]:

$F_{y\_te} := 33\text{ksi}$ Yield Strength for A7 Steel [52]

$F_{u\_te} := 60\text{ksi}$ Ultimate Strength for A7 Steel [52]

$E_{te} := 29000\text{ksi}$ Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Tee Ears:

$$t_{te} := \left[2 \cdot \left(\frac{1}{2}\text{in}\right)\right]^T$$

Combined thickness of both plates forming the upper portion of the clamp, in. (mm) [18, Sheet 2], [20, Detail 52]

$$w_{te} := (3\text{in})^T$$

Width of plates forming the ears conservatively chosen from supplied dimensions of trapezoidal form [20, Detail 52]

$$A_{te_i} := t_{te_i} \cdot w_{te_i}$$

$$A_{te}^T = (3)\ \text{in}^2$$

Total cross sectional area of both sides of clamp

$$d_{te\_bolt} := \left(1\frac{1}{4}\text{in}\right)^T$$

Bolt diameter [18, Sheet 2], [20, Detail 52]

$$d_{te\_hole} := \left(1\frac{1}{4}\text{in}\right)^T$$

Nominal bolt hole Diameter [20, Detail 52]

$$a_{parrallel\_te} := \left(1\frac{3}{8}\text{in}\right)^T$$

Shortest distance from edge of the pin hole to the edge of the member measured parallel to the direction of the force from top of bolt hole to top of clamp bracket, in. (mm) hand calculated from d_{cl_hole} and [20, Detail 52] data

$$a_{normal\_te_i} := \frac{w_{te_i} - d_{te\_hole_i}}{2}$$

$$a_{normal\_te} = (0.875)\ \text{in}$$

Shortest distance from edge of pin hole to the edge of the member measured normal to the direction of the force

EYE ROD (Welded Eye Rod FIG 278 1-1/8" [18, Sheet 2])

Material Properties of Eye Rod as Defined in the Material Section of Report [32]:

$F_{y\_I} := 33\text{ksi}$ Yield Strength for A7 Steel [52]

$F_{u\_I} := 60\text{ksi}$ Ultimate Strength for A7 Steel [52]

$E_I := 29000\text{ksi}$ Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Eye Rod:

$$d_I := \left(1\frac{1}{8}\text{in}\right)^T$$

Unthreaded diameter of eye rod, [22, Fig 278 ph-52]

$$Z_{I_i} := \frac{\left(d_{I_i}\right)^3}{6}$$

Plastic section modulus about the axis of bending [8, Table 17-27 pg17-39]

TURNBUCKLE (Turnbuckle FIG 230 1-1/8" [18, Sheet 2])

Material Properties of Turnbuckle as Defined in the Material Section of Report [32]:

$$F_{y\_tb} := 33\text{ksi}$$

Yield Strength for A7 Steel [52]

$$F_{u\_tb} := 60\text{ksi}$$

Ultimate Strength for A7 Steel [52]

$$E_{tb} := 29000\text{ksi}$$

Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Turnbuckle:

The turnbuckle legs have a unique cross section, therefore for these calculations treat each leg as a rectangular cross section where the width of the turnbuckle legs were conservatively scaled to be 9/8 the diameter of the rod as scaled from photo dsc00080 and the thickness of the turnbuckle legs were scaled to be 1/2 the diameter of the corresponding rod diameter as scaled from photo dsc00079.

$$w_{tb_i} := \left(\frac{9}{8}\right) \cdot d_{I_i}$$

$$w_{tb}^T = (1.266)\ \text{in}$$

Width of turnbuckle [22, Fig 230 ph-57]

$$t_{tb_i} := \left(\frac{1}{2}\right) \cdot d_{I_i}$$

$$t_{tb}^T = (0.563)\ \text{in}$$

Thickness of turnbuckle [22, Fig 230 ph-57]

$$A_{tb_i} := 2 \cdot w_{tb_i} \cdot t_{tb_i}$$

$$A_{tb}^T = (1.424)\ \text{in}^2$$

Total area of turnbuckle cross section

ROD (Rod FIG 253 1-1/8" [18, Sheet 2])

Material Properties of Rod as Defined in the Material Section of Report [32]:

$$F_{y\_rd} := 33\text{ksi}$$

Yield Strength for A7 Steel [52]

$$F_{u\_rd} := 60\text{ksi}$$

Ultimate Strength for A7 Steel [52]

$$E_{rd} := 29000\text{ksi}$$

Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Rod:

$d_{rd} := \left(1\frac{1}{8}in\right)^T$ — Unthreaded diameter of eye rod [22, Fig 278 ph-52]

$Z_{rd_i} := \frac{\left(d_{rd_i}\right)^3}{6}$ — Plastic section modulus about the axis of bending, in.^{3} (mm^3) [8, Table 17-27 pg17-39]

WELDED BOX STRUCTURE ([20])

Material Properties of Welded Box Structure as Defined in the Material Section of Report [32]:

$F_{y\_wbs} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{u\_wbs} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E\_wbs := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Welded Box Structure:

$t_{wbs\_top} := (1in)^T$ — Combined thickness of welded box structure's top portion [20]

$w_{wbs\_top} := (4in)^T$ — Width and length of welded box structure's top portion [20]

$t_{wbs\_sides} := \left[2\cdot\left(\frac{1}{2}in\right)\right]^T$ — Combined thickness of welded box structure sides [20]

$w_{wbs\_sides} := (4in)^T$ — Width of welded beam attachment [22, Fig 66 ph-33]

$A_{wbs\_sides_i} := t_{wbs\_sides_i}\cdot w_{wbs\_sides_i}$ — Cross sectional area of welded beam attachment

$A_{wbs\_sides} = (4)\ in^2$

$F_{EXX} := 60ksi$ — E6013 weld material ultimate strength [50, pg I-9], [51]

$\theta_{transverse} := \frac{\pi}{2}$ — Angle between loading and traverse welds

$$F_{w\_transverse} := 0.60\cdot F_{EXX}\cdot\left(1.0 + 0.5\cdot\sin\left(\theta_{transverse}\right)^{1.5}\right) \quad (J2\text{-}5)$$

Nominal Shear Strength of transverse welds

$F_{w\_transverse} = 54\ ksi$

$\omega := \left(\frac{3}{16}in\right)^T$ — Minimum size of fillet given that thinner joined part (plate) = 1/2" [8, Table J2.4, pg 16.1-96] [120923]

$L_{w\_traverse} := 2 \cdot w_{wbs\_top}$ — Traverse length of welds [120923]

$A_{w\_traverse_i} := L_{w\_traverse_i} \cdot 0.707\,\omega_i$ — Effective area of weld throat of traverse welds

$A_{w\_traverse} = (1.06)\,in^2$

Capacities For Upward Loading

TEE EARS

Tension, capacity of tee ears [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$b_{te_i} := 2\,t_{te_i} + 0.63in$

$b_{te}^{T} = (2.63)\,in$

$b_{eff\_te_i} := \min\left(b_{te_i}, a_{normal\_te_i}\right)$

$b_{eff\_te}^{T} = (0.875)\,in$

b_{eff} is an effective length calculated as (2t + 0.63in) which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$P_{n\_te\_trp_i} := 2 \cdot t_{te_i} \cdot b_{eff\_te_i} \cdot F_{u\_te}$ — Nominal axial strength (P_n) (D5-1)

$\phi_{n\_trp} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_te\_trp_i} := \phi_{n\_trp} \cdot P_{n\_te\_trp_i}$

$\boxed{\phi P_{n\_te\_trp}^{T} = (78.75)\,kip}$ — Design tensile strength

(b) For shear rupture on the effective area:

$A_{sf\_te_i} := 2 \cdot t_{te_i} \cdot \left(a_{parallel\_te_i} + \frac{d_{te\_hole_i}}{2}\right)$

$A_{sf\_te}^{T} = (4)\,in^2$ — Effective area

$P_{n\_te\_srp_i} := 0.6 \cdot F_{u\_te} \cdot A_{sf\_te_i}$ — Nominal axial strength (P_n)

$\phi_{n\_srp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_te\_srp_i} := \phi_{n\_srp} \cdot P_{n\_te\_srp_i}$ (D5-2)

$\phi P_{n\_te\_srp}{}^T = (108)\ \text{kip}$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_te_i} := d_{te\_bolt_i} \cdot t_{te_i}$ Projected bearing area in.^{2} (mm^2)

$R_{n\_te\_bs_i} := 1.8 \cdot F_{y\_te} \cdot A_{pd\_te_i}$ Nominal bearing strength

$\phi := 0.75$ Resistance factor

$\phi R_{n\_te\_bs_i} := \phi \cdot R_{n\_te\_bs_i}$

$\phi R_{n\_te\_bs}{}^T = (55.688)\ \text{kip}$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_te_i} := A_{te_i}$ Gross area

(D3-1)

(a) For tensile yielding in the gross section:

$P_{n\_te\_ty_i} := F_{y\_te} \cdot A_{g\_te_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_te\_ty_i} := \phi_{t\_ty} \cdot P_{n\_te\_ty_i}$

$\phi P_{n\_te\_ty}{}^T = (89.1)\ \text{kip}$ Design tensile strength

Shear, capacity of tee ear's upper bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$A_{te\_bolt_i} := \pi \cdot \left(\frac{d_{te\_bolt_i}}{2}\right)^2$$

Nominal unthreaded body area

$$A_{te\_bolt\_ds_i} := 2 \cdot A_{te\_bolt_i}$$

Applicable area for this case since the bolt is in double shear

$$F_{nv\_te\_bolt} := 24ksi$$

Nominal shear stress in bearing type connections (A307) [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment and includes an allowance for threads in shear plane

$$R_{nv\_te\_bolt_i} := F_{nv\_te\_bolt} \cdot A_{te\_bolt\_ds_i}$$

Nominal strength (R_n) (J3-1)

$$\phi_{b\_sr} := 0.75$$

Resistance factor

$$\phi R_{nv\_te\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_te\_bolt_i}$$

$$\phi R_{nv\_te\_bolt}^{T} = (44.179)\,kip$$

Design shear strength

EYE ROD

NOTE:It was observed during inspection that all of the applicable eye rods have welded eyes even though they indicate otherwise on Drawing 120925, thus all eye rods in these calculations will be treated as welded eye rods

Tension, capacity of lower eye rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$A_{b\_I_i} := \pi \cdot \left(\frac{d_{I_i}}{2}\right)^2$$

Nominal unthreaded body area

$$F_{nt\_I} := 45ksi$$

Nominal tensile stress (A307) [8, Table J3.2] [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment

$$R_{nt\_I_i} := F_{nt\_I} \cdot A_{b\_I_i}$$

Nominal strength (R_n) (J3-1)

$$\phi_{b\_tr} := 0.75$$

Resistance factor

$$\phi R_{nt\_I_i} := \phi_{b\_tr} \cdot R_{nt\_I_i}$$

$$\phi R_{nt\_I}^{T} = (33.548)\,kip$$

Design tension strength

TURNBUCKLE

Tension, capacity of turnbuckle [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D2. Tensile Strength

D3. Area Determination

1. Gross Area

$A_{g\_tb_i} := A_{tb_i}$ — Gross area

2. Net Area

$A_{n\_tb_i} := A_{g\_tb_i}$ — Net area

3. Effective Net Area

$U_{tb} := 1.0$ — Shear lag factor [8, Table D3.1 pg 16.1-29 (case 1)]

$A_{e\_tb_i} := A_{n\_tb_i} \cdot U_{tb}$ — Effective net area (D3-1)

(a) For tensile yielding in the gross section:

$P_{n\_tb\_ty_i} := F_{y\_tb} \cdot A_{g\_tb_i}$ — Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_tb\_ty_i} := \phi_{t\_ty} \cdot P_{n\_tb\_ty_i}$

$\phi P_{n\_tb\_ty}^{T} = (42.288)\ kip$ — Design tensile strength

(b) For tensile rupture in the net section:

$P_{n\_tb\_tr_i} := F_{u\_tb} \cdot A_{e\_tb_i}$ — Nominal axial strength (P_n) (D2-2)

$\phi_{t\_tr} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_tb\_tr_i} := \phi_{t\_tr} \cdot P_{n\_tb\_tr_i}$

$\phi P_{n\_tb\_tr}^{T} = (64.072)\ kip$ — Design tensile strength

ROD

NOTE:It was observed during inspection that all of the applicable eye rods have welded eyes even though they indicate otherwise on Drawing 120925, thus all eye rods in these calculations will be treated as welded eye rods

Tension, capacity of upper eye rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

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6. Tension and Shear Strength of Bolts and Threaded Parts

$$A_{b\_rd_i} := \pi \cdot \left(\frac{d_{rd_i}}{2}\right)^2$$ Nominal unthreaded body area

$$F_{nt\_rd} := 45ksi$$ Nominal tensile stress (A307) [8, Table J3.2] [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment

$$R_{nt\_rd_i} := F_{nt\_rd} \cdot A_{b\_rd_i}$$ Nominal strength (R_n) (J3-1)

$$\phi_{b\_tr} := 0.75$$ Resistance factor

$$\phi R_{nt\_rd_i} := \phi_{b\_tr} \cdot R_{nt\_rd_i}$$

$$\phi R_{nt\_rd}^{T} = (33.548)\,kip$$ Design tension strength

WELDED BOX STRUCTURE

Shear, capacity of welded box structure's upper section [8, Ch. G pg 16.1-64 thru 69]

G7. Weak Axis Shear in Singly and Doubly Symmetric Shapes

For singly and doubly symmetric shapes loaded in the weak axis without torsion, the nominal shear strength, V_n, for each shear resisting element shall be determined using Equation G2-1 and Section G2.1(b) with $A_w = b_f t_f$ and $k_v = 1.2$.

$$C_v := 1.0$$ Web shear coefficient [8, pg16.1-291]

$$A_{w\_wbs} := 2 \cdot t_{wbs\_top} \cdot w_{wbs\_top}$$ Cross sectional area of top portion of welded box structure, 2 is included to account for double shear

$$V_{n\_wbs} := 0.6 \cdot F_{y\_wbs} \cdot A_{w\_wbs} \cdot C_v$$ Nominal shear (G2-1)

$$\phi_v := 1.00$$ Resistance factor

$$\phi V_{n\_wbs} := \phi_v \cdot V_{n\_wbs}$$

$$\phi V_{n\_wbs} = 158.4\,kip$$ Design shear strength

Shear, capacity of welded box structure's upper welds [8, Ch. J pg 16.1-90 thru 121]

J2. Welds

4. Strength

$$\phi_{weld} := 0.75$$ Resistance factor of weld

$R_{n\_weld_i} := \phi_{weld} \cdot \left(F_{w\_transverse} \cdot A_{w\_traverse_i}\right)$ (J2-4)

$\boxed{R_{n\_weld} = (42.95)\,kip}$ Nominal shear strength of weld

Tension, capacity of welded box structure's side sections [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D2. Tensile Strength

Must solve for applicable areas presented in D3 prior to proceeding through D2

D3. Area Determination

1. Gross Area

The gross area, A_g, of a member is the total cross-sectional area

$A_{g\_wbs} := 2 \cdot w_{wbs\_sides} \cdot t_{wbs\_sides}$ Gross area

2. Net Area

$A_{n\_wbs} := A_{g\_wbs}$ Net area

3. Effective Net Area

$U := 1$ The shear lag factor

$A_{e\_wbs} := U \cdot A_{n\_wbs}$ The effective area

(a) For tensile yielding in the gross section:

$P_{n\_ty\_wbs_i} := F_{y\_wbs} \cdot A_{g\_wbs}$

$\phi_{n\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_ty\_wbs_i} := \phi_{n\_ty} \cdot P_{n\_ty\_wbs_i}$

$\boxed{\phi P_{n\_ty\_wbs}^{T} = (237.6)\,kip}$ Design tensile strength (D2-1)

(b) For tensile rupture in the net section:

$P_{n\_tr\_wbs_i} := F_{u\_wbs} \cdot A_{e\_wbs}$

$\phi_{n\_tr} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_tr\_wbs_i} := \phi_{n\_tr} \cdot P_{n\_tr\_wbs_i}$

$\boxed{\phi P_{n\_tr\_wbs}^{T} = (360)\,kip}$ Design tensile strength (D5-1)

SUMMARY OF RESULTS

Capacities For Upward Loading

TEE EARS

Tension, capacity of tee ears [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_te\_trp}^{T} = (78.75)\ kip$$ Design tensile strength

(b) For shear rupture on the effective area:

$$\phi P_{n\_te\_srp}^{T} = (108)\ kip$$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\phi R_{n\_te\_bs}^{T} = (55.688)\ kip$$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_te\_ty}^{T} = (89.1)\ kip$$ Design tensile strength

Shear, capacity of tee ear's upper bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nv\_te\_bolt}^{T} = (44.179)\ kip$$ Design shear strength

EYE ROD

Tension, capacity of lower eye rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nt\_l}^{T} = (33.548)\ kip$$ Design tension strength

TURNBUCKLE

Tension, capacity of turnbuckle [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_tb\_ty}^{T} = (42.288)\ kip$$

Design tensile strength

(b) For tensile rupture in the net section:

$$\phi P_{n\_tb\_tr}^{T} = (64.072)\ kip$$

Design tensile strength

ROD

Tension, capacity of upper eye rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nt\_rd}^{T} = (33.548)\ kip$$

Design tension strength

WELDED BOX STRUCTURE

Shear, capacity of welded box structure's upper section [8, Ch. G pg 16.1-64 thru 69]

G7. Weak Axis Shear in Singly and Doubly Symmetric Shapes

$$\phi V_{n\_wbs} = 158.4\ kip$$

Design shear strength

Shear, capacity of welded box structure's upper welds [8, Ch. J pg 16.1-90 thru 121]

J2. Welds

4. Strength

$$R_{n\_weld} = (42.95)\ kip$$

Nominal shear strength of weld

Tension, capacity of welded box structure's side sections [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_ty\_wbs}^{T} = (237.6)\ kip$$

Design tensile strength

(b) For tensile rupture in the net section:

$$\phi P_{n\_tr\_wbs}^{T} = (360)\ kip$$

Design tensile strength

Appendix B.10.6

Capacity of PS-3 Support

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

PS-3 CAPACITY

The PS-3 supports are composed of a plate fastened to the floor by bolts into a grout pad, a support pipe extending up from the floor plate, and a curved plate plate welded to the top of the support pipe supporting under a flange attaching a primary pump to the the piping of lines 1-22 through 1-25. Since the anchorage for these supports was not able to be credited for any significant amount of capacity as discussed in the anchorage portion of [32, App E], only the capacity for downward compressive loading on the pipe sections was applied.

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Component Capacity Overview:

- Downward Loading:
  - Compression capacity in pipe section

(**Procedures from AISC 13th Edition (applying LRFD)**)

References contained in Appendix B.11 of this Report

$i := 0$ — Assigned indices corresponding to number of support types associated with these calculations

Geometric and Material Properties of Support Components

PIPE SECTION

Material Properties as Defined in the Material Section of Report [32]:

$F_y := 33ksi$ — Yield Strength for A7 Steel [52]

$F_u := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Section Properties:

Pipe section is defined to be Schedule 40 as defined by [21] and all related geometric information was acquired from [8, Table 1-14 pg 1-99]

$Sch40_D := (4in)$ — Defined size of schedule 40 pipe[21]

$OD := (4.5in)$ — Outside diameter [8, Table 1-14 pg 1-99], [21]

$t := (0.237in)$ — Pipe thickness [8, Table 1-14 pg 1-99], [21]

$A := \left(2.97in^2\right)$ — Cross sectional area of pipe [8, Table 1-14 pg 1-99], [21]

$r_{gyration} := (1.51in)$ — Radius of gyration [8, Table 1-14 pg 1-99], [21]

$L := (25in)$ — Pipe length [21]

Capacities for Downward Loading

Determine if supports are ***compact (1)***, ***non-compact (2)***, or ***slender (3)*** as defined in first paragraph of B4

B4. Classification of sections for local buckling (Table B4.1 Case 15)

$$D2t_i := \frac{OD_i}{t_i} \qquad D2t^T = (18.987)$$

Definition of λ_p and λ_r from Table B4.1 Case 15 (Circular hollow sections in uniform compression) to be applied in classification logic. λ_p is the separation point between a compact and non compact member. λ_r is separation point between a non compact and slender member. However, Table B4.1 Case 15 defines λ_p = NA because the only thing of concern is if the support is slender or non-slender, thus only if the classification is 3 do we apply slenderness considerations, otherwise we treat the member as not having slender elements.

$$\lambda_p := 0 \qquad \lambda_r := 0.11\frac{E}{F_y}$$

$$Classification_i := \begin{cases} 1 & \text{if } D2t_i \le \lambda_p \\ 2 & \text{if } \lambda_p < D2t_i \le \lambda_r \\ 3 & \text{if } \lambda_r < D2t_i \end{cases}$$

$$Classification^T = (2)$$

Compression, capacity in pipe [8, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

$\phi_c := 0.9$ — Resistance factor for compression

E2. Slenderness Limitations and Effective Length

$K := 1.0$ — Effective length in accordance with C2.b1, [8, comm.C2 (Table C-C2.2) (case d) pg 16.1-240] Case d was chosen because the support was allowed to rotate on the top as well as on the bottom of the support.

The Slenderness ratio KL/r should preferably not exceed 200

$$KLr_i := \left(\frac{K \cdot L_i}{r_{gyration_i}}\right)$$

The below KLr value verifies that PS-3 do not exceed the 200 recommended limitation

$$KLr^T = (16.556)$$

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified BY classification)

$$F_{e_i} := \frac{\pi^2 E}{\left(KLr_i\right)^2}$$

F_e is the elastic critical buckling stress (E3-4)

$$F_e^T = \left(1.044 \times 10^3\right) \text{ksi}$$

Calculating the variables Limit, Op1, and Op2 to be utilized in logic to determine flexural buckling stress.

$$Limit := 4.71 \cdot \sqrt{\frac{E}{F_y}} \qquad Op1_i := \left(0.658^{\frac{F_y}{F_{e_i}}}\right) F_y \qquad Op2_i := 0.877 \cdot F_{e_i}$$

$$Limit = 139.625$$

Calculating the flexural buckling stress

$$F_{cr_i} := \begin{cases} Op1_i & \text{if } KLr_i \le Limit \\ Op2_i & \text{if } KLr_i > Limit \end{cases}$$

(E3-2)

(E3-3)

$$F_{cr}^T = (32.566) \text{ksi}$$

$$\phi P_{n_i} := \phi_c \cdot F_{cr_i} \cdot A_i$$

Design compressive strength

$$\boxed{\phi P_n^T = (87.05) \text{kip}}$$

Summary of Results

Compression, capacity in pipe [8, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

E2. Slenderness Limitations and Effective Length

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified by classification)

$$\boxed{\phi P_n^T = (87.05) \text{kip}}$$

Design compressive strength

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Appendix B.10.7

Capacity of RH-23A Support

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

RH-23A CAPACITY

The RH-23A supports are composed of a 36" pipe riser clamp fastened to a vertically oriented PCS pipe on line 1-27, a 1-1/4" eye rod is attached to the cantilever portion of the pipe clamp by means of a 1-3/8" bolt, a turnbuckle with tap sizes of 1-1/4" joins the lower1-1/4" eye rod to an upper 1-1/4" eye rod, the upper eye rod is attached to a welded beam attachment appropriately sized for 1-1/4" eye rods by means of a 1-3/8" bolt. The capacities for these components are calculated below, however, the capacity for the welds attaching the welded beam attachment and the associated capacities of the ceiling embedment are found in the anchorage and embedment portions of [32, App E].

Component Capacity Overview:

- Downward Loading:
- Shear capacity of pipe tabs
- Tension capacity of clamp in area of rod connection
- Flexure capacity of clamp's cantilever section
- Shear capacity of clamp's upper bolt
- Tension capacity of lower eye rod
- Tension capacity of turnbuckle
- Tension capacity of upper eye rod
- Tension capacity of welded beam attachment
- Shear capacity of welded beam attachment's bolt

Procedures from AISC 13th Edition (Applying LRFD)

References contained in Appendix B.11 of this Report

$i := 0$

Assigned indices corresponding to number of support types associated with these calculations

Support =	0
	(RH-23A)

Relationship between support and corresponding indices

Geometric and Material Properties of Support Components

PIPE TABS

$N_{p\_tab} := (3)^T$

Number of pipe tabs [DSC00143] & [DSCN2917]

$w_{p\_tab} := (4in)^T$

Width (horizontal) of pipe tab as scaled from photo [DSCN2917]

$H_{p\_tab} := (3in)^T$ — Height (vertical) of pipe tab as scaled from photo [DSCN2917]

$t_{p\_tab} := \left(\frac{1}{2}in\right)^T$ — Thickness of pipe tab as scaled from photo [DSC00143]

$F_{EXX} := 60ksi$ — E6013 weld material ultimate strength [50, pg I-9], [51]

$\theta_{transverse} := \frac{\pi}{2}$ — Angle between loading and traverse welds

$$F_{w\_transverse} := 0.60 \cdot F_{EXX} \cdot \left(1.0 + 0.5 \cdot \sin\left(\theta_{transverse}\right)^{1.5}\right) \quad \text{(J2-5)}$$

$F_{w\_transverse} = 54\,ksi$ — Nominal Shear Strength of transverse welds

$\theta_{longitudinal} := 0$ — Angle between loading and traverse welds

$$F_{w\_longitudinal} := 0.60 \cdot F_{EXX} \cdot \left(1.0 + 0.5 \cdot \sin\left(\theta_{longitudinal}\right)^{1.5}\right) \quad \text{(J2-5)}$$

$F_{w\_longitudinal} = 36\,ksi$ — Nominal Shear Strength of longitudinal welds

$\omega := \left(\frac{1}{4}in\right)^T$ — Minimum size of fillet given that thinner joined part (plate) = 3/4" [8, Table J2.4, pg 16.1-96] [30]

$L_{w\_traverse} := w_{p\_tab}$

$L_{w\_traverse} = (4)\,in$ — Traverse length of weld [30]

$L_{w\_longitudinal} := 2 \cdot H_{p\_tab}$

$L_{w\_longitudinal} = (6)\,in$ — Longitudal length of weld [30]

$A_{w\_traverse_i} := L_{w\_traverse_i} \cdot \omega_i$

$A_{w\_traverse} = (1)\,in^2$ — Effective area of weld throat of traverse welds

$A_{w\_longitudinal_i} := L_{w\_longitudinal_i} \cdot \omega_i$

$A_{w\_longitudinal} = (1.5)\,in^2$ — Effective area of weld throat of traverse welds

$$J_{w_i} := \frac{\left(2\,H_{p\_tab_i} + w_{p\_tab_i}\right)^3}{12} - \frac{\left(H_{p\_tab_i}\right)^2 \cdot \left(H_{p\_tab_i} + w_{p\_tab_i}\right)^2}{2\,H_{p\_tab_i} + w_{p\_tab_i}}$$

Polar moment of inertia [39, Table 5, pg 7.4-7]

$$J_w = (39.233)\,in^3$$

RISER CLAMP (HGR STD 40 Riser 36" Pipe Clamp [18, Sheet 2])

Material Properties of Clamp as Defined in the Material Section of Report [32]:

$F_{y\_cl} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{u\_cl} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E_{cl} := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Clamp:

$$t_{cl} := \left(\frac{3}{4}in\right)^T$$

Thickness of plates forming cantilever portion of the clamp, [18, Sheet 2]

$$w_{cl} := (6in)^T$$

Width of plates forming the clamp [18, Sheet 2]

$$I_{cl} := \frac{t_{cl} \cdot w_{cl}^3}{12}$$

Moment of inertia about major axis of plate comprising clamp

$$A_{cl_i} := \left(2\,t_{cl_i}\right) \cdot w_{cl_i}$$

Total cross sectional area of both sides of clamp

$$A_{cl}^T = (9)\,in^2$$

$$d_{cl\_bolt} := \left(1\frac{3}{8}in\right)^T$$

Bolt diameter, in. of all three bolts based on allowable provided by rod [18, Sheet 2], [22, Fig 278 ph-52]

$$d_{cl\_hole} := \left(1\frac{1}{2}in\right)^T$$

Nominal bolt hole diameter as estimated from welded beam attachment dimensions [22, Fig 66 ph-33]

$$a_{parrallel\_cl} := \left(2\frac{1}{4}in\right)^T$$

Shortest distance from edge of the pin hole to the edge of the member measured parallel to the direction of the force from top of bolt hole to top of clamp bracket, in. (mm) hand calculated from d_{cl_hole} and [22, Fig 212 ph-18] data

$$a_{normal\_cl} := \left(1\frac{3}{4}in\right)^T$$

Shortest distance from edge of pin hole to the edge of the member measured normal to the direction of the force, in. scaled from photo DSC00143

$$L_{cl\_cantilever} := (11in)^T$$

Length of cantilever section scaled (conservatively) from photo DSC00143

LOWER EYE ROD (Welded Eye Rod FIG 278 1-1/4" [18, Sheet 2])

Material Properties of Lower Eye Rod as Defined in the Material Section of Report [32]:

$F_{y\_I} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{u\_I} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E_I := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Lower Eye Rod:

$$d_{LI} := \left(1\frac{1}{4}in\right)^T$$

Unthreaded diameter of eye rod, in. [22, Fig 278 ph-52]

$$Z_{LI_i} := \frac{\left(d_{LI_i}\right)^3}{6}$$

Plastic section modulus about the axis of bending [8, Table 17-27 pg17-39]

TURNBUCKLE (Turnbuckle FIG 230 1-1/4" [18, Sheet 2])

Material Properties of Turnbuckle as Defined in the Material Section of Report [32]:

$F_{y\_tb} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{u\_tb} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E_{tb} := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Turnbuckle:

The turnbuckle legs have a unique cross section, therefore for these calculations treat each leg as a rectangular cross section where the width of the turnbuckle legs were conservatively scaled to be 9/8 the diameter of the rod as scaled from photo dsc00080 and the thickness of the turnbuckle legs were scaled to be 1/2 the diameter of the corresponding rod diameter as scaled from photo dsc00079.

$$w_{tb_i} := \left(\frac{9}{8}\right) \cdot d_{LI_i}$$

$$w_{tb}^T = (1.406)\ in$$

Width of turnbuckle, in. [22, Fig 230 ph-57]

$$t_{tb_i} := \left(\frac{1}{2}\right) \cdot d_{LI_i}$$

$$t_{tb}^T = (0.625)\ in$$

Thickness of turnbuckle, in. [22, Fig 230 ph-57]

$A_{tb_i} := 2 \cdot w_{tb_i} \cdot t_{tb_i}$ — Total area of turnbuckle cross section

$A_{tb}^T = (1.758)\,in^2$

UPPER EYE ROD (Welded Eye Rod FIG 278 1-1/4" [18, Sheet 2])

Material Properties of Upper Eye Rod as Defined in the Material Section of Report [32]:

$F_{y\_UI} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{u\_UI} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E_{UI} := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Upper Eye Rod:

$d_{UI} := \left(1\frac{1}{4}in\right)^T$ — Unthreaded diameter of eye rod, in. [22, Fig 278 ph-52]

$Z_{UI_i} := \frac{\left(d_{UI_i}\right)^3}{6}$ — Plastic section modulus about the axis of bending, in.^{3} (mm^3) [8, Table 17-27 pg17-39]

WELDED BEAM ATTACHMENT (Welded Beam Attachment FIG 66 1-1/4" Rod [18, Sheet 2])

Material Properties of Welded Beam Attachment as Defined in the Material Section of Report [32]:

$F_{y\_wba} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{u\_wba} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E\_wba := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Welded Beam Attachment:

$t_{wba} := \left[2 \cdot \left(\frac{5}{8}in\right)\right]^T$ — Combined thickness of welded beam attachment [22, Fig 66 ph-33]

$w_{wba} := (4in)^T$ — Width of welded beam attachment [22, Fig 66 ph-33]

$A_{wba_i} := t_{wba_i} \cdot w_{wba_i}$

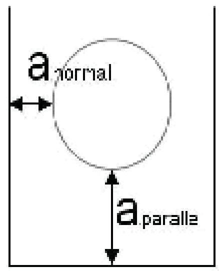
$A_{wba} = (5)\,in^2$ — Cross sectional area of welded beam attachment

$d_{wba\_bolt} := \left(1\frac{3}{8}in\right)^T$ — Diameter of welded beam attachment bolt [22, Fig 66 ph-33]

$d_{wba\_hole} := \left(1\frac{1}{2}in\right)^T$ — Diameter of welded beam attachment bolt hole [22, Fig 66 ph-33], [8, Table J3.3 pg 16.1-105]

$$a_{parrallel\_wba} := \left(1\frac{1}{4}in\right)^T$$

Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force from bottom of bolt hole to the bottom of the welded beam attachment, in. (mm) hand calculated from d_{wba_hole} and [22, Fig 66 ph-33] data



$$a_{normal\_wba_i} := \frac{w_{wba_i} - d_{wba\_hole_i}}{2}$$

$$a_{normal\_wba}^T = (1.25)\,in$$

Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force, in. (mm) [22, Fig 66 ph-33]

Capacities For Downward Loading

PIPE TABS

Shear, capacity of pipe tab welds [8, Ch. J pg 16.1-90 thru 121] & [39, Ch 7.4]

As shown in photo [DSCN2917] the pipe clamp only appears to contact one corner of the pipe tabs. Therefore both a vertical applied shear and torsion component will be considered in the evaluation of the weld. The following calculations will appropriately incorporate the AISC code requirements with the Blodgett treatment of a member in shear and torsion for each tab before they are combined in the final step. Since a constant shear strength value is applied for the Blodgett approach, $F_{w\_longitudinal}$ will be the only value applied as it is the most conservative.

J3. Welds

4. Strength

$$\phi_{weld} := 0.75$$

Resistance factor of weld

*For each of the following calculations **f** (the allowable force on a fillet weld, lbs per linear inch) will be calculated with the load variable R_n factored out of the equation. It will be appropriately presented with relation to **f** at the end of this calculation set.*

$$f_{th_i} := \frac{\frac{w_{p\_tab}}{2} \cdot \frac{w_{p\_tab}}{2}}{J_{w_i}}$$

$$f_{th} = (0.102)\,\frac{1}{in}$$

$$f_{tv_i} := \frac{\frac{w_{p\_tab}}{2} \cdot \frac{H_{p\_tab}}{2}}{J_{w_i}}$$

$$f_{tv} = (0.076)\,\frac{1}{in}$$

$$f_{sv_i} := \frac{1}{L_{w\_traverse_i} + L_{w\_longitudinal_i}}$$

$$f_{sv} = (0.1)\,\frac{1}{in}$$

$$f_{r_i} := \sqrt{\left(f_{tv_i} + f_{sv_i}\right)^2 + \left(f_{th_i}\right)^2}$$

$$f_r = (0.204)\,\frac{1}{in}$$

$$R_{n\_weld_i} := \left(\frac{0.707 \cdot \omega_i \cdot F_{w\_longitudinal}}{f_{r_i}}\right) \cdot N_{p\_tab_i}$$

$$R_{n\_weld} = (93.665)\,kip$$ Nominal shear strength of weld

$$\phi R_{n\_weld_i} := \phi_{weld} \cdot R_{n\_weld_i}$$

$$\boxed{\phi R_{n\_weld} = (70.249)\,kip}$$ (J2-4)

CLAMP

Tension, capacity of clamp in area of rod connection [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$b_{cl_i} := 2\left(2\,t_{cl_i}\right) + 0.63in$$

$$b_{cl}^{T} = (3.63)\,in$$

$b_{eff\_cl_i} := \min\left(b_{cl_i}, a_{normal\_cl_i}\right)$

$b_{eff\_cl}^T = (1.75)\ in$

b_{eff} is an effective length calculated as (2t + 0.63in) which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$P_{n\_cl\_trp_i} := 2 \cdot t_{cl_i} \cdot b_{eff\_cl_i} \cdot F_{u\_cl}$ — Nominal axial strength (P_n)

(D5-1)

$\phi_{n\_trp} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_cl\_trp_i} := \phi_{n\_trp} \cdot P_{n\_cl\_trp_i}$

$\boxed{\phi P_{n\_cl\_trp}^T = (118.125)\ kip}$ — Design tensile strength

(b) For shear rupture on the effective area:

$A_{sf\_cl_i} := 2\left(2\,t_{cl_i}\right) \cdot \left(a_{parrallel\_cl_i} + \frac{d_{cl\_bolt_i}}{2}\right)$

$A_{sf\_cl}^T = (8.813)\ in^2$ — Effective area

$P_{n\_cl\_srp_i} := 0.6 \cdot F_{u\_cl} \cdot A_{sf\_cl_i}$ — Nominal axial strength (P_n)

$\phi_{n\_srp} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_cl\_srp_i} := \phi_{n\_srp} \cdot P_{n\_cl\_srp_i}$ (D5-2)

$\boxed{\phi P_{n\_cl\_srp}^T = (237.938)\ kip}$ — Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_cl_i} := d_{cl\_bolt_i} \cdot \left(2\,t_{cl_i}\right)$ — Projected bearing area in.^{2} (mm^2)

$R_{n\_cl\_bs_i} := 1.8 \cdot F_{y\_cl} \cdot A_{pd\_cl_i}$ — Nominal bearing strength

$\phi := 0.75$ — Resistance factor

$\phi R_{n\_cl\_bs_i} := \phi \cdot R_{n\_cl\_bs_i}$

$\boxed{\phi R_{n\_cl\_bs}^T = (91.884)\ kip}$ — Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_cl_i} := A_{cl_i}$ Gross area (D3-1)

(a) For tensile yielding in the gross section:

$P_{n\_cl\_ty_i} := F_{y\_cl} \cdot A_{g\_cl_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_cl\_ty_i} := \phi_{t\_ty} \cdot P_{n\_cl\_ty_i}$

$\phi P_{n\_cl\_ty}^T = (267.3)\,kip$ Design tensile strength

Flexure, capacity of clamp's cantilever section [8, Ch. F pg 16.1-44 thru 16.1-63]

In order to determine the clamp's cantilever section flexure capacity each plate will conservatively be treated separately without considering the influence of the intermediate bolts then the final capacity is to doubled to account for the presence of both plates.

F1. General Provisions

Given resistance factor for shear

$\phi_b := 0.9$

Calculate the lateral-torsional buckling modification factor for a nonuniform moment loading on the beam caused by downward loading of the pipe

$M_{max}(F, Length) := F \cdot Length$ Absolute value of maximum moment in the unbraced segment

$M_A(F, Length) := \frac{3}{4} \cdot F \cdot Length$ Absolute value of moment at quarter point of the unbraced segment

$M_B(F, Length) := \frac{1}{2} \cdot F \cdot Length$ Absolute value of moment at centerline of the unbraced segment

$M_C(F, Length) := \frac{1}{4} \cdot F \cdot Length$ Absolute value of moment at three-quarter point of the unbraced segment

$R_m := 1.0$ Cross-section monosymmetry parameter (value of 1.0 is assigned because it correlates to singly symmetric members subjected to single curvature bending)

$$C_b(F, Length) := \left(\frac{12.5 \cdot M_{max}(F, Length)}{2.5 \cdot M_{max}(F, Length) + 3 \cdot M_A(F, Length) + 4 \cdot M_B(F, Length) + 3 \cdot M_C(F, Length)} \cdot R_m \right.$$

$$C_b\left(F, L_{IB_i}\right) \rightarrow 1.6666666666666666667$$

F11. Rectangular Bars and Rounds

1. Yielding

$$\frac{L_{cl\_cantilever} \cdot w_{cl}}{t_{cl}^{2}} = (117.333)$$

Geometric ratio of cantilever length, width, and thickness

$$\frac{0.08 \cdot E_{cl}}{F_{y\_cl}} = 70.303$$

Low end ratio of cantilever modulus and yield strength

Since the geometric ratio is greater than the low end ratio yielding will not be the limiting mode given flexure

2. Lateral-Torsional Buckling

$$\frac{1.9 \cdot E_{cl}}{F_{y\_cl}} = 1.67 \times 10^{3}$$

High end ratio of cantilever modulus and yield strength

Since the geometric ratio is greater than the low end ratio and less than the high end ratio to following moment equation applies.

$$M_{y\_cl_i} := \frac{F_{y\_cl} \cdot I_{cl}}{\frac{w_{cl_i}}{2}}$$

Yield moment about major axis

$$M_{y\_cl} = (148.5)\ kip \cdot in$$

$$M_{n\_cl_i} := 1.667 \cdot \left[1.52 - 0.274 \cdot \left[\frac{L_{cl\_cantilever_i} \cdot w_{cl_i}}{\left(t_{cl_i}\right)^{2}} \right] \cdot \frac{F_{y\_cl}}{E_{cl}} \right] M_{y\_cl_i}$$

$$M_{n\_cl} = (367.219)\ kip \cdot in$$

$$\phi M_{n\_cl_i} := \phi_b \cdot M_{n\_cl_i}$$

$$\boxed{\phi M_{n\_cl}^{T} = (330.497)\ kip \cdot in}$$

Design flexural strength

$$\phi F_{n\_cl_i} := 2 \frac{\phi M_{n\_cl_i}}{L_{cl\_cantilever_i}}$$

Converting flexural strength to strength at applied load by dividing the design flexural strength by the moment arm comprised of the angle iron length, the leg length of the horizontal angle iron section, and the radius of the pipe which the clamp is connected to (a factor of 2 is included to account for both sections of clamp)

$$\phi F_{n\_cl}^{T} = (60.09)\ kip$$

Total design strength of angle iron section given flexural loading

Shear, capacity of clamp's bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$A_{cl\_bolt_i} := \pi \cdot \left(\frac{d_{cl\_bolt_i}}{2}\right)^2$$

Nominal unthreaded body area

$$A_{cl\_bolt\_ds_i} := 2 \cdot A_{cl\_bolt_i}$$

Applicable area for this case since the bolt is in double shear

$$F_{nv\_cl\_bolt} := 24ksi$$

Nominal shear stress in bearing type connections (A307) [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment and includes an allowance for threads in the shear plane

$$R_{nv\_cl\_bolt_i} := F_{nv\_cl\_bolt} \cdot A_{cl\_bolt\_ds_i}$$

Nominal strength (R_n) (J3-1)

$$\phi_{b\_sr} := 0.75$$

Resistance factor

$$\phi R_{nv\_cl\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_cl\_bolt_i}$$

$$\phi R_{nv\_cl\_bolt}^{T} = (53.456)\ kip$$

Design shear strength

LOWER EYE ROD

NOTE:It was observed during inspection that all of the applicable eye rods have welded eyes even though they indicate otherwise on Drawing 120925, thus all eye rods in these calculations will be treated as welded eye rods

Tension, capacity of lower eye rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$A_{b\_LI_i} := \pi \cdot \left(\frac{d_{LI_i}}{2}\right)^2$ Nominal unthreaded body area

$F_{nt\_LI} := 45\text{ksi}$ Nominal tensile stress (A307) [8, Table J3.2] [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment

$R_{nt\_LI_i} := F_{nt\_LI} \cdot A_{b\_LI_i}$ Nominal strength (R_n) (J3-1)

$\phi_{b\_tr} := 0.75$ Resistance factor

$\phi R_{nt\_LI_i} := \phi_{b\_tr} \cdot R_{nt\_LI_i}$

$\phi R_{nt\_LI}{}^T = (41.417)\,\text{kip}$ Design tension strength

TURNBUCKLE

Tension, capacity of turnbuckle [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D2. Tensile Strength

D3. Area Determination

1. Gross Area

$A_{g\_tb_i} := A_{tb_i}$ Gross area

2. Net Area

$A_{n\_tb_i} := A_{g\_tb_i}$ Net area

3. Effective Net Area

$U_{tb} := 1.0$ Shear lag factor [8, Table D3.1 pg 16.1-29 (case 1)]

$A_{e\_tb_i} := A_{n\_tb_i} \cdot U_{tb}$ Effective net area (D3-1)

(a) For tensile yielding in the gross section:

$P_{n\_tb\_ty_i} := F_{y\_tb} \cdot A_{g\_tb_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_tb\_ty_i} := \phi_{t\_ty} \cdot P_{n\_tb\_ty_i}$

$\phi P_{n\_tb\_ty}{}^T = (52.207)\,\text{kip}$ Design tensile strength

(b) For tensile rupture in the net section:

$P_{n\_tb\_tr_i} := F_{u\_tb} \cdot A_{e\_tb_i}$ — Nominal axial strength (P_n) (D2-2)

$\phi_{t\_tr} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_tb\_tr_i} := \phi_{t\_tr} \cdot P_{n\_tb\_tr_i}$

$\phi P_{n\_tb\_tr}^{T} = (79.102)\,kip$ — Design tensile strength

UPPER EYE ROD

NOTE:It was observed during inspection that all of the applicable eye rods have welded eyes even though they indicate otherwise on Drawing 120925, thus all eye rods in these calculations will be treated as welded eye rods

Tension, capacity of upper eye rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$A_{b\_UI_i} := \pi \cdot \left(\frac{d_{UI_i}}{2}\right)^2$ — Nominal unthreaded body area

$F_{nt\_UI} := 45ksi$ — Nominal tensile stress (A307) [8, Table J3.2] [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment

$R_{nt\_UI_i} := F_{nt\_UI} \cdot A_{b\_UI_i}$ — Nominal strength (R_n) (J3-1)

$\phi_{b\_tr} := 0.75$ — Resistance factor

$\phi R_{nt\_UI_i} := \phi_{b\_tr} \cdot R_{nt\_UI_i}$

$\phi R_{nt\_UI}^{T} = (41.417)\,kip$ — Design tension strength

WELDED BEAM ATTACHMENT

Tension, capacity of welded beam attachment [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$b_i := 2\,t_{wba_i} + 0.63in$

$b^T = (3.13)\ in$

$b_{eff_i} := \min\left(b_i, a_{normal\_wba_i}\right)$

$b_{eff}^T = (1.25)\ in$

b_{eff} is an effective length calculated as (2t + 0.63in) which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$P_{n\_wba\_trp_i} := 2 \cdot t_{wba_i} \cdot b_{eff_i} \cdot F_{u\_wba}$ Nominal axial strength (P_n) (D5-1)

$\phi_{n\_trp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_wba\_trp_i} := \phi_{n\_trp} \cdot P_{n\_wba\_trp_i}$

$\boxed{\phi P_{n\_wba\_trp}^T = (140.625)\ kip}$ Design tensile strength

(b) For shear rupture on the effective area:

$A_{sf\_wba_i} := 2 \cdot t_{wba_i} \cdot \left(a_{parrallel\_wba_i} + \dfrac{d_{wba\_bolt_i}}{2}\right)$

$A_{sf\_wba}^T = (4.844)\ in^2$ Effective area

$P_{n\_wba\_srp_i} := 0.6 \cdot F_{u\_wba} \cdot A_{sf\_wba_i}$ Nominal axial strength (P_n) (D5-2)

$\phi_{n\_srp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_wba\_srp_i} := \phi_{n\_srp} \cdot P_{n\_wba\_srp_i}$

$\boxed{\phi P_{n\_wba\_srp}^T = (130.781)\ kip}$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_wba_i} := d_{wba\_bolt_i} \cdot t_{wba_i}$ Projected bearing area $in.^2$ (mm^2)

$R_{n\_wba\_bs_i} := 1.8 \cdot F_{y\_wba} \cdot A_{pd\_wba_i}$ Nominal bearing strength (J7-1)

$\phi := 0.75$ Resistance factor

$\phi R_{n\_wba\_bs_i} := \phi \cdot R_{n\_wba\_bs_i}$

$\boxed{\phi R_{n\_wba\_bs}^T = (76.57)\ kip}$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_wba_i} := A_{wba_i}$ Gross area

(a) For tensile yielding in the gross section:

$P_{n\_wba\_ty_i} := F_{y\_wba} \cdot A_{g\_wba_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} = 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_wba\_ty_i} := \phi_{t\_ty} \cdot P_{n\_wba\_ty_i}$

$\boxed{\phi P_{n\_wba\_ty}{}^T = (148.5)\,kip}$ Design tensile strength

Shear, capacity of welded beam attachment's bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$A_{wba\_bolt_i} := \pi \cdot \left(\frac{d_{wba\_bolt_i}}{2}\right)^2$ Nominal unthreaded body area

$A_{wba\_bolt\_ds_i} := 2 \cdot A_{wba\_bolt_i}$ Applicable area for this case since the bolt is in double shear

$F_{nv\_wba\_bolt} := 24ksi$ Nominal shear stress in bearing type connections (A307) [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment and includes an allowance for threads in the shear plane

$R_{nv\_wba\_bolt_i} := F_{nv\_wba\_bolt} \cdot A_{wba\_bolt\_ds_i}$ Nominal strength (R_n) (J3-1)

$\phi_{b\_sr} = 0.75$ Resistance factor

$\phi R_{nv\_wba\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_wba\_bolt_i}$

$\boxed{\phi R_{nv\_wba\_bolt}{}^T = (53.456)\,kip}$ Design shear strength

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Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

SUMMARY OF RESULTS

Capacities For Downward Loading

PIPE TABS

Shear, capacity of pipe tab welds [8, Ch. J pg 16.1-90 thru 121] & [39, Ch 7.4]

J3. Welds

4. Strength

$$\phi R_{n\_weld} = (70.249)\ kip$$

CLAMP

Tension, capacity of clamp in area of rod connection [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_cl\_trp}^{T} = (118.125)\ kip$$ Design tensile strength

(b) For shear rupture on the effective area:

$$\phi P_{n\_cl\_srp}^{T} = (237.938)\ kip$$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\phi R_{n\_cl\_bs}^{T} = (91.884)\ kip$$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_cl\_ty}^{T} = (267.3)\ kip$$ Design tensile strength

Flexure, capacity of clamp's cantilever section [8, Ch. F pg 16.1-44 thru 16.1-63]

F1. General Provisions

F11. Rectangular Bars and Rounds

1. Yielding

Since the geometric ratio is greater than the low end ratio yielding will not be the limiting mode given flexure

2. Lateral-Torsional Buckling

$$\phi F_{n\_cl}^{T} = (60.09)\ kip$$

Total design strength of angle iron section given flexural loading

Shear, capacity of clamp's bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nv\_cl\_bolt}^{T} = (53.456)\ kip$$

Design shear strength

LOWER EYE ROD

Tension, capacity of lower eye rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nt\_LI}^{T} = (41.417)\ kip$$

Design tension strength

TURNBUCKLE

Tension, capacity of turnbuckle [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_tb\_ty}^{T} = (52.207)\ kip$$

Design tensile strength

(b) For tensile rupture in the net section:

$$\phi P_{n\_tb\_tr}^{T} = (79.102)\ kip$$

Design tensile strength

UPPER EYE ROD

Tension, capacity of upper eye rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nt\_UI}^{T} = (41.417)\ kip$$

Design tension strength

WELDED BEAM ATTACHMENT

Tension, capacity of welded beam attachment [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_wba\_trp}^{T} = (140.625)\, kip$ — Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_wba\_srp}^{T} = (130.781)\, kip$ — Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_wba\_bs}^{T} = (76.57)\, kip$ — Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_wba\_ty}^{T} = (148.5)\, kip$ — Design tensile strength

Shear, capacity of welded beam attachment's bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$\phi R_{nv\_wba\_bolt}^{T} = (53.456)\, kip$ — Design shear strength

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Appendix B.10.8

Capacity of RH-25Ax & RH-25Bx Support

RH-25Ax & 25Bx CAPACITY

RH-25Ax + 25Bx comprise the two legs of a hanging support attached to a U shaped cradle plate supporting a 36" diameter pipe. Each leg of the support is attached to the cradle plate by a bolt that is connected through a clevis, each clevis is attached to a rod, the rods connect to turnbuckles, each turnbuckle is attached from above by eye rods , each eye rod is attached to a welded beam attachment on the ceiling by means of a bolt. The capacities for these components are calculated below, however the capacity for the welds attaching the tab and the associated capacities of the ceiling embedment are found in the anchorage and embedment portions of [32, App E].

Component Capacity Overview:

- Downward Loading:
- Tension capacity of cradle plate
- Tension capacity of clevis's intermediate cross section
- Tension capacity of clevis's pin connection
- Shear capacity of clevis's pin
- Tension capacity of lower rod
- Tension capacity of turnbuckle
- Tension capacity of upper eye rod
- Tension capacity of welded beam attachment
- Shear capacity of welded beam attachment's bolt

(**Procedures from AISC 13th Edition (Applying LRFD))**

References contained in Appendix B.11 of this Report

NOTE: The geometric properties only represent one of the two legs for each support. Therefore the result is multiplied by an additional factor of 2 when implementing the resistance factor into the capacity calculations.

$i := 0$

Assigned indices corresponding to number of support types associated with these calculations

Support = 0
(RH-25Ax + 25Bx)

Relationship between support and corresponding indices

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Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

Geometric and Material Properties of Support Components

CRADLE PLATE (6" x 3/4" bar [21, Detail 26])

Material Properties of Cradle Plate as Defined in the Material Section of Report [32]:

$F_{y\_cp} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{u\_cp} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E_{cp} := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Cradle Plate:

$$t_{cp} := \left(\frac{3}{4} in\right)^T$$

Combined thickness of both plates forming the upper portion of the cradle plate [21, Detail 26]

$$w_{cp} := (6in)^T$$

Width of plates forming the cradle plate, [21, Detail 26]

$$A_{cp_i} := t_{cp_i} \cdot w_{cp_i}$$

Cross sectional area of one side of cradle plate

$$A_{cp}^T = (4.5)\,in^2$$

$$d_{cp\_bolt} := \left(1\frac{3}{8} in\right)^T$$

Bolt diameter, in. (mm) [21, Detail 26]

$$d_{cp\_hole} := \left(1\frac{7}{16} in\right)^T$$

Nominal bolt hole Diameter [8, Table J3.3 pg 16.1-105]

$$a_{parallel\_cp} := (1in)^T$$

Shortest distance from edge of the pin hole to the edge of the member measured parallel to the direction of the force from top of bolt hole to top of cradle plate bracket, in. (mm) estimated from photo dscn2934

$$a_{normal\_cp_i} := \frac{w_{cp_i} - d_{cp\_hole_i}}{2}$$

Shortest distance from edge of pin hole to the edge of the member measured normal to the direction of the force.

$$a_{normal\_cp}^T = (2.281)\,in$$

CLEVIS (Clevis FIG 299 1-1/4" [22, Sheet 2])

Material Properties of Clevis as Defined in the Material Section of Report [32]:

$F_{y\_cv} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{u\_cv} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E_{cv} := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Clevis:

The thickness of the intermediate portion of the clevis's present in this piping system was observed to be approximately the same thickness as that defined at the bolt hole connection as shown in photo dsc00034

$$t_{cv\_int} := \left[2 \cdot \left(\frac{1}{2} in\right)\right]^T$$

Combined thickness of intermediate portions of clevis [22, Fig 299 ph-56]

$$w_{cv\_int} := \left(1\frac{1}{2} in\right)^T$$

Width of intermediate portions of clevis [22, Fig 299 ph-56]

$$A_{cv\_int_i} := t_{cv\_int_i} \cdot w_{cv\_int_i}$$

$$A_{cv\_int}{}^T = (1.5)\ in^2 \quad .1$$

Intermediate cross sectional area of clevis [22, Fig 299 ph-56]

$$d_{cv\_bolt} := \left(1\frac{3}{8} in\right)^T$$

Diameter of clevis bolt [22, Fig 299 ph-56]

$$d_{cv\_hole} := \left(1\frac{7}{16} in\right)^T$$

Nominal bolt hole Diameter, in. (mm) [8, Table J3.3 pg 16.1-105]

$$t_{cv\_con} := \left[2 \cdot \left(\frac{1}{2} in\right)\right]^T$$

Combined thickness of plates forming clevis's bolt hole connection [22, Fig 299 ph-56]

$$w_{cv\_con} := (3 in)^T$$

Width of clevis's bolt hole connection [22, Fig 299 ph-56]

$$A_{cv\_con_i} := t_{cv\_con_i} \cdot w_{cv\_con_i}$$

$$A_{cv\_con}{}^T = (3)\ in^2$$

Cross sectional area of clevis at the bolt connection

$$a_{parallel\_cv} := \left(\frac{25}{32} in\right)^T$$

Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force from bottom of bolt hole to bottom of cradle plate bracket, in. (mm) hand calculated from d_{cv_hole} and [22, Fig 299 ph-56] data

$$a_{normal\_cv} := \left(\frac{25}{32} in\right)^T$$

Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force

LOWER ROD (Treaded Rod FIG 140 1-1/4" [22, Sheet 2])

Material Properties of Lower Rod as Defined in the Material Section of Report [32]:

$F_{yR} := 33\text{ksi}$ — Yield Strength for A7 Steel [52]

$F_{uR} := 60\text{ksi}$ — Ultimate Strength for A7 Steel [52]

$E_R := 29000\text{ksi}$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Lower Rod:

$d_R := \left(1\frac{1}{4}\text{in}\right)$ — Unthreaded diameter of rod [18], [22, Fig 140 ph-51]

$Z_{R_i} := \frac{\left(d_{R_i}\right)^3}{6}$ — Plastic section modulus about the axis of bending [8, Table 17-27 pg17-39]

TURNBUCKLE (Turnbuckle FIG 230 1-1/4" [22, Sheet 2])

Material Properties of Turnbuckle as Defined in the Material Section of Report [32]:

$F_{y\_tb} := 33\text{ksi}$ — Yield Strength for A7 Steel [52]

$F_{u\_tb} := 60\text{ksi}$ — Ultimate Strength for A7 Steel [52]

$E_{tb} := 29000\text{ksi}$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Turnbuckle:

The turnbuckle legs have a unique cross section, therefore for these calculations treat each leg as a rectangular cross section where the width of the turnbuckle legs were conservatively scaled to be 9/8 the diameter of the rod as scaled from photo dsc00080 and the thickness of the turnbuckle legs were scaled to be 1/2 the diameter of the corresponding rod diameter as scaled from photo dsc00079.

$w_{tb_i} := \left(\frac{9}{8}\right) \cdot d_{R_i}$ — Width of turnbuckle [22, Fig 230 ph-57]

$w_{tb}^T = (1.406)\text{ in}$

$t_{tb_i} := \left(\frac{1}{2}\right) \cdot d_{R_i}$ — Thickness of turnbuckle [22, Fig 230 ph-57]

$t_{tb}^T = (0.625)\text{ in}$

$A_{tb_i} := 2 \cdot w_{tb_i} \cdot t_{tb_i}$ — Total area of turnbuckle cross section

$A_{tb}^T = (1.758)\text{ in}^2$

UPPER EYE ROD (Welded Eye Rod FIG 278 1-1/4" [22, Sheet 2])

Material Properties of Upper Eye Rod as Defined in the Material Section of Report [32]:

$F_{yI} := 33ksi$ Yield Strength for A7 Steel [52]

$F_{uI} := 60ksi$ Ultimate Strength for A7 Steel [52]

$E_{UI} := 29000ksi$ Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Upper Eye Rod:

$d_I := \left(1\frac{1}{4}in\right)$ Unthreaded diameter of eye rod [22, Fig 278 ph-52]

$Z_{I_i} := \frac{\left(d_{I_i}\right)^3}{6}$ Plastic section modulus about the axis of bending, in.^{3} (mm^3) [8, Table 17-27 pg17-39]

WELDED BEAM ATTACHMENT (Welded Beam Attachment FIG 66 1-1/4" Rod [22, Sheet 2])

Material Properties of Welded Beam Attachment as Defined in the Material Section of Report [32]:

$F_{y\_wba} := 33ksi$ Yield Strength for A7 Steel [52]

$F_{u\_wba} := 60ksi$ Ultimate Strength for A7 Steel [52]

$E\_wba := 29000ksi$ Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Welded Beam Attachment (Fig 66):

$t_{wba} := \left[2 \cdot \left(\frac{5}{8}in\right)\right]^T$ Combined thickness of welded beam attachment [22, Fig 66 ph-33]

$w_{wba} := (4in)^T$ Width of welded beam attachment [22, Fig 66 ph-33]

$A_{wba_i} := t_{wba_i} \cdot w_{wba_i}$

$A_{wba} = (5)\ in^2$ Cross sectional area of welded beam attachment

$d_{wba\_bolt} := \left(1\frac{3}{8}in\right)^T$ Diameter of welded beam attachment bolt [22, Fig 66 ph-33]

$d_{wba\_hole} := \left(1\frac{1}{2}in\right)^T$ Diameter of welded beam attachment bolt hole [22, Fig 66 ph-33]

$a_{parallel\_wba} := \left(1\frac{1}{4}in\right)^T$ Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force from bottom of bolt hole to the bottom of the welded beam attachment, in. (mm) hand calculated from d_{wba_hole} and [22, Fig 66 ph-33] data

$$a_{normal\_wba_i} := \frac{w_{wba_i} - d_{wba\_hole_i}}{2}$$

$$a_{normal\_wba}^T = (1.25)\ in$$

Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force, in. (mm) [22, Fig 66 ph-33]

Capacities Due to Downward Loading

CRADLE PLATE

Tension, capacity of cradle plate [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$b_{cp_i} := 2\,t_{cp_i} + 0.63in$$

$$b_{cp}^T = (2.13)\ in$$

$$b_{eff\_cp_i} := \min\left(b_{cp_i}, a_{normal\_cp_i}\right)$$

$$b_{eff\_cp}^T = (2.13)\ in$$

b_{eff} is an effective length calculated as (2t + 0.63in) for which can not be larger than the actual distance fro the edge of th hole to the edge of the part measured in the direction normal to the applied force

$$P_{n\_cp\_trp_i} := 2 \cdot t_{cp_i} \cdot b_{eff\_cp_i} \cdot F_{u\_cp}$$

Nominal axial strength (P_n) (D5-1)

$$\phi_{n\_trp} := 0.75$$

Resistance factor for tension (ϕ_t)

$$\phi P_{n\_cp\_trp_i} := 2 \cdot \phi_{n\_trp} \cdot P_{n\_cp\_trp_i}$$

Additional 2 incorporated to account for both legs of the support

$$\boxed{\phi P_{n\_cp\_trp}^T = (287.55)\ kip}$$

Design tensile strength

(b) For shear rupture on the effective area:

$$A_{sf\_cp_i} := 2 \cdot t_{cp_i} \cdot \left(a_{parallel\_cp_i} + \frac{d_{cp\_bolt_i}}{2}\right)$$

$$A_{sf\_cp}^T = (2.531)\ in^2$$

Effective area

$$P_{n\_cp\_srp_i} := 0.6 \cdot F_{u\_cp} \cdot A_{sf\_cp_i}$$

Nominal axial strength (P_n) (D5-2)

$$\phi_{n\_srp} := 0.75$$

Resistance factor for tension (ϕ_t)

$$\phi P_{n\_cp\_srp_i} := 2 \cdot \phi_{n\_srp} \cdot P_{n\_cp\_srp_i}$$

Additional 2 incorporated to account for both legs of the support

$$\boxed{\phi P_{n\_cp\_srp}^T = (136.687)\ kip}$$

Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_cp_i} := d_{cp\_bolt_i} \cdot t_{cp_i}$ Projected bearing area in.^{2} (mm^2)

$R_{n\_cp\_bs_i} := 1.8 \cdot F_{y\_cp} \cdot A_{pd\_cp_i}$ Nominal bearing strength (J7-1)

$\phi := 0.75$ Resistance factor

$\phi R_{n\_cp\_bs_i} := 2 \cdot \phi \cdot R_{n\_cp\_bs_i}$ Additional 2 incorporated to account for both legs of the support

$\phi R_{n\_cp\_bs}^{T} = (91.884)\ kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_cp_i} := A_{cp_i}$ Gross area

(a) For tensile yielding in the gross section:

$P_{n\_cp\_ty_i} := F_{y\_cp} \cdot A_{g\_cp_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_cp\_ty_i} := 2 \cdot \phi_{t\_ty} \cdot P_{n\_cp\_ty_i}$ Additional 2 incorporated to account for both legs of the support

$\phi P_{n\_cp\_ty}^{T} = (267.3)\ kip$ Design tensile strength

CLEVIS

Tension, capacity of clevis' intermediate section [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D2. Tensile Strength

D3. Area Determination

1. Gross Area

$A_{g\_cv\_int_i} := A_{cv\_int_i}$ Gross Area

2. Net Area

$A_{n\_cv\_int_i} := A_{g\_cv\_int_i}$ — Net Area

3. Effective Net Area

$U_{cv\_int} := 1.0$ — Shear lag factor [8, Table D3.1 pg 16.1-29 (case 1)]

$A_{e\_cv\_int_i} := A_{n\_cv\_int_i} \cdot U_{cv\_int}$ — Effective Net Area (D3-1)

(a) For tensile yielding in the gross section:

$P_{n\_cv\_int\_ty_i} := F_{y\_cv} \cdot A_{g\_cv\_int_i}$ — Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} = 0.9$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_cv\_int\_ty_i} := 2 \cdot \phi_{t\_ty} \cdot P_{n\_cv\_int\_ty_i}$ — Additional 2 incorporated to account for both legs of the support

$\phi P_{n\_cv\_int\_ty}{}^{T} = (89.1)\ kip$ — Design tensile strength

(b) For tensile rupture in the net section:

$P_{n\_cv\_int\_tr_i} := F_{u\_cv} \cdot A_{e\_cv\_int_i}$ — Nominal axial strength (P_n) (D2-2)

$\phi_{t\_tr} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_cv\_int\_tr_i} := 2 \cdot \phi_{t\_tr} \cdot P_{n\_cv\_int\_tr_i}$ — Additional 2 incorporated to account for both legs of the support

$\phi P_{n\_cv\_int\_tr}{}^{T} = (135)\ kip$ — Design tensile strength

Tension, capacity of clevis's pin connection [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$b_{cv_i} := 2\, t_{cv\_con_i} + 0.63in$

$b_{cv}{}^{T} = (2.63)\ in$

$b_{eff\_cv_i} := \min\left(b_{cv_i}, a_{normal\_cv_i}\right)$

$b_{eff\_cv}{}^{T} = (0.781)\ in$

b_{eff} is an effective length calculated as (2t + 0.63in) for which can not be larger than the actual distance fro the edge of the hole to the edge of the part measured in the direction normal to the applied force

$P_{n\_cv\_con\_trp_i} := 2 \cdot t_{cv\_con_i} \cdot b_{eff\_cv_i} \cdot F_{u\_cv}$ Nominal axial strength (P_n)

(D5-1)

$\phi_{n\_trp} = 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_cv\_con\_trp_i} := 2 \cdot \phi_{n\_trp} \cdot P_{n\_cv\_con\_trp_i}$ Additional 2 incorporated to account for both legs of the support

$\phi P_{n\_cv\_con\_trp}^T = (140.625)\ kip$ Design tensile strength

(b) For shear rupture on the effective area:

$$A_{sf\_cv\_bolt_i} := 2 \cdot t_{cv\_con_i} \cdot \left(a_{parallel\_cv_i} + \frac{d_{cv\_bolt_i}}{2}\right)$$

$A_{sf\_cv\_bolt}^T = (2.938)\ in^2$ Effective Area

$P_{n\_cv\_bolt\_srp_i} := 0.6 \cdot F_{u\_cv} \cdot A_{sf\_cv\_bolt_i}$ Nominal axial strength (P_n)

(D5-2)

$\phi_{n\_srp} = 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_cv\_bolt\_srp_i} := 2 \cdot \phi_{n\_srp} \cdot P_{n\_cv\_bolt\_srp_i}$ Additional 2 incorporated to account for both legs of the support

$\phi P_{n\_cv\_bolt\_srp}^T = (158.625)\ kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_cv_i} := d_{cv\_bolt_i} \cdot t_{cv\_con_i}$ Projected bearing area in.^{2} (mm^2)

$R_{n\_cv\_bs_i} := 1.8 \cdot F_{y\_cv} \cdot A_{pd\_cv_i}$ Nominal bearing strength

$\phi := 0.75$ Resistance factor

$\phi R_{n\_cv\_bs_i} := 2 \cdot \phi \cdot R_{n\_cv\_bs_i}$ Additional 2 incorporated to account for both legs of the support

$\phi R_{n\_cv\_bs}^T = (122.512)\ kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_cv\_con_i} := A_{cv\_con_i}$ Gross Area

(a) For tensile yielding in the gross section:

$P_{n\_cv\_con\_ty_i} := F_{y\_cv} \cdot A_{g\_cv\_con_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} = 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_cv\_con\_ty_i} := 2 \cdot \phi_{t\_ty} \cdot P_{n\_cv\_con\_ty_i}$ Additional 2 incorporated to account for both legs of the support

$\boxed{\phi P_{n\_cv\_con\_ty}{}^T = (178.2)\,kip}$ Design tensile strength

Shear, capacity of clevis's bolts [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$A_{bolt_i} := \pi \cdot \left(\frac{d_{cv\_bolt_i}}{2}\right)^2$ Nominal unthreaded body area

$A_{bolt\_ds_i} := 2 \cdot A_{bolt_i}$ Applicable area for this case since the bolt is in double shear

$F_{nv\_bolt} := 24ksi$ Nominal shear stress in bearing type connections (A307) [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment and includes an allowance for threads in the shear plane

$R_{nv\_bolt_i} := F_{nv\_bolt} \cdot A_{bolt\_ds_i}$ Nominal strength (R_n) (J3-1)

$\phi_{b\_sr} := 0.75$ Resistance factor

$\phi R_{nv\_bolt_i} := 2 \cdot \phi_{b\_sr} \cdot R_{nv\_bolt_i}$ Additional 2 incorporated to account for both legs of the support

$\boxed{\phi R_{nv\_bolt}{}^T = (106.912)\,kip}$ Design shear strength

LOWER ROD

Tension, capacity of rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$A_{b\_R_i} := \pi \cdot \left(\frac{d_{R_i}}{2}\right)^2$$ Nominal unthreaded body area

$$F_{nt\_R} := 45ksi$$ Nominal tensile stress (A307) [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment

$$R_{nt\_R_i} := F_{nt\_R} \cdot A_{b\_R_i}$$ Nominal strength (R_n) (J3-1)

$$\phi_{b\_tr} := 0.75$$ Resistance factor

$$\phi R_{nt\_R_i} := 2 \cdot \phi_{b\_tr} \cdot R_{nt\_R_i}$$ Additional 2 incorporated to account for both legs of the support

$$\boxed{\phi R_{nt\_R}^{T} = (82.835)\,kip}$$ Design tension strength

TURNBUCKLE

Tension, capacity of turnbuckle [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D2. Tensile Strength

D3. Area Determination

1. Gross Area

$$A_{g\_tb_i} := A_{tb_i}$$ Gross area

2. Net Area

$$A_{n\_tb_i} := A_{g\_tb_i}$$ Net area

3. Effective Net Area

$$U_{tb} := 1.0$$ Shear lag factor [8, Table D3.1 pg 16.1-29 (case 1)]

$$A_{e\_tb_i} := A_{n\_tb_i} \cdot U_{tb}$$ Effective net area (D3-1)

(a) For tensile yielding in the gross section:

$$P_{n\_tb\_ty_i} := F_{y\_tb} \cdot A_{g\_tb_i}$$ Nominal axial strength (P_n) (D2-1)

$$\phi_{t\_ty} := 0.9$$ Resistance factor for tension (ϕ_t)

$$\phi P_{n\_tb\_ty_i} := 2 \cdot \phi_{t\_ty} \cdot P_{n\_tb\_ty_i}$$ Additional 2 incorporated to account for both legs of the support

$$\boxed{\phi P_{n\_tb\_ty}^{T} = (104.414)\,kip}$$ Design tensile strength

(b) For tensile rupture in the net section:

$P_{n\_tb\_tr_i} := F_{u\_tb} \cdot A_{e\_tb_i}$ — Nominal axial strength (P_n) (D2-2)

$\phi_{t\_tr} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_tb\_tr_i} := 2 \cdot \phi_{t\_tr} \cdot P_{n\_tb\_tr_i}$ — Additional 2 incorporated to account for both legs of the support

$\phi P_{n\_tb\_tr}^{T} = (158.203)\,kip$ — Design tensile strength

UPPER EYE ROD

NOTE:It was observed during inspection that all of the applicable eye rods have welded eyes even though they indic otherwise on Drawing 120925, thus all eye rods in these calculations will be treated as welded eye rods

Tension, capacity of rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$A_{b\_I_i} := \pi \cdot \left(\frac{d_{I_i}}{2}\right)^2$ — Nominal unthreaded body area

$F_{nt\_I} := 45ksi$ — Nominal tensile stress (A307) [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment

$R_{nt\_I_i} := F_{nt\_I} \cdot A_{b\_I_i}$ — Nominal strength (R_n) (J3-1)

$\phi_{b\_tr} := 0.75$ — Resistance factor

$\phi R_{nt\_I_i} := 2 \cdot \phi_{b\_tr} \cdot R_{nt\_I_i}$ — Additional 2 incorporated to account for both legs of the support

$\phi R_{nt\_I}^{T} = (82.835)\,kip$ — Design tension strength

WELDED BEAM ATTACHMENT

Tension, capacity of welded beam attachment [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$b_i := 2\,t_{wba_i} + 0.63in$

$b^T = (3.13)\ in$

$b_{eff_i} := \min(b_i, a_{normal\_wba_i})$

$b_{eff}{}^T = (1.25)\ in$

b_{eff} is an effective length calculated as (2t + 0.63in) for which can not be larger than the actual distance fro the edge of the hole to the edge of the part measured in the direction normal to the applied force

$P_{n\_wba\_trp_i} := 2 \cdot t_{wba_i} \cdot b_{eff_i} \cdot F_{u\_wba}$ — Nominal axial strength (P_n) (D5-1)

$\phi_{n\_trp} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_wba\_trp_i} := 2 \cdot \phi_{n\_trp} \cdot P_{n\_wba\_trp_i}$ — Additional 2 incorporated to account for both legs of the support

$\boxed{\phi P_{n\_wba\_trp}{}^T = (281.25)\ kip}$ — Design tensile strength

(b) For shear rupture on the effective area:

$$A_{sf\_wba_i} := 2 \cdot t_{wba_i} \cdot \left(a_{parallel\_wba_i} + \frac{d_{wba\_bolt_i}}{2}\right)$$

$A_{sf\_wba}{}^T = (4.844)\ in^2$ — Effective area

$P_{n\_wba\_srp_i} := 0.6 \cdot F_{u\_wba} \cdot A_{sf\_wba_i}$ — Nominal axial strength (P_n) (D5-2)

$\phi_{n\_srp} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_wba\_srp_i} := 2 \cdot \phi_{n\_srp} \cdot P_{n\_wba\_srp_i}$ — Additional 2 incorporated to account for both legs of the support

$\boxed{\phi P_{n\_wba\_srp}{}^T = (261.563)\ kip}$ — Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_wba_i} := d_{wba\_bolt_i} \cdot t_{wba_i}$ — Projected bearing area in.^{2} (mm^2)

$R_{n\_wba\_bs_i} := 1.8 \cdot F_{y\_wba} \cdot A_{pd\_wba_i}$ — Nominal bearing strength (J7-1)

$\phi := 0.75$ — Resistance factor

$\phi R_{n\_wba\_bs_i} := 2 \cdot \phi \cdot R_{n\_wba\_bs_i}$ — Additional 2 incorporated to account for both legs of the support

$\boxed{\phi R_{n\_wba\_bs}{}^T = (153.141)\ kip}$ — Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_wba_i} := A_{wba_i}$ Gross area

(a) For tensile yielding in the gross section:

$P_{n\_wba\_ty_i} := F_{y\_wba} \cdot A_{g\_wba_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} = 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_wba\_ty_i} := 2 \cdot \phi_{t\_ty} \cdot P_{n\_wba\_ty_i}$ Additional 2 incorporated to account for both legs of the support

$\boxed{\phi P_{n\_wba\_ty}^{T} = (297)\ \text{kip}}$ Design tensile strength

Shear, capacity of welded beam attachment's bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$A_{wba\_bolt_i} := \pi \cdot \left(\frac{d_{wba\_bolt_i}}{2}\right)^2$ Nominal unthreaded body area

$A_{wba\_bolt\_ds_i} := 2 \cdot A_{wba\_bolt_i}$ Applicable area for this case since the bolt is in double shear

$F_{nv\_wba\_bolt} := 24\text{ksi}$ Nominal shear stress in bearing type connections (A307) [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment and includes an allowance for threads in the shear plane

$R_{nv\_wba\_bolt_i} := F_{nv\_wba\_bolt} \cdot A_{wba\_bolt\_ds_i}$ Nominal strength (R_n) (J3-1)

$\phi_{b\_sr} = 0.75$ Resistance factor

$\phi R_{nv\_wba\_bolt_i} := 2 \cdot \phi_{b\_sr} \cdot R_{nv\_wba\_bolt_i}$ Additional 2 incorporated to account for both legs of the support

$\boxed{\phi R_{nv\_wba\_bolt}^{T} = (106.912)\ \text{kip}}$ Design shear strength

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SUMMARY OF RESULTS

Capacities Due to Downward Loading

CRADLE PLATE

Tension, capacity of cradle plate [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_cp\_trp}^{T} = (287.55)\ kip$$ Design tensile strength

(b) For shear rupture on the effective area:

$$\phi P_{n\_cp\_srp}^{T} = (136.687)\ kip$$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\phi R_{n\_cp\_bs}^{T} = (91.884)\ kip$$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_cp\_ty}^{T} = (267.3)\ kip$$ Design tensile strength

CLEVIS

Tension, capacity of clevis' intermediate section [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_cv\_int\_ty}^{T} = (89.1)\ kip$$ Design tensile strength

(b) For tensile rupture in the net section:

$$\phi P_{n\_cv\_int\_tr}^{T} = (135)\ kip$$ Design tensile strength

Tension, capacity of clevis's pin connection [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_cv\_con\_trp}{}^{T} = (140.625)\ kip$$ Design tensile strength

(b) For shear rupture on the effective area:

$$\phi P_{n\_cv\_bolt\_srp}{}^{T} = (158.625)\ kip$$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\phi R_{n\_cv\_bs}{}^{T} = (122.512)\ kip$$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_cv\_con\_ty}{}^{T} = (178.2)\ kip$$ Design tensile strength

Shear, capacity of clevis's bolts [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$\phi R_{nv\_bolt}{}^{T} = (106.912)\ kip$$ Design shear strength

LOWER ROD

Tension, capacity of rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nt\_R}{}^{T} = (82.835)\ kip$$ Design tension strength

TURNBUCKLE

Tension, capacity of turnbuckle [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_tb\_ty}^{T} = (104.414)\ kip$ Design tensile strength

(b) For tensile rupture in the net section:

$\phi P_{n\_tb\_tr}^{T} = (158.203)\ kip$ Design tensile strength

UPPER EYE ROD

Tension, capacity of rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$\phi R_{nt\_I}^{T} = (82.835)\ kip$ Design tension strength

WELDED BEAM ATTACHMENT

Tension, capacity of welded beam attachment [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_wba\_trp}^{T} = (281.25)\ kip$ Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_wba\_srp}^{T} = (261.563)\ kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_wba\_bs}^{T} = (153.141)\ kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_wba\_ty}^{T} = (297)\ kip$ Design tensile strength

Shear, capacity of welded beam attachment's bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$\phi R_{nv\_wba\_bolt}^{T} = (106.912)\ \text{kip}$ Design shear strength

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Appendix B.10.9

Capacity of RH-26x Support

RH-26x CAPACITY

RH-26x is comprised of two dissimilar legs of a hanging support attached to a U shaped cradle plate supporting a 36" diameter pipe. One leg is attached to the cradle plate by a bolt that is connected through a clevis, the clevis is attached to a rod, the rod is connected to a turnbuckle, the turnbuckle is attached from above by an eye rod, the eye rod is attached to a welded beam attachment on the ceiling by means of a bolt. The other leg is attached to the cradle plate by a bolt that is connected through a clevis, the clevis is attached to a rod, the rod is connected to a turnbuckle, the turnbuckle is attached from above by an eye rod, the eye rod is connected to the center of two spanning parallel channel iron sections by a bolt, the spanning parallel channel iron sections are bolted to the threaded portion of two eye rods protruding from the top of the channel iron sections on either side of the 10" line 8-14, the eye rods are attached to the welded beam attachments on the ceiling by means of bolts. The capacities for these components are calculated below, however the capacity for the welds attaching the tab and the associated capacities of the ceiling embedment are found in the anchorage and embedment portions of [32, App E].

Component Capacity Overview:

- Downward Loading:

- Tension capacity of cradle plate
- Tension capacity of clevis's intermediate cross section
- Tension capacity of clevis's pin connection
- Shear capacity of clevis's pin
- Tension capacity of lower rod
- Tension capacity of turnbuckle
- Tension capacity of upper eye rod
- Tension capacity of welded beam attachment
- Shear capacity of welded beam attachment's bolt
- Flexure capacity of line 8-14 support channel iron sections
- Shear capacity of line 8-14 support channel iron sections
- Tension capacity of line 8-14 support eye rods
- Tension capacity of line 8-14 support welded beam attachment
- Shear capacity of line 8-14 support welded beam attachment bolt

(**Procedures from AISC 13th Edition (Applying LRFD)**)

References contained in Appendix B.11 of this Report

NOTE: The limiting capacity for each leg will be compared and the minimum one will be doubled to yield the capacity of the entire support.

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$i := 0$

Assigned indices corresponding to number of support types associated with these calculations

Support = 0
(RH-26x)

Relationship between support and corresponding indices

Geometric and Material Properties of Support Components

CRADLE PLATE (6" x 3/4" bar [21, Detail 26])

Material Properties of Cradle Plate as Defined in the Material Section of Report [32]:

$F_{y\_cp} := 33\text{ksi}$ Yield Strength for A7 Steel [52]

$F_{u\_cp} := 60\text{ksi}$ Ultimate Strength for A7 Steel [52]

$E_{cp} := 29000\text{ksi}$ Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Cradle Plate:

$$t_{cp} := \left(\frac{3}{4}\text{in}\right)^T$$

Thickness of plate forming the upper portions of the cradle plate [21, Detail 26]

$$w_{cp} := (6\text{in})^T$$

Width of plates forming the cradle plate [21, Detail 26]

$$A_{cp_i} := t_{cp_i} \cdot w_{cp_i}$$

$$A_{cp}^T = (4.5)\,\text{in}^2$$

Cross sectional area of one side of cradle plate

$$d_{cp\_bolt} := \left(1\frac{3}{8}\text{in}\right)^T$$

Bolt diameter [21, Detail 26]

$$d_{cp\_hole} := \left(1\frac{7}{16}\text{in}\right)^T$$

Nominal bolt hole Diameter [8, Table J3.3 pg 16.1-105]

$$a_{parallel\_cp} := (1\text{in})^T$$

Shortest distance from edge of the pin hole to the edge of the member measured parallel to the direction of the force from top of bolt hole to top of cradle plate bracket, in. (mm) estimated from photo dscn2934

$$a_{normal\_cp_i} := \frac{w_{cp_i} - d_{cp\_hole_i}}{2}$$

$$a_{normal\_cp}^T = (2.281)\,\text{in}$$

Shortest distance from edge of pin hole to the edge of the member measured normal to the direction of the force, in. (mm)

CLEVIS (Clevis FIG 299 1-1/4" [18, Sheet 2])

Material Properties of Clevis as Defined in the Material Section of Report [32]:

$F_{y\_cv} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{u\_cv} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E_{cv} := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Clevis:

The thickness of the intermediate portion of the clevis's present in this piping system was observed to be approximately the same thickness as that defined at the bolt hole connection as shown in photo dsc00034

$$t_{cv\_int} := \left[2 \cdot \left(\frac{1}{2}in\right)\right]^T$$

Combined thickness of intermediate portions of clevis [18, Fig 299 ph-56]

$$w_{cv\_int} := \left(1\frac{1}{2}in\right)^T$$

Width of intermediate portions of clevis [18, Fig 299 ph-56]

$$A_{cv\_int_i} := t_{cv\_int_i} \cdot w_{cv\_int_i}$$

$$A_{cv\_int}{}^T = (1.5)\,in^2$$

Intermediate cross sectional area of clevis [18, Fig 299 ph-56]

$$d_{cv\_bolt} := \left(1\frac{3}{8}in\right)^T$$

Diameter of clevis bolt [18, Fig 299 ph-56]

$$d_{cv\_hole} := \left(1\frac{7}{16}in\right)^T$$

Nominal bolt hole Diameter, in. (mm) [8, Table J3.3 pg 16.1-105]

$$t_{cv\_con} := \left[2 \cdot \left(\frac{1}{2}in\right)\right]^T$$

Combined thickness of plates forming clevis's bolt hole connection [18, Fig 299 ph-56]

$$w_{cv\_con} := (3in)^T$$

Width of clevis's bolt hole connection [18, Fig 299 ph-56]

$$A_{cv\_con_i} := t_{cv\_con_i} \cdot w_{cv\_con_i}$$

$$A_{cv\_con}{}^T = (3)\,in^2$$

Cross sectional area of clevis at the bolt connection

$$a_{parallel\_cv} := \left(\frac{25}{32}in\right)^T$$

Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force from bottom of bolt hole to bottom of cradle plate bracket, in. (mm) hand calculated from d_{cv_hole} and [18, Fig 299 ph-56] data.

$$a_{normal\_cv} := \left(\frac{25}{32}in\right)^T$$

Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force

LOWER ROD (Treaded Rod FIG 140 1-1/4" [18, Sheet 2])

Material Properties of Lower Rod as Defined in the Material Section of Report [32]:

$F_{yR} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{uR} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E_R := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Lower Rod:

$$d_R := \left(1\frac{1}{4}in\right)$$

Unthreaded diameter of rod [18], [18, Fig 140 ph-51]

$$Z_{R_i} := \frac{\left(d_{R_i}\right)^3}{6}$$

Plastic section modulus about the axis of bending [8, Table 17-27 pg17-39]

TURNBUCKLE (Turnbuckle FIG 230 1-1/4" [18, Sheet 2])

Material Properties of Turnbuckle as Defined in the Material Section of Report [32]:

$F_{y\_tb} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{u\_tb} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E_{tb} := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Turnbuckle:

The turnbuckle legs have a unique cross section, therefore for these calculations treat each leg as a rectangular cross section where the width of the turnbuckle legs were conservatively scaled to be 9/8 the diameter of the rod as scaled from photo dsc00080 and the thickness of the turnbuckle legs were scaled to be 1/2 the diameter of the corresponding rod diameter as scaled from photo dsc00079.

$$w_{tb_i} := \left(\frac{9}{8}\right) \cdot d_{R_i}$$

Width of turnbuckle [18, Fig 230 ph-57]

$$w_{tb}^T = (1.406)\ in$$

$$t_{tb_i} := \left(\frac{1}{2}\right) \cdot d_{R_i}$$

Thickness of turnbuckle [18, Fig 230 ph-57]

$$t_{tb}^T = (0.625)\ in$$

$$A_{tb_i} := 2 \cdot w_{tb_i} \cdot t_{tb_i}$$

Total area of turnbuckle cross section

$$A_{tb}^T = (1.758)\ in^2$$

UPPER EYE ROD (Welded Eye Rod FIG 278 1-1/4" [18, Sheet 2])

Material Properties of Upper Eye Rod as Defined in the Material Section of Report [32]:

$F_{yI} := 33\text{ksi}$ — Yield Strength for A7 Steel [52]

$F_{uI} := 60\text{ksi}$ — Ultimate Strength for A7 Steel [52]

$E_{UI} := 29000\text{ksi}$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Upper Eye Rod:

$d_I := \left(1\frac{1}{4}\text{in}\right)$ — Unthreaded diameter of eye rod [18, Fig 278 ph-52]

$Z_{I_i} := \frac{\left(d_{I_i}\right)^3}{6}$ — Plastic section modulus about the axis of bending [8, Table 17-27 pg17-39]

WELDED BEAM ATTACHMENT (Welded Beam Attachment FIG 66 1-1/4" Rod [18, Sheet 2])

Material Properties of Welded Beam Attachment as Defined in the Material Section of Report [32]:

$F_{y\_wba} := 33\text{ksi}$ — Yield Strength for A7 Steel [52]

$F_{u\_wba} := 60\text{ksi}$ — Ultimate Strength for A7 Steel [52]

$E\_wba := 29000\text{ksi}$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Welded Beam Attachment (Fig 66):

$t_{wba} := \left[2 \cdot \left(\frac{5}{8}\text{in}\right)\right]^T$ — Combined thickness of welded beam attachment [18, Fig 66 ph-33]

$w_{wba} := (4\text{in})^T$ — Width of welded beam attachment [18, Fig 66 ph-33]

$A_{wba_i} := t_{wba_i} \cdot w_{wba_i}$

$A_{wba} = (5)\,\text{in}^2$ — Cross sectional area of welded beam attachment

$d_{wba\_bolt} := \left(1\frac{3}{8}\text{in}\right)^T$ — Diameter of welded beam attachment bolt [18, Fig 66 ph-33]

$d_{wba\_hole} := \left(1\frac{1}{2}\text{in}\right)^T$ — Diameter of welded beam attachment bolt hole [18, Fig 66 ph-33]

$a_{parallel\_wba} := \left(1\frac{1}{4}\text{in}\right)^T$ — Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force from bottom of bolt hole to the bottom of the welded beam attachment, in. (mm) hand calculated from d_{wba_hole} and [18, Fig 66 ph-33] data

$$a_{normal\_wba_i} := \frac{w_{wba_i} - d_{wba\_hole_i}}{2}$$

$$a_{normal\_wba}^T = (1.25)\,in$$

Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force, in. (mm) [18, Fig 66 ph-33]

LINE 8-14 SUPPORT CHANNEL IRON SECTIONS (6" 10.5# Channel [21, Detail 26])

Material Properties of Line 8-14 Support Channel Iron Sections as Defined in the Material Section of Report [32]:

$F_{y\_SCh} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{u\_SCh} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E_{SCh} := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Support Channel Iron Section (6" x 10.5#):

$A_{SCh} := \left(3.08in^2\right)^T$ — Area of support channel iron section

$D_{SCh} := (6in)^T$ — Overall depth of channel iron section

$t_{SCh\_flange} := (0.343in)^T$ — Thickness of support channel iron section flange

$W_{SCh} := (2.03in)^T$ — Width of support channel iron section

$t_{SCh\_web} := (0.314in)^T$ — Thickness of support channel iron section web

$h_{SCh\_web} := \left(4\frac{3}{8}in\right)^T$ — Clear distance between flanges less the fillet or corner radius for rolled shapes [8 1958, pg 24]

$Z_{x\_SCh} := \left(2.22in^3\right)^T$ — Plastic section modulus about the x-axis

$r_{y\_SCh} := (0.529in)^T$ — Radius of gyration about the y-axis

$L_{b\_SCh} := (10in)^T$ — Length between points that are braced against lateral displacement of compression flange or braced against twist of the cross section.

LINE 8-14 SUPPORT EYE RODS (Welded Eye Rod FIG 278 1" [21, Detail 26])

Material Properties of Line 8-14 Support Eye Rods as Defined in the Material Section of Report [32]:

$F_{y\_SCh\_I} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{u\_SCh\_I} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E_{SCh\_I} := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Welded Beam Attachment (Fig 66):

$d_{SCh\_I} := (1in)$ — Unthreaded diameter of eye rod [18, Fig 278 ph-52]

$$Z_{SCh\_I_i} := \frac{\left(d_{SCh\_I_i}\right)^3}{6}$$

Plastic section modulus about the axis of bending [8, Table 17-27 pg17-39]

LINE 8-14 SUPPORT WELDED BEAM ATTACHMENTS (FIG 66 1" Rod [21, Detail 26])

Material Properties of Line 8-14 Support Welded Beam Attachments as Defined in the Material Section of Report [32]:

$F_{y\_SCh\_wba} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{u\_SCh\_wba} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E_{SCh\_wba} := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Line 8-14 Support Welded Beam Attachments (Fig 66):

$$t_{SCh\_wba} := \left[2 \cdot \left(\frac{1}{2}in\right)\right]^T$$

Combined thickness of welded beam attachment [18, Fig 66 ph-33]

$$w_{SCh\_wba} := (3in)^T$$

Width of welded beam attachment [18, Fig 66 ph-33]

$$A_{SCh\_wba_i} := t_{SCh\_wba_i} \cdot w_{SCh\_wba_i}$$

$$A_{SCh\_wba} = (3)\,in^2$$

Cross sectional area of welded beam attachment

$$d_{SCh\_wba\_bolt} := \left(1\frac{1}{8}in\right)^T$$

Diameter of welded beam attachment bolt [18, Fig 66 ph-33]

$$d_{SCh\_wba\_hole} := \left(1\frac{1}{4}in\right)^T$$

Diameter of welded beam attachment bolt hole [18, Fig 66 ph-33]

$$a_{normal\_SCh\_wba_i} := \frac{w_{SCh\_wba_i} - d_{SCh\_wba\_hole_i}}{2}$$

$$a_{normal\_SCh\_wba}^T = (0.875)\,in$$

Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force [18, Fig 66 ph-33]

$$a_{parallel\_SCh\_wba} := \left(\frac{7}{8} in\right)^T$$

Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force from bottom of bolt hole to the bottom of the welded beam attachment, hand calculated from d_{wba_hole} and [18, Fig 66 ph-33] data

Capacities Due to Downward Loading

CRADLE PLATE

Tension, capacity of cradle plate (each side) [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$b_{cp_i} := 2\, t_{cp_i} + 0.63in$$

$$b_{cp}^T = (2.13)\ in$$

$$b_{eff\_cp_i} := \min\left(b_{cp_i}, a_{normal\_cp_i}\right)$$

$$b_{eff\_cp}^T = (2.13)\ in$$

b_{eff} is an effective length calculated as (2t + 0.63in) for which can not be larger than the actual distance fro the edge of the hole to the edge of the part measured in the direction normal to the applied force

$$P_{n\_cp\_trp_i} := 2 \cdot t_{cp_i} \cdot b_{eff\_cp_i} \cdot F_{u\_cp}$$

Nominal axial strength (P_n) (D5-1)

$$\phi_{n\_trp} := 0.75$$

Resistance factor for tension (ϕ_t)

$$\phi P_{n\_cp\_trp_i} := \phi_{n\_trp} \cdot P_{n\_cp\_trp_i}$$

$$\boxed{\phi P_{n\_cp\_trp}^T = (143.775)\ kip}$$

Design tensile strength

(b) For shear rupture on the effective area:

$$A_{sf\_cp_i} := 2 \cdot t_{cp_i} \cdot \left(a_{parallel\_cp_i} + \frac{d_{cp\_bolt_i}}{2}\right)$$

$$A_{sf\_cp}^T = (2.531)\ in^2$$

Effective area

$$P_{n\_cp\_srp_i} := 0.6 \cdot F_{u\_cp} \cdot A_{sf\_cp_i}$$

Nominal axial strength (P_n) (D5-2)

$$\phi_{n\_srp} := 0.75$$

Resistance factor for tension (ϕ_t)

$\phi P_{n\_cp\_srp_i} := \phi_{n\_srp} \cdot P_{n\_cp\_srp_i}$

$\phi P_{n\_cp\_srp}{}^{T} = (68.344)\ kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_cp_i} := d_{cp\_bolt_i} \cdot t_{cp_i}$ Projected bearing area in.^{2} (mm^2)

$R_{n\_cp\_bs_i} := 1.8 \cdot F_{y\_cp} \cdot A_{pd\_cp_i}$ Nominal bearing strength (J7-1)

$\phi := 0.75$ Resistance factor

$\phi R_{n\_cp\_bs_i} := \phi \cdot R_{n\_cp\_bs_i}$

$\phi R_{n\_cp\_bs}{}^{T} = (45.942)\ kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_cp_i} := A_{cp_i}$ Gross area

(a) For tensile yielding in the gross section:

$P_{n\_cp\_ty_i} := F_{y\_cp} \cdot A_{g\_cp_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_cp\_ty_i} := \phi_{t\_ty} \cdot P_{n\_cp\_ty_i}$

$\phi P_{n\_cp\_ty}{}^{T} = (133.65)\ kip$ Design tensile strength

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CLEVIS

Tension, capacity of clevis' intermediate section [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D2. Tensile Strength

D3. Area Determination

1. Gross Area

$A_{g\_cv\_int_i} := A_{cv\_int_i}$ — Gross Area

2. Net Area

$A_{n\_cv\_int_i} := A_{g\_cv\_int_i}$ — Net Area

3. Effective Net Area

$U_{cv\_int} := 1.0$ — Shear lag factor [8, Table D3.1 pg 16.1-29 (case 1)]

$A_{e\_cv\_int_i} := A_{n\_cv\_int_i} \cdot U_{cv\_int}$ — Effective Net Area (D3-1)

(a) For tensile yielding in the gross section:

$P_{n\_cv\_int\_ty_i} := F_{y\_cv} \cdot A_{g\_cv\_int_i}$ — Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} = 0.9$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_cv\_int\_ty_i} := \phi_{t\_ty} \cdot P_{n\_cv\_int\_ty_i}$

$\boxed{\phi P_{n\_cv\_int\_ty}^{T} = (44.55)\ kip}$ — Design tensile strength

(b) For tensile rupture in the net section:

$P_{n\_cv\_int\_tr_i} := F_{u\_cv} \cdot A_{e\_cv\_int_i}$ — Nominal axial strength (P_n) (D2-2)

$\phi_{t\_tr} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_cv\_int\_tr_i} := \phi_{t\_tr} \cdot P_{n\_cv\_int\_tr_i}$

$\boxed{\phi P_{n\_cv\_int\_tr}^{T} = (67.5)\ kip}$ — Design tensile strength

Tension, capacity of clevis's pin connection [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$b_{cv_i} := 2\, t_{cv\_con_i} + 0.63in$

$b_{cv}^T = (2.63)\ in$

b_{eff} is an effective length calculated as (2t + 0.63in) for which can not be larger than the actual distance fro the edge of the hole to the edge of the part measured in the direction normal to the applied force

$b_{eff\_cv_i} := \min\left(b_{cv_i}, a_{normal\_cv_i}\right)$

$b_{eff\_cv}^T = (0.781)\ in$

$P_{n\_cv\_con\_trp_i} := 2 \cdot t_{cv\_con_i} \cdot b_{eff\_cv_i} \cdot F_{u\_cv}$ Nominal axial strength (P_n) (D5-1)

$\phi_{n\_trp} = 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_cv\_con\_trp_i} := \phi_{n\_trp} \cdot P_{n\_cv\_con\_trp_i}$

$\boxed{\phi P_{n\_cv\_con\_trp}^T = (70.313)\ kip}$ Design tensile strength

(b) For shear rupture on the effective area:

$A_{sf\_cv\_bolt_i} := 2 \cdot t_{cv\_con_i} \cdot \left(a_{parallel\_cv_i} + \frac{d_{cv\_bolt_i}}{2}\right)$

$A_{sf\_cv\_bolt}^T = (2.938)\ in^2$ Effective Area

$P_{n\_cv\_bolt\_srp_i} := 0.6 \cdot F_{u\_cv} \cdot A_{sf\_cv\_bolt_i}$ Nominal axial strength (P_n) (D5-2)

$\phi_{n\_srp} = 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_cv\_bolt\_srp_i} := \phi_{n\_srp} \cdot P_{n\_cv\_bolt\_srp_i}$

$\boxed{\phi P_{n\_cv\_bolt\_srp}^T = (79.312)\ kip}$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_cv_i} := d_{cv\_bolt_i} \cdot t_{cv\_con_i}$ Projected bearing area in.^{2} (mm^2)

$R_{n\_cv\_bs_i} := 1.8 \cdot F_{y\_cv} \cdot A_{pd\_cv_i}$ Nominal bearing strength

$\phi := 0.75$ Resistance factor

$\phi R_{n\_cv\_bs_i} := \phi \cdot R_{n\_cv\_bs_i}$

$\boxed{\phi R_{n\_cv\_bs}^T = (61.256)\ kip}$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_cv\_con_i} := A_{cv\_con_i}$ Gross Area

(a) For tensile yielding in the gross section:

$P_{n\_cv\_con\_ty_i} := F_{y\_cv} \cdot A_{g\_cv\_con_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} = 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_cv\_con\_ty_i} := \phi_{t\_ty} \cdot P_{n\_cv\_con\_ty_i}$

$\boxed{\phi P_{n\_cv\_con\_ty}^{T} = (89.1)\ \text{kip}}$ Design tensile strength

Shear, capacity of clevis's bolts [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$A_{bolt_i} := \pi \cdot \left(\frac{d_{cv\_bolt_i}}{2}\right)^2$ Nominal unthreaded body area

$A_{bolt\_ds_i} := 2 \cdot A_{bolt_i}$ Applicable area for this case since the bolt is in double shear

$F_{nv\_bolt} := 24\text{ksi}$ Nominal shear stress in bearing type connections (A307) [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment and includes an allowance for threads in the shear plane

$R_{nv\_bolt_i} := F_{nv\_bolt} \cdot A_{bolt\_ds_i}$ Nominal strength (R_n) (J3-1)

$\phi_{b\_sr} := 0.75$ Resistance factor

$\phi R_{nv\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_bolt_i}$

$\boxed{\phi R_{nv\_bolt}^{T} = (53.456)\ \text{kip}}$ Design shear strength

LOWER ROD

Tension, capacity of rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$A_{b\_R_i} := \pi \cdot \left(\frac{d_{R_i}}{2}\right)^2$$ Nominal unthreaded body area

$$F_{nt\_R} := 45\text{ksi}$$ Nominal tensile stress (A307) [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment

$$R_{nt\_R_i} := F_{nt\_R} \cdot A_{b\_R_i}$$ Nominal strength (R_n) (J3-1)

$$\phi_{b\_tr} := 0.75$$ Resistance factor

$$\phi R_{nt\_R_i} := \phi_{b\_tr} \cdot R_{nt\_R_i}$$

$$\phi R_{nt\_R}^{\ T} = (41.417)\ \text{kip}$$ Design tension strength

TURNBUCKLE

Tension, capacity of turnbuckle [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D2. Tensile Strength

D3. Area Determination

1. Gross Area

$$A_{g\_tb_i} := A_{tb_i}$$ Gross area

2. Net Area

$$A_{n\_tb_i} := A_{g\_tb_i}$$ Net area

3. Effective Net Area

$$U_{tb} := 1.0$$ Shear lag factor [8, Table D3.1 pg 16.1-29 (case 1)]

$$A_{e\_tb_i} := A_{n\_tb_i} \cdot U_{tb}$$ Effective net area (D3-1)

(a) For tensile yielding in the gross section:

$$P_{n\_tb\_ty_i} := F_{y\_tb} \cdot A_{g\_tb_i}$$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_tb\_ty_i} := \phi_{t\_ty} \cdot P_{n\_tb\_ty_i}$

$\phi P_{n\_tb\_ty}{}^T = (52.207)\,kip$ Design tensile strength

(b) For tensile rupture in the net section:

$P_{n\_tb\_tr_i} := F_{u\_tb} \cdot A_{e\_tb_i}$ Nominal axial strength (P_n) (D2-2)

$\phi_{t\_tr} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_tb\_tr_i} := \phi_{t\_tr} \cdot P_{n\_tb\_tr_i}$

$\phi P_{n\_tb\_tr}{}^T = (79.102)\,kip$ Design tensile strength

UPPER EYE ROD

NOTE:It was observed during inspection that all of the applicable eye rods have welded eyes even though they indicate otherwise on Drawing 120925, thus all eye rods in these calculations will be treated as welded eye rods

Tension, capacity of rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$A_{b\_I_i} := \pi \cdot \left(\frac{d_{I_i}}{2}\right)^2$ Nominal unthreaded body area

$F_{nt\_I} := 45ksi$ Nominal tensile stress (A307) [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment

$R_{nt\_I_i} := F_{nt\_I} \cdot A_{b\_I_i}$ Nominal strength (R_n) (J3-1)

$\phi_{b\_tr} := 0.75$ Resistance factor

$\phi R_{nt\_I_i} := \phi_{b\_tr} \cdot R_{nt\_I_i}$

$\phi R_{nt\_I}{}^T = (41.417)\,kip$ Design tension strength

WELDED BEAM ATTACHMENT

Tension, capacity of welded beam attachment [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

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Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$b_i := 2\, t_{wba_i} + 0.63in$

$b^T = (3.13)\ in$

$b_{eff_i} := \min\left(b_i, a_{normal\_wba_i}\right)$

$b_{eff}^T = (1.25)\ in$

b_{eff} is an effective length calculated as (2t + 0.63in) for which can not be larger than the actual distance fro the edge of the hole to the edge of the part measured in the direction normal to the applied force

$P_{n\_wba\_trp_i} := 2 \cdot t_{wba_i} \cdot b_{eff_i} \cdot F_{u\_wba}$ Nominal axial strength (P_n) (D5-1)

$\phi_{n\_trp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_wba\_trp_i} := \phi_{n\_trp} \cdot P_{n\_wba\_trp_i}$

$\boxed{\phi P_{n\_wba\_trp}^T = (140.625)\ kip}$ Design tensile strength

(b) For shear rupture on the effective area:

$A_{sf\_wba_i} := 2 \cdot t_{wba_i} \cdot \left(a_{parallel\_wba_i} + \frac{d_{wba\_bolt_i}}{2}\right)$

$A_{sf\_wba}^T = (4.844)\ in^2$ Effective area

$P_{n\_wba\_srp_i} := 0.6 \cdot F_{u\_wba} \cdot A_{sf\_wba_i}$ Nominal axial strength (P_n) (D5-2)

$\phi_{n\_srp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_wba\_srp_i} := \phi_{n\_srp} \cdot P_{n\_wba\_srp_i}$

$\boxed{\phi P_{n\_wba\_srp}^T = (130.781)\ kip}$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_wba_i} := d_{wba\_bolt_i} \cdot t_{wba_i}$ Projected bearing area in.^{2} (mm^2)

$R_{n\_wba\_bs_i} := 1.8 \cdot F_{y\_wba} \cdot A_{pd\_wba_i}$ Nominal bearing strength (J7-1)

$\phi := 0.75$ Resistance factor

$\phi R_{n\_wba\_bs_i} := \phi \cdot R_{n\_wba\_bs_i}$

$\boxed{\phi R_{n\_wba\_bs}^T = (76.57)\ kip}$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_wba_i} := A_{wba_i}$ Gross area

(a) For tensile yielding in the gross section:

$P_{n\_wba\_ty_i} := F_{y\_wba} \cdot A_{g\_wba_i}$ Nominal axial strength (P_n)

(D2-1)

$\phi_{t\_ty} = 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_wba\_ty_i} := \phi_{t\_ty} \cdot P_{n\_wba\_ty_i}$

$\phi P_{n\_wba\_ty}{}^T = (148.5)\ \text{kip}$ Design tensile strength

Shear, capacity of welded beam attachment's bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$A_{wba\_bolt_i} := \pi \cdot \left(\frac{d_{wba\_bolt_i}}{2}\right)^2$ Nominal unthreaded body area

$A_{wba\_bolt\_ds_i} := 2 \cdot A_{wba\_bolt_i}$ Applicable area for this case since the bolt is in double shear

$F_{nv\_wba\_bolt} := 24\text{ksi}$ Nominal shear stress in bearing type connections (A307) [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment and includes an allowance for threads in the shear plane

$R_{nv\_wba\_bolt_i} := F_{nv\_wba\_bolt} \cdot A_{wba\_bolt\_ds_i}$ Nominal strength (R_n)

(J3-1)

$\phi_{b\_sr} = 0.75$ Resistance factor

$\phi R_{nv\_wba\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_wba\_bolt_i}$

$\phi R_{nv\_wba\_bolt}{}^T = (53.456)\ \text{kip}$ Design shear strength

LINE 8-14 SUPPORT CHANNEL IRON SECTIONS (6" 10.5# Channel [21, Detail 26])

Flexure,capacity of line 8-14 support channel iron sections [8, Ch. F pg16.1-44 thru 63]

F1. General Provisions

Given resistance factor for shear

$$\phi_b := 0.9$$

Calculate the lateral-torsional buckling modification factor for a nonuniform moment loading on the beam caused by downward loading of the pipe

$$M_{max}(F, Length) := F \cdot Length$$

Absolute value of maximum moment in the unbraced segment

$$M_A(F, Length) := \frac{3}{4} \cdot F \cdot Length$$

Absolute value of moment at quarter point of the unbraced segment

$$M_B(F, Length) := \frac{1}{2} \cdot F \cdot Length$$

Absolute value of moment at centerline of the unbraced segment

$$M_C(F, Length) := \frac{1}{4} \cdot F \cdot Length$$

Absolute value of moment at three-quarter point of the unbraced segment

$$R_m := 1.0$$

Cross-section monosymmetry parameter (value of 1.0 is assigned because it correlates to singly symmetric members subjected to single curvature bending)

$$C_b(F, Length) := \left(\frac{12.5 \cdot M_{max}(F, Length)}{2.5 \cdot M_{max}(F, Length) + 3 \cdot M_A(F, Length) + 4 \cdot M_B(F, Length) + 3 \cdot M_C(F, Length)} \cdot R_m\right)$$

$$C_b\left(F, L_{IB_i}\right) \rightarrow 1.6666666666666666667$$

F2. Doubly Symmetric Compact I-Shaped Members and Channels Bent About Their Major Axis

It must first be verified if section is compact for F2 to be applied

Determine if supports are ***compact (1), non-compact (2),*** *or* ***slender (3)***

B4. Classification of sections for local buckling (See Case 1 of Table B4.1)

$$b_{tB4p1_i} := \frac{W_{SCh}}{2}$$

Applicable width as applied to Width/ Thickness ratio of [8, Table B4.1 pg16.1-16]

$$t_{TB4p1_i} := t_{SCh\_flange}$$

Applicable thickness as applied to Width/ Thickness ratio of [8, Table B4.1 pg16.1-16]

$$b2t_i := \frac{b_{tB4p1_i}}{t_{TB4p1_i}}$$

Width to thickness ratio

$$b2t^T = (2.959)$$

Definition of λ_p and λ_r from Table B4.1 Case 1 (Flexure in flanges of rolled I-shaped sections and channels) to be applied in classification logic. λ_p is the separation point between a compact and noncompact member. λ_r is separation point between a noncompact and slender member.

$$\lambda_p := 0.38 \cdot \sqrt{\frac{E_{SCh}}{F_{y\_SCh}}} \qquad \lambda_r := 1.0 \cdot \sqrt{\frac{E_{SCh}}{F_{y\_SCh}}}$$

$$Classification_i := \begin{vmatrix} 1 \text{ if } b2t_i \le \lambda_p \\ 2 \text{ if } \lambda_p < b2t_i \le \lambda_r \\ 3 \text{ if } \lambda_r < b2t_i \end{vmatrix}$$

$$Classification^T = (1)$$

Since it has been verified that the I-Beam member is compact F2 is applicable

1. Yielding

$$M_p := F_{y\_SCh} \cdot Z_{x\_SCh}$$

$$M_{ny} := M_p$$

$$M_{ny}^T = (73.26)\ kip \cdot in$$

Nominal flexural strength (F2-1)

$$\phi M_{ny\_EW} := \phi_b \cdot M_{ny}$$

$$\phi M_{ny\_EW}^T = (65.934)\ kip \cdot in$$

Design flexural strength

$$\phi F_{ny\_EW\_Tot_i} := 2\left[2\left(\frac{\phi M_{ny\_EW_i}}{\frac{L_{b\_SCh_i}}{2}}\right)\right]$$

Converting flexural strength to strength at applied load by dividing the design flexural strength by the moment arm comprised of half the I-Beam length (the two additional factors of 2 are included to account for both partial sections and both spans)

$$\boxed{\phi F_{ny\_EW\_Tot}^T = (52.747)\ kip}$$

Total design strength of channel iron section given flexural loading

2. Lateral-Torsional Buckling

(a) When $L_b < L_p$, the limit state of lateral-torsional buckling does not apply

$$L_{b_i} := L_{b\_SCh_i}$$

Length between points that are either braced against lateral displacement of compression flange or braced against twist of the cross section

$L_{p_i} := 1.76 \cdot r_{y\_SCh_i} \cdot \sqrt{\dfrac{E_{SCh}}{F_{y\_SCh}}}$ Limit laterally unbraced length for the limit state of yielding

$L_b^T = (10)\ in$ $L_p^T = (27.6)\ in$

Since $L_b \le L_p$ the limit state of lateral-torsional buckling does not apply

Shear, capacity of line 8-14 support channel iron sections [8, Ch. G pg 16.1-64 thru 69]

G1. General Provisions

$\phi_v := 0.9$ Resistance factor for shear

G2. Members with Unstiffened or Stiffened Webs

1. Nominal Shear Strength

(a) For webs of rolled I-shaped members with $h/t_w < 2.24*(E/F_y)$^0.5

$t_{w_i} := t_{SCh\_web_i}$

$h_i := h_{SCh\_web_i}$

$h2t_i := \dfrac{h_{SCh\_web_i}}{t_{SCh\_web_i}}$

Ratio between thickness of web to the uniform web height to simplify below calculations

$\dfrac{h_i}{t_{w_i}} = 13.933$ $2.24 \cdot \sqrt{\dfrac{E_{SCh}}{F_{y\_SCh}}} = 66.403$

Since the condition $h/t_w < 2.24*(E/F_y)$^0.5 applies the following definitions apply

$\phi_v := 1.00$ Modified resistance factor for shear

$C_v := (1)^T$ Web shear coefficient

Apply previously defined variables to (G2-1)

$A_{w_i} := 2 \cdot D_{SCh_i} \cdot t_{SCh\_web_i}$ The overall depth times the web thickness, dt_w (a factor of 2 is included to account for double shear)

$V_{n\_SCh_i} := 0.6 \cdot F_{y\_SCh} \cdot A_{w_i} \cdot C_{v_i}$ Nominal shear strength

$\phi V_{n\_SCh_i} := 2 \cdot \phi_v \cdot V_{n\_SCh_i}$ Additional 2 incorporated to account for eye rods connected to either side of line 8-14 PCS pipe

$\phi V_{n\_SCh}^T = (149.213)\ kip$ Design shear strength

LINE 8-14 SUPPORT EYE RODS (Welded Eye Rod FIG 278 1" [21, Detail 26])

NOTE:It was observed during inspection that all of the applicable eye rods have welded eyes even though they indicate otherwise on Drawing 120925, thus all eye rods in these calculations will be treated as welded eye rods

Tension, capacity of line 8-14 support eye rods [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$A_{b\_I\_SCh_i} := \pi \cdot \left(\frac{d_{SCh\_I_i}}{2}\right)^2$$

Nominal unthreaded body area

$$F_{nt\_I\_SCh} := 45ksi$$

Nominal tensile stress (A307) [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment

$$R_{nt\_I\_SCh_i} := F_{nt\_I\_SCh} \cdot A_{b\_I\_SCh_i}$$

Nominal strength (R_n) (J3-1)

$$\phi_{b\_tr} := 0.75$$

Resistance factor

$$\phi R_{nt\_I\_SCh_i} := 2 \cdot \phi_{b\_tr} \cdot R_{nt\_I\_SCh_i}$$

Additional 2 incorporated to account for eye rods connected to either side of line 8-14 PCS pipe

$$\phi R_{nt\_I\_SCh}^{T} = (53.014)\,kip$$

Design tension strength

LINE 8-14 SUPPORT WELDED BEAM ATTACHMENTS (FIG 66 1" Rod [21, Detail 26])

Tension, capacity of line 8-14 support welded beam attachments [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$b_{SCh_i} := 2\,t_{SCh\_wba_i} + 0.63in$$

$$b_{SCh}^{T} = (2.63)\,in$$

$$b_{eff\_SCh_i} := \min\left(b_i, a_{normal\_SCh\_wba_i}\right)$$

$$b_{eff\_SCh}^{T} = (0.875)\,in$$

b_{eff} is an effective length calculated as (2t + 0.63in) for which can not be larger than the actual distance fro the edge of the hole to the edge of the part measured in the direction normal to the applied force

$$P_{n\_SCh\_wba\_trp_i} := 2 \cdot t_{SCh\_wba_i} \cdot b_{eff_i} \cdot F_{u\_SCh\_wba}$$

Nominal axial strength (P_n) (D5-1)

$$\phi_{n\_trp} := 0.75$$

Resistance factor for tension (ϕ_t)

$\phi P_{n\_SCh\_wba\_trp_i} := 2 \cdot \phi_{n\_trp} \cdot P_{n\_SCh\_wba\_trp_i}$ Additional 2 incorporated to account for eye rods connected to either side of line 8-14 PCS pipe

$\phi P_{n\_SCh\_wba\_trp}{}^T = (225)\ kip$ Design tensile strength

(b) For shear rupture on the effective area:

$$A_{sf\_SCh\_wba_i} := 2 \cdot t_{wba_i} \cdot \left(a_{parallel\_SCh\_wba_i} + \frac{d_{SCh\_wba\_bolt_i}}{2} \right)$$

$A_{sf\_SCh\_wba}{}^T = (3.594)\ in^2$ Effective area

$P_{n\_SCh\_wba\_srp_i} := 0.6 \cdot F_{u\_SCh\_wba} \cdot A_{sf\_SCh\_wba_i}$ Nominal axial strength (P_n) (D5-2)

$\phi_{n\_srp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_SCh\_wba\_srp_i} := 2 \cdot \phi_{n\_srp} \cdot P_{n\_SCh\_wba\_srp_i}$ Additional 2 incorporated to account for eye rods connected to either side of line 8-14 pipe

$\phi P_{n\_SCh\_wba\_srp}{}^T = (194.062)\ kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_SCh\_wba_i} := d_{SCh\_wba\_bolt_i} \cdot t_{SCh\_wba_i}$ Projected bearing area

$R_{n\_SCh\_wba\_bs_i} := 1.8 \cdot F_{y\_SCh\_wba} \cdot A_{pd\_SCh\_wba_i}$ Nominal bearing strength (J7-1)

$\phi := 0.75$ Resistance factor

$\phi R_{n\_SCh\_wba\_bs_i} := 2 \cdot \phi \cdot R_{n\_SCh\_wba\_bs_i}$ Additional 2 incorporated to account for eye rods connected to either side of line 8-14 pipe

$\phi R_{n\_SCh\_wba\_bs}{}^T = (100.238)\ kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_SCh\_wba_i} := A_{SCh\_wba_i}$ Gross area

(a) For tensile yielding in the gross section:

$P_{n\_SCh\_wba\_ty_i} := F_{y\_SCh\_wba} \cdot A_{g\_SCh\_wba_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} = 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_SCh\_wba\_ty_i} := 2 \cdot \phi_{t\_ty} \cdot P_{n\_SCh\_wba\_ty_i}$ Additional 2 incorporated to account for eye rods connected to either side of line 8-14 pipe

$\phi P_{n\_SCh\_wba\_ty}{}^T = (178.2)\ kip$ Design tensile strength

Shear,capacity of line 8-14 support welded beam attachment bolts [8, Ch. J pg 16.1-90thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$A_{SCh\_wba\_bolt_i} := \pi \cdot \left(\frac{d_{SCh\_wba\_bolt_i}}{2}\right)^2$ Nominal unthreaded body area

$A_{SCh\_wba\_bolt\_ds_i} := 2 \cdot A_{SCh\_wba\_bolt_i}$ Applicable area for this case since the bolt is in double shear

$F_{nv\_SCh\_wba\_bolt} := 24ksi$ Nominal shear stress in bearing type connections (A307) [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment and includes an allowance for threads in the shear plane

$R_{nv\_SCh\_wba\_bolt_i} := F_{nv\_SCh\_wba\_bolt} \cdot A_{SCh\_wba\_bolt\_ds_i}$ Nominal strength (R_n) (J3-1)

$\phi_{b\_sr} = 0.75$ Resistance factor

$\phi R_{nv\_SCh\_wba\_bolt_i} := 2 \cdot \phi_{b\_sr} \cdot R_{nv\_SCh\_wba\_bolt_i}$ Additional 2 incorporated to account for eye rods connected to either side of line 8-14 PCS pipe

$\phi R_{nv\_SCh\_wba\_bolt}{}^T = (71.569)\ kip$ Design shear strength

SUMMARY RESULTS FOR EACH LEG

Capacities of West Leg Due to Downward Loading

CRADLE PLATE

Tension, capacity of cradle plate [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_cp\_trp}{}^{T} = (143.775)\ kip$ — Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_cp\_srp}{}^{T} = (68.344)\ kip$ — Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_cp\_bs}{}^{T} = (45.942)\ kip$ — Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_cp\_ty}{}^{T} = (133.65)\ kip$ — Design tensile strength

CLEVIS

Tension, capacity of clevis' intermediate section [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_cv\_int\_ty}{}^{T} = (44.55)\ kip$ — Design tensile strength

(b) For tensile rupture in the net section:

$\phi P_{n\_cv\_int\_tr}{}^{T} = (67.5)\ kip$ — Design tensile strength

Tension, capacity of clevis's pin connection [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_cv\_con\_trp}{}^{T} = (70.313)\,kip$ Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_cv\_bolt\_srp}{}^{T} = (79.312)\,kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_cv\_bs}{}^{T} = (61.256)\,kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_cv\_con\_ty}{}^{T} = (89.1)\,kip$ Design tensile strength

Shear, capacity of clevis's bolts [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$\phi R_{nv\_bolt}{}^{T} = (53.456)\,kip$ Design shear strength

LOWER ROD

Tension, capacity of rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$\phi R_{nt\_R}{}^{T} = (41.417)\,kip$ Design tension strength

TURNBUCKLE

Tension, capacity of turnbuckle [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_tb\_ty}{}^{T} = (52.207)\,kip$ Design tensile strength

(b) For tensile rupture in the net section:

$\phi P_{n\_tb\_tr}^{T} = (79.102)\ kip$ Design tensile strength

UPPER EYE ROD

Tension, capacity of rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$\phi R_{nt\_I}^{T} = (41.417)\ kip$ Design tension strength

WELDED BEAM ATTACHMENT

Tension, capacity of welded beam attachment [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_wba\_trp}^{T} = (140.625)\ kip$ Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_wba\_srp}^{T} = (130.781)\ kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_wba\_bs}^{T} = (76.57)\ kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_wba\_ty}^{T} = (148.5)\ kip$ Design tensile strength

Shear, capacity of welded beam attachment's bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$\phi R_{nv\_wba\_bolt}^{T} = (53.456)\ kip$ Design shear strength

Capacities of East Leg Due to Downward Loading

CRADLE PLATE

Tension, capacity of cradle plate [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_cp\_trp}^{T} = (143.775)\ kip$ Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_cp\_srp}^{T} = (68.344)\ kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_cp\_bs}^{T} = (45.942)\ kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_cp\_ty}^{T} = (133.65)\ kip$ Design tensile strength

CLEVIS

Tension, capacity of clevis' intermediate section [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_cv\_int\_ty}^{T} = (44.55)\ kip$ Design tensile strength

(b) For tensile rupture in the net section:

$\phi P_{n\_cv\_int\_tr}^{T} = (67.5)\ kip$ Design tensile strength

Tension, capacity of clevis's pin connection [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_cv\_con\_trp}^{T} = (70.313)\ kip$$ Design tensile strength

(b) For shear rupture on the effective area:

$$\phi P_{n\_cv\_bolt\_srp}^{T} = (79.312)\ kip$$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\phi R_{n\_cv\_bs}^{T} = (61.256)\ kip$$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_cv\_con\_ty}^{T} = (89.1)\ kip$$ Design tensile strength

Shear, capacity of clevis's bolts [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$\phi R_{nv\_bolt}^{T} = (53.456)\ kip$$ Design shear strength

LOWER ROD

Tension, capacity of rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nt\_R}^{T} = (41.417)\ kip$$ Design tension strength

TURNBUCKLE

Tension, capacity of turnbuckle [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_tb\_ty}^{T} = (52.207)\ kip$$ Design tensile strength

(b) For tensile rupture in the net section:

$\phi P_{n\_tb\_tr}^{T} = (79.102)\ kip$ — Design tensile strength

UPPER EYE ROD

Tension, capacity of rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$\phi R_{nt\_I}^{T} = (41.417)\ kip$ — Design tension strength

LINE 8-14 SUPPORT CHANNEL IRON SECTIONS (6" 10.5# Channel [21, Detail 26])

Flexure,capacity of line 8-14 support channel iron sections [8, Ch. F pg16.1-44 thru 63]

F1. General Provisions

F2. Doubly Symmetric Compact I-Shaped Members and Channels Bent About Their Major Axis

1. Yielding

$\phi F_{ny\_EW\_Tot}^{T} = (52.747)\ kip$ — Total design strength of channel iron section given flexural loading

2. Lateral-Torsional Buckling

(a) When $L_b < L_p$, the limit state of lateral-torsional buckling does not apply

Since $L_b \le L_p$ the limit state of lateral-torsional buckling does not apply

Shear, capacity of line 8-14 support channel iron sections [8, Ch. G pg 16.1-64 thru 69]

G1. General Provisions

G2. Members with Unstiffened or Stiffened Webs

1. Nominal Shear Strength

(a) For webs of rolled I-shaped members with $h/t_w < 2.24*(E/F_y)$^0.5

$\phi V_{n\_SCh}^{T} = (149.213)\ kip$ — Design shear strength

LINE 8-14 SUPPORT EYE RODS (Welded Eye Rod FIG 278 1" [21, Detail 26])

Tension, capacity of line 8-14 support eye rods [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$\phi R_{nt\_I\_SCh}^{T} = (53.014)\ kip$ — Design tension strength

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LINE 8-14 SUPPORT WELDED BEAM ATTACHMENTS (FIG 66 1" Rod [21, Detail 26])

Tension, capacity of line 8-14 support welded beam attachments [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_SCh\_wba\_trp}{}^{T} = (225)\ kip$$ Design tensile strength

(b) For shear rupture on the effective area:

$$\phi P_{n\_SCh\_wba\_srp}{}^{T} = (194.062)\ kip$$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\phi R_{n\_SCh\_wba\_bs}{}^{T} = (100.238)\ kip$$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

D3. Area Determination

1. Gross Area

(a) For tensile yielding in the gross section:

$$\phi P_{n\_SCh\_wba\_ty}{}^{T} = (178.2)\ kip$$ Design tensile strength

Shear,capacity of line 8-14 support welded beam attachment bolts [8, Ch. J pg 16.1-90thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$\phi R_{nv\_SCh\_wba\_bolt}{}^{T} = (71.569)\ kip$$ Design shear strength

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SUMMARY AND COMBINATION OF RESULTS

Capacities of West Leg Due to Downward Loading

LOWER ROD

Tension, capacity of rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nt\_R}{}^{T} = (41.417)\,kip$$

Design tension strength

UPPER EYE ROD

Tension, capacity of rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nt\_I}{}^{T} = (41.417)\,kip$$

Design tension strength

Capacities of East Leg Due to Downward Loading

LOWER ROD

Tension, capacity of rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nt\_R}{}^{T} = (41.417)\,kip$$

Design tension strength

UPPER EYE ROD

Tension, capacity of rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nt\_I}{}^{T} = (41.417)\,kip$$

Design tension strength

LINE 8-14 SUPPORT CHANNEL IRON SECTIONS (6" 10.5# Channel [21, Detail 26])

Flexure,capacity of line 8-14 support channel iron sections [8, Ch. F pg16.1-44 thru 63]

F1. General Provisions

F2. Doubly Symmetric Compact I-Shaped Members and Channels Bent About Their Major Axis

1. Yielding

$$\phi F_{ny\_EW\_Tot}{}^{T} = (52.747)\,kip$$

Total design strength of channel iron section given flexural loading

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Capacities Due to Downward Loading for Lines 1-27 and 8-14

Note: The capacities for line 1-27 and line 8-14 assume that the load is not shared between the two and the associated gang hanger properties should be considered when applying these capacities.

$$Line_{127} := 2 \cdot \phi R_{nt\_I}^{T}$$

$$Line_{127} = (82.835)\ kip$$

$$Line_{814} := \left(\phi F_{ny\_EW\_Tot}^{T}\right)$$

$$Line_{814} = (52.747)\ kip$$

Appendix B.10.10

Capacity of RH-24 Support

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RH-24 CAPACITY

The RH-24 supports hang from the ceiling to support a horizontal PCS pipe on line 1-49 traveling in the north/south direction. The RH-33 supports are composed of a 4" adjustable clevis, a 5/8" rod attached to the top of the adjustable clevis, and a welded beam attachment welded to the ceiling embedment. The capacities for these components are calculated below, however, the capacity for the welds attaching the welded beam attachment and the associated capacities of the ceiling embedment are found in the anchorage and embedment portions of [32, App E].

Photo [M3-1-47-N49-CSUG-DSCN2775]

Component Capacity Overview:

- Downward Loading:
- Tension capacity of lower adjustable clevis pin connection
- Tension capacity of upper adjustable clevis pin connection
- Shear capacity of adjustable clevis bolt
- Tension capacity of rod
- Tension capacity of welded beam attachment

(**Procedures from AISC 13th Edition (LRFD) [8]**)

References for following calculations are contained in App B.11

Note: There are two RH-24 in Model 3 that differ from that defined in [3] and information from the above photo was used for the following calculations.

$i := 0$ — Assigned indices corresponding to number of support types associated with these calculations

Support =	0
	(RH-33)

Relationship between support and corresponding indices

Geometric and Material Properties of Support Components

ADJUSTABLE CLEVIS (Clevis FIG 260 6")

Material Properties of Adjustable Clevis as Defined in the Material Section of Report [32]:

$F_{y\_acv} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{u\_acv} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E_{acv} := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Adjustable Clevis:

$$t_{acv\_up} := \left[2\cdot\left(\frac{1}{4}in\right)\right]^T$$

Combined thickness of upper portions of adjustable clevis [18, Fig 260]

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$w_{acv\_up} := \left(1\frac{1}{2}in\right)^T$ — Width of upper portions of adjustable clevis [18, Fig 260]

$A_{acv\_up_i} := t_{acv\_up_i} \cdot w_{acv\_up_i}$ — Cross sectional area of upper portion of adjustable clevis [22, Fig 260]

$A_{acv\_up}{}^T = (0.75)\,in^2$

$t_{acv\_low} := \left[2 \cdot \left(\frac{3}{16}in\right)\right]^T$ — Combined thickness of lower portions of adjustable clevis [22, Fig 260]

$w_{acv\_low} := \left(1\frac{1}{2}in\right)^T$ — Width of lower portions of adjustable clevis [22, Fig 260]

$A_{acv\_low_i} := t_{acv\_low_i} \cdot w_{acv\_low_i}$ — Cross sectional area of lower portion of adjustable clevis [22, Fig 260]

$A_{acv\_low}{}^T = (0.562)\,in^2$

$d_{acv\_bolt} := \left(\frac{1}{2}in\right)^T$ — Diameter of adjustable clevis bolt [22, Fig 260]

$d_{acv\_hole} := \left(\frac{9}{16}in\right)^T$ — Nominal bolt hole Diameter, in. (mm) [8, Table J3.3]

$a_{parrallel\_acv\_up} := d_{acv\_bolt}$ — Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force, in. (mm) relation estimated from photo DSCN2683

$a_{normal\_acv\_up_i} := \frac{w_{acv\_up_i} - d_{acv\_hole_i}}{2}$ — Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force

$a_{parrallel\_acv\_low} := d_{acv\_bolt}$ — Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force, in. (mm) relation estimated from photo DSCN2683

$a_{normal\_acv\_low_i} := \frac{w_{acv\_low_i} - d_{acv\_hole_i}}{2}$ — Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force

ROD (Rod FIG 140 1/2")

Material Properties of Rod as Defined in the Material Section of Report [32]:

$F_{y\_rod} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{u\_rod} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E_{rod} := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Rod:

$$d_R := \left(\frac{5}{8}in\right)^T$$

Unthreaded diameter of eye rod[18]

$$Z_{R_i} := \frac{\left(d_{R_i}\right)^3}{6}$$

Plastic section modulus about the axis of bending, in.^{3} [8, Table 17-27 pg17-39]

WELDED BEAM ATTACHMENT

Material Properties of Welded Beam Attachment as Defined in the Material Section of Report [32]:

$F_{y\_wba} := 33ksi$ — Yield Strength for A7 Steel [52]

$F_{u\_wba} := 60ksi$ — Ultimate Strength for A7 Steel [52]

$E\_wba := 29000ksi$ — Modulus of Elasticity for A7 Steel [52]

Geometric Properties of Welded Beam Attachment:

$$t_{wba} := \left[2\cdot\left(\frac{5}{8}in\right)\right]^T$$

Combined thickness of welded beam attachment [22, Fig 66 ph-33]

$$w_{wba} := (4in)^T$$

Width of welded beam attachment [22, Fig 66 ph-33]

$$A_{wba_i} := t_{wba_i}\cdot w_{wba_i}$$

$$A_{wba} = (5)\,in^2$$

Cross sectional area of welded beam attachment

$$d_{wba\_bolt} := \left(1\frac{3}{8}in\right)^T$$

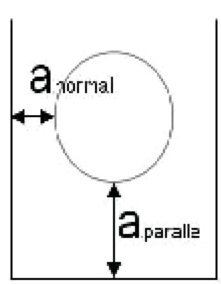
Diameter of welded beam attachment bolt [22, Fig 66 ph-33]

$$d_{wba\_hole} := \left(1\frac{1}{2}in\right)^T$$

Diameter of welded beam attachment bolt hole [22, Fig 66 ph-33], [8, Table J3.3 pg 16.1-105]

$$a_{parrallel\_wba} := \left(1\frac{1}{4}in\right)^T$$

Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force from bottom of bolt hole to the bottom of the welded beam attachment, in. (mm) hand calculated from d_{wba_hole} and [22, Fig 66 ph-33] data



$$a_{normal\_wba_i} := \frac{w_{wba_i} - d_{wba\_hole_i}}{2}$$

$$a_{normal\_wba}{}^T = (1.25)\,in$$

Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force, in. (mm) [22, Fig 66 ph-33]

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Capacities Resulting From Downward Loading

ADJUSTABLE CLEVIS

Tension, capacity of upper adjustable clevis's pin connection [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$b_{acv\_up_i} := 2\,t_{acv\_up_i} + 0.63in$$

$$b_{acv\_up}^{\,T} = (1.63)\,in$$

$$b_{eff\_acv\_up_i} := \min\left(b_{acv\_up_i}, a_{normal\_acv\_up_i}\right)$$

$$b_{eff\_acv\_up}^{\,T} = (0.469)\,in$$

b_{eff} is an effective length calculated as (2t + 0.63in) for which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$$P_{n\_acv\_up\_trp_i} := 2\cdot t_{acv\_up_i}\cdot b_{eff\_acv\_up_i}\cdot F_{u\_acv}$$

Nominal axial strength (P_n) (D5-1)

$$\phi_{n\_trp} := 0.75$$

Resistance factor for tension (ϕ_t)

$$\phi P_{n\_acv\_up\_trp_i} := \phi_{n\_trp}\cdot P_{n\_acv\_up\_trp_i}$$

$$\boxed{\phi P_{n\_acv\_up\_trp}^{\,T} = (21.094)\,kip}$$

Design tensile strength

(b) For shear rupture on the effective area:

$$A_{sf\_acv\_up\_bolt_i} := 2\cdot t_{acv\_up_i}\cdot\left(a_{parrallel\_acv\_up_i} + \frac{d_{acv\_bolt_i}}{2}\right)$$

$$A_{sf\_acv\_up\_bolt}^{\,T} = (0.75)\,in^2$$

Effective Area

$$P_{n\_acv\_up\_bolt\_srp_i} := 0.6\cdot F_{u\_acv}\cdot A_{sf\_acv\_up\_bolt_i}$$

Nominal axial strength (P_n) (D5-2)

$$\phi_{n\_srp} := 0.75$$

Resistance factor for tension (ϕ_t)

$$\phi P_{n\_acv\_up\_bolt\_srp_i} := \phi_{n\_srp}\cdot P_{n\_acv\_up\_bolt\_srp_i}$$

$$\boxed{\phi P_{n\_acv\_up\_bolt\_srp}^{\,T} = (20.25)\,kip}$$

Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_acv\_up_i} := d_{acv\_bolt_i} \cdot t_{acv\_up_i}$ Projected bearing area in.^{2} (mm^2)

$R_{n\_acv\_up\_bs_i} := 1.8 \cdot F_{y\_acv} \cdot A_{pd\_acv\_up_i}$ Nominal bearing strength

$\phi := 0.75$ Resistance factor

$\phi R_{n\_acv\_up\_bs_i} := \phi \cdot R_{n\_acv\_up\_bs_i}$

$\phi R_{n\_acv\_up\_bs}{}^T = (11.138)\ kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_acv\_up_i} := A_{acv\_up_i}$ Gross Area

(a) For tensile yielding in the gross section:

$P_{n\_acv\_up\_ty_i} := F_{y\_acv} \cdot A_{g\_acv\_up_i}$ Nominal axial strength (P_n)

(D2-1)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_acv\_up\_ty_i} := \phi_{t\_ty} \cdot P_{n\_acv\_up\_ty_i}$

$\phi P_{n\_acv\_up\_ty}{}^T = (22.275)\ kip$ Design tensile strength

Tension, capacity of lower adjustable clevis's pin connection [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$b_{acv\_low_i} := 2\,t_{acv\_low_i} + 0.63in$

$b_{acv\_low}{}^T = (1.38)\ in$

$$b_{eff\_acv\_low_i} := \min\left(b_{acv\_low_i}, a_{normal\_acv\_low_i}\right)$$

$$b_{eff\_acv\_low}^T = (0.469)\ in$$

b_{eff} is an effective length calculated as (2t + 0.63in) for which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$$P_{n\_acv\_low\_trp_i} := 2 \cdot t_{acv\_low_i} \cdot b_{eff\_acv\_low_i} \cdot F_{u\_acv}$$

Nominal axial strength (P_n) (D5-1)

$$\phi_{n\_trp} := 0.75$$

Resistance factor for tension (ϕ_t)

$$\phi P_{n\_acv\_low\_trp_i} := \phi_{n\_trp} \cdot P_{n\_acv\_low\_trp_i}$$

$$\boxed{\phi P_{n\_acv\_low\_trp}^T = (15.82)\ kip}$$

Design tensile strength

(b) For shear rupture on the effective area:

$$A_{sf\_acv\_low\_bolt_i} := 2 \cdot t_{acv\_low_i} \cdot \left(a_{parrallel\_acv\_low_i} + \frac{d_{acv\_bolt_i}}{2}\right)$$

$$A_{sf\_acv\_low\_bolt}^T = (0.562)\ in^2$$

Effective Area

$$P_{n\_acv\_low\_bolt\_srp_i} := 0.6 \cdot F_{u\_acv} \cdot A_{sf\_acv\_low\_bolt_i}$$

Nominal axial strength (P_n) (D5-2)

$$\phi_{n\_srp} := 0.75$$

Resistance factor for tension (ϕ_t)

$$\phi P_{n\_acv\_low\_bolt\_srp_i} := \phi_{n\_srp} \cdot P_{n\_acv\_low\_bolt\_srp_i}$$

$$\boxed{\phi P_{n\_acv\_low\_bolt\_srp}^T = (15.187)\ kip}$$

Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$A_{pd\_acv\_low_i} := d_{acv\_bolt_i} \cdot t_{acv\_low_i}$$

Projected bearing area in.^{2} (mm^2)

$$R_{n\_acv\_low\_bs_i} := 1.8 \cdot F_{y\_acv} \cdot A_{pd\_acv\_low_i}$$

Nominal bearing strength

$$\phi := 0.75$$

Resistance factor

$$\phi R_{n\_acv\_low\_bs_i} := \phi \cdot R_{n\_acv\_low\_bs_i}$$

$$\boxed{\phi R_{n\_acv\_low\_bs}^T = (8.353)\ kip}$$

Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_acv\_low_i} := A_{acv\_low_i}$ — Gross Area

(a) For tensile yielding in the gross section:

$P_{n\_acv\_low\_ty_i} := F_{y\_acv} \cdot A_{g\_acv\_low_i}$ — Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_acv\_low\_ty_i} := \phi_{t\_ty} \cdot P_{n\_acv\_low\_ty_i}$

$\phi P_{n\_acv\_low\_ty}^{T} = (16.706)\,kip$ — Design tensile strength

Shear, capacity of adjustable clevis's pin [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$A_{acv\_bolt_i} := \pi \cdot \left(\frac{d_{acv\_bolt_i}}{2}\right)^2$ — Nominal unthreaded body area

$A_{acv\_bolt\_ds_i} := 2 \cdot A_{acv\_bolt_i}$ — Applicable area for this case since the bolt is in double shear

$F_{nv\_bolt} := 24ksi$ — Nominal Shear Stress in Bearing Type Connections (A307) [8, Table J3.2]

$R_{nv\_acv\_bolt_i} := F_{nv\_bolt} \cdot A_{acv\_bolt\_ds_i}$ — Nominal strength (R_n) (J3-1)

$\phi_{b\_sr} := 0.75$ — Resistance factor

$\phi R_{nv\_acv\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_acv\_bolt_i}$

$\phi R_{nv\_acv\_bolt}^{T} = (7.069)\,kip$ — Design shear strength

ROD

Tension, capacity of rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$A_{b\_R_i} := \pi \cdot \left(\frac{d_{R_i}}{2}\right)^2$ — Nominal unthreaded body area

$F_{nt\_R} := 45\text{ksi}$ — Nominal tensile stress (A307) [8, Table J3.2]

$R_{nt\_R_i} := F_{nt\_R} \cdot A_{b\_R_i}$ — Nominal strength (R_n) (J3-1)

$\phi_{b\_tr} := 0.75$ — Resistance factor

$\phi R_{nt\_R_i} := \phi_{b\_tr} \cdot R_{nt\_R_i}$

$\boxed{\phi R_{nt\_R}^{T} = (10.354)\,\text{kip}}$ — Design tension strength

WELDED BEAM ATTACHMENT

Tension, capacity of welded beam attachment [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$b_i := 2\,t_{wba_i} + 0.63\text{in}$

$b^T = (3.13)\,\text{in}$

$b_{eff_i} := \min\left(b_i, a_{normal\_wba_i}\right)$

$b_{eff}^{T} = (1.25)\,\text{in}$

b_{eff} is an effective length calculated as (2t + 0.63in) which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$P_{n\_wba\_trp_i} := 2 \cdot t_{wba_i} \cdot b_{eff_i} \cdot F_{u\_wba}$ — Nominal axial strength (P_n) (D5-1)

$\phi_{n\_trp} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_wba\_trp_i} := \phi_{n\_trp} \cdot P_{n\_wba\_trp_i}$

$\boxed{\phi P_{n\_wba\_trp}^{T} = (140.625)\,\text{kip}}$ — Design tensile strength

(b) For shear rupture on the effective area:

$$A_{sf\_wba_i} := 2 \cdot t_{wba_i} \cdot \left(a_{parrallel\_wba_i} + \frac{d_{wba\_bolt_i}}{2} \right)$$

$$A_{sf\_wba}^{T} = (4.844)\ in^2$$ Effective area

$$P_{n\_wba\_srp_i} := 0.6 \cdot F_{u\_wba} \cdot A_{sf\_wba_i}$$ Nominal axial strength (P_n) (D5-2)

$$\phi_{n\_srp} := 0.75$$ Resistance factor for tension (ϕ_t)

$$\phi P_{n\_wba\_srp_i} := \phi_{n\_srp} \cdot P_{n\_wba\_srp_i}$$

$$\boxed{\phi P_{n\_wba\_srp}^{T} = (130.781)\ kip}$$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$A_{pd\_wba_i} := d_{wba\_bolt_i} \cdot t_{wba_i}$$ Projected bearing area in.^{2} (mm^2)

$$R_{n\_wba\_bs_i} := 1.8 \cdot F_{y\_wba} \cdot A_{pd\_wba_i}$$ Nominal bearing strength (J7-1)

$$\phi := 0.75$$ Resistance factor

$$\phi R_{n\_wba\_bs_i} := \phi \cdot R_{n\_wba\_bs_i}$$

$$\boxed{\phi R_{n\_wba\_bs}^{T} = (76.57)\ kip}$$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$$A_{g\_wba_i} := A_{wba_i}$$ Gross area

(a) For tensile yielding in the gross section:

$$P_{n\_wba\_ty_i} := F_{y\_wba} \cdot A_{g\_wba_i}$$ Nominal axial strength (P_n) (D2-1)

$$\phi_{t\_ty} = 0.9$$ Resistance factor for tension (ϕ_t)

$$\phi P_{n\_wba\_ty_i} := \phi_{t\_ty} \cdot P_{n\_wba\_ty_i}$$

$$\boxed{\phi P_{n\_wba\_ty}^{T} = (148.5)\ kip}$$ Design tensile strength

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Summary of Results

ADJUSTABLE CLEVIS

Tension, capacity of upper adjustable clevis's pin connection [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_acv\_up\_trp}{}^{T} = (21.094)\ kip$ Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_acv\_up\_bolt\_srp}{}^{T} = (20.25)\ kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_acv\_up\_bs}{}^{T} = (11.138)\ kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_acv\_up\_ty}{}^{T} = (22.275)\ kip$ Design tensile strength

Tension, capacity of lower adjustable clevis's pin connection [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_acv\_low\_trp}{}^{T} = (15.82)\ kip$ Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_acv\_low\_bolt\_srp}{}^{T} = (15.187)\ kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_acv\_low\_bs}{}^{T} = (8.353)\ kip$ Design bearing strength

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(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_acv\_low\_ty}{}^{T} = (16.706)\ kip$ Design tensile strength

Shear, capacity of adjustable clevis's pin [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$\phi R_{nv\_acv\_bolt}{}^{T} = (7.069)\ kip$ Design shear strength

ROD

Tension, capacity of rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$\phi R_{nt\_R}{}^{T} = (10.354)\ kip$ Design tension strength

WELDED BEAM ATTACHMENT

Tension, capacity of welded beam attachment [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_wba\_trp}{}^{T} = (140.625)\ kip$ Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_wba\_srp}{}^{T} = (130.781)\ kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_wba\_bs}{}^{T} = (76.57)\ kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

D3. Area Determination

1. Gross Area

(a) For tensile yielding in the gross section:

$\phi P_{n\_wba\_ty}{}^{T} = (\,148.5\,)\,\text{kip}$ Design tensile strength

Appendix B.10.11

Anchorage Refinements for MS-5, MS-7, MS-8, PS-21, and PR-8

The purpose of this section is to perform analysis refinement of select anchorage capacities, previously determined in a previous analysis [32, Appendix E7].

From previous capacity anlaysis [32, Appendix E7]:

Common Weld parameters

$Fy_{cs} := 33 \cdot ksi$ $\quad Fu_{cs} := 60 \cdot ksi$ Minimum yield and tensile strengths of ASTM A7 [33] carbon steel, used to evaluate support and anchorage structures.

$F_{exx} := 60 \cdot ksi$ E6010 & E6011 weld filler electrode ultimate strength [34]

$Fy_{a36} := 36 \cdot ksi$ Minimum material yield and tensile strengths of ASTM A36 [35] carbon steel, used to evaluate some anchorage structures.

$Fu_{a36} := 58 \cdot ksi$

$\phi_{fw} := 0.75$ Fillet weld resistance factor [8, Table J2.5]

$F_w = 0.6 \cdot F_{exx} \cdot \left(1.0 + 0.5 \cdot \sin(\theta)^{1.5}\right)$ Nominal strength of the weld metal [8, eqn J2-5]

For => $\theta := 0 \cdot deg$

$F_{wl} := \left[0.6 \cdot F_{exx} \cdot \left(1.0 + 0.5 \cdot \sin(\theta)^{1.5}\right)\right]$ $\quad F_{wl} = 36\,ksi$ Nominal strength for longitudinal loaded fillet welds

For => $\theta := 90 \cdot deg$

$F_{wt} := \left[0.6 \cdot F_{exx} \cdot \left(1.0 + 0.5 \cdot \sin(\theta)^{1.5}\right)\right]$ $\quad F_{wt} = 54\,ksi$ Nominal strength for transversely loaded fillet welds

$Rt_w := \dfrac{F_{wt}}{F_{wl}}$ $\quad Rt_w = 1.5$ Strength capacity ratio of transverse to longitudinal welds

As indicated above, transverse welds provide 50% strength capacity increase over that of longitudinal welds.

Note - If there are combinations of longitudinal and transverse segments within the same weld pattern, Rwl (longitudinal nominal strength) will be used to determine corresponding weld capacities. Also, if the weld is loaded in differing orthogonal directions, Rwl is used to determine weld capacities.

$A_w := \dfrac{\sqrt{2}}{2} \cdot \dfrac{1}{16} \cdot in^2$ $\quad A_w = 0.044\,in^2$ Area of 1/16-in fillet per inch of weld

Let => $Rn_w := F_{wl} \cdot A_w$ $Rn_w = 1.591\ kip$ Nominal strength of weld [8, eqn J2-4] to be used for longitudinal and mixed weld patterns.

$Vn_w := \phi_{fw} \cdot Rn_w$ $Vn_w = 1.19\ kip$ Nominal shear strength of longitudinal & mixed fillet per 1/16-in of weld per inch [8, Table J2.5]

$Vnt_w := Rt_w \cdot Vn_w$ $Vnt_w = 1.79\ kip$ Nominal shear strength of transverse fillet per 1/16-in of weld per inch [8, Table J2.5]

Steel Plate Embed parameters

$w_{emb} := 4 \cdot in$ $t_{emb} := 0.5 \cdot in$ Width and thickness of steel plate embed [21, det. 25] that anchorage welds are attached to.

When the load acts in same direction as the axis of the weld, the base metal (or steel plate embed) capacity must also be considered to determine which condition is limiting.

$\phi F_{cs} := 0.9 \cdot 0.6 \cdot Fy_{cs}$ $\phi F_{cs} = 17.82\ ksi$ Nominal shear strength of steel plate embed (or base material) [38, p. 345].

$Rn_{emb} := w_{emb} \cdot t_{emb} \cdot \phi F_{cs}$ Nominal shear strength of steel plate embed along width [38, eqn 7.23].

$Rn_{emb} = 35.64\ kip$

When the resultant load acts in differing directions (i.e., out of plane) to the weld axis, the steel plate embed anchorage governs the design strength capacity of weld. All weld resultant loads are SRSS using methods as defined by Blodgett [39, p. 7.4-7].

$\phi t_{emb} := 11.25 \cdot kip$ $\phi s_{emb} := 12.188 \cdot kip$ Design pull-out strength of steel plate embed's anchor in tension and shear, obtained from Appendix C.

$Lemb_{anc} := 1 \cdot ft$ Anchor spacing along steel plate embed

$n\phi t_{emb} := 9.38 \cdot kip$

$n\phi s_{emb} := 12.188 \cdot kip$

Design axial and shear capacity for a group of steel plate embed anchors remote from edges, obtained from Appendix C. The "n" corresponds to the number of anchors overlapped.

Common Bolted Anchor parameters

$f_c := 3000 \cdot psi$ ATR concrete strength [40, note 1]

Nominal allowable pullout and shear capacities for Phillip Red Head self-drill shell expansion anchors and minimum spacing between anchors [36, Tables 6.3-1 & 6.3-5], are shown following. The numbers 3, 4, ... 7, correspond to the anchor diameter based on 1/8th inch. For example, P3 = 3/8 diameter, P4 = 4/8 diameter, and so on.

$P3_{rh} := 1.46 \cdot kip$	$V3_{rh} := 1.42 \cdot kip$	$R3_s := 3.75 \cdot in$	3/8 diameter
$P4_{rh} := 2.29 \cdot kip$	$V4_{rh} := 2.38 \cdot kip$	$R4_s := 5 \cdot in$	1/2 diameter
$P5_{rh} := 3.17 \cdot kip$	$V5_{rh} := 3.79 \cdot kip$	$R3_s := 6.25 \cdot in$	5/8 diameter
$P6_{rh} := 4.69 \cdot kip$	$V6_{rh} := 5.48 \cdot kip$	$R6_s := 7.5 \cdot in$	3/4 diameter
$P7_{rh} := 6.09 \cdot kip$	$V7_{rh} := 7.70 \cdot kip$	$R7_s := 8.75 \cdot in$	7/8 diameter

$RF_p := \dfrac{f_c}{4000 \cdot psi}$ $RF_p = 0.75$ Pull-out reduction factor for low concrete strength [36, Sect. 6.3.6.1]

$RF_s := \dfrac{\frac{f_c}{psi}}{10000} + 0.65$ $RF_s = 0.95$ Shear factor for reduced strength concrete [36, Section 6.3.6.1]

$RFp_{rh} := \dfrac{f_c}{3500 \cdot psi}$ $RFp_{rh} = 0.857$ Concrete pull-out reduction factor [36, Sect. 6.3.6.1] adapted for manufacturer's ultimate strength capacities based on 3,500-psi concrete strength.

$P6u_{rh} := \dfrac{16.2 \cdot kip}{3}$ $P6u_{rh} = 5.4\,kip$

$V6u_{rh} := \dfrac{16.2 \cdot kip}{3}$ $V6u_{rh} = 5.4\,kip$

Allowable tension and shear capacity of 3/4-in S-34 shell anchors [41], used commonly with mechanical snubber support anchorage.

All other reduction factors (minimum embedment, edge, concrete cracking, relay, & inspection) equate to 1.0. Appendix B contains inspection notes indicating that the anchors adhere to and meet DOE/EH-0545 [36] inspection criteria.

If anchor type or style is known (or identified in drawings), the manufacturer's allowable pull-out and shear strength capacities are computed based on corresponding ultimate tensile and shear strengths divided by a factor of three [42, p. 2-20]. Many of the support anchor bolts have been quality inspected for tightness and bolt length in accordance with DOE/EH-0545 criteria [36] and are reprinted in Appendix B.

Common Anchor Structure parameters

$\phi_t := 0.75$ Resistance factor for tensile rupture [8, Sect. D2]

$\phi_{sf} := 0.75$ Resistance factor for shear rupture [8, Sect. D5]

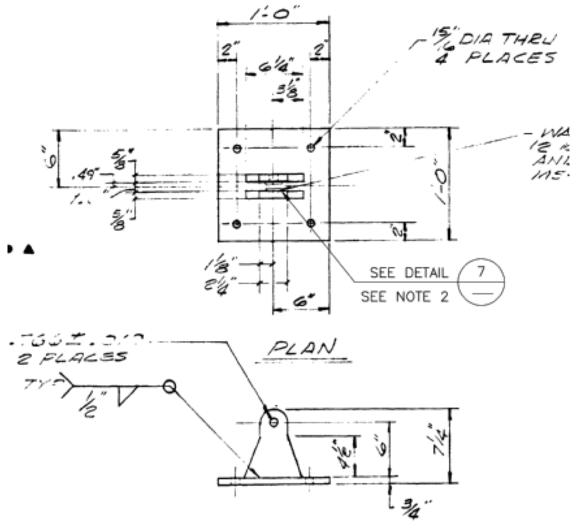
$\phi := 0.75$ Resistance factor for bearing [8, Sect. J7]

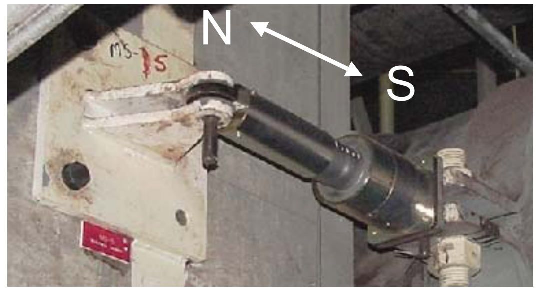
$\phi_b := 0.9$ Resistance factor for flexure [8, Sect. F1]

MS-5, (Type 7), -7, -8 (Type 13) Anchorage

Supports MS-5, MS-7, and MS-8, are horizontal mechanical snubbers that are bolted through a clevis structure [37] on the side of three concrete columns. The snubbers are rated for 6-kips [43, PSA-3], each. The clevis structure is anchored with two Phillips Redhead 3/4-in bolts and two weld segments (to a steel plate embed). The snubbers are loaded in the N-S direction. The anchor bolts and welds are evaluated independently in shear, provided that sufficient pull-out capacity (in weld or bolts) exists for each load scenario.

MS-5





$db_{ms5} := \frac{3}{4} \cdot in$ Anchor bolt diameter

$t_{s\_ms5} := \frac{1}{4} \cdot in$ Weld filler size of structure attachment to steel plate embed

Determine pull-out and shear capacities of anchor bolts:

$$P_{all} = P_{nom} \cdot RT_p \cdot RL_p \cdot RS_p \cdot RE_p \cdot RF_p \cdot RC_p \cdot RR_p \cdot RI_p$$

Where: P_{all} = Allowable Pullout capacity of installed anchor (kip)

P_{nom} = Nominal allowable Pullout capacity (kip)

RT_p = Reduction factor for the Type of expansion anchor

RL_p = Reduction factor for short embedment Lengths

RS_p = Reduction factor for closely Spaced anchors

RE_p = Reduction factor for near Edge anchors

RF_p = Reduction factor for low strength concrete

RC_p = Reduction factor for Cracked concrete

RR_p = Red. factor for anchors securing equip. with essential Relays

RI_p = Reduction factor for reduced Inspection procedure

$Ls_{ms5} := 12 \cdot in - 2 \cdot (2 \cdot in)$ $Ls_{ms5} = 8\ in$ Bolt spacing [37]

$\frac{Ls_{ms5}}{10 \cdot db_{ms5}} = 1.067$ < $\frac{Ls_{ms5}}{2 \cdot db_{ms5}} = 5.333$ Spacing reduction factor [36, Sect. 6.3.4.1]

=> $RSp_{ms5} := 1.0$ $RSs_{ms5} := 1.0$

$Pall_{ms5} := P6u_{rh} \cdot RFp_{rh} \cdot (1)$ $Pall_{ms5} = 4.629\ kip$ Maximum allowable pull-out capacity of 3/4 S-34 anchor

Maximum shear capacity of anchor bolts are determined, using DOE/EH-0545 [36, Section 6.3].

$$V_{all} = V_{nom} \cdot RT_s \cdot RL_s \cdot RS_s \cdot RE_s \cdot RF_s \cdot RR_s \cdot RI_s$$

where:

V_{all} allowable shear capacity of installed anchor (kip)

V_{nom} nominal allowable shear capacity (kip)

RT_s reduction factor the the type of expansion anchor

RL_s reduction factor the short embedment lengths

RS_s reduction factor for closely spaced anchors

RE_s reduction factor for near edge anchors

RF_s reduction factor for low strength concrete

RR_s reduction factor for expansion anchors securing equipment with essential relays

RI_s reduced factor for reduced inspection procedure

$Vall_{ms5} := V6u_{rh} \cdot RF_s \cdot (1)$ $Vall_{ms5} = 5.13\ kip$ Maximum allowable shear capacity of 3/4 S-34 anchor

$Ptb_{ms5} := 2 \cdot Pall_{ms5}$ $Ptb_{ms5} = 9.257\ kip$ Maximum pull-out & shear capacity of 2 x anchor bolts due to clevis structure loaded in North direction

$Vsb_{ms5} := 2 \cdot Vall_{ms5}$ $Vsb_{ms5} = 10.3\ kip$

Determine MS-5 weld shear and pull-out (tension) capacities:

Consider shear loading:

$$Vnw_{ms5} := Vn_w \cdot t_{s\_ms5} \cdot \left(\frac{16}{in}\right) \cdot \frac{2 \cdot w_{emb}}{in}$$

Maximum design shear strength capacity of MS-5 longitudinal weld loaded in shear

$$Vnw_{ms5} = 38.18\ kip$$

$$Vntw_{ms5} := Vnt_w \cdot t_{s\_ms5} \cdot \left(\frac{16}{in}\right) \cdot \frac{2 \cdot w_{emb}}{in}$$

Maximum shear transverse fillet strength capacity of MS-5 welds loaded in tension

$$Vntw_{ms5} = 57.28\ kip$$

$$\frac{Vnw_{ms5}}{Vsb_{ms5}} = 3.722 \qquad \frac{Vntw_{ms5}}{Ptb_{ms5}} = 6.187$$

Shear and tension (or pull-out) capacities of weld exceed that of anchors

MS-5 North/South Loading

Anchor bolts - In the North direction, the bolts are subject to shear - provided that the plate/embed welds have sufficient tension (or pull-out) capacity as a result of the clevis plate pivoting about its short side (between plate edge and bolts) and placing the welds in tension. In the South direction, the bolts are subject to pull-out (or tension), provided the plate/embed welds have sufficient shear capacity.

North Direction Loading

$$P_{psa3} := 6 \cdot kip$$

Rated capacity of PSA-3 snubber used for MS-5.

$$P_{psa3} \cdot (6.75 \cdot in) = Ptw_{ms5} \cdot (12 \cdot in - 1 \cdot in)$$

Moment about the North plate edge. Weld is in tension, anchors are in shear.

$$Ptw_{ms5} := \frac{P_{psa3} \cdot (6.75 \cdot in)}{12 \cdot in - 1 \cdot in} \qquad Ptw_{ms5} = 3.682\ kip$$

Tension (or pull-out) load that weld must carry to put anchors in shear

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$\frac{Ptw_{ms5}}{Vntw_{ms5}} = 0.064$ < $\frac{P_{psa3}}{Ptb_{ms5}} = 0.648$ < 1.0 Weld and anchors withstand North loading on MS-5. Limiting anchorage loading is based on rated capacity of PSA-3 snubber.

South Direction Loading

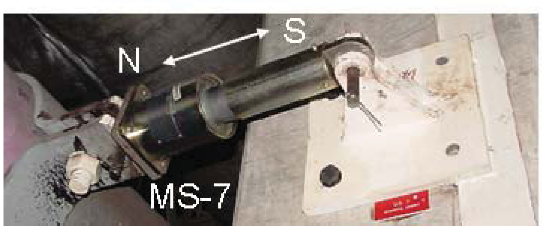
$P_{psa3}\cdot(6.75\cdot in) = Pta_{ms5}\cdot(12\cdot in - 2\cdot in)$ Moment about the South plate edge. Anchors are in tension and weld is in shear.

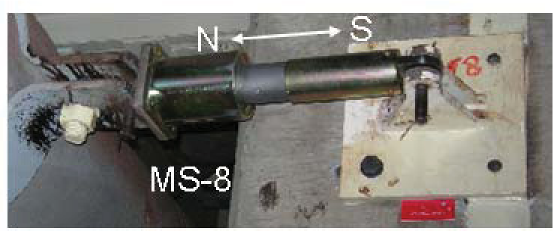
$Pta_{ms5} := \frac{P_{psa3}\cdot(6.75\cdot in)}{12\cdot in - 2\cdot in}$ $Pta_{ms5} = 4.05\,kip$ Tension (or pull-out) load that anchors must carry to put weld in shear

$\frac{P_{psa3}}{Vntw_{ms5}} = 0.105$ < $\frac{Pta_{ms5}}{Ptb_{ms5}} = 0.438$ < 1.0 Weld and anchors withstand South loading on MS-5. Limiting anchorage loading is based on rated capacity of PSA-3 snubber.

MS-5 clevis structure and connection capacities are sufficiently documented in original anchorage analysis [32].

MS-7 & MS-8





Anchorage for MS-7 & MS-8 is similar to that of MS-5. MS-8 anchorage loading is identical to that of MS-5, but is connected to piping that is North of the column. MS-7 has similar anchorage to both MS-5 & MS-8, but its clevis structure is welded at its back corners to the steel plate embed. In this weld arrangement, bending capacity of the corner welds is anticipated to be consistent with that already analyzed. Thus, the two bolt arrangement governs this anchor configuration. Therefore, anchorage capacity for supports MS-7 and MS-8 is consistant with that of MS-5.

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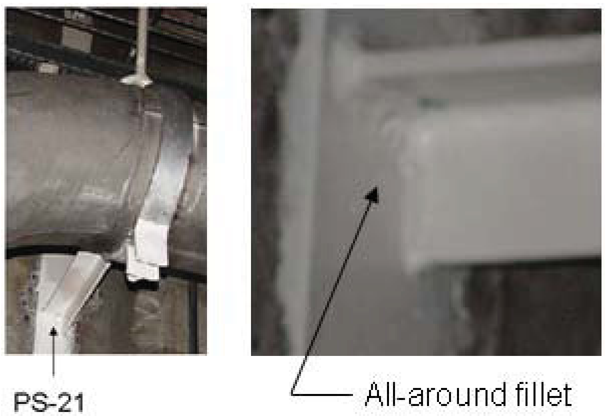
PS-21 Anchorage Refinement Calculations

The purpose of this refinement calculation is to determine if the PS-21 angle support attachment weld has at least 25% more capacity as that of the horizontal 1.5 x 1.5 x .25 angle support.



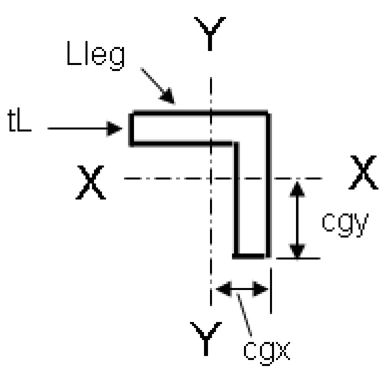
$L_{leg} := 1.5 \cdot in$ Common leg length of support angle

$A_L := 0.688 \cdot in^2$ $t_L := 0.25 \cdot in$ Area, thickness, moment of inertia & section modulus of 1.5 x 1.5 x 0.25 angle [44].

$I_L := 0.139 \cdot in^4$ $S_L := 0.134 \cdot in^3$

$J_L := 2 \cdot I_L$ $J_L = 0.278\ in^4$ Angle's polar moment of inertia

Determine angle's weld properties, treated as lines:



$tr_L := 0.707 \cdot t_L$ Fillet throat

$tr_L = 0.177\ in$

$A_W := 4 \cdot L_{leg}$ $A_W = 6\ in$ Linea area of weld

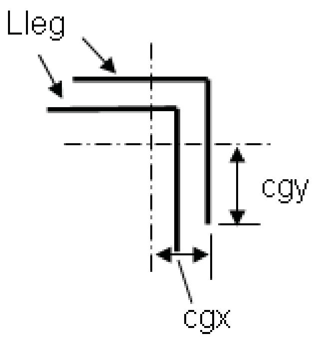
$$cg_x := \frac{t_L \cdot \left(\frac{t_L}{2} + L_{leg}\right) + \left(L_{leg} - t_L\right) \cdot \left[t_L + \left[t_L + \left(\frac{L_{leg} - t_L}{2}\right)\right]\right] + L_{leg} \cdot \frac{L_{leg}}{2}}{A_W}$$

$cg_x = 0.49\,in$ Weld pattern CG along X-direction, as measured from section's bottom right corner.

$cg_y := L_{leg} - cg_x$ $cg_y = 1.01\,in$ Using symmetry, weld pattern CG along Y-direction as measured from section's bottom right corner.

For S and J Sections:

Let =>



Will estimate weld pattern section modulus and polar moment of inertia, approximated as lines. This approach conservatively does not account for spacing between weld lines. Line sections approximated by Blodget [39, Table 5, p. 7.4-7].

where b = d (equal leg length angle)

$St_w = 2\left(\frac{4\cdot b\cdot d + d^2}{6}\right) = 2\left(\frac{5\cdot d^2}{6}\right)$ Approximated line weld pattern top section modulus

$St_w := 2\cdot\left(\frac{5\cdot L_{leg}^2}{6}\right)$ $St_w = 3.75\,in^2$

$Sb_w = 2\left[\frac{d^2\cdot(4b + d)}{6\cdot(2b + d)}\right] = 2\left(\frac{5\cdot d^2}{18}\right)$ Approximated line weld pattern bottom section modulus

$Sb_w := 2\left(\frac{5\cdot L_{leg}^2}{18}\right)$ $Sb_w = 1.25\,in^2$

Let => $Sw_{ave} := \frac{St_w + Sb_w}{2}$ $Sw_{ave} = 2.5\,in^2$ Approximated average line weld pattern section modulus

$$J_w = 2\left[\frac{(b+d)^4 - 6 \cdot b^2 \cdot d^2}{12 \cdot (b+d)}\right] = 2 \cdot \left[\frac{(2 \cdot d)^4 - 6 \cdot d^4}{24 \cdot d}\right] = 2 \cdot \left(\frac{10 \cdot d^3}{24}\right)$$

$$J_w := 2 \cdot \left(\frac{10 \cdot L_{leg}^3}{24}\right) \qquad J_w = 2.812\ in^3$$

Approximated line polar moment of inertia

Compare weld patern sections to support angle sections:

$$\frac{A_w \cdot tr_L}{A_L} = 1.541 \quad < \quad \frac{J_w \cdot tr_L}{J_L} = 1.788 \quad < \quad \frac{Sw_{ave} \cdot tr_L}{S_L} = 3.298 \quad < 1.25$$

Angle support weld pattern sections have at least 25% greater capacity than the support angle. Thus, the angle will go plastic before weld pattern reaches its load limit.

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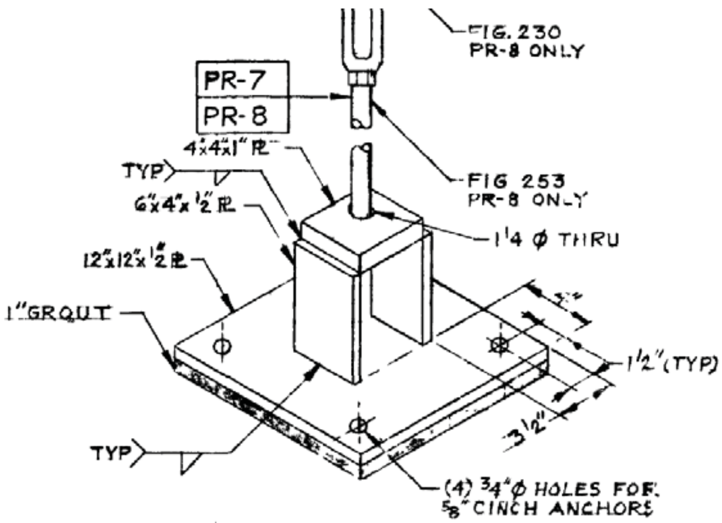
PR-8 Anchorage Capacity

The purpose of this section is to determine the anchorage capacity of support PR-8. Anchorage capacity for PR-8 was overlooked from previous capacity analysis [32, Appendix E]. PR-8 anchorage is loaded in tension only.

As shown in the pictures below, PR-8 anchorage consists of four anchors that extend through a 1/2-in plate [20, det. 52], built-up grout, and into the concrete floor.



DETAIL 52
SCALE: 1 1/2" = 1'-0
REF DWG 670-P-6..

PR-8 pictures and drawing detail do not agree. The drawing calls for 1-in thick grout, but the above pictures indicate more grout as proportioned to the 1/2-in plate.

The grout thickness inaccuracy is further reaffirmed due to anchor embedment inspections, shown in Appendix B.

From Appendix B of capacity analysis [32], the actual anchor concrete embedment for PR-8 is determined.

$L_{stud} := (3.638\ \ 3.596\ \ 3.535\ \ 3.622)^T \cdot in$ UT recorded stud length

$L_{surf} := (3.12\ \ 2.62\ \ 3.25\ \ 3.06)^T \cdot in$ Distance between top of stud and concrete surface

$L_{emb} := L_{stud} - L_{surf}$ $L_{emb}^T = (0.518\ \ 0.976\ \ 0.285\ \ 0.562)\ in$

$\min(L_{emb}) = 0.285\ in$ $\frac{\sum L_{emb}}{4} = 0.585\ in$ Minimum and average concrete anchor embedment

From drawing, PR-8 uses 5/8-in cinch anchors. This anchor is assumed to be a Ramset trubolt style anchor, which is used in other areas of the PCS. A 5/8-in Ramset trubolt expansion anchor that has a pull-out capacity of 8-kips in 4000-psi with a minimum embedment of 2.75-inches [58]. Using DOE/EH-0545 [36] as a guide for pull-out capacity determination, Section 6.3.3.1 defines any embedment less than 2.75-in an outliner and is outside its determination scope.

Without anchor spacing, concrete strength, and other reduction factors considered, the PR-8 anchorage pull-out capacity is insignificant and for this evalaution is considered to have a pull-out capacity of zero.

Appendix B.11

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Engineering Calculations and Analysis Report

ATR Primary Coolant System Piping Seismic Evaluation

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A. L. Crawford
K. D. Ellis
R. E. Spears

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Appendix C

Idaho National Laboratory

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Appendix C

Calculations Associated with Models 2-6-5 Seismic Evaluation

Contents

Appendix C.1

Identified Components Associated with Model 2-6-5

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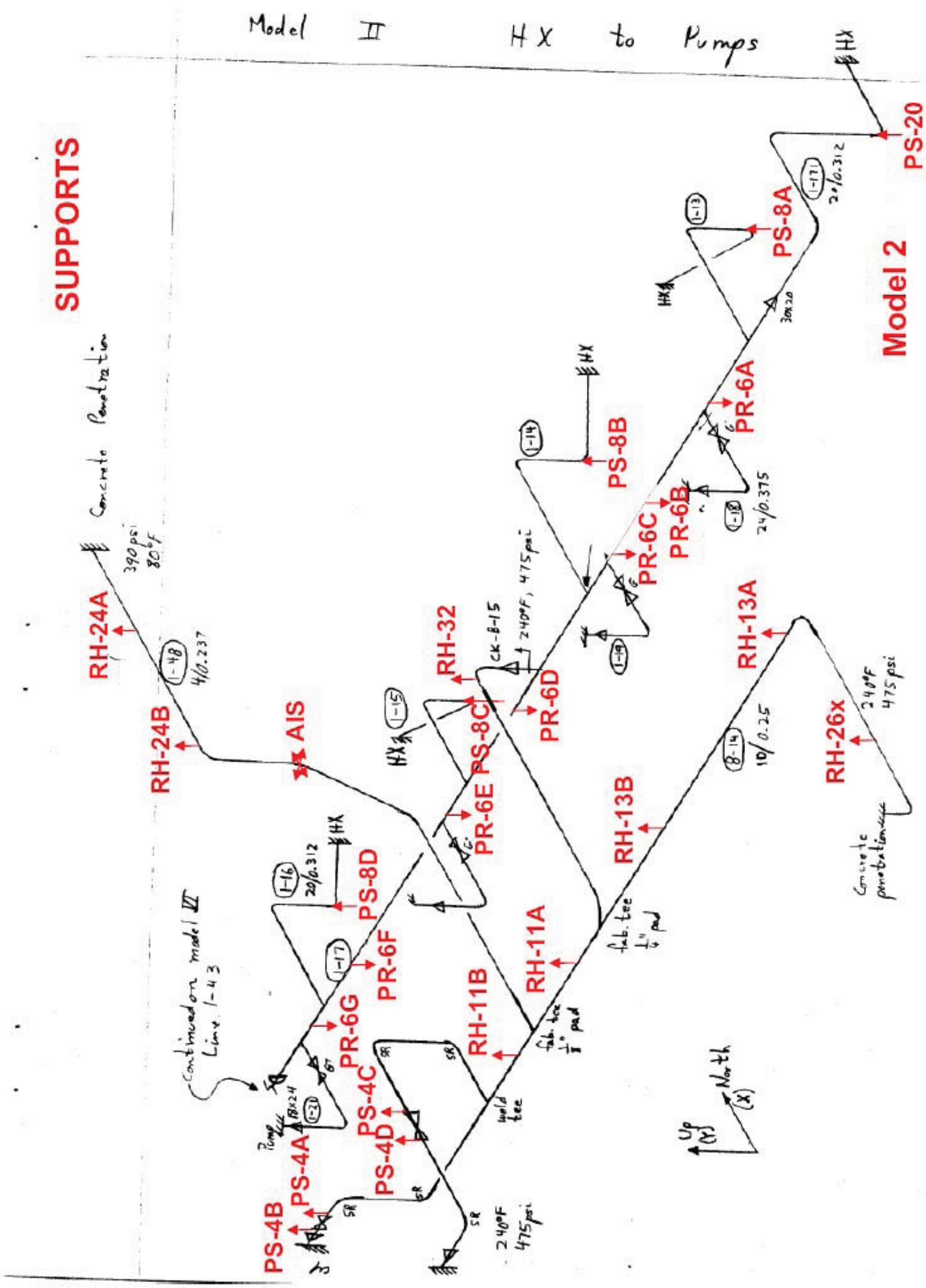

Figure C.1- 1. Supports Associated with Model 2 [1]

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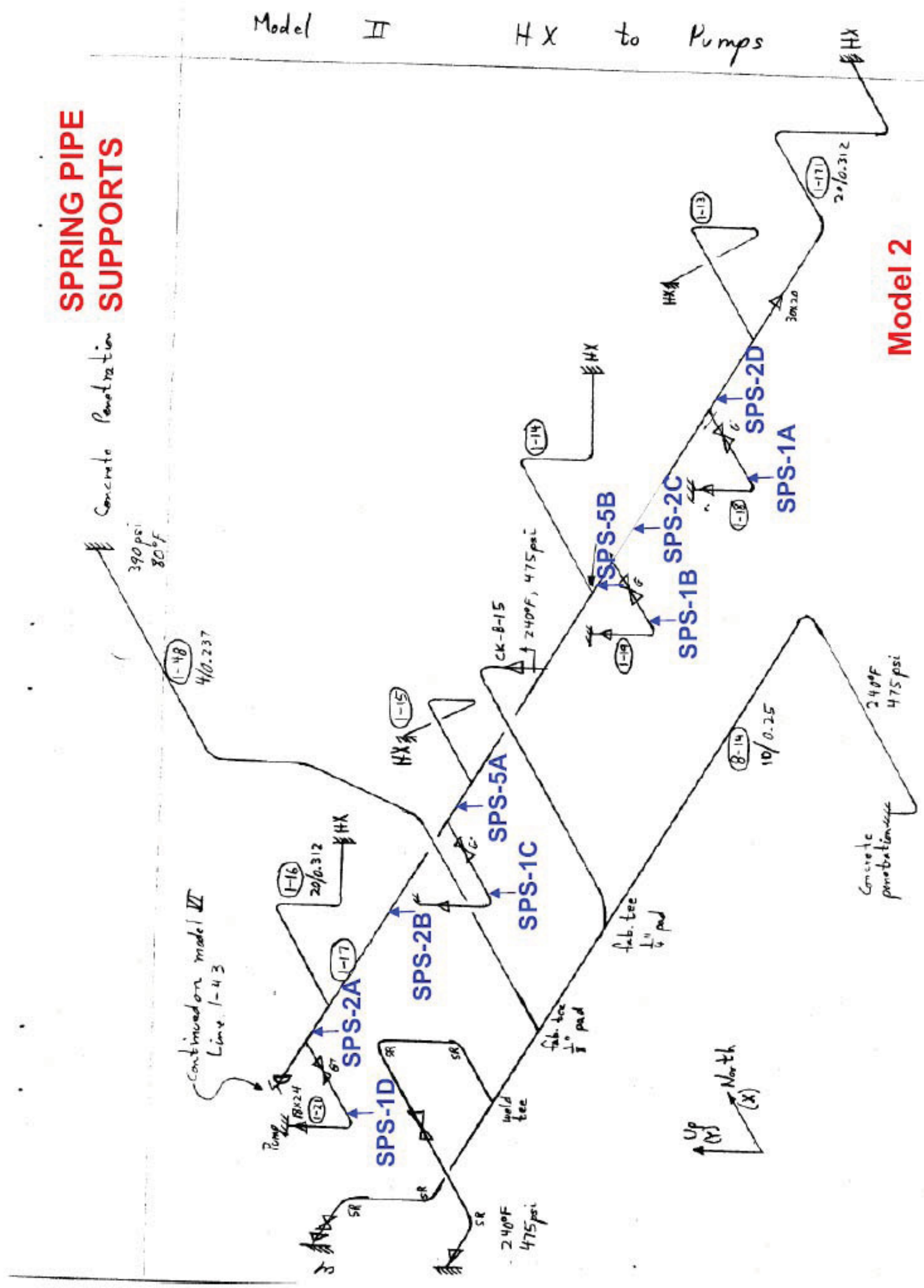

Figure C.1- 2. Spring Pipe Supports Associated with Model 2 [1]

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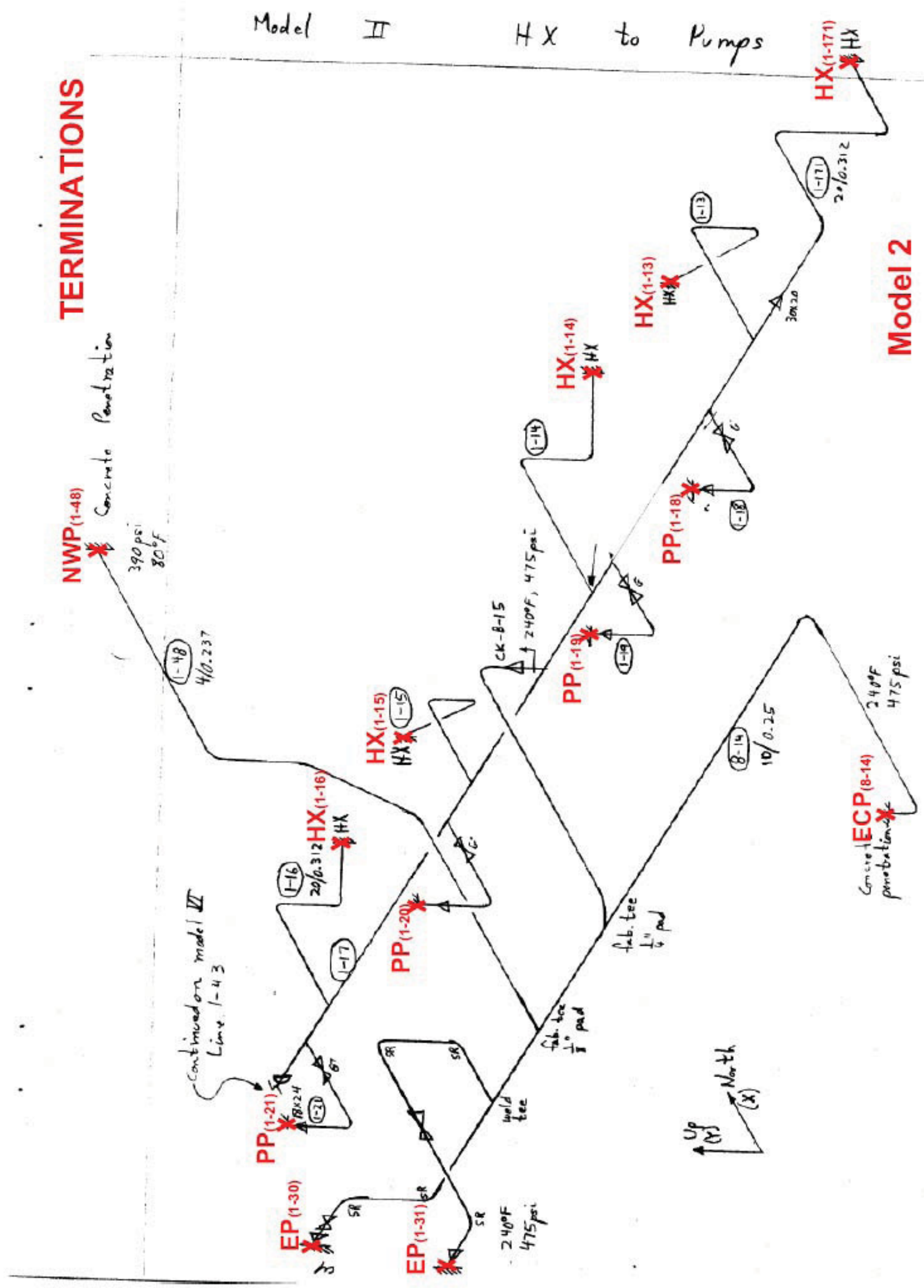

Figure C.1- 3. Terminations Associated with Model 2 [1]

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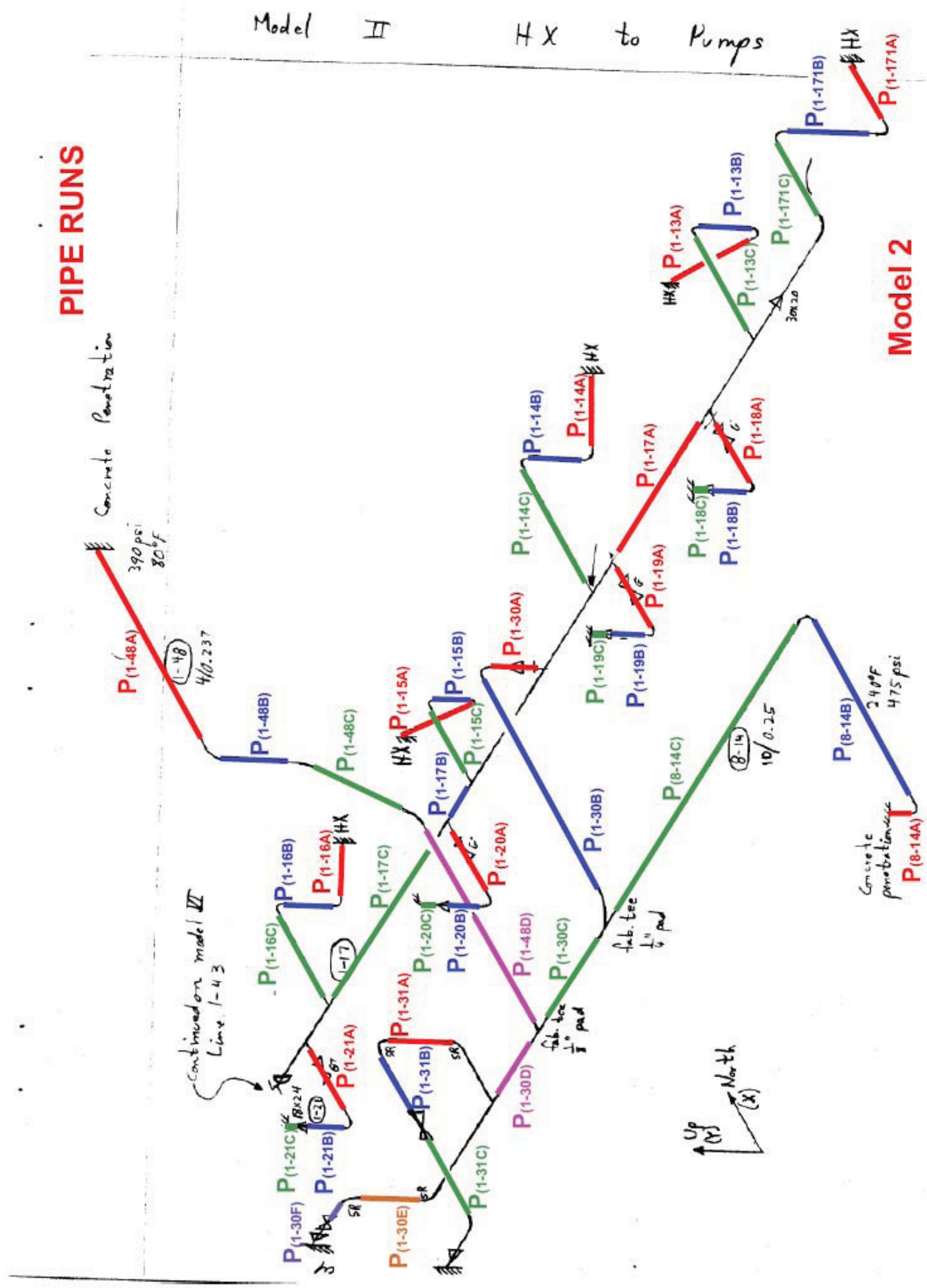

Figure C.1- 4. Pipe Runs Associated with Model 2 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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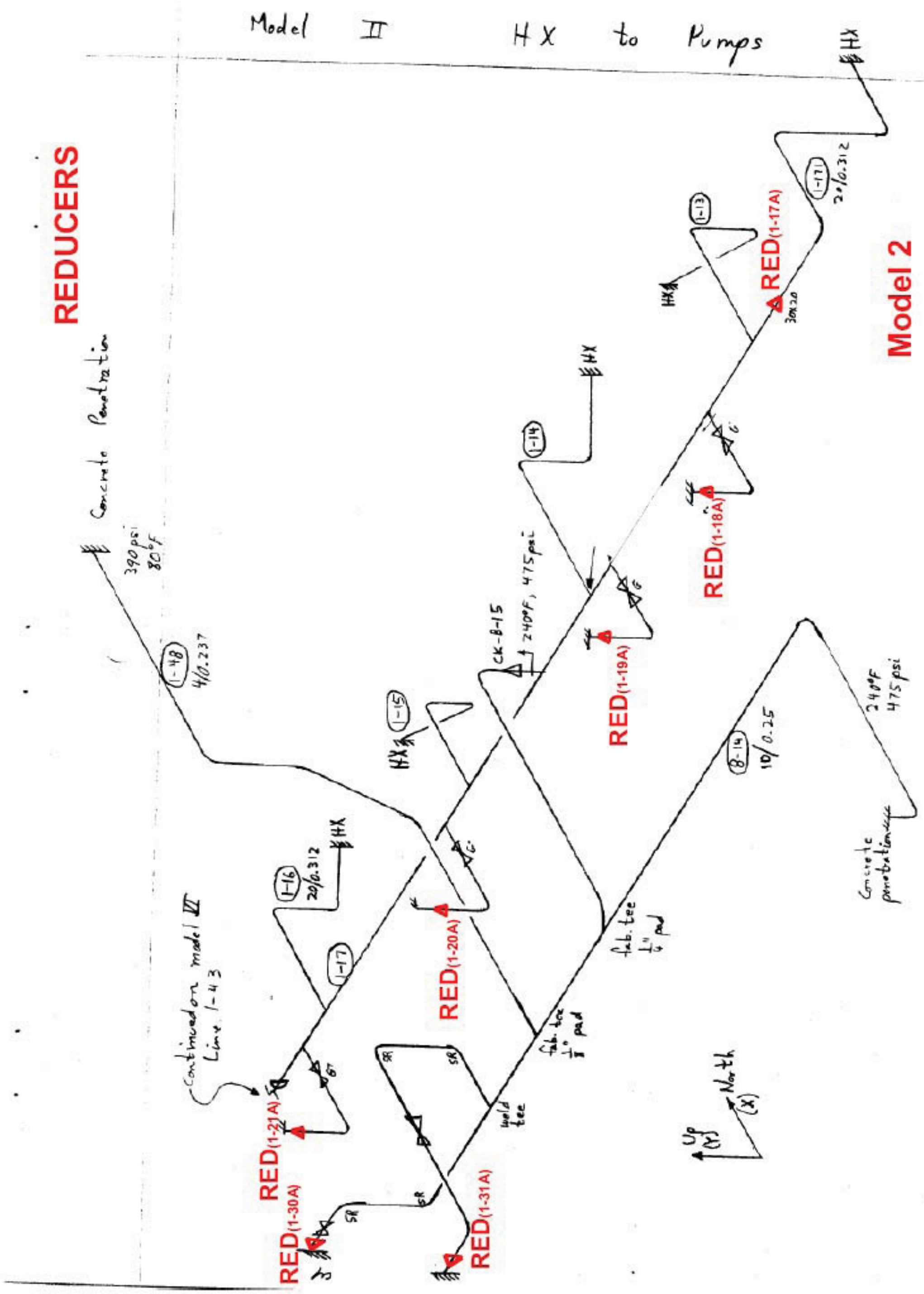

Figure C.1- 5. Reducers Associated with Model 2 [1]

Project:	ATR Life-Time Extension Project		**ECAR No.:**	ECAR-194		**Rev.:**	0
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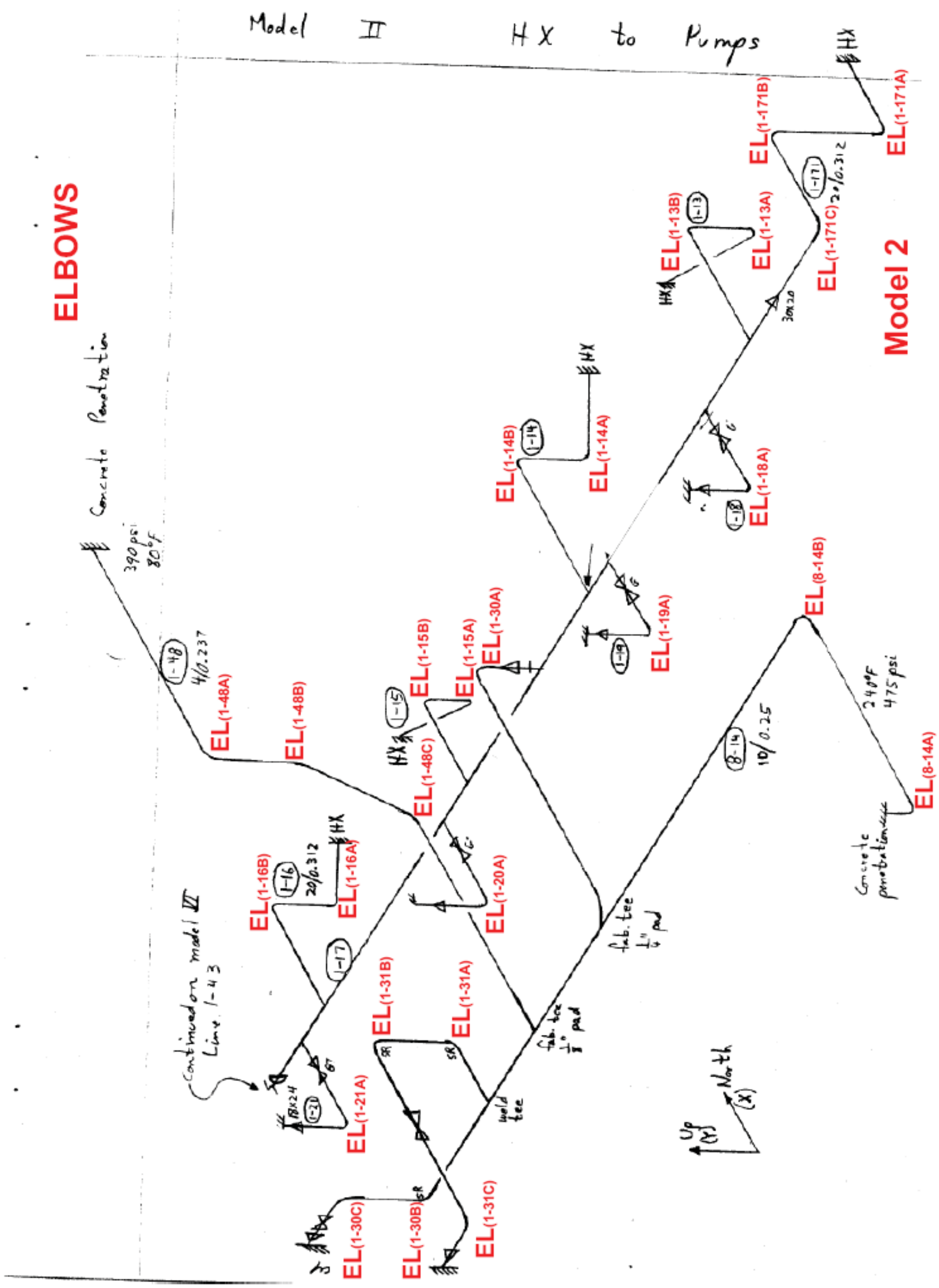

Figure C.1- 6. Elbows Associated with Model 2 [1]

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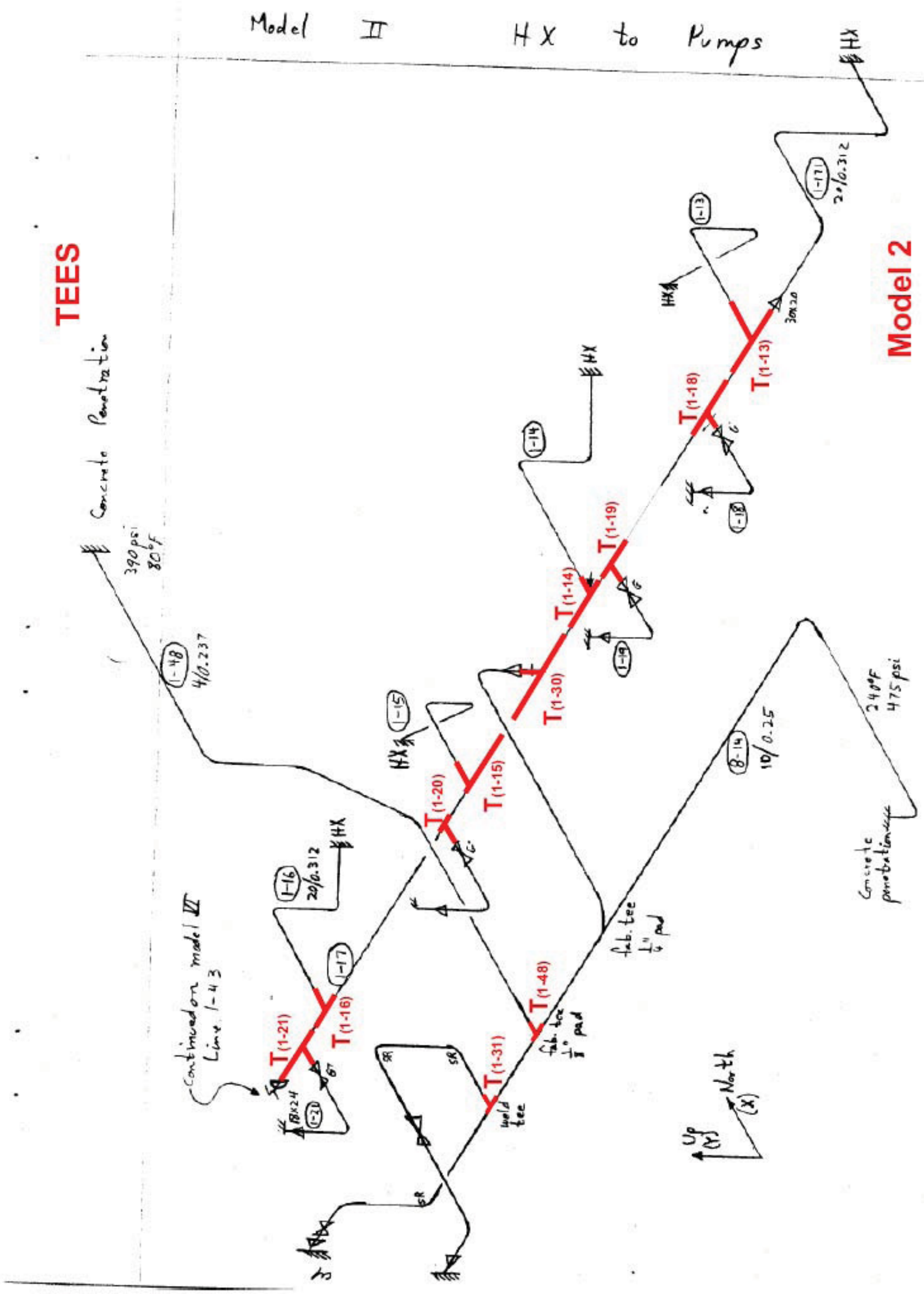

Figure C.1- 7. Tees Associated with Model 2 [1]

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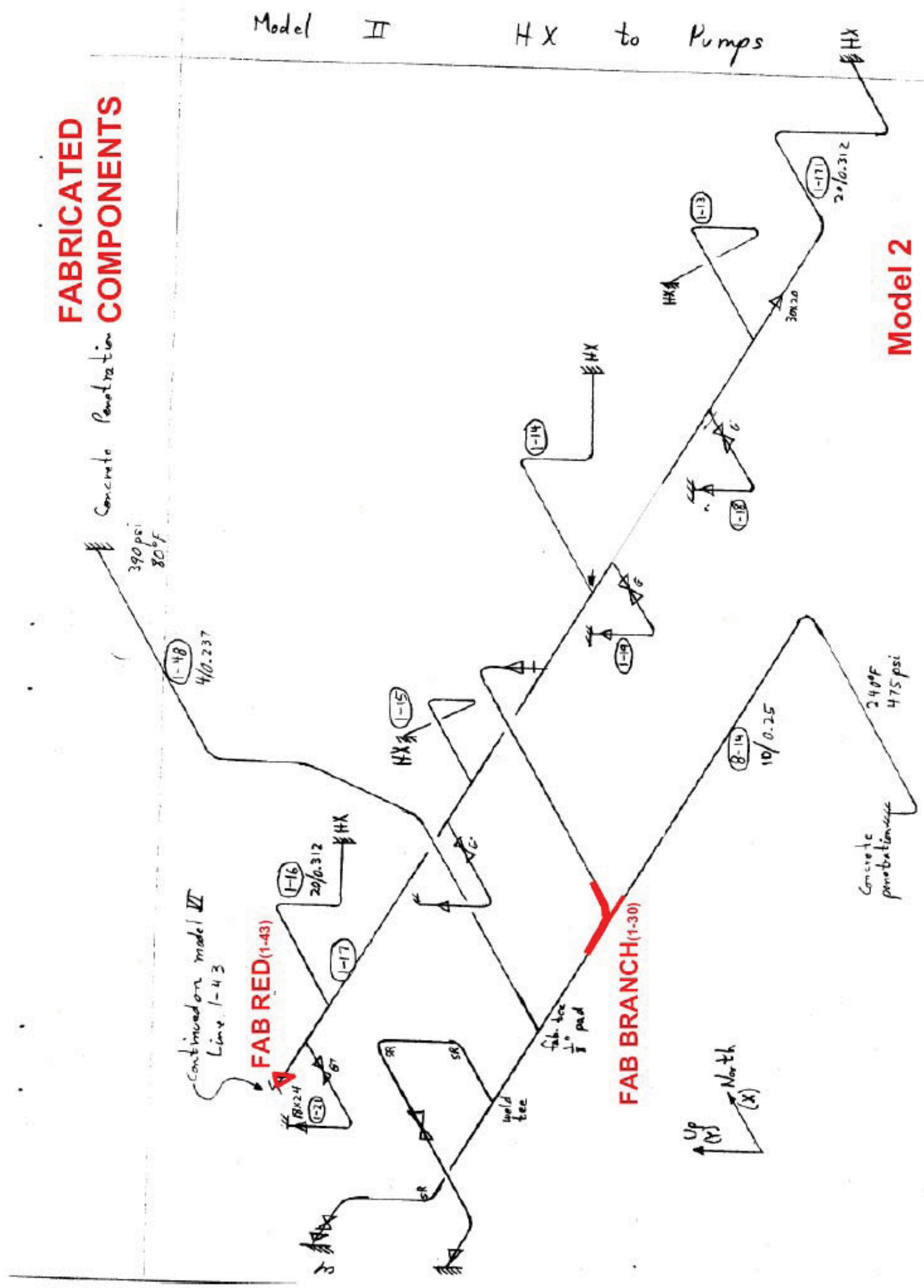

Figure C.1- 8. Fabricated Components Associated with Model 2 [1]

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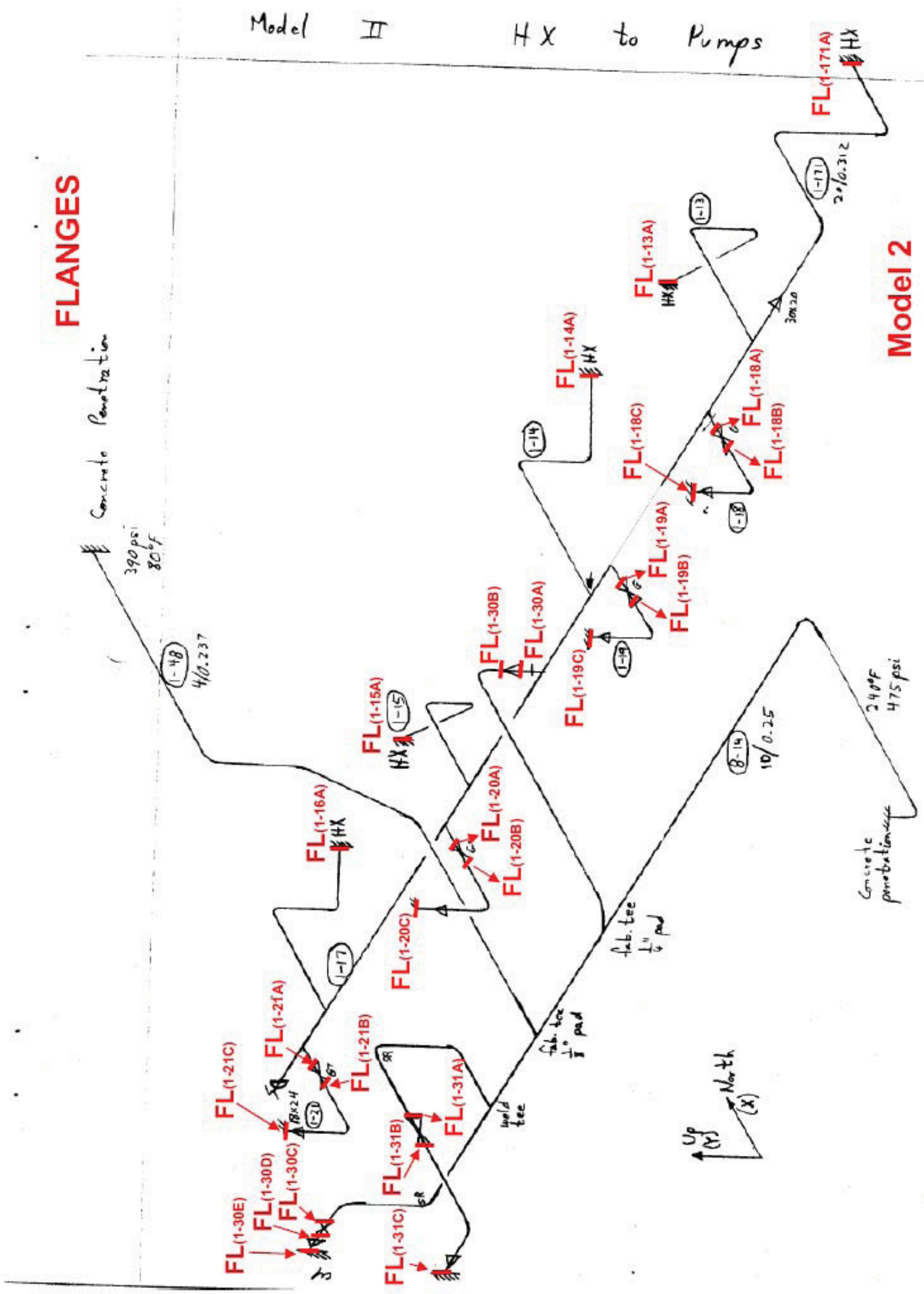

Figure C.1- 9. Flanges Associated with Model 2 [1]

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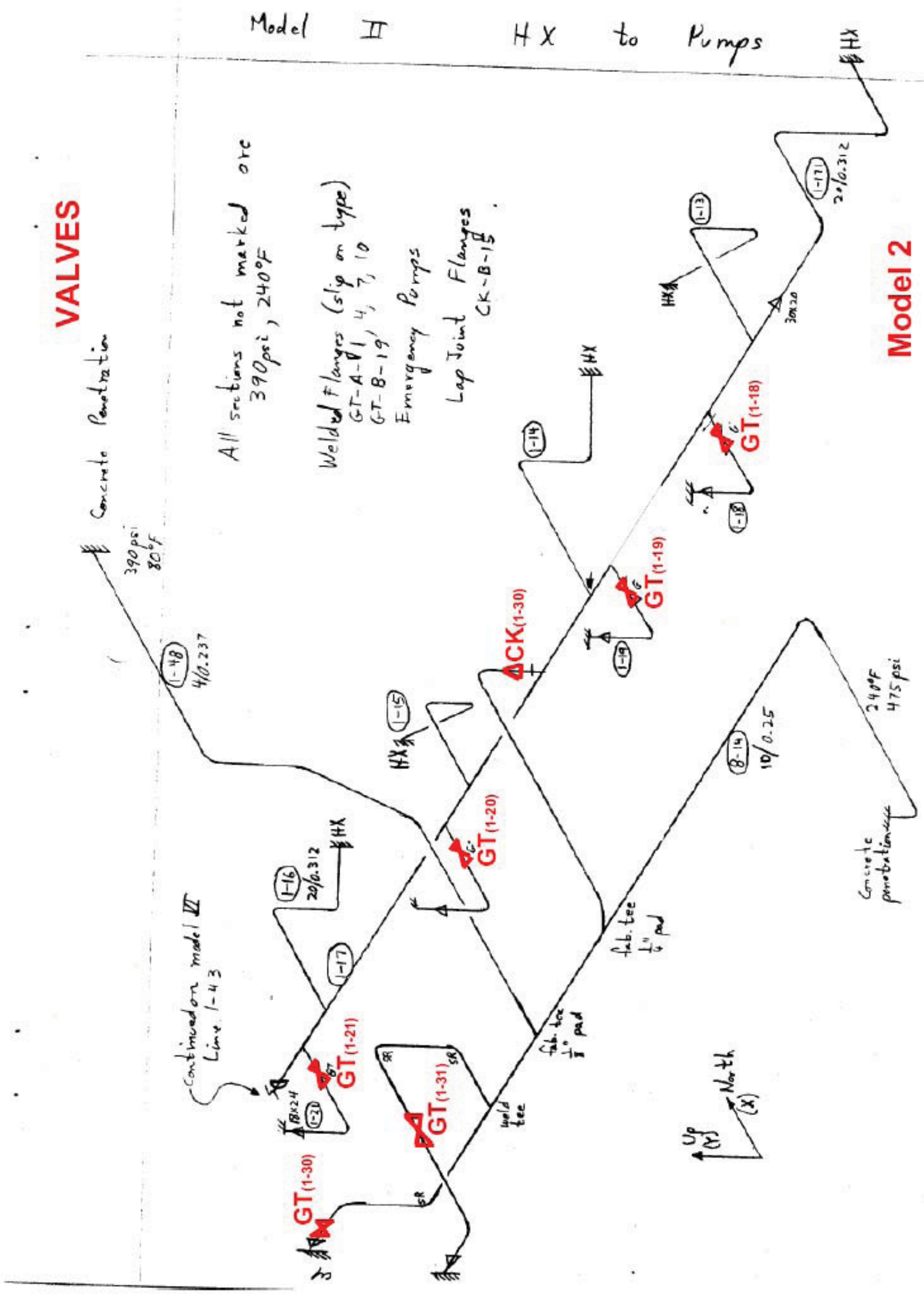

Figure C.1- 10. Valves Associated with Model 2 [1]

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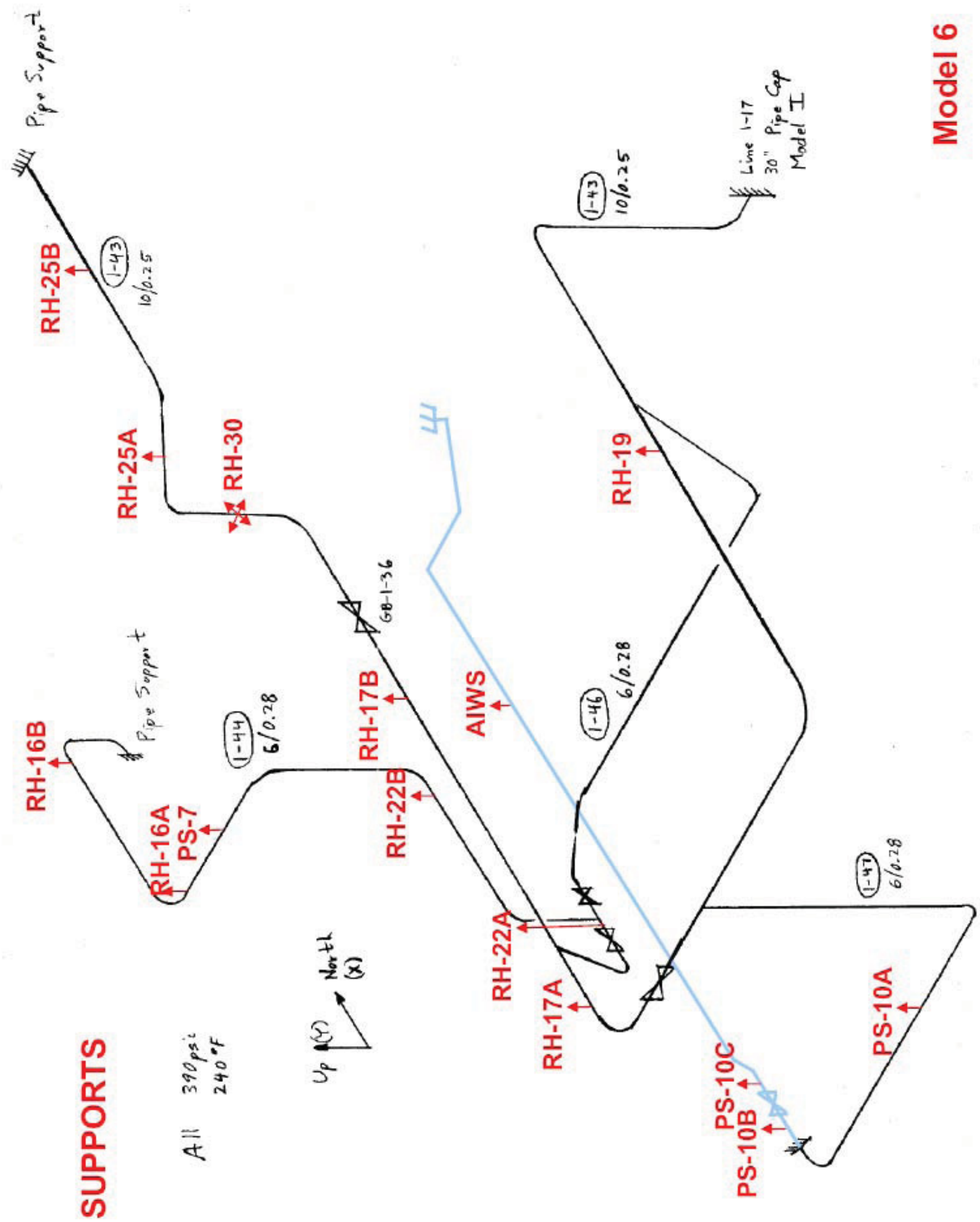

Figure C.1- 11. Supports Associated with Model 6 [1]

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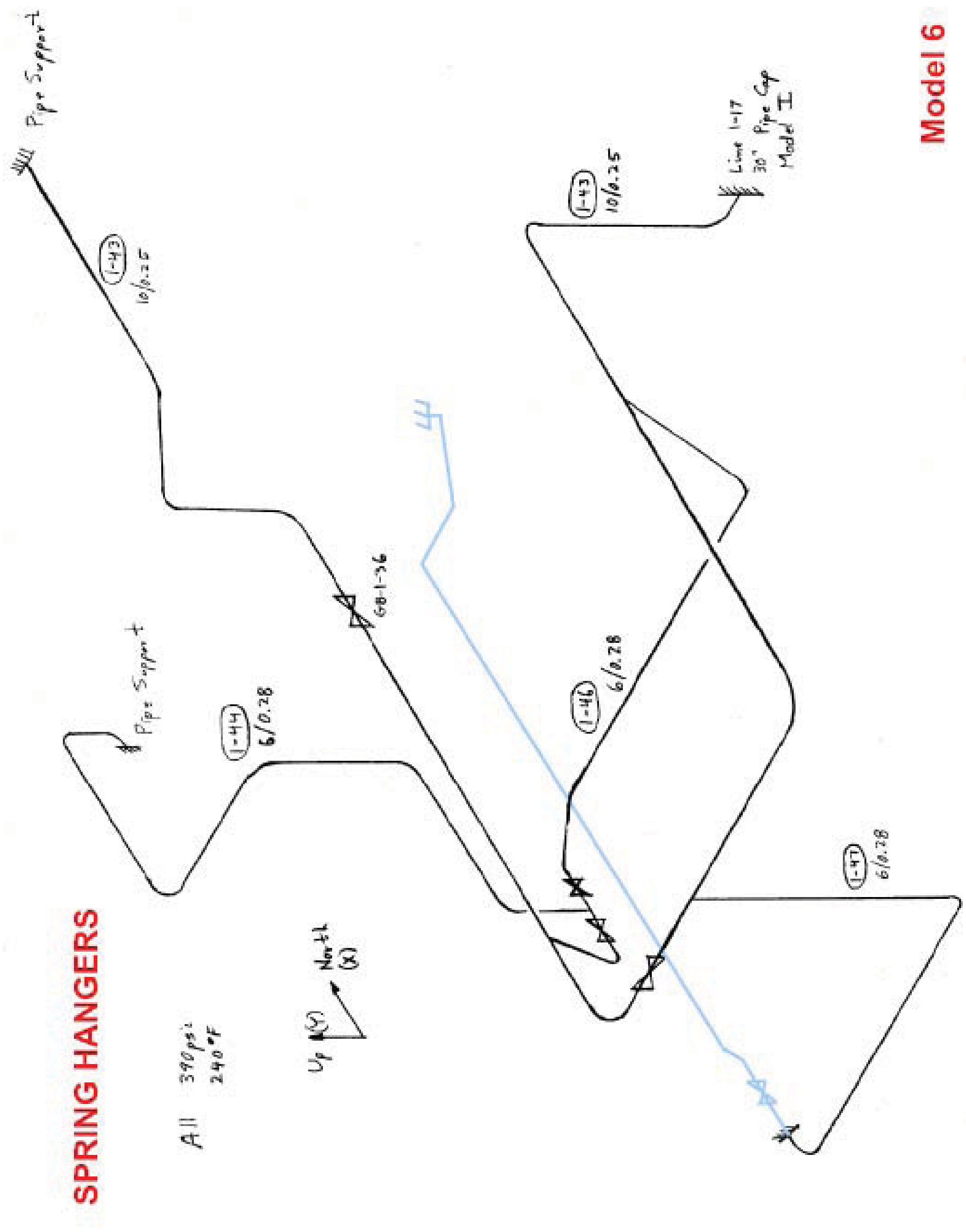

Figure C.1- 12. Spring Hangers Associated with Model 6 [1]

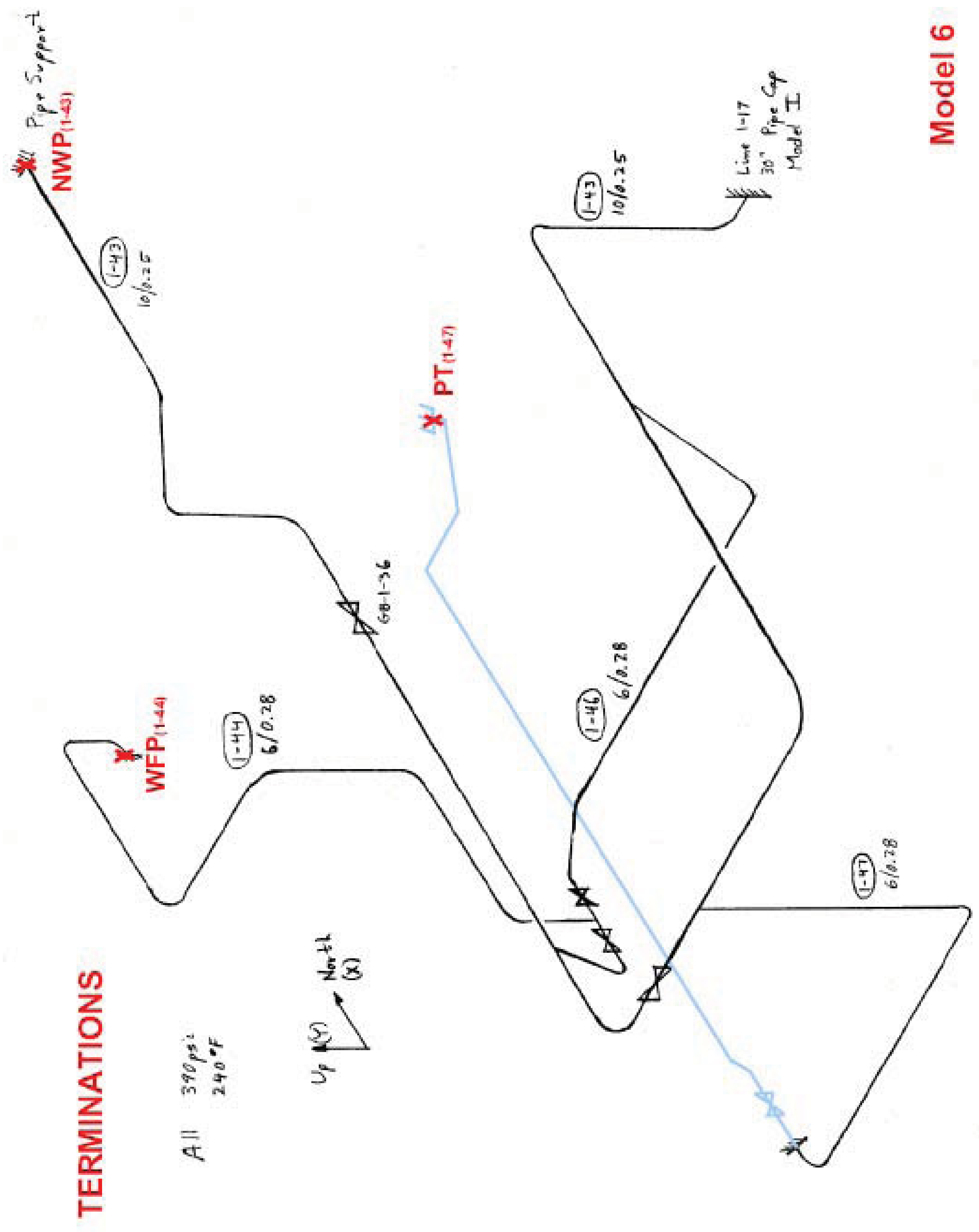

Figure C.1- 13. Terminations Associated with Model 6 [1]

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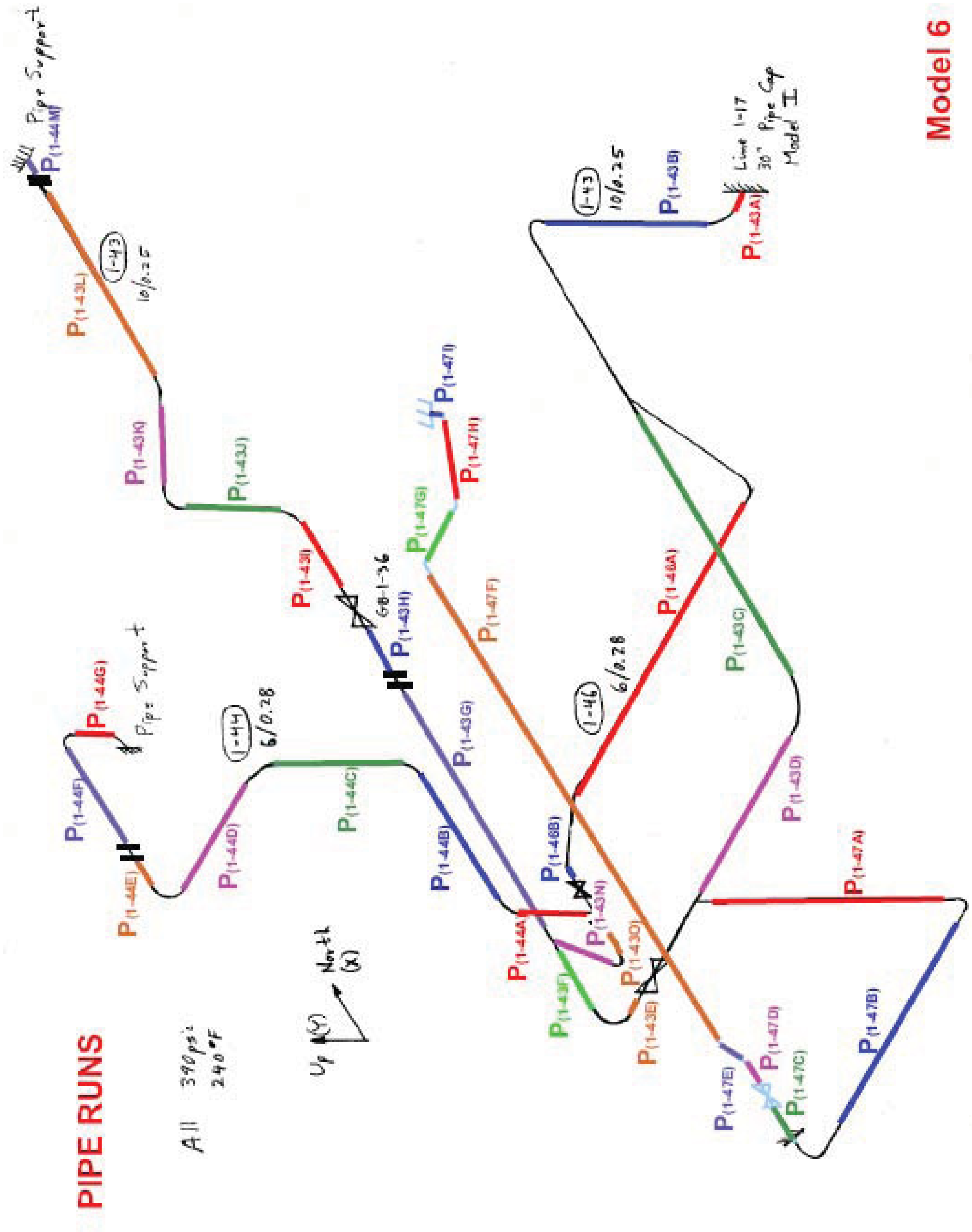

Figure C.1- 14. Pipe Runs Associated with Model 6 [1]

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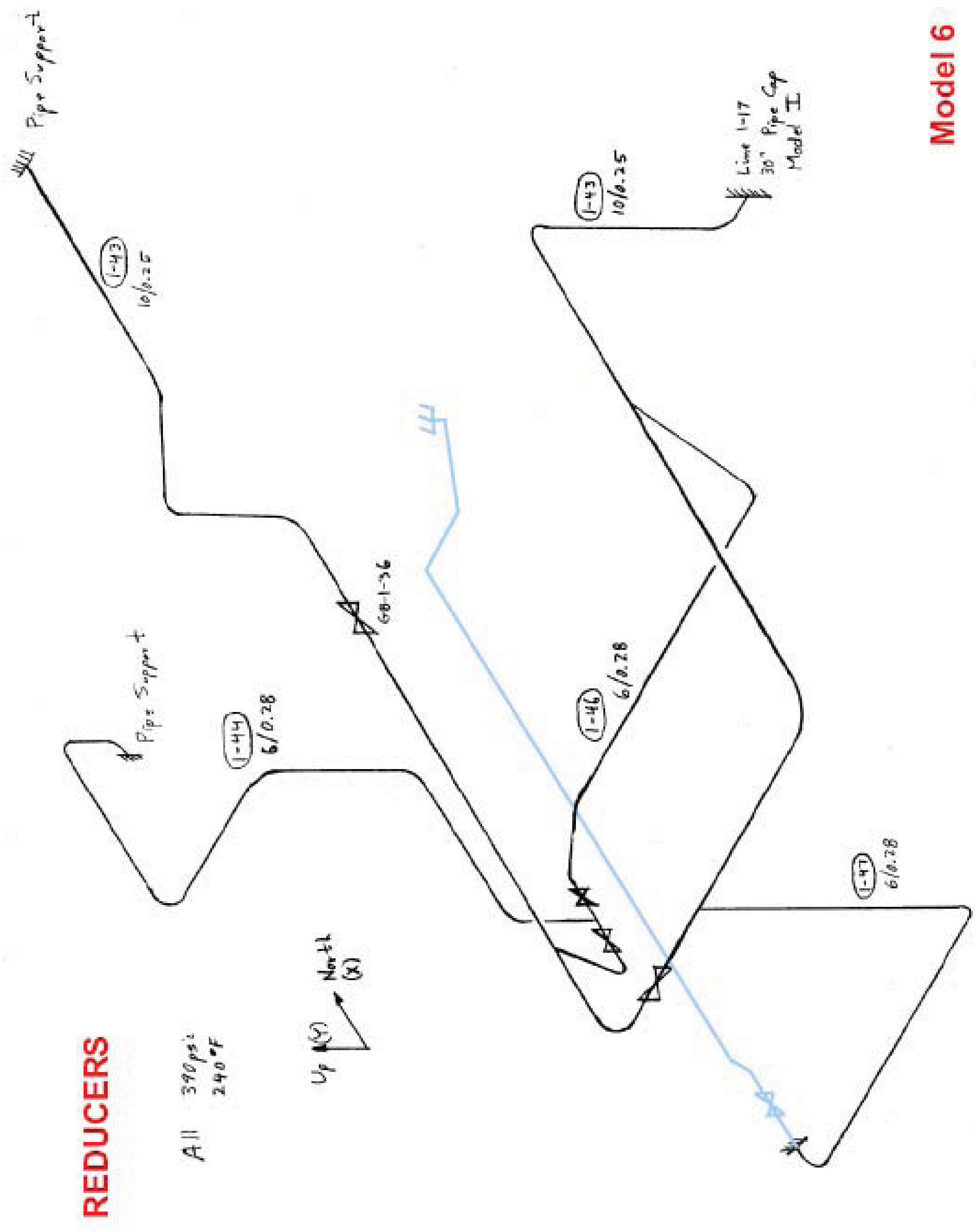

Figure C.1- 15. Reducers Associated with Model 6 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

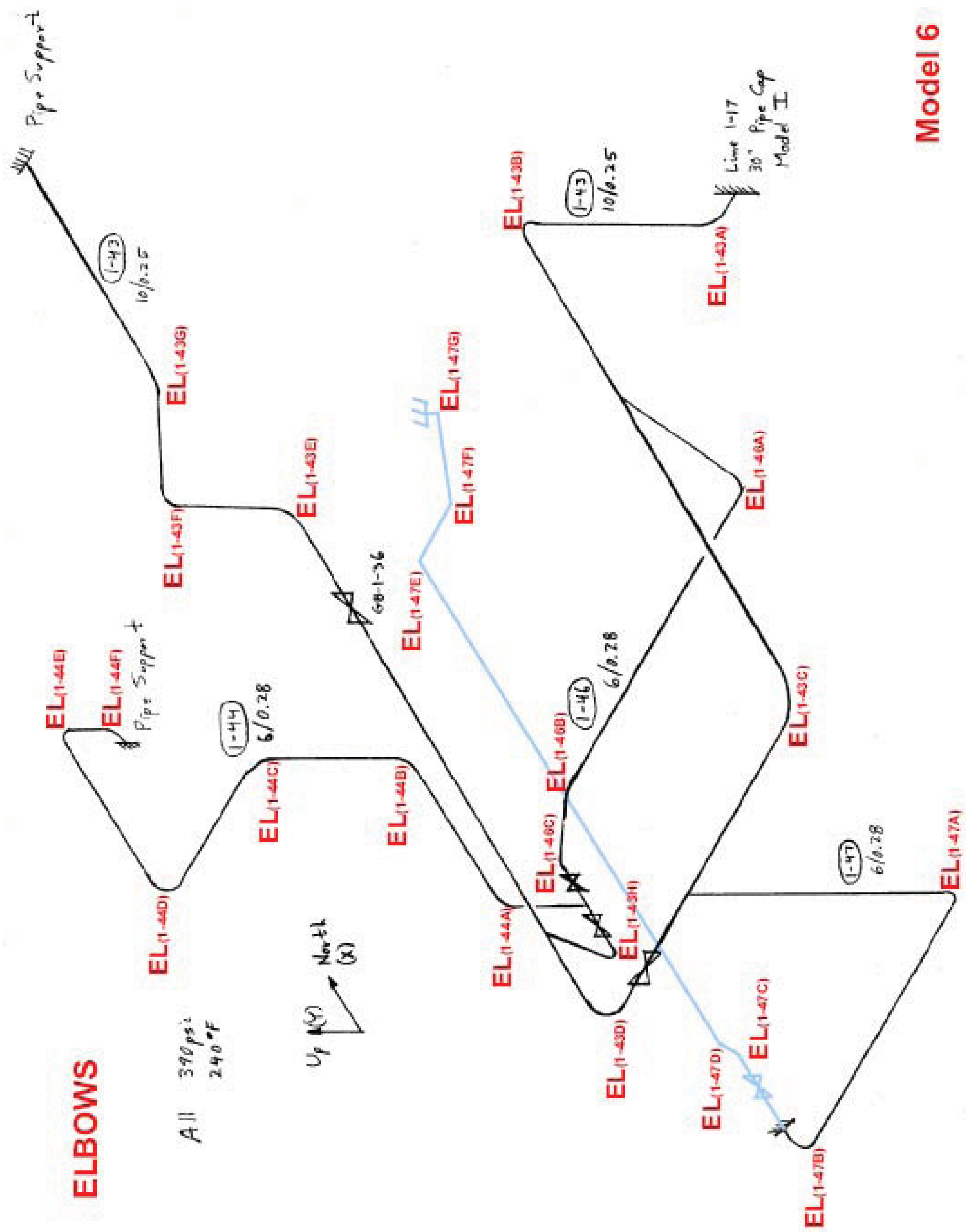

Figure C.1- 16. Elbows Associated with Model 6 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

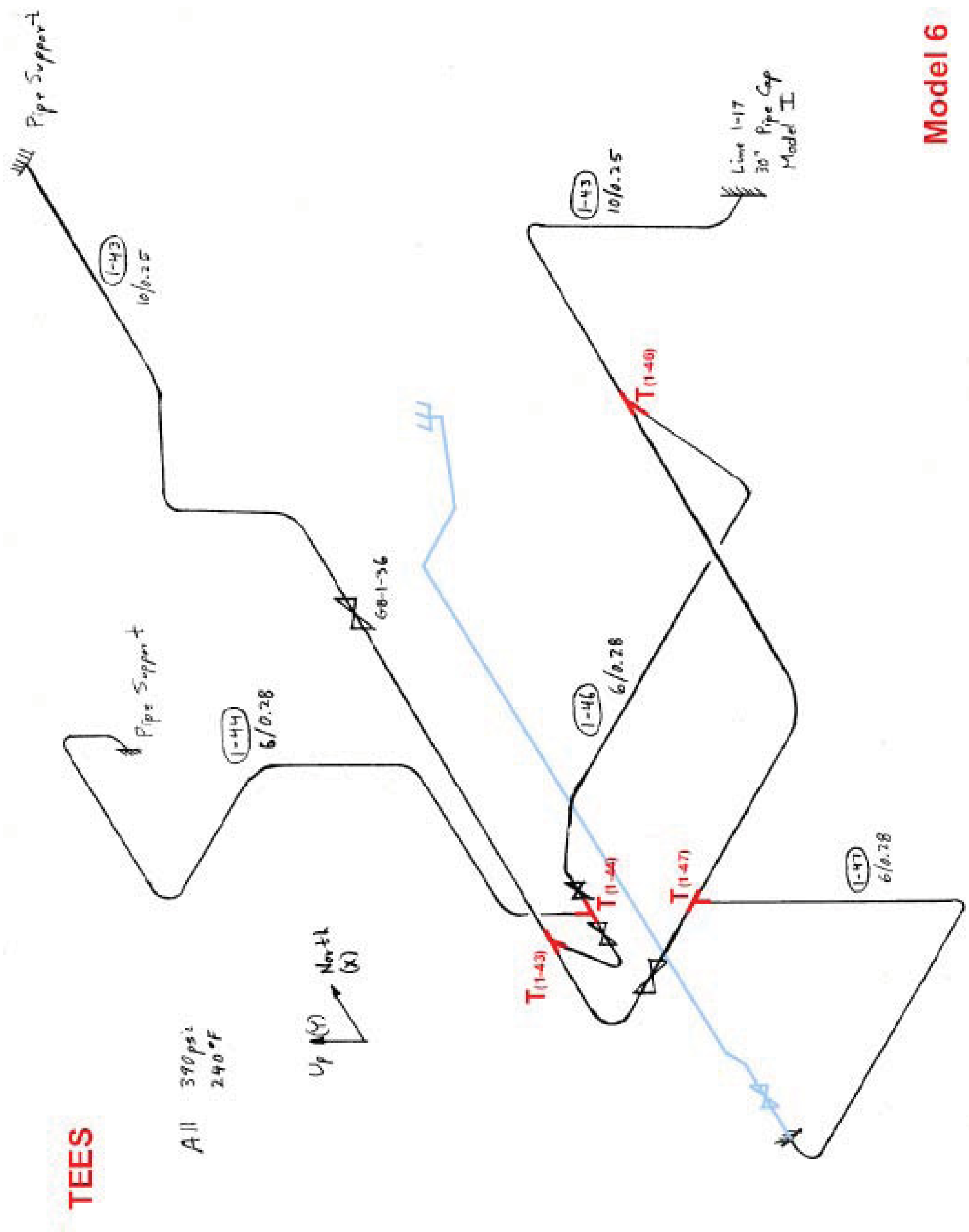

Figure C.1- 17. Tees Associated with Model 6 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

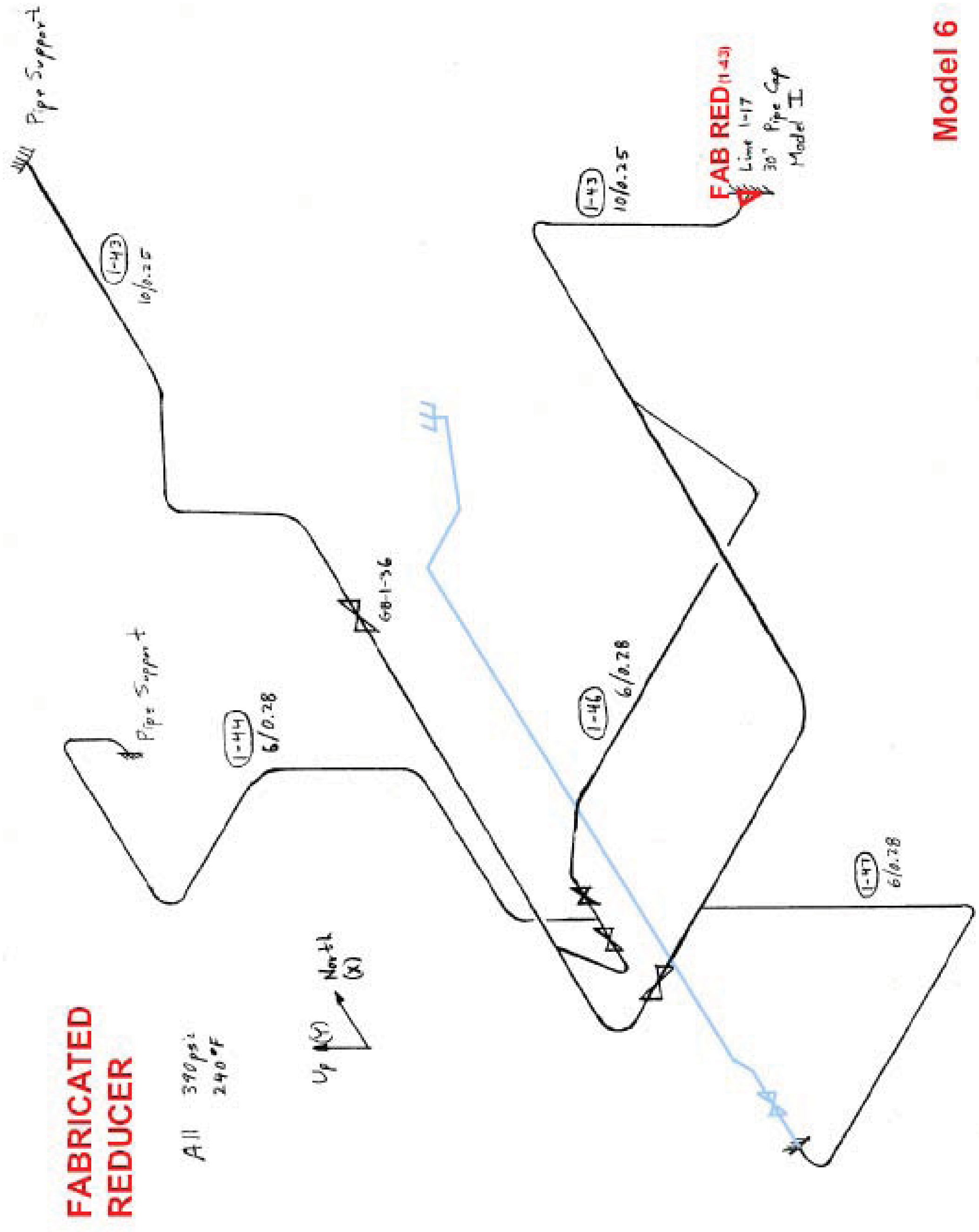

Figure C.1- 18. Fabricated Reducer Associated with Model 6 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

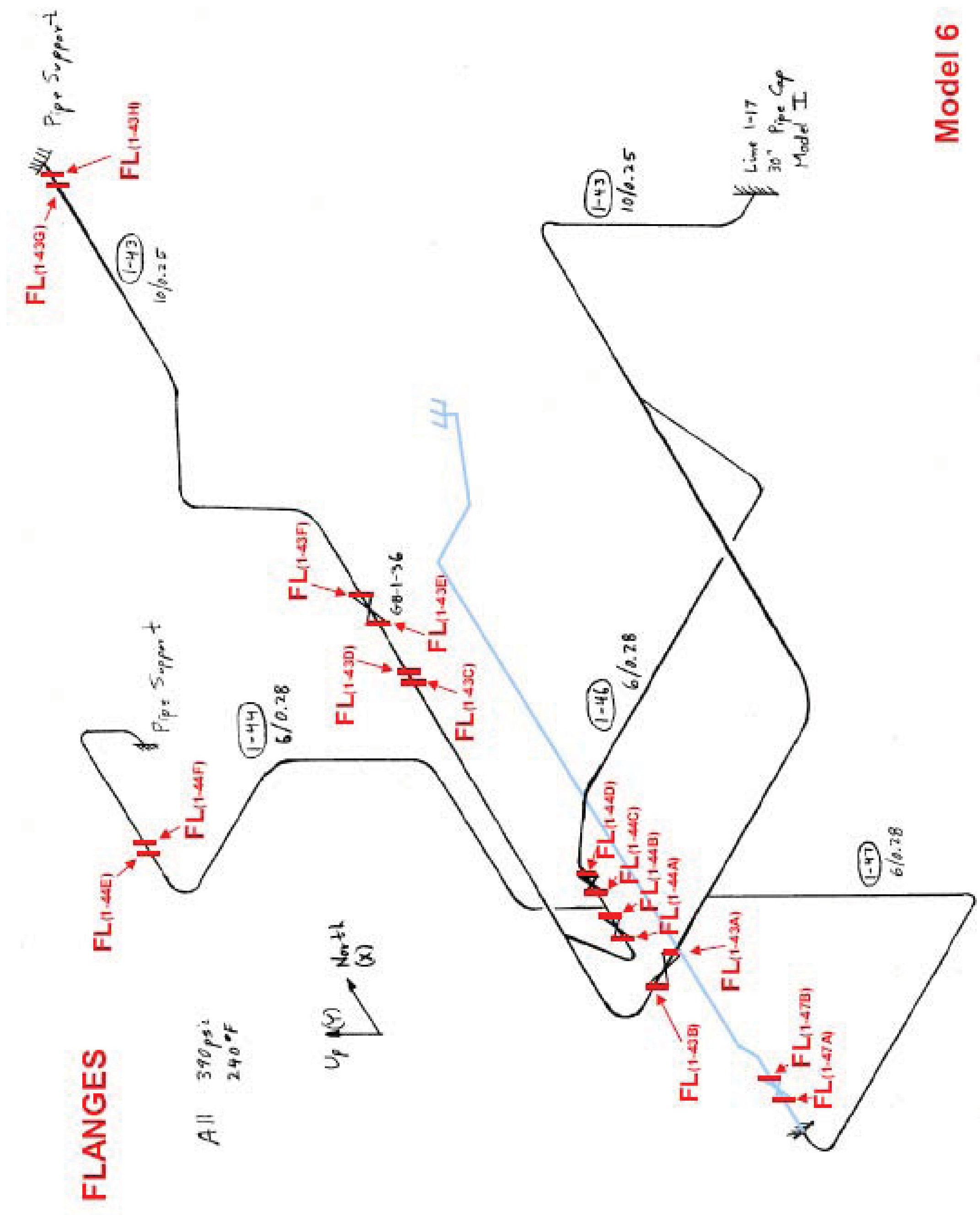

Figure C.1- 19. Flanges Associated with Model 6 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

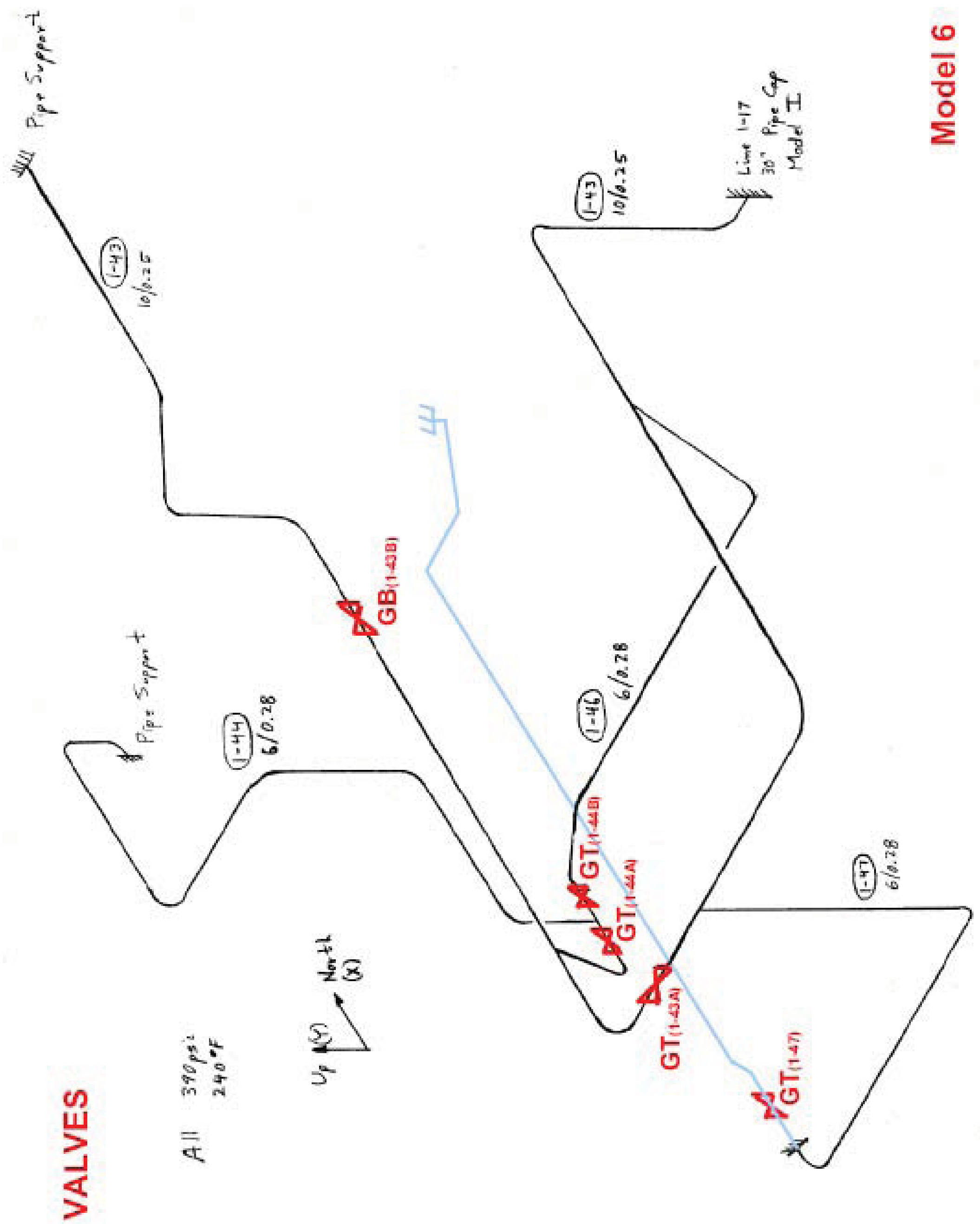

Figure C.1- 20. Valves Associated with Model 6 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

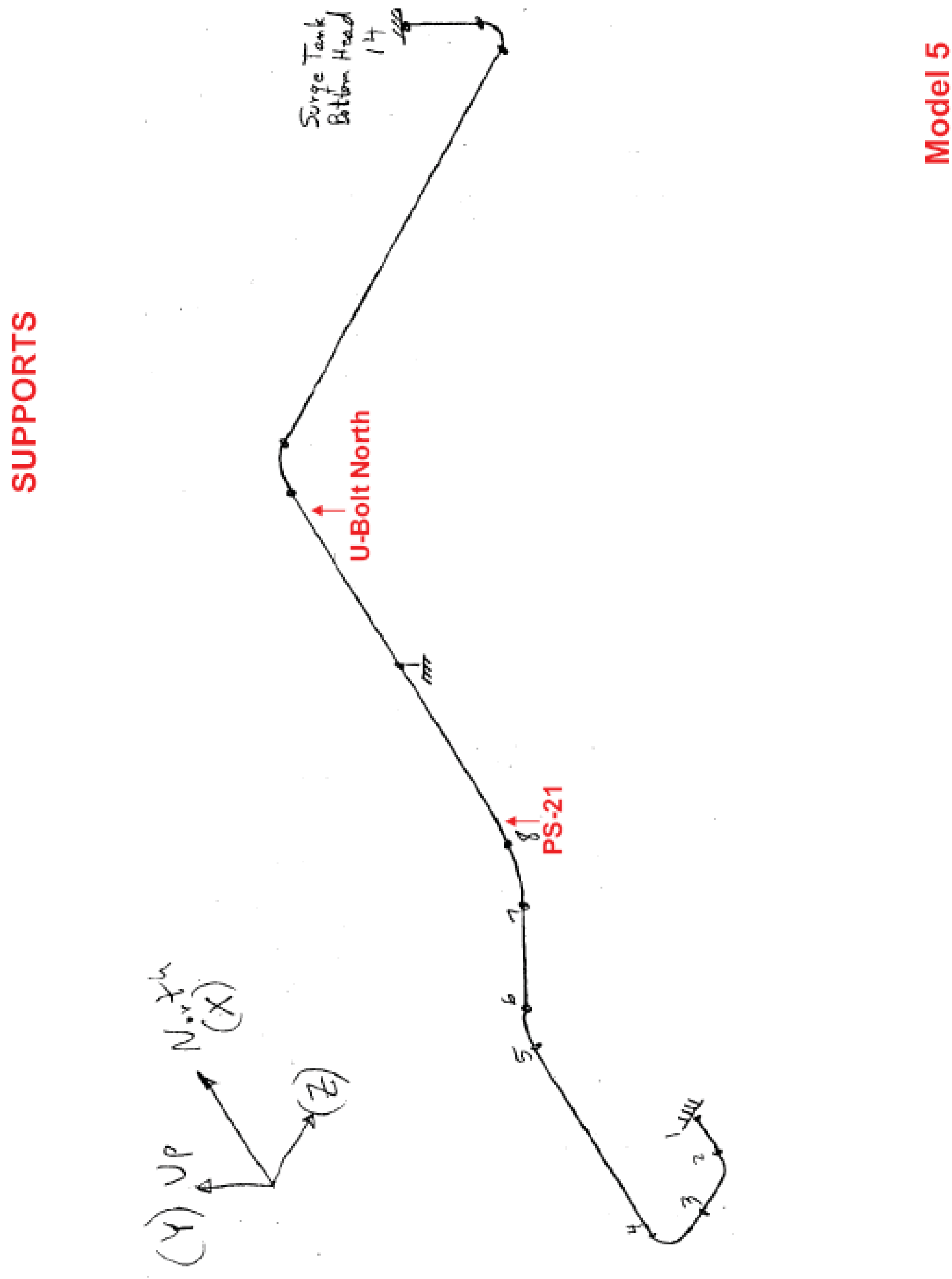

Figure C.1- 21. Supports Associated with Model 5 [1]

Project:	ATR Life-Time Extension Project			**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation						
Performer:	A. L. Crawford	**Date:**	09/30/08	**Checker:**	R. K. Blandford	**Date:**	09/30/08

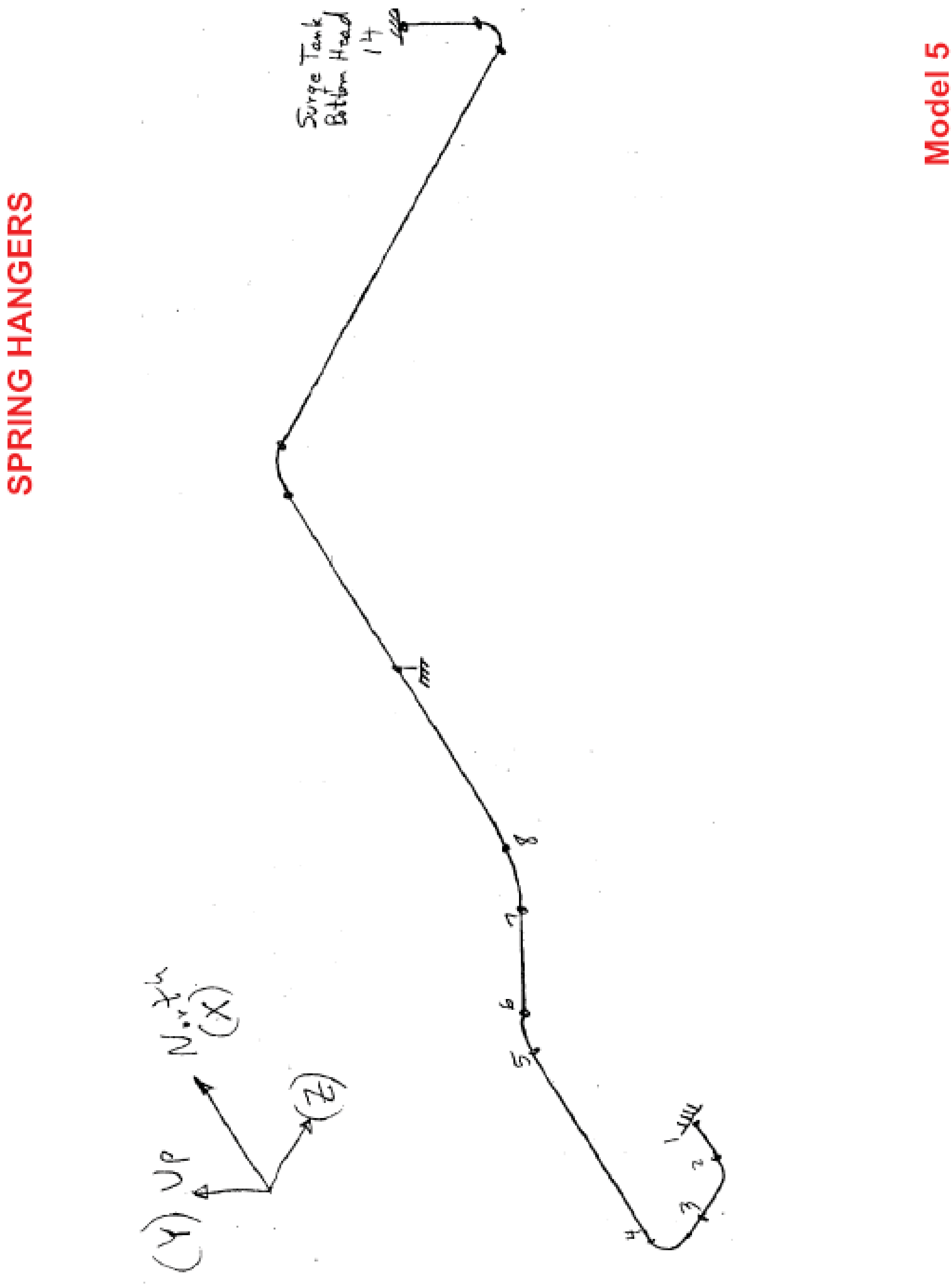

Figure C.1- 22. Spring Hangers Associated with Model 5 [1]

Project:	ATR Life-Time Extension Project		**ECAR No.:**	ECAR-194		**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation						
Performer:	A. L. Crawford	**Date:**	09/30/08	**Checker:**	R. K. Blandford	**Date:**	09/30/08

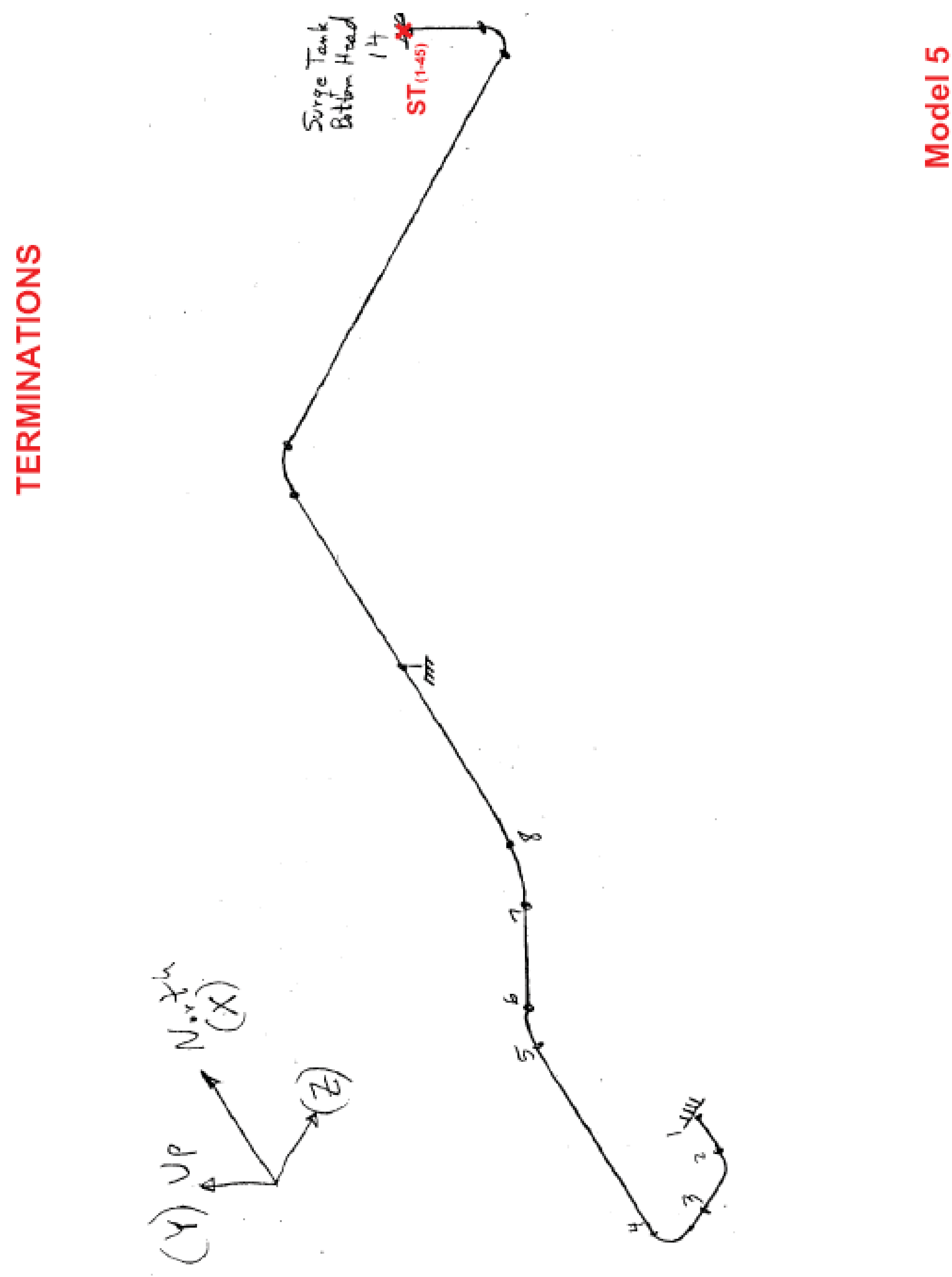

Figure C.1- 23. Terminations Associated with Model 5 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

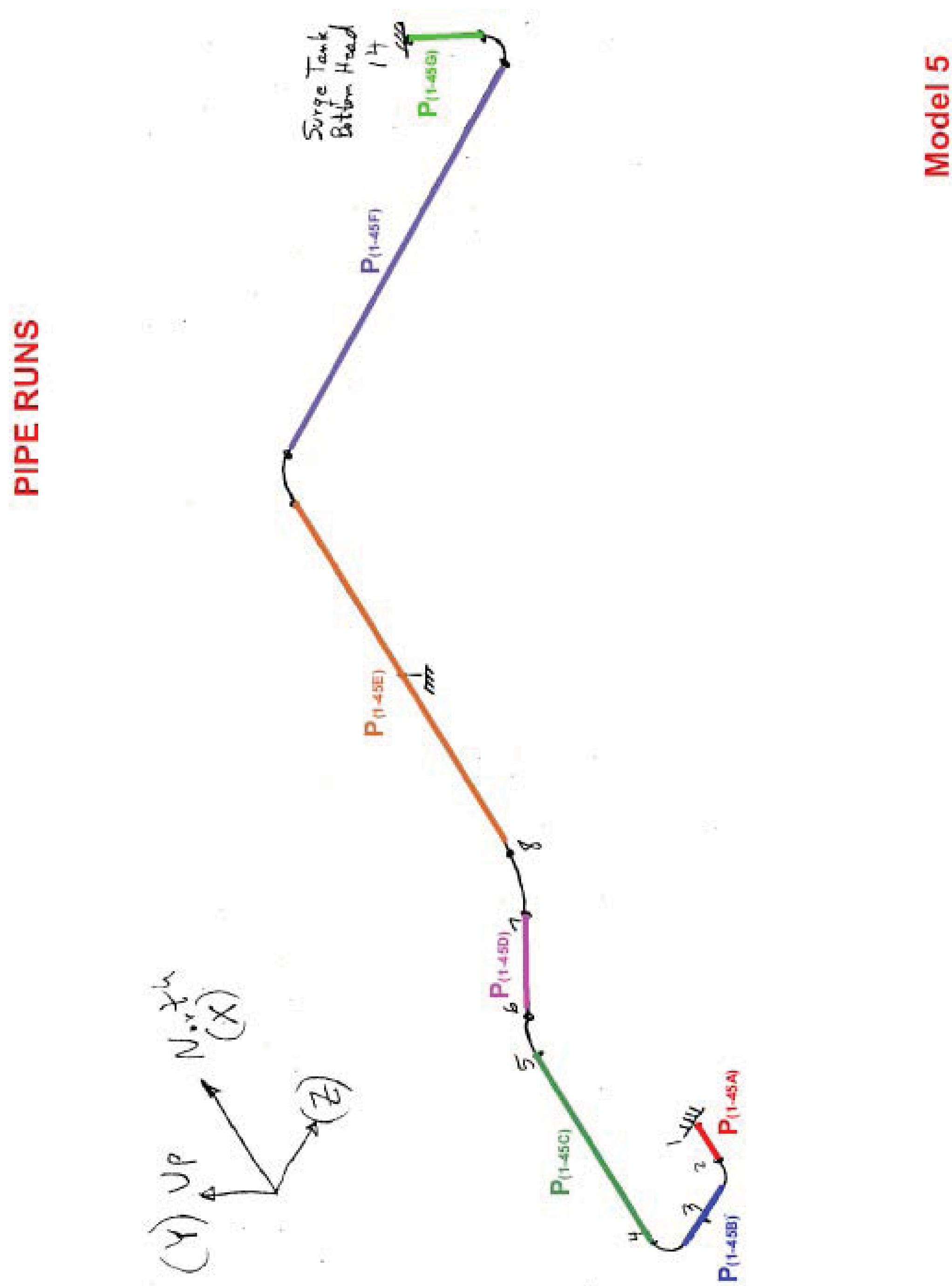

Figure C.1- 24. Pipe Runs Associated with Model 5 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

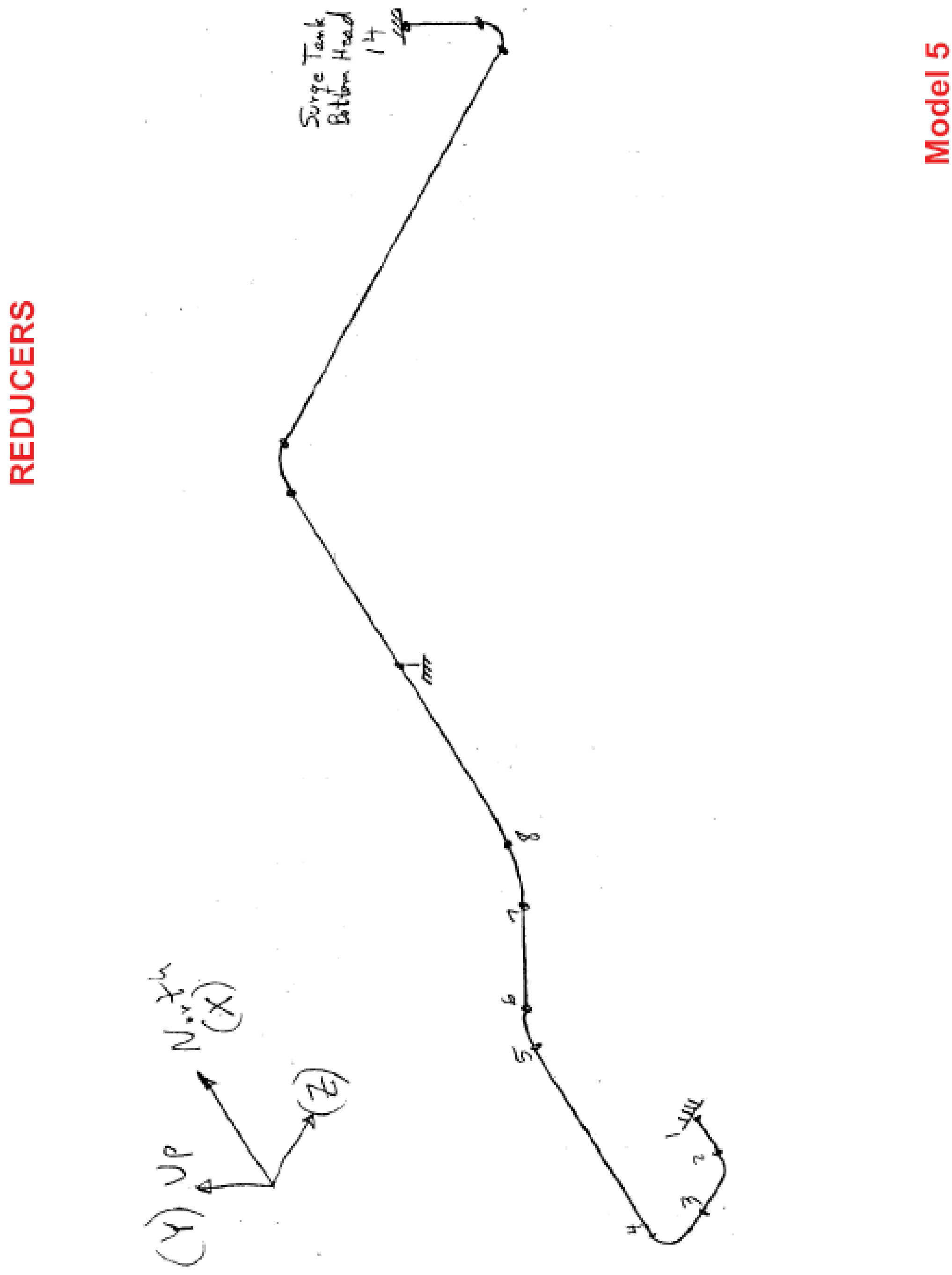

Figure C.1- 25. Reducers Associated with Model 5 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

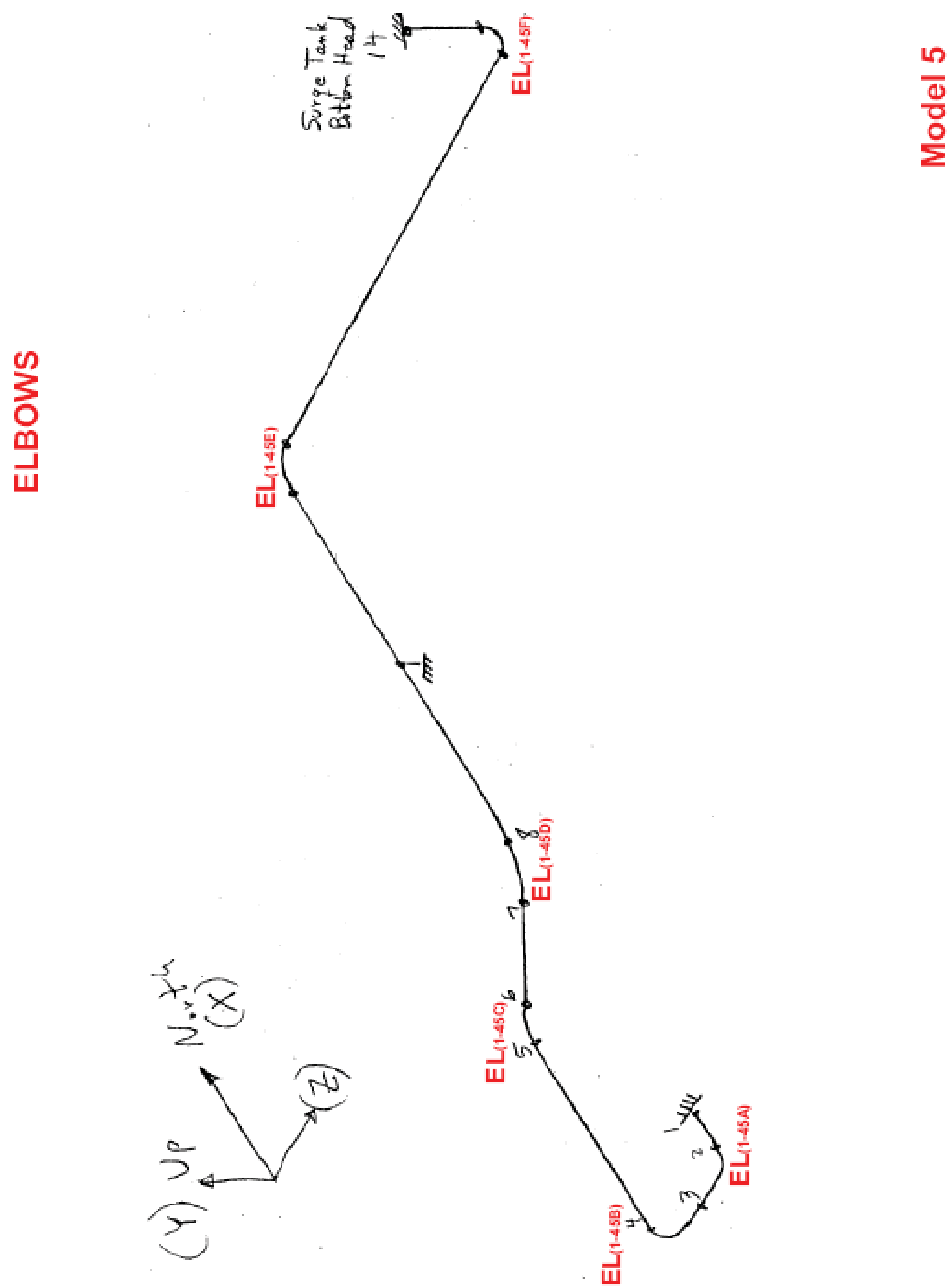

Figure C.1- 26. Elbows Associated with Model 5 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

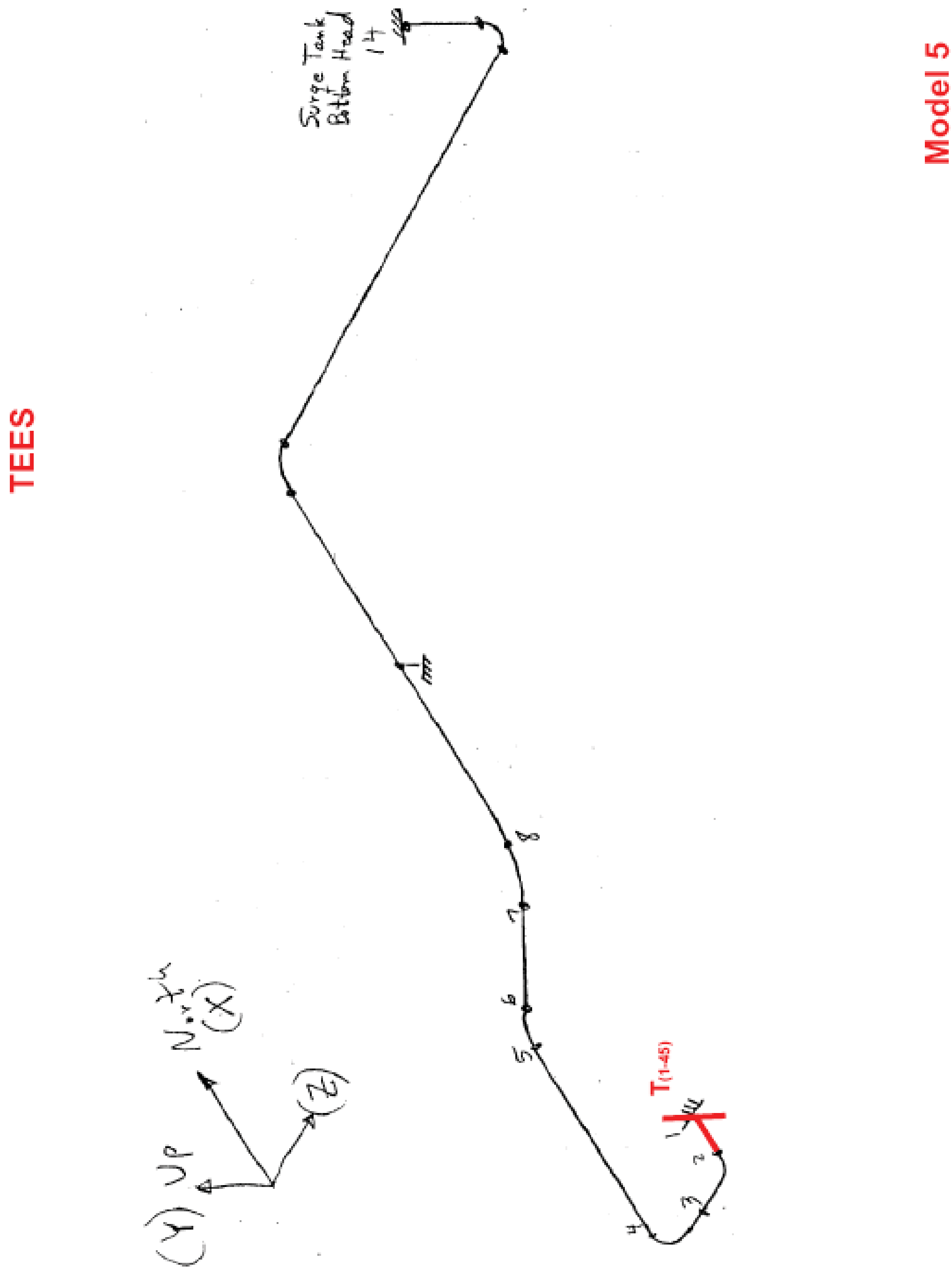

Figure C.1- 27. Tees Associated with Model 5 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

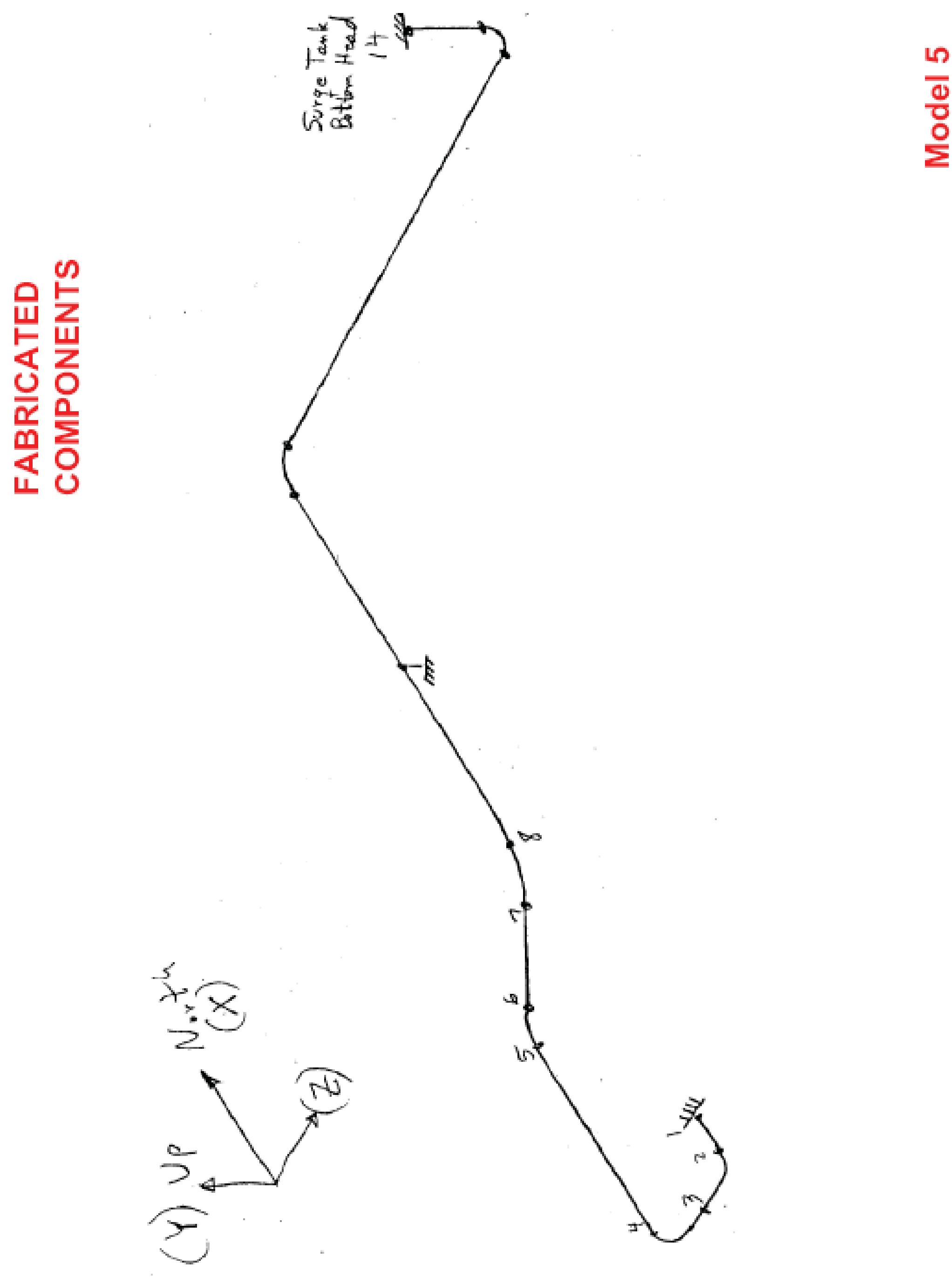

Figure C.1- 28. Fabricated Components Associated with Model 5 [1]

Project:	ATR Life-Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation				
Performer:	A. L. Crawford	**Date:**	09/30/08		
Checker:	R. K. Blandford	**Date:**	09/30/08		

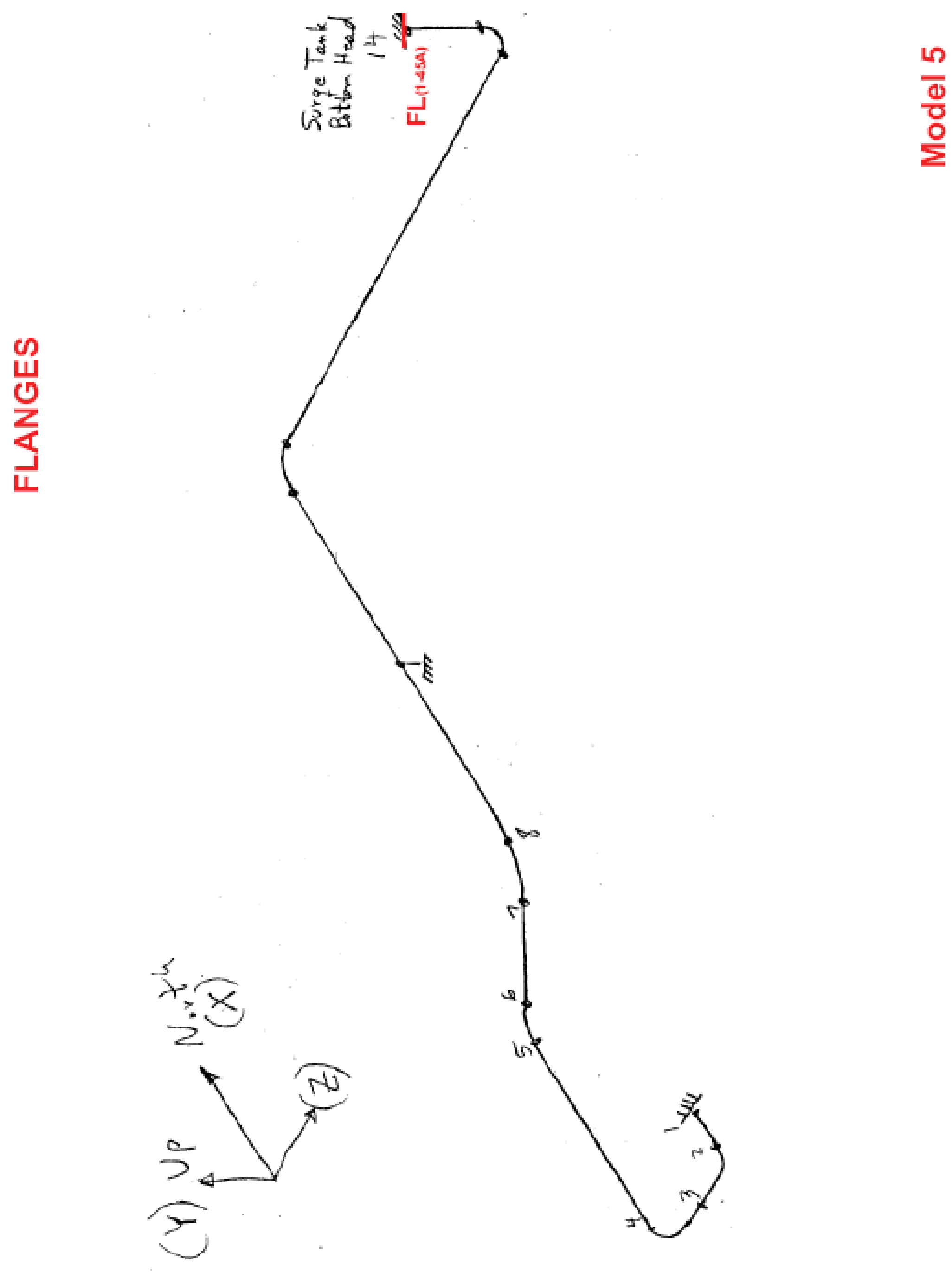

Figure C.1- 29. Flanges Associated with Model 5 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

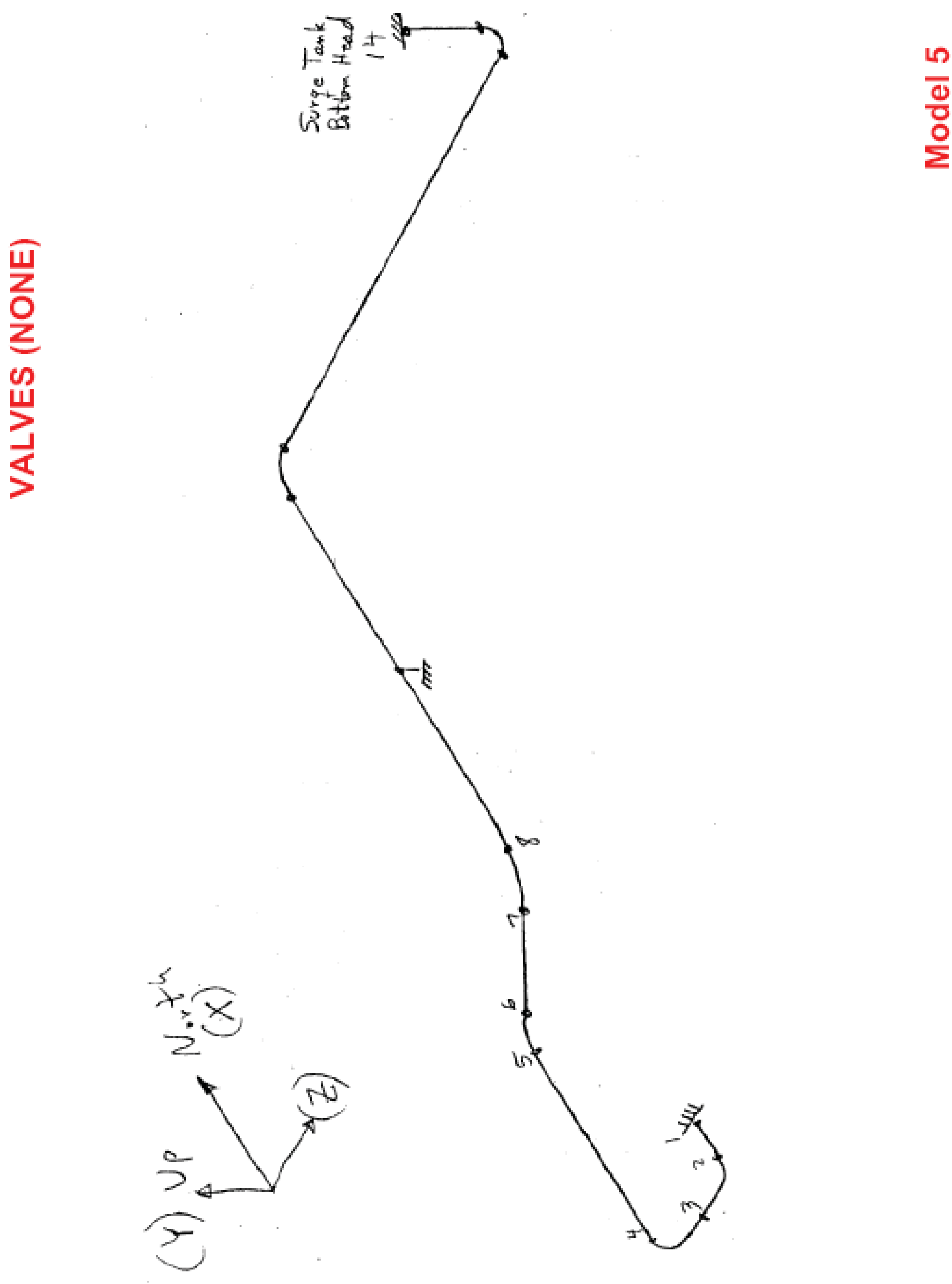

Figure C.1- 30. Valves Associated with Model 5 [1]

Project:	ATR Life-Time Extension Project			**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation						
Performer:	A. L. Crawford	**Date:**	09/30/08	**Checker:**	R. K. Blandford	**Date:**	09/30/08

Appendix C.2

I-DEAS Model of Model 2-6-5

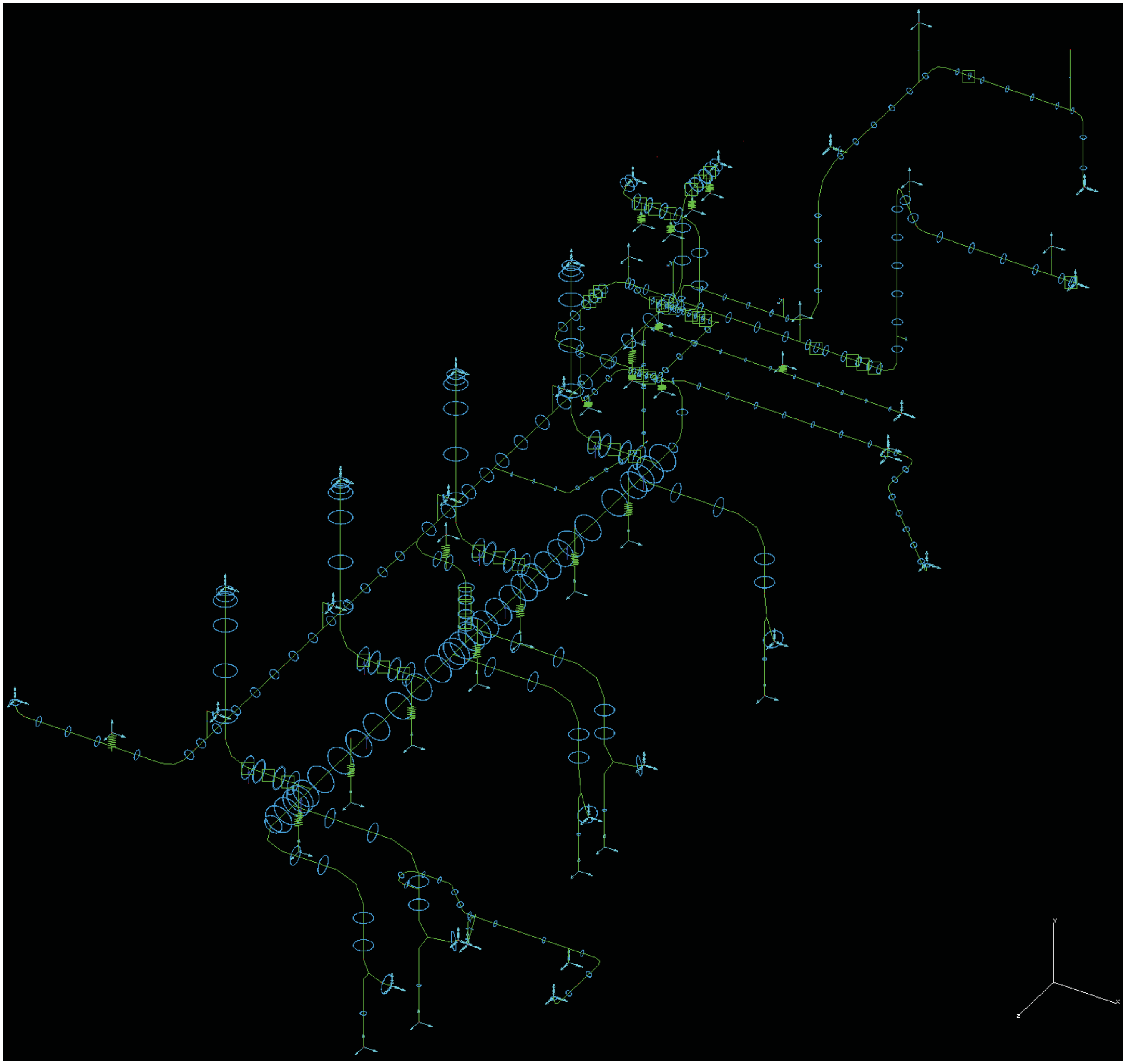

Figure C.2-1. Complete Model 2-6-5 Piping System

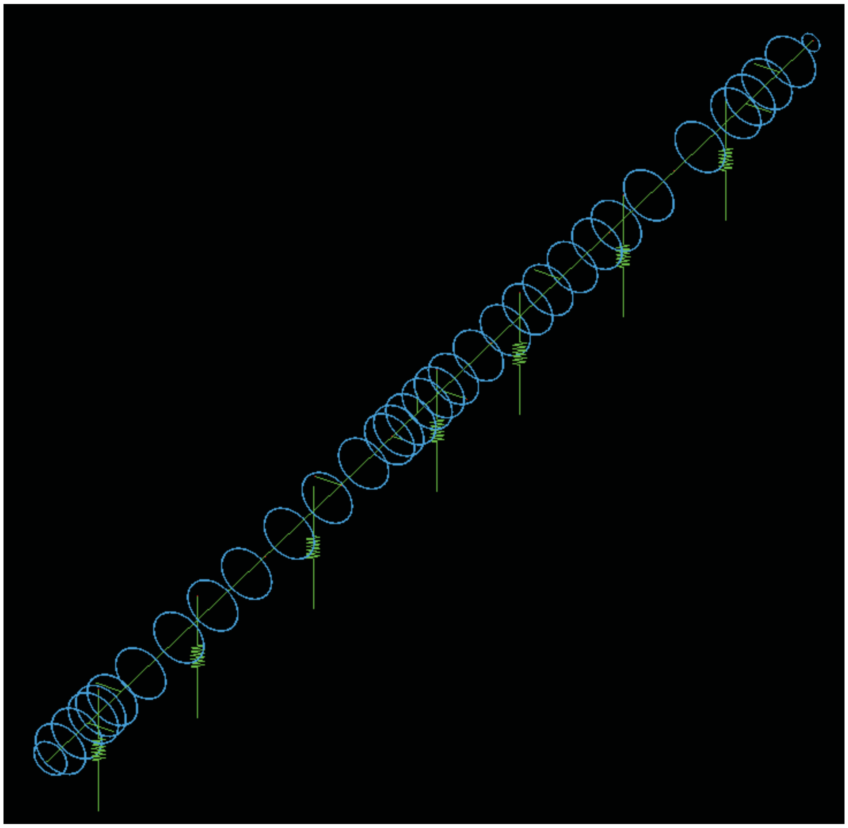

Figure C.2-2. Components Associated with Line 1-17 of Model 2

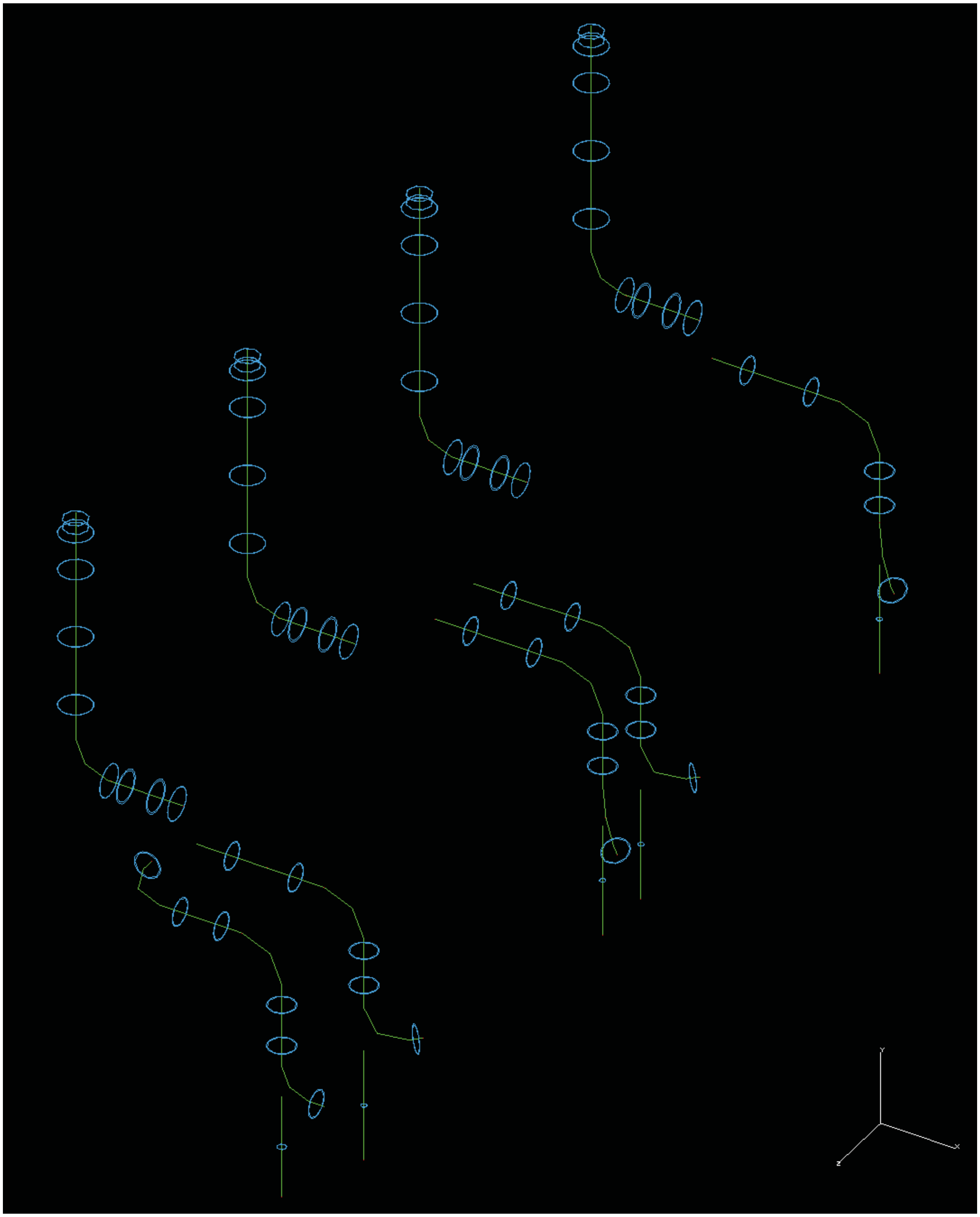

Figure C.2-3. Components Associated With Lines 13-16, 18-21, and 171 of Model 2

Project:	ATR Life-Time Extension Project			**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation						
Performer:	A. L. Crawford	**Date:**	09/30/08	**Checker:**	R. K. Blandford	**Date:**	09/30/08

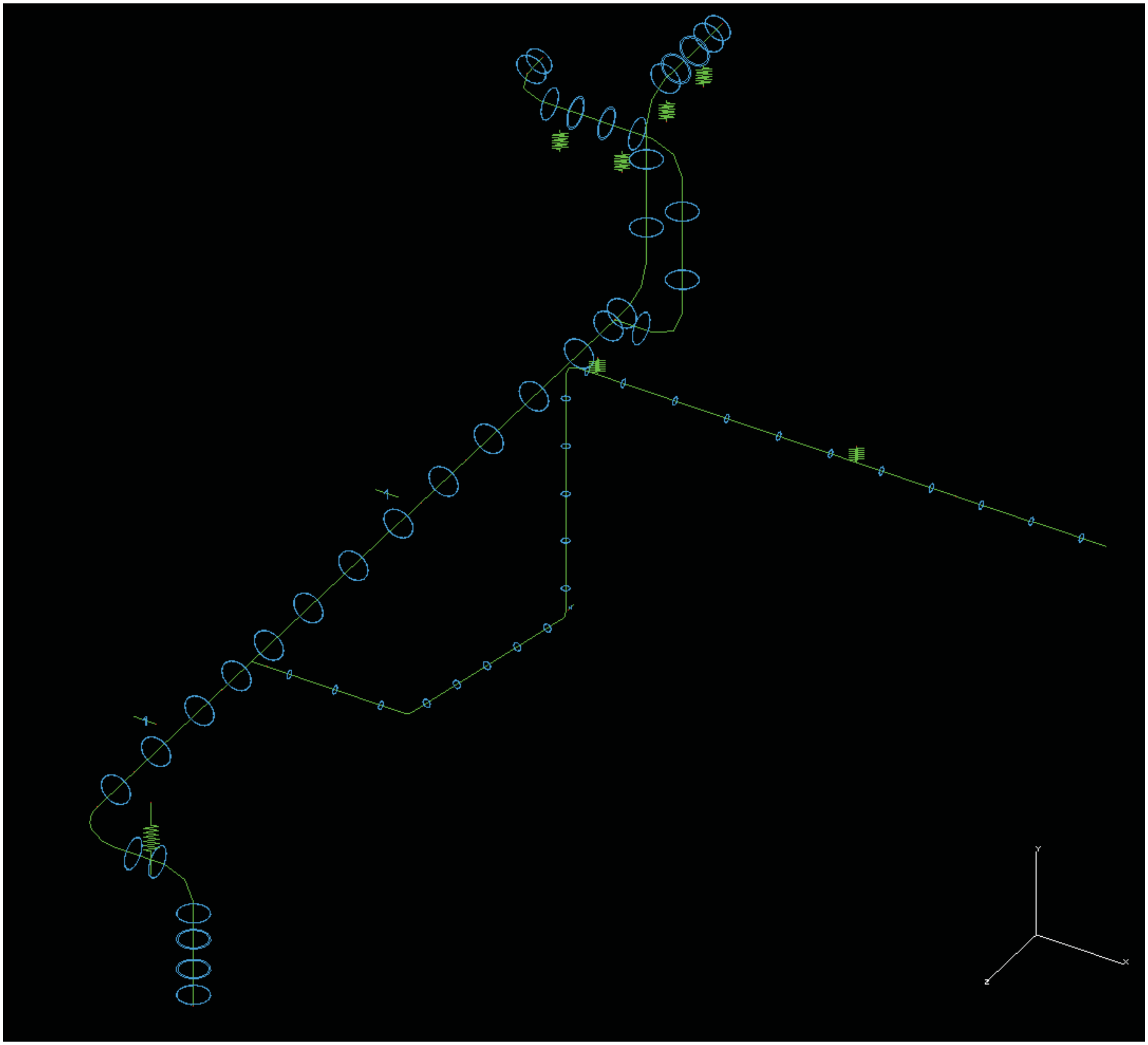

Figure C.2-4. Components Associated With Lines 30-31 and 48 of Model 2

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

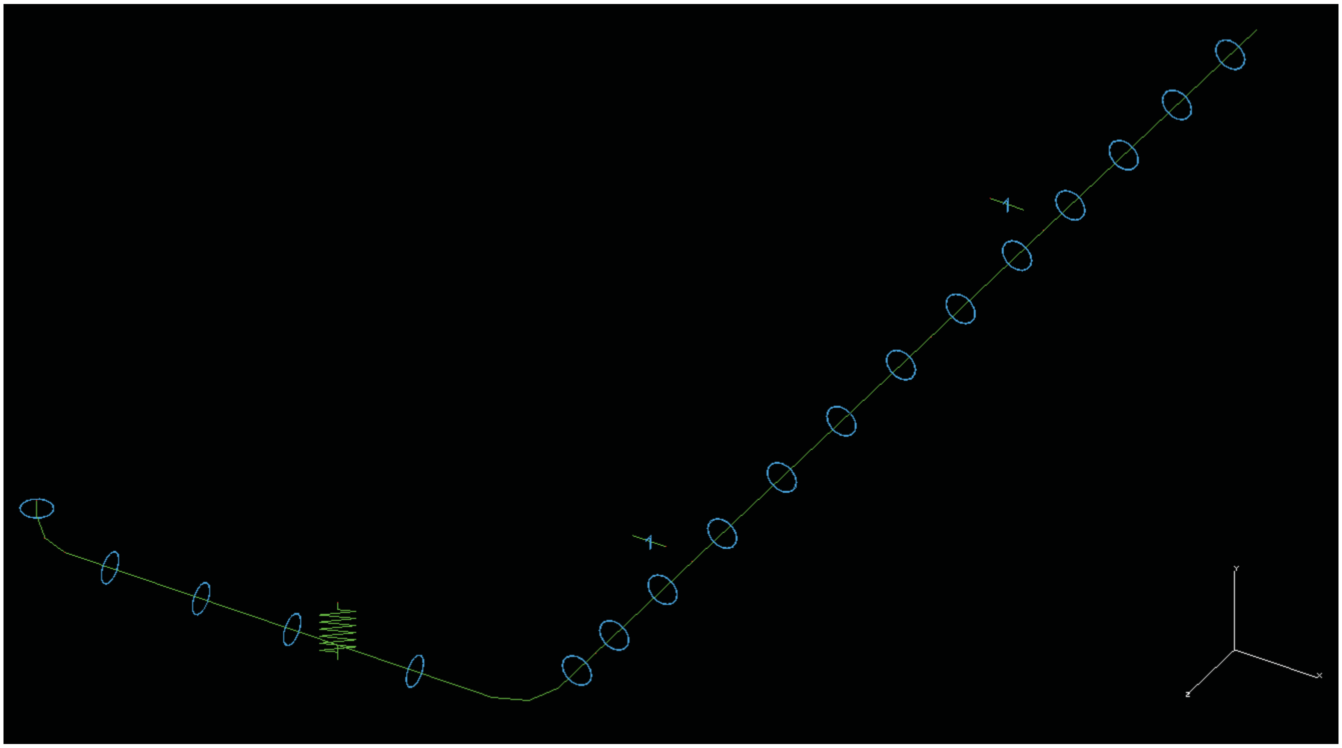

Figure C.2-5. Components Associated With Lines 8-14 of Model 2

Project:	ATR Life-Time Extension Project			**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation						
Performer:	A. L. Crawford	**Date:**	09/30/08	**Checker:**	R. K. Blandford	**Date:**	09/30/08

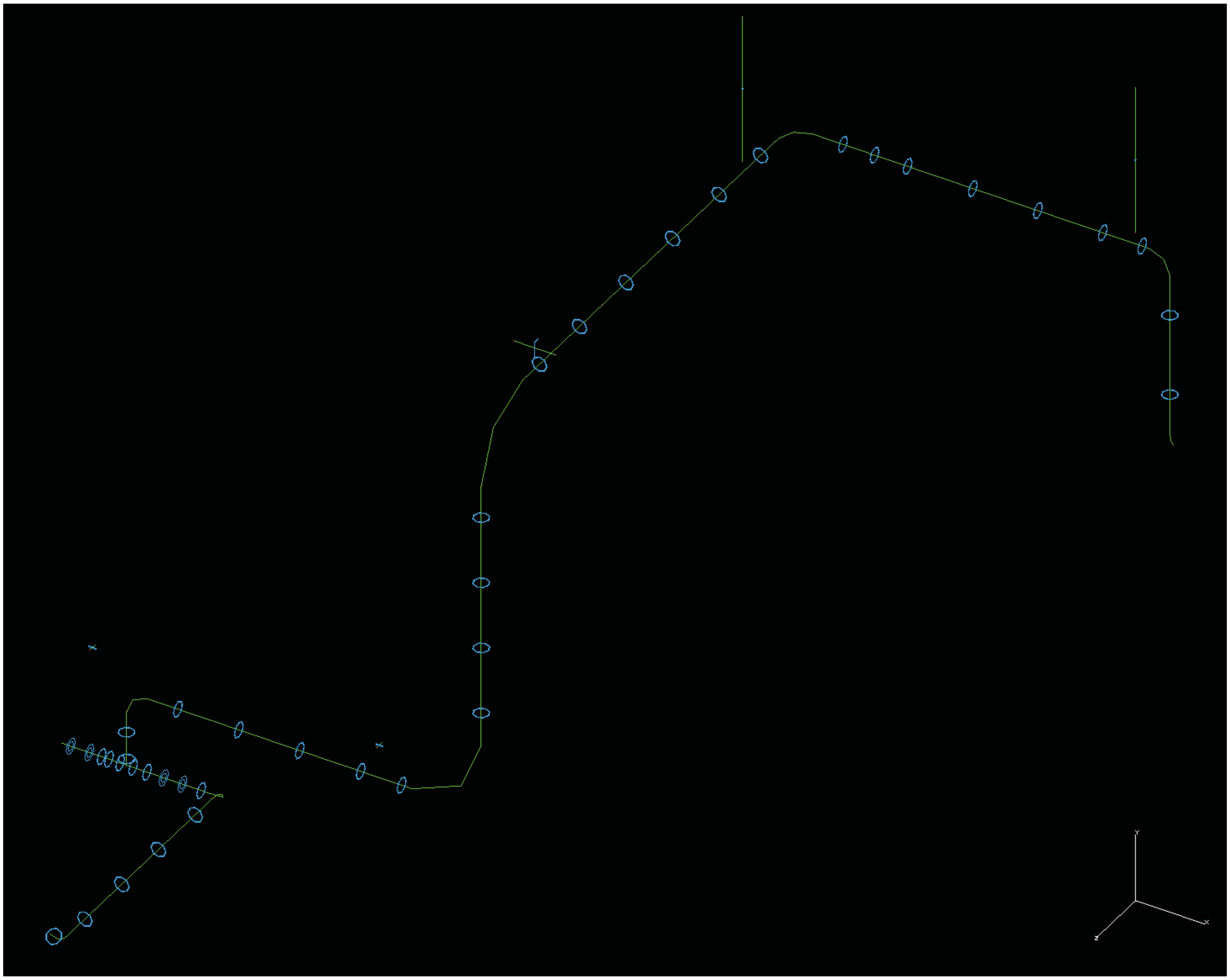

Figure C.2-6. Components Associated With Lines 44 and 46 of Model 6

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

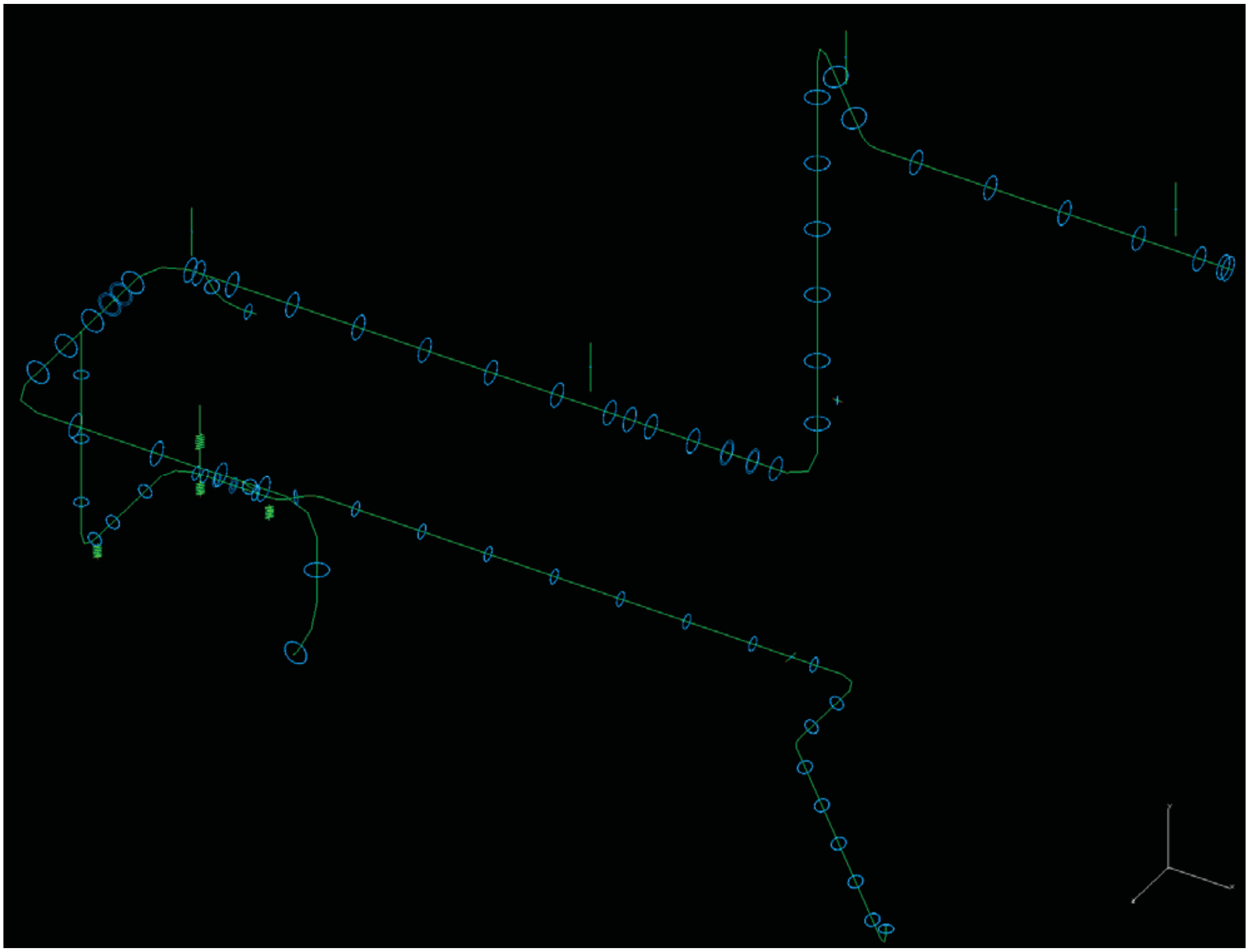

Figure C.2-7. Components Associated With Lines 43 and 47 of Model 6

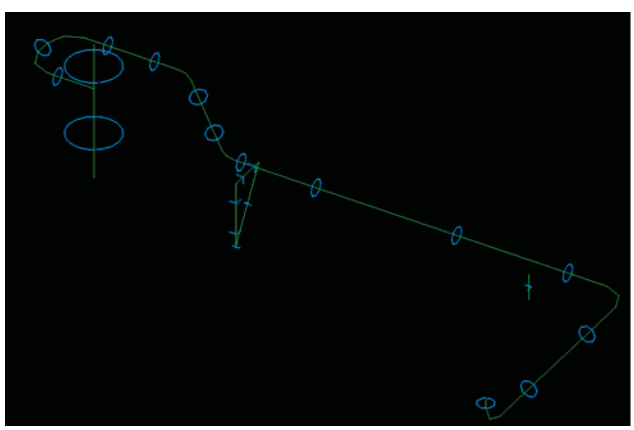

Figure C.2-8. Components Associated With Line 45 of Model 5

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

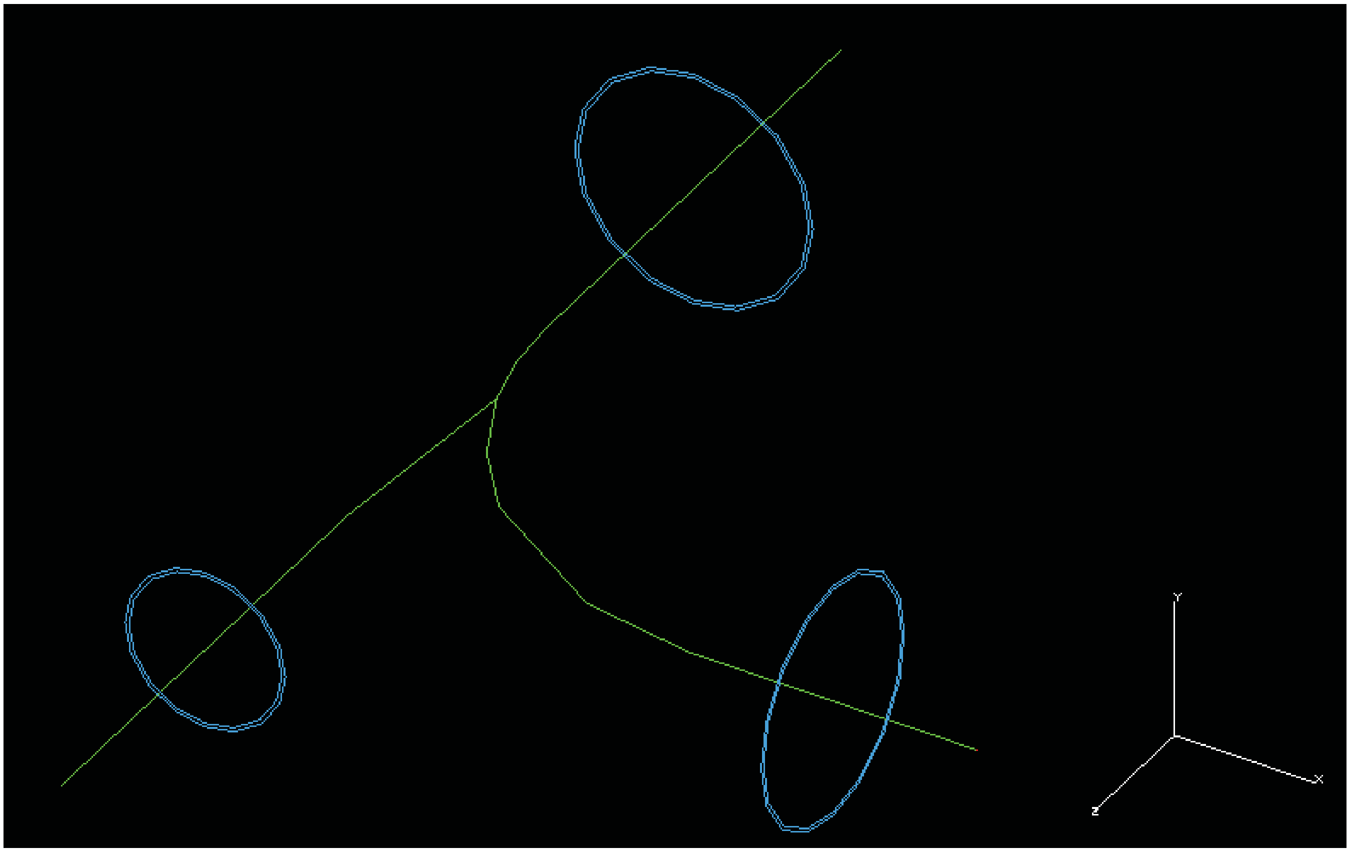

Figure C.2-9. Components Associated With Nonstandard Elbow of Model 2

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

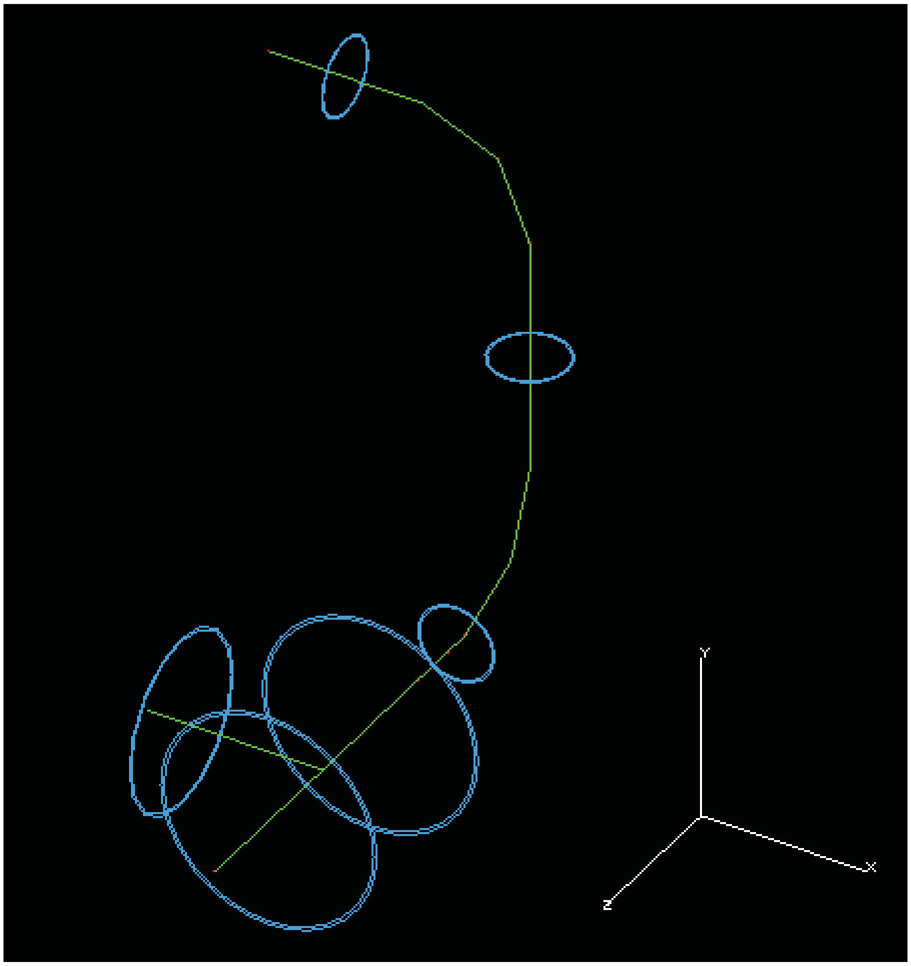

Figure C.2-10. Components Associated With Nonstandard Reducer Connecting Model 2 to Model 6

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

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**%                     ... TEMPERATURE : deg Fahrenheit
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     46,      59,      65
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    603,      64,     933
*ELEMENT, TYPE=B31      , ELSET=PIPE_41
     49,      60,    1055
*ELEMENT, TYPE=B31      , ELSET=PIPE_42
     91,     113,     122
     92,     122,     114
*ELEMENT, TYPE=B31      , ELSET=PIPE_43
    613,     122,    1019
*ELEMENT, TYPE=B31      , ELSET=PIPE_44
    118,     177,     176
    119,     176,     175
*ELEMENT, TYPE=B31      , ELSET=PIPE_45
    302,     176,     672
*ELEMENT, TYPE=B31      , ELSET=PIPE_46
    176,     262,     261
    177,     261,     234
*ELEMENT, TYPE=B31      , ELSET=PIPE_47
    170,     229,     230
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    270,     620,     238
*ELEMENT, TYPE=B31      , ELSET=PIPE_48
    652,    1053,     284
*ELEMENT, TYPE=B31      , ELSET=PIPE_49
    271,     261,     626
*ELEMENT, TYPE=B31      , ELSET=PIPE_50
    212,     230,    1053
    225,     238,    1054
*ELEMENT, TYPE=B31      , ELSET=PIPE_51
     40,       3,     917
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    578,     920,      25
*ELEMENT, TYPE=B31      , ELSET=PIPE_52
    395,     158,     914
    567,     914,     159
*ELEMENT, TYPE=B31      , ELSET=PIPE_53
    394,      67,     916
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    573,     916,     145
*ELEMENT, TYPE=B31      , ELSET=PIPE_54
    389,     234,     921
    583,     921,     235
*ELEMENT, TYPE=B31      , ELSET=PIPE_55
    390,     241,     922
    585,     922,     242
*ELEMENT, TYPE=B31      , ELSET=PIPE_56
    391,     634,     923
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    589,     925,     296
*ELEMENT, TYPE=B31      , ELSET=ELBOW
    107,     141,     138
*ELEMENT, TYPE=B32      , ELSET=ELBOW_1
    492,     140,     813,     138
*ELEMENT, TYPE=B32      , ELSET=ELBOW_2
    493,     136,     134,     135
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(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    502,    110,     93,    105
*ELEMENT, TYPE=B32      , ELSET=ELBOW_3
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(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    501,    126,    763,    117
*ELEMENT, TYPE=B32      , ELSET=ELBOW_4
    494,    143,    133,    132
*ELEMENT, TYPE=B32      , ELSET=ELBOW_5
    540,    674,    791,    675
*ELEMENT, TYPE=B32      , ELSET=ELBOW_6
    542,    680,    754,    681
*ELEMENT, TYPE=B32      , ELSET=ELBOW_7
    612,    678,    943,    677
*ELEMENT, TYPE=B32      , ELSET=ELBOW_8
    503,      6,      2,      7
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
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*ELEMENT, TYPE=B32      , ELSET=ELBOW_9
    507,    146,    147,    148
    510,    186,    749,    188
*ELEMENT, TYPE=B32      , ELSET=ELBOW_10
    509,    184,    744,    185
*ELEMENT, TYPE=B32      , ELSET=ELBOW_11
    508,    153,    742,    154
    511,    156,    748,    157
*ELEMENT, TYPE=B32      , ELSET=ELBOW_12
    512,    192,    750,    193
*ELEMENT, TYPE=B32      , ELSET=ELBOW_13
    513,    164,    909,    905
    514,    905,    913,    893
    515,    893,    912,    165
*ELEMENT, TYPE=B32      , ELSET=ELBOW_14
    490,    200,    199,    201
*ELEMENT, TYPE=B32      , ELSET=ELBOW_15
    517,    228,    756,    229
*ELEMENT, TYPE=B32      , ELSET=ELBOW_16
    520,    244,    724,    245
*ELEMENT, TYPE=B32      , ELSET=ELBOW_17
    521,    247,    797,    250
*ELEMENT, TYPE=B32      , ELSET=ELBOW_18
    516,    224,    758,    226
*ELEMENT, TYPE=B32      , ELSET=ELBOW_19
    518,    232,    722,    233
*ELEMENT, TYPE=B32      , ELSET=ELBOW_20
    491,    202,    198,    203
    519,    281,    720,    237
    522,    264,    794,    263
*ELEMENT, TYPE=B32      , ELSET=ELBOW_21
    533,    349,    807,    805
*ELEMENT, TYPE=B32      , ELSET=ELBOW_22
    539,    301,    740,    302
*ELEMENT, TYPE=B32      , ELSET=ELBOW_23
    528,    667,    710,    668
*ELEMENT, TYPE=B32      , ELSET=ELBOW_24
    626,   1013,   1028,   1014
*ELEMENT, TYPE=B32      , ELSET=ELBOW_25
    621,   1007,   1022,   1008
*ELEMENT, TYPE=B32      , ELSET=ELBOW_26
    524,    632,    716,    633
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    625,   1011,   1029,   1012
*ELEMENT, TYPE=B32      , ELSET=ELBOW_27
    532,    288,    804,    290
*ELEMENT, TYPE=B32      , ELSET=ELBOW_28
    535,    320,    733,    321
*ELEMENT, TYPE=B32      , ELSET=ELBOW_29
    523,    629,    718,    630
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(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)

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*ELEMENT, TYPE=B32     , ELSET=ELBOW_30
    537,    324,    736,    325
*ELEMENT, TYPE=B32     , ELSET=ELBOW_31
    538,    330,    730,    331
*MPC
 BEAM,    613,    614
*MPC
 BEAM,    306,    611
*MPC
 BEAM,    333,    604
*MPC
 BEAM,    602,    603
*MPC
 BEAM,    624,    251
*MPC
 BEAM,    640,    637
*MPC
 BEAM,    643,    642
*MPC
 BEAM,    645,    636
*MPC
 BEAM,    616,    268
*MPC
 BEAM,    618,    265
*MPC
 BEAM,    623,    254
*MPC
 BEAM,    621,    620
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 BEAM,    827,    763
*MPC
 BEAM,    826,    764
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 BEAM,    825,    765
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 BEAM,    766,    824
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 BEAM,    823,    813
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 BEAM,    835,    653
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 BEAM,    150,    818
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 BEAM,    841,    678
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 BEAM,    845,    190
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 BEAM,    846,    189
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 BEAM,    843,    158
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 BEAM,    844,    159
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 BEAM,    853,    172
*MPC
 BEAM,    852,    851
*MPC
 BEAM,    856,    207
*MPC
 BEAM,    859,    181
*MPC
 BEAM,    864,     85
*MPC
 BEAM,    868,     89
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 BEAM,    862,     81
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 BEAM,    874,    873
*MPC
 BEAM,    877,     76
*MPC
 BEAM,    875,     74
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 BEAM,    887,    886
*MPC
 BEAM,    884,     82
*MPC
 BEAM,    883,    882
*MPC
 BEAM,    880,     77
*MPC
 BEAM,    878,     70
*MPC
 BEAM,    892,     24
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 BEAM,    891,     17
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 BEAM,    890,     10
*MPC
 BEAM,    889,      3
*MPC
 BEAM,    926,    273
*MPC
 BEAM,    867,   1139
*MPC
 BEAM,    871,   1140
*ELEMENT, TYPE=SPRINGA , ELSET=RH24_SPRING
    409,    695,    816
    410,    815,    693
*ELEMENT, TYPE=SPRINGA , ELSET=PS10_SPRING
    413,    640,    641
    414,    643,    644
    415,    645,    646
*ELEMENT, TYPE=SPRINGA , ELSET=RH19_SPRING
    416,    624,    625
*ELEMENT, TYPE=SPRINGA , ELSET=PS4_SPRING
    433,    845,    847
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    436,    844,    850
*ELEMENT, TYPE=SPRINGA , ELSET=RH26X8-14_SPRING
    443,    856,    222
*ELEMENT, TYPE=SPRINGA , ELSET=RH32_SPRING
    445,    859,    860
*ELEMENT, TYPE=SPRINGA , ELSET=PR6_SPRING
    464,    863,    862
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    471,    878,    879
*ELEMENT, TYPE=MASS    , ELSET=LMASS24LAP
    545,      3
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    552,     25
*ELEMENT, TYPE=MASS    , ELSET=LMASS16LAP
    563,    158
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    572,    145
*ELEMENT, TYPE=MASS    , ELSET=LMASS10LAP
    559,    242
    560,    241
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    609,    934
*ELEMENT, TYPE=MASS    , ELSET=LMASS6LAP
    553,    295
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(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    558,    634
*ELEMENT, TYPE=MASS    , ELSET=LMASS16GT_SUCTION
    569,    914
    570,    915
*ELEMENT, TYPE=MASS    , ELSET=LMASS16CK
    574,    916
*ELEMENT, TYPE=MASS    , ELSET=LMASS24GT
    579,    920
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    582,    917
*ELEMENT, TYPE=MASS    , ELSET=LMASS10GT
    584,    921
*ELEMENT, TYPE=MASS    , ELSET=LMASS10GB
    586,    922
*ELEMENT, TYPE=MASS    , ELSET=LMASS6GT
    590,    925
    591,    924
    592,    923
*ELEMENT, TYPE=MASS    , ELSET=LMASS6WNF
    610,    317
    611,    318
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**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=A7_STEEL
*ELASTIC,TYPE=ISOTROPIC
 3.00000E+07,  2.90000E-01
*DENSITY
 7.31737E-04,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE4_5X0_237
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_1,
 SECTION=PIPE
 0.22500E+01, 0.23700E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: ROD0_625
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_2,
 SECTION=CIRC
 0.31250E+00,
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: ROD0_75
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_3,
 SECTION=CIRC
 0.37500E+00,
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: ANGLE1_5X1_5X0_1875
**%
*BEAM GENERAL SECTION,
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 ELSET=BEAM_4,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.53112E+00, 0.44829E-01, 0.00000E+00, 0.17121E+00, 0.67404E-02, 0, 0.00000E+00
-0.70710E+00,-0.70710E+00, 0.00000E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00,-0.48686E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**%INFO: THE ABOVE CROSS SECTION CANNOT BE TRANSLATED TO AN
**%INFO: ABAQUS LIBRARY SECTION AND HENCE IS WRITTEN AS BEAM
**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
**%
**% I-DEAS BEAM CROSS SECTION: ANGLE1_5X1_5X0_1875
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_5,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.53112E+00, 0.44829E-01, 0.00000E+00, 0.17121E+00, 0.67404E-02, 0, 0.00000E+00
-0.70710E+00, 0.00000E+00,-0.70710E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00,-0.48686E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
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**%INFO: THE ABOVE CROSS SECTION CANNOT BE TRANSLATED TO AN
**%INFO: ABAQUS LIBRARY SECTION AND HENCE IS WRITTEN AS BEAM
**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
**%
**% I-DEAS BEAM CROSS SECTION: ANGLE1_5X1_5X0_1875
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_6,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.53112E+00, 0.44829E-01, 0.00000E+00, 0.17121E+00, 0.67404E-02, 0, 0.00000E+00
-0.70710E+00, 0.62521E+00,-0.33030E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00,-0.48686E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**%INFO: THE ABOVE CROSS SECTION CANNOT BE TRANSLATED TO AN
**%INFO: ABAQUS LIBRARY SECTION AND HENCE IS WRITTEN AS BEAM
**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
**%
**% I-DEAS BEAM CROSS SECTION: ANGLE1_5X1_5X0_1875
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_7,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.53112E+00, 0.44829E-01, 0.00000E+00, 0.17121E+00, 0.67404E-02, 0, 0.00000E+00
 0.70710E+00, 0.00000E+00,-0.70710E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
```

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

```
*SHEAR CENTER
 0.00000E+00,-0.48686E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
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**%INFO: THE ABOVE CROSS SECTION CANNOT BE TRANSLATED TO AN
**%INFO: ABAQUS LIBRARY SECTION AND HENCE IS WRITTEN AS BEAM
**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
**%
**% I-DEAS BEAM CROSS SECTION: ANGLE5_0X3_0X0_5
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_8,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.37768E+01, 0.10229E+02, 0.00000E+00, 0.15786E+01, 0.34085E+00, 0, 0.00000E+00
 0.00000E+00,-0.33444E+00, 0.94241E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
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*SHEAR CENTER
-0.95274E+00,-0.12368E+01
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
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**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
**%
**% I-DEAS BEAM CROSS SECTION: ANGLE3_0X4_375X0_375
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_9,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.37651E+01, 0.15362E+01, 0.00000E+00, 0.21902E+02, 0.18475E+00, 0, 0.00000E+00
 0.00000E+00,-0.98296E+00, 0.18378E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
-0.24537E+01,-0.84509E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
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**%INFO: THE ABOVE CROSS SECTION CANNOT BE TRANSLATED TO AN
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**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
**%
**% I-DEAS BEAM CROSS SECTION: ANGLE1_75X1_75_0_25
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_10 ,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.81921E+00, 0.92892E-01, 0.00000E+00, 0.35176E+00, 0.18699E-01, 0, 0.00000E+00
 0.70710E+00, 0.70710E+00, 0.00000E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00,-0.56083E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**%INFO: THE ABOVE CROSS SECTION CANNOT BE TRANSLATED TO AN
**%INFO: ABAQUS LIBRARY SECTION AND HENCE IS WRITTEN AS BEAM
**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
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**%
**% I-DEAS BEAM CROSS SECTION: RECT0_5X4_0
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_11 ,
 SECTION=RECT
 0.50000E+00, 0.40000E+01
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: RECT3_0X0_5
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_12 ,
 SECTION=RECT
 0.30000E+01, 0.50000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: ANGLE4_0X3_0X0_5
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_13 ,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.32768E+01, 0.59991E+01, 0.00000E+00, 0.13108E+01, 0.29918E+00, 0, 0.00000E+00
-0.87872E+00,-0.47732E+00, 0.00000E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
-0.10010E+01,-0.66503E+00
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**%INFO: GENERAL SECTION (SECTION=GENERAL).
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**%
**% I-DEAS BEAM CROSS SECTION: ANGLE3_0X3_0X0_5
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*BEAM GENERAL SECTION,
 ELSET=BEAM_14 ,
 DENSITY= 0.73174E-03,
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 0.27768E+01, 0.91043E+00, 0.00000E+00, 0.34046E+01, 0.25752E+00, 0, 0.00000E+00
-0.70710E+00,-0.36380E+00,-0.60633E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
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*SHEAR CENTER
 0.00000E+00,-0.94507E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
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**%INFO: GENERAL SECTION (SECTION=GENERAL).
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**%
**% I-DEAS BEAM CROSS SECTION: ANGLE3_0X3_0X0_5
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_15 ,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
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-0.70710E+00, 0.00000E+00, 0.70710E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
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Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

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*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00,-0.94507E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
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**%INFO: THE ABOVE CROSS SECTION CANNOT BE TRANSLATED TO AN
**%INFO: ABAQUS LIBRARY SECTION AND HENCE IS WRITTEN AS BEAM
**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
**%
**% I-DEAS BEAM CROSS SECTION: ANGLE3_0X3_0X0_5
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_16 ,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.27768E+01, 0.91043E+00, 0.00000E+00, 0.34046E+01, 0.25752E+00, 0, 0.00000E+00
-0.70710E+00, 0.70710E+00, 0.00000E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00,-0.94507E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
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**%INFO: THE ABOVE CROSS SECTION CANNOT BE TRANSLATED TO AN
**%INFO: ABAQUS LIBRARY SECTION AND HENCE IS WRITTEN AS BEAM
**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
**%
**% I-DEAS BEAM CROSS SECTION: ANGLE2_5X2_5X0_25
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_17 ,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.11942E+01, 0.28548E+00, 0.00000E+00, 0.11021E+01, 0.26511E-01, 0, 0.00000E+00
 0.70710E+00, 0.00000E+00, 0.70710E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00,-0.82582E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**%INFO: THE ABOVE CROSS SECTION CANNOT BE TRANSLATED TO AN
**%INFO: ABAQUS LIBRARY SECTION AND HENCE IS WRITTEN AS BEAM
**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
**%
**% I-DEAS BEAM CROSS SECTION: RECTANGLE3_0X0_5
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_18 ,
 SECTION=RECT
 0.30000E+01, 0.50000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: UBOLT_STIFF_ELEMENT
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_19 ,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.55763E+02, 0.50000E+03, 0.00000E+00, 0.50000E+03, 0.20000E+05, 0, 0.00000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
```

```
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304_20X0312,
 ELSET=PIPE,
 SECTION=PIPE
 0.10000E+02, 0.31200E+00
-0.70710E+00, 0.00000E+00,-0.70710E+00
*MATERIAL,NAME=SST304_20X0312
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15200E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304_20X0312,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.10000E+02, 0.31200E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304_20X0312,
 ELSET=PIPE_2,
 SECTION=PIPE
 0.10000E+02, 0.31200E+00
 0.70710E+00, 0.00000E+00,-0.70710E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE18_0X0_3125
**%
*BEAM SECTION,
 MATERIAL=SST304_18X0312,
 ELSET=PIPE_3,
 SECTION=PIPE
 0.90000E+01, 0.31250E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_18X0312
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.00200E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE4_5X0_237
**%
*BEAM SECTION,
 MATERIAL=SST304_4X0237 ,
 ELSET=PIPE_4,
 SECTION=PIPE
 0.22500E+01, 0.23700E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_4X0237
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.10000E-03,
```

```
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304_24X0375,
 ELSET=PIPE_5,
 SECTION=PIPE
 0.12000E+02, 0.37500E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_24X0375
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE16_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_16X025 ,
 ELSET=PIPE_6,
 SECTION=PIPE
 0.80000E+01, 0.25000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_16X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE16_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_16X025 ,
 ELSET=PIPE_7,
 SECTION=PIPE
 0.80000E+01, 0.25000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE16_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_16X025 ,
 ELSET=PIPE_8,
 SECTION=PIPE
 0.80000E+01, 0.25000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_438
**%
*BEAM SECTION,
 MATERIAL=SST304_30X0438,
 ELSET=PIPE_9,
 SECTION=PIPE
 0.15000E+02, 0.43800E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_30X0438
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.25000E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: FABREDUCER30_0TO10_75
**%
*BEAM GENERAL SECTION,
```

```
 ELSET=PIPE_10 ,
 DENSITY= 0.22500E-02,
 ZERO= 0.00000E+00
 0.82470E+01, 0.55467E+02, 0.00000E+00, 0.55467E+02, 0.34747E+03, 0, 0.00000E+00
 0.00000E+00, 0.10000E+01, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00

*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE10_75X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_10X025 ,
 ELSET=PIPE_11 ,
 SECTION=PIPE
 0.53750E+01, 0.25000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_10X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.66000E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE10_75X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_10X025 ,
 ELSET=PIPE_12 ,
 SECTION=PIPE
 0.53750E+01, 0.25000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE10_75X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_10X025 ,
 ELSET=PIPE_13 ,
 SECTION=PIPE
 0.53750E+01, 0.25000E+00
 0.70707E+00, 0.00000E+00,-0.70714E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE10_75X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_10X025 ,
 ELSET=PIPE_14 ,
 SECTION=PIPE
 0.53750E+01, 0.25000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: BR_16X10_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_15 ,
 DENSITY= 0.16600E-02,
 ZERO= 0.00000E+00
 0.82470E+01, 0.11371E+03, 0.00000E+00, 0.11371E+03, 0.10374E+03, 0, 0.00000E+00
-0.99636E+00, 0.00000E+00,-0.85150E-01
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
```

```
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6X028,
 ELSET=PIPE_16 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
-0.70710E+00, 0.00000E+00,-0.70710E+00
*MATERIAL,NAME=SST304_6X028
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.20900E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6X028,
 ELSET=PIPE_17 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6X028,
 ELSET=PIPE_18 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6X028,
 ELSET=PIPE_19 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.00000E+00, 0.51517E+00,-0.85708E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6X028,
 ELSET=PIPE_20 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.70710E+00, 0.00000E+00,-0.70710E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6X028,
 ELSET=PIPE_21 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE16_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_RED16X025,
 ELSET=PIPE_22 ,
 SECTION=PIPE
```

```
 0.80000E+01, 0.25000E+00
 0.00000E+00,-0.99741E+00,-0.71910E-01
*MATERIAL,NAME=SST304_RED16X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE16_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_RED16X025,
 ELSET=PIPE_23 ,
 SECTION=PIPE
 0.80000E+01, 0.25000E+00
 0.44000E-03,-0.99816E+00,-0.60510E-01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE14_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_RED14X025,
 ELSET=PIPE_24 ,
 SECTION=PIPE
 0.70000E+01, 0.25000E+00
-0.44000E-03,-0.99816E+00,-0.60470E-01
*MATERIAL,NAME=SST304_RED14X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.96300E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE14_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_RED14X025,
 ELSET=PIPE_25 ,
 SECTION=PIPE
 0.70000E+01, 0.25000E+00
 0.00000E+00,-0.99741E+00,-0.71850E-01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304_RED24X0375 ,
 ELSET=PIPE_26 ,
 SECTION=PIPE
 0.12000E+02, 0.37500E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_RED24X0375
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE18_0X0_3125
**%
*BEAM SECTION,
 MATERIAL=SST304_RED18X0312 ,
 ELSET=PIPE_27 ,
 SECTION=PIPE
 0.90000E+01, 0.31250E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_RED18X0312
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
```

```
*DENSITY
 2.00200E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: RED30_0X0_5
**%
*BEAM SECTION,
 MATERIAL=SST304_RED30X05 ,
 ELSET=PIPE_28 ,
 SECTION=PIPE
 0.15000E+02, 0.50000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_RED30X05
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.00200E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: RED20_0X0_5
**%
*BEAM SECTION,
 MATERIAL=SST304_RED20X05 ,
 ELSET=PIPE_29 ,
 SECTION=PIPE
 0.10000E+02, 0.50000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_RED20X05
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.59000E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE16_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_T16X025,
 ELSET=PIPE_30 ,
 SECTION=PIPE
 0.80000E+01, 0.25000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_T16X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE16_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_T16X025,
 ELSET=PIPE_31 ,
 SECTION=PIPE
 0.80000E+01, 0.25000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE16_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_T16X025,
 ELSET=PIPE_32 ,
 SECTION=PIPE
 0.80000E+01, 0.25000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: BR_16X16_BRANCH
```

```
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_33 ,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.14987E+02, 0.00000E+00, 0.42389E+02, 0.76733E+03, 0, 0.00000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_T6X028 ,
 ELSET=PIPE_34 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_T6X028
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.20900E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_438
**%
*BEAM SECTION,
 MATERIAL=SST304_B30X0438_R ,
 ELSET=PIPE_35 ,
 SECTION=PIPE
 0.15000E+02, 0.43800E+00
-0.10000E+01, 0.00000E+00,-0.10000E-04
*MATERIAL,NAME=SST304_B30X0438_R
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.25500E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_438
**%
*BEAM SECTION,
 MATERIAL=SST304_B30X0438_R ,
 ELSET=PIPE_36 ,
 SECTION=PIPE
 0.15000E+02, 0.43800E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: RED30_0X0_5
**%
*BEAM SECTION,
 MATERIAL=SST304_B30X0438_R ,
 ELSET=PIPE_37 ,
 SECTION=PIPE
 0.15000E+02, 0.50000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304_B24X0312_BR,
 ELSET=PIPE_38 ,
 SECTION=PIPE
```

```
 0.12000E+02, 0.37500E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_B24X0312_BR
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: BR_30X24_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_39 ,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.27833E+02, 0.52149E+02, 0.00000E+00, 0.22323E+03, 0.10760E+04, 0, 0.00000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: BR_30X20_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_40 ,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.19298E+02, 0.32379E+02, 0.00000E+00, 0.14610E+03, 0.13652E+04, 0, 0.00000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: BR_30X16_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_41 ,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.12370E+02, 0.15890E+02, 0.00000E+00, 0.75887E+02, 0.76733E+03, 0, 0.00000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304_B20X0312_R ,
 ELSET=PIPE_42 ,
 SECTION=PIPE
 0.10000E+02, 0.31200E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_B20X0312_R
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15200E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
```

```
**%
**% I-DEAS BEAM CROSS SECTION: BR_20X6_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_43 ,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55810E+01, 0.49250E+01, 0.00000E+00, 0.14691E+02, 0.56284E+02, 0, 0.00000E+00
 0.00000E+00,-0.10000E+01, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE16_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_B16X025_R,
 ELSET=PIPE_44 ,
 SECTION=PIPE
 0.80000E+01, 0.25000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_B16X025_R
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: BR_16X4_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_45 ,
 DENSITY= 0.11000E-02,
 ZERO= 0.00000E+00
 0.31740E+01, 0.48600E+00, 0.00000E+00, 0.19450E+01, 0.14465E+02, 0, 0.00000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE10_75X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_B10X025_R,
 ELSET=PIPE_46 ,
 SECTION=PIPE
 0.53750E+01, 0.25000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_B10X025_R
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.66000E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE10_75X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_B10X025_R,
 ELSET=PIPE_47 ,
 SECTION=PIPE
 0.53750E+01, 0.25000E+00
```

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

```
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_B6X0625_BR ,
 ELSET=PIPE_48 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.00000E+00, 0.70710E+00,-0.70710E+00
*MATERIAL,NAME=SST304_B6X0625_BR
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.20900E-03,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: BR_10X6_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_49 ,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55810E+01, 0.68370E+00, 0.00000E+00, 0.31960E+01, 0.56284E+02, 0, 0.00000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: BR_10X6_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_50 ,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55810E+01, 0.68370E+00, 0.00000E+00, 0.31960E+01, 0.56284E+02, 0, 0.00000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: VALVE24X1_258
**%
*BEAM SECTION,
 MATERIAL=SST304_V24,
 ELSET=PIPE_51 ,
 SECTION=PIPE
 0.12000E+02, 0.12580E+01
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_V24
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.24600E-05,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: VALVE16_0X0_838
**%
*BEAM SECTION,
 MATERIAL=SST304_V16,
 ELSET=PIPE_52 ,
 SECTION=PIPE
```

```
 0.80000E+01, 0.83800E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_V16
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.24700E-05,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: VALVE16_0X0_838
**%
*BEAM SECTION,
 MATERIAL=SST304_V16,
 ELSET=PIPE_53 ,
 SECTION=PIPE
 0.80000E+01, 0.83800E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: VALVE10_75X0_902
**%
*BEAM SECTION,
 MATERIAL=SST304_V10,
 ELSET=PIPE_54 ,
 SECTION=PIPE
 0.53750E+01, 0.90200E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_V10
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.14300E-05,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: VALVE10_75X0_902
**%
*BEAM SECTION,
 MATERIAL=SST304_V10,
 ELSET=PIPE_55 ,
 SECTION=PIPE
 0.53750E+01, 0.90200E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: VALVE6_625X1_417
**%
*BEAM SECTION,
 MATERIAL=SST304_V6 ,
 ELSET=PIPE_56 ,
 SECTION=PIPE
 0.33125E+01, 0.14170E+01
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_V6
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.74600E-05,
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304_20X0312,
 ELSET=ELBOW ,
 SECTION=PIPE
 0.10000E+02, 0.31200E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW20_0X0_3125SR20P253
**%
```

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

```
*BEAM GENERAL SECTION,
 ELSET=ELBOW_1 ,
 DENSITY= 0.21520E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.44494E+02, 0.00000E+00, 0.44494E+02, 0.18734E+04, 0, 0.00000E+00
-0.70710E+00,-0.70710E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW20_0X0_3125LR30P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_2 ,
 DENSITY= 0.21520E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.68452E+02, 0.00000E+00, 0.68452E+02, 0.18734E+04, 0, 0.00000E+00
-0.70710E+00,-0.70710E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW20_0X0_3125LR30P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_3 ,
 DENSITY= 0.21520E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.68452E+02, 0.00000E+00, 0.68452E+02, 0.18734E+04, 0, 0.00000E+00
-0.81649E+00,-0.57734E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW20_0X0_3125LR30P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_4 ,
 DENSITY= 0.21520E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.68452E+02, 0.00000E+00, 0.68452E+02, 0.18734E+04, 0, 0.00000E+00
 0.00000E+00,-0.10000E+01, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW4_5X0_237LR6P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_5 ,
 DENSITY= 0.11000E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.13980E+01, 0.00000E+00, 0.13980E+01, 0.14500E+02, 0, 0.00000E+00
-0.38268E+00, 0.92387E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
```

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

```
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW4_5X0_237LR6P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_6 ,
 DENSITY= 0.11000E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.13980E+01, 0.00000E+00, 0.13980E+01, 0.14500E+02, 0, 0.00000E+00
-0.70711E+00, 0.70709E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW4_5X0_237LR6P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_7 ,
 DENSITY= 0.11000E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.13980E+01, 0.00000E+00, 0.13980E+01, 0.14500E+02, 0, 0.00000E+00
 0.92387E+00,-0.38269E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW24_0X0_375SR24P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_8 ,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.92264E+02, 0.00000E+00, 0.92264E+02, 0.38846E+04, 0, 0.00000E+00
-0.70710E+00,-0.70710E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW16_0X0_25SR16P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_9 ,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.18225E+02, 0.00000E+00, 0.18225E+02, 0.76730E+03, 0, 0.00000E+00
-0.70710E+00,-0.70710E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW16_0X0_25SR16P253
**%
*BEAM GENERAL SECTION,
```

```
 ELSET=ELBOW_10,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.18225E+02, 0.00000E+00, 0.18225E+02, 0.76730E+03, 0, 0.00000E+00
-0.70710E+00, 0.70710E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW16_0X0_25SR16P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_11,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.18225E+02, 0.00000E+00, 0.18225E+02, 0.76730E+03, 0, 0.00000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW16_0X0_25SR16P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_12,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.18225E+02, 0.00000E+00, 0.18225E+02, 0.76730E+03, 0, 0.00000E+00
 0.00000E+00,-0.10000E+01, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: FAB_BRANCH16_0X0_25LR24P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_13,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.25207E+02, 0.00000E+00, 0.25207E+02, 0.76730E+03, 0, 0.00000E+00
 0.00000E+00,-0.10000E+01, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW10_75X0_25SR10P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_14,
 DENSITY= 0.16600E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.67620E+01, 0.00000E+00, 0.67620E+01, 0.22740E+03, 0, 0.00000E+00
 0.70710E+00, 0.70710E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
```

```
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW10_75X0_25LR15P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_15,
 DENSITY= 0.16600E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.10254E+02, 0.00000E+00, 0.10254E+02, 0.22740E+03, 0, 0.00000E+00
-0.70710E+00,-0.70710E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW10_75X0_25LR15P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_16,
 DENSITY= 0.16600E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.10254E+02, 0.00000E+00, 0.10254E+02, 0.22740E+03, 0, 0.00000E+00
-0.70710E+00, 0.70710E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW10_75X0_25LR15P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_17,
 DENSITY= 0.16600E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.10254E+02, 0.00000E+00, 0.10254E+02, 0.22740E+03, 0, 0.00000E+00
-0.81649E+00, 0.57734E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW10_75X0_25LR15P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_18,
 DENSITY= 0.16600E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.10254E+02, 0.00000E+00, 0.10254E+02, 0.22740E+03, 0, 0.00000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW10_75X0_25LR15P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_19,
```

```
 DENSITY= 0.16600E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.10254E+02, 0.00000E+00, 0.10254E+02, 0.22740E+03, 0, 0.00000E+00
 0.00000E+00,-0.10000E+01, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW10_75X0_25LR15P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_20,
 DENSITY= 0.16600E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.10254E+02, 0.00000E+00, 0.10254E+02, 0.22740E+03, 0, 0.00000E+00
 0.00000E+00, 0.10000E+01, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28LR9P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_21,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.43650E+01, 0.00000E+00, 0.43650E+01, 0.56300E+02, 0, 0.00000E+00
-0.65075E+00,-0.75929E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28LR9P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_22,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.43650E+01, 0.00000E+00, 0.43650E+01, 0.56300E+02, 0, 0.00000E+00
-0.70710E+00, 0.70710E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28LR9P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_23,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.43650E+01, 0.00000E+00, 0.43650E+01, 0.56300E+02, 0, 0.00000E+00
-0.81649E+00, 0.57734E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
```

```
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28LR9P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_24,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.43650E+01, 0.00000E+00, 0.43650E+01, 0.56300E+02, 0, 0.00000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28LR9P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_25,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.43650E+01, 0.00000E+00, 0.43650E+01, 0.56300E+02, 0, 0.00000E+00
 0.00000E+00,-0.10000E+01, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28LR9P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_26,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.43650E+01, 0.00000E+00, 0.43650E+01, 0.56300E+02, 0, 0.00000E+00
 0.00000E+00, 0.10000E+01, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28LR9P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_27,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.43650E+01, 0.00000E+00, 0.43650E+01, 0.56300E+02, 0, 0.00000E+00
 0.57640E+00,-0.81716E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28LR9P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_28,
 DENSITY= 0.12090E-02,
```

```
 ZERO= 0.00000E+00
 0.27832E+02, 0.43650E+01, 0.00000E+00, 0.43650E+01, 0.56300E+02, 0, 0.00000E+00
 0.70710E+00, 0.70710E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28LR9P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_29,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.43650E+01, 0.00000E+00, 0.43650E+01, 0.56300E+02, 0, 0.00000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28XLR30P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_30,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.14705E+02, 0.00000E+00, 0.14705E+02, 0.56300E+02, 0, 0.00000E+00
-0.70710E+00, 0.70710E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28XLR30P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_31,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.14705E+02, 0.00000E+00, 0.14705E+02, 0.56300E+02, 0, 0.00000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
*SPRING, ELSET=RH24_SPRING,NONLINEAR

    -1.0000E+6, -1.14803
   0.0000E+0, -0.625
   0.0000E+0, 0.0000E+0
   1.0000E+6, 0.52313
*SPRING, ELSET=PS10_SPRING,NONLINEAR

  -1.0000E+6, -0.36782
   0.0000E+0, 0.0000E+0
*SPRING, ELSET=RH19_SPRING,NONLINEAR

   0.0000E+0, 0.0000E+0
   1.0000E+6, 2.08636
```

```
*SPRING, ELSET=PS4_SPRING,NONLINEAR

  -1.0000E+6, -0.13932
   0.0000E+0, 0.0000E+0
*SPRING, ELSET=RH26X8-14_SPRING,NONLINEAR

   0.0000E+0, 0.0000E+0
   1.0000E+6, 0.81498
*SPRING, ELSET=RH32_SPRING

  1E+01,
*SPRING, ELSET=PR6_SPRING

  1E+01,
*MASS, ALPHA=0.4295,
 ELSET=LMASS24LAP
  1.23800E+00,
*MASS, ALPHA=0.4295,
 ELSET=LMASS16LAP
  5.39000E-01,
*MASS, ALPHA=0.4295,
 ELSET=LMASS10LAP
  2.02000E-01,
*MASS, ALPHA=0.4295,
 ELSET=LMASS6LAP
  1.01000E-01,
*MASS, ALPHA=0.4295,
 ELSET=LMASS16GT_SUCTION
  6.47500E+00,
*MASS, ALPHA=0.4295,
 ELSET=LMASS16CK
  8.02900E+00,
*MASS, ALPHA=0.4295,
 ELSET=LMASS24GT
  1.73920E+01,
*MASS, ALPHA=0.4295,
 ELSET=LMASS10GT
  2.83900E+00,
*MASS, ALPHA=0.4295,
 ELSET=LMASS10GB
  3.85000E+00,
*MASS, ALPHA=0.4295,
 ELSET=LMASS6GT
  1.27200E+00,
*MASS, ALPHA=0.4295,
 ELSET=LMASS6WNF
  1.06000E-01,
**%
*ELSET, ELSET=ALLELEMENTS
 BEAM,
 BEAM_1,
 BEAM_2,
 BEAM_3,
 BEAM_4,
 BEAM_5,
 BEAM_6,
 BEAM_7,
 BEAM_8,
 BEAM_9,
 BEAM_10 ,
 BEAM_11 ,
 BEAM_12 ,
 BEAM_13 ,
 BEAM_14 ,
 BEAM_15 ,
 BEAM_16 ,
 BEAM_17 ,
 BEAM_18 ,
```

```
BEAM_19 ,
PIPE,
PIPE_1,
PIPE_2,
PIPE_3,
PIPE_4,
PIPE_5,
PIPE_6,
PIPE_7,
PIPE_8,
PIPE_9,
PIPE_10 ,
PIPE_11 ,
PIPE_12 ,
PIPE_13 ,
PIPE_14 ,
PIPE_15 ,
PIPE_16 ,
PIPE_17 ,
PIPE_18 ,
PIPE_19 ,
PIPE_20 ,
PIPE_21 ,
PIPE_22 ,
PIPE_23 ,
PIPE_24 ,
PIPE_25 ,
PIPE_26 ,
PIPE_27 ,
PIPE_28 ,
PIPE_29 ,
PIPE_30 ,
PIPE_31 ,
PIPE_32 ,
PIPE_33 ,
PIPE_34 ,
PIPE_35 ,
PIPE_36 ,
PIPE_37 ,
PIPE_38 ,
PIPE_39 ,
PIPE_40 ,
PIPE_41 ,
PIPE_42 ,
PIPE_43 ,
PIPE_44 ,
PIPE_45 ,
PIPE_46 ,
PIPE_47 ,
PIPE_48 ,
PIPE_49 ,
PIPE_50 ,
PIPE_51 ,
PIPE_52 ,
PIPE_53 ,
PIPE_54 ,
PIPE_55 ,
PIPE_56 ,
ELBOW ,
ELBOW_1 ,
ELBOW_2 ,
ELBOW_3 ,
ELBOW_4 ,
ELBOW_5 ,
ELBOW_6 ,
ELBOW_7 ,
ELBOW_8 ,
ELBOW_9 ,
```

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

```
 ELBOW_10,
 ELBOW_11,
 ELBOW_12,
 ELBOW_13,
 ELBOW_14,
 ELBOW_15,
 ELBOW_16,
 ELBOW_17,
 ELBOW_18,
 ELBOW_19,
 ELBOW_20,
 ELBOW_21,
 ELBOW_22,
 ELBOW_23,
 ELBOW_24,
 ELBOW_25,
 ELBOW_26,
 ELBOW_27,
 ELBOW_28,
 ELBOW_29,
 ELBOW_30,
 ELBOW_31,
 LMASS24LAP,
 RH24_SPRING ,
 PS10_SPRING ,
 RH19_SPRING ,
 PS4_SPRING,
 RH26X8-14_SPRING,
 RH32_SPRING ,
 PR6_SPRING,
 LMASS16LAP,
 LMASS10LAP,
 LMASS6LAP ,
 LMASS16GT_SUCTION ,
 LMASS16CK ,
 LMASS24GT ,
 LMASS10GT ,
 LMASS10GB ,
 LMASS6GT,
 LMASS6WNF ,
**%
*NSET,NSET=ALL
       1,       2,       3,       4,       5,       6,       7,       9,      10,      11,      12
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1138,    1139,    1140
*NSET,NSET=LINES_13-16_18-21_171
       1,       2,       3,       4,       6,       7,       9,      10,      11,      13,      14
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1061,    1063,    1064
*NSET,NSET=LINE_17
       5,      12,      19,      26,      58,      59,      60,      61,      62,      63,      64
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1139,    1140
*NSET,NSET=LINES_30-31_48
      67,     145,     146,     147,     148,     152,     153,     154,     156,     157,     158
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1085,    1086,    1087,    1088
*NSET,NSET=LINES_43_47
     224,     225,     226,     228,     229,     230,     232,     233,     234,     235,     237
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1111,    1112
*NSET,NSET=LINES_44_46_814
     149,     150,     198,     199,     200,     201,     202,     203,     207,     208,     222
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1127,    1130,    1131,    1132,    1133,    1134,    1135,    1136,    1137,    1138
*NSET,NSET=UNLIST_COMPS
      25,      26,      63,     149,     164,     165,     181,     224,     225,     226,     228
     229,     230,     756,     851,     873,     893,     905,     909,     912,     913,    1051
```

```
    1138,
*NSET,NSET=LINE_45
     113,     114,     122,    1006,    1007,    1008,    1009,    1010,    1011,    1012,    1013
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1044,    1045,    1046,    1047
*NSET,NSET=BC_NS_X_N552
       1,      15,      22,      31,     127,     128,     129,     130,     139,     160,     194
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     876,     879,     881,     885,     888,    1006
*NSET,NSET=BC_NS_X_N815
     601,
*NSET,NSET=BC_V_Y_N552
       1,      15,      22,      31,     160,     194,     222,     345,     601,     606,     608
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     869,     876,     879,     881,     885,     888,    1006,    1045,    1047
*NSET,NSET=BC_V_Y_N892
     617,     619
*NSET,NSET=BC_V_Y_N4119
     127,     128,     129,     130,     139,     828,     829,     830,     831,     832
*NSET,NSET=BC_EW_Z_N542
       1,      15,      22,      31,     127,     128,     129,     130,     139,     160,     194
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     869,     876,     879,     881,     885,     888,    1006,    1045,    1047
*ELSET,ELSET=ALL, GENERATE
         1,         8,         1
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
       652,       736,         1
*ELSET,ELSET=SUPPORT_RELEASE
     404,     405,     406,     411,     412,     426,     427,     440,     441,     481,     482
     483,     484,     643,     644
*ELSET,ELSET=LINES_13-16_18-21_171
       1,       2,       3,       4,       5,       6,       7,       8,      13,      14,      16
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     654,     655,     656,     657,     658,     659,     660,     661,     662
*ELSET,ELSET=LINE_17
      15,      31,      39,      44,      46,      47,      48,      49,      50,      51,      54
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     601,     602,     603,     604,     735,     736
*ELSET,ELSET=LINES_30-31_48
     111,     112,     113,     114,     118,     119,     120,     123,     129,     130,     132
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     680,     681,     682,     683,     684,     685,     686
*ELSET,ELSET=LINES_43_47
     167,     168,     170,     171,     172,     174,     175,     176,     177,     180,     181
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     709,     710
*ELSET,ELSET=LINES_44_46_814
     151,     159,     160,     165,     213,     217,     218,     219,     220,     221,     222
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     733,     734
*ELSET,ELSET=UNLIST_COMPS
      39,      78,     113,     114,     166,     167,     168,     170,     489,     513,     514
     515,     516,     517,     604,     649,     734
*ELSET,ELSET=LINE_45
      91,      92,     613,     614,     615,     616,     617,     618,     619,     620,     621
     622,     623,     624,     625,     626,     627,     628,     629,     631,     632,     633
     637,     638,     639,     640,     641,     642,     645
**%
<<--Replace Time History-->> (KEY PHRASE USED IN SCRIPTING PROCESS)
**%
*NSET,NSET=BS000001
222,606,617,619,622,625,641,644,646,815,816,828,829,830,831,832
833,847,848,849,850,860,863,865,869,876,879,881,885
*NSET,NSET=BS000002
1,15,22,31,127,128,129,130,139,160,194,345,601,608,669,682
820,822,857,858,888,1006
*RELEASE
SUPPORT_RELEASE, S1, M1-M2
```

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Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

```
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
**% Note: Nodes vertical is possitive z
**%       Elements vertical is possitive y
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.01
 0.005,1.0,1.0E-08,1.0
**%  STATIC PLUS SEISMIC
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
BS000001,    1, 3,      0.00000E+00
        837,  4, 6,      0.00000E+00
        836,  2,,       0.00000E+00
        836,  4, 6,      0.00000E+00
       1045,  2, 6,      0.00000E+00
       1047,  2, 6,      0.00000E+00
BS000002,    1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
        890,    2, 7.2000E+03
        889,    2, 7.8000E+03
        891,    2, 7.8000E+03
        892,    2, 7.8000E+03
        871,    2, 8.1000E+03
        883,    2, 8.4000E+03
        867,    2, 8.7000E+03
        874,    2, 8.9000E+03
        877,    2, 9.0000E+03
        887,    2, 9.6000E+03
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
**%OUTPUT, FIELD
**%NODE OUTPUT
**%ELEMENT OUTPUT
*OUTPUT, HISTORY,FREQUENCY=10000
**%ELEMENT OUTPUT
*NODE PRINT, TOTAL=YES
*MONITOR, NODE=1, DOF=1
*END STEP
**%
**% ====== SEISMIC WITH G-LOAD ======
**%
**% Note: Damping is address in the material properties
**%
*STEP,INC=10000000,NLGEOM
*DYNAMIC, DIRECT
 0.005,20.0,1.0E-08,0.005
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%
*BOUNDARY,OP=NEW
BS000002,    4, 6,      0.00000E+00
       836,  4, 6,      0.00000E+00
       837,  4, 6,      0.00000E+00
       1045, 4, 6,            0.00000E+00
       1047, 4, 6,      0.00000E+00
*<<--H2_X_N552_TIME_HISTORY_INPUT-->> (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_NS_X_N552, 1,,              1.0000E+00
*<<--H2_X_N815_TIME_HISTORY_INPUT-->> (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_NS_X_N815, 1,,              1.0000E+00
*<<--V_Y_N552_TIME_HISTORY_INPUT-->> (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_V_Y_N552, 2,,               1.0000E+00
*<<--H1_Z_N542_TIME_HISTORY_INPUT-->> (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_EW_Z_N542, 3,,              1.0000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
```

```
        890,    2, 7.2000E+03
        889,    2, 7.8000E+03
        891,    2, 7.8000E+03
        892,    2, 7.8000E+03
        871,    2, 8.1000E+03
        883,    2, 8.4000E+03
        867,    2, 8.7000E+03
        874,    2, 8.9000E+03
        877,    2, 9.0000E+03
        887,    2, 9.6000E+03
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT
 NFORC,SF,S
*OUTPUT, HISTORY,FREQUENCY=1
***NODE OUTPUT, NSET=CRANEND
** U,V,A
***ELEMENT OUTPUT
** UC
*NODE PRINT
*MONITOR, NODE=1, DOF=1
*END STEP
```

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Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

Appendix C.3

Calculations Associated with Model 2-6-5 Seismic Evaluation

Contents

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** R. K. Blandford **Date:** 09/30/2008

Appendix C.3.1

Demand to Capacity Ratio Calculations for Components Associated with Line 1-17 of ATR PCS Model 265

(NOTE: Values represented here are shown for one realization (Nodal Force file = LINE17_test_R1.dat and Element/Nodal order file = EL_17.xls) and may or may not be consistent with the 80th percentile results contained in Appendix C.4)

Force Outputs from Abaqus

NF := ...\LINES_17.dat — (N)odal (F)orces for the (M)edium (L)ines of Model 3

Defined Elemental and Corresponding Nodal Order

EL := ...\EL_17(9-22-08).xls — Element and corresponding nodal order for the (M)edium (L)ines of Model 3

Time Boundaries

$t_{initial} := 1$ — Initial time for which dynamic loading is applied

$t_{final} := 21$ — Final time for which dynamic loading stops

Seismic Scale Factor (F_a)

$F_a := 1$ — Seismic scale factor

Allowable Design Stress Intensity Factor (S_m): *S_m is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{m\_125} := 20\text{ksi}$ — For SS304 at 125°F [2, pg 312-314] [3, pg 23]

$S_{m\_125L} := 16.7\text{ksi}$ — For SS304L at 125°F [2, pg 312-314] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Yield Strength (S_y): *S_y is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{y\_125} := 28.35\text{ksi}$ — For SS304 at 125°F [2, pg 642-644] [3, pg 23]

$S_{y\_125L} := 23.85\text{ksi}$ — For SS304L at 125°F [2, pg 642-644] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Maximum Strength Applicable for Equation 9 (S): *S is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{125} := \min\left(3 \cdot S_{m\_125}, 2 \cdot S_{y\_125}\right)$ — Maximum allowable stress applied to SS304 piping [9, NB-3656]

$\boxed{S_{125} = 56.7\,\text{ksi}}$

$S_{125L} := \min\left(3 \cdot S_{m\_125L}, 2 \cdot S_{y\_125L}\right)$ — Maximum allowable stress applied to SS304L piping [9, NB-3656]

$\boxed{S_{125L} = 47.7\,\text{ksi}}$

SUPPORTS

Supports Strategy: *Search based on the node for which the support acts. If this node is a termination point there will only be one node to evaluate. If this node is in line with a section of pipe there will be two representations of the same node (one for each element on each side of the node) to combine and the difference between them is the force required of the support. The D/C ratio for each support will be found by dividing the the required force found above by the support capacity.*

$$\mathrm{SupDC}(P_r, P_c) := \frac{P_r}{P_c}$$

$$\mathrm{Support}(nf, nd, C_o, EL) :=$$

$$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$$

$$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$$

$$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$$

$$\text{for } i \in 1 .. \mathrm{last}(nd) \quad \text{if } \mathrm{rows}(nd) > 1$$

$$\quad ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$$

$$\begin{pmatrix} Int1_5 & Int2_5 \end{pmatrix} \leftarrow \begin{pmatrix} 0 & 0 \end{pmatrix}$$

$$\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$$

$$\quad \text{for } j \in 0 .. \mathrm{last}(ind_{nd})$$

$$\quad\quad P_{rg_j} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}-1},\, ind_{nd_j}}$$

$$\quad\quad P_{r_j} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}-1}+i,\, ind_{nd_j}} - P_{rg_j}\right) \cdot C_{o_{2,0}} + P_{rg_j}$$

$$\quad PR_i \leftarrow \sum_{n=0}^{j} P_{r_n}$$

$$\quad \text{if } PR_i < Int1_1 \wedge C_{o_{0,0}} \neq 0$$

$$\quad\quad Int1' \leftarrow \mathrm{SupDC}\left(\left|PR_i\right|, C_{o_{0,0}}\right)$$

$$\quad\quad Int1 \leftarrow \mathrm{stack}\left(Int1', PR_i, nf_{ind_{nfi_{C_{o_{0,1}}}-1}+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd}\right)$$

$$\quad \text{if } PR_i > Int2_1 \wedge C_{o_{1,0}} \neq 0$$

$$\quad\quad Int2' \leftarrow \mathrm{SupDC}\left(\left|PR_i\right|, C_{o_{1,0}}\right)$$

$$\quad\quad Int2 \leftarrow \mathrm{stack}\left(Int2', PR_i, nf_{ind_{nfi_{C_{o_{0,1}}}-1}+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd}\right)$$

$$\begin{pmatrix} Int1 & Int2 \end{pmatrix}$$

PR-6 Support (7x)

$P_{1\_PR6} := \frac{0 \cdot kip}{lbf}$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.10.1]

$P_{2\_PR6} := \frac{11.256 \cdot kip}{lbf}$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.10.1]

$$Sup\_C_{o\_PR6} := \begin{pmatrix} P_{1\_PR6} & 2 \\ P_{2\_PR6} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3

PR-6A (Node 876)

PR-6A vertically supports line 1-171 just east of Tfrom any upward movement supports EL(1-13A) on line 1-13.

$nd876_{PR6A_0} := 876$ Node associated with support

$$\left(AL1_{PR6A\_nd876} \;\; AL2_{PR6A\_nd876}\right) := Support\left(NF, nd876_{PR6A}, Sup\_C_{o\_PR6}, EL\right)$$

$$AL1_{PR6A\_nd876}^{T} = (0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0)$$

$$AL2_{PR6A\_nd876}^{T} = \left(2.466 \times 10^{-4} \;\; 2.775 \;\; 10.04 \;\; 876 \;\; 86\right)$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PR-6B (Node 885)

PR-6B vertically supports EL(1-14A) on line 1-14.

$nd885_{PR6B_0} := 885$ Node associated with support

$$\left(AL1_{PR6B\_nd885} \;\; AL2_{PR6B\_nd885}\right) := Support\left(NF, nd885_{PR6B}, Sup\_C_{o\_PR6}, EL\right)$$

$$AL1_{PR6B\_nd885}^{T} = (0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0)$$

$$AL2_{PR6B\_nd885}^{T} = \left(2.405 \times 10^{-4} \;\; 2.707 \;\; 10.045 \;\; 885 \;\; 84\right)$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PR-6C (Node 881)

PR-6C vertically supports EL(1-15A) on line 1-15.

$nd881_{PR6C_0} := 881$ Node associated with support

$$\left(AL1_{PR6C\_nd881} \;\; AL2_{PR6C\_nd881}\right) := Support\left(NF, nd881_{PR6C}, Sup\_C_{o\_PR6}, EL\right)$$

$$AL1_{PR6C\_nd881}^{T} = (0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0)$$

$$AL2_{PR6C\_nd881}^{T} = \left(2.267 \times 10^{-4} \;\; 2.552 \;\; 10.055 \;\; 881 \;\; 82\right)$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

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PR-6D (Node 879)

PR-6D vertically supports EL(1-16A) on line 1-16.

$nd879_{PR6D_0} := 879$ Node associated with support

$\left(AL1_{PR6D\_nd879} \;\; AL2_{PR6D\_nd879}\right) := Support\left(NF, nd879_{PR6D}, Sup\_C_{o\_PR6}, EL\right)$

$AL1_{PR6D\_nd879}{}^{T} = (0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0)$

$AL2_{PR6D\_nd879}{}^{T} = \left(2.289 \times 10^{-4} \;\; 2.577 \;\; 4.005 \;\; 879 \;\; 88\right)$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PR-6E (Node 865)

PR-6E vertically supports EL(1-14A) on line 1-14.

$nd865_{PR6E_0} := 865$ Node associated with support

$\left(AL1_{PR6E\_nd865} \;\; AL2_{PR6E\_nd865}\right) := Support\left(NF, nd865_{PR6E}, Sup\_C_{o\_PR6}, EL\right)$

$AL1_{PR6E\_nd865}{}^{T} = (0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0)$

$AL2_{PR6E\_nd865}{}^{T} = \left(2.381 \times 10^{-4} \;\; 2.68 \;\; 4.005 \;\; 865 \;\; 80\right)$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PR-6F (Node 869)

PR-6F vertically supports EL(1-15A) on line 1-15.

$nd869_{PR6F_0} := 869$ Node associated with support

$\left(AL1_{PR6F\_nd869} \;\; AL2_{PR6F\_nd869}\right) := Support\left(NF, nd869_{PR6F}, Sup\_C_{o\_PR6}, EL\right)$

$AL1_{PR6F\_nd869}{}^{T} = (0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0)$

$AL2_{PR6F\_nd869}{}^{T} = \left(2.432 \times 10^{-4} \;\; 2.737 \;\; 7.66 \;\; 869 \;\; 78\right)$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PR-6G (Node 863)

PR-6G vertically supports EL(1-16A) on line 1-16.

$nd863_{PR6G_0} := 863$ Node associated with support

$\left(AL1_{PR6G\_nd863} \;\; AL2_{PR6G\_nd863}\right) := Support\left(NF, nd863_{PR6G}, Sup\_C_{o\_PR6}, EL\right)$

$AL1_{PR6G\_nd863}{}^{T} = (0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0)$

$AL2_{PR6G\_nd863}{}^{T} = \left(2.584 \times 10^{-4} \;\; 2.909 \;\; 8.85 \;\; 863 \;\; 76\right)$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

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Writing Output Data for Supports Associated with Line 17

$SA1 := AL1_{PR6A\_nd876}^{T}$ PR-6 Compression

$SA2 := AL2_{PR6A\_nd876}^{T}$ PR-6 Tension

$SB1 := AL1_{PR6B\_nd885}^{T}$ PR-6 Compression

$SB2 := AL2_{PR6B\_nd885}^{T}$ PR-6 Tension

$SC1 := AL1_{PR6C\_nd881}^{T}$ PR-6 Compression

$SC2 := AL2_{PR6C\_nd881}^{T}$ PR-6 Tension

$SD1 := AL1_{PR6D\_nd879}^{T}$ PR-6 Compression

$SD2 := AL2_{PR6D\_nd879}^{T}$ PR-6 Tension

$SE1 := AL1_{PR6E\_nd865}^{T}$ PR-6 Compression

$SE2 := AL2_{PR6E\_nd865}^{T}$ PR-6 Tension

$SF1 := AL1_{PR6F\_nd869}^{T}$ PR-6 Compression

$SF2 := AL2_{PR6F\_nd869}^{T}$ PR-6 Tension

$SG1 := AL1_{PR6G\_nd863}^{T}$ PR-6 Compression

$SG2 := AL2_{PR6G\_nd863}^{T}$ PR-6 Tension

SupportsLine_17 := WRITEPRN["SupLine_17.prn" , (SA1 SA2 SB1 SB2 SC1 SC2 SD1 SD2 SE1 SE2 SF1 SF2 SG1 S

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PIPE RUNS

Pipe Runs Strategy: *Search based on the nodes present in each run of pipe. Find the maximum moment combination among all of the nodes and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation.*

$$\text{PipeRunDC}\left(P, D_o, t, I, B_1, B_2, M, S\right) := \frac{B_1\cdot\frac{P\cdot D_o}{2\cdot t} + B_2\cdot\frac{D_o}{2\cdot I}\cdot[M\cdot(1\text{lbf}\cdot\text{in})]}{S}$$

$\text{PipeRun}\left(P, D_o, t, I, B_1, B_2, S, nf, el, C_o, EL\right) :=$

$$ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0\rangle}\right)$$
$$ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0\rangle}\right)$$
$$ind_{el} \leftarrow \text{match}\left(el_0, EL^{\langle 0\rangle}\right)$$
$$\text{for } i \in 1..\text{last}(el) \quad \text{if rows}(el) > 1$$
$$\quad ind_{el} \leftarrow \text{stack}\left[ind_{el}, \left(\text{match}\left(el_i, EL^{\langle 0\rangle}\right)\right)\right]$$
$$\left(M \quad Int_{5,\text{last}(ind_{el})}\right) \leftarrow (0 \quad 0)$$
$$\text{for } i \in 0..ind_{nfo_0} - ind_{nfi_0}$$
$$\quad \text{for } j \in 0..\text{last}(ind_{el})$$
$$\quad\quad M_{rxg} \leftarrow nf_{ind_{nfi}C_{o_{0,1}}+2,\, ind_{el_j}}$$
$$\quad\quad M_{ryg} \leftarrow nf_{ind_{nfi}C_{o_{1,1}}+2,\, ind_{el_j}}$$
$$\quad\quad M_{rzg} \leftarrow nf_{ind_{nfi}C_{o_{2,1}}+2,\, ind_{el_j}}$$
$$\quad\quad M_{rx_j} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}}+2+i,\, ind_{el_j}} - M_{rxg}\right)\cdot C_{o_{3,0}} + M_{rxg}$$
$$\quad\quad M_{ry_j} \leftarrow \left(nf_{ind_{nfi}C_{o_{1,1}}+2+i,\, ind_{el_j}} - M_{ryg}\right)\cdot C_{o_{3,0}} + M_{ryg}$$
$$\quad\quad M_{rz_j} \leftarrow \left(nf_{ind_{nfi}C_{o_{2,1}}+2+i,\, ind_{el_j}} - M_{rzg}\right)\cdot C_{o_{3,0}} + M_{rzg}$$
$$\quad\quad M'_j \leftarrow \sqrt{\left(M_{rx_j}\right)^2 + \left(M_{ry_j}\right)^2 + \left(M_{rz_j}\right)^2}$$
$$\quad\quad Int'_j \leftarrow \text{PipeRunDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$$
$$\quad\quad \text{if } Int'_j > Int_{0,j}$$
$$\quad\quad\quad H \leftarrow \left(Int'_j \quad M'_j \quad nf_{ind_{nfi}C_{o_{0,1}}-1+i,0} \quad EL_{ind_{el_j},0} \quad EL_{ind_{el_j},1} \quad ind_{el_j} \quad M_{r}\right.$$
$$\quad\quad\quad \text{for } k \in 0..5$$
$$\quad\quad\quad\quad Int_{k,j} \leftarrow H_k$$
$$Int$$

Conditions applicable to all pipe runs

$M_{cx} := 0 \qquad M_{cy} := 0 \qquad M_{cz} := 0$

Defining place holding directional moment variables

$$PipeRun\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3 and seismic factor

Pipe Properties for Line 1-17

Define pertinent pipe variables

$D_o := 30in$

Outside Diameter [127008]

$t := 0.438in$

Thickness [127008]

$P := 253psi$

Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\ 4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 4.445 \times 10^3\ in^4$$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{cases} 1.0 & \text{if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50 & \begin{array}{l} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \dfrac{D_o}{t}\right) \\ Y \leftarrow 1.033 - 0.00033 \cdot T \\ 1.0 \cdot \dfrac{1}{X \cdot Y} \end{array} \end{cases}$$

$B_{2PR} = 1.134$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-17A (Elements 50, 54, 55, 456, & 57)

$el_{P117A} := (50\ \ 54\ \ 55\ \ 456\ \ 57)^T$

$AL_{P117A} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P117A}, PipeRun\_C_o, EL)$

$AL_{P117A}^T =$

	0	1	2	3	4	5
0	0.107	4.583·105	4.055	50	74	17
1	0.108	4.714·105	4.055	50	886	18
2	0.092	2.368·105	3.97	54	58	21
3	0.098	3.217·105	3.98	54	82	22
4	0.098	3.218·105	3.98	55	82	23
5	0.105	4.25·105	3.985	55	882	24
6	0.104	4.053·105	6.7	456	83	71
7	0.105	4.251·105	3.985	456	882	72
8	0.108	4.669·105	6.705	57	77	25
9	0.104	4.054·105	6.7	57	83	26

Pipe Run 1-17B (Elements 66, 735, & 68)

$el_{P117B} := (66\ \ 735\ \ 68)^T$

$AL_{P117B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P117B}, PipeRun\_C_o, EL)$

$$AL_{P117B}^T = \begin{pmatrix} 0.115 & 5.783\times10^5 & 5.345 & 66 & 78 & 43 \\ 0.116 & 5.796\times10^5 & 5.35 & 66 & 1.139\times10^3 & 44 \\ 0.112 & 5.244\times10^5 & 5.345 & 735 & 85 & 97 \\ 0.116 & 5.794\times10^5 & 5.35 & 735 & 1.139\times10^3 & 98 \\ 0.11 & 4.975\times10^5 & 5.34 & 68 & 80 & 45 \\ 0.112 & 5.243\times10^5 & 5.345 & 68 & 85 & 46 \end{pmatrix}$$

Pipe Run 1-17C (Elements 71, 736, 72, & 74)

$el_{P117C} := (71\ \ 736\ \ 72\ \ 74)^T$

$AL_{P117C} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P117C}, PipeRun\_C_o, EL)$

$$AL_{P117C}^T = \begin{pmatrix} 0.104 & 4.032\times10^5 & 4.005 & 71 & 79 & 51 \\ 0.108 & 4.698\times10^5 & 4 & 71 & 1.14\times10^3 & 52 \\ 0.105 & 4.277\times10^5 & 4.005 & 736 & 89 & 99 \\ 0.108 & 4.698\times10^5 & 4 & 736 & 1.14\times10^3 & 100 \\ 0.096 & 2.948\times10^5 & 4.005 & 72 & 87 & 53 \\ 0.105 & 4.276\times10^5 & 4.005 & 72 & 89 & 54 \\ 0.093 & 2.418\times10^5 & 9.705 & 74 & 81 & 55 \\ 0.096 & 2.946\times10^5 & 4.005 & 74 & 87 & 56 \end{pmatrix}$$

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Writing Output Data for Pipe Runs Associated with Line 17

$PR1 := AL_{P117A}{}^{T}$

$PR2 := AL_{P117B}{}^{T}$

$PR3 := AL_{P117C}{}^{T}$

$PR := (PR1 \quad PR2 \quad PR3)$

PipeRunsLine_17 := WRITEPRN("PRLine_17.prn" , PR)

REDUCERS

Reducers Strategy: *Search based on the nodes comprising either end of the reducers. SRSS combine the three moments of each of the four node representations (one for each element connected by the node in question). Find the maximum of the moment combinations for each element and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. It is important to not combine the data from both nodes as the geometry for each is different and (9) must be applied for each node. The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\text{ReducerDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

$\text{Reducer}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \text{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. \text{last}(nd)$ if $\text{rows}(nd) > 1$

  $ind_{nd} \leftarrow \text{stack}\left[ind_{nd}, \left(\text{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$(M \;\; Int_0) \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \text{last}(ind_{nd})$

    $M_{rxg} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}}+2,\, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi_{C_{o_{1,1}}}}+2,\, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi_{C_{o_{2,1}}}}+2,\, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi_{C_{o_{1,1}}}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi_{C_{o_{2,1}}}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow \text{ReducerDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$

    if $Int'_j > Int_0$

      $Int \leftarrow \text{stack}\Big(Int'_j, M'_j, nf_{ind_{nfi_{C_{o_{0,1}}}}-1+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd_j}, M_{rx}, M_{ry},$

      $Result \leftarrow M'$

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Int

Conditions applicable to all reducers

$M_{cx} := 0$ $M_{cy} := 0$ $M_{cz} := 0$

Defining place holding variables

$$Reducer\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3 and seismic factor

Reducer Properties for Lines 1-17

Define pertinent reducer variables

$D_o := (30in \quad 20in)^T$

Outside Diameter [4] [5] [6] [7]

$t := \left(\frac{1}{2}in \quad \frac{1}{2}in\right)^T$

Thickness [4] [5] [6] [7]

$P := (253psi \quad 253psi)^T$

Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

$$I = \begin{pmatrix} 5.042 \times 10^3 \\ 1.457 \times 10^3 \end{pmatrix} in^4$$

Moment of inertia [8, Table 17-27, pg 17-39]

Define primary stress indices

$\alpha := atan\left(\frac{1in}{9in}\right)$

Angular slope of reducer

$\alpha = 6.34\,deg$

$$B_1 := \begin{vmatrix} 0.5 \;\; \text{if} \;\; \alpha \le 30deg \\ 1.0 \;\; \text{if} \;\; 30deg < \alpha \le 60deg \end{vmatrix}$$

B_1 primary stress indice [9, NB-3683.7]

$B_1 = 0.5$

$B_2 := 1.0$

B_2 primary stress indice [9, NB-3683.7]

Reducer 1-17A (Nodes 932 & 132)

$nd_{RD117A\_L} := (932)^T$

Node associated with Large end of reducer

$$AL_{RD117A\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF, nd_{RD117A\_L}, Reducer\_C_o, EL\right)$$

$$AL_{RD117A\_L}^{\;T} = \left(0.079 \quad 2.224 \times 10^5 \quad 10.04 \quad 932 \quad 91 \quad -7.91 \times 10^4 \quad 2.066 \times 10^4 \quad 2.068 \times 10^5\right)$$

$nd_{RD117A\_S} := (132)^T$ Node associated with Small end of reducer

$AL_{RD117A\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF, nd_{RD117A\_S}, Reducer\_C_o, EL\right)$

$$AL_{RD117A\_S}^T = \begin{pmatrix} 0.07 & 2.087 \times 10^5 & 10.04 & 132 & 64 & -2.694 \times 10^4 & 9.703 \times 10^3 & 2.067 \times 10^5 \end{pmatrix}$$

Writing Output Data for Reducer Associated with Line 17

$Red1 := {AL_{RD117A\_L}^T}^T$

$Red2 := {AL_{RD117A\_S}^T}^T$

$Red := (Red1 \quad Red2)$

ReducerLine_17 := WRITEPRN("RedLine_17.prn" , Red)

FORGED TEES AND FABRICATED BRANCH TEES

Tees Strategy: *Search based on the elements comprising the tee. The input identifies which elements are associated with the pipe run and which element is associated with the branch from the run. The indices for the defined common node for all three elements is identified and the associated SRSS moment is identified for each time step. The maximum moment for the elements comprising the pipe run is found and applied as M_r in equation (9) of ASME III, Division I - NB - 3652 which is modified to represent tees. The maximum moment for the branch element is found and applied as M_b in equation (9) of ASME III, Division I - NB - 3652 [9]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{TeeDC}(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_b, M_r, Z_b, Z_r, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot T_r} + B_{2b} \cdot \left[\frac{M_b \cdot (1 lbf \cdot in)}{Z_b}\right] + B_{2r} \cdot \left[\frac{M_r \cdot (1 lbf \cdot in)}{Z_r}\right]}{S}$$

$\mathrm{Tee}(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S, nf, el_R, el_B, nd_R, nd_B, C_o, EL) :=$

```
ind_nfi ← match(t_initial, nf^<0>)
ind_nfo ← match(t_final, nf^<0>)
ind_elR ← match(el_R_0, EL^<0>)
for i ∈ 1 .. last(el_R)                                          if rows
    ind_elR ← stack[ind_elR, (match(el_R_i, EL^<0>))]
EL'R_last(EL^<0>) ← 0
for i ∈ 0 .. last(ind_elR)
    EL'R_ind_elR_i ← EL_ind_elR_i, 1
ind_ndR ← match(nd_R_0, EL'R^<0>)
for i ∈ 1 .. last(nd_R)                                          if r
    ind_ndR ← stack[ind_ndR, (match(nd_R_i, EL'R^<0>))]
ind_elB ← match(el_B_0, EL^<0>)
for i ∈ 1 .. last(el_B)                                          if rows
    ind_elB ← stack[ind_elB, (match(el_B_i, EL^<0>))]
EL'B_last(EL^<0>) ← 0
for i ∈ 0 .. last(ind_elB)
    EL'B_ind_elB_i ← EL_ind_elB_i, 1
ind_ndB ← match(nd_B_0, EL'B^<0>)
```

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for $i \in 1 .. last(nd_B)$ if r

$ind_{ndB} \leftarrow stack\left[ind_{ndB}, \left(match\left(nd_{B_i}, EL'B^{\langle 0 \rangle}\right)\right)\right]$

$(M_R \;\; M_B \;\; Int_0) \leftarrow (0 \;\; 0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

for $j \in 0 .. last(ind_{ndR})$

for $k \in 0 .. last(ind_{ndB})$

$M_{rxgR_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{ndR_j}}$

$M_{rygR_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{ndR_j}}$

$M_{rzgR_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{ndR_j}}$

$M_{rxR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{ndR_j}} - M_{rxgR_j}\right) \cdot C$

$M_{ryR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{ndR_j}} - M_{rygR_j}\right) \cdot C$

$M_{rzR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{ndR_j}} - M_{rzgR_j}\right) \cdot C$

$M_{R_j} \leftarrow \sqrt{\left(M_{rxR_j}\right)^2 + \left(M_{ryR_j}\right)^2 + \left(M_{rzR_j}\right)^2}$

$M_{rxgB_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{ndB_k}}$

$M_{rygB_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{ndB_k}}$

$M_{rzgB_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{ndB_k}}$

$M_{rxB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{ndB_k}} - M_{rxgB_j}\right) \cdot C$

$M_{ryB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{ndB_k}} - M_{rygB_j}\right) \cdot C$

$M_{rzB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{ndB_k}} - M_{rzgB_j}\right) \cdot C$

$M_{B_j} \leftarrow \sqrt{\left(M_{rxB_j}\right)^2 + \left(M_{ryB_j}\right)^2 + \left(M_{rzB_j}\right)^2}$

$Int'_j \leftarrow TeeDC\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_{B_j}, M_R\right.$

if $Int'_j > Int_0$

$Int \leftarrow stack\left(Int'_j, M_{R_j}, M_{B_j}, nf_{ind_{nfiC_{o_{0,1}}}-1+i}\right.$

$Result \leftarrow stack(M_{R_j}, M_{B_j}, M_{rxR_j}, M_{ryR_j}, M$

$M \leftarrow M_R$

Int

Conditions applicable to forged tee

$M_{ox} := 0 \quad M_{oy} := 0 \quad M_{oz} := 0$

Defining place holding directional moment variables

$$Tee\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3 and seismic factor

TEE (Lines 1-13, 1-14, 1-15, and 1-16) attached to Line 1-17

Define pertinent tee variables

$P := 253psi$ — Internal Pressure [3, pg 23]

$D_o := 30in$ — Outside Diameter [10]

$B_1 := 0.5$ — B_1 primary stress Indice for tees and branches [9, NB-3683.9]

$T_r := 0.438in$ — Nominal wall thickness of designated run pipe [14]

$R_m := 15in$ — Mean radius of designated run pipe [10]

$Z_r := \pi \cdot R_m^{\,2} \cdot T_r$ — Approximate section modulus of designated run pipe [9, NB-3683.1(d)]

$Z_r = 309.604\ in^3$

$$B_{2b} := \begin{cases} 0.4 \cdot \left(\dfrac{R_m}{T_r}\right)^{\frac{2}{3}} & \text{if } 0.4 \cdot \left(\dfrac{R_m}{T_r}\right)^{\frac{2}{3}} > 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Indice for tees and branches [9, NB-3683.9]

$B_{2b} = 4.218$

$T'_b := 0.312in$ — Nominal wall thickness of attached branch pipe [14]

$r'_m := 10in$ — Mean radius of attached branch pipe [10]

$Z_b := \pi \cdot {r'_m}^2 \cdot T'_b$

Approximate section modulus of attached branch pipe [9, NB-3683.1(d)]

$Z_b = 98.018\ in^3$

$$B_{2r} := \begin{cases} 0.5 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} & \text{if } 0.5 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} > 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Indice for tees and branches [9, NB-3683.9]

$B_{2r} = 5.273$

Tee 1-13 (Node 933)

$elR_{Tee113} := (602\ \ 110)^T$ Elements associated with pipe run

$ndR_{Tee113} := (933)^T$ Node between pipe run elements

$elB_{Tee113} := (603)^T$ Element associated with branch

$ndB_{Tee113} := (933)^T$ Node where branch intersects pipe run

$AL_{Tee113} := Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF, elR_{Tee113}, elB_{Tee113}, ndR_{Tee113}, ndB_{Tee113}, Tee\_C$

$AL_{Tee113}{}^T = (0.397\ \ 4.316 \times 10^5\ \ 2.509 \times 10^5\ \ 4.06\ \ 933\ \ 66\ \ 92\ \ 94)$

Tee 1-14 (Node 59)

$elR_{Tee114} := (60\ \ 61)^T$ Elements associated with pipe run

$ndR_{Tee114} := (59)^T$ Node between pipe run elements

$elB_{Tee114} := (46)^T$ Element associated with branch

$ndB_{Tee114} := (59)^T$ Node where branch intersects pipe run

$AL_{Tee114} := Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF, elR_{Tee114}, elB_{Tee114}, ndR_{Tee114}, ndB_{Tee114}, Tee\_C$

$AL_{Tee114}{}^T = (0.4\ \ 4.547 \times 10^5\ \ 2.469 \times 10^5\ \ 4.06\ \ 59\ \ 31\ \ 33\ \ 9)$

Tee 1-15 (Node 61)

$elR_{Tee115} := (64 \;\; 65)^T$ Elements associated with pipe run

$ndR_{Tee115} := (61)^T$ Node between pipe run elements

$elB_{Tee115} := (47)^T$ Element associated with branch

$ndB_{Tee115} := (61)^T$ Node where branch intersects pipe run

$AL_{Tee115} := Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF, elR_{Tee115}, elB_{Tee115}, ndR_{Tee115}, ndB_{Tee115}, Tee\_C$

$$AL_{Tee115}^T = (0.373 \;\; 3.261\times10^5 \;\; 2.622\times10^5 \;\; 9.265 \;\; 61 \;\; 39 \;\; 41 \;\; 11)$$

Tee 1-16 (Node 62)

$elR_{Tee116} := (75 \;\; 76)^T$ Elements associated with pipe run

$ndR_{Tee116} := (62)^T$ Node between pipe run elements

$elB_{Tee116} := (48)^T$ Element associated with branch

$ndB_{Tee116} := (62)^T$ Node where branch intersects pipe run

$AL_{Tee116} := Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF, elR_{Tee116}, elB_{Tee116}, ndR_{Tee116}, ndB_{Tee116}, Tee\_C$

$$AL_{Tee116}^T = (0.429 \;\; 4.264\times10^5 \;\; 2.961\times10^5 \;\; 9.125 \;\; 62 \;\; 57 \;\; 59 \;\; 13)$$

TEE (Lines 1-18, 1-19, 1-20, and 1-21) attached to Line 1-17

Define pertinent tee variables

$P := 253psi$ Internal Pressure [3, pg 23]

$D_o := 30in$ Outside Diameter [10]

$B_1 := 0.5$ B_1 primary stress Indice for tees and branches [9, NB-3683.9]

$T_r := 0.438in$ Nominal wall thickness of designated run pipe [14]

$R_m := 15in$ Mean radius of designated run pipe [10]

$Z_r := \pi \cdot R_m^{\,2} \cdot T_r$

Approximate section modulus of designated run pipe [9, NB-3683.1(d)]

$Z_r = 309.604\ in^3$

$$B_{2b} := \begin{cases} 0.4 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} & \text{if } 0.4 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} > 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Indice for tees and branches [9, NB-3683.9]

$B_{2b} = 4.218$

$T'_b := 0.375 in$

Nominal wall thickness of attached branch pipe [14]

$r'_m := 12in$

Mean radius of attached branch pipe [10]

$Z_b := \pi \cdot r'^{\,2}_m \cdot T'_b$

Approximate section modulus of attached branch pipe [9, NB-3683.1(d)]

$Z_b = 169.646\ in^3$

$$B_{2r} := \begin{cases} 0.5 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} & \text{if } 0.5 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} > 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Indice for tees and branches [9, NB-3683.9]

$B_{2r} = 5.273$

Tee 1-18 (Node 5)

$elR_{Tee118} := (457\ \ 51)^T$

Elements associated with pipe run

$ndR_{Tee118} := (5)^T$

Node between pipe run elements

$elB_{Tee118} := (15)^T$

Element associated with branch

$ndB_{Tee118} := (5)^T$

Node where branch intersects pipe run

$AL_{Tee118} := Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF, elR_{Tee118}, elB_{Tee118}, ndR_{Tee118}, ndB_{Tee118}, Tee\_C$

$AL_{Tee118}^{\ T} = (0.368\ \ 4.054 \times 10^5\ \ 3.88 \times 10^5\ \ 4.06\ \ 5\ \ 19\ \ 73\ \ 1)$

Tee 1-19 (Node 12)

$elR_{Tee119} := (58 \quad 59)^T$ Elements associated with pipe run

$ndR_{Tee119} := (12)^T$ Node between pipe run elements

$elB_{Tee119} := (44)^T$ Element associated with branch

$ndB_{Tee119} := (12)^T$ Node where branch intersects pipe run

$AL_{Tee119} := Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF, elR_{Tee119}, elB_{Tee119}, ndR_{Tee119}, ndB_{Tee119}, Tee\_C$

$AL_{Tee119}{}^T = (0.39 \quad 5.143 \times 10^5 \quad 3.627 \times 10^5 \quad 4.065 \quad 12 \quad 27 \quad 29 \quad 7)$

Tee 1-20 (Node 19)

$elR_{Tee120} := (69 \quad 70)^T$ Elements associated with pipe run

$ndR_{Tee120} := (19)^T$ Node between pipe run elements

$elB_{Tee120} := (31)^T$ Element associated with branch

$ndB_{Tee120} := (19)^T$ Node where branch intersects pipe run

$AL_{Tee120} := Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF, elR_{Tee120}, elB_{Tee120}, ndR_{Tee120}, ndB_{Tee120}, Tee\_C$

$AL_{Tee120}{}^T = (0.346 \quad 3.419 \times 10^5 \quad 3.798 \times 10^5 \quad 9.265 \quad 19 \quad 47 \quad 49 \quad 3)$

Tee 1-21 (Node 26)

$elR_{Tee121} := (604 \quad 78)^T$ Elements associated with pipe run

$ndR_{Tee121} := (26)^T$ Node between pipe run elements

$elB_{Tee121} := (39)^T$ Element associated with branch

$ndB_{Tee121} := (26)^T$ Node where branch intersects pipe run

$AL_{Tee121} := Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF, elR_{Tee121}, elB_{Tee121}, ndR_{Tee121}, ndB_{Tee121}, Tee\_C$

$AL_{Tee121}{}^T = (0.371 \quad 4.408 \times 10^5 \quad 3.688 \times 10^5 \quad 9.255 \quad 26 \quad 61 \quad 95 \quad 5)$

TEE (Lines 1-30) attached to Line 1-17

Define pertinent tee variables

$P := 253\,psi$ — Internal Pressure [3, pg 23]

$D_o := 30\,in$ — Outside Diameter [10]

$B_1 := 0.5$ — B_1 primary stress Indice for tees and branches [9, NB-3683.9]

$T_r := 0.438\,in$ — Nominal wall thickness of designated run pipe [14]

$R_m := 15\,in$ — Mean radius of designated run pipe [10]

$Z_r := \pi \cdot R_m^{\;2} \cdot T_r$ — Approximate section modulus of designated run pipe [9, NB-3683.1(d)]

$Z_r = 309.604\,in^3$

$$B_{2b} := \begin{cases} 0.4 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} & \text{if } 0.4 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} > 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Indice for tees and branches [9, NB-3683.9]

$B_{2b} = 4.218$

$T'_b := 0.25\,in$ — Nominal wall thickness of attached branch pipe [14]

$r'_m := 8\,in$ — Mean radius of attached branch pipe [10]

$Z_b := \pi \cdot r'^{\;2}_m \cdot T'_b$ — Approximate section modulus of attached branch pipe [9, NB-3683.1(d)]

$Z_b = 50.265\,in^3$

$$B_{2r} := \begin{cases} 0.5 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} & \text{if } 0.5 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} > 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Indice for tees and branches [9, NB-3683.9]

$B_{2r} = 5.273$

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Tee 1-30 (Node 60)

$elR_{Tee130} := (62\ \ 63)^T$ Elements associated with pipe run

$ndR_{Tee130} := (60)^T$ Node between pipe run elements

$elB_{Tee130} := (49)^T$ Element associated with branch

$ndB_{Tee130} := (60)^T$ Node where branch intersects pipe run

$AL_{Tee130} := Tee\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF, elR_{Tee130}, elB_{Tee130}, ndR_{Tee130}, ndB_{Tee130}, Tee\_C\right.$

$$AL_{Tee130}^{\ T} = \left(0.771\ \ 5.842\times10^5\ \ 3.507\times10^5\ \ 6.835\ \ 60\ \ 35\ \ 37\ \ 15\right)$$

Writing Output Data for Tees Associated with Line 1-30) attached to Line 1-17

$Tee1 := AL_{Tee113}^{\ T}$

$Tee2 := AL_{Tee114}^{\ T}$

$Tee3 := AL_{Tee115}^{\ T}$

$Tee4 := AL_{Tee116}^{\ T}$

$Tee5 := AL_{Tee118}^{\ T}$

$Tee6 := AL_{Tee119}^{\ T}$

$Tee7 := AL_{Tee120}^{\ T}$

$Tee8 := AL_{Tee121}^{\ T}$

$Tee9 := AL_{Tee130}^{\ T}$

$Tee := (Tee1\ \ Tee2\ \ Tee3\ \ Tee4\ \ Tee5\ \ Tee6\ \ Tee7\ \ Tee8\ \ Tee9)$

TeeLine_17 := WRITEPRN("TeeLine_17.prn" , Tee)

Appendix C.3.2

Demand to Capacity Ratio Calculations for Components Associated with Lines 1-13 though 1-16, 1-18 through 1-21, and 1-171 of ATR PCS Model 265

(NOTE: Values represented here are shown for one realization (Nodal Force file = LINES_13-16_18-21_171_test_R1.dat and Element/Nodal order file = EL_13-16_18-21_171.xls) and may or may not be consistent with the 80th percentile results contained in Appendix C.4)

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Force Outputs from Abaqus

NF := ..\LINES_13-16_18-21_171.dat

(N)odal (F)orces for the (M)edium (L)ines of Model 3

Defined Elemental and Corresponding Nodal Order

EL := ..\EL_13-16_18-21_171(9-22-08).xls

Element and corresponding nodal order for the (M)edium (L)ines of Model 3

Time Boundaries

$t_{initial} := 1$

Initial time for which dynamic loading is applied

$t_{final} := 21$

Final time for which dynamic loading stops

Seismic Scale Factor (F_a)

$F_a := 1$

Seismic scale factor [30]

Allowable Design Stress Intensity Factor (S_m): *S_m is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{m\_125} := 20ksi$

For SS304 at 125°F [2, pg 316-318] [3, pg 23]

$S_{m\_125L} := 16.7ksi$

For SS304L at 125°F [2, pg 316-318] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Yield Strength (S_y): *S_y is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{y\_125} := 28.35ksi$

For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_125L} := 23.85ksi$

For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Maximum Strength Applicable for Equation 9 (S): *S is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{125} := \min\left(3 \cdot S_{m\_125}, 2 \cdot S_{y\_125}\right)$

$\boxed{S_{125} = 56.7\,ksi}$

Maximum allowable stress applied to SS304 piping [9, NB-3656]

$S_{125L} := \min\left(3 \cdot S_{m\_125L}, 2 \cdot S_{y\_125L}\right)$

$\boxed{S_{125L} = 47.7\,ksi}$

Maximum allowable stress applied to SS304L piping [9, NB-3656]

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SUPPORTS

Supports Strategy: *Search based on the node for which the support acts. If this node is a termination point there will only be one node to evaluate. If this node is in line with a section of pipe there will be two representations of the same node (one for each element on each side of the node) to combine and the difference between them is the force required of the support. The D/C ratio for each support will be found by dividing the the required force found above by the support capacity.*

$$\mathrm{SupDC}(P_r, P_c) := \frac{P_r}{P_c}$$

$$\begin{array}{l}
\mathrm{Support}(nf, nd, C_o, EL) := \\
\quad ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
\quad ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
\quad ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right) \\
\quad \text{for } i \in 1 .. \mathrm{last}(nd) \qquad\qquad\qquad \text{if } \mathrm{rows}(nd) > 1 \\
\quad\quad ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \\
\quad \begin{pmatrix} Int1_5 & Int2_5 \end{pmatrix} \leftarrow (0 \quad 0) \\
\quad \text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0} \\
\quad\quad \text{for } j \in 0 .. \mathrm{last}(ind_{nd}) \\
\quad\quad\quad P_{rg_j} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}-1}}, ind_{nd_j}} \\
\quad\quad\quad P_{r_j} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}-1}}+i, ind_{nd_j}} - P_{rg_j}\right) \cdot C_{o_{2,0}} + P_{rg_j} \\
\quad\quad PR_i \leftarrow \sum_{n=0}^{j} P_{r_n} \\
\quad\quad \text{if } PR_i < Int1_1 \wedge C_{o_{0,0}} \neq 0 \\
\quad\quad\quad Int1' \leftarrow \mathrm{SupDC}\left(\left|PR_i\right|, C_{o_{0,0}}\right) \\
\quad\quad\quad Int_1 \leftarrow \mathrm{stack}\left(Int1', PR_i, nf_{ind_{nfi_{C_{o_{0,1}}-1}}+i, 0}, EL_{ind_{nd_j}, 1}, ind_{nd}\right) \\
\quad\quad \text{if } PR_i > Int2_1 \wedge C_{o_{1,0}} \neq 0 \\
\quad\quad\quad Int2' \leftarrow \mathrm{SupDC}\left(\left|PR_i\right|, C_{o_{1,0}}\right) \\
\quad\quad\quad Int_2 \leftarrow \mathrm{stack}\left(Int2', PR_i, nf_{ind_{nfi_{C_{o_{0,1}}-1}}+i, 0}, EL_{ind_{nd_j}, 1}, ind_{nd}\right) \\
\quad \begin{pmatrix} Int_1 & Int_2 \end{pmatrix}
\end{array}$$

PS-20 Support (1x)

$P_{1\_PS20} := \frac{155.021 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$P_{2\_PS20} := \frac{14.07 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_PS20} := \begin{pmatrix} P_{1\_PS20} & 2 \\ P_{2\_PS20} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

PS-20 (Node 828)

PS-20 vertically supports EL(1-171A) on line 1-171.

$nd828_{PS20_0} := 828$ Node associated with support

$$\left(AL1_{PS20\_nd828} \;\; AL2_{PS20\_nd828}\right) := Support\left(NF, nd828_{PS20}, Sup\_C_{o\_PS20}, EL\right)$$

$$AL1_{PS20\_nd828}{}^T = \left(0.076 \;\; -1.178 \times 10^4 \;\; 7.455 \;\; 828 \;\; 108\right)$$

$$AL2_{PS20\_nd828}{}^T = \left(0.568 \;\; 7.99 \times 10^3 \;\; 10.02 \;\; 828 \;\; 108\right)$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PS-8 Support (4x)

$P_{1\_PS8} := \frac{75.565 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_PS8} := \frac{14.07 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_PS8} := \begin{pmatrix} P_{1\_PS8} & 2 \\ P_{2\_PS8} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

PS-8A (Node 829)

PS-8A vertically supports EL(1-13A) on line 1-13.

$nd829_{PS8A_0} := 829$ Node associated with support

$$\left(AL1_{PS8A\_nd829}\ \ AL2_{PS8A\_nd829}\right) := \text{Support}\left(NF, nd829_{PS8A}, Sup\_C_{o\_PS8}, EL\right)$$

$$AL1_{PS8A\_nd829}^{\ T} = \left(0.113\ \ -8.557\times10^{3}\ \ 6.14\ \ 829\ \ 106\right)$$

$$AL2_{PS8A\_nd829}^{\ T} = \left(0.359\ \ 5.048\times10^{3}\ \ 6.245\ \ 829\ \ 106\right)$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PS-8B (Node 830)

PS-8B vertically supports EL(1-14A) on line 1-14.

$nd830_{PS8B_0} := 830$ Node associated with support

$$\left(AL1_{PS8B\_nd830}\ \ AL2_{PS8B\_nd830}\right) := \text{Support}\left(NF, nd830_{PS8B}, Sup\_C_{o\_PS8}, EL\right)$$

$$AL1_{PS8B\_nd830}^{\ T} = \left(0.16\ \ -1.211\times10^{4}\ \ 5.23\ \ 830\ \ 104\right)$$

$$AL2_{PS8B\_nd830}^{\ T} = \left(0.64\ \ 9.012\times10^{3}\ \ 4.035\ \ 830\ \ 104\right)$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PS-8C (Node 831)

PS-8C vertically supports EL(1-15A) on line 1-15.

$nd831_{PS8C_0} := 831$ Node associated with support

$$\left(AL1_{PS8C\_nd831}\ \ AL2_{PS8C\_nd831}\right) := \text{Support}\left(NF, nd831_{PS8C}, Sup\_C_{o\_PS8}, EL\right)$$

$$AL1_{PS8C\_nd831}^{\ T} = \left(0.13\ \ -9.797\times10^{3}\ \ 10.575\ \ 831\ \ 102\right)$$

$$AL2_{PS8C\_nd831}^{\ T} = \left(0.519\ \ 7.303\times10^{3}\ \ 6.7\ \ 831\ \ 102\right)$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PS-8D (Node 832)

PS-8D vertically supports EL(1-16A) on line 1-16.

$nd832_{PS8D_0} := 832$ Node associated with support

$$\left(AL1_{PS8D\_nd832}\ \ AL2_{PS8D\_nd832}\right) := \text{Support}\left(NF, nd832_{PS8D}, Sup\_C_{o\_PS8}, EL\right)$$

$$AL1_{PS8D\_nd832}^{\ T} = \left(0.169\ \ -1.277\times10^{4}\ \ 10.26\ \ 832\ \ 100\right)$$

$$AL2_{PS8D\_nd832}^{\ T} = \left(0.672\ \ 9.461\times10^{3}\ \ 10.11\ \ 832\ \ 100\right)$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

Writing Output Data for Supports Associated with Lines 1-13 to 1-16, 1-18 to 1-21, and 1-171.

$SA1 := AL1_{PS20\_nd828}^{T}$ PS-20 Compression

$SA2 := AL2_{PS20\_nd828}^{T}$ PS-20 Tension

$SB1 := AL1_{PS8A\_nd829}^{T}$ PS-8A Compression

$SB2 := AL2_{PS8A\_nd829}^{T}$ PS-8A Tension

$SC1 := AL1_{PS8B\_nd830}^{T}$ PS-8A Compression

$SC2 := AL2_{PS8B\_nd830}^{T}$ PS-8A Tension

$SD1 := AL1_{PS8C\_nd831}^{T}$ PS-8A Compression

$SD2 := AL2_{PS8C\_nd831}^{T}$ PS-8A Tension

$SE1 := AL1_{PS8D\_nd832}^{T}$ PS-8A Compression

$SE2 := AL2_{PS8D\_nd832}^{T}$ PS-8A Tension

$S := (SA1\ \ SA2\ \ SB1\ \ SB2\ \ SC1\ \ SC2\ \ SD1\ \ SD2\ \ SE1\ \ SE2)$

SupportsLines_13to16_18to21_171 := WRITEPRN("SupLines_13to16_18to21_171.prn" , S)

TERMINATION LOCATIONS

Termination Locations Strategy: *Search based on the node for which the termination location acts as well as the next node inward. The D/C ratio for each termination location will be found by dividing the the required force found above by the support capacity.*

$$\text{TermDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

$\text{Term}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$$\begin{aligned}
&ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
&ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
&ind_{nd} \leftarrow \text{match}\left(nd_0, EL^{\langle 1 \rangle}\right) \\
&\text{for } i \in 1..\text{last}(nd) \quad \text{if rows}(nd) > 1 \\
&\quad ind_{nd} \leftarrow \text{stack}\left[ind_{nd}, \left(\text{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \\
&(M \;\; Int_0) \leftarrow (0 \;\; 0) \\
&\text{for } i \in 0..ind_{nfo_0} - ind_{nfi_0} \\
&\quad \text{for } j \in 0..\text{last}(ind_{nd}) \\
&\qquad M_{rxg} \leftarrow nf_{ind_{nfi}C_{o_{0,1}}+2, ind_{nd_j}} \\
&\qquad M_{ryg} \leftarrow nf_{ind_{nfi}C_{o_{1,1}}+2, ind_{nd_j}} \\
&\qquad M_{rzg} \leftarrow nf_{ind_{nfi}C_{o_{2,1}}+2, ind_{nd_j}} \\
&\qquad M_{rx} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}}+2+i, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg} \\
&\qquad M_{ry} \leftarrow \left(nf_{ind_{nfi}C_{o_{1,1}}+2+i, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg} \\
&\qquad M_{rz} \leftarrow \left(nf_{ind_{nfi}C_{o_{2,1}}+2+i, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg} \\
&\qquad M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2} \\
&\qquad Int'_j \leftarrow \text{TermDC}(P, D_o, t, I, B_1, B_2, M'_j, S) \\
&\qquad \text{if } Int'_j > Int_0 \\
&\qquad\quad Int \leftarrow \text{stack}\left(Int'_j, M'_j, nf_{ind_{nfi}C_{o_{0,1}}-1+i, 0}, EL_{ind_{nd_j}, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M_{1}\right. \\
&\qquad\quad \text{Result} \leftarrow M' \\
&Int
\end{aligned}$$

Conditions applicable to all terminations

$M_{cx} := 0 \qquad M_{cy} := 0 \qquad M_{cz} := 0$

Defining place holding variables

$$Term\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Heat Exchanger Outlet (5x)

Define pertinent pipe variables

$D_o := 20in$ — Outside Diameter [4]

$t := 0.312in$ — Thickness [4]

$P := 253psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

$I = 935.251\ in^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$S := S_{125}$ — Allowable design stress intensity value

Define primary stress indices

$B_1 := 0.5$

$$B_2 := \begin{vmatrix} 1.0 \ \text{ if } \ \frac{D_o}{t} \le 50 \\ \text{if } \ \frac{D_o}{t} > 50 \\ \quad \begin{vmatrix} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006\cdot\frac{D_o}{t}\right) \\ Y \leftarrow 1 \\ 1.0\cdot\frac{1}{X\cdot Y} \end{vmatrix} \end{vmatrix} \qquad B_2 = 1.092$$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Heat Exchanger 1-13 (Node 130)

$nd130_{HX113_0} := 130$

$AL_{HX113\_nd130} := Term\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd130_{HX113}, Term\_C_o, EL\right)$

$$AL_{HX113\_nd130}^{\,T} = \left(0.119 \quad 2.281\times10^5 \quad 4.05 \quad 130 \quad 82 \quad 1.685\times10^5 \quad 1.082\times10^5 \quad -1.093\times10^5\right)$$

Heat Exchanger 1-14 (Node 128)

$nd128_{HX114_0} := 128$

$AL_{HX114\_nd128} := Term(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd128_{HX114}, Term\_C_o, EL)$

$$AL_{HX114\_nd128}^T = \begin{pmatrix} 0.134 & 3.054 \times 10^5 & 6.7 & 128 & 84 & -2.965 \times 10^5 & -5.114 \times 10^4 & -5.233 \times 10^4 \end{pmatrix}$$

Heat Exchanger 1-15 (Node 129)

$nd129_{HX115_0} := 129$

$AL_{HX115\_nd129} := Term(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd129_{HX115}, Term\_C_o, EL)$

$$AL_{HX115\_nd129}^T = \begin{pmatrix} 0.133 & 2.984 \times 10^5 & 6.695 & 129 & 86 & 2.94 \times 10^5 & 3.442 \times 10^4 & -3.725 \times 10^4 \end{pmatrix}$$

Heat Exchanger 1-16 (Node 127)

$nd127_{HX116_0} := 127$

$AL_{HX116\_nd127} := Term(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd127_{HX116}, Term\_C_o, EL)$

$$AL_{HX116\_nd127}^T = \begin{pmatrix} 0.13 & 2.857 \times 10^5 & 10.115 & 127 & 88 & -2.853 \times 10^5 & -7.425 \times 10^3 & -1.36 \times 10^4 \end{pmatrix}$$

Heat Exchanger 1-171 (Node 139)

$nd139_{HX1171_0} := 139$

$AL_{HX1171\_nd139} := Term(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd139_{HX1171}, Term\_C_o, EL)$

$$AL_{HX1171\_nd139}^T = \begin{pmatrix} 0.104 & 1.566 \times 10^5 & 4.055 & 139 & 97 & 9.373 \times 10^4 & 5.223 \times 10^4 & 1.141 \times 10^5 \end{pmatrix}$$

Primary Pump Suction (4x)

Define pertinent pipe variables

$D_o := 18in$ — Outside Diameter [5]

$t := 0.3125in$ — Thickness [5]

$P := 253psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^4 - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 679.274\ in^4$

$S := S_{125}$ — Allowable design stress intensity value

Define primary stress indices

$B_1 := 0.5$

$$B_2 := \begin{cases} 1.0 & \text{if } \frac{D_o}{t} \le 50 \\ \begin{aligned} & T \leftarrow 125 \\ & X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \frac{D_o}{t}\right) \\ & Y \leftarrow 1 \\ & 1.0 \cdot \frac{1}{X \cdot Y} \end{aligned} & \text{if } \frac{D_o}{t} > 50 \end{cases}$$

$B_2 = 1.048$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Primary Pump 1-18 (Node 1)

$nd1_{PP118_0} := 1$

$AL_{PP118\_nd1} := Term(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd1_{PP118}, Term\_C_o, EL)$

$AL_{PP118\_nd1}^T = (0.338 \quad 1.118 \times 10^6 \quad 9.26 \quad 1 \quad 1 \quad 1.084 \times 10^6 \quad 1.721 \times 10^5 \quad -2.16 \times 10^5)$

Primary Pump 1-19 (Node 31)

$nd31_{PP119_0} := 31$

$AL_{PP119\_nd31} := Term(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd31_{PP119}, Term\_C_o, EL)$

$AL_{PP119\_nd31}^T = (0.337 \quad 1.113 \times 10^6 \quad 9.26 \quad 31 \quad 5 \quad 1.078 \times 10^6 \quad 1.866 \times 10^5 \quad -2.059 \times 10^5)$

Primary Pump 1-20 (Node 15)

$nd15_{PP120_0} := 15$

$AL_{PP120\_nd15} := Term(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd15_{PP120}, Term\_C_o, EL)$

$AL_{PP120\_nd15}^T = (0.33 \quad 1.086 \times 10^6 \quad 4.05 \quad 15 \quad 9 \quad -8.54 \times 10^5 \quad -1.308 \times 10^5 \quad 6.58 \times 10^5)$

Primary Pump 1-21 (Node 22)

$nd22_{PP121_0} := 22$

$AL_{PP121\_nd22} := Term(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd22_{PP121}, Term\_C_o, EL)$

$AL_{PP121\_nd22}^T = (0.36 \quad 1.208 \times 10^6 \quad 10.26 \quad 22 \quad 13 \quad 1.469 \times 10^5 \quad 6.434 \times 10^4 \quad -1.197 \times 10^6)$

Writing Output Data for Terminations Associated with Lines 1-13 to 1-16, 1-18 to 1-21, and 1-171.

$T1 := \left(AL_{HX113\_nd130}^{T}\right)$ Heat Exchanger 1-13 (Node 130)

$T2 := \left(AL_{HX114\_nd128}^{T}\right)$ Heat Exchanger 1-14 (Node 128)

$T3 := \left(AL_{HX115\_nd129}^{T}\right)$ Heat Exchanger 1-15 (Node 129)

$T4 := \left(AL_{HX116\_nd127}^{T}\right)$ Heat Exchanger 1-16 (Node 127)

$T5 := \left(AL_{HX1171\_nd139}^{T}\right)$ Heat Exchanger 1-171 (Node 139)

$T6 := \left(AL_{PP118\_nd1}^{T}\right)$ Primary Pump 1-18 (Node 1)

$T7 := \left(AL_{PP119\_nd31}^{T}\right)$ Primary Pump 1-19 (Node 31)

$T8 := \left(AL_{PP120\_nd15}^{T}\right)$ Primary Pump 1-20 (Node 15)

$T9 := \left(AL_{PP121\_nd22}^{T}\right)$ Primary Pump 1-21 (Node 22)

$T := (T1\ \ T2\ \ T3\ \ T4\ \ T5\ \ T6\ \ T7\ \ T8\ \ T9)$

TerminationsLines_13to16_18to21_171 := WRITEPRN("TermLines_13to16_18to21_171.prn" , T)

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** R. K. Blandford **Date:** 09/30/2008

PIPE RUNS

Pipe Runs Strategy: *Search based on the nodes present in each run of pipe. Find the maximum moment combination among all of the nodes and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{PipeRunDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$$\mathrm{PipeRun}(P, D_o, t, I, B_1, B_2, S, nf, el, C_o, EL) :=$$

$$\begin{array}{l}
ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
ind_{el} \leftarrow \mathrm{match}\left(el_0, EL^{\langle 0 \rangle}\right) \\
\text{for } i \in 1 .. \mathrm{last}(el) \quad \text{if } \mathrm{rows}(el) > 1 \\
\quad ind_{el} \leftarrow \mathrm{stack}\left[ind_{el}, \left(\mathrm{match}\left(el_i, EL^{\langle 0 \rangle}\right)\right)\right] \\
\left(M \quad Int_{5, \mathrm{last}(ind_{el})}\right) \leftarrow (0 \quad 0) \\
\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0} \\
\quad \text{for } j \in 0 .. \mathrm{last}(ind_{el}) \\
\quad\quad M_{rxg} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2, ind_{el_j}} \\
\quad\quad M_{ryg} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2, ind_{el_j}} \\
\quad\quad M_{rzg} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2, ind_{el_j}} \\
\quad\quad M_{rx_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i, ind_{el_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg} \\
\quad\quad M_{ry_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i, ind_{el_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg} \\
\quad\quad M_{rz_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i, ind_{el_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg} \\
\quad\quad M'_j \leftarrow \sqrt{\left(M_{rx_j}\right)^2 + \left(M_{ry_j}\right)^2 + \left(M_{rz_j}\right)^2} \\
\quad\quad Int'_j \leftarrow \mathrm{PipeRunDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right) \\
\quad\quad \text{if } Int'_j > Int_{0,j} \\
\quad\quad\quad H \leftarrow \left(Int'_j \quad M'_j \quad nf_{ind_{nfiC_{o_{0,1}}}-1+i, 0} \quad EL_{ind_{el_j}, 0} \quad EL_{ind_{el_j}, 1} \quad ind_{el_j} \quad M_{r\ldots}\right. \\
\quad\quad\quad \text{for } k \in 0 .. 5 \\
\quad\quad\quad\quad Int_{k,j} \leftarrow H_k
\end{array}$$

Int

Conditions applicable to all pipe runs

$M_{cx} := 0$ $M_{cy} := 0$ $M_{cz} := 0$

Defining place holding directional moment variables

$$PipeRun\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties for Lines 1-13, 14, 15, 16, and 171

Define pertinent pipe variables

$D_o := 20\text{in}$ Outside Diameter [4]

$t := 0.312\text{in}$ Thickness [4]

$P := 253\text{psi}$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 935.251\ \text{in}^4$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \left| \begin{array}{l} 1.0 \ \text{ if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50 \\ \quad \left| \begin{array}{l} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \dfrac{D_o}{t}\right) \\ Y \leftarrow 1.033 - 0.00033 \cdot T \\ 1.0 \cdot \dfrac{1}{X \cdot Y} \end{array} \right. \end{array} \right.$$

$B_{2PR} = 1.102$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-13A (Element 99)

$el_{P113A} := (99)^T$

$AL_{P113A} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P113A}, PipeRun\_C_o, EL)$

$$AL_{P113A}^T = \begin{pmatrix} 0.116 & 2.141\times10^5 & 4.05 & 99 & 123 & 81 \\ 0.119 & 2.281\times10^5 & 4.05 & 99 & 130 & 82 \end{pmatrix}$$

Pipe Run 1-13B (Elements 91 & 92)

$el_{P113B} := (91 \;\; 92)^T$

$AL_{P113B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P113B}, PipeRun\_C_o, EL)$

$$AL_{P113B}^T = \begin{pmatrix} 0.091 & 9.597\times10^4 & 9.26 & 91 & 113 & 65 \\ 0.09 & 8.808\times10^4 & 11.275 & 91 & 122 & 66 \\ 0.105 & 1.616\times10^5 & 10.025 & 92 & 114 & 67 \\ 0.088 & 7.977\times10^4 & 11.275 & 92 & 122 & 68 \end{pmatrix}$$

Pipe Run 1-13C (Elements 81 & 79)

$el_{P113C} := (81 \;\; 79)^T$

$AL_{P113C} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P113C}, PipeRun\_C_o, EL)$

$$AL_{P113C}^T = \begin{pmatrix} 0.11 & 1.873\times10^5 & 9.26 & 81 & 94 & 51 \\ 0.103 & 1.5\times10^5 & 9.26 & 81 & 96 & 52 \\ 0.124 & 2.549\times10^5 & 9.26 & 79 & 64 & 49 \\ 0.11 & 1.874\times10^5 & 9.26 & 79 & 94 & 50 \end{pmatrix}$$

Pipe Run 1-14A (Element 100)

$el_{P114A} := (100)^T$

$AL_{P114A} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P114A}, PipeRun\_C_o, EL)$

$$AL_{P114A}^T = \begin{pmatrix} 0.125 & 2.561\times10^5 & 6.7 & 100 & 125 & 83 \\ 0.135 & 3.054\times10^5 & 6.7 & 100 & 128 & 84 \end{pmatrix}$$

Pipe Run 1-14B (Elements 94 & 93)

$el_{P114B} := (94 \;\; 93)^T$

$AL_{P114B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P114B}, PipeRun\_C_o, EL)$

$$AL_{P114B}^T = \begin{pmatrix} 0.119 & 2.277\times10^5 & 6.7 & 94 & 115 & 71 \\ 0.099 & 1.34\times10^5 & 4.05 & 94 & 121 & 72 \\ 0.098 & 1.284\times10^5 & 4.055 & 93 & 112 & 69 \\ 0.099 & 1.339\times10^5 & 4.05 & 93 & 121 & 70 \end{pmatrix}$$

Pipe Run 1-14C (Elements 84 & 82)

$el_{P114C} := (84 \;\; 82)^T$

$AL_{P114C} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P114C}, PipeRun\_C_o, EL)$

$$AL_{P114C}^T = \begin{pmatrix} 0.111 & 1.906\times10^5 & 5.805 & 84 & 97 & 55 \\ 0.109 & 1.828\times10^5 & 9.26 & 84 & 98 & 56 \\ 0.122 & 2.419\times10^5 & 9.26 & 82 & 65 & 53 \\ 0.11 & 1.829\times10^5 & 9.26 & 82 & 98 & 54 \end{pmatrix}$$

Pipe Run 1-15A (Element 101)

$el_{P115A} := (101)^T$

$AL_{P115A} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P115A}, PipeRun\_C_o, EL)$

$$AL_{P115A}^T = \begin{pmatrix} 0.122 & 2.448\times10^5 & 6.69 & 101 & 124 & 85 \\ 0.133 & 2.984\times10^5 & 6.695 & 101 & 129 & 86 \end{pmatrix}$$

Pipe Run 1-15B (Elements 96 & 95)

$el_{P115B} := (96 \;\; 95)^T$

$AL_{P115B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P115B}, PipeRun\_C_o, EL)$

$$AL_{P115B}^T = \begin{pmatrix} 0.12 & 2.312\times10^5 & 6.695 & 96 & 116 & 75 \\ 0.095 & 1.152\times10^5 & 10.425 & 96 & 120 & 76 \\ 0.097 & 1.208\times10^5 & 6.69 & 95 & 111 & 73 \\ 0.095 & 1.152\times10^5 & 10.425 & 95 & 120 & 74 \end{pmatrix}$$

Pipe Run 1-15C (Elements 87 & 85)

$el_{P115C} := (87\ \ 85)^T$

$AL_{P115C} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P115C}, PipeRun\_C_o, EL\right)$

$$AL_{P115C}^T = \begin{pmatrix} 0.108 & 1.755\times10^5 & 9.26 & 87 & 100 & 59 \\ 0.107 & 1.725\times10^5 & 6.695 & 87 & 102 & 60 \\ 0.122 & 2.432\times10^5 & 9.26 & 85 & 66 & 57 \\ 0.108 & 1.755\times10^5 & 9.26 & 85 & 100 & 58 \end{pmatrix}$$

Pipe Run 1-16A (Element 102)

$el_{P116A} := (102)^T$

$AL_{P116A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P116A}, PipeRun\_C_o, EL\right)$

$$AL_{P116A}^T = \begin{pmatrix} 0.118 & 2.235\times10^5 & 10.11 & 102 & 126 & 87 \\ 0.131 & 2.857\times10^5 & 10.115 & 102 & 127 & 88 \end{pmatrix}$$

Pipe Run 1-16B (Elements 98 & 97)

$el_{P116B} := (98\ \ 97)^T$

$AL_{P116B} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P116B}, PipeRun\_C_o, EL\right)$

$$AL_{P116B}^T = \begin{pmatrix} 0.123 & 2.498\times10^5 & 10.11 & 98 & 117 & 79 \\ 0.1 & 1.372\times10^5 & 10.105 & 98 & 119 & 80 \\ 0.105 & 1.632\times10^5 & 5.795 & 97 & 110 & 77 \\ 0.1 & 1.372\times10^5 & 10.105 & 97 & 119 & 78 \end{pmatrix}$$

Pipe Run 1-16C (Elements 90 & 88)

$el_{P116C} := (90\ \ 88)^T$

$AL_{P116C} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P116C}, PipeRun\_C_o, EL\right)$

$$AL_{P116C}^T = \begin{pmatrix} 0.114 & 2.041\times10^5 & 9.265 & 90 & 103 & 63 \\ 0.119 & 2.278\times10^5 & 5.79 & 90 & 105 & 64 \\ 0.128 & 2.725\times10^5 & 9.265 & 88 & 68 & 61 \\ 0.114 & 2.042\times10^5 & 9.265 & 88 & 103 & 62 \end{pmatrix}$$

Pipe Run 1-171A (Element 109)

$el_{P1171A} := (109)^T$

$AL_{P1171A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P1171A}, PipeRun\_C_o, EL\right)$

$$AL_{P1171A}^T = \begin{pmatrix} 0.104 & 1.566 \times 10^5 & 4.055 & 109 & 139 & 97 \\ 0.097 & 1.216 \times 10^5 & 9.265 & 109 & 140 & 98 \end{pmatrix}$$

Pipe Run 1-171B (Elements 107 & 106)

$el_{P1171B} := (107 \quad 106)^T$

$AL_{P1171B} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P1171B}, PipeRun\_C_o, EL\right)$

$$AL_{P1171B}^T = \begin{pmatrix} 0.103 & 1.534 \times 10^5 & 10.02 & 107 & 138 & 95 \\ 0.091 & 9.156 \times 10^4 & 10.035 & 107 & 141 & 96 \\ 0.09 & 8.69 \times 10^4 & 3.96 & 106 & 136 & 93 \\ 0.091 & 9.151 \times 10^4 & 10.035 & 106 & 141 & 94 \end{pmatrix}$$

Pipe Run 1-171C (Elements 662 & 105)

$el_{P1171C} := (662 \quad 105)^T$

$AL_{P1171C} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P1171C}, PipeRun\_C_o, EL\right)$

$$AL_{P1171C}^T = \begin{pmatrix} 0.093 & 1.041 \times 10^5 & 6.9 & 662 & 135 & 186 \\ 0.095 & 1.136 \times 10^5 & 4.195 & 662 & 1.064 \times 10^3 & 187 \\ 0.103 & 1.496 \times 10^5 & 10.04 & 105 & 143 & 91 \\ 0.095 & 1.137 \times 10^5 & 4.195 & 105 & 1.064 \times 10^3 & 92 \end{pmatrix}$$

Pipe Properties for Line 1-18, 19, 20, 21 (A&B)

Define pertinent pipe variables

$D_o := 24in$ Outside Diameter [5]

$t := 0.375in$ Thickness [5]

$P := 253psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 1.942 \times 10^3\ in^4$$

Define primary stress indices

$$B_{1PR} := 0.5$$

$$B_{2PR} := \begin{cases} 1.0 \text{ if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 \\ \quad T \leftarrow 125 \\ \quad X \leftarrow \min\left(1, 1.3 - 0.006\cdot\frac{D_o}{t}\right) \\ \quad Y \leftarrow 1.033 - 0.00033\cdot T \\ \quad 1.0\cdot\frac{1}{X\cdot Y} \end{cases}$$

$$B_{2PR} = 1.101$$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-18A (Element 646 and 14)

$$el_{P118A} := (646\ \ 14)^T$$

$$AL_{P118A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P118A}, PipeRun\_C_o, EL\right)$$

$AL_{P118A}^{\ T} =$

0.114	3.538×10^5	9.26	646	4	162
0.115	3.615×10^5	9.26	646	1.048×10^3	163
0.107	2.933×10^5	9.26	14	3	19
0.107	2.94×10^5	9.265	14	6	20

Pipe Run 1-18B (Elements 655, 654, & 13)

$$el_{P118B} := (655\ \ 654\ \ 13)^T$$

$$AL_{P118B} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P118B}, PipeRun\_C_o, EL\right)$$

$AL_{P118B}^{\ T} =$

0.102	2.568×10^5	4.055	655	7	172
0.113	3.449×10^5	4.055	655	1.057×10^3	173
0.145	6.16×10^5	4.205	654	1.056×10^3	170
0.113	3.451×10^5	4.055	654	1.057×10^3	171
0.19	9.893×10^5	9.26	13	30	17
0.145	6.162×10^5	4.205	13	1.056×10^3	18

Pipe Run 1-19A (Element 647 & 23)

$$el_{P119A} := (647\ \ 23)^T$$

$$AL_{P119A} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P119A}, PipeRun\_C_o, EL)$$

$$AL_{P119A}^T = \begin{pmatrix} 0.116 & 3.692\times10^5 & 9.26 & 647 & 11 & 164 \\ 0.117 & 3.77\times10^5 & 9.26 & 647 & 1.049\times10^3 & 165 \\ 0.11 & 3.179\times10^5 & 9.265 & 23 & 10 & 27 \\ 0.11 & 3.194\times10^5 & 9.265 & 23 & 13 & 28 \end{pmatrix}$$

Pipe Run 1-19B (Elements 657, 656, & 22)

$$el_{P119B} := (657\ \ 656\ \ 22)^T$$

$$AL_{P119B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P119B}, PipeRun\_C_o, EL)$$

$$AL_{P119B}^T = \begin{pmatrix} 0.101 & 2.5\times10^5 & 9.265 & 657 & 14 & 176 \\ 0.115 & 3.638\times10^5 & 4.045 & 657 & 1.059\times10^3 & 177 \\ 0.15 & 6.589\times10^5 & 4.05 & 656 & 1.058\times10^3 & 174 \\ 0.115 & 3.64\times10^5 & 4.045 & 656 & 1.059\times10^3 & 175 \\ 0.191 & 9.944\times10^5 & 6.7 & 22 & 33 & 25 \\ 0.15 & 6.59\times10^5 & 4.05 & 22 & 1.058\times10^3 & 26 \end{pmatrix}$$

Pipe Run 1-20A (Elements 648 and 30)

$$el_{P120A} := (648\ \ 30)^T$$

$$AL_{P120A} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P120A}, PipeRun\_C_o, EL)$$

$$AL_{P120A}^T = \begin{pmatrix} 0.114 & 3.554\times10^5 & 9.26 & 648 & 18 & 166 \\ 0.115 & 3.635\times10^5 & 9.26 & 648 & 1.05\times10^3 & 167 \\ 0.108 & 3.087\times10^5 & 9.26 & 30 & 17 & 33 \\ 0.109 & 3.103\times10^5 & 9.26 & 30 & 20 & 34 \end{pmatrix}$$

Pipe Run 1-20B (Elements 659, 658, & 29)

$el_{P120B} := (659 \quad 658 \quad 29)^T$

$AL_{P120B} := \text{PipeRun}(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P120B}, \text{PipeRun\_C}_o, EL)$

$$AL_{P120B}^{T} = \begin{pmatrix} 0.101 & 2.481\times10^{5} & 9.265 & 659 & 21 & 180 \\ 0.114 & 3.556\times10^{5} & 4.035 & 659 & 1.061\times10^{3} & 181 \\ 0.149 & 6.475\times10^{5} & 4.045 & 658 & 1.06\times10^{3} & 178 \\ 0.114 & 3.558\times10^{5} & 4.035 & 658 & 1.061\times10^{3} & 179 \\ 0.188 & 9.732\times10^{5} & 4.05 & 29 & 35 & 31 \\ 0.149 & 6.477\times10^{5} & 4.045 & 29 & 1.06\times10^{3} & 32 \end{pmatrix}$$

Pipe Run 1-21A (Elements 649 & 38)

$el_{P121A} := (649 \quad 38)^T$

$AL_{P121A} := \text{PipeRun}(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P121A}, \text{PipeRun\_C}_o, EL)$

$$AL_{P121A}^{T} = \begin{pmatrix} 0.113 & 3.483\times10^{5} & 9.26 & 649 & 25 & 168 \\ 0.114 & 3.549\times10^{5} & 9.26 & 649 & 1.051\times10^{3} & 169 \\ 0.109 & 3.126\times10^{5} & 9.265 & 38 & 24 & 39 \\ 0.109 & 3.153\times10^{5} & 9.265 & 38 & 27 & 40 \end{pmatrix}$$

Pipe Run 1-21B (Elements 661, 660, & 37)

$el_{P121B} := (661 \quad 660 \quad 37)^T$

$AL_{P121B} := \text{PipeRun}(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P121B}, \text{PipeRun\_C}_o, EL)$

$$AL_{P121B}^{T} = \begin{pmatrix} 0.103 & 2.608\times10^{5} & 9.265 & 661 & 28 & 184 \\ 0.122 & 4.193\times10^{5} & 10.115 & 661 & 1.063\times10^{3} & 185 \\ 0.16 & 7.383\times10^{5} & 10.115 & 660 & 1.062\times10^{3} & 182 \\ 0.122 & 4.195\times10^{5} & 10.115 & 660 & 1.063\times10^{3} & 183 \\ 0.201 & 1.078\times10^{6} & 10.26 & 37 & 37 & 37 \\ 0.16 & 7.384\times10^{5} & 10.115 & 37 & 1.062\times10^{3} & 38 \end{pmatrix}$$

Pipe Properties for Line 1-18, 19, 20, 21 (C)

Define pertinent pipe variables

$D_o := 18in$ — Outside Diameter [5]

$t := 0.3135in$ — Thickness [5]

$P := 253psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$ — Moment of inertia [8, Table 17-27, pg 17-39]

$I = 681.333\ in^4$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{cases} 1.0 \ \text{if} \ \frac{D_o}{t} \le 50 \\ \text{if} \ \frac{D_o}{t} > 50 \\ \quad T \leftarrow 125 \\ \quad X \leftarrow \min\left(1, 1.3 - 0.006\cdot\frac{D_o}{t}\right) \\ \quad Y \leftarrow 1.033 - 0.00033\cdot T \\ \quad 1.0\cdot\frac{1}{X\cdot Y} \end{cases}$$

$B_{2PR} = 1.055$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-18C (Element 1)

$el_{P118C} := (1)^T$

$AL_{P118C} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P118C}, PipeRun\_C_o, EL\right)$

$$AL_{P118C}^{\ T} = \begin{pmatrix} 0.339 & 1.118\times10^6 & 9.26 & 1 & 1 & 1 \\ 0.323 & 1.054\times10^6 & 9.26 & 1 & 29 & 2 \end{pmatrix}$$

Pipe Run 1-19C (Element 3)

$el_{P119C} := (3)^T$

$AL_{P119C} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P119C}, PipeRun\_C_o, EL\right)$

$$AL_{P119C}^{\ T} = \begin{pmatrix} 0.338 & 1.113\times10^6 & 9.26 & 3 & 31 & 5 \\ 0.322 & 1.051\times10^6 & 6.7 & 3 & 32 & 6 \end{pmatrix}$$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** R. K. Blandford **Date:** 09/30/2008

Pipe Run 1-20C (Element 5)

$el_{P120C} := (5)^T$

$AL_{P120C} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P120C}, PipeRun\_C_o, EL)$

$$AL_{P120C}^T = \begin{pmatrix} 0.331 & 1.086\times10^6 & 4.05 & 5 & 15 & 9 \\ 0.317 & 1.03\times10^6 & 4.05 & 5 & 34 & 10 \end{pmatrix}$$

Pipe Run 1-21C (Element 7)

$el_{P121C} := (7)^T$

$AL_{P121C} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P121C}, PipeRun\_C_o, EL)$

$$AL_{P121C}^T = \begin{pmatrix} 0.361 & 1.208\times10^6 & 10.26 & 7 & 22 & 13 \\ 0.345 & 1.143\times10^6 & 10.26 & 7 & 36 & 14 \end{pmatrix}$$

Writing Output Data for Pipe Runs Associated with Lines 1-13 to 1-16, 1-18 to 1-21, and 1-171.

$PR1 := (AL_{P113A}^T)$
$PR2 := (AL_{P113B}^T)$
$PR3 := (AL_{P113C}^T)$
$PR4 := (AL_{P114A}^T)$
$PR5 := (AL_{P114B}^T)$
$PR6 := (AL_{P114C}^T)$
$PR7 := (AL_{P115A}^T)$
$PR8 := (AL_{P115B}^T)$
$PR9 := (AL_{P115C}^T)$
$PR10 := (AL_{P116A}^T)$
$PR11 := (AL_{P116B}^T)$
$PR12 := (AL_{P116C}^T)$

$PR13 := (AL_{P118A}^T)$
$PR14 := (AL_{P118B}^T)$
$PR15 := (AL_{P118C}^T)$
$PR16 := (AL_{P119A}^T)$
$PR17 := (AL_{P119B}^T)$
$PR18 := (AL_{P119C}^T)$
$PR19 := (AL_{P120A}^T)$
$PR20 := (AL_{P120B}^T)$
$PR21 := (AL_{P120C}^T)$
$PR22 := (AL_{P121A}^T)$
$PR23 := (AL_{P121B}^T)$
$PR24 := (AL_{P121C}^T)$

$PR25 := (AL_{P1171A}^T)$
$PR26 := (AL_{P1171B}^T)$
$PR27 := (AL_{P1171C}^T)$

P := (PR1 PR2 PR3 PR4 PR5 PR6 PR7 PR8 PR9 PR10 PR11 PR12 PR13 PR14 PR15 PR16 PR17 PR18 PR19 I

PipeRunsLines_13to16_18to21_171 := WRITEPRN("PRLines_13to16_18to21_171.prn" , P)

REDUCERS

Reducers Strategy: *Search based on the nodes comprising either end of the reducers. SRSS combine the three moments of each of the four node representations (one for each element connected by the node in question). Find the maximum of the moment combinations for each element and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. It is important to not combine the data from both nodes as the geometry for each is different and (9) must be applied for each node. The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\mathrm{ReducerDC}\left(P, D_o, t, I, B_1, B_2, M, S\right) := \frac{B_1\cdot\frac{P\cdot D_o}{2\cdot t} + B_2\cdot\frac{D_o}{2\cdot I}\cdot[M\cdot(1\mathrm{lbf}\cdot\mathrm{in})]}{S}$$

$\mathrm{Reducer}\left(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL\right) :=$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0\rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0\rangle}\right)$

$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1\rangle}\right)$

for $i \in 1 .. \mathrm{last}(nd)$ if $\mathrm{rows}(nd) > 1$

  $ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1\rangle}\right)\right)\right]$

$\left(M \;\; Int_0\right) \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \mathrm{last}\left(ind_{nd}\right)$

    $M_{rxg} \leftarrow nf_{ind_{nfi}C_{o_{0,1}}+2,\, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi}C_{o_{1,1}}+2,\, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi}C_{o_{2,1}}+2,\, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}}+2+i,\, ind_{nd_j}} - M_{rxg}\right)\cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi}C_{o_{1,1}}+2+i,\, ind_{nd_j}} - M_{ryg}\right)\cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi}C_{o_{2,1}}+2+i,\, ind_{nd_j}} - M_{rzg}\right)\cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow \mathrm{ReducerDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$

    if $Int'_j > Int_0$

      $Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfi}C_{o_{0,1}}-1+i,0}, EL_{ind_{nd_j},1}, ind_{nd_j}, M_{rx}, M_{ry},\right.$

      $Result \leftarrow M'$

Int

Conditions applicable to all reducers

$M_{cx} := 0$ $M_{cy} := 0$ $M_{cz} := 0$ — Defining place holding variables

$$Reducer\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Reducer Properties for Top of Lines 1-18, 1-19, 1-20, 1-21

Define pertinent reducer variables

$D_o := (20in \;\; 18in)^T$ — Outside Diameter [5]

$t := \left(\frac{3}{8}in \;\; \frac{3}{8}in\right)^T$ — Thickness [5]

$P := (253psi \;\; 253psi)^T$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^4 - (D_o - 2 \cdot t)^4\right]}{64}$$

$$I = \begin{pmatrix} 1.113 \times 10^3 \\ 806.631 \end{pmatrix} in^4$$

Moment of inertia [8, Table 17-27, pg 17-39]

Define primary stress indices

$\alpha := atan\left(\frac{1in}{9in}\right)$ — Angular slope of reducer [5]

$\alpha = 6.34\,deg$

$$B_1 := \begin{cases} 0.5 & \text{if } \alpha \le 30deg \\ 1.0 & \text{if } 30deg < \alpha \le 60deg \end{cases}$$

B_1 primary stress Index [9, NB-3683.7]

$B_1 = 0.5$

$B_2 := 1.0$ — B_2 primary stress Index [9, NB-3683.7]

Reducer 1-18A (Nodes 30 & 29)

$nd_{RD118A\_L} := (30)^T$ — Node associated with Large end of reducer

$$AL_{RD118A\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF, nd_{RD118A\_L}, Reducer\_C_o, EL\right)$$

$$AL_{RD118A\_L}{}^T = \left(0.216 \;\; 9.894 \times 10^5 \;\; 9.26 \;\; 30 \;\; 21 \;\; -9.549 \times 10^5 \;\; -1.721 \times 10^5 \;\; 1.933 \times 10^5\right)$$

$nd_{RD118A\_S} := (29)^T$ Node associated with Small end of reducer

$AL_{RD118A\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF, nd_{RD118A\_S}, Reducer\_C_o, EL\right)$

$AL_{RD118A\_S}{}^T = \left(0.261 \quad 1.054\times10^6 \quad 9.26 \quad 29 \quad 2 \quad -1.019\times10^6 \quad -1.721\times10^5 \quad 2.046\times10^5\right)$

Reducer 1-19A (Nodes 33 & 32)

$nd_{RD119A\_L} := (33)^T$ Node associated with Large end of reducer

$AL_{RD119A\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF, nd_{RD119A\_L}, Reducer\_C_o, EL\right)$

$AL_{RD119A\_L}{}^T = \left(0.217 \quad 9.945\times10^5 \quad 6.7 \quad 33 \quad 23 \quad -7.922\times10^4 \quad -2.219\times10^3 \quad -9.913\times10^5\right)$

$nd_{RD119A\_S} := (32)^T$ Node associated with Small end of reducer

$AL_{RD119A\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF, nd_{RD119A\_S}, Reducer\_C_o, EL\right)$

$AL_{RD119A\_S}{}^T = \left(0.26 \quad 1.051\times10^6 \quad 6.7 \quad 32 \quad 7 \quad 8.456\times10^4 \quad 2.22\times10^3 \quad 1.047\times10^6\right)$

Reducer 1-20A (Nodes 35 & 34)

$nd_{RD120A\_L} := (35)^T$ Node associated with Large end of reducer

$AL_{RD120A\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF, nd_{RD120A\_L}, Reducer\_C_o, EL\right)$

$AL_{RD120A\_L}{}^T = \left(0.214 \quad 9.733\times10^5 \quad 4.05 \quad 35 \quad 29 \quad 7.528\times10^5 \quad 1.308\times10^5 \quad -6.029\times10^5\right)$

$nd_{RD120A\_S} := (34)^T$ Node associated with Small end of reducer

$AL_{RD120A\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF, nd_{RD120A\_S}, Reducer\_C_o, EL\right)$

$AL_{RD120A\_S}{}^T = \left(0.256 \quad 1.03\times10^6 \quad 4.05 \quad 34 \quad 10 \quad 8.034\times10^5 \quad 1.308\times10^5 \quad -6.304\times10^5\right)$

Reducer 1-21A (Nodes 37 & 36)

$nd_{RD121A\_L} := (37)^T$ Node associated with Large end of reducer

$AL_{RD121A\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF, nd_{RD121A\_L}, Reducer\_C_o, EL\right)$

$AL_{RD121A\_L}{}^T = \left(0.23 \quad 1.078\times10^6 \quad 10.26 \quad 37 \quad 35 \quad -1.284\times10^5 \quad -6.434\times10^4 \quad 1.069\times10^6\right)$

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$nd_{RD121A\_S} := (36)^T$ Node associated with Small end of reducer

$AL_{RD121A\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF, nd_{RD121A\_S}, Reducer\_C_o, EL\right)$

$AL_{RD121A\_S}^T = \left(0.278 \quad 1.143\times10^6 \quad 10.26 \quad 36 \quad 14 \quad -1.376\times10^5 \quad -6.434\times10^4 \quad 1.133\times10^6\right)$

Writing Output Data for Reducers Associated with Lines 1-13 to 1-16, 1-18 to 1-21, and 1-171.

$RL1 := AL_{RD118A\_L}^T$

$RS1 := AL_{RD118A\_S}^T$

$RL2 := AL_{RD119A\_L}^T$

$RS2 := AL_{RD119A\_S}^T$

$RL3 := AL_{RD120A\_L}^T$

$RS3 := AL_{RD120A\_S}^T$

$RL4 := AL_{RD121A\_L}^T$

$RS4 := AL_{RD121A\_S}^T$

$R := (RL1 \quad RS1 \quad RL2 \quad RS2 \quad RL3 \quad RS3 \quad RL4 \quad RS4)$

ReducersLines_13to16_18to21_171 := WRITEPRN("RedLines_13to16_18to21_171.prn" , R)

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ELBOWS

Elbows Strategy: *Search based on the two nodes comprising the ends of each elbow. SRSS combine the three moments of each of the four node representations (one for each element connected by the nodes in question). Find the maximum of the four moment combinations and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{ElbowDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Elbow}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$$
\begin{aligned}
& ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
& ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
& ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right) \\
& \text{for } i \in 1 .. \mathrm{last}(nd) \quad \text{if } \mathrm{rows}(nd) > 1 \\
& \quad ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \\
& (M \ \ Int_0) \leftarrow (0 \ \ 0) \\
& \text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0} \\
& \quad \text{for } j \in 0 .. \mathrm{last}(ind_{nd}) \\
& \quad\quad M_{rxg} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2, ind_{nd_j}} \\
& \quad\quad M_{ryg} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2, ind_{nd_j}} \\
& \quad\quad M_{rzg} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2, ind_{nd_j}} \\
& \quad\quad M_{rx} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg} \\
& \quad\quad M_{ry} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg} \\
& \quad\quad M_{rz} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg} \\
& \quad\quad M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2} \\
& \quad\quad Int'_j \leftarrow \mathrm{ElbowDC}(P, D_o, t, I, B_1, B_2, M'_j, S) \\
& \quad\quad \text{if } Int'_j > Int_0 \\
& \quad\quad\quad Int \leftarrow \mathrm{stack}\Big(Int'_j, M'_j, nf_{ind_{nfiC_{o_{0,1}}}-1+i, 0}, EL_{ind_{nd_j}, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M
\\
& \quad\quad\quad Result \leftarrow M' \\
& Int
\end{aligned}
$$

Conditions applicable to all elbows

$M_{ox} := 0 \quad M_{oy} := 0 \quad M_{oz} := 0$

Defining place holding variables

$$Elb\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Elbow Properties for Lines 1-13, 1-14, 1-15, and 1-16

Define pertinent elbow variables

$D_o := 20in$ — Outside Diameter [4]

$t := 0.312in$ — Thickness [4]

$P := 253psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 935.251\ in^4$

$R := 1.5 \cdot D_o$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$

Mean pipe radius

Define primary stress indices

$$h := \frac{t \cdot R}{r_m^{\,2}}$$

$h = 0.097$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h > 0.5 \\ -0.1 + 0.4 \cdot h & \text{otherwise} \end{cases}$$

$B_1 = 0$ — B_1 primary stress Index [9, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 6.175$ — B_2 primary stress Index [9, NB-3683.7]

Elbow 1-13A (Nodes 123 & 114)

$nd_{EL113A\_1} := (123)^T$

$AL_{EL113A\_nd123} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL113A\_1}, Elb\_C_o, EL)$

$AL_{EL113A\_nd123}^T = (0.249 \quad 2.141\times10^5 \quad 4.05 \quad 123 \quad 81 \quad -1.537\times10^5 \quad -8.248\times10^4 \quad 1.24\times10^5)$

$nd_{EL113A\_2} := (114)^T$

$AL_{EL113A\_nd114} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL113A\_2}, Elb\_C_o, EL)$

$AL_{EL113A\_nd114}^T = (0.188 \quad 1.616\times10^5 \quad 10.025 \quad 114 \quad 118 \quad -5.982\times10^3 \quad 4.016\times10^4 \quad 1.564\times10^5)$

Elbow 1-13B (Nodes 113 & 96)

$nd_{EL113B\_1} := (113)^T$

$AL_{EL113B\_nd113} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL113B\_1}, Elb\_C_o, EL)$

$AL_{EL113B\_nd113}^T = (0.112 \quad 9.597\times10^4 \quad 9.26 \quad 113 \quad 65 \quad -7.568\times10^4 \quad 5.719\times10^4 \quad -1.455\times10^4)$

$nd_{EL113B\_2} := (96)^T$

$AL_{EL113B\_nd96} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL113B\_2}, Elb\_C_o, EL)$

$AL_{EL113B\_nd96}^T = (0.175 \quad 1.5\times10^5 \quad 9.26 \quad 96 \quad 52 \quad 1.486\times10^5 \quad 1.361\times10^4 \quad -1.499\times10^4)$

Elbow 1-14A (Nodes 125 & 115)

$nd_{EL114A\_1} := (125)^T$

$AL_{EL114A\_nd125} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL114A\_1}, Elb\_C_o, EL)$

$AL_{EL114A\_nd125}^T = (0.298 \quad 2.561\times10^5 \quad 6.7 \quad 125 \quad 83 \quad 2.211\times10^5 \quad 1.995\times10^4 \quad 1.278\times10^5)$

$nd_{EL114A\_2} := (115)^T$

$AL_{EL114A\_nd115} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL114A\_2}, Elb\_C_o, EL)$

$AL_{EL114A\_nd115}^T = (0.265 \quad 2.277\times10^5 \quad 6.7 \quad 115 \quad 124 \quad 920.416 \quad -8.159\times10^4 \quad 2.126\times10^5)$

Elbow 1-14B (Nodes 112 & 97)

$nd_{EL114B\_1} := (112)^T$

$AL_{EL114B\_nd112} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL114B\_1}, Elb\_C_o, EL\right)$

$AL_{EL114B\_nd112}{}^T = \left(0.149 \quad 1.284\times10^5 \quad 4.055 \quad 112 \quad 69 \quad 7.692\times10^4 \quad -1.025\times10^5 \quad -6.933\times10^3\right)$

$nd_{EL114B\_2} := (97)^T$

$AL_{EL114B\_nd97} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL114B\_2}, Elb\_C_o, EL\right)$

$AL_{EL114B\_nd97}{}^T = \left(0.222 \quad 1.906\times10^5 \quad 5.805 \quad 97 \quad 55 \quad 1.448\times10^5 \quad -2.854\times10^4 \quad -1.205\times10^5\right)$

Elbow 1-15A (Nodes 124 & 116)

$nd_{EL115A\_1} := (124)^T$

$AL_{EL115A\_nd124} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL115A\_1}, Elb\_C_o, EL\right)$

$AL_{EL115A\_nd124}{}^T = \left(0.285 \quad 2.448\times10^5 \quad 6.69 \quad 124 \quad 85 \quad -2.144\times10^5 \quad -6.562\times10^3 \quad 1.18\times10^5\right)$

$nd_{EL115A\_2} := (116)^T$

$AL_{EL115A\_nd116} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL115A\_2}, Elb\_C_o, EL\right)$

$AL_{EL115A\_nd116}{}^T = \left(0.269 \quad 2.313\times10^5 \quad 6.695 \quad 116 \quad 130 \quad 7.601\times10^3 \quad 8.811\times10^4 \quad 2.137\times10^5\right)$

Elbow 1-15B (Nodes 111 & 102)

$nd_{EL115B\_1} := (111)^T$

$AL_{EL115B\_nd111} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL115B\_1}, Elb\_C_o, EL\right)$

$AL_{EL115B\_nd111}{}^T = \left(0.141 \quad 1.208\times10^5 \quad 6.69 \quad 111 \quad 135 \quad 4.106\times10^4 \quad -8.903\times10^4 \quad 7.059\times10^4\right)$

$nd_{EL115B\_2} := (102)^T$

$AL_{EL115B\_nd102} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL115B\_2}, Elb\_C_o, EL\right)$

$AL_{EL115B\_nd102}{}^T = \left(0.201 \quad 1.725\times10^5 \quad 6.695 \quad 102 \quad 134 \quad -6.898\times10^4 \quad 6.15\times10^4 \quad -1.457\times10^5\right)$

Elbow 1-16A (Nodes 126 & 117)

$nd_{EL116A\_1} := (126)^T$

$$AL_{EL116A\_nd126} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL116A\_1}, Elb\_C_o, EL)$$

$$AL_{EL116A\_nd126}^T = \left(0.26 \quad 2.235\times10^5 \quad 10.11 \quad 126 \quad 87 \quad 1.984\times10^5 \quad -1.796\times10^4 \quad 1.013\times10^5\right)$$

$$nd_{EL116A\_2} := (117)^T$$

$$AL_{EL116A\_nd117} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL116A\_2}, Elb\_C_o, EL)$$

$$AL_{EL116A\_nd117}^T = \left(0.291 \quad 2.499\times10^5 \quad 10.11 \quad 117 \quad 136 \quad -2.823\times10^4 \quad -9.283\times10^4 \quad 2.303\times10^5\right)$$

Elbow 1-16B (Nodes 110 & 105)

$$nd_{EL116B\_1} := (110)^T$$

$$AL_{EL116B\_nd110} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL116B\_1}, Elb\_C_o, EL)$$

$$AL_{EL116B\_nd110}^T = \left(0.19 \quad 1.632\times10^5 \quad 5.795 \quad 110 \quad 141 \quad 9.179\times10^4 \quad -1.021\times10^5 \quad -8.829\times10^4\right)$$

$$nd_{EL116B\_2} := (105)^T$$

$$AL_{EL116B\_nd105} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL116B\_2}, Elb\_C_o, EL)$$

$$AL_{EL116B\_nd105}^T = \left(0.265 \quad 2.278\times10^5 \quad 5.79 \quad 105 \quad 140 \quad -1.52\times10^5 \quad 4.115\times10^4 \quad 1.646\times10^5\right)$$

Elbow Properties for Lines 1-18, 1-19, 1-20, and 1-21

Define pertinent elbow variables

$D_o := 24in$ — Outside Diameter [5]

$t := 0.375in$ — Thickness [5]

$P := 253psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o^4 - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 1.942\times10^3\, in^4$$

$R := D_o$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$

Mean pipe radius

Define primary stress indices

$$h := \frac{t\cdot R}{r_m^2} \qquad h = 0.064$$

Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h > 0.5 \\ -0.1 + 0.4 \cdot h & \text{otherwise} \end{cases}$$

$B_1 = 0$ — B_1 primary stress Index [9, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 8.083$ — B_2 primary stress Index [9, NB-3683.7]

Elbow 1-18A (Nodes 6 & 7)

$$nd_{EL118A\_1} := (6)^T$$

$$AL_{EL118A\_nd6} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL118A\_1}, Elb\_C_o, EL\right)$$

$$AL_{EL118A\_nd6}^T = \left(0.259 \quad 2.94 \times 10^5 \quad 9.265 \quad 6 \quad 20 \quad -2.926 \times 10^5 \quad 2.599 \times 10^4 \quad -1.16 \times 10^4\right)$$

$$nd_{EL118A\_2} := (7)^T$$

$$AL_{EL118A\_nd7} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL118A\_2}, Elb\_C_o, EL\right)$$

$$AL_{EL118A\_nd7}^T = \left(0.226 \quad 2.568 \times 10^5 \quad 4.055 \quad 7 \quad 172 \quad -1.348 \times 10^5 \quad 1.554 \times 10^5 \quad -1.538 \times 10^5\right)$$

Elbow 1-19A (Nodes 13 & 14)

$$nd_{EL119A\_1} := (13)^T$$

$$AL_{EL119A\_nd13} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL119A\_1}, Elb\_C_o, EL\right)$$

$$AL_{EL119A\_nd13}^T = \left(0.281 \quad 3.194 \times 10^5 \quad 9.265 \quad 13 \quad 28 \quad -3.171 \times 10^5 \quad 3.774 \times 10^4 \quad 7.535 \times 10^3\right)$$

$$nd_{EL119A\_2} := (14)^T$$

$$AL_{EL119A\_nd14} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL119A\_2}, Elb\_C_o, EL\right)$$

$$AL_{EL119A\_nd14}^T = \left(0.22 \quad 2.5 \times 10^5 \quad 9.265 \quad 14 \quad 176 \quad 1.655 \times 10^5 \quad -1.869 \times 10^5 \quad -1.325 \times 10^4\right)$$

Elbow 1-20A (Nodes 20 & 21)

$$nd_{EL120A\_1} := (20)^T$$

$$AL_{EL120A\_nd20} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL120A\_1}, Elb\_C_o, EL\right)$$

$$AL_{EL120A\_nd20}{}^{T} = \left(0.273 \quad 3.103\times10^{5} \quad 9.26 \quad 20 \quad 34 \quad -3.074\times10^{5} \quad 4.274\times10^{4} \quad -1.231\times10^{3}\right)$$

$$nd_{EL120A\_2} := (21)^{T}$$

$$AL_{EL120A\_nd21} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL120A\_2}, Elb\_C_o, EL\right)$$

$$AL_{EL120A\_nd21}{}^{T} = \left(0.219 \quad 2.481\times10^{5} \quad 9.265 \quad 21 \quad 180 \quad 1.59\times10^{5} \quad -1.892\times10^{5} \quad -2.16\times10^{4}\right)$$

Elbow 1-21A (Nodes 27 & 28)

$$nd_{EL121A\_1} := (27)^{T}$$

$$AL_{EL121A\_nd27} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL121A\_1}, Elb\_C_o, EL\right)$$

$$AL_{EL121A\_nd27}{}^{T} = \left(0.278 \quad 3.153\times10^{5} \quad 9.265 \quad 27 \quad 40 \quad -3.096\times10^{5} \quad 5.58\times10^{4} \quad 2.136\times10^{4}\right)$$

$$nd_{EL121A\_2} := (28)^{T}$$

$$AL_{EL121A\_nd28} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL121A\_2}, Elb\_C_o, EL\right)$$

$$AL_{EL121A\_nd28}{}^{T} = \left(0.23 \quad 2.608\times10^{5} \quad 9.265 \quad 28 \quad 184 \quad 1.649\times10^{5} \quad -1.983\times10^{5} \quad -3.896\times10^{4}\right)$$

Elbow Properties for Line 1-171 (Short Radius Elbow)

Define pertinent elbow variables

$D_o := 20in$ — Outside Diameter [18]

$t := 0.312in$ — Thickness [18]

$P := 253psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o{}^4 - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 935.251\ in^4$$

$R := D_o$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$

Mean pipe radius

Define primary stress indices

$h := \frac{t \cdot R}{r_m^2}$ — $h = 0.064$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h > 0.5 \\ -0.1 + 0.4 \cdot h & \text{otherwise} \end{cases}$ — $B_1 = 0$ — B_1 primary stress Index [9, NB-3683.7]

$B_2 := \begin{cases} 1.0 & \text{if } \frac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \frac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$ — $B_2 = 8.092$ — B_2 primary stress Index [9, NB-3683.7]

Elbow 1-171A (Nodes 140 & 138)

$nd_{EL1171A\_1} := (140)^T$

$AL_{EL1171A\_nd140} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL1171A\_1}, Elb\_C_o, EL)$

$AL_{EL1171A\_nd140}^T = (0.186 \quad 1.216 \times 10^5 \quad 9.265 \quad 140 \quad 98 \quad 7.419 \times 10^4 \quad 9.629 \times 10^4 \quad -3.356 \times 10^3)$

$nd_{EL1171A\_2} := (138)^T$

$AL_{EL1171A\_nd138} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL1171A\_2}, Elb\_C_o, EL)$

$AL_{EL1171A\_nd138}^T = (0.234 \quad 1.535 \times 10^5 \quad 10.02 \quad 138 \quad 109 \quad -3.764 \times 10^4 \quad 1.09 \times 10^4 \quad 1.484 \times 10^5)$

Elbow Properties for Line 1-171 (Long Radius Elbows)

Define pertinent elbow variables

$D_o := 20in$ — Outside Diameter [18]

$t := 0.312in$ — Thickness [18]

$P := 253psi$ — Internal Pressure [3, pg 23]

$I := \frac{\pi \cdot \left[D_o^4 - (D_o - 2 \cdot t)^4\right]}{64}$ — Moment of inertia [8, Table 17-27, pg 17-39]

$I = 935.251\ in^4$

$R := D_o$ — Nominal bend radius of curved pipe or elbow

$r_m := \frac{D_o - t}{2}$ — Mean pipe radius

Define primary stress indices

$h := \frac{t \cdot R}{r_m^{\,2}}$ $h = 0.064$ Characteristic bend parameter of a curved pipe or butt welding elbow

$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h > 0.5 \\ -0.1 + 0.4 \cdot h & \text{otherwise} \end{cases}$ $B_1 = 0$ B_1 primary stress Index [9, NB-3683.7]

$B_2 := \begin{cases} 1.0 & \text{if } \frac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \frac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$ $B_2 = 8.092$ B_2 primary stress Index [9, NB-3683.7]

Elbow 1-171B (Nodes 136 & 135)

$nd_{EL1171B\_1} := (136)^T$

$AL_{EL1171B\_nd136} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL1171B\_1}, Elb\_C_o, EL)$

$AL_{EL1171B\_nd136}^{\;T} = \begin{pmatrix} 0.133 & 8.69 \times 10^4 & 3.96 & 136 & 93 & -6.276 \times 10^4 & 5.054 \times 10^4 & 3.251 \times 10^4 \end{pmatrix}$

$nd_{EL1171B\_2} := (135)^T$

$AL_{EL1171B\_nd135} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL1171B\_2}, Elb\_C_o, EL)$

$AL_{EL1171B\_nd135}^{\;T} = \begin{pmatrix} 0.159 & 1.041 \times 10^5 & 6.9 & 135 & 186 & 3.426 \times 10^4 & -1.392 \times 10^3 & -9.833 \times 10^4 \end{pmatrix}$

Elbow 1-171C (Nodes 143 & 132)

$nd_{EL1171C\_1} := (143)^T$

$AL_{EL1171C\_nd143} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL1171C\_1}, Elb\_C_o, EL)$

$AL_{EL1171C\_nd143}^{\;T} = \begin{pmatrix} 0.228 & 1.496 \times 10^5 & 10.04 & 143 & 117 & 4.16 \times 10^4 & -1.675 \times 10^4 & 1.427 \times 10^5 \end{pmatrix}$

$nd_{EL1171C\_2} := (132)^T$

$AL_{EL1171C\_nd132} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL1171C\_2}, Elb\_C_o, EL)$

$AL_{EL1171C\_nd132}^{\;T} = \begin{pmatrix} 0.318 & 2.087 \times 10^5 & 10.04 & 132 & 90 & -2.694 \times 10^4 & 9.703 \times 10^3 & 2.067 \times 10^5 \end{pmatrix}$

Writing Output Data for Elbows Associated with Lines 13 to 16, 18 to 21, and 171

$EL1A := \left(AL_{EL113A\_nd123}^{T}\right)$

$EL1B := \left(AL_{EL113A\_nd114}^{T}\right)$

$EL2A := \left(AL_{EL113B\_nd113}^{T}\right)$

$EL2B := \left(AL_{EL113B\_nd96}^{T}\right)$

$EL3A := \left(AL_{EL114A\_nd125}^{T}\right)$

$EL3B := \left(AL_{EL114A\_nd115}^{T}\right)$

$EL4A := \left(AL_{EL114B\_nd112}^{T}\right)$

$EL4B := \left(AL_{EL114B\_nd97}^{T}\right)$

$EL5A := \left(AL_{EL115A\_nd124}^{T}\right)$

$EL5B := \left(AL_{EL115A\_nd116}^{T}\right)$

$EL6A := \left(AL_{EL115B\_nd111}^{T}\right)$

$EL6B := \left(AL_{EL115B\_nd102}^{T}\right)$

$EL7A := \left(AL_{EL116A\_nd126}^{T}\right)$

$EL7B := \left(AL_{EL116A\_nd117}^{T}\right)$

$EL8A := \left(AL_{EL116B\_nd110}^{T}\right)$

$EL8B := \left(AL_{EL116B\_nd105}^{T}\right)$

$EL9A := \left(AL_{EL118A\_nd6}^{T}\right)$

$EL9B := \left(AL_{EL118A\_nd7}^{T}\right)$

$EL10A := \left(AL_{EL119A\_nd13}^{T}\right)$

$EL10B := \left(AL_{EL119A\_nd14}^{T}\right)$

$EL11A := \left(AL_{EL120A\_nd20}^{T}\right)$

$EL11B := \left(AL_{EL120A\_nd21}^{T}\right)$

$EL12A := \left(AL_{EL121A\_nd27}^{T}\right)$

$EL12B := \left(AL_{EL121A\_nd28}^{T}\right)$

$EL13A := \left(AL_{EL1171A\_nd140}^{T}\right)$

$EL13B := \left(AL_{EL1171A\_nd138}^{T}\right)$

$EL14A := \left(AL_{EL1171B\_nd136}^{T}\right)$

$EL14B := \left(AL_{EL1171B\_nd135}^{T}\right)$

$EL15A := \left(AL_{EL1171C\_nd143}^{T}\right)$

$EL15B := \left(AL_{EL1171C\_nd132}^{T}\right)$

vEL := (EL1A EL1B EL2A EL2B EL3A EL3B EL4A EL4B EL5A EL5B EL6A EL6B EL7A EL7B EL8A EL8B EI

ElbowLines_13to16_18to21_171 := WRITEPRN("ElbowLines_13to16_18to21_171.prn" , vEL)

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FLANGES

Flange Strategy: *Search based on the nodes where flanges occur. Find the maximum moment combination for the node and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\text{FlangeDC}\left(P, D_o, t, I, B_1, B_2, M, S\right) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

$\text{Flange}\left(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL\right) :=$

$ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \text{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. \text{last}(nd)$ if $\text{rows}(nd) > 1$

  $ind_{nd} \leftarrow \text{stack}\left[ind_{nd}, \left(\text{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$\left(M \;\; Int_0\right) \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \text{last}\left(ind_{nd}\right)$

    $M_{rxg} \leftarrow nf_{ind_{nfi}C_{o_{0,1}}+2,\, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi}C_{o_{1,1}}+2,\, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi}C_{o_{2,1}}+2,\, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi}C_{o_{1,1}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi}C_{o_{2,1}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^{\;2} + M_{ry}^{\;2} + M_{rz}^{\;2}}$

    $Int'_j \leftarrow \text{FlangeDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$

    if $Int'_j > Int_0$

      $Int \leftarrow \text{stack}\left(Int'_j, M'_j, nf_{ind_{nfi}C_{o_{0,1}-1}+i,0}, EL_{ind_{nd_j},1}, ind_{nd_j}, M_{rx}, M_{ry}, M\right.$

      $Result \leftarrow M'$

Int

Conditions applicable to all flanges

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$ — Defining place holding variables

$$Flange\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties of Line 1-13, 1-14, 1-15, and 1-16

Define pertinent pipe variables

$D_o := 20in$ — Outside Diameter [4]

$t := 0.312in$ — Thickness [4]

$P := 253psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$ — Moment of inertia [8, Table 17-27, pg 17-39]

$I = 935.251\ in^4$

Define primary stress indices (Utilize girth weld characteristic associated with lap joint flanges in determining values)

$B_1 := 0.5$ — B_1 for a girth weld [9, Table NB-3681(a)-1, pg 130]

$B_2 := 1$ — B_2 for a girth weld [9, Table NB-3681(a)-1, pg 130]

Flange (Heat Exchanger) 1-13A (Node 130)

$nd_{FL113A} := (130)^T$

$AL_{FL113A} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL113A}, Flange\_C_o, EL)$

$$AL_{FL113A}^{\,T} = \begin{pmatrix} 0.115 & 2.281 \times 10^5 & 4.05 & 130 & 82 & 1.685 \times 10^5 & 1.082 \times 10^5 & -1.093 \times 10^5 \end{pmatrix}$$

Flange (Heat Exchanger) 1-14A (Node 128)

$nd_{FL114B} := (128)^T$

$AL_{FL114B} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL114B}, Flange\_C_o, EL)$

$$AL_{FL114B}^{\,T} = \begin{pmatrix} 0.129 & 3.054 \times 10^5 & 6.7 & 128 & 84 & -2.965 \times 10^5 & -5.114 \times 10^4 & -5.233 \times 10^4 \end{pmatrix}$$

Flange (Heat Exchanger) 1-15A (Node 129)

$nd_{FL115A} := (129)^T$

$AL_{FL115A} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL115A}, Flange\_C_o, EL\right)$

$AL_{FL115A}^{\ T} = \left(0.128 \quad 2.984\times10^5 \quad 6.695 \quad 129 \quad 86 \quad 2.94\times10^5 \quad 3.442\times10^4 \quad -3.725\times10^4\right)$

Flange (Heat Exchanger) 1-16A (Node 127)

$nd_{FL116B} := (127)^T$

$AL_{FL116B} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL116B}, Flange\_C_o, EL\right)$

$AL_{FL116B}^{\ T} = \left(0.125 \quad 2.857\times10^5 \quad 10.115 \quad 127 \quad 88 \quad -2.853\times10^5 \quad -7.425\times10^3 \quad -1.36\times10^4\right)$

Pipe Properties Lower Portions of Lines 1-18, 1-19, 1-20, and 1-21

Define pertinent pipe variables

$D_o := 24in$ Outside Diameter [5]

$t := 0.375in$ Thickness [5]

$P := 253psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o^{\ 4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$ Moment of inertia [8, Table 17-27, pg 17-39]

$I = 1.942\times10^3\ in^4$

Define primary stress indices (Utilize girth weld characteristic associated with lap joint flanges in determining values)

$B_1 := 0.5$ B_1 for a girth weld [9, Table NB-3681(a)-1, pg 130]

$B_2 := 1$ B_2 for a girth weld [9, Table NB-3681(a)-1, pg 130]

Flange (Gate Valves) 1-18A (Node 4)

$nd_{FL118A} := (4)^T$

$AL_{FL118A} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL118A}, Flange\_C_o, EL\right)$

$AL_{FL118A}^{\ T} = \left(0.11 \quad 3.538\times10^5 \quad 9.26 \quad 4 \quad 162 \quad -2.928\times10^5 \quad -1.78\times10^5 \quad 8.813\times10^4\right)$

Flange (Gate Valves) 1-18B (Node 3)

$nd_{FL118B} := (3)^T$

$AL_{FL118B} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL118B}, Flange\_C_o, EL)$

$AL_{FL118B}^T = \begin{pmatrix} 0.103 & 2.934 \times 10^5 & 9.26 & 3 & 41 & -2.928 \times 10^5 & 1.036 \times 10^4 & -1.607 \times 10^4 \end{pmatrix}$

Flange (Gate Valves) 1-19A (Node 11)

$nd_{FL119A} := (11)^T$

$AL_{FL119A} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL119A}, Flange\_C_o, EL)$

$AL_{FL119A}^T = \begin{pmatrix} 0.112 & 3.692 \times 10^5 & 9.26 & 11 & 164 & -3.17 \times 10^5 & -1.742 \times 10^5 & 7.422 \times 10^4 \end{pmatrix}$

Flange (Gate Valves) 1-19B (Node 10)

$nd_{FL119B} := (10)^T$

$AL_{FL119B} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL119B}, Flange\_C_o, EL)$

$AL_{FL119B}^T = \begin{pmatrix} 0.106 & 3.18 \times 10^5 & 9.265 & 10 & 43 & -3.172 \times 10^5 & 2.258 \times 10^4 & 3.294 \times 10^3 \end{pmatrix}$

Flange (Gate Valves) 1-20A (Node 18)

$nd_{FL120A} := (18)^T$

$AL_{FL120A} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL120A}, Flange\_C_o, EL)$

$AL_{FL120A}^T = \begin{pmatrix} 0.11 & 3.554 \times 10^5 & 9.26 & 18 & 166 & -3.075 \times 10^5 & -1.654 \times 10^5 & 6.628 \times 10^4 \end{pmatrix}$

Flange (Gate Valves) 1-20B (Node 17)

$nd_{FL120B} := (17)^T$

$AL_{FL120B} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL120B}, Flange\_C_o, EL)$

$AL_{FL120B}^T = \begin{pmatrix} 0.105 & 3.088 \times 10^5 & 9.26 & 17 & 45 & -3.075 \times 10^5 & 2.787 \times 10^4 & -6.678 \times 10^3 \end{pmatrix}$

Flange (Gate Valves) 1-21A (Node 25)

$nd_{FL121A} := (25)^T$

$AL_{FL121A} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL121A}, Flange\_C_o, EL)$

$AL_{FL121A}^T = \begin{pmatrix} 0.109 & 3.483 \times 10^5 & 9.26 & 25 & 168 & -3.09 \times 10^5 & -1.486 \times 10^5 & 6.147 \times 10^4 \end{pmatrix}$

Flange (Gate Valves) 1-21B (Node 24)

$nd_{FL121B} := (24)^T$

$AL_{FL121B} := \text{Flange}(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL121B}, \text{Flange\_C}_o, EL)$

$AL_{FL121B}^T = (0.105 \quad 3.127\times10^5 \quad 9.265 \quad 24 \quad 47 \quad -3.097\times10^5 \quad 4.131\times10^4 \quad 1.442\times10^4)$

Pipe Properties of Upper Portion of Lines 1-18, 1-19, 1-20, and 1-21

Define pertinent pipe variables

$D_o := 18\text{in}$ Outside Diameter [5]

$t := 0.3125\text{in}$ Thickness [5]

$P := 253\text{psi}$ Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o^{\,4} - (D_o - 2\cdot t)^4\right]}{64}$$ Moment of inertia [8, Table 17-27, pg 17-39]

$I = 679.274\ \text{in}^4$

Define primary stress indices (Utilize girth weld characteristic associated with lap joint flanges in determining values)

$B_1 := 0.5$ B_1 for a girth weld [9, Table NB-3681(a)-1, pg 130]

$B_2 := 1$ B_2 for a girth weld [9, Table NB-3681(a)-1, pg 130]

Flange (Primary Pump) 1-18C (Node 1)

$nd_{FL118C} := (1)^T$

$AL_{FL118C} := \text{Flange}(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL118C}, \text{Flange\_C}_o, EL)$

$AL_{FL118C}^T = (0.326 \quad 1.118\times10^6 \quad 9.26 \quad 1 \quad 1 \quad 1.084\times10^6 \quad 1.721\times10^5 \quad -2.16\times10^5)$

Flange (Primary Pump) 1-19C (Node 31)

$nd_{FL119C} := (31)^T$

$AL_{FL119C} := \text{Flange}(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL119C}, \text{Flange\_C}_o, EL)$

$AL_{FL119C}^T = (0.324 \quad 1.113\times10^6 \quad 9.26 \quad 31 \quad 5 \quad 1.078\times10^6 \quad 1.866\times10^5 \quad -2.059\times10^5)$

Flange (Primary Pump) 1-20C (Node 15)

$nd_{FL120C} := (15)^T$

$AL_{FL120C} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL120C}, Flange\_C_o, EL)$

$AL_{FL120C}^T = (0.318 \quad 1.086 \times 10^6 \quad 4.05 \quad 15 \quad 9 \quad -8.54 \times 10^5 \quad -1.308 \times 10^5 \quad 6.58 \times 10^5)$

Flange (Primary Pump) 1-21C (Node 22)

$nd_{FL121C} := (22)^T$

$AL_{FL121C} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL121C}, Flange\_C_o, EL)$

$AL_{FL121C}^T = (0.347 \quad 1.208 \times 10^6 \quad 10.26 \quad 22 \quad 13 \quad 1.469 \times 10^5 \quad 6.434 \times 10^4 \quad -1.197 \times 10^6)$

Pipe Properties of Lines 1-171

Define pertinent pipe variables

$D_o := 20in$ — Outside Diameter [18]

$t := 0.312in$ — Thickness [18]

$P := 253psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - (D_o - 2 \cdot t)^4\right]}{64}$$ Moment of inertia [8, Table 17-27, pg 17-39]

$I = 935.251\ in^4$

Define primary stress indices (Utilize girth weld characteristic associated with lap joint flanges in determining values)

$B_1 := 0.5$ — B_1 for a girth weld [9, Table NB-3681(a)-1, pg 130]

$B_2 := 1$ — B_2 for a girth weld [9, Table NB-3681(a)-1, pg 130]

Flange (Heat Exchanger) 1-171A (Node 139)

$nd_{FL1171A} := (139)^T$

$AL_{FL1171A} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL1171A}, Flange\_C_o, EL)$

$AL_{FL1171A}^T = (0.101 \quad 1.566 \times 10^5 \quad 4.055 \quad 139 \quad 97 \quad 9.373 \times 10^4 \quad 5.223 \times 10^4 \quad 1.141 \times 10^5)$

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Writing Output Data for Flanges Associated with Lines 1-13 to 1-16, 1-18 to 1-21, and 1-171.

$F1 := \left(AL_{FL113A}{}^{T}\right)$

$F2 := \left(AL_{FL114B}{}^{T}\right)$

$F3 := \left(AL_{FL115A}{}^{T}\right)$

$F4 := \left(AL_{FL116B}{}^{T}\right)$

$F5 := \left(AL_{FL118A}{}^{T}\right)$

$F6 := \left(AL_{FL118B}{}^{T}\right)$

$F7 := AL_{FL119A}{}^{T}$

$F8 := \left(AL_{FL119B}{}^{T}\right)$

$F9 := \left(AL_{FL120A}{}^{T}\right)$

$F10 := \left(AL_{FL120B}{}^{T}\right)$

$F11 := \left(AL_{FL121A}{}^{T}\right)$

$F12 := \left(AL_{FL121B}{}^{T}\right)$

$F13 := \left(AL_{FL118C}{}^{T}\right)$

$F14 := \left(AL_{FL119C}{}^{T}\right)$

$F15 := \left(AL_{FL120C}{}^{T}\right)$

$F16 := \left(AL_{FL121C}{}^{T}\right)$

$F17 := \left(AL_{FL1171A}{}^{T}\right)$

$F := (F1\ \ F2\ \ F3\ \ F4\ \ F5\ \ F6\ \ F7\ \ F8\ \ F9\ \ F10\ \ F11\ \ F12\ \ F13\ \ F14\ \ F15\ \ F16\ \ F17)$

FlangeLines_13to16_18to21_171 := WRITEPRN("FlangeLines_13to16_18to21_171.prn" , F)

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Appendix C.3.3

Demand to Capacity Ratio Calculations for Components Associated with Line 1-30, 1-31, and 1-48 of ATR PCS Model 265

(NOTE: Values represented here are shown for one realization (Nodal Force file = LINES_30-31_48_test_R1.dat and Element/Nodal order file = EL_30-31_48.xls) and may or may not be consistent with the 80th percentile results contained in Appendix C.4)

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Force Outputs from Abaqus

NF := ...\LINES_30-31_48.dat

(N)odal (F)orces for the (M)edium (L)ines of Model 3

Defined Elemental and Corresponding Nodal Order

EL := ..\EL_30-31_48(9-22-08).xls

Element and corresponding nodal order for the (M)edium (L)ines of Model 3

Time Boundaries

$t_{initial} := 1$

Initial time for which dynamic loading is applied

$t_{final} := 21$

Final time for which dynamic loading stops

Seismic Scale Factor (F_a)

$F_a := 1$

Seismic scale factor [30]

Allowable Design Stress Intensity Factor (S_m): *S_m is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{m\_125} := 20\text{ksi}$

For SS304 at 125°F [2, pg 316-318] [3, pg 23]

$S_{m\_125L} := 16.7\text{ksi}$

For SS304L at 125°F [2, pg 316-318] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Yield Strength (S_y): *S_y is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{y\_125} := 28.35\text{ksi}$

For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_125L} := 23.85\text{ksi}$

For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Maximum Strength Applicable for Equation 9 (S): *S is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{125} := \min(3 \cdot S_{m\_125}, 2 \cdot S_{y\_125})$

$\boxed{S_{125} = 56.7\,\text{ksi}}$

Maximum allowable stress applied to SS304 piping [9, NB-3656]

$S_{125L} := \min(3 \cdot S_{m\_125L}, 2 \cdot S_{y\_125L})$

$\boxed{S_{125L} = 47.7\,\text{ksi}}$

Maximum allowable stress applied to SS304L piping [9, NB-3656]

SUPPORTS

Supports Strategy: *Search based on the node for which the support acts. If this node is a termination point there will only be one node to evaluate. If this node is in line with a section of pipe there will be two representations of the same node (one for each element on each side of the node) to combine and the difference between them is the force required of the support. The D/C ratio for each support will be found by dividing the the required force found above by the support capacity.*

$$SupDC(P_r, P_c) := \frac{P_r}{P_c}$$

$$\begin{aligned}
Support(nf, nd, C_o, EL) := \; & ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
& ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
& ind_{nd} \leftarrow match\left(nd_0, EL^{\langle 1 \rangle}\right) \\
& \text{for } i \in 1..last(nd) \quad \text{if } rows(nd) > 1 \\
& \quad ind_{nd} \leftarrow stack\left[ind_{nd}, \left(match\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \\
& \left(Int1_5 \;\; Int2_5\right) \leftarrow (0 \;\; 0) \\
& \text{for } i \in 0..ind_{nfo_0} - ind_{nfi_0} \\
& \quad \text{for } j \in 0..last(ind_{nd}) \\
& \quad\quad P_{rg_j} \leftarrow nf_{ind_{nfi}C_{o_{0,1}}-1,\, ind_{nd_j}} \\
& \quad\quad P_{r_j} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}}-1+i,\, ind_{nd_j}} - P_{rg_j}\right)\cdot C_{o_{2,0}} + P_{rg_j} \\
& \quad PR_i \leftarrow \sum_{n=0}^{j} P_{r_n} \\
& \quad \text{if } PR_i < Int1_1 \wedge C_{o_{0,0}} \neq 0 \\
& \quad\quad Int1' \leftarrow SupDC\left(\left|PR_i\right|, C_{o_{0,0}}\right) \\
& \quad\quad Int1 \leftarrow stack\left(Int1', PR_i, nf_{ind_{nfi}C_{o_{0,1}}-1+i,0}, EL_{ind_{nd_j},1}, ind_{nd}\right) \\
& \quad \text{if } PR_i > Int2_1 \wedge C_{o_{1,0}} \neq 0 \\
& \quad\quad Int2' \leftarrow SupDC\left(\left|PR_i\right|, C_{o_{1,0}}\right) \\
& \quad\quad Int2 \leftarrow stack\left(Int2', PR_i, nf_{ind_{nfi}C_{o_{0,1}}-1+i,0}, EL_{ind_{nd_j},1}, ind_{nd}\right) \\
& \left(Int1 \;\; Int2\right)
\end{aligned}$$

RH-32 Support (1x)

$P_{1\_RH32} := \frac{4.755 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_RH32} := \frac{0 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_RH32} := \begin{pmatrix} P_{1\_RH32} & 2 \\ P_{2\_RH32} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

RH-32 (Node 860)

RH-32 vertically supports line 1-30 just south of EL(1-30A) from any downward movement.

$nd860_{RH32_0} := 860$ Node associated with support

$$\left(AL1_{RH32\_nd860} \;\; AL2_{RH32\_nd860}\right) := Support\left(NF, nd860_{RH32}, Sup\_C_{o\_RH32}, EL\right)$$

$$AL1_{RH32\_nd860}^{\;T} = \left(4.239 \times 10^{-4} \;\; -2.016 \;\; 3.875 \;\; 860 \;\; 80\right)$$

$$AL2_{RH32\_nd860}^{\;T} = \left(0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0\right)$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-11 Support (2x)

$P_{1\_RH11} := \frac{14.91 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_RH11} := \frac{7.266 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_RH11} := \begin{pmatrix} P_{1\_RH11} & 2 \\ P_{2\_RH11} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

RH-11A (Node 857)

RH-11A vertically supports line 1-30 just west of Fab Branch(1-30) from any downward movement.

$nd857_{RH11A_0} := 857$ Node associated with support

$$\left(AL1_{RH11A\_nd857}\ \ AL2_{RH11A\_nd857}\right) := \text{Support}\left(NF, nd857_{RH11A}, Sup\_C_{o\_RH11}, EL\right)$$

$$AL1_{RH11A\_nd857}{}^{T} = \left(0.504\ \ -7.513\times10^{3}\ \ 6.835\ \ 857\ \ 82\right)$$

$$AL2_{RH11A\_nd857}{}^{T} = \left(0.237\ \ 1.72\times10^{3}\ \ 6.735\ \ 857\ \ 82\right)$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-11B (Node 858)

RH-11B vertically supports line 1-30 between T(1-48) and T(1-31) from any downward movement.

$nd858_{RH11B_0} := 858$ Node associated with support

$$\left(AL1_{RH11B\_nd858}\ \ AL2_{RH11B\_nd858}\right) := \text{Support}\left(NF, nd858_{RH11B}, Sup\_C_{o\_RH11}, EL\right)$$

$$AL1_{RH11B\_nd858}{}^{T} = \left(0.312\ \ -4.646\times10^{3}\ \ 8.055\ \ 858\ \ 84\right)$$

$$AL2_{RH11B\_nd858}{}^{T} = \left(0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0\right)$$

PS-4 Support (4x)

$P_{1\_PS4} := \dfrac{87.941\cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_PS4} := \dfrac{0\cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_PS4} := \begin{pmatrix} P_{1\_PS4} & 2 \\ P_{2\_PS4} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

PS-4A (Node 849)

PS-4A vertically supports line 1-30 at FL(1-30C) from any downward movement.

$nd849_{PS4A_0} := 849$ Node associated with support

$$\left(AL1_{PS4A\_nd849}\ \ AL2_{PS4A\_nd849}\right) := \text{Support}\left(NF, nd849_{PS4A}, Sup\_C_{o\_PS4}, EL\right)$$

$$AL1_{PS4A\_nd849}{}^{T} = \left(0.112\ \ -9.892\times10^{3}\ \ 6.675\ \ 849\ \ 74\right)$$

$$AL2_{PS4A\_nd849}{}^{T} = \left(0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0\right)$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PS-4B (Node 850)

PS-4B vertically supports line 1-30 at FL(1-30D) from any downward movement.

$nd850_{PS4B_0} := 850$ Node associated with support

$\left(AL1_{PS4B\_nd850} \;\; AL2_{PS4B\_nd850}\right) := Support\left(NF, nd850_{PS4B}, Sup\_C_{o\_PS4}, EL\right)$

$AL1_{PS4B\_nd850}^{T} = \left(0.03 \;\; -2.681\times 10^{3} \;\; 10.955 \;\; 850 \;\; 76\right)$

$AL2_{PS4B\_nd850}^{T} = \left(0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0\right)$

PS-4C (Node 848)

PS-4C vertically supports line 1-31 at FL(1-31A) from any downward movement.

$nd848_{PS4A_0} := 848$ Node associated with support

$\left(AL1_{PS4A\_nd848} \;\; AL2_{PS4A\_nd848}\right) := Support\left(NF, nd848_{PS4A}, Sup\_C_{o\_PS4}, EL\right)$

$AL1_{PS4A\_nd848}^{T} = \left(0.222 \;\; -1.948\times 10^{4} \;\; 4.2 \;\; 848 \;\; 72\right)$

$AL2_{PS4A\_nd848}^{T} = \left(0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0\right)$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PS-4D (Node 847)

PS-4D vertically supports line 1-31 at FL(1-31B) from any downward movement.

$nd847_{PS4B_0} := 847$ Node associated with support

$\left(AL1_{PS4B\_nd847} \;\; AL2_{PS4B\_nd847}\right) := Support\left(NF, nd847_{PS4B}, Sup\_C_{o\_PS4}, EL\right)$

$AL1_{PS4B\_nd847}^{T} = \left(0.086 \;\; -7.529\times 10^{3} \;\; 10.79 \;\; 847 \;\; 70\right)$

$AL2_{PS4B\_nd847}^{T} = \left(0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0\right)$

AIS Support (1x)

$P_{1\_AISX} := \frac{18.435 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_AISX} := \frac{13.254 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

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$$Sup\_C_{o\_AISX} := \begin{pmatrix} P_{1\_AISX} & 3 \\ P_{2\_AISX} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

$$P_{1\_AISZ} := \frac{0.546 \cdot kip}{lbf}$$

Flexure

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$$P_{2\_AISZ} := \frac{0.546 \cdot kip}{lbf}$$

Flexure

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_AISZ} := \begin{pmatrix} P_{1\_AISZ} & 1 \\ P_{2\_AISZ} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

AIS (EW) (Node 842)

AIS supports line 1-48 at top side of EL(1-48B) from horizontal movement.

$$nd842_{AISX_0} := 842$$

Node associated with support

$$\begin{pmatrix} AL1_{AISX\_nd842} & AL2_{AISX\_nd842} \end{pmatrix} := Support\left(NF, nd842_{AISX}, Sup\_C_{o\_AISX}, EL\right)$$

$$AL1_{AISX\_nd842}^{T} = \begin{pmatrix} 1.288 \times 10^{-4} & -2.375 & 12.62 & 842 & 119 \end{pmatrix}$$

$$AL2_{AISX\_nd842}^{T} = \begin{pmatrix} 1.557 \times 10^{-4} & 2.063 & 12.54 & 842 & 119 \end{pmatrix}$$

D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

AIS (NS) (Node 842)

AIS supports line 1-48 at top side of EL(1-48B) from horizontal movement.

$$nd842_{AISZ_0} := 842$$

Node associated with support

$$\begin{pmatrix} AL1_{AISZ\_nd842} & AL2_{AISZ\_nd842} \end{pmatrix} := Support\left(NF, nd842_{AISZ}, Sup\_C_{o\_AISZ}, EL\right)$$

$$AL1_{AISZ\_nd842}^{T} = \begin{pmatrix} 1.223 \times 10^{-3} & -0.668 & 5.365 & 842 & 119 \end{pmatrix}$$

$$AL2_{AISZ\_nd842}^{T} = \begin{pmatrix} 1.446 \times 10^{-3} & 0.79 & 6.835 & 842 & 119 \end{pmatrix}$$

RH-24 Support (2x)

$$P_{1\_RH24} := \frac{7.069 \cdot kip}{lbf}$$

Tension

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$$P_{2\_RH24} := \frac{0.001 \cdot kip}{lbf}$$

Doesn't experience uplift

Compression

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_RH24} := \begin{pmatrix} P_{1\_RH24} & 2 \\ P_{2\_RH24} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

RH-24A (Node 816)

RH-24A vertically supports line 1-48 just north of EL(1-48A) from any downward movement.

$nd816_{RH24A_0} := 816$ Node associated with support

$(AL1_{RH24A\_nd816} \;\; AL2_{RH24A\_nd816}) := Support(NF, nd816_{RH24A}, Sup\_C_{o\_RH24}, EL)$

$AL1_{RH24A\_nd816}{}^T = (0.069 \;\; -490.226 \;\; 5.435 \;\; 816 \;\; 66)$

$AL2_{RH24A\_nd816}{}^T = (0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0)$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-24B (Node 815)

RH-24A vertically supports line 1-48 near the runs midpoint from any downward movement.

$nd815_{RH24B_0} := 815$ Node associated with support

$(AL1_{RH24B\_nd815} \;\; AL2_{RH24B\_nd815}) := Support(NF, nd815_{RH24B}, Sup\_C_{o\_RH24}, EL)$

$AL1_{RH24B\_nd815}{}^T = (0.151 \;\; -1.068 \times 10^3 \;\; 10.825 \;\; 815 \;\; 68)$

$AL2_{RH24B\_nd815}{}^T = (0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0)$

Writing Output Data for Supports Associated with Lines 1-30, 31, & 48

$SA1 := AL1_{RH32\_nd860}{}^T$ $SE1 := AL1_{PS4B\_nd850}{}^T$ $SI1 := AL1_{AISZ\_nd842}{}^T$

$SA2 := AL2_{RH32\_nd860}{}^T$ $SE2 := AL2_{PS4B\_nd850}{}^T$ $SI2 := AL2_{AISZ\_nd842}{}^T$

$SB1 := AL1_{RH11A\_nd857}{}^T$ $SF1 := AL1_{PS4A\_nd848}{}^T$ $SJ1 := AL1_{RH24A\_nd816}{}^T$

$SB2 := AL2_{RH11A\_nd857}{}^T$ $SF2 := AL2_{PS4A\_nd848}{}^T$ $SJ2 := AL2_{RH24A\_nd816}{}^T$

$SC1 := AL1_{RH11B\_nd858}{}^T$ $SG1 := AL1_{PS4B\_nd847}{}^T$ $SK1 := AL1_{RH24B\_nd815}{}^T$

$SC2 := AL2_{RH11B\_nd858}{}^T$ $SG2 := AL2_{PS4B\_nd847}{}^T$ $SK2 := AL2_{RH24B\_nd815}{}^T$

$SD1 := AL1_{PS4A\_nd849}{}^T$ $SH1 := AL1_{AISX\_nd842}{}^T$

$SD2 := AL2_{PS4A\_nd849}{}^T$ $SH2 := AL2_{AISX\_nd842}{}^T$

$S := (SA1 \;\; SA2 \;\; SB1 \;\; SB2 \;\; SC1 \;\; SC2 \;\; SD1 \;\; SD2 \;\; SE1 \;\; SE2 \;\; SF1 \;\; SF2 \;\; SG1 \;\; SG2 \;\; SH1 \;\; SH2 \;\; SI1 \;\; SI2 \;\; SJ1 \;\; SJ2 \;\; SK1 \;\; SK2)$

SupportLines_30to31_48 := WRITEPRN("SupLines_30to31_48.prn" , S)

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TERMINATION LOCATIONS

Termination Locations Strategy: *Search based on the node for which the termination location acts as well as the next node inward. The D/C ratio for each termination location will be found by dividing the the required force found above by the support capacity.*

$$\mathrm{TermDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Term}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$$
$$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$$
$$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$$
$$\text{for } i \in 1 .. \mathrm{last}(nd) \quad \text{if } \mathrm{rows}(nd) > 1$$
$$\quad ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$$
$$(M \quad Int_0) \leftarrow (0 \quad 0)$$
$$\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$$
$$\quad \text{for } j \in 0 .. \mathrm{last}(ind_{nd})$$
$$\qquad M_{rxg} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{nd_j}}$$
$$\qquad M_{ryg} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{nd_j}}$$
$$\qquad M_{rzg} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{nd_j}}$$
$$\qquad M_{rx} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$$
$$\qquad M_{ry} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$$
$$\qquad M_{rz} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$$
$$\qquad M'_j \leftarrow \sqrt{M_{rx}^{\,2} + M_{ry}^{\,2} + M_{rz}^{\,2}}$$
$$\qquad Int'_j \leftarrow \mathrm{TermDC}(P, D_o, t, I, B_1, B_2, M'_j, S)$$
$$\qquad \text{if } Int'_j > Int_0$$
$$\qquad\quad Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfiC_{o_{0,1}}-1}+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M_{r}\right.$$
$$\qquad\quad Result \leftarrow M'$$
$$Int$$

Conditions applicable to all terminations

$M_{cx} := 0 \qquad M_{cy} := 0 \qquad M_{cz} := 0$

Defining place holding variables

$$Term\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Emergency Pump Suction (2x)

Define pertinent pipe variables

$D_o := 14in$ — Outside Diameter [7] [10]

$t := 0.25in$ — Thickness [7] [10]

$P := 253psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

$$I = 255.3\ in^4$$

Moment of inertia [8, Table 17-27, pg 17-39]

$S := S_{125}$ — Allowable design stress intensity value

Define primary stress indices

$B_1 := 0.5$

$$B_2 := \begin{array}{l} 1.0 \ \text{ if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50 \\ \quad \begin{array}{|l} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006\cdot\dfrac{D_o}{t}\right) \\ Y \leftarrow 1 \\ 1.0\cdot\dfrac{1}{X\cdot Y} \end{array} \end{array}$$

$B_2 = 1.037$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Emergency Pump 1-30 (Node 160)

$nd160_{EP130_0} := 160$

$AL_{EP130\_nd160} := Term(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd160_{EP130}, Term\_C_o, EL)$

$$AL_{EP130\_nd160}^T = \begin{pmatrix} 0.197 & 2.677 \times 10^5 & 6.485 & 160 & 27 & 9.971 \times 10^3 & -2.18 \times 10^5 & -1.55 \times 10^5 \end{pmatrix}$$

Emergency Pump 1-31 (Node 194)

$nd194_{EP131_0} := 194$

$AL_{EP131\_nd194} := Term(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd194_{EP131}, Term\_C_o, EL)$

$$AL_{EP131\_nd194}^T = \begin{pmatrix} 0.16 & 1.946 \times 10^5 & 6.33 & 194 & 41 & 7.884 \times 10^4 & 1.747 \times 10^5 & 3.375 \times 10^4 \end{pmatrix}$$

North Wall Penetration 1-48 (1x)

Define pertinent pipe variables

$D_o := 4.5in$ — Outside Diameter [17]

$t := 0.237in$ — Thickness [17]

$P := 253psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^4 - (D_o - 2 \cdot t)^4\right]}{64}$$

$I = 7.233\ in^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$S := S_{125}$ — Allowable design stress intensity value

Define primary stress indices

$B_1 := 0.5$

$$B_2 := \begin{cases} 1.0 \text{ if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 \\ \quad T \leftarrow 125 \\ \quad X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \frac{D_o}{t}\right) \\ \quad Y \leftarrow 1 \\ \quad 1.0 \cdot \frac{1}{X \cdot Y} \end{cases}$$

$B_2 = 1$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

North Wall Penetration 1-48 (Node 682)

$nd682_{NWP148_0} := 682$

$AL_{NWP148\_nd682} := Term\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd682_{NWP148}, Term\_C_o, EL\right)$

$$AL_{NWP148\_nd682}^{T} = \left(0.196 \quad 3.195 \times 10^4 \quad 12.885 \quad 682 \quad 151 \quad -6.869 \times 10^3 \quad -3.104 \times 10^4 \quad 3.15 \times 10^3\right)$$

Writing Output Data for Terminations Associated with Lines 1-30, 1-31, & 1-48

$T1 := \left(AL_{EP130\_nd160}^{T}\right)$ Emergency Pump 1-30 (Node 160)

$T2 := \left(AL_{EP131\_nd194}^{T}\right)$ Emergency Pump 1-31 (Node 194)

$T3 := \left(AL_{NWP148\_nd682}^{T}\right)$ North Wall Penetration 1-48 (Node 682)

$T := (T1 \quad T2 \quad T3)$

TerminationsLines_30to31_48 := WRITEPRN("TermLines_30to31_48.prn" , T)

PIPE RUNS

Pipe Runs Strategy: *Search based on the nodes present in each run of pipe. Find the maximum moment combination among all of the nodes and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{PipeRunDC}\left(P, D_o, t, I, B_1, B_2, M, S\right) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\,\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{PipeRun}\left(P, D_o, t, I, B_1, B_2, S, nf, el, C_o, EL\right) :=$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{el} \leftarrow \mathrm{match}\left(el_0, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(el)$ if $\mathrm{rows}(el) > 1$

$\quad ind_{el} \leftarrow \mathrm{stack}\left[ind_{el}, \left(\mathrm{match}\left(el_i, EL^{\langle 0 \rangle}\right)\right)\right]$

$\left(M \quad Int_{5, \mathrm{last}(ind_{el})}\right) \leftarrow (0 \quad 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

$\quad$ for $j \in 0 .. \mathrm{last}\left(ind_{el}\right)$

$\quad\quad M_{rxg} \leftarrow nf_{ind_{nfi}{C_o}_{0,1}+2,\, ind_{el_j}}$

$\quad\quad M_{ryg} \leftarrow nf_{ind_{nfi}{C_o}_{1,1}+2,\, ind_{el_j}}$

$\quad\quad M_{rzg} \leftarrow nf_{ind_{nfi}{C_o}_{2,1}+2,\, ind_{el_j}}$

$\quad\quad M_{rx_j} \leftarrow \left(nf_{ind_{nfi}{C_o}_{0,1}+2+i,\, ind_{el_j}} - M_{rxg}\right) \cdot {C_o}_{3,0} + M_{rxg}$

$\quad\quad M_{ry_j} \leftarrow \left(nf_{ind_{nfi}{C_o}_{1,1}+2+i,\, ind_{el_j}} - M_{ryg}\right) \cdot {C_o}_{3,0} + M_{ryg}$

$\quad\quad M_{rz_j} \leftarrow \left(nf_{ind_{nfi}{C_o}_{2,1}+2+i,\, ind_{el_j}} - M_{rzg}\right) \cdot {C_o}_{3,0} + M_{rzg}$

$\quad\quad M'_j \leftarrow \sqrt{\left(M_{rx_j}\right)^2 + \left(M_{ry_j}\right)^2 + \left(M_{rz_j}\right)^2}$

$\quad\quad Int'_j \leftarrow \mathrm{PipeRunDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$

$\quad\quad$ if $Int'_j > Int_{0,j}$

$\quad\quad\quad H \leftarrow \left(Int'_j \quad M'_j \quad nf_{ind_{nfi}{C_o}_{0,1}-1+i,0} \quad EL_{ind_{el_j},0} \quad EL_{ind_{el_j},1} \quad ind_{el_j} \quad M_{r}\right.$

$\quad\quad\quad$ for $k \in 0 .. 5$

$Int_{k,j} \leftarrow H_k$

Int

Conditions applicable to all pipe runs

$M_{cx} := 0 \quad M_{cy} := 0 \quad M_{cz} := 0$

Defining place holding directional moment variables

$$PipeRun\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties for Line 1-30

Define pertinent pipe variables

$D_o := 16in$ — Outside Diameter [7]

$t := 0.25in$ — Thickness [7]

$P := 253psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 383.664\ in^4$$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{vmatrix} 1.0 \ \text{ if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50 \\ \quad \begin{vmatrix} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \dfrac{D_o}{t}\right) \\ Y \leftarrow 1.033 - 0.00033 \cdot T \\ 1.0 \cdot \dfrac{1}{X \cdot Y} \end{vmatrix} \end{vmatrix}$$

$B_{2PR} = 1.101$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

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Pipe Run 1-30A (Element 653 and 111)

$el_{P130A} := (653 \quad 111)^T$

$AL_{P130A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P130A}, PipeRun\_C_o, EL\right)$

$$AL_{P130A}{}^T = \begin{pmatrix} 0.166 & 2.337\times10^5 & 6.34 & 653 & 67 & 131 \\ 0.179 & 2.655\times10^5 & 6.335 & 653 & 1.055\times10^3 & 132 \\ 0.15 & 1.941\times10^5 & 6.34 & 111 & 145 & 1 \\ 0.152 & 2\times10^5 & 6.335 & 111 & 146 & 2 \end{pmatrix}$$

Pipe Run 1-30B (Elements 112 & 113)

$el_{P130B} := (112 \quad 113)^T$

$AL_{P130B} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P130B}, PipeRun\_C_o, EL\right)$

$$AL_{P130B}{}^T = \begin{pmatrix} 0.151 & 1.976\times10^5 & 6.835 & 112 & 148 & 3 \\ 0.14 & 1.703\times10^5 & 6.835 & 112 & 181 & 4 \\ 0.121 & 1.221\times10^5 & 10.655 & 113 & 164 & 5 \\ 0.14 & 1.703\times10^5 & 6.835 & 113 & 181 & 6 \end{pmatrix}$$

Pipe Run 1-30C (Elements 114, 437, & 663)

$el_{P130C} := (114 \quad 437 \quad 663)^T$

$AL_{P130C} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P130C}, PipeRun\_C_o, EL\right)$

$$AL_{P130C}{}^T = \begin{pmatrix} 0.112 & 9.934\times10^4 & 10.655 & 114 & 165 & 7 \\ 0.144 & 1.786\times10^5 & 6.835 & 114 & 851 & 8 \\ 0.144 & 1.795\times10^5 & 6.835 & 437 & 851 & 77 \\ 0.139 & 1.671\times10^5 & 5.365 & 437 & 1.065\times10^3 & 78 \\ 0.163 & 2.269\times10^5 & 5.365 & 663 & 177 & 133 \\ 0.139 & 1.671\times10^5 & 5.365 & 663 & 1.065\times10^3 & 134 \end{pmatrix}$$

Pipe Run 1-30D (Elements 120, 664, 123, 665, 666, 667, & 668)

$$el_{P130D} := (120 \quad 664 \quad 123 \quad 665 \quad 666 \quad 667 \quad 668)^{T}$$

$$AL_{P130D} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P130D}, PipeRun\_C_o, EL\right)$$

$AL_{P130D}^{\ T} =$

	0	1	2	3	4	5
0	0.185	$2.796\cdot10^5$	5.695	120	175	13
1	0.193	$3.009\cdot10^5$	10.815	120	$1.066\cdot10^3$	14
2	0.202	$3.22\cdot10^5$	10.815	664	172	135
3	0.193	$3.009\cdot10^5$	10.815	664	$1.066\cdot10^3$	136
4	0.202	$3.222\cdot10^5$	10.815	123	172	15
5	0.187	$2.849\cdot10^5$	10.82	123	$1.067\cdot10^3$	16
6	0.187	$2.849\cdot10^5$	10.82	665	$1.067\cdot10^3$	137
7	0.175	$2.561\cdot10^5$	10.82	665	$1.068\cdot10^3$	138
8	0.175	$2.561\cdot10^5$	10.82	666	$1.068\cdot10^3$	139
9	0.164	$2.297\cdot10^5$	10.815	666	$1.069\cdot10^3$	140
10	0.164	$2.296\cdot10^5$	10.815	667	$1.069\cdot10^3$	141
11	0.155	$2.063\cdot10^5$	6.345	667	$1.07\cdot10^3$	142
12	0.146	$1.841\cdot10^5$	10.805	668	166	143
13	0.155	$2.063\cdot10^5$	6.345	668	$1.07\cdot10^3$	144

Pipe Run 1-30E (Element 130, & 132)

$$el_{P130E} := (130 \quad 132)^{T}$$

$$AL_{P130E} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P130E}, PipeRun\_C_o, EL\right)$$

$$AL_{P130E}^{\ T} = \begin{pmatrix} 0.113 & 1.018\times10^{5} & 4.215 & 130 & 154 & 19 \\ 0.094 & 5.67\times10^{4} & 6.835 & 130 & 162 & 20 \\ 0.128 & 1.394\times10^{5} & 10.955 & 132 & 156 & 21 \\ 0.094 & 5.67\times10^{4} & 6.835 & 132 & 162 & 22 \end{pmatrix}$$

Pipe Run 1-30F (Element 133)

$$el_{P130F} := (133)^{T}$$

$$AL_{P130F} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P130F}, PipeRun\_C_o, EL\right)$$

$$AL_{P130F}^{\ T} = \begin{pmatrix} 0.159 & 2.164\times10^{5} & 6.345 & 133 & 157 & 23 \\ 0.162 & 2.232\times10^{5} & 6.345 & 133 & 158 & 24 \end{pmatrix}$$

Pipe Properties for Line 1-31

Define pertinent pipe variables

$D_o := 16in$ — Outside Diameter [10]

$t := 0.25in$ — Thickness [10]

$P := 253psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^4 - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 383.664\ in^4$$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \left| \begin{array}{l} 1.0 \ \text{ if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50 \\ \quad \left| \begin{array}{l} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006\cdot\dfrac{D_o}{t}\right) \\ Y \leftarrow 1.033 - 0.00033\cdot T \\ 1.0\cdot\dfrac{1}{X\cdot Y} \end{array} \right. \end{array} \right.$$

$B_{2PR} = 1.101$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-31A (Elements 650, 139, & 357)

$$el_{P131A} := (650\ \ 139\ \ 357)^T$$

$$AL_{P131A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P131A}, PipeRun\_C_o, EL\right)$$

$$AL_{P131A}^T = \begin{pmatrix} 0.127 & 1.362\times10^5 & 9.265 & 650 & 184 & 129 \\ 0.124 & 1.309\times10^5 & 9.265 & 650 & 1.052\times10^3 & 130 \\ 0.14 & 1.696\times10^5 & 4.21 & 139 & 185 & 33 \\ 0.123 & 1.28\times10^5 & 9.27 & 139 & 196 & 34 \\ 0.127 & 1.362\times10^5 & 9.265 & 357 & 186 & 57 \\ 0.123 & 1.28\times10^5 & 9.27 & 357 & 196 & 58 \end{pmatrix}$$

Pipe Run 1-31B (Elements 142 & 143)

$$el_{P131B} := (142 \quad 143)^T$$

$$AL_{P131B} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P131B}, PipeRun\_C_o, EL\right)$$

$$AL_{P131B}^T = \begin{pmatrix} 0.159 & 2.155\times10^5 & 4.215 & 142 & 188 & 35 \\ 0.212 & 3.464\times10^5 & 4.2 & 142 & 189 & 36 \\ 0.121 & 1.227\times10^5 & 9.27 & 143 & 190 & 37 \\ 0.119 & 1.172\times10^5 & 9.27 & 143 & 192 & 38 \end{pmatrix}$$

Pipe Properties for Line 1-48

Define pertinent pipe variables

$D_o := 4.5in$ Outside Diameter [17]

$t := 0.237in$ Thickness [17]

$P := 253psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$ Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 7.233\ in^4$$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{array}{l} 1.0 \ \text{ if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50 \\ \quad \left| \begin{array}{l} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006\cdot\dfrac{D_o}{t}\right) \\ Y \leftarrow 1.033 - 0.00033\cdot T \\ 1.0\cdot\dfrac{1}{X\cdot Y} \end{array}\right. \end{array}$$

$B_{2PR} = 1$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

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Pipe Run 1-48A (Elements 672, 671, 670, 669, 317, 676, 675, 674, 673, 314, & 301)

$el_{P148A} := (672\ \ 671\ \ 670\ \ 669\ \ 317\ \ 676\ \ 675\ \ 674\ \ 673\ \ 314\ \ 301)^T$

$AL_{P148A} := \text{PipeRun}\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P148A}, \text{PipeRun\_C}_o, EL\right)$

$AL_{P148A}^T =$

	0	1	2	3	4	5
0	0.196	$3.195 \cdot 10^4$	12.885	672	682	151
1	0.169	$2.694 \cdot 10^4$	12.885	672	$1.074 \cdot 10^3$	152
2	0.144	$2.241 \cdot 10^4$	12.89	671	$1.073 \cdot 10^3$	149
3	0.169	$2.694 \cdot 10^4$	12.885	671	$1.074 \cdot 10^3$	150
4	0.122	$1.835 \cdot 10^4$	12.9	670	$1.072 \cdot 10^3$	147
5	0.144	$2.24 \cdot 10^4$	12.89	670	$1.073 \cdot 10^3$	148
6	0.102	$1.473 \cdot 10^4$	12.905	669	$1.071 \cdot 10^3$	145
7	0.122	$1.835 \cdot 10^4$	12.9	669	$1.072 \cdot 10^3$	146
8	0.085	$1.169 \cdot 10^4$	10.175	317	695	55
9	0.102	$1.473 \cdot 10^4$	12.905	317	$1.071 \cdot 10^3$	56
10	0.085	$1.169 \cdot 10^4$	10.175	676	695	159
11	0.077	$1.013 \cdot 10^4$	10.175	676	$1.078 \cdot 10^3$	160
12	0.077	$1.01 \cdot 10^4$	6.165	675	$1.077 \cdot 10^3$	157
13	0.077	$1.013 \cdot 10^4$	10.175	675	$1.078 \cdot 10^3$	158
14	0.081	$1.085 \cdot 10^4$	6.165	674	$1.076 \cdot 10^3$	155
15	0.077	$1.009 \cdot 10^4$	6.165	674	$1.077 \cdot 10^3$	156
16	0.099	$1.422 \cdot 10^4$	5.365	673	$1.075 \cdot 10^3$	153
17	0.081	$1.085 \cdot 10^4$	6.165	673	$1.076 \cdot 10^3$	154
18	0.136	$2.09 \cdot 10^4$	5.365	314	693	53
19	0.099	$1.422 \cdot 10^4$	5.365	314	$1.075 \cdot 10^3$	54
20	0.12	$1.801 \cdot 10^4$	5.87	301	681	45
21	0.136	$2.09 \cdot 10^4$	5.365	301	693	46

Pipe Run 1-48B (Elements 680, 679, 678, 677, & 310)

$el_{P148B} := (680\ \ 679\ \ 678\ \ 677\ \ 310)^T$

$AL_{P148B} := \text{PipeRun}\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P148B}, \text{PipeRun\_C}_o, EL\right)$

$AL_{P148B}^T =$

	0	1	2	3	4	5
0	0.131	$2.007 \cdot 10^4$	5.875	680	680	167
1	0.115	$1.714 \cdot 10^4$	5.89	680	$1.082 \cdot 10^3$	168
2	0.119	$1.777 \cdot 10^4$	5.9	679	$1.081 \cdot 10^3$	165
3	0.115	$1.714 \cdot 10^4$	5.89	679	$1.082 \cdot 10^3$	166
4	0.132	$2.027 \cdot 10^4$	5.9	678	$1.08 \cdot 10^3$	163
5	0.119	$1.777 \cdot 10^4$	5.9	678	$1.081 \cdot 10^3$	164
6	0.148	$2.31 \cdot 10^4$	5.895	677	$1.079 \cdot 10^3$	161
7	0.132	$2.027 \cdot 10^4$	5.9	677	$1.08 \cdot 10^3$	162
8	0.162	$2.565 \cdot 10^4$	5.885	310	678	51
9	0.148	$2.31 \cdot 10^4$	5.895	310	$1.079 \cdot 10^3$	52

Pipe Run 1-48C (Elements 684, 683, 682, 681, & 299)

$$el_{P148C} := (684 \quad 683 \quad 682 \quad 681 \quad 299)^T$$

$$AL_{P148C} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P148C}, PipeRun\_C_o, EL\right)$$

$AL_{P148C}{}^T =$

	0	1	2	3	4	5
0	0.161	$2.547 \cdot 10^4$	5.885	684	677	175
1	0.138	$2.132 \cdot 10^4$	5.885	684	$1.086 \cdot 10^3$	176
2	0.125	$1.893 \cdot 10^4$	6.165	683	$1.085 \cdot 10^3$	173
3	0.138	$2.132 \cdot 10^4$	5.885	683	$1.086 \cdot 10^3$	174
4	0.113	$1.682 \cdot 10^4$	6.16	682	$1.084 \cdot 10^3$	171
5	0.125	$1.893 \cdot 10^4$	6.165	682	$1.085 \cdot 10^3$	172
6	0.102	$1.469 \cdot 10^4$	6.155	681	$1.083 \cdot 10^3$	169
7	0.113	$1.682 \cdot 10^4$	6.16	681	$1.084 \cdot 10^3$	170
8	0.097	$1.38 \cdot 10^4$	12.9	299	675	43
9	0.102	$1.469 \cdot 10^4$	6.155	299	$1.083 \cdot 10^3$	44

Pipe Run 1-48D (Element 686, 685, & 303)

$$el_{P148D} := (686 \quad 685 \quad 303)^T$$

$$AL_{P148D} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P148D}, PipeRun\_C_o, EL\right)$$

$$AL_{P148D}{}^T = \begin{pmatrix} 0.097 & 1.378 \times 10^4 & 12.9 & 686 & 674 & 179 \\ 0.13 & 1.983 \times 10^4 & 9.9 & 686 & 1.088 \times 10^3 & 180 \\ 0.195 & 3.176 \times 10^4 & 9.9 & 685 & 1.087 \times 10^3 & 177 \\ 0.13 & 1.983 \times 10^4 & 9.9 & 685 & 1.088 \times 10^3 & 178 \\ 0.264 & 4.427 \times 10^4 & 9.9 & 303 & 672 & 49 \\ 0.195 & 3.176 \times 10^4 & 9.9 & 303 & 1.087 \times 10^3 & 50 \end{pmatrix}$$

Writing Output Data for Pipe Runs Associated with Lines 1-30, 1-31, & 1-48

$PR1 := \left(AL_{P130A}{}^T\right)$ $PR5 := \left(AL_{P130E}{}^T\right)$ $PR9 := \left(AL_{P148A}{}^T\right)$

$PR2 := \left(AL_{P130B}{}^T\right)$ $PR6 := \left(AL_{P130F}{}^T\right)$ $PR10 := \left(AL_{P148B}{}^T\right)$

$PR3 := \left(AL_{P130C}{}^T\right)$ $PR7 := \left(AL_{P131A}{}^T\right)$ $PR11 := \left(AL_{P148C}{}^T\right)$

$PR4 := \left(AL_{P130D}{}^T\right)$ $PR8 := \left(AL_{P131B}{}^T\right)$ $PR12 := \left(AL_{P148D}{}^T\right)$

$PR := (PR1 \quad PR2 \quad PR3 \quad PR4 \quad PR5 \quad PR6 \quad PR7 \quad PR8 \quad PR9 \quad PR10 \quad PR11 \quad PR12)$

PipeRunsLines_30to31_48 := WRITEPRN("PRLines_30to31_48.prn" , PR)

REDUCERS

Reducers Strategy: *Search based on the nodes comprising either end of the reducers. SRSS combine the three moments of each of the four node representations (one for each element connected by the node in question). Find the maximum of the moment combinations for each element and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. It is important to not combine the data from both nodes as the geometry for each is different and (9) must be applied for each node. The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\text{ReducerDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

$\text{Reducer}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$$ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$$
$$ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$$
$$ind_{nd} \leftarrow \text{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$$

for $i \in 1 .. \text{last}(nd)$ if $\text{rows}(nd) > 1$

$$ind_{nd} \leftarrow \text{stack}\left[ind_{nd}, \left(\text{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$$

$$\left(M \quad Int_0\right) \leftarrow (0 \quad 0)$$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

for $j \in 0 .. \text{last}\left(ind_{nd}\right)$

$$M_{rxg} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}}+2,\, ind_{nd_j}}$$
$$M_{ryg} \leftarrow nf_{ind_{nfi_{C_{o_{1,1}}}}+2,\, ind_{nd_j}}$$
$$M_{rzg} \leftarrow nf_{ind_{nfi_{C_{o_{2,1}}}}+2,\, ind_{nd_j}}$$
$$M_{rx} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$$
$$M_{ry} \leftarrow \left(nf_{ind_{nfi_{C_{o_{1,1}}}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$$
$$M_{rz} \leftarrow \left(nf_{ind_{nfi_{C_{o_{2,1}}}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$$
$$M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$$
$$Int'_j \leftarrow \text{ReducerDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$$

if $Int'_j > Int_0$

$$Int \leftarrow \text{stack}\left(Int'_j, M'_j, nf_{ind_{nfi_{C_{o_{0,1}}}}-1+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd_j}, M_{rx}, M_{ry},\right.$$

$$Result \leftarrow M'$$

Int

Conditions applicable to all reducers

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$ — Defining place holding variables

$$Reducer\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Reducer Properties for Lines 1-30 and 1-31

Define pertinent reducer variables

$D_o := (16in \;\; 14in)^T$ — Outside Diameter [7] [10]

$t := \left(\frac{1}{4}in \;\; \frac{1}{4}in\right)^T$ — Thickness [7] [10]

$P := (253psi \;\; 253psi)^T$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

$$I = \begin{pmatrix} 383.664 \\ 255.3 \end{pmatrix} in^4$$

Moment of inertia [8, Table 17-27, pg 17-39]

Define primary stress indices

$$\alpha := atan\left(\frac{1in}{13.875in}\right)$$

$\alpha = 4.122\ deg$ — Angular slope of reducer [7] [10]

$$B_1 := \begin{cases} 0.5 & \text{if } \alpha \le 30deg \\ 1.0 & \text{if } 30deg < \alpha \le 60deg \end{cases}$$

$B_1 = 0.5$ — B_1 primary stress Index [9, NB-3683.7]

$B_2 := 1.0$ — B_2 primary stress Index [9, NB-3683.7]

Reducer 1-30A (Nodes 159 & 160)

$nd_{RD130A\_L} := (159)^T$ — Node associated with Large end of reducer

$$AL_{RD130A\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF, nd_{RD130A\_L}, Reducer\_C_o, EL\right)$$

$$AL_{RD130A\_L}^{\ T} = \left(0.155 \;\; 2.27\times10^5 \;\; 6.485 \;\; 159 \;\; 25 \;\; 5.451\times10^3 \;\; 1.685\times10^5 \;\; 1.52\times10^5\right)$$

$nd_{RD130A\_S} := (160)^T$ Node associated with Small end of reducer

$AL_{RD130A\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF, nd_{RD130A\_S}, Reducer\_C_o, EL\right)$

$$AL_{RD130A\_S}^{T} = \left(0.192 \quad 2.677 \times 10^5 \quad 6.485 \quad 160 \quad 27 \quad 9.971 \times 10^3 \quad -2.18 \times 10^5 \quad -1.55 \times 10^5\right)$$

Reducer 1-31A (Nodes 193 & 194)

$nd_{RD131A\_L} := (193)^T$ Node associated with Large end of reducer

$AL_{RD131A\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF, nd_{RD131A\_L}, Reducer\_C_o, EL\right)$

$$AL_{RD131A\_L}^{T} = \left(0.132 \quad 1.638 \times 10^5 \quad 10.64 \quad 193 \quad 39 \quad 5.556 \times 10^4 \quad 1.498 \times 10^5 \quad 3.588 \times 10^4\right)$$

$nd_{RD131A\_S} := (194)^T$ Node associated with Small end of reducer

$AL_{RD131A\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF, nd_{RD131A\_S}, Reducer\_C_o, EL\right)$

$$AL_{RD131A\_S}^{T} = \left(0.157 \quad 1.946 \times 10^5 \quad 6.33 \quad 194 \quad 41 \quad 7.884 \times 10^4 \quad 1.747 \times 10^5 \quad 3.375 \times 10^4\right)$$

Writing Output Data for Reducers Associated with Lines 1-30, 1-31, & 1-48

$RL1 := AL_{RD130A\_L}^{T}$

$RS1 := AL_{RD130A\_S}^{T}$

$RL2 := AL_{RD131A\_L}^{T}$

$RS2 := AL_{RD131A\_S}^{T}$

$R := (RL1 \quad RS1 \quad RL2 \quad RS2)$

ReducersLines_30to31_48 := WRITEPRN("RedLines_30to31_48.prn" , R)

ELBOWS

Elbows Strategy: *Search based on the two nodes comprising the ends of each elbow. SRSS combine the three moments of each of the four node representations (one for each element connected by the nodes in question). Find the maximum of the four moment combinations and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\text{ElbowDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

$\text{Elbow}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \text{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. \text{last}(nd)$ if $\text{rows}(nd) > 1$

  $ind_{nd} \leftarrow \text{stack}\left[ind_{nd}, \left(\text{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$(M \;\; Int_0) \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \text{last}(ind_{nd})$

    $M_{rxg} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}}+2,\, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi_{C_{o_{1,1}}}}+2,\, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi_{C_{o_{2,1}}}}+2,\, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi_{C_{o_{1,1}}}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi_{C_{o_{2,1}}}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow \text{ElbowDC}(P, D_o, t, I, B_1, B_2, M'_j, S)$

    if $Int'_j > Int_0$

      $Int \leftarrow \text{stack}\left(Int'_j, M'_j, nf_{ind_{nfi_{C_{o_{0,1}}}}-1+i,\,0}, EL_{ind_{nd_j},1}, ind_{nd_j}, M_{rx}, M_{ry}, M\right.$

      $Result \leftarrow M'$

Int

Conditions applicable to all elbows

$M_{cx} := 0$ $M_{cy} := 0$ $M_{cz} := 0$ — Defining place holding variables

$$Elb\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Elbow Properties for Lines 1-30 and 1-31

Define pertinent elbow variables

$D_o := 16in$ — Outside Diameter [7] [10]

$t := 0.25in$ — Thickness [7] [10]

$P := 253psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 383.664\ in^4$$

$R := 1\cdot D_o$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$

Mean pipe radius

Define primary stress indices

$$h := \frac{t\cdot R}{r_m^{\,2}} \qquad h = 0.064$$

Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4\cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4\cdot h > 0.5 \\ -0.1 + 0.4\cdot h & \text{otherwise} \end{cases} \qquad B_1 = 0$$

B_1 primary stress Index [9, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases} \qquad B_2 = 8.083$$

B_2 primary stress Index [9, NB-3683.7]

Elbow 1-30A (Nodes 146 & 148)

$nd_{EL130A\_1} := (146)^T$

$AL_{EL130A\_nd146} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL130A\_1}, Elb\_C_o, EL)$

$AL_{EL130A\_nd146}^T = (0.594 \quad 2\times10^5 \quad 6.335 \quad 146 \quad 2 \quad -3.743\times10^4 \quad 1.917\times10^5 \quad -4.295\times10^4)$

$nd_{EL130A\_2} := (148)^T$

$AL_{EL130A\_nd148} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL130A\_2}, Elb\_C_o, EL)$

$AL_{EL130A\_nd148}^T = (0.587 \quad 1.976\times10^5 \quad 6.835 \quad 148 \quad 87 \quad -6.008\times10^4 \quad 1.235\times10^4 \quad 1.878\times10^5)$

Elbow 1-30B (Nodes 153 & 154)

$nd_{EL130B\_1} := (153)^T$

$AL_{EL130B\_nd153} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL130B\_1}, Elb\_C_o, EL)$

$AL_{EL130B\_nd153}^T = (0.354 \quad 1.192\times10^5 \quad 10.805 \quad 153 \quad 18 \quad -1.044\times10^5 \quad 1.85\times10^4 \quad -5.458\times10^4)$

$nd_{EL130B\_2} := (154)^T$

$AL_{EL130B\_nd154} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL130B\_2}, Elb\_C_o, EL)$

$AL_{EL130B\_nd154}^T = (0.303 \quad 1.019\times10^5 \quad 4.215 \quad 154 \quad 89 \quad -7.597\times10^4 \quad -2.799\times10^4 \quad 6.182\times10^4)$

Elbow 1-30C (Nodes 156 & 157)

$nd_{EL130C\_1} := (156)^T$

$AL_{EL130C\_nd156} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL130C\_1}, Elb\_C_o, EL)$

$AL_{EL130C\_nd156}^T = (0.414 \quad 1.394\times10^5 \quad 10.955 \quad 156 \quad 97 \quad 1.04\times10^5 \quad 1.897\times10^4 \quad 9.085\times10^4)$

$nd_{EL130C\_2} := (157)^T$

$AL_{EL130C\_nd157} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL130C\_2}, Elb\_C_o, EL)$

$AL_{EL130C\_nd157}^T = (0.643 \quad 2.164\times10^5 \quad 6.345 \quad 157 \quad 23 \quad -1.266\times10^5 \quad -5.108\times10^4 \quad -1.679\times10^5)$

Elbow 1-31A (Nodes 184 & 185)

$nd_{EL131A\_1} := (184)^T$

$AL_{EL131A\_nd184} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL131A\_1}, Elb\_C_o, EL)$

$AL_{EL131A\_nd184}^T = (0.405 \quad 1.362\times10^5 \quad 9.265 \quad 184 \quad 129 \quad -9.45\times10^4 \quad -9.758\times10^4 \quad 9.235\times10^3)$

$nd_{EL131A\_2} := (185)^T$

$AL_{EL131A\_nd185} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL131A\_2}, Elb\_C_o, EL)$

$AL_{EL131A\_nd185}{}^T = (0.505 \quad 1.697\times10^5 \quad 4.21 \quad 185 \quad 92 \quad -5.238\times10^4 \quad -1.141\times10^5 \quad 1.142\times10^5)$

Elbow 1-31B (Nodes 186 & 188)

$nd_{EL131B\_1} := (186)^T$

$AL_{EL131B\_nd186} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL131B\_1}, Elb\_C_o, EL)$

$AL_{EL131B\_nd186}{}^T = (0.405 \quad 1.362\times10^5 \quad 9.265 \quad 186 \quad 57 \quad 6.13\times10^4 \quad -1.191\times10^5 \quad 2.418\times10^4)$

$nd_{EL131B\_2} := (188)^T$

$AL_{EL131B\_nd188} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL131B\_2}, Elb\_C_o, EL)$

$AL_{EL131B\_nd188}{}^T = (0.641 \quad 2.155\times10^5 \quad 4.215 \quad 188 \quad 35 \quad -6.574\times10^4 \quad 9.099\times10^4 \quad 1.839\times10^5)$

Elbow 1-31C (Nodes 192 & 193)

$nd_{EL131C\_1} := (192)^T$

$AL_{EL131C\_nd192} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL131C\_1}, Elb\_C_o, EL)$

$AL_{EL131C\_nd192}{}^T = (0.348 \quad 1.172\times10^5 \quad 9.27 \quad 192 \quad 100 \quad -9.62\times10^4 \quad -6.642\times10^4 \quad 7.711\times10^3)$

$nd_{EL131C\_2} := (193)^T$

$AL_{EL131C\_nd193} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL131C\_2}, Elb\_C_o, EL)$

$AL_{EL131C\_nd193}{}^T = (0.487 \quad 1.638\times10^5 \quad 10.64 \quad 193 \quad 39 \quad 5.556\times10^4 \quad 1.498\times10^5 \quad 3.588\times10^4)$

Elbow Properties for Line 1-48

Define pertinent elbow variables

$D_o := 4.5in$ Outside Diameter [17]

$t := 0.237in$ Thickness [17]

$P := 253psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o{}^4 - (D_o - 2\cdot t)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 7.233\ in^4$

$R := 1.5 \cdot D_o$ — Nominal bend radius of curved pipe or elbow

$r_m := \dfrac{D_o - t}{2}$ — Mean pipe radius

Define primary stress indices

$h := \dfrac{t \cdot R}{r_m^2}$ — $h = 0.352$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h > 0.5 \\ -0.1 + 0.4 \cdot h & \text{otherwise} \end{cases}$ — $B_1 = 0.041$ — B_1 primary stress Index [9, NB-3683.7]

$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$ — $B_2 = 2.607$ — B_2 primary stress Index [9, NB-3683.7]

Elbow 1-48A (Nodes 681 & 680)

$nd_{EL148A\_1} := (681)^T$

$AL_{EL148A\_nd681} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL148A\_1}, Elb\_C_o, EL)$

$AL_{EL148A\_nd681}^T = (0.259 \quad 1.801 \times 10^4 \quad 5.87 \quad 681 \quad 45 \quad -3.511 \times 10^3 \quad -1.298 \times 10^4 \quad 1.199 \times 10^4)$

$nd_{EL148A\_2} := (680)^T$

$AL_{EL148A\_nd680} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL148A\_2}, Elb\_C_o, EL)$

$AL_{EL148A\_nd680}^T = (0.289 \quad 2.007 \times 10^4 \quad 5.875 \quad 680 \quad 115 \quad -2.7 \times 10^3 \quad -1.475 \times 10^4 \quad 1.335 \times 10^4)$

Elbow 1-48B (Nodes 678 & 677)

$nd_{EL148B\_1} := (678)^T$

$AL_{EL148B\_nd678} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL148B\_1}, Elb\_C_o, EL)$

$AL_{EL148B\_nd678}^T = (0.369 \quad 2.565 \times 10^4 \quad 5.885 \quad 678 \quad 51 \quad 1.476 \times 10^4 \quad -1.56 \times 10^4 \quad -1.404 \times 10^4)$

$nd_{EL148B\_2} := (677)^T$

$AL_{EL148B\_nd677} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL148B\_2}, Elb\_C_o, EL)$

$AL_{EL148B\_nd677}^T = (0.366 \quad 2.547 \times 10^4 \quad 5.885 \quad 677 \quad 175 \quad -1.454 \times 10^4 \quad 1.547 \times 10^4 \quad 1.408 \times 10^4)$

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Elbow 1-48C (Nodes 675 & 674)

$nd_{EL148C\_1} := (675)^T$

$AL_{EL148C\_nd675} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL148C\_1}, Elb\_C_o, EL)$

$AL_{EL148C\_nd675}^T = (0.199 \quad 1.38\times10^4 \quad 12.9 \quad 675 \quad 113 \quad 1.367\times10^4 \quad 1.598\times10^3 \quad 1.015\times10^3)$

$nd_{EL148C\_2} := (674)^T$

$AL_{EL148C\_nd674} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL148C\_2}, Elb\_C_o, EL)$

$AL_{EL148C\_nd674}^T = (0.199 \quad 1.378\times10^4 \quad 12.9 \quad 674 \quad 179 \quad 1.367\times10^4 \quad 1.607\times10^3 \quad 615.948)$

Writing Output Data for Elbows Associated with Lines 1-30, 1-31, & 1-48

$EL1A := (AL_{EL130A\_nd146}^T)$

$EL1B := (AL_{EL130A\_nd148}^T)$

$EL2A := (AL_{EL130B\_nd153}^T)$

$EL2B := (AL_{EL130B\_nd154}^T)$

$EL3A := (AL_{EL130C\_nd156}^T)$

$EL3B := (AL_{EL130C\_nd157}^T)$

$EL4A := (AL_{EL131A\_nd184}^T)$

$EL4B := (AL_{EL131A\_nd185}^T)$

$EL5A := (AL_{EL131B\_nd186}^T)$

$EL5B := (AL_{EL131B\_nd188}^T)$

$EL6A := (AL_{EL131C\_nd192}^T)$

$EL6B := (AL_{EL131C\_nd193}^T)$

$EL7A := (AL_{EL148A\_nd681}^T)$

$EL7B := (AL_{EL148A\_nd680}^T)$

$EL8A := (AL_{EL148B\_nd678}^T)$

$EL8B := (AL_{EL148B\_nd677}^T)$

$EL9A := (AL_{EL148C\_nd675}^T)$

$EL9B := (AL_{EL148C\_nd674}^T)$

vEL := (EL1A EL1B EL2A EL2B EL3A EL3B EL4A EL4B EL5A EL5B EL6A EL6B EL7A EL7B EL8A EL8B EI

ElbowLines_30to31_48 := WRITEPRN("ElbowLines_30to31_48.prn" , vEL)

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FORGED TEES AND FABRICATED BRANCH TEES

Tees Strategy: *Search based on the elements comprising the tee. The input identifies which elements are associated with the pipe run and which element is associated with the branch from the run. The indices for the defined common node for all three elements is identified and the associated SRSS moment is identified for each time step. The maximum moment for the elements comprising the pipe run is found and applied as M_r in equation (9) of ASME III, Division I - NB - 3652 which is modified to represent tees. The maximum moment for the branch element is found and applied as M_b in equation (9) of ASME III, Division I - NB - 3652 [9]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$TeeDC(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_b, M_r, Z_b, Z_r, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot T_r} + B_{2b} \cdot \left[\frac{M_b \cdot (1lbf \cdot in)}{Z_b}\right] + B_{2r} \cdot \left[\frac{M_r \cdot (1lbf \cdot in)}{Z_r}\right]}{S}$$

$Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S, nf, el_R, el_B, nd_R, nd_B, C_o, EL) :=$

$ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{elR} \leftarrow match\left(el_{R_0}, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(el_R)$ if rows

  $ind_{elR} \leftarrow stack\left[ind_{elR}, \left(match\left(el_{R_i}, EL^{\langle 0 \rangle}\right)\right)\right]$

$EL'R_{last\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$

for $i \in 0 .. last(ind_{elR})$

  $EL'R_{ind_{elR_i}} \leftarrow EL_{ind_{elR_i}, 1}$

$ind_{ndR} \leftarrow match\left(nd_{R_0}, EL'R^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(nd_R)$ if r

  $ind_{ndR} \leftarrow stack\left[ind_{ndR}, \left(match\left(nd_{R_i}, EL'R^{\langle 0 \rangle}\right)\right)\right]$

$ind_{elB} \leftarrow match\left(el_{B_0}, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(el_B)$ if rows

  $ind_{elB} \leftarrow stack\left[ind_{elB}, \left(match\left(el_{B_i}, EL^{\langle 0 \rangle}\right)\right)\right]$

$EL'B_{last\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$

for $i \in 0 .. last(ind_{elB})$

  $EL'B_{ind_{elB_i}} \leftarrow EL_{ind_{elB_i}, 1}$

$ind_{ndB} \leftarrow match\left(nd_{B_0}, EL'B^{\langle 0 \rangle}\right)$

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for $i \in 1 .. \text{last}(nd_B)$ if r

$ind_{ndB} \leftarrow \text{stack}\left[ind_{ndB}, \left(\text{match}\left(nd_{B_i}, EL'B^{\langle 0 \rangle}\right)\right)\right]$

$\left(M_R \;\; M_B \;\; Int_0\right) \leftarrow (0 \;\; 0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

for $j \in 0 .. \text{last}(ind_{ndR})$

for $k \in 0 .. \text{last}(ind_{ndB})$

$M_{rxgR_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2, ind_{ndR_j}}$

$M_{rygR_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2, ind_{ndR_j}}$

$M_{rzgR_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2, ind_{ndR_j}}$

$M_{rxR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i, ind_{ndR_j}} - M_{rxgR_j}\right) \cdot C$

$M_{ryR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i, ind_{ndR_j}} - M_{rygR_j}\right) \cdot C$

$M_{rzR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i, ind_{ndR_j}} - M_{rzgR_j}\right) \cdot C$

$M_{R_j} \leftarrow \sqrt{\left(M_{rxR_j}\right)^2 + \left(M_{ryR_j}\right)^2 + \left(M_{rzR_j}\right)^2}$

$M_{rxgB_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2, ind_{ndB_k}}$

$M_{rygB_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2, ind_{ndB_k}}$

$M_{rzgB_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2, ind_{ndB_k}}$

$M_{rxB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i, ind_{ndB_k}} - M_{rxgB_j}\right) \cdot C$

$M_{ryB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i, ind_{ndB_k}} - M_{rygB_j}\right) \cdot C$

$M_{rzB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i, ind_{ndB_k}} - M_{rzgB_j}\right) \cdot C$

$M_{B_j} \leftarrow \sqrt{\left(M_{rxB_j}\right)^2 + \left(M_{ryB_j}\right)^2 + \left(M_{rzB_j}\right)^2}$

$Int'_j \leftarrow \text{TeeDC}\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_{B_j}, M_R\right.$

if $Int'_j > Int_0$

$Int \leftarrow \text{stack}\left(Int'_j, M_{R_j}, M_{B_j}, nf_{ind_{nfiC_{o_{0,1}}}-1+i}\right.$

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$Result \leftarrow stack\left(M_{R_j}, M_{B_j}, M_{rxR_j}, M_{ryR_j}, M\right.$

$M \leftarrow M_R$

Int

Conditions applicable to forged tee

$M_{ox} := 0 \quad M_{oy} := 0 \quad M_{oz} := 0$

Defining place holding directional moment variables

$$Tee\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

TEE (Line 1-31)

Define pertinent tee variables

$P := 253psi$ — Internal Pressure [3, pg 23]

$D_o := 16in$ — Outside Diameter of Pipe Run [10]

$d_o := 16in$ — Outside Diameter of Branch [10]

$B_1 := 0.5$ — B_1 primary stress Index for tees and branches [9, NB-3683.9]

$T_r := 0.25in$ — Nominal wall thickness of designated run pipe [10]

$R_m := \frac{D_o - T_r}{2}$ — Mean radius of designated run pipe [10]

$Z_r := \pi \cdot R_m^2 \cdot T_r$ — Approximate section modulus of designated run pipe [9, NB-3683.1(d)]

$Z_r = 48.707\ in^3$

$T'_b := 0.25in$ — Nominal wall thickness of attached branch pipe [10]

$r'_m := \frac{d_o - T'_b}{2}$ — Mean radius of attached branch pipe [10]

$Z_b := \pi \cdot r'^2_m \cdot T'_b$ — Approximate section modulus of attached branch pipe [9, NB-3683.1(d)]

$Z_b = 48.707\ in^3$

C_{2b} Secondary stress Index [9,NB-3683.8]

$$C_{2b} := \begin{cases} 1.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}}\left(\frac{r'_m}{R_m}\right)^{\frac{1}{2}}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{\frac{d_o}{2}}\right) & \text{if } 1.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}}\left(\frac{r'_m}{R_m}\right)^{\frac{1}{2}}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{\frac{d_o}{2}}\right) \ge 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$$C_{2b} = 14.727$$

C_{2r} Secondary stress Index [9,NB-3683.8]

$$t_n := T'_b$$

Wall thickness of nozzle or branch connection reinforcement associated with [9, NB-3643.4(A)-1, sketch (d)]

$$C_{2r} := \begin{cases} 1.15\cdot\left(\frac{r'_m}{t_n}\right)^{\frac{1}{4}} & \text{if } 1.15\cdot\left(\frac{r'_m}{t_n}\right)^{\frac{1}{4}} \ge 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$$C_{2r} = 2.724$$

$$B_{2b} := \begin{cases} 0.5\cdot C_{2b} & \text{if } 0.5\cdot C_{2b} \ge 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Index for branches [9, NB-3683.8]

$$B_{2b} = 7.364$$

$$B_{2r} := \begin{cases} 0.75\cdot C_{2r} & \text{if } 0.75\cdot C_{2r} \ge 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Index for branches [9, NB-3683.8]

$$B_{2r} = 2.043$$

Tee 1-31 (Node 152)

$elR_{Tee131} := (136 \quad 129)^T$ — Elements associated with pipe run

$ndR_{Tee131} := (152)^T$ — Node between pipe run elements

$elB_{Tee131} := (138)^T$ — Element associated with branch

$ndB_{Tee131} := (152)^T$ — Node where branch intersects pipe run

$$AL_{Tee131} := Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF, elR_{Tee131}, elB_{Tee131}, ndR_{Tee131}, ndB_{Tee131}, Tee\_C$$

$$AL_{Tee131}{}^T = \begin{pmatrix} 0.544 & 1.485\times10^5 & 1.361\times10^5 & 9.265 & 152 & 17 & 29 & 31 \end{pmatrix}$$

TEE (Line 1-48)

Define pertinent tee variables

$P := 253\,psi$ — Internal Pressure [3, pg 23]

$D_o := 16\,in$ — Outside Diameter of Pipe Run [7]

$d_o := 4.5\,in$ — Outside Diameter of Branch [17]

$B_1 := 0.5$ — B_1 primary stress Index for tees and branches [9, NB-3683.9]

$T_r := 0.25\,in$ — Nominal wall thickness of designated run pipe [7]

$R_m := \dfrac{D_o - T_r}{2}$ — Mean radius of designated run pipe

$Z_r := \pi \cdot R_m^{\,2} \cdot T_r$ — Approximate section modulus of designated run pipe [9, NB-3683.1(d)]

$Z_r = 48.707\,in^3$

$T'_b := 0.237\,in$ — Nominal wall thickness of attached branch pipe [17]

$r'_m := \dfrac{d_o - T'_b}{2}$ — Mean radius of attached branch pipe

$Z_b := \pi \cdot r'^{\,2}_m \cdot T'_b$ — Approximate section modulus of attached branch pipe [9, NB-3683.1(d)]

$Z_b = 3.383\,in^3$

C_{2b} Secondary stress Index [9,NB-3683.8]

$$C_{2b} := \begin{cases} 1.5\cdot\left(\dfrac{R_m}{T_r}\right)^{\frac{2}{3}}\left(\dfrac{r'_m}{R_m}\right)^{\frac{1}{2}}\left(\dfrac{T'_b}{T_r}\right)\left(\dfrac{r'_m}{\frac{d_o}{2}}\right) & \text{if } 1.5\cdot\left(\dfrac{R_m}{T_r}\right)^{\frac{2}{3}}\left(\dfrac{r'_m}{R_m}\right)^{\frac{1}{2}}\left(\dfrac{T'_b}{T_r}\right)\left(\dfrac{r'_m}{\frac{d_o}{2}}\right) \ge 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$C_{2b} = 6.99$

C_{2r} Secondary stress Index [9,NB-3683.8]

$t_n := T'_b$ — Wall thickness of nozzle or branch connection reinforcement associated with [9, NB-3643.4(A)-1, sketch (d)]

$$C_{2r} := \begin{cases} 1.15\cdot\left(\frac{r'_m}{t_n}\right)^{\frac{1}{4}} & \text{if } 1.15\cdot\left(\frac{r'_m}{t_n}\right)^{\frac{1}{4}} \geq 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$C_{2r} = 1.992$

$$B_{2b} := \begin{cases} 0.5\cdot C_{2b} & \text{if } 0.5\cdot C_{2b} \geq 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Index for branches [9, NB-3683.8]

$B_{2b} = 3.495$

$$B_{2r} := \begin{cases} 0.75\cdot C_{2r} & \text{if } 0.75\cdot C_{2r} \geq 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Index for branches [9, NB-3683.8]

$B_{2r} = 1.494$

Tee 1-48 (Node 176 for Pipe Run and 673 for Branch (NB 3683.8)

$elR_{Tee148} := (118 \quad 119)^T$ Elements associated with pipe run

$ndR_{Tee148} := (176)^T$ Node between pipe run elements

$elB_{Tee148} := (302)^T$ Element associated with branch

$ndB_{Tee148} := (672)^T$ Node where branch intersects pipe run

$AL_{Tee148} := Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF, elR_{Tee148}, elB_{Tee148}, ndR_{Tee148}, ndB_{Tee148}, Tee\_C$

$AL_{Tee148}{}^T = (0.918 \quad 7.445\times10^4 \quad 4.427\times10^4 \quad 9.9 \quad 176 \quad 9 \quad 12 \quad 48)$

Writing Output Data for Tees Associated with Lines 1-30, 1-31, & 1-48

$Tee1 := AL_{Tee131}{}^T$

$Tee2 := AL_{Tee148}{}^T$

$Tee := (Tee1 \quad Tee2)$

TeeLines22to26 := WRITEPRN("TeeLines_30to31_48.prn" , Tee)

Appendix C.3.4

Demand to Capacity Ratio Calculations for Components Associated with Lines 1-43 and 1-47 of ATR PCS Model 265

(NOTE: Values represented here are shown for one realization (Nodal Force file = LINES_43_47_test_R1.dat and Element/Nodal order file = EL_43_47 .xls) and may or may not be consistent with the 80th percentile results contained in Appendix C.4)

Force Outputs from Abaqus

NF := ...\LINES_43_47.dat

(N)odal (F)orces for the (M)edium (L)ines of Model 3

Defined Elemental and Corresponding Nodal Order

EL := Y:\P...\EL_43_47(9-22-08).xls

Element and corresponding nodal order for the (M)edium (L)ines of Model 3

Time Boundaries

$t_{initial} := 1$

Initial time for which dynamic loading is applied

$t_{final} := 21$

Final time for which dynamic loading stops

Seismic Scale Factor (F_a)

$F_a := 1$

Seismic scale factor [30]

Allowable Design Stress Intensity Factor (S_m): *S_m is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{m\_125} := 20\text{ksi}$

For SS304 at 125°F [2, pg 316-318] [3, pg 23]

$S_{m\_125L} := 16.7\text{ksi}$

For SS304L at 125°F [2, pg 316-318] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Yield Strength (S_y): *S_y is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{y\_125} := 28.35\text{ksi}$

For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_125L} := 23.85\text{ksi}$

For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Maximum Strength Applicable for Equation 9 (S): *S is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{125} := \min\left(3 \cdot S_{m\_125}, 2 \cdot S_{y\_125}\right)$

$\boxed{S_{125} = 56.7\,\text{ksi}}$

Maximum allowable stress applied to SS304 piping [9, NB-3656]

$S_{125L} := \min\left(3 \cdot S_{m\_125L}, 2 \cdot S_{y\_125L}\right)$

$\boxed{S_{125L} = 47.7\,\text{ksi}}$

Maximum allowable stress applied to SS304L piping [9, NB-3656]

SUPPORTS

Supports Strategy: *Search based on the node for which the support acts. If this node is a termination point there will only be one node to evaluate. If this node is in line with a section of pipe there will be two representations of the same node (one for each element on each side of the node) to combine and the difference between them is the force required of the support. The D/C ratio for each support will be found by dividing the the required force found above by the support capacity.*

$$\mathrm{SupDC}(P_r, P_c) := \frac{P_r}{P_c}$$

$\mathrm{Support}(nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

$\text{for } i \in 1..\mathrm{last}(nd) \quad \text{if } \mathrm{rows}(nd) > 1$

$\quad ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$\begin{pmatrix} Int1_4 & Int2_4 \end{pmatrix} \leftarrow \begin{pmatrix} 0 & 0 \end{pmatrix}$

$\text{for } i \in 0..ind_{nfo_0} - ind_{nfi_0}$

$\quad \text{for } j \in 0..\mathrm{last}(ind_{nd})$

$\quad\quad P_{rg_j} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}}-1,\, ind_{nd_j}}$

$\quad\quad P_{r_j} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}}-1+i,\, ind_{nd_j}} - P_{rg_j}\right) \cdot C_{o_{2,0}} + P_{rg_j}$

$\quad PR_i \leftarrow \sum_{n=0}^{j} P_{r_n}$

$\quad \text{if } PR_i < Int1_1 \wedge C_{o_{0,0}} \neq 0$

$\quad\quad Int1' \leftarrow \mathrm{SupDC}\left(\left|PR_i\right|, C_{o_{0,0}}\right)$

$\quad\quad Int1 \leftarrow \mathrm{stack}\left(Int1', PR_i, nf_{ind_{nfi_{C_{o_{0,1}}}}-1+i,\,0}, EL_{ind_{nd_j},\,1}, ind_{nd}\right)$

$\quad \text{if } PR_i > Int2_1 \wedge C_{o_{1,0}} \neq 0$

$\quad\quad Int2' \leftarrow \mathrm{SupDC}\left(\left|PR_i\right|, C_{o_{1,0}}\right)$

$\quad\quad Int2 \leftarrow \mathrm{stack}\left(Int2', PR_i, nf_{ind_{nfi_{C_{o_{0,1}}}}-1+i,\,0}, EL_{ind_{nd_j},\,1}, ind_{nd}\right)$

$\begin{pmatrix} Int1 & Int2 \end{pmatrix}$

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RH-19 Support (1x)

$P_{1\_RH19} := \frac{5.109 \cdot kip}{lbf}$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_RH19} := \frac{0 \cdot kip}{lbf}$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_RH19} := \begin{pmatrix} P_{1\_RH19} & 2 \\ P_{2\_RH19} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

RH-19 (Node 625)

RH-19 vertically supports line 1-43 just south of T(1-46A) from any downward movement.

$nd625_{RH19_0} := 625$ Node associated with support

$$\begin{pmatrix} AL1_{RH19\_nd625} & AL2_{RH19\_nd625} \end{pmatrix} := Support\left(NF, nd625_{RH19}, Sup\_C_{o\_RH19}, EL\right)$$

$$AL1_{RH19\_nd625}^{T} = \begin{pmatrix} 1.824 & -9.32 \times 10^{3} & 5.77 & 625 & 110 \end{pmatrix}$$

$$AL2_{RH19\_nd625}^{T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-17 Support (2x)

$P_{1\_RH17} := \frac{11.25 \cdot kip}{lbf}$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_RH17} := \frac{5.829 \cdot kip}{lbf}$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_RH17} := \begin{pmatrix} P_{1\_RH17} & 2 \\ P_{2\_RH17} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

RH-17A (Node 622)

RH-17A vertically supports line 1-43 just north of EL(1-43D) from any downward movement.

$nd622_{RH17A_0} := 622$ Node associated with support

$$\left(AL1_{RH17A\_nd622}\ \ AL2_{RH17A\_nd622}\right) := \text{Support}\left(NF, nd622_{RH17A}, Sup\_C_{o\_RH17}, EL\right)$$

$$AL1_{RH17A\_nd622}{}^{T} = \left(0.534\ \ -6.011\times10^{3}\ \ 8.81\ \ 622\ \ 102\right)$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

$$AL2_{RH17A\_nd622}{}^{T} = \left(0\ \ 0\ \ 0\ \ 0\ \ 0\right)$$

RH-17B (Node 833)

RH-17B vertically supports line 1-43 just south of GB(1-43B) from any downward movement.

$nd833_{RH17B_0} := 833$ Node associated with support

$$\left(AL1_{RH17B\_nd833}\ \ AL2_{RH17B\_nd833}\right) := \text{Support}\left(NF, nd833_{RH17B}, Sup\_C_{o\_RH17}, EL\right)$$

$$AL1_{RH17B\_nd833}{}^{T} = \left(0.456\ \ -5.134\times10^{3}\ \ 4.625\ \ 833\ \ 100\right)$$

$$AL2_{RH17B\_nd833}{}^{T} = \left(0\ \ 0\ \ 0\ \ 0\ \ 0\right)$$

RH-30 Support (1x)

$P_{1\_RH30X} := \dfrac{3.47\cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_RH30X} := \dfrac{21.648\cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_RH30X} := \begin{pmatrix} P_{1\_RH30X} & 1 \\ P_{2\_RH30X} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

$P_{1\_RH30Y} := \dfrac{21.648\cdot kip}{lbf}$ ***Flexure*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_RH30Y} := \dfrac{21.648\cdot kip}{lbf}$ ***Flexure*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_RH30Y} := \begin{pmatrix} P_{1\_RH30Y} & 2 \\ P_{2\_RH30Y} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

$P_{1\_RH30Z} := \frac{0.65 \cdot kip}{lbf}$ ***Flexure*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_RH30Z} := \frac{0.65 \cdot kip}{lbf}$ ***Flexure*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_RH30Z} := \begin{pmatrix} P_{1\_RH30Z} & 3 \\ P_{2\_RH30Z} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

RH-30 (NS) (Node 927)

RH-30 supports line 1-43 at the bottom portion of P(1-43G) from movement in any direction.

$nd927_{RH30X_0} := 927$ Node associated with support

$$\left(AL1_{RH30X\_nd927} \quad AL2_{RH30X\_nd927} \right) := Support\left(NF, nd927_{RH30X}, Sup\_C_{o\_RH30X}, EL \right)$$

$$AL1_{RH30X\_nd927}^{\ T} = \left(4.788 \times 10^{-4} \quad -1.661 \quad 11.505 \quad 927 \quad 165 \right)$$

$$AL2_{RH30X\_nd927}^{\ T} = \left(3.954 \times 10^{-5} \quad 0.856 \quad 12.23 \quad 927 \quad 165 \right)$$

C,demand force, occurrence time, ned node, associated index for the reaction force at the selected node eing in the positive (AL1) and negative AL2) directions of the global coordinate system)

RH-30 (V) (Node 927)

RH-30 supports line 1-43 at the bottom portion of P(1-43G) from movement in any direction.

$nd927_{RH30Y_0} := 927$ Node associated with support

$$\left(AL1_{RH30Y\_nd927} \quad AL2_{RH30Y\_nd927} \right) := Support\left(NF, nd927_{RH30Y}, Sup\_C_{o\_RH30Y}, EL \right)$$

$$AL1_{RH30Y\_nd927}^{\ T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \right)$$

$$AL2_{RH30Y\_nd927}^{\ T} = \left(8.25 \times 10^{-5} \quad 1.786 \quad 5.28 \quad 927 \quad 165 \right)$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-30 (EW) (Node 927)

RH-30 supports line 1-43 at the bottom portion of P(1-43G) from movement in any direction.

$nd927_{RH30Z_0} := 927$ Node associated with support

$$\left(AL1_{RH30Z\_nd927} \quad AL2_{RH30Z\_nd927} \right) := Support\left(NF, nd927_{RH30Z}, Sup\_C_{o\_RH30Z}, EL \right)$$

$$AL1_{RH30Z\_nd927}^{\ T} = \left(1.248 \times 10^{-3} \quad -0.811 \quad 9.89 \quad 927 \quad 165 \right)$$

$$AL2_{RH30Z\_nd927}^{\ T} = \left(1.158 \times 10^{-3} \quad 0.752 \quad 9.515 \quad 927 \quad 165 \right)$$

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RH-25 Support (2x)

$P_{1\_RH25} := \frac{10.354 \cdot kip}{lbf}$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_RH25} := \frac{0 \cdot kip}{lbf}$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_RH25} := \begin{pmatrix} P_{1\_RH25} & 2 \\ P_{2\_RH25} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

RH-25A (Node 619)

RH-25A vertically supports line 1-43 between EL(1-43F) and EL(1-43G) from any downward movement.

$nd619_{RH25A_0} := 619$ Node associated with support

$$\left(AL1_{RH25A\_nd619} \;\; AL2_{RH25A\_nd619}\right) := Support\left(NF, nd619_{RH25A}, Sup\_C_{o\_RH25}, EL\right)$$

$$AL1_{RH25A\_nd619}^{T} = \left(0.485 \;\; -5.021 \times 10^{3} \;\; 5.82 \;\; 619 \;\; 98\right)$$

$$AL2_{RH25A\_nd619}^{T} = \left(0 \;\; 0 \;\; 0 \;\; 0 \;\; 0\right)$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-25B (Node 617)

RH-25B vertically supports line 1-43 near the center of P(1-43J) from any downward movement.

$nd617_{RH25B_0} := 617$ Node associated with support

$$\left(AL1_{RH25B\_nd617} \;\; AL2_{RH25B\_nd617}\right) := Support\left(NF, nd617_{RH25B}, Sup\_C_{o\_RH25}, EL\right)$$

$$AL1_{RH25B\_nd617}^{T} = \left(0.571 \;\; -5.908 \times 10^{3} \;\; 4.805 \;\; 617 \;\; 96\right)$$

$$AL2_{RH25B\_nd617}^{T} = \left(0 \;\; 0 \;\; 0 \;\; 0 \;\; 0\right)$$

PS-10 Supports (3x)

$P_{1\_PS10} := \frac{22.1 \cdot kip}{lbf}$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_PS10} := \frac{0kip}{lbf}$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_PS10} := \begin{pmatrix} P_{1\_PS10} & 2 \\ P_{2\_PS10} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

PS-10A (Node 641)

PS-10 vertically supports 1-47 just west of EL(1-47A).

$nd641_{PS10_0} := 641$

Node associated with support

$$\left(AL1_{PS10\_nd641} \;\; AL2_{PS10\_nd641}\right) := Support\left(NF, nd641_{PS10}, Sup\_C_{o\_PS10}, EL\right)$$

$$AL1_{PS10\_nd641}{}^T = \left(0.874 \;\; -1.932\times10^4 \;\; 10.715 \;\; 641 \;\; 104\right)$$

$$AL2_{PS10\_nd641}{}^T = \left(0 \;\; 0 \;\; 0 \;\; 0 \;\; 0\right)$$

(C,demand force, occurrence time, fined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PS-10B (Node 644)

PS-10 vertically supports 1-47 just south of FL(1-47A).

$nd644_{PS10_0} := 644$

Node associated with support

$$\left(AL1_{PS10\_nd644} \;\; AL2_{PS10\_nd644}\right) := Support\left(NF, nd644_{PS10}, Sup\_C_{o\_PS10}, EL\right)$$

$$AL1_{PS10\_nd644}{}^T = \left(0.609 \;\; -1.346\times10^4 \;\; 7.89 \;\; 644 \;\; 106\right)$$

$$AL2_{PS10\_nd644}{}^T = \left(0 \;\; 0 \;\; 0 \;\; 0 \;\; 0\right)$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PS-10C (Node 646)

PS-10 vertically supports 1-47 just north of FL(1-47B).

$nd646_{PS10_0} := 646$

Node associated with support

$$\left(AL1_{PS10\_nd646} \;\; AL2_{PS10\_nd646}\right) := Support\left(NF, nd646_{PS10}, Sup\_C_{o\_PS10}, EL\right)$$

$$AL1_{PS10\_nd646}{}^T = \left(0.253 \;\; -5.582\times10^3 \;\; 9.905 \;\; 646 \;\; 108\right)$$

$$AL2_{PS10\_nd646}{}^T = \left(0 \;\; 0 \;\; 0 \;\; 0 \;\; 0\right)$$

(D/C,demand force, occurrence time, efined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

AIWS Support (1x)

$$P_{1\_AIWSY} := \frac{1.539 \cdot kip}{lbf}$$

Downward Flexure

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$$P_{2\_AIWSY} := \frac{1.539 \cdot kip}{lbf}$$

Upward Flexure

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_AIWSY} := \begin{pmatrix} P_{1\_AIWSY} & 2 \\ P_{2\_AIWSY} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

$$P_{1\_AIWSZ} := \frac{0 \cdot kip}{lbf}$$

Westward Flexure

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$$P_{2\_AIWSZ} := \frac{0 \cdot kip}{lbf}$$

Eastward Flexure

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_AIWSZ} := \begin{pmatrix} P_{1\_AIWSZ} & 3 \\ P_{2\_AIWSZ} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

AIWS (V) (Node 836)

AIWS supports line 1-43 at the bottom portion of P(1-43G) from movement in the vertical and east/west directions.

$$nd836_{AIWSY_0} := 836$$

Node associated with support

$$\left(AL1_{AIWSY\_nd836} \;\; AL2_{AIWSY\_nd836}\right) := Support\left(NF, nd836_{AIWSY}, Sup\_C_{o\_AIWSY}, EL\right)$$

$$AL1_{AIWSY\_nd836}{}^T = \begin{pmatrix} 0.688 & -1.059 \times 10^3 & 7.92 & 836 & 112 \end{pmatrix}$$

$$AL2_{AIWSY\_nd836}{}^T = \begin{pmatrix} 0.038 & 59.14 & 7.935 & 836 & 112 \end{pmatrix}$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

AIWS (EW) (Node 836)

AIWS supports line 1-43 at the bottom portion of P(1-43G) from movement in the vertical and east/west directions.

$$nd836_{AIWSZ_0} := 836$$

Node associated with support

$\left(AL1_{AIWSZ\_nd836}\;\; AL2_{AIWSZ\_nd836}\right) := \text{Support}\left(NF, nd836_{AIWSZ}, Sup\_C_{o\_AIWSZ}, EL\right)$

$AL1_{AIWSZ\_nd836}{}^{T} = (0\;\;0\;\;0\;\;0\;\;0)$

$AL2_{AIWSZ\_nd836}{}^{T} = (0\;\;0\;\;0\;\;0\;\;0)$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

Writing Output Data for Supports Associated with Lines 43 and 47

$SA1 := AL1_{RH19\_nd625}{}^{T}$

$SA2 := AL2_{RH19\_nd625}{}^{T}$

$SB1 := AL1_{RH17A\_nd622}{}^{T}$

$SB2 := AL2_{RH17A\_nd622}{}^{T}$

$SC1 := AL1_{RH17B\_nd833}{}^{T}$

$SC2 := AL2_{RH17B\_nd833}{}^{T}$

$SD1 := AL1_{RH30X\_nd927}{}^{T}$

$SD2 := AL2_{RH30X\_nd927}{}^{T}$

$SE1 := AL1_{RH30Y\_nd927}{}^{T}$

$SE2 := AL2_{RH30Y\_nd927}{}^{T}$

$SF1 := AL1_{RH30Z\_nd927}{}^{T}$

$SF2 := AL2_{RH30Z\_nd927}{}^{T}$

$SG1 := AL1_{RH25A\_nd619}{}^{T}$

$SG2 := AL2_{RH25A\_nd619}{}^{T}$

$SH1 := AL1_{RH25B\_nd617}{}^{T}$

$SH2 := AL2_{RH25B\_nd617}{}^{T}$

$SI1 := AL1_{PS10\_nd641}{}^{T}$

$SI2 := AL2_{PS10\_nd641}{}^{T}$

$SJ1 := AL1_{PS10\_nd644}{}^{T}$

$SJ2 := AL2_{PS10\_nd644}{}^{T}$

$SK1 := AL1_{PS10\_nd646}{}^{T}$

$SK2 := AL2_{PS10\_nd646}{}^{T}$

$SL1 := AL1_{AIWSY\_nd836}{}^{T}$

$SL2 := AL2_{AIWSY\_nd836}{}^{T}$

$SM1 := AL1_{AIWSZ\_nd836}{}^{T}$

$SM2 := AL2_{AIWSZ\_nd836}{}^{T}$

$S := (SA1\;\; SA2\;\; SB1\;\; SB2\;\; SC1\;\; SC2\;\; SD1\;\; SD2\;\; SE1\;\; SE2\;\; SF1\;\; SF2\;\; SG1\;\; SG2\;\; SH1\;\; SH2\;\; SI1\;\; SI2\;\; SJ1\;\; SJ2\;\; SK1\;\; SK2$

SupportsLines_43_47 := WRITEPRN("SupLines_43_47.prn" , S)

TERMINATION LOCATIONS

Termination Locations Strategy: *Search based on the node for which the termination location acts as well as the next node inward. The D/C ratio for each termination location will be found by dividing the the required force found above by the support capacity.*

$$\mathrm{TermDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Term}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \mathrm{match}(t_{initial}, nf^{\langle 0 \rangle})$

$ind_{nfo} \leftarrow \mathrm{match}(t_{final}, nf^{\langle 0 \rangle})$

$ind_{nd} \leftarrow \mathrm{match}(nd_0, EL^{\langle 1 \rangle})$

for $i \in 1 .. \mathrm{last}(nd)$ if $\mathrm{rows}(nd) > 1$

  $ind_{nd} \leftarrow \mathrm{stack}[ind_{nd}, (\mathrm{match}(nd_i, EL^{\langle 1 \rangle}))]$

$(M \;\; Int_0) \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \mathrm{last}(ind_{nd})$

    $M_{rxg} \leftarrow nf_{ind_{nfi}C_{o_{0,1}}+2,\, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi}C_{o_{1,1}}+2,\, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi}C_{o_{2,1}}+2,\, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi}C_{o_{1,1}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi}C_{o_{2,1}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow \mathrm{TermDC}(P, D_o, t, I, B_1, B_2, M'_j, S)$

    if $Int'_j > Int_0$

      $Int \leftarrow \mathrm{stack}(Int'_j, M'_j, nf_{ind_{nfi}C_{o_{0,1}}-1+i,0}, EL_{ind_{nd_j},1}, ind_{nd_j}, M_{rx}, M_{ry}, M_{\text{I}}$

      $Result \leftarrow M'$

Int

Conditions applicable to all terminations

$M_{cx} := 0 \qquad M_{cy} := 0 \qquad M_{cz} := 0$ — Defining place holding variables

$$Term\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

North Wall Penetration 1-43 (1x)

Define pertinent pipe variables

$D_o := 10.75in$ — Outside Diameter [11]

$t := 0.25in$ — Thickness [11]

$P := 253psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

$I = 113.714\ in^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$S := S_{125}$ — Allowable design stress intensity value

Define primary stress indices

$B_1 := 0.5$

$$B_2 := \begin{cases} 1.0 \ \text{if} \ \dfrac{D_o}{t} \le 50 \\ \text{if} \ \dfrac{D_o}{t} > 50 \\ \quad T \leftarrow 125 \\ \quad X \leftarrow \min\left(1, 1.3 - 0.006\cdot\dfrac{D_o}{t}\right) \\ \quad Y \leftarrow 1 \\ \quad 1.0\cdot\dfrac{1}{X\cdot Y} \end{cases}$$

$B_2 = 1$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

North Wall Penetration 1-43 (Node 601)

$nd601_{NWP143_0} := 601$

$AL_{NWP143\_nd601} := Term\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd601_{NWP143}, Term\_C_o, EL\right)$

$$\left(AL_{NWP143\_nd601}\right)^T = \left(0.2 \quad 1.829\times10^5 \quad 5.405 \quad 601 \quad 166 \quad -5.355\times10^4 \quad 1.287\times10^5 \quad -1.184\times10^5\right)$$

Pipe Termination 1-47 (1x)

Define pertinent pipe variables

$D_o := 6.625\,in$ — Outside Diameter [15] [16]

$t := 0.28\,in$ — Thickness [15] [16]

$P := 253\,psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

$I = 28.142\,in^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$S := S_{125}$ — Allowable design stress intensity value

Define primary stress indices

$B_1 := 0.5$

$$B_2 := \begin{cases} 1.0 & \text{if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 & \left| \begin{array}{l} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \frac{D_o}{t}\right) \\ Y \leftarrow 1 \\ 1.0 \cdot \frac{1}{X \cdot Y} \end{array} \right. \end{cases}$$

$B_2 = 1$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Termination 1-47 (Node 669)

$nd669_{PT147_0} := 669$

$AL_{PT147\_nd669} := Term\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd669_{PT147}, Term\_C_o, EL\right)$

$$AL_{PT147\_nd669}^{\,T} = \left(0.173 \quad 7.048 \times 10^4 \quad 10.275 \quad 669 \quad 82 \quad -5.434 \times 10^3 \quad -6.874 \times 10^4 \quad 1.461 \times 10^4\right)$$

Writing Output Data for Terminations Associated with Lines 1-43 & 1-47

$T1 := \left(AL_{NWP143\_nd601}^{\,T}\right)$ — North Wall Penetration 1-43 (Node 601)

$T2 := \left(AL_{PT147\_nd669}^{\,T}\right)$ — Pipe Termination 1-47 (Node 669)

$T := (T1 \quad T2)$

TerminationsLines_43_47 := WRITEPRN("TermLines_43_47.prn" , T)

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** R. K. Blandford **Date:** 09/30/2008

PIPE RUNS

Pipe Runs Strategy: *Search based on the nodes present in each run of pipe. Find the maximum moment combination among all of the nodes and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{PipeRunDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$$\mathrm{PipeRun}(P, D_o, t, I, B_1, B_2, S, nf, el, C_o, EL) :=$$

$$\begin{array}{l}
ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
ind_{el} \leftarrow \mathrm{match}\left(el_0, EL^{\langle 0 \rangle}\right) \\
\text{for } i \in 1 .. \mathrm{last}(el) \quad \text{if } \mathrm{rows}(el) > 1 \\
\quad ind_{el} \leftarrow \mathrm{stack}\left[ind_{el}, \left(\mathrm{match}\left(el_i, EL^{\langle 0 \rangle}\right)\right)\right] \\
\left(M \quad Int_{5, \mathrm{last}(ind_{el})}\right) \leftarrow (0 \quad 0) \\
\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0} \\
\quad \text{for } j \in 0 .. \mathrm{last}(ind_{el}) \\
\quad\quad M_{rxg} \leftarrow nf_{ind_{nfi}{C_o}_{0,1}+2,\, ind_{el_j}} \\
\quad\quad M_{ryg} \leftarrow nf_{ind_{nfi}{C_o}_{1,1}+2,\, ind_{el_j}} \\
\quad\quad M_{rzg} \leftarrow nf_{ind_{nfi}{C_o}_{2,1}+2,\, ind_{el_j}} \\
\quad\quad M_{rx_j} \leftarrow \left(nf_{ind_{nfi}{C_o}_{0,1}+2+i,\, ind_{el_j}} - M_{rxg}\right) \cdot {C_o}_{3,0} + M_{rxg} \\
\quad\quad M_{ry_j} \leftarrow \left(nf_{ind_{nfi}{C_o}_{1,1}+2+i,\, ind_{el_j}} - M_{ryg}\right) \cdot {C_o}_{3,0} + M_{ryg} \\
\quad\quad M_{rz_j} \leftarrow \left(nf_{ind_{nfi}{C_o}_{2,1}+2+i,\, ind_{el_j}} - M_{rzg}\right) \cdot {C_o}_{3,0} + M_{rzg} \\
\quad\quad M'_j \leftarrow \sqrt{\left(M_{rx_j}\right)^2 + \left(M_{ry_j}\right)^2 + \left(M_{rz_j}\right)^2} \\
\quad\quad Int'_j \leftarrow \mathrm{PipeRunDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right) \\
\quad\quad \text{if } Int'_j > Int_{0,j} \\
\quad\quad\quad H \leftarrow \left(Int'_j \quad M'_j \quad nf_{ind_{nfi}{C_o}_{0,1}-1+i,0} \quad EL_{ind_{el_j},0} \quad EL_{ind_{el_j},1} \quad ind_{el_j} \quad M_{r\ldots}\right. \\
\quad\quad\quad \text{for } k \in 0 .. 5 \\
\quad\quad\quad\quad \ldots \leftarrow H
\end{array}$$

$Int_{k,j} \leftarrow H_k$

Int

Conditions applicable to all pipe runs

$M_{ox} := 0 \quad M_{oy} := 0 \quad M_{oz} := 0$

Defining place holding directional moment variables

$$PipeRun\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties for Line 1-43 (A-J)

Define pertinent pipe variables

$D_o := 10.75\text{in}$

Outside Diameter [11]

$t := 0.25\text{in}$

Thickness [11]

$P := 253\text{psi}$

Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 113.714\ \text{in}^4$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{cases} 1.0 & \text{if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50 & \left| \begin{array}{l} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006\cdot\dfrac{D_o}{t}\right) \\ Y \leftarrow 1.033 - 0.00033\cdot T \\ 1.0\cdot\dfrac{1}{X\cdot Y} \end{array} \right. \end{cases}$$

$B_{2PR} = 1$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-43A (Element 167)

$el_{P143A} := (167)^T$

$AL_{P143A} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P143A}, PipeRun\_C_o, EL)$

$$AL_{P143A}^T = \begin{pmatrix} 0.22 & 2.061\times10^5 & 9.165 & 167 & 224 & 1 \\ 0.212 & 1.967\times10^5 & 9.165 & 167 & 225 & 2 \end{pmatrix}$$

Pipe Run 1-43B (Elements 168)

$el_{P143B} := (168)^T$

$AL_{P143B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P143B}, PipeRun\_C_o, EL)$

$$AL_{P143B}^T = \begin{pmatrix} 0.205 & 1.887\times10^5 & 8.88 & 168 & 226 & 3 \\ 0.182 & 1.607\times10^5 & 8.885 & 168 & 228 & 4 \end{pmatrix}$$

Pipe Run 1-43C (Elements 172 & 174)

$el_{P143C} := (172 \quad 174)^T$

$AL_{P143C} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P143C}, PipeRun\_C_o, EL)$

$$AL_{P143C}^T = \begin{pmatrix} 0.276 & 2.739\times10^5 & 5.77 & 172 & 251 & 9 \\ 0.17 & 1.464\times10^5 & 8.895 & 172 & 252 & 10 \\ 0.18 & 1.582\times10^5 & 10.345 & 174 & 232 & 11 \\ 0.17 & 1.464\times10^5 & 8.895 & 174 & 252 & 12 \end{pmatrix}$$

Pipe Run 1-43D (Element 175)

$el_{P143D} := (175)^T$

$AL_{P143D} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P143D}, PipeRun\_C_o, EL)$

$$AL_{P143D}^T = \begin{pmatrix} 0.176 & 1.531\times10^5 & 10.345 & 175 & 233 & 13 \\ 0.19 & 1.7\times10^5 & 8.03 & 175 & 262 & 14 \end{pmatrix}$$

Pipe Run 1-43E (Elements 211)

$el_{P143E} := (211)^T$

$AL_{P143E} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P143E}, PipeRun\_C_o, EL)$

$$AL_{P143E}^T = \begin{pmatrix} 0.136 & 1.052\times10^5 & 9.33 & 211 & 235 & 45 \\ 0.154 & 1.276\times10^5 & 5.315 & 211 & 281 & 46 \end{pmatrix}$$

Pipe Run 1-43F (Element 180)

$el_{P143F} := (180)^T$

$AL_{P143F} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P143F}, PipeRun\_C_o, EL)$

$$AL_{P143F}^T = \begin{pmatrix} 0.182 & 1.604 \times 10^5 & 5.305 & 180 & 237 & 19 \\ 0.181 & 1.6 \times 10^5 & 5.305 & 180 & 620 & 20 \end{pmatrix}$$

Pipe Run 1-43G (Elements 182, 687, 688, 689, 690, & 188)

$el_{P143G} := (182 \quad 687 \quad 688 \quad 689 \quad 690 \quad 188)^T$

$AL_{P143G} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P143G}, PipeRun\_C_o, EL)$

$AL_{P143G}^T =$

	0	1	2	3	4	5
0	0.197	$1.789 \cdot 10^5$	9.295	182	260	23
1	0.176	$1.537 \cdot 10^5$	9.3	182	$1.089 \cdot 10^3$	24
2	0.176	$1.537 \cdot 10^5$	9.3	687	$1.089 \cdot 10^3$	170
3	0.156	$1.292 \cdot 10^5$	9.3	687	$1.09 \cdot 10^3$	171
4	0.156	$1.291 \cdot 10^5$	9.3	688	$1.09 \cdot 10^3$	172
5	0.146	$1.171 \cdot 10^5$	15.57	688	$1.091 \cdot 10^3$	173
6	0.146	$1.171 \cdot 10^5$	15.57	689	$1.091 \cdot 10^3$	174
7	0.174	$1.509 \cdot 10^5$	15.565	689	$1.092 \cdot 10^3$	175
8	0.213	$1.984 \cdot 10^5$	15.56	690	254	176
9	0.174	$1.509 \cdot 10^5$	15.565	690	$1.092 \cdot 10^3$	177
10	0.168	$1.44 \cdot 10^5$	15.565	188	239	25
11	0.213	$1.98 \cdot 10^5$	15.56	188	254	26

Pipe Run 1-43H (Elements 190 & 691)

$el_{P143H} := (190 \quad 691)^T$

$AL_{P143H} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P143H}, PipeRun\_C_o, EL)$

$$AL_{P143H}^T = \begin{pmatrix} 0.167 & 1.431 \times 10^5 & 15.565 & 190 & 240 & 29 \\ 0.131 & 9.953 \times 10^4 & 15.57 & 190 & 1.093 \times 10^3 & 30 \\ 0.124 & 9.111 \times 10^4 & 9.84 & 691 & 241 & 178 \\ 0.131 & 9.953 \times 10^4 & 15.57 & 691 & 1.093 \times 10^3 & 179 \end{pmatrix}$$

Pipe Run 1-43I (Elements 192)

$el_{P143I} := (192)^T$

$AL_{P143I} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P143I}, PipeRun\_C_o, EL)$

$$AL_{P143I}^T = \begin{pmatrix} 0.13 & 9.824 \times 10^4 & 9.84 & 192 & 242 & 31 \\ 0.13 & 9.825 \times 10^4 & 15.53 & 192 & 244 & 32 \end{pmatrix}$$

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Pipe Run 1-43J (Elements 193, 198, 692, 693, 694, & 695)

$el_{P143J} := (193\ \ 198\ \ 692\ \ 693\ \ 694\ \ 695)^T$

$AL_{P143J} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P143J}, PipeRun\_C_o, EL)$

$AL_{P143J}^T =$

	0	1	2	3	4	5
0	0.13	$9.802\cdot10^4$	15.53	193	245	33
1	0.123	$8.946\cdot10^4$	9.87	193	273	34
2	0.123	$8.948\cdot10^4$	9.87	198	273	35
3	0.119	$8.489\cdot10^4$	9.875	198	$1.094\cdot10^3$	36
4	0.119	$8.49\cdot10^4$	9.875	692	$1.094\cdot10^3$	180
5	0.116	$8.188\cdot10^4$	9.875	692	$1.095\cdot10^3$	181
6	0.116	$8.189\cdot10^4$	9.875	693	$1.095\cdot10^3$	182
7	0.116	$8.216\cdot10^4$	9.875	693	$1.096\cdot10^3$	183
8	0.116	$8.217\cdot10^4$	9.875	694	$1.096\cdot10^3$	184
9	0.125	$9.262\cdot10^4$	9.485	694	$1.097\cdot10^3$	185
10	0.142	$1.131\cdot10^5$	9.485	695	247	186
11	0.125	$9.263\cdot10^4$	9.485	695	$1.097\cdot10^3$	187

Pipe Run 1-43K (Elements 201 & 203)

$el_{P143K} := (201\ \ 203)^T$

$AL_{P143K} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P143K}, PipeRun\_C_o, EL)$

$$AL_{P143K}^T = \begin{pmatrix} 0.132 & 1.014\times10^5 & 15.555 & 201 & 250 & 37 \\ 0.159 & 1.334\times10^5 & 9.89 & 201 & 265 & 38 \\ 0.137 & 1.065\times10^5 & 9.89 & 203 & 264 & 39 \\ 0.159 & 1.334\times10^5 & 9.89 & 203 & 265 & 40 \end{pmatrix}$$

Pipe Run 1-43L (Elements 205, 696, 697, 698, & 210)

$el_{P143L} := (205\ \ 696\ \ 697\ \ 698\ \ 210)^T$

$AL_{P143L} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P143L}, PipeRun\_C_o, EL)$

$AL_{P143L}^T =$

	0	1	2	3	4	5
0	0.132	$1.014\cdot10^5$	9.895	205	263	41
1	0.135	$1.046\cdot10^5$	9.89	205	$1.098\cdot10^3$	42
2	0.135	$1.046\cdot10^5$	9.89	696	$1.098\cdot10^3$	188
3	0.144	$1.157\cdot10^5$	9.88	696	$1.099\cdot10^3$	189
4	0.144	$1.157\cdot10^5$	9.88	697	$1.099\cdot10^3$	190
5	0.159	$1.337\cdot10^5$	9.86	697	$1.1\cdot10^3$	191
6	0.179	$1.567\cdot10^5$	9.855	698	268	192
7	0.159	$1.337\cdot10^5$	9.86	698	$1.1\cdot10^3$	193
8	0.191	$1.718\cdot10^5$	5.405	210	249	43
9	0.179	$1.567\cdot10^5$	9.855	210	268	44

Pipe Run 1-43M (Element 607)

$el_{P143M} := (607)^T$

$AL_{P143M} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P143M}, PipeRun\_C_o, EL)$

$$AL_{P143M}^T = \begin{pmatrix} 0.2 & 1.829\times10^5 & 5.405 & 607 & 601 & 166 \\ 0.192 & 1.727\times10^5 & 5.405 & 607 & 934 & 167 \end{pmatrix}$$

Pipe Properties for Line 1-43 (N-O)

Define pertinent pipe variables

$D_o := 6.625in$ — Outside Diameter [11]

$t := 0.28in$ — Thickness [11]

$P := 253psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o^4 - (D_o - 2\cdot t)^4\right]}{64}$$ — Moment of inertia [8, Table 17-27, pg 17-39]

$I = 28.142\,in^4$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{cases} 1.0 \text{ if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 \\ \quad T \leftarrow 125 \\ \quad X \leftarrow \min\left(1, 1.3 - 0.006\cdot\frac{D_o}{t}\right) \\ \quad Y \leftarrow 1.033 - 0.00033\cdot T \\ \quad 1.0\cdot\frac{1}{X\cdot Y} \end{cases}$$

$B_{2PR} = 1$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-43N (Element 380)

$el_{P143N} := (380)^T$

$AL_{P143N} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P143N}, PipeRun\_C_o, EL)$

$$AL_{P143N}^T = \begin{pmatrix} 0.231 & 9.853\times10^4 & 15.195 & 380 & 805 & 87 \\ 0.233 & 9.972\times10^4 & 15.19 & 380 & 1.054\times10^3 & 88 \end{pmatrix}$$

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Pipe Run 1-43O (Element 227)

$$el_{P143O} := (227)^T$$

$$AL_{P143O} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P143O}, PipeRun\_C_o, EL\right)$$

$$AL_{P143O}^T = \begin{pmatrix} 0.166 & 6.727\times10^4 & 15.205 & 227 & 299 & 51 \\ 0.198 & 8.26\times10^4 & 15.195 & 227 & 349 & 52 \end{pmatrix}$$

Pipe Properties for Line 1-47

Define pertinent pipe variables

$D_o := 10.75in$ — Outside Diameter [15] [16]

$t := 0.25in$ — Thickness [15] [16]

$P := 253psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o^4 - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 113.714\,in^4$$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{cases} 1.0 & \text{if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50: & \begin{array}{l} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006\cdot\dfrac{D_o}{t}\right) \\ Y \leftarrow 1.033 - 0.00033\cdot T \\ 1.0\cdot\dfrac{1}{X\cdot Y} \end{array} \end{cases}$$

$B_{2PR} = 1$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-47A (Elements 272, 699, & 700)

$el_{P147A} := (272 \;\; 699 \;\; 700)^T$

$AL_{P147A} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P147A}, PipeRun\_C_o, EL)$

$$AL_{P147A}^T = \begin{pmatrix} 0.18 & 1.581\times10^5 & 9.585 & 272 & 626 & 59 \\ 0.114 & 7.977\times10^4 & 9.575 & 272 & 1.101\times10^3 & 60 \\ 0.114 & 7.976\times10^4 & 9.575 & 699 & 1.101\times10^3 & 194 \\ 0.089 & 4.937\times10^4 & 8.87 & 699 & 1.102\times10^3 & 195 \\ 0.142 & 1.127\times10^5 & 8.87 & 700 & 629 & 196 \\ 0.089 & 4.937\times10^4 & 8.87 & 700 & 1.102\times10^3 & 197 \end{pmatrix}$$

Pipe Run 1-47B (Elements 273, 276,& 277)

$el_{P147B} := (273 \;\; 276 \;\; 277)^T$

$AL_{P147B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P147B}, PipeRun\_C_o, EL)$

$$AL_{P147B}^T = \begin{pmatrix} 0.148 & 1.2\times10^5 & 9.775 & 273 & 630 & 61 \\ 0.164 & 1.386\times10^5 & 9.775 & 273 & 637 & 62 \\ 0.168 & 1.444\times10^5 & 9.775 & 276 & 637 & 67 \\ 0.115 & 8.027\times10^4 & 9.775 & 276 & 638 & 68 \\ 0.09 & 5.019\times10^4 & 5.055 & 277 & 632 & 69 \\ 0.115 & 8.025\times10^4 & 9.775 & 277 & 638 & 70 \end{pmatrix}$$

Pipe Run 1-47C (Elements 274 & 281)

$el_{P147C} := (274 \;\; 281)^T$

$AL_{P147C} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P147C}, PipeRun\_C_o, EL)$

$$AL_{P147C}^T = \begin{pmatrix} 0.098 & 6.034\times10^4 & 7.89 & 274 & 633 & 63 \\ 0.119 & 8.468\times10^4 & 7.89 & 274 & 642 & 64 \\ 0.1 & 6.285\times10^4 & 7.89 & 281 & 634 & 71 \\ 0.122 & 8.916\times10^4 & 7.89 & 281 & 642 & 72 \end{pmatrix}$$

Pipe Run 1-47D (Element 275)

$el_{P147D} := (275)^T$

$AL_{P147D} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P147D}, PipeRun\_C_o, EL)$

$$AL_{P147D}^T = \begin{pmatrix} 0.095 & 5.59\times10^4 & 7.845 & 275 & 635 & 65 \\ 0.096 & 5.766\times10^4 & 7.84 & 275 & 636 & 66 \end{pmatrix}$$

Pipe Run 1-47E (Element 284)

$el_{P147E} := (284)^T$

$AL_{P147E} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P147E}, PipeRun\_C_o, EL)$

$$AL_{P147E}^T = \begin{pmatrix} 0.093 & 5.342\times10^4 & 7.845 & 284 & 648 & 73 \\ 0.09 & 5.06\times10^4 & 8.04 & 284 & 649 & 74 \end{pmatrix}$$

Pipe Run 1-47F (Elements 285, 701, 702, 703, 704, 705, 706, & 295)

$el_{P147F} := (285 \;\; 701 \;\; 702 \;\; 703 \;\; 704 \;\; 705 \;\; 706 \;\; 295)^T$

$AL_{P147F} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P147F}, PipeRun\_C_o, EL)$

$AL_{P147F}^T =$

	0	1	2	3	4	5
0	0.091	$5.132\cdot10^4$	8.04	285	651	75
1	0.093	$5.346\cdot10^4$	8.04	285	$1.103\cdot10^3$	76
2	0.093	$5.346\cdot10^4$	8.04	701	$1.103\cdot10^3$	198
3	0.089	$4.966\cdot10^4$	8.035	701	$1.104\cdot10^3$	199
4	0.089	$4.965\cdot10^4$	8.035	702	$1.104\cdot10^3$	200
5	0.083	$4.16\cdot10^4$	8.875	702	$1.105\cdot10^3$	201
6	0.083	$4.16\cdot10^4$	8.875	703	$1.105\cdot10^3$	202
7	0.076	$3.413\cdot10^4$	8.875	703	$1.106\cdot10^3$	203
8	0.076	$3.413\cdot10^4$	8.875	704	$1.106\cdot10^3$	204
9	0.071	$2.819\cdot10^4$	10.225	704	$1.107\cdot10^3$	205
10	0.071	$2.819\cdot10^4$	10.225	705	$1.107\cdot10^3$	206
11	0.08	$3.867\cdot10^4$	7.86	705	$1.108\cdot10^3$	207
12	0.094	$5.556\cdot10^4$	7.86	706	653	208
13	0.08	$3.869\cdot10^4$	7.86	706	$1.108\cdot10^3$	209
14	0.091	$5.187\cdot10^4$	9.445	295	653	83
15	0.1	$6.249\cdot10^4$	7.87	295	661	84

Pipe Run 1-47G (Elements 292 & 337)

$el_{P147G} := (292 \;\; 337)^T$

$AL_{P147G} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P147G}, PipeRun\_C_o, EL\right)$

$$AL_{P147G}{}^T = \begin{pmatrix} 0.098 & 6.008 \times 10^4 & 7.87 & 292 & 662 & 77 \\ 0.085 & 4.405 \times 10^4 & 7.86 & 292 & 703 & 78 \\ 0.072 & 2.903 \times 10^4 & 7.84 & 337 & 665 & 85 \\ 0.085 & 4.405 \times 10^4 & 7.86 & 337 & 703 & 86 \end{pmatrix}$$

Pipe Run 1-47H (Elements 293, 707, 708, 709, & 710)

$el_{P147H} := (293 \;\; 707 \;\; 708 \;\; 709 \;\; 710)^T$

$AL_{P147H} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P147H}, PipeRun\_C_o, EL\right)$

$AL_{P147H}{}^T =$

	0	1	2	3	4	5
0	0.069	$2.575 \cdot 10^4$	7.84	293	664	79
1	0.065	$2.061 \cdot 10^4$	8.56	293	$1.109 \cdot 10^3$	80
2	0.065	$2.061 \cdot 10^4$	8.56	707	$1.109 \cdot 10^3$	210
3	0.069	$2.473 \cdot 10^4$	11.35	707	$1.11 \cdot 10^3$	211
4	0.069	$2.473 \cdot 10^4$	11.35	708	$1.11 \cdot 10^3$	212
5	0.077	$3.453 \cdot 10^4$	11.35	708	$1.111 \cdot 10^3$	213
6	0.077	$3.453 \cdot 10^4$	11.35	709	$1.111 \cdot 10^3$	214
7	0.087	$4.718 \cdot 10^4$	10.265	709	$1.112 \cdot 10^3$	215
8	0.101	$6.367 \cdot 10^4$	10.27	710	667	216
9	0.087	$4.718 \cdot 10^4$	10.265	710	$1.112 \cdot 10^3$	217

Pipe Run 1-47I (Element 294)

$el_{P147I} := (294)^T$

$AL_{P147I} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P147I}, PipeRun\_C_o, EL\right)$

$$AL_{P147I}{}^T = \begin{pmatrix} 0.106 & 6.996 \times 10^4 & 10.275 & 294 & 668 & 81 \\ 0.107 & 7.048 \times 10^4 & 10.275 & 294 & 669 & 82 \end{pmatrix}$$

Writing Output Data for Pipe Runs Associated with Lines 1-43 & 1-47

$PR1 := \left(AL_{P143A}{}^{T}\right)$ $PR13 := \left(AL_{P143M}{}^{T}\right)$

$PR2 := \left(AL_{P143B}{}^{T}\right)$ $PR14 := \left(AL_{P143N}{}^{T}\right)$

$PR3 := \left(AL_{P143C}{}^{T}\right)$ $PR15 := \left(AL_{P143O}{}^{T}\right)$

$PR4 := \left(AL_{P143D}{}^{T}\right)$ $PR16 := \left(AL_{P147A}{}^{T}\right)$

$PR5 := \left(AL_{P143E}{}^{T}\right)$ $PR17 := \left(AL_{P147B}{}^{T}\right)$

$PR6 := \left(AL_{P143F}{}^{T}\right)$ $PR18 := \left(AL_{P147C}{}^{T}\right)$

$PR7 := \left(AL_{P143G}{}^{T}\right)$ $PR19 := \left(AL_{P147D}{}^{T}\right)$

$PR8 := \left(AL_{P143H}{}^{T}\right)$ $PR20 := \left(AL_{P147E}{}^{T}\right)$

$PR9 := \left(AL_{P143I}{}^{T}\right)$ $PR21 := \left(AL_{P147F}{}^{T}\right)$

$PR10 := \left(AL_{P143J}{}^{T}\right)$ $PR22 := \left(AL_{P147G}{}^{T}\right)$

$PR11 := \left(AL_{P143K}{}^{T}\right)$ $PR23 := \left(AL_{P147H}{}^{T}\right)$

$PR12 := \left(AL_{P143L}{}^{T}\right)$ $PR24 := \left(AL_{P147I}{}^{T}\right)$

P := (PR1 PR2 PR3 PR4 PR5 PR6 PR7 PR8 PR9 PR10 PR11 PR12 PR13 PR14 PR15 PR16 PR17 PR18 PR19 I

PipeRunsLines_43_47 := WRITEPRN("PRLines_43_47.prn" , P)

ELBOWS

Elbows Strategy: *Search based on the two nodes comprising the ends of each elbow. SRSS combine the three moments of each of the four node representations (one for each element connected by the nodes in question). Find the maximum of the four moment combinations and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\text{ElbowDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

$\text{Elbow}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \text{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

$\text{for } i \in 1 .. \text{last}(nd)$ $\quad$ if rows(nd) > 1

$\quad ind_{nd} \leftarrow \text{stack}\left[ind_{nd}, \left(\text{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$(M \;\; Int_0) \leftarrow (0 \;\; 0)$

$\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

$\quad \text{for } j \in 0 .. \text{last}(ind_{nd})$

$\quad\quad M_{rxg} \leftarrow nf_{ind_{nfi}C_{o_{0,1}}+2,\, ind_{nd_j}}$

$\quad\quad M_{ryg} \leftarrow nf_{ind_{nfi}C_{o_{1,1}}+2,\, ind_{nd_j}}$

$\quad\quad M_{rzg} \leftarrow nf_{ind_{nfi}C_{o_{2,1}}+2,\, ind_{nd_j}}$

$\quad\quad M_{rx} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

$\quad\quad M_{ry} \leftarrow \left(nf_{ind_{nfi}C_{o_{1,1}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

$\quad\quad M_{rz} \leftarrow \left(nf_{ind_{nfi}C_{o_{2,1}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

$\quad\quad M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

$\quad\quad Int'_j \leftarrow \text{ElbowDC}(P, D_o, t, I, B_1, B_2, M'_j, S)$

$\quad\quad \text{if } Int'_j > Int_0$

$\quad\quad\quad Int \leftarrow \text{stack}\left(Int'_j, M'_j, nf_{ind_{nfi}C_{o_{0,1}}-1+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M\right.$

$\quad\quad\quad Result \leftarrow M'$

Int

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** R. K. Blandford **Date:** 09/30/2008

Conditions applicable to all elbows

$M_{cx} := 0 \quad M_{cy} := 0 \quad M_{cz} := 0$ — Defining place holding variables

$$Elb\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Elbow Properties for Line 1-43

Define pertinent elbow variables

$D_o := 10.75\,in$ — Outside Diameter [11]

$t := 0.25\,in$ — Thickness [11]

$P := 253\,psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

$I = 113.714\,in^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$R := 1.5\cdot D_o$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$ — Mean pipe radius

Define primary stress indices

$$h := \frac{t\cdot R}{r_m^{\,2}}$$ $h = 0.146$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4\cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4\cdot h > 0.5 \\ -0.1 + 0.4\cdot h & \text{otherwise} \end{cases}$$

$B_1 = 0$ — B_1 primary stress Index [9, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 4.683$ — B_2 primary stress Index [9, NB-3683.7]

Elbow 1-43A (Nodes 224 & 226)

$nd_{EL143A\_1} := (224)^T$

$AL_{EL143A\_nd224} := \text{Elbow}\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL143A\_1}, Elb\_C_o, EL\right)$

$AL_{EL143A\_nd224}{}^T = \left(0.805 \quad 2.061\times10^5 \quad 9.165 \quad 224 \quad 1 \quad -1.394\times10^5 \quad -9.123\times10^4 \quad 1.214\times10^5\right)$

$nd_{EL143A\_2} := (226)^T$

$AL_{EL143A\_nd226} := \text{Elbow}\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL143A\_2}, Elb\_C_o, EL\right)$

$AL_{EL143A\_nd226}{}^T = \left(0.737 \quad 1.887\times10^5 \quad 8.88 \quad 226 \quad 114 \quad 6.742\times10^4 \quad 1.502\times10^5 \quad -9.217\times10^4\right)$

Elbow 1-43B (Nodes 228 & 229)

$nd_{EL143B\_1} := (228)^T$

$AL_{EL143B\_nd228} := \text{Elbow}\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL143B\_1}, Elb\_C_o, EL\right)$

$AL_{EL143B\_nd228}{}^T = \left(0.628 \quad 1.607\times10^5 \quad 8.885 \quad 228 \quad 116 \quad 5.525\times10^4 \quad -1.504\times10^5 \quad -1.249\times10^4\right)$

$nd_{EL143B\_2} := (229)^T$

$AL_{EL143B\_nd229} := \text{Elbow}\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL143B\_2}, Elb\_C_o, EL\right)$

$AL_{EL143B\_nd229}{}^T = \left(0.627 \quad 1.606\times10^5 \quad 9.165 \quad 229 \quad 5 \quad -1.185\times10^5 \quad 7.611\times10^4 \quad 7.711\times10^4\right)$

Elbow 1-43C (Nodes 232 & 233)

$nd_{EL143C\_1} := (232)^T$

$AL_{EL143C\_nd232} := \text{Elbow}\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL143C\_1}, Elb\_C_o, EL\right)$

$AL_{EL143C\_nd232}{}^T = \left(0.618 \quad 1.582\times10^5 \quad 10.345 \quad 232 \quad 119 \quad 1.142\times10^5 \quad 1.039\times10^5 \quad 3.468\times10^4\right)$

$nd_{EL143C\_2} := (233)^T$

$AL_{EL143C\_nd233} := \text{Elbow}\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL143C\_2}, Elb\_C_o, EL\right)$

$AL_{EL143C\_nd233}{}^T = \left(0.598 \quad 1.531\times10^5 \quad 10.345 \quad 233 \quad 120 \quad -1.203\times10^5 \quad -9.064\times10^4 \quad -2.735\times10^4\right.$

Elbow 1-43D (Nodes 281 & 237)

$nd_{EL143D\_1} := (281)^T$

$AL_{EL143D\_nd281} := \text{Elbow}\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL143D\_1}, Elb\_C_o, EL\right)$

$AL_{EL143D\_nd281}{}^T = \left(0.498 \quad 1.276\times10^5 \quad 5.315 \quad 281 \quad 123 \quad -2.702\times10^4 \quad -1.247\times10^5 \quad 514.231\right)$

$nd_{EL143D\_2} := (237)^T$

$AL_{EL143D\_nd237} := \text{Elbow}\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL143D\_2}, Elb\_C_o, EL\right)$

$AL_{EL143D\_nd237}{}^T = \left(0.626 \quad 1.604\times10^5 \quad 5.305 \quad 237 \quad 122 \quad 5.752\times10^4 \quad 1.467\times10^5 \quad 3.021\times10^4\right)$

Elbow 1-43E (Nodes 244 & 245)

$nd_{EL143E\_1} := (244)^T$

$AL_{EL143E\_nd244} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL143E\_1}, Elb\_C_o, EL)$

$AL_{EL143E\_nd244}^T = (0.384 \;\; 9.825\times10^4 \;\; 15.53 \;\; 244 \;\; 32 \;\; 5.501\times10^4 \;\; -6.705\times10^4 \;\; -4.617\times10^4)$

$nd_{EL143E\_2} := (245)^T$

$AL_{EL143E\_nd245} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL143E\_2}, Elb\_C_o, EL)$

$AL_{EL143E\_nd245}^T = (0.383 \;\; 9.802\times10^4 \;\; 15.53 \;\; 245 \;\; 126 \;\; 5.104\times10^4 \;\; -6.4\times10^4 \;\; -5.391\times10^4)$

Elbow 1-43F (Nodes 247 & 250)

$nd_{EL143F\_1} := (247)^T$

$AL_{EL143F\_nd247} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL143F\_1}, Elb\_C_o, EL)$

$AL_{EL143F\_nd247}^T = (0.442 \;\; 1.131\times10^5 \;\; 9.485 \;\; 247 \;\; 128 \;\; -1.008\times10^5 \;\; -4.656\times10^4 \;\; 2.145\times10^4)$

$nd_{EL143F\_2} := (250)^T$

$AL_{EL143F\_nd250} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL143F\_2}, Elb\_C_o, EL)$

$AL_{EL143F\_nd250}^T = (0.396 \;\; 1.014\times10^5 \;\; 15.555 \;\; 250 \;\; 37 \;\; 8.376\times10^4 \;\; 5.695\times10^4 \;\; -4.642\times10^3)$

Elbow 1-43G (Nodes 264 & 263)

$nd_{EL143G\_1} := (264)^T$

$AL_{EL143G\_nd264} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL143G\_1}, Elb\_C_o, EL)$

$AL_{EL143G\_nd264}^T = (0.416 \;\; 1.065\times10^5 \;\; 9.89 \;\; 264 \;\; 132 \;\; 1.045\times10^5 \;\; 1.91\times10^4 \;\; -6.895\times10^3)$

$nd_{EL143G\_2} := (263)^T$

$AL_{EL143G\_nd263} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL143G\_2}, Elb\_C_o, EL)$

$AL_{EL143G\_nd263}^T = (0.396 \;\; 1.014\times10^5 \;\; 9.895 \;\; 263 \;\; 41 \;\; 1.009\times10^5 \;\; 1.017\times10^4 \;\; 963.507)$

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Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** R. K. Blandford **Date:** 09/30/2008

Elbow Properties for Line 1-47

Define pertinent elbow variables

$D_o := 6.625\,in$ — Outside Diameter [15] [16]

$t := 0.28\,in$ — Thickness [15] [16]

$P := 253\,psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

$I = 28.142\,in^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$R := 1.5\cdot D_o$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$ — Mean pipe radius

Define primary stress indices

$$h := \frac{t\cdot R}{r_m^{\,2}}$$ $h = 0.276$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4\cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4\cdot h > 0.5 \\ -0.1 + 0.4\cdot h & \text{otherwise} \end{cases}$$

$B_1 = 0.011$ — B_1 primary stress Index [9, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 3.063$ — B_2 primary stress Index [9, NB-3683.7]

Elbow 1-47A (Nodes 629 & 630)

$nd_{EL147A\_1} := (629)^T$

$AL_{EL147A\_nd629} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL147A\_1}, Elb\_C_o, EL\right)$

$$AL_{EL147A\_nd629}^{\;T} = \left(0.717 \quad 1.127\times10^5 \quad 8.87 \quad 629 \quad 134 \quad -1.058\times10^5 \quad -1.325\times10^4 \quad -3.653\times10^4\right)$$

$nd_{EL147A\_2} := (630)^T$

$AL_{EL147A\_nd630} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL147A\_2}, Elb\_C_o, EL\right)$

$$AL_{EL147A\_nd630}^{\;T} = \left(0.764 \quad 1.201\times10^5 \quad 9.775 \quad 630 \quad 135 \quad 1.152\times10^5 \quad 1.375\times10^4 \quad 3.079\times10^4\right)$$

Elbow 1-47B (Nodes 632 & 633)

$nd_{EL147B\_1} := (632)^T$

$AL_{EL147B\_nd632} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL147B\_1}, Elb\_C_o, EL)$

$AL_{EL147B\_nd632}^T = (0.32 \quad 5.019\times10^4 \quad 5.055 \quad 632 \quad 69 \quad -2.137\times10^3 \quad 1.89\times10^4 \quad -4.645\times10^4)$

$nd_{EL147B\_2} := (633)^T$

$AL_{EL147B\_nd633} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL147B\_2}, Elb\_C_o, EL)$

$AL_{EL147B\_nd633}^T = (0.384 \quad 6.034\times10^4 \quad 7.89 \quad 633 \quad 63 \quad 1.134\times10^3 \quad 2.752\times10^4 \quad -5.369\times10^4)$

Elbow 1-47C (Nodes 636 & 648)

$nd_{EL147C\_1} := (636)^T$

$AL_{EL147C\_nd636} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL147C\_1}, Elb\_C_o, EL)$

$AL_{EL147C\_nd636}^T = (0.369 \quad 5.788\times10^4 \quad 7.84 \quad 636 \quad 140 \quad -3.855\times10^3 \quad 5.348\times10^4 \quad -2.18\times10^4)$

$nd_{EL147C\_2} := (648)^T$

$AL_{EL147C\_nd648} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL147C\_2}, Elb\_C_o, EL)$

$AL_{EL147C\_nd648}^T = (0.34 \quad 5.342\times10^4 \quad 7.845 \quad 648 \quad 73 \quad -127.51 \quad 5.198\times10^4 \quad -1.233\times10^4)$

Elbow 1-47D (Nodes 649 & 651)

$nd_{EL147D\_1} := (649)^T$

$AL_{EL147D\_nd649} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL147D\_1}, Elb\_C_o, EL)$

$AL_{EL147D\_nd649}^T = (0.322 \quad 5.06\times10^4 \quad 8.04 \quad 649 \quad 143 \quad 2.309\times10^3 \quad -4.179\times10^4 \quad 2.844\times10^4)$

$nd_{EL147D\_2} := (651)^T$

$AL_{EL147D\_nd651} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL147D\_2}, Elb\_C_o, EL)$

$AL_{EL147D\_nd651}^T = (0.327 \quad 5.132\times10^4 \quad 8.04 \quad 651 \quad 75 \quad 3.361\times10^3 \quad -4.088\times10^4 \quad 3.084\times10^4)$

Elbow 1-47E (Nodes 661 & 662)

$nd_{EL147E\_1} := (661)^T$

$AL_{EL147E\_nd661} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL147E\_1}, Elb\_C_o, EL)$

$AL_{EL147E\_nd661}^T = (0.398 \quad 6.25\times10^4 \quad 7.87 \quad 661 \quad 152 \quad 5.424\times10^3 \quad -6.225\times10^4 \quad 1.295\times10^3)$

$nd_{EL147E\_2} := (662)^T$

$AL_{EL147E\_nd662} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL147E\_2}, Elb\_C_o, EL)$

$AL_{EL147E\_nd662}^T = (0.383 \quad 6.008\times10^4 \quad 7.87 \quad 662 \quad 153 \quad -4\times10^3 \quad 5.988\times10^4 \quad -2.694\times10^3)$

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Elbow 1-47F (Nodes 665 & 664)

$nd_{EL147F\_1} := (665)^T$

$AL_{EL147F\_nd665} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL147F\_1}, Elb\_C_o, EL)$

$AL_{EL147F\_nd665}{}^T = (0.185 \quad 2.903\times10^4 \quad 7.84 \quad 665 \quad 147 \quad -5.965\times10^3 \quad -2.827\times10^4 \quad 2.87\times10^3)$

$nd_{EL147F\_2} := (664)^T$

$AL_{EL147F\_nd664} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL147F\_2}, Elb\_C_o, EL)$

$AL_{EL147F\_nd664}{}^T = (0.164 \quad 2.575\times10^4 \quad 7.84 \quad 664 \quad 79 \quad -7.251\times10^3 \quad -2.449\times10^4 \quad 3.333\times10^3)$

Elbow 1-47G (Nodes 667 & 668)

$nd_{EL147G\_1} := (667)^T$

$AL_{EL147G\_nd667} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL147G\_1}, Elb\_C_o, EL)$

$AL_{EL147G\_nd667}{}^T = (0.405 \quad 6.367\times10^4 \quad 10.27 \quad 667 \quad 149 \quad 4.005\times10^3 \quad 6.35\times10^4 \quad -2.475\times10^3)$

$nd_{EL147G\_2} := (668)^T$

$AL_{EL147G\_nd668} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL147G\_2}, Elb\_C_o, EL)$

$AL_{EL147G\_nd668}{}^T = (0.445 \quad 6.996\times10^4 \quad 10.275 \quad 668 \quad 81 \quad 5.789\times10^3 \quad 6.874\times10^4 \quad -1.167\times10^4)$

Writing Output Data for Elbows Associated with Lines 43 and 47

$EL1A := (AL_{EL143A\_nd224}{}^T)$
$EL1B := (AL_{EL143A\_nd226}{}^T)$
$EL2A := (AL_{EL143B\_nd228}{}^T)$
$EL2B := (AL_{EL143B\_nd229}{}^T)$
$EL3A := (AL_{EL143C\_nd232}{}^T)$
$EL3B := (AL_{EL143C\_nd233}{}^T)$
$EL4A := (AL_{EL143D\_nd281}{}^T)$
$EL4B := (AL_{EL143D\_nd237}{}^T)$
$EL5A := (AL_{EL143E\_nd244}{}^T)$
$EL5B := (AL_{EL143E\_nd245}{}^T)$
$EL6A := (AL_{EL143F\_nd247}{}^T)$
$EL6B := (AL_{EL143F\_nd250}{}^T)$
$EL7A := (AL_{EL143G\_nd264}{}^T)$
$EL7B := (AL_{EL143G\_nd263}{}^T)$
$EL8A := (AL_{EL147A\_nd629}{}^T)$
$EL8B := (AL_{EL147A\_nd630}{}^T)$
$EL9A := (AL_{EL147B\_nd632}{}^T)$
$EL9B := (AL_{EL147B\_nd633}{}^T)$
$EL10A := (AL_{EL147C\_nd636}{}^T)$
$EL10B := (AL_{EL147C\_nd648}{}^T)$
$EL11A := (AL_{EL147D\_nd649}{}^T)$
$EL11B := (AL_{EL147D\_nd651}{}^T)$
$EL12A := (AL_{EL147E\_nd661}{}^T)$
$EL12B := (AL_{EL147E\_nd662}{}^T)$
$EL13A := (AL_{EL147F\_nd665}{}^T)$
$EL13B := (AL_{EL147F\_nd664}{}^T)$
$EL14A := (AL_{EL147G\_nd667}{}^T)$
$EL14B := (AL_{EL147G\_nd668}{}^T)$

vEL := (EL1A EL1B EL2A EL2B EL3A EL3B EL4A EL4B EL5A EL5B EL6A EL6B EL7A EL7B EL8A EL8B EI

ElbowLines_43_47 := WRITEPRN("ElbowLines_43_47.prn" , vEL)

FORGED TEES AND FABRICATED BRANCH TEES

Tees Strategy: *Search based on the elements comprising the tee. The input identifies which elements are associated with the pipe run and which element is associated with the branch from the run. The indices for the defined common node for all three elements is identified and the associated SRSS moment is identified for each time step. The maximum moment for the elements comprising the pipe run is found and applied as* M_r *in equation (9) of ASME III, Division I - NB - 3652 which is modified to represent tees. The maximum moment for the branch element is found and applied as* M_b *in equation (9) of ASME III, Division I - NB - 3652 [9]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{TeeDC}(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_b, M_r, Z_b, Z_r, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot T_r} + B_{2b} \cdot \left[\frac{M_b \cdot (1 \mathrm{lbf} \cdot \mathrm{in})}{Z_b}\right] + B_{2r} \cdot \left[\frac{M_r \cdot (1 \mathrm{lbf} \cdot \mathrm{in})}{Z_r}\right]}{S}$$

$\mathrm{Tee}(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S, nf, el_R, el_B, nd_R, nd_B, C_o, EL) :=$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{elR} \leftarrow \mathrm{match}\left(el_{R_0}, EL^{\langle 0 \rangle}\right)$

$\text{for } i \in 1 .. \mathrm{last}(el_R)$ if rows

$\quad ind_{elR} \leftarrow \mathrm{stack}\left[ind_{elR}, \left(\mathrm{match}\left(el_{R_i}, EL^{\langle 0 \rangle}\right)\right)\right]$

$EL'R_{\mathrm{last}\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$

$\text{for } i \in 0 .. \mathrm{last}(ind_{elR})$

$\quad EL'R_{ind_{elR_i}} \leftarrow EL_{ind_{elR_i}, 1}$

$ind_{ndR} \leftarrow \mathrm{match}\left(nd_{R_0}, EL'R^{\langle 0 \rangle}\right)$

$\text{for } i \in 1 .. \mathrm{last}(nd_R)$ if r

$\quad ind_{ndR} \leftarrow \mathrm{stack}\left[ind_{ndR}, \left(\mathrm{match}\left(nd_{R_i}, EL'R^{\langle 0 \rangle}\right)\right)\right]$

$ind_{elB} \leftarrow \mathrm{match}\left(el_{B_0}, EL^{\langle 0 \rangle}\right)$

$\text{for } i \in 1 .. \mathrm{last}(el_B)$ if rows

$\quad ind_{elB} \leftarrow \mathrm{stack}\left[ind_{elB}, \left(\mathrm{match}\left(el_{B_i}, EL^{\langle 0 \rangle}\right)\right)\right]$

$EL'B_{\mathrm{last}\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$

$\text{for } i \in 0 .. \mathrm{last}(ind_{elB})$

$\quad EL'B_{ind_{elB_i}} \leftarrow EL_{ind_{elB_i}, 1}$

$ind_{ndB} \leftarrow \mathrm{match}\left(nd_{B_0}, EL'B^{\langle 0 \rangle}\right)$

for $i \in 1 .. \text{last}(nd_B)$ if r

$ind_{ndB} \leftarrow \text{stack}\left[ind_{ndB}, \left(\text{match}\left(nd_{B_i}, EL'B^{\langle 0 \rangle}\right)\right)\right]$

$\left(M_R \;\; M_B \;\; Int_0\right) \leftarrow (0 \;\; 0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

for $j \in 0 .. \text{last}(ind_{ndR})$

for $k \in 0 .. \text{last}(ind_{ndB})$

$M_{rxgR_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{ndR_j}}$

$M_{rygR_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{ndR_j}}$

$M_{rzgR_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{ndR_j}}$

$M_{rxR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{ndR_j}} - M_{rxgR_j}\right) \cdot C$

$M_{ryR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{ndR_j}} - M_{rygR_j}\right) \cdot C$

$M_{rzR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{ndR_j}} - M_{rzgR_j}\right) \cdot C$

$M_{R_j} \leftarrow \sqrt{\left(M_{rxR_j}\right)^2 + \left(M_{ryR_j}\right)^2 + \left(M_{rzR_j}\right)^2}$

$M_{rxgB_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{ndB_k}}$

$M_{rygB_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{ndB_k}}$

$M_{rzgB_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{ndB_k}}$

$M_{rxB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{ndB_k}} - M_{rxgB_j}\right) \cdot C$

$M_{ryB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{ndB_k}} - M_{rygB_j}\right) \cdot C$

$M_{rzB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{ndB_k}} - M_{rzgB_j}\right) \cdot C$

$M_{B_j} \leftarrow \sqrt{\left(M_{rxB_j}\right)^2 + \left(M_{ryB_j}\right)^2 + \left(M_{rzB_j}\right)^2}$

$Int'_j \leftarrow \text{TeeDC}\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_{B_j}, M_R\right.$

if $Int'_j > Int_0$

$Int \leftarrow \text{stack}\left(Int'_j, M_{R_j}, M_{B_j}, nf_{ind_{nfiC_{o_{0,1}}}-1+i}\right.$

$\text{Result} \leftarrow \text{stack}\left(M_{R_j}, M_{B_j}, M_{rxR_j}, M_{ryR_j}, M\right.$

$M \leftarrow M_R$

Int

Conditions applicable to forged tee

$M_{ox} := 0 \quad M_{oy} := 0 \quad M_{oz} := 0$

Defining place holding directional moment variables

$$Tee\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

TEES (Line 1-43 and Lines 1-46 & 1-47 attached to Line 1-43)

Define pertinent tee variables

$P := 253\,psi$ — Internal Pressure [3, pg 23]

$D_o := 10.75\,in$ — Outside Diameter of Pipe Run [11]

$d_o := 6.625\,in$ — Outside Diameter of Branch [11]

$B_1 := 0.5$ — B_1 primary stress Index for tees and branches [9, NB-3683.9]

$T_r := 0.25\,in$ — Nominal wall thickness of designated run pipe [11]

$R_m := \dfrac{D_o - T_r}{2}$ — Mean radius of designated run pipe

$Z_r := \pi \cdot R_m^{\,2} \cdot T_r$ — Approximate section modulus of designated run pipe [9, NB-3683.1(d)]

$Z_r = 21.6475\,in^3$

$T'_b := 0.28\,in$ — Nominal wall thickness of attached branch pipe [11]

$r'_m := \dfrac{d_o - T'_b}{2}$ — Mean radius of attached branch pipe

$Z_b := \pi \cdot r'^{\,2}_m \cdot T'_b$ — Approximate section modulus of attached branch pipe [9, NB-3683.1(d)]

$Z_b = 8.853\,in^3$

C_{2b} Secondary stress Index [9,NB-3683.8]

$$C_{2b} := \begin{cases} 1.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}}\left(\frac{r'_m}{R_m}\right)^{\frac{1}{2}}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{\frac{d_o}{2}}\right) & \text{if } 1.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}}\left(\frac{r'_m}{R_m}\right)^{\frac{1}{2}}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{\frac{d_o}{2}}\right) \ge 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$$C_{2b} = 9.52$$

C_{2r} Secondary stress Index [9,NB-3683.8]

$t_n := T'_b$

Wall thickness of nozzle or branch connection reinforcement associated with [9, NB-3643.4(A)-1, sketch (d)]

$$C_{2r} := \begin{cases} 1.15\cdot\left(\frac{r'_m}{t_n}\right)^{\frac{1}{4}} & \text{if } 1.15\cdot\left(\frac{r'_m}{t_n}\right)^{\frac{1}{4}} \ge 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$$C_{2r} = 2.11$$

$$B_{2b} := \begin{cases} 0.5\cdot C_{2b} & \text{if } 0.5\cdot C_{2b} \ge 1 \\ 1 & \text{otherwise} \end{cases}$$

$$B_{2b} = 4.76$$

B_{2b} primary stress Index for branches [9, NB-3683.8]

$$B_{2r} := \begin{cases} 0.75\cdot C_{2r} & \text{if } 0.75\cdot C_{2r} \ge 1 \\ 1 & \text{otherwise} \end{cases}$$

$$B_{2r} = 1.582$$

B_{2r} primary stress Index for branches [9, NB-3683.8]

Tee 1-43 (Node 238)

$elR_{Tee143} := (181\ \ 270)^T$ Elements associated with pipe run

$ndR_{Tee143} := (238)^T$ Node between pipe run elements

$elB_{Tee143} := (225)^T$ Element associated with branch

$ndB_{Tee143} := (238)^T$ Node where branch intersects pipe run

$AL_{Tee143} := Tee\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF, elR_{Tee143}, elB_{Tee143}, ndR_{Tee143}, ndB_{Tee143}, Tee\_C\right.$

$$AL_{Tee143}{}^T = \left(1.224\ \ 1.588\times10^5\ \ 1.025\times10^5\ \ 15.185\ \ 238\ \ 21\ \ 55\ \ 49\right)$$

Tee 1-46 (Node 230)

$elR_{Tee146} := (170 \;\; 171)^T$ Elements associated with pipe run

$ndR_{Tee146} := (230)^T$ Node between pipe run elements

$elB_{Tee146} := (212)^T$ Element associated with branch

$ndB_{Tee146} := (230)^T$ Node where branch intersects pipe run

$AL_{Tee146} := Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF, elR_{Tee146}, elB_{Tee146}, ndR_{Tee146}, ndB_{Tee146}, Tee\_C$

$$AL_{Tee146}^T = (1.15 \;\; 1.34 \times 10^5 \;\; 9.805 \times 10^4 \;\; 9.175 \;\; 230 \;\; 6 \;\; 7 \;\; 47)$$

Tee 1-47 (Node 261)

$elR_{Tee147} := (176 \;\; 177)^T$ Elements associated with pipe run

$ndR_{Tee147} := (261)^T$ Node between pipe run elements

$elB_{Tee147} := (271)^T$ Element associated with branch

$ndB_{Tee147} := (261)^T$ Node where branch intersects pipe run

$AL_{Tee147} := Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF, elR_{Tee147}, elB_{Tee147}, ndR_{Tee147}, ndB_{Tee147}, Tee\_C$

$$AL_{Tee147}^T = (1.809 \;\; 9.799 \times 10^4 \;\; 1.724 \times 10^5 \;\; 9.585 \;\; 261 \;\; 15 \;\; 18 \;\; 57)$$

Writing Output Data for Tees Associated with Lines 1-43 & 1-47

$Tee1 := (AL_{Tee143}^T)$

$Tee2 := (AL_{Tee146}^T)$

$Tee3 := (AL_{Tee147}^T)$

$Tee := (Tee1 \;\; Tee2 \;\; Tee3)$

TeeLines_43_47 := WRITEPRN("TeeLines_43_47.prn" , Tee)

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FLANGES

Flange Strategy: *Search based on the nodes where flanges occur. Find the maximum moment combination for the node and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\text{FlangeDC}\left(P, D_o, t, I, B_1, B_2, M, S\right) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1 \text{lbf} \cdot \text{in})]}{S}$$

$\text{Flange}\left(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL\right) :=$

$ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \text{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

$\text{for } i \in 1 .. \text{last}(nd) \quad \text{if rows}(nd) > 1$

$\quad ind_{nd} \leftarrow \text{stack}\left[ind_{nd}, \left(\text{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$\left(M \;\; Int_0\right) \leftarrow (0 \;\; 0)$

$\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

$\quad \text{for } j \in 0 .. \text{last}\left(ind_{nd}\right)$

$\quad\quad M_{rxg} \leftarrow nf_{ind_{nfi}C_{o_{0,1}}+2,\, ind_{nd_j}}$

$\quad\quad M_{ryg} \leftarrow nf_{ind_{nfi}C_{o_{1,1}}+2,\, ind_{nd_j}}$

$\quad\quad M_{rzg} \leftarrow nf_{ind_{nfi}C_{o_{2,1}}+2,\, ind_{nd_j}}$

$\quad\quad M_{rx} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

$\quad\quad M_{ry} \leftarrow \left(nf_{ind_{nfi}C_{o_{1,1}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

$\quad\quad M_{rz} \leftarrow \left(nf_{ind_{nfi}C_{o_{2,1}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

$\quad\quad M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

$\quad\quad Int'_j \leftarrow \text{FlangeDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$

$\quad\quad \text{if } Int'_j > Int_0$

$\quad\quad\quad Int \leftarrow \text{stack}\left(Int'_j, M'_j, nf_{ind_{nfi}C_{o_{0,1}}-1+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M\right.$

$\quad\quad\quad Result \leftarrow M'$

Int

Conditions applicable to all flanges

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$ Defining place holding variables

$$Flange\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties of Lines 1-43

Define pertinent pipe variables

$D_o := 10.75 in$ Outside Diameter [11]

$t := 0.25 in$ Thickness [11]

$P := 253 psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t \right)^4 \right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 113.714\ in^4$

Define primary stress indices (Utilize girth weld characteristic associated with lap joint flanges in determining values)

$B_1 := 0.5$ B_1 for a girth weld [9, Table NB-3681(a)-1, pg 130]

$B_2 := 1$ B_2 for a girth weld [9, Table NB-3681(a)-1, pg 130]

Flange (Gate Valve) 1-43A (Node 234)

$nd_{FL143A} := (234)^T$

$AL_{FL143A} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL143A}, Flange\_C_o, EL\right)$

$$AL_{FL143A}^{\ T} = \begin{pmatrix} 0.13 & 9.79 \times 10^4 & 9.595 & 234 & 17 & -8.9 \times 10^4 & -3.468 \times 10^4 & -2.146 \times 10^4 \end{pmatrix}$$

Flange (Gate Valve) 1-43B (Node 235)

$nd_{FL143B} := (235)^T$

$AL_{FL143B} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL143B}, Flange\_C_o, EL\right)$

$$AL_{FL143B}^{\ T} = \begin{pmatrix} 0.136 & 1.052 \times 10^5 & 9.33 & 235 & 45 & 2.997 \times 10^4 & -9.943 \times 10^4 & 1.653 \times 10^4 \end{pmatrix}$$

Flange (Gate Valve) 1-43C (Node 239)

$nd_{FL143C} := (239)^T$

$AL_{FL143C} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL143C}, Flange\_C_o, EL)$

$AL_{FL143C}^T = (0.168 \quad 1.44\times10^5 \quad 15.565 \quad 239 \quad 25 \quad 5.878\times10^4 \quad -1.733\times10^4 \quad 1.304\times10^5)$

Flange (Gate Valve) 1-43D (Node 240)

$nd_{FL143D} := (240)^T$

$AL_{FL143D} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL143D}, Flange\_C_o, EL)$

$AL_{FL143D}^T = (0.167 \quad 1.431\times10^5 \quad 15.565 \quad 240 \quad 28 \quad 5.879\times10^4 \quad -1.77\times10^4 \quad 1.292\times10^5)$

Flange (Gate Valve) 1-43E (Node 241)

$nd_{FL143E} := (241)^T$

$AL_{FL143E} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL143E}, Flange\_C_o, EL)$

$AL_{FL143E}^T = (0.124 \quad 9.111\times10^4 \quad 9.84 \quad 241 \quad 178 \quad 5.751\times10^4 \quad -6.883\times10^4 \quad 1.598\times10^4)$

Flange (Gate Valve) 1-43F (Node 242)

$nd_{FL143F} := (242)^T$

$AL_{FL143F} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL143F}, Flange\_C_o, EL)$

$AL_{FL143F}^T = (0.13 \quad 9.824\times10^4 \quad 9.84 \quad 242 \quad 160 \quad 5.775\times10^4 \quad -7.872\times10^4 \quad -1.098\times10^4)$

Flange (Gate Valve) 1-43G (Node 249)

$nd_{FL143G} := (249)^T$

$AL_{FL143G} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL143G}, Flange\_C_o, EL)$

$AL_{FL143G}^T = (0.191 \quad 1.718\times10^5 \quad 5.405 \quad 249 \quad 53 \quad 5.355\times10^4 \quad -1.248\times10^5 \quad 1.051\times10^5)$

Flange (Gate Valve) 1-43H (Node 934)

$nd_{FL143H} := (934)^T$

$AL_{FL143H} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL143H}, Flange\_C_o, EL)$

$AL_{FL143H}^T = (0.192 \quad 1.727\times10^5 \quad 5.405 \quad 934 \quad 167 \quad 5.355\times10^4 \quad -1.252\times10^5 \quad 1.063\times10^5)$

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Pipe Properties of Line 1-47

Define pertinent pipe variables

$D_o := 6.625\,in$ — Outside Diameter [15] [16]

$t := 0.28\,in$ — Thickness [15] [16]

$P := 253\,psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$ — Moment of inertia [8, Table 17-27, pg 17-39]

$I = 28.142\,in^4$

Define primary stress indices (Utilize girth weld characteristic associated with lap joint flanges in determining values)

$B_1 := 0.5$ — B_1 for a girth weld [9, Table NB-3681(a)-1, pg 130]

$B_2 := 1$ — B_2 for a girth weld [9, Table NB-3681(a)-1, pg 130]

Flange (Gate Valve) 1-47A (Node 634)

$nd_{FL147A} := (634)^T$

$AL_{FL147A} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL147A}, Flange\_C_o, EL\right)$

$AL_{FL147A}^{\ T} = \left(0.157 \quad 6.287\times10^4 \quad 7.89 \quad 634 \quad 93 \quad 7.031\times10^3 \quad 3.465\times10^4 \quad -5.198\times10^4\right)$

Flange (Gate Valve) 1-47B (Node 635)

$nd_{FL147B} := (635)^T$

$AL_{FL147B} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL147B}, Flange\_C_o, EL\right)$

$AL_{FL147B}^{\ T} = \left(0.142 \quad 5.59\times10^4 \quad 7.845 \quad 635 \quad 65 \quad -2.76\times10^3 \quad 5.057\times10^4 \quad -2.367\times10^4\right)$

Writing Output Data for Flanges Associated with Lines 43 and 47

$F1 := \left(AL_{FL143A}^{\ T}\right)$ $F6 := \left(AL_{FL143F}^{\ T}\right)$

$F2 := \left(AL_{FL143B}^{\ T}\right)$ $F7 := \left(AL_{FL143G}^{\ T}\right)$

$F3 := \left(AL_{FL143C}^{\ T}\right)$ $F8 := \left(AL_{FL143H}^{\ T}\right)$

$F4 := \left(AL_{FL143D}^{\ T}\right)$ $F9 := \left(AL_{FL147A}^{\ T}\right)$

$F5 := \left(AL_{FL143E}^{\ T}\right)$ $F10 := \left(AL_{FL147B}^{\ T}\right)$

$F := (F1 \quad F2 \quad F3 \quad F4 \quad F5 \quad F6 \quad F7 \quad F8 \quad F9 \quad F10)$

FlangeLines_43_47 := WRITEPRN("FlangeLines_43_47.prn" , F)

Appendix C.3.5

Demand to Capacity Ratio Calculations for Components Associated with Lines 1-44, 1-46, and 8-14 of ATR PCS Model 265

(NOTE: Values represented here are shown for one realization (Nodal Force file = LINES_44_46_814_test_R1.dat and Element/Nodal order file = EL_44_46_814.xls) and may or may not be consistent with the 80th percentile results contained in Appendix C.4)

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Force Outputs from Abaqus

NF := ..\LINES_44_46_814.dat

(N)odal (F)orces for the (M)edium (L)ines of Model 3

Defined Elemental and Corresponding Nodal Order

EL := ..\EL_44_46_814(9-22-08).xls

Element and corresponding nodal order for the (M)edium (L)ines of Model 3

Time Boundaries

$t_{initial} := 1$

Initial time for which dynamic loading is applied

$t_{final} := 21$

Final time for which dynamic loading stops

Seismic Scale Factor (F_a)

$F_a := 1$

Seismic scale factor [30]

Allowable Design Stress Intensity Factor (S_m): *S_m is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{m\_125} := 20ksi$

For SS304 at 125°F [2, pg 316-318] [3, pg 23]

$S_{m\_125L} := 16.7ksi$

For SS304L at 125°F [2, pg 316-318] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Yield Strength (S_y): *S_y is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{y\_125} := 28.35ksi$

For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_125L} := 23.85ksi$

For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Maximum Strength Applicable for Equation 9 (S): *S is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{125} := \min(3 \cdot S_{m\_125}, 2 \cdot S_{y\_125})$

$\boxed{S_{125} = 56.7\,ksi}$

Maximum allowable stress applied to SS304 piping [9, NB-3656]

$S_{125L} := \min(3 \cdot S_{m\_125L}, 2 \cdot S_{y\_125L})$

$\boxed{S_{125L} = 47.7\,ksi}$

Maximum allowable stress applied to SS304L piping [9, NB-3656]

SUPPORTS

Supports Strategy: *Search based on the node for which the support acts. If this node is a termination point there will only be one node to evaluate. If this node is in line with a section of pipe there will be two representations of the same node (one for each element on each side of the node) to combine and the difference between them is the force required of the support. The D/C ratio for each support will be found by dividing the the required force found above by the support capacity.*

$$SupDC(P_r, P_c) := \frac{P_r}{P_c}$$

$$Support(nf, nd, C_o, EL) :=$$

$ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow match\left(nd_0, EL^{\langle 1 \rangle}\right)$

$\text{for } i \in 1 .. last(nd)$ $\quad \text{if } rows(nd) > 1$

$\quad ind_{nd} \leftarrow stack\left[ind_{nd}, \left(match\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$\begin{pmatrix} Int_{1_4} & Int_{2_4} \end{pmatrix} \leftarrow (0 \quad 0)$

$\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

$\quad \text{for } j \in 0 .. last\left(ind_{nd}\right)$

$\quad\quad P_{rg_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}-1,\, ind_{nd_j}}$

$\quad\quad P_{r_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}-1+i,\, ind_{nd_j}} - P_{rg_j}\right) \cdot C_{o_{2,0}} + P_{rg_j}$

$\quad PR_i \leftarrow \sum_{n=0}^{j} P_{r_n}$

$\quad \text{if } PR_i < Int_{1_1} \wedge C_{o_{0,0}} \neq 0$

$\quad\quad Int_{1'} \leftarrow SupDC\left(\left|PR_i\right|, C_{o_{0,0}}\right)$

$\quad\quad Int_1 \leftarrow stack\left(Int_{1'}, PR_i, nf_{ind_{nfiC_{o_{0,1}}}-1+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd}\right)$

$\quad \text{if } PR_i > Int_{2_1} \wedge C_{o_{1,0}} \neq 0$

$\quad\quad Int_{2'} \leftarrow SupDC\left(\left|PR_i\right|, C_{o_{1,0}}\right)$

$\quad\quad Int_2 \leftarrow stack\left(Int_{2'}, PR_i, nf_{ind_{nfiC_{o_{0,1}}}-1+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd}\right)$

$\begin{pmatrix} Int_1 & Int_2 \end{pmatrix}$

RH-22A Support (x)

$P_{1\_RH22A} := \frac{0.524 \cdot kip}{lbf}$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_RH22A} := \frac{0.691 \cdot kip}{lbf}$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_RH22A} := \begin{pmatrix} P_{1\_RH22A} & 2 \\ P_{2\_RH22A} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

RH-22A (Node 931)

RH-22A vertically supports line 1-44 just south of T(1-44) from any downward movement.

$nd931_{RH22A_0} := 931$ Node associated with support

$$\left(AL1_{RH22A\_nd931} \quad AL2_{RH22A\_nd931}\right) := Support\left(NF, nd931_{RH22A}, Sup\_C_{o\_RH22A}, EL\right)$$

$$AL1_{RH22A\_nd931}^{T} = \left(7.191 \times 10^{-4} \quad -0.377 \quad 5.785 \quad 931 \quad 115\right)$$

$$AL2_{RH22A\_nd931}^{T} = \left(3.333 \times 10^{-3} \quad 2.303 \quad 9.635 \quad 931 \quad 115\right)$$

/C,demand force, occurrence time, fined node, associated index for the reaction force at the selected node eing in the positive (AL1) and negative AL2) directions of the global coordinate system)

RH-22B Support (x)

$P_{1\_RH22B} := \frac{0.524 \cdot kip}{lbf}$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_RH22B} := \frac{5.32 \cdot kip}{lbf}$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_RH22B} := \begin{pmatrix} P_{1\_RH22B} & 2 \\ P_{2\_RH22B} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

RH-22B (Node 930)

RH-22B vertically supports line 1-44 just south of EL(1-44B) from any downward movement.

$nd930_{RH22B_0} := 930$ Node associated with support

$$\left(AL1_{RH22B\_nd930} \quad AL2_{RH22B\_nd930}\right) := Support\left(NF, nd930_{RH22B}, Sup\_C_{o\_RH22B}, EL\right)$$

$$AL1_{RH22B\_nd930}^{T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0\right)$$

$$AL2_{RH22B\_nd930}^{T} = \left(2.347 \times 10^{-4} \quad 1.248 \quad 5.73 \quad 930 \quad 117\right)$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

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PS-7 Support (1x)

$P_{1\_PS7\_NS} := \frac{6.686 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_PS7\_NS} := \frac{3.37 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$Sup\_C_{o\_PS7\_NS} := \begin{pmatrix} P_{1\_PS7\_NS} & 1 \\ P_{2\_PS7\_NS} & 0 \\ F_a & 0 \end{pmatrix}$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

$P_{1\_PS7\_V} := \frac{2.2 \cdot kip}{lbf}$ ***Flexure*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_PS7\_V} := \frac{2.2 \cdot kip}{lbf}$ ***Flexure*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$Sup\_C_{o\_PS7\_V} := \begin{pmatrix} P_{1\_PS7\_V} & 2 \\ P_{2\_PS7\_V} & 0 \\ F_a & 0 \end{pmatrix}$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

PS-7 (NS) (Node 608)

PS-7 supports line 1-44 at the bottom portion of P(1-44G) from movement in the vertical and east/west directions.

$nd608_{PS7X_0} := 608$ Node associated with support

$\left(AL1_{PS7X\_nd608} \;\; AL2_{PS7X\_nd608}\right) := Support\left(NF, nd608_{PS7X}, Sup\_C_{o\_PS7\_NS}, EL\right)$

$AL1_{PS7X\_nd608}^{\,T} = \left(0.154 \;\; -1.033 \times 10^3 \;\; 4.84 \;\; 608 \;\; 109\right)$

$AL2_{PS7X\_nd608}^{\,T} = \left(0.296 \;\; 998.455 \;\; 6.005 \;\; 608 \;\; 109\right)$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PS-7 (V) (Node 608)

PS-7 supports line 1-44 at the bottom portion of P(1-44G) from movement in the vertical and east/west directions.

$nd608_{PS7Y_0} := 608$ Node associated with support

$\left(AL1_{PS7Y\_nd608} \;\; AL2_{PS7Y\_nd608}\right) := Support\left(NF, nd608_{PS7Y}, Sup\_C_{o\_PS7\_V}, EL\right)$

$AL1_{PS7Y\_nd608}^{\,T} = \left(1.746 \;\; -3.841 \times 10^3 \;\; 5.29 \;\; 608 \;\; 109\right)$

$AL2_{PS7Y\_nd608}^{\,T} = \left(0 \;\; 0 \;\; 0 \;\; 0 \;\; 0\right)$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

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RH-16 Support (2x)

$P_{1\_RH16} := \frac{1.047 \cdot kip}{lbf}$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_RH16} := \frac{0.397 \cdot kip}{lbf}$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_RH16} := \begin{pmatrix} P_{1\_RH16} & 2 \\ P_{2\_RH16} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

RH-16A (Node 606)

RH-16A vertically supports line 1-44 just east of EL(1-44D) from any downward movement.

$nd606_{RH16A_0} := 606$ Node associated with support

$$\left(AL1_{RH16A\_nd606} \;\; AL2_{RH16A\_nd606}\right) := Support\left(NF, nd606_{RH16A}, Sup\_C_{o\_RH16}, EL\right)$$

$$AL1_{RH16A\_nd606}^{\;T} = \begin{pmatrix} 0.882 & -923.918 & 5.5 & 606 & 64 \end{pmatrix}$$

$$AL2_{RH16A\_nd606}^{\;T} = \begin{pmatrix} 0.897 & 355.988 & 5.3 & 606 & 64 \end{pmatrix}$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-16B (Node 605)

RH-16B vertically supports line 1-44 just south of EL(1-44E) from any downward movement.

$nd605_{RH16B_0} := 605$ Node associated with support

$$\left(AL1_{RH16B\_nd605} \;\; AL2_{RH16B\_nd605}\right) := Support\left(NF, nd605_{RH16B}, Sup\_C_{o\_RH16}, EL\right)$$

$$AL1_{RH16B\_nd605}^{\;T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

$$AL2_{RH16B\_nd605}^{\;T} = \begin{pmatrix} 8.804 \times 10^{-3} & 3.495 & 5.26 & 605 & 62 \end{pmatrix}$$

RH-26x Support (1x)

$P_{1\_RH26x} := \frac{28.14 \cdot kip}{lbf}$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_RH26x} := \frac{0 \cdot kip}{lbf}$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_RH26x} := \begin{pmatrix} P_{1\_RH26x} & 2 \\ P_{2\_RH26x} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

RH-26x (Node 222)

RH-26x vertically supports line 8-14 south of EL(8-14B) from any downward movement.

$$nd222_{RH26x_0} := 222$$

Node associated with support

$$\left(AL1_{RH26x\_nd222} \quad AL2_{RH26x\_nd222}\right) := Support\left(NF, nd222_{RH26x}, Sup\_C_{o\_RH26x}, EL\right)$$

$$AL1_{RH26x\_nd222}{}^{T} = \begin{pmatrix} 0.039 & -1.107 \times 10^{3} & 8.535 & 222 & 65 \end{pmatrix}$$

$$AL2_{RH26x\_nd222}{}^{T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-13 Support (2x)

$$P_{1\_RH13} := \frac{14.91 \cdot kip}{lbf}$$

Tension

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$$P_{2\_RH13} := \frac{6.123 \cdot kip}{lbf}$$

Compression

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_RH13} := \begin{pmatrix} P_{1\_RH13} & 2 \\ P_{2\_RH13} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

RH-13A (Node 822)

RH-13A vertically supports line 8-14 west of EL(8-14B) from any downward movement.

$$nd822_{RH13A_0} := 822$$

Node associated with support

$$\left(AL1_{RH13A\_nd822} \quad AL2_{RH13A\_nd822}\right) := Support\left(NF, nd822_{RH13A}, Sup\_C_{o\_RH13}, EL\right)$$

$$AL1_{RH13A\_nd822}{}^{T} = \begin{pmatrix} 0.094 & -1.397 \times 10^{3} & 5.43 & 822 & 72 \end{pmatrix}$$

$$AL2_{RH13A\_nd822}{}^{T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate

system)

RH-13B (Node 820)

RH-13A vertically supports line 8-14 east of Fab Branch(1-30) from any downward movement.

$nd820_{RH13B_0} := 820$ Node associated with support

$\left(AL1_{RH13B\_nd820} \quad AL2_{RH13B\_nd820}\right) := Support\left(NF, nd820_{RH13B}, Sup\_C_{o\_RH13}, EL\right)$

$AL1_{RH13B\_nd820}{}^T = \left(0.132 \quad -1.962\times10^3 \quad 6.83 \quad 820 \quad 70\right)$

$AL2_{RH13B\_nd820}{}^T = \left(0 \quad 0 \quad 0 \quad 0 \quad 0\right)$

Writing Output Data for Supports Associated with Lines 44, 46, and 8-14

$SA1 := AL1_{RH22A\_nd931}{}^T$

$SA2 := AL2_{RH22A\_nd931}{}^T$

$SB1 := AL1_{RH22B\_nd930}{}^T$

$SB2 := AL2_{RH22B\_nd930}{}^T$

$SC1 := AL1_{PS7X\_nd608}{}^T$

$SC2 := AL2_{PS7X\_nd608}{}^T$

$SD1 := AL1_{PS7Y\_nd608}{}^T$

$SD2 := AL2_{PS7Y\_nd608}{}^T$

$SE1 := AL1_{RH16A\_nd606}{}^T$

$SE2 := AL2_{RH16A\_nd606}{}^T$

$SF1 := AL1_{RH16B\_nd605}{}^T$

$SF2 := AL2_{RH16B\_nd605}{}^T$

$SG1 := AL1_{RH26x\_nd222}{}^T$

$SG2 := AL2_{RH26x\_nd222}{}^T$

$SH1 := AL1_{RH13A\_nd822}{}^T$

$SH2 := AL2_{RH13A\_nd822}{}^T$

$SI1 := AL1_{RH13B\_nd820}{}^T$

$SI2 := AL2_{RH13B\_nd820}{}^T$

$S := (SA1 \quad SA2 \quad SB1 \quad SB2 \quad SC1 \quad SC2 \quad SD1 \quad SD2 \quad SE1 \quad SE2 \quad SF1 \quad SF2 \quad SG1 \quad SG2 \quad SH1 \quad SH2 \quad SI1 \quad SI2)$

SupportsLines_44_46_814 := WRITEPRN("SupLines_44_46_814.prn" , S)

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TERMINATION LOCATIONS

Termination Locations Strategy: *Search based on the node for which the termination location acts as well as the next node inward. The D/C ratio for each termination location will be found by dividing the the required force found above by the support capacity.*

$$\mathrm{TermDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\,\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$$\mathrm{Term}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$$

```
ind_nfi ← match(t_initial, nf^<0>)
ind_nfo ← match(t_final, nf^<0>)
ind_nd ← match(nd_0, EL^<1>)
for i ∈ 1 .. last(nd)                                   if rows(nd) > 1
   ind_nd ← stack[ind_nd, (match(nd_i, EL^<1>))]
(M  Int_0) ← (0  0)
for i ∈ 0 .. ind_nfo_0 − ind_nfi_0
   for j ∈ 0 .. last(ind_nd)
      M_rxg ← nf_{ind_nfiC_o_{0,1}+2, ind_nd_j}
      M_ryg ← nf_{ind_nfiC_o_{1,1}+2, ind_nd_j}
      M_rzg ← nf_{ind_nfiC_o_{2,1}+2, ind_nd_j}
      M_rx ← (nf_{ind_nfiC_o_{0,1}+2+i, ind_nd_j} − M_rxg)·C_o_{3,0} + M_rxg
      M_ry ← (nf_{ind_nfiC_o_{1,1}+2+i, ind_nd_j} − M_ryg)·C_o_{3,0} + M_ryg
      M_rz ← (nf_{ind_nfiC_o_{2,1}+2+i, ind_nd_j} − M_rzg)·C_o_{3,0} + M_rzg
      M'_j ← sqrt(M_rx^2 + M_ry^2 + M_rz^2)
      Int'_j ← TermDC(P, D_o, t, I, B_1, B_2, M'_j, S)
      if Int'_j > Int_0
         Int ← stack(Int'_j, M'_j, nf_{ind_nfiC_o_{0,1}−1+i, 0}, EL_{ind_nd_j, 1}, ind_nd_j, M_rx, M_ry, M_r
         Result ← M'
Int
```

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Conditions applicable to all terminations

$M_{cx} := 0 \qquad M_{cy} := 0 \qquad M_{cz} := 0$

Defining place holding variables

$$Term\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

West Floor Penetration 1-44 (1x)

Define pertinent pipe variables

$D_o := 6.625 in$ — Outside Diameter [12] [13]

$t := 0.28 in$ — Thickness [12] [13]

$P := 253 psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

$$I = 28.142\, in^4$$

Moment of inertia [8, Table 17-27, pg 17-39]

$S := S_{125}$ — Allowable design stress intensity value

Define primary stress indices

$B_1 := 0.5$

$$B_2 := \left| \begin{array}{l} 1.0 \ \text{ if } \ \frac{D_o}{t} \le 50 \\ \text{if } \ \frac{D_o}{t} > 50 \\ \quad \left| \begin{array}{l} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \frac{D_o}{t}\right) \\ Y \leftarrow 1 \\ 1.0 \cdot \frac{1}{X \cdot Y} \end{array} \right. \end{array} \right. \qquad B_2 = 1$$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

West Floor Penetration 1-44 (Node 345)

$nd345_{WFP144_0} := 345$

$AL_{WFP144\_nd345} := Term\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd345_{WFP144}, Term\_C_o, EL\right)$

$$AL_{WFP144\_nd345}^{\,T} = \begin{pmatrix} 0.123 & 4.664 \times 10^4 & 5.99 & 345 & 97 & -2.638 \times 10^3 & 1.293 \times 10^3 & 4.654 \times 10^4 \end{pmatrix}$$

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East Ceiling Penetration 8-14 (1x)

Define pertinent pipe variables

$D_o := 10.75\,in$ — Outside Diameter [19]

$t := 0.25\,in$ — Thickness [19]

$P := 253\,psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

$I = 113.714\,in^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$S := S_{125}$ — Allowable design stress intensity value

Define primary stress indices

$B_1 := 0.5$

$$B_2 := \begin{cases} 1.0 \text{ if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 \\ \quad T \leftarrow 125 \\ \quad X \leftarrow \min\left(1, 1.3 - 0.006\cdot\frac{D_o}{t}\right) \\ \quad Y \leftarrow 1 \\ \quad 1.0\cdot\frac{1}{X\cdot Y} \end{cases}$$

$B_2 = 1$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

East Ceiling Penetration 8-14 (Node 888)

$nd888_{ECP814_0} := 888$

$AL_{ECP814\_nd888} := Term\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd888_{ECP814}, Term\_C_o, EL\right)$

$$AL_{ECP814\_nd888}^{\;T} = \left(0.097 \quad 5.862\times10^4 \quad 10.625 \quad 888 \quad 68 \quad -1.209\times10^3 \quad -5.832\times10^4 \quad -5.792\times10^3\right)$$

Writing Output Data for Terminations Associated with Lines 1-44, 1-46, & 8-14

$T1 := \left(AL_{WFP144\_nd345}^{\;T}\right)$ — West Floor Penetration 1-44 (Node 345)

$T2 := \left(AL_{ECP814\_nd888}^{\;T}\right)$ — East Ceiling Penetration 8-14 (Node 888)

$T := (T1 \quad T2)$

TerminationsLines_44_46_814 := WRITEPRN("TermLines_44_46_814.prn" , T)

PIPE RUNS

Pipe Runs Strategy: *Search based on the nodes present in each run of pipe. Find the maximum moment combination among all of the nodes and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{PipeRunDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{PipeRun}(P, D_o, t, I, B_1, B_2, S, nf, el, C_o, EL) :=$

$ind_{nfi} \leftarrow \mathrm{match}(t_{initial}, nf^{\langle 0 \rangle})$

$ind_{nfo} \leftarrow \mathrm{match}(t_{final}, nf^{\langle 0 \rangle})$

$ind_{el} \leftarrow \mathrm{match}(el_0, EL^{\langle 0 \rangle})$

for $i \in 1 .. \mathrm{last}(el)$ if $\mathrm{rows}(el) > 1$

  $ind_{el} \leftarrow \mathrm{stack}[ind_{el}, (\mathrm{match}(el_i, EL^{\langle 0 \rangle}))]$

$(M \;\; Int_{5, \mathrm{last}(ind_{el})}) \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \mathrm{last}(ind_{el})$

    $M_{rxg} \leftarrow nf_{ind_{nfi}{C_o}_{0,1}+2,\, ind_{el_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi}{C_o}_{1,1}+2,\, ind_{el_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi}{C_o}_{2,1}+2,\, ind_{el_j}}$

    $M_{rx_j} \leftarrow \left(nf_{ind_{nfi}{C_o}_{0,1}+2+i,\, ind_{el_j}} - M_{rxg}\right) \cdot {C_o}_{3,0} + M_{rxg}$

    $M_{ry_j} \leftarrow \left(nf_{ind_{nfi}{C_o}_{1,1}+2+i,\, ind_{el_j}} - M_{ryg}\right) \cdot {C_o}_{3,0} + M_{ryg}$

    $M_{rz_j} \leftarrow \left(nf_{ind_{nfi}{C_o}_{2,1}+2+i,\, ind_{el_j}} - M_{rzg}\right) \cdot {C_o}_{3,0} + M_{rzg}$

    $M'_j \leftarrow \sqrt{(M_{rx_j})^2 + (M_{ry_j})^2 + (M_{rz_j})^2}$

    $Int'_j \leftarrow \mathrm{PipeRunDC}(P, D_o, t, I, B_1, B_2, M'_j, S)$

    if $Int'_j > Int_{0,j}$

      $H \leftarrow \left(Int'_j \;\; M'_j \;\; nf_{ind_{nfi}{C_o}_{0,1}-1+i,0} \;\; EL_{ind_{el_j},0} \;\; EL_{ind_{el_j},1} \;\; ind_{el_j} \;\; M_r\right.$

      for $k \in 0 .. 5$

$Int_{k,j} \leftarrow H_k$

Int

Conditions applicable to all pipe runs

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$

Defining place holding directional moment variables

$$PipeRun\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties for Line 1-44

Define pertinent pipe variables

$D_o := 16in$ Outside Diameter [12] [13]

$t := 0.25in$ Thickness [12] [13]

$P := 253psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 383.664\ in^4$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{vmatrix} 1.0 \ \text{if} \ \frac{D_o}{t} \le 50 \\ \text{if} \ \frac{D_o}{t} > 50 \\ \quad \begin{vmatrix} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006\cdot\frac{D_o}{t}\right) \\ Y \leftarrow 1.033 - 0.00033\cdot T \\ 1.0\cdot\frac{1}{X\cdot Y} \end{vmatrix} \end{vmatrix}$$

$B_{2PR} = 1.101$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-44A (Element 224)

$el_{P144A} := (224)^T$

$AL_{P144A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P144A}, PipeRun\_C_o, EL\right)$

$$AL_{P144A}^{\,T} = \begin{pmatrix} 0.11 & 9.574\times10^4 & 10.325 & 224 & 301 & 25 \\ 0.109 & 9.275\times10^4 & 10.325 & 224 & 305 & 26 \end{pmatrix}$$

Pipe Run 1-44B (Elements 228, 711, 712, 713, & 263)

$el_{P144B} := (228\ \ 711\ \ 712\ \ 713\ \ 263)^T$

$AL_{P144B} := \text{PipeRun}\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P144B}, \text{PipeRun\_C}_o, EL\right)$

$AL_{P144B}^T =$

	0	1	2	3	4	5
0	0.109	$9.176\cdot10^4$	5.685	228	302	27
1	0.103	$7.687\cdot10^4$	5.68	228	$1.113\cdot10^3$	28
2	0.103	$7.687\cdot10^4$	5.68	711	$1.113\cdot10^3$	120
3	0.097	$6.387\cdot10^4$	5.675	711	$1.114\cdot10^3$	121
4	0.097	$6.387\cdot10^4$	5.675	712	$1.114\cdot10^3$	122
5	0.097	$6.314\cdot10^4$	11.405	712	$1.115\cdot10^3$	123
6	0.098	$6.601\cdot10^4$	11.41	713	306	124
7	0.097	$6.314\cdot10^4$	11.405	713	$1.115\cdot10^3$	125
8	0.098	$6.608\cdot10^4$	11.41	263	306	53
9	0.098	$6.659\cdot10^4$	11.41	263	324	54

Pipe Run 1-44C (Elements 235, 714, 239, & 715)

$el_{P144C} := (235\ \ 714\ \ 239\ \ 715)^T$

$AL_{P144C} := \text{PipeRun}\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P144C}, \text{PipeRun\_C}_o, EL\right)$

$$AL_{P144C}^T = \begin{pmatrix} 0.101 & 7.384\times10^4 & 9.345 & 235 & 325 & 29 \\ 0.094 & 5.517\times10^4 & 9.345 & 235 & 1.116\times10^3 & 30 \\ 0.088 & 4.167\times10^4 & 9.35 & 714 & 326 & 126 \\ 0.094 & 5.517\times10^4 & 9.345 & 714 & 1.116\times10^3 & 127 \\ 0.088 & 4.167\times10^4 & 9.35 & 239 & 326 & 31 \\ 0.092 & 5.211\times10^4 & 5.515 & 239 & 1.117\times10^3 & 32 \\ 0.101 & 7.426\times10^4 & 5.515 & 715 & 330 & 128 \\ 0.092 & 5.212\times10^4 & 5.515 & 715 & 1.117\times10^3 & 129 \end{pmatrix}$$

Pipe Run 1-44D (Elements 242, 243, 716, 717, 718, & 249)

$el_{P144D} := (242 \quad 243 \quad 716 \quad 717 \quad 718 \quad 249)^T$

$AL_{P144D} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P144D}, PipeRun\_C_o, EL)$

$AL_{P144D}^T =$

	0	1	2	3	4	5
0	0.11	$9.54 \cdot 10^4$	9.34	242	331	33
1	0.13	$1.448 \cdot 10^5$	9.345	242	332	34
2	0.126	$1.337 \cdot 10^5$	9.985	243	332	35
3	0.111	$9.713 \cdot 10^4$	9.985	243	$1.118 \cdot 10^3$	36
4	0.111	$9.713 \cdot 10^4$	9.985	716	$1.118 \cdot 10^3$	130
5	0.098	$6.475 \cdot 10^4$	5.695	716	$1.119 \cdot 10^3$	131
6	0.098	$6.475 \cdot 10^4$	5.695	717	$1.119 \cdot 10^3$	132
7	0.086	$3.666 \cdot 10^4$	6.31	717	$1.12 \cdot 10^3$	133
8	0.079	$1.799 \cdot 10^4$	5.5	718	333	134
9	0.086	$3.666 \cdot 10^4$	6.31	718	$1.12 \cdot 10^3$	135
10	0.075	$7.709 \cdot 10^3$	9.36	249	315	37
11	0.079	$1.799 \cdot 10^4$	5.5	249	333	38

Pipe Run 1-44E (Element 250)

$el_{P144E} := (250)^T$

$AL_{P144E} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P144E}, PipeRun\_C_o, EL)$

$$AL_{P144E}^T = \begin{pmatrix} 0.076 & 1.102 \times 10^4 & 9.345 & 250 & 316 & 39 \\ 0.078 & 1.628 \times 10^4 & 6.305 & 250 & 317 & 40 \end{pmatrix}$$

Pipe Run 1-44F (Elements 252, 719, 256, 720, & 261)

$el_{P144F} := (252 \quad 719 \quad 256 \quad 720 \quad 261)^T$

$AL_{P144F} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P144F}, PipeRun\_C_o, EL)$

$AL_{P144F}^T =$

	0	1	2	3	4	5
0	0.078	$1.635 \cdot 10^4$	6.305	252	318	43
1	0.079	$1.884 \cdot 10^4$	6.305	252	$1.121 \cdot 10^3$	44
2	0.079	$1.913 \cdot 10^4$	6.305	719	339	136
3	0.079	$1.884 \cdot 10^4$	6.305	719	$1.121 \cdot 10^3$	137
4	0.079	$1.913 \cdot 10^4$	6.305	256	339	45
5	0.079	$1.912 \cdot 10^4$	5.99	256	$1.122 \cdot 10^3$	46
6	0.079	$1.824 \cdot 10^4$	5.995	720	602	138
7	0.079	$1.912 \cdot 10^4$	5.99	720	$1.122 \cdot 10^3$	139
8	0.079	$1.798 \cdot 10^4$	5.995	261	320	51
9	0.079	$1.843 \cdot 10^4$	5.99	261	602	52

Pipe Run 1-44G (Elements 257 & 259)

$$el_{P144G} := (257 \ \ 259)^T$$

$$AL_{P144G} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P144G}, PipeRun\_C_o, EL\right)$$

$$AL_{P144G}^T = \begin{pmatrix} 0.077 & 1.408 \times 10^4 & 6.23 & 257 & 321 & 47 \\ 0.078 & 1.747 \times 10^4 & 5.98 & 257 & 346 & 48 \\ 0.088 & 4.224 \times 10^4 & 5.99 & 259 & 344 & 49 \\ 0.078 & 1.747 \times 10^4 & 5.98 & 259 & 346 & 50 \end{pmatrix}$$

Pipe Properties for Line 1-46

Define pertinent pipe variables

$D_o := 16in$ Outside Diameter [12] [13]

$t := 0.25in$ Thickness [12] [13]

$P := 253psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\ 4} - (D_o - 2 \cdot t)^4\right]}{64}$$ Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 383.664\ in^4$$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{array}{|l} 1.0 \ \text{ if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 \\ \quad \begin{array}{|l} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \frac{D_o}{t}\right) \\ Y \leftarrow 1.033 - 0.00033 \cdot T \\ 1.0 \cdot \frac{1}{X \cdot Y} \end{array} \end{array}$$

$B_{2PR} = 1.101$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** R. K. Blandfod **Date:** 09/30/2008

Pipe Run 1-46A (Elements 652, 213, 721, 217, and 722)

$$el_{P146A} := (652\ \ 213\ \ 721\ \ 217\ \ 722)^T$$

$$AL_{P146A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P146A}, PipeRun\_C_o, EL\right)$$

$AL_{P146A}{}^T =$

	0	1	2	3	4	5
0	0.104	7.963·104	9.17	652	284	118
1	0.108	8.929·104	9.175	652	1.053·103	119
2	0.1	7.177·104	9.17	213	283	9
3	0.089	4.432·104	5.105	213	1.123·103	10
4	0.084	3.201·104	5.69	721	291	140
5	0.089	4.431·104	5.105	721	1.123·103	141
6	0.084	3.204·104	5.69	217	291	11
7	0.088	4.107·104	8.83	217	1.124·103	12
8	0.098	6.457·104	10.345	722	287	142
9	0.088	4.107·104	8.83	722	1.124·103	143

Pipe Run 1-46B (Element 218)

$$el_{P146B} := (218)^T$$

$$AL_{P146B} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P146B}, PipeRun\_C_o, EL\right)$$

$$AL_{P146B}{}^T = \begin{pmatrix} 0.097 & 6.321\times 10^4 & 9.185 & 218 & 290 & 13 \\ 0.094 & 5.556\times 10^4 & 6.015 & 218 & 295 & 14 \end{pmatrix}$$

Pipe Properties for Line 8-14

Define pertinent pipe variables

$D_o := 20in$ Outside Diameter [17]

$t := 0.312in$ Thickness [17]

$P := 253psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o{}^4 - \left(D_o - 2\cdot t\right)^4\right]}{64}$$ Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 935.251\ in^4$$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{cases} 1.0 \text{ if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 \\ \quad T \leftarrow 125 \\ \quad X \leftarrow 1.3 - 0.006 \cdot \frac{D_o}{t} \\ \quad Y \leftarrow 1.033 - 0.00033 \cdot T \\ \quad 1.0 \cdot \frac{1}{X \cdot Y} \end{cases}$$

$B_{2PR} = 1.102$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 8-14A (Element 470)

$el_{P814A} := (470)^T$

$AL_{P814A} := \text{PipeRun}(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P814A}, \text{PipeRun\_C}_o, EL)$

$AL_{P814A}^T =$

0.084	5.85×10^4	10.625	470	200	67
0.084	5.862×10^4	10.625	470	888	68

Pipe Run 8-14B (Elements 724, 723, 165, & 160)

$el_{P814B} := (724 \;\; 723 \;\; 165 \;\; 160)^T$

$AL_{P814B} := \text{PipeRun}(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P814B}, \text{PipeRun\_C}_o, EL)$

$AL_{P814B}^T =$

0.082	5.278×10^4	10.63	724	201	146
0.08	3.915×10^4	10.95	724	1.126×10^3	147
0.077	2.681×10^4	10.95	723	1.125×10^3	144
0.08	3.914×10^4	10.95	723	1.126×10^3	145
0.079	3.476×10^4	6.855	165	207	7
0.077	2.68×10^4	10.95	165	1.125×10^3	8
0.081	4.486×10^4	6.71	160	202	5
0.079	3.476×10^4	6.855	160	207	6

Pipe Run 8-14C (Elements 725, 159, 730, 729, 728, 727, 726, 151, 488, 731, 732, 733, & 734)

$el_{P814C} := (725\ \ 159\ \ 730\ \ 729\ \ 728\ \ 727\ \ 726\ \ 151\ \ 488\ \ 731\ \ 732\ \ 733\ \ 734)^T$

$AL_{P814C} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P814C}, PipeRun\_C_o, EL\right)$

$AL_{P814C}{}^T =$

	0	1	2	3	4	5
0	0.08	3.96·10^4	10.6	725	203	148
1	0.078	2.892·10^4	10.61	725	1.127·10^3	149
2	0.079	3.568·10^4	10.81	159	208	3
3	0.078	2.892·10^4	10.61	159	1.127·10^3	4
4	0.079	3.599·10^4	10.81	730	208	158
5	0.083	5.353·10^4	6.485	730	1.134·10^3	159
6	0.087	7.519·10^4	6.485	729	1.133·10^3	156
7	0.083	5.355·10^4	6.485	729	1.134·10^3	157
8	0.09	9.077·10^4	6.485	728	1.132·10^3	154
9	0.087	7.52·10^4	6.485	728	1.133·10^3	155
10	0.092	9.892·10^4	6.485	727	1.131·10^3	152
11	0.09	9.078·10^4	6.485	727	1.132·10^3	153
12	0.092	1.003·10^5	6.485	726	1.13·10^3	150
13	0.092	9.892·10^4	6.485	726	1.131·10^3	151
14	0.092	9.778·10^4	6.485	151	150	1
15	0.092	1.003·10^5	6.485	151	1.13·10^3	2
16	0.092	9.766·10^4	6.485	488	150	73
17	0.089	8.318·10^4	6.48	488	1.135·10^3	74
18	0.089	8.317·10^4	6.48	731	1.135·10^3	160
19	0.086	6.857·10^4	6.48	731	1.136·10^3	161
20	0.086	6.856·10^4	6.48	732	1.136·10^3	162
21	0.084	6.133·10^4	6.34	732	1.137·10^3	163
22	0.084	6.133·10^4	6.34	733	1.137·10^3	164
23	0.086	7.137·10^4	3.88	733	1.138·10^3	165
24	0.093	1.012·10^5	6.845	734	149	166
25	0.086	7.136·10^4	3.88	734	1.138·10^3	167

Writing Output Data for Pipe Runs Associated with Lines 1-44, 1-46, & 8-14

$PR1 := \left(AL_{P144A}{}^T\right)$ $PR5 := \left(AL_{P144E}{}^T\right)$ $PR9 := \left(AL_{P146B}{}^T\right)$

$PR2 := \left(AL_{P144B}{}^T\right)$ $PR6 := \left(AL_{P144F}{}^T\right)$ $PR10 := \left(AL_{P814A}{}^T\right)$

$PR3 := \left(AL_{P144C}{}^T\right)$ $PR7 := \left(AL_{P144G}{}^T\right)$ $PR11 := \left(AL_{P814B}{}^T\right)$

$PR4 := \left(AL_{P144D}{}^T\right)$ $PR8 := \left(AL_{P146A}{}^T\right)$ $PR12 := \left(AL_{P814C}{}^T\right)$

$P := (PR1\ \ PR2\ \ PR3\ \ PR4\ \ PR5\ \ PR6\ \ PR7\ \ PR8\ \ PR9\ \ PR10\ \ PR11\ \ PR12)$

PipeRunsLines_44_46_814 := WRITEPRN("PRLines_44_46_814.prn" , P)

ELBOWS

Elbows Strategy: *Search based on the two nodes comprising the ends of each elbow. SRSS combine the three moments of each of the four node representations (one for each element connected by the nodes in question). Find the maximum of the four moment combinations and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{ElbowDC}\left(P, D_o, t, I, B_1, B_2, M, S\right) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\,\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$$\mathrm{Elbow}\left(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL\right) :=$$

$$\begin{aligned}
& ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
& ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
& ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right) \\
& \text{for } i \in 1 .. \mathrm{last}(nd) \qquad\qquad \text{if } \mathrm{rows}(nd) > 1 \\
& \quad ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \\
& \left(M \;\; Int_0\right) \leftarrow (0 \;\; 0) \\
& \text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0} \\
& \quad \text{for } j \in 0 .. \mathrm{last}\left(ind_{nd}\right) \\
& \qquad M_{rxg} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}}+2,\, ind_{nd_j}} \\
& \qquad M_{ryg} \leftarrow nf_{ind_{nfi_{C_{o_{1,1}}}}+2,\, ind_{nd_j}} \\
& \qquad M_{rzg} \leftarrow nf_{ind_{nfi_{C_{o_{2,1}}}}+2,\, ind_{nd_j}} \\
& \qquad M_{rx} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg} \\
& \qquad M_{ry} \leftarrow \left(nf_{ind_{nfi_{C_{o_{1,1}}}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg} \\
& \qquad M_{rz} \leftarrow \left(nf_{ind_{nfi_{C_{o_{2,1}}}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg} \\
& \qquad M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2} \\
& \qquad Int'_j \leftarrow \mathrm{ElbowDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right) \\
& \qquad \text{if } Int'_j > Int_0 \\
& \qquad\quad Int \leftarrow \mathrm{stack}\Big(Int'_j, M'_j, nf_{ind_{nfi_{C_{o_{0,1}}}}-1+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M \\
& \qquad\quad Result \leftarrow M' \\
& Int
\end{aligned}$$

Conditions applicable to all elbows

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$ — Defining place holding variables

$$Elb\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Elbow Properties for Lines 1-44 and 1-46

Define pertinent elbow variables

$D_o := 6.625\,in$ — Outside Diameter [12] [13] [14]

$t := 0.28\,in$ — Thickness [12] [13] [14]

$P := 253\,psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

$I = 28.142\,in^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$R := 1.5 \cdot D_o$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$ — Mean pipe radius

Define primary stress indices

$$h := \frac{t \cdot R}{r_m^{\,2}}$$ $h = 0.276$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h > 0.5 \\ -0.1 + 0.4 \cdot h & \text{otherwise} \end{cases}$$

$B_1 = 0.011$ — B_1 primary stress Index [9, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 3.063$ — B_2 primary stress Index [9, NB-3683.7]

Elbow 1-44A (Nodes 301 & 302)

$nd_{EL144A\_1} := (301)^T$

$AL_{EL144A\_nd301} := \text{Elbow}(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL144A\_1}, Elb\_C_o, EL)$

$AL_{EL144A\_nd301}^T = \begin{pmatrix} 0.609 & 9.574\times10^4 & 10.325 & 301 & 25 & -3.283\times10^4 & -8.772\times10^4 & -1.985\times10^4 \end{pmatrix}$

$nd_{EL144A\_2} := (302)^T$

$AL_{EL144A\_nd302} := \text{Elbow}(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL144A\_2}, Elb\_C_o, EL)$

$AL_{EL144A\_nd302}^T = \begin{pmatrix} 0.584 & 9.176\times10^4 & 5.685 & 302 & 27 & 4.328\times10^4 & 6.624\times10^4 & 4.647\times10^4 \end{pmatrix}$

Elbow 1-44B (Nodes 324 & 325)

$nd_{EL144B\_1} := (324)^T$

$AL_{EL144B\_nd324} := \text{Elbow}(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL144B\_1}, Elb\_C_o, EL)$

$AL_{EL144B\_nd324}^T = \begin{pmatrix} 0.424 & 6.659\times10^4 & 11.41 & 324 & 99 & 1.494\times10^4 & 1.621\times10^4 & 6.283\times10^4 \end{pmatrix}$

$nd_{EL144B\_2} := (325)^T$

$AL_{EL144B\_nd325} := \text{Elbow}(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL144B\_2}, Elb\_C_o, EL)$

$AL_{EL144B\_nd325}^T = \begin{pmatrix} 0.47 & 7.384\times10^4 & 9.345 & 325 & 100 & -3.181\times10^4 & 3.116\times10^4 & 5.89\times10^4 \end{pmatrix}$

Elbow 1-44C (Nodes 330 & 331)

$nd_{EL144C\_1} := (330)^T$

$AL_{EL144C\_nd330} := \text{Elbow}(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL144C\_1}, Elb\_C_o, EL)$

$AL_{EL144C\_nd330}^T = \begin{pmatrix} 0.473 & 7.427\times10^4 & 5.515 & 330 & 102 & 5.992\times10^4 & 2.149\times10^4 & -3.825\times10^4 \end{pmatrix}$

$nd_{EL144C\_2} := (331)^T$

$AL_{EL144C\_nd331} := \text{Elbow}(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL144C\_2}, Elb\_C_o, EL)$

$AL_{EL144C\_nd331}^T = \begin{pmatrix} 0.607 & 9.54\times10^4 & 9.34 & 331 & 33 & -6.246\times10^4 & -3.955\times10^3 & 7.2\times10^4 \end{pmatrix}$

Elbow 1-44D (Nodes 315 & 316)

$nd_{EL144D\_1} := (315)^T$

$AL_{EL144D\_nd315} := \text{Elbow}(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL144D\_1}, Elb\_C_o, EL)$

$AL_{EL144D\_nd315}^T = \begin{pmatrix} 0.05 & 7.709\times10^3 & 9.36 & 315 & 37 & -3.617\times10^3 & 659.622 & -6.775\times10^3 \end{pmatrix}$

$nd_{EL144D\_2} := (316)^T$

$AL_{EL144D\_nd316} := \text{Elbow}(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL144D\_2}, Elb\_C_o, EL)$

$AL_{EL144D\_nd316}^T = \begin{pmatrix} 0.071 & 1.102\times10^4 & 9.345 & 316 & 39 & 6.011\times10^3 & -363.374 & 9.231\times10^3 \end{pmatrix}$

Elbow 1-44E (Nodes 320 & 321)

$nd_{EL144E\_1} := (320)^T$

$AL_{EL144E\_nd320} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL144E\_1}, Elb\_C_o, EL)$

$AL_{EL144E\_nd320}^T = (0.115 \quad 1.798 \times 10^4 \quad 5.995 \quad 320 \quad 51 \quad -7.064 \times 10^3 \quad 2.807 \times 10^3 \quad -1.63 \times 10^4)$

$nd_{EL144E\_2} := (321)^T$

$AL_{EL144E\_nd321} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL144E\_2}, Elb\_C_o, EL)$

$AL_{EL144E\_nd321}^T = (0.09 \quad 1.408 \times 10^4 \quad 6.23 \quad 321 \quad 94 \quad -3.566 \times 10^3 \quad 688.326 \quad 1.36 \times 10^4)$

Elbow 1-44F (Nodes 344 & 345)

$nd_{EL144F\_1} := (344)^T$

$AL_{EL144F\_nd344} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL144F\_1}, Elb\_C_o, EL)$

$AL_{EL144F\_nd344}^T = (0.269 \quad 4.224 \times 10^4 \quad 5.99 \quad 344 \quad 96 \quad 4.182 \times 10^3 \quad -3.211 \times 10^3 \quad -4.191 \times 10^4)$

$nd_{EL144F\_2} := (345)^T$

$AL_{EL144F\_nd345} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL144F\_2}, Elb\_C_o, EL)$

$AL_{EL144F\_nd345}^T = (0.297 \quad 4.664 \times 10^4 \quad 5.99 \quad 345 \quad 97 \quad -2.638 \times 10^3 \quad 1.293 \times 10^3 \quad 4.654 \times 10^4)$

Elbow 1-46A (Nodes 284 & 283)

$nd_{EL146A\_1} := (284)^T$

$AL_{EL146A\_nd284} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL146A\_1}, Elb\_C_o, EL)$

$AL_{EL146A\_nd284}^T = (0.507 \quad 7.963 \times 10^4 \quad 9.17 \quad 284 \quad 82 \quad -2.163 \times 10^4 \quad -7.279 \times 10^4 \quad -2.398 \times 10^4)$

$nd_{EL146A\_2} := (283)^T$

$AL_{EL146A\_nd283} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL146A\_2}, Elb\_C_o, EL)$

$AL_{EL146A\_nd283}^T = (0.457 \quad 7.177 \times 10^4 \quad 9.17 \quad 283 \quad 9 \quad -1.325 \times 10^4 \quad -6.507 \times 10^4 \quad -2.724 \times 10^4)$

Elbow 1-46B (Nodes 287 & 288)

$nd_{EL146B\_1} := (287)^T$

$AL_{EL146B\_nd287} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL146B\_1}, Elb\_C_o, EL)$

$AL_{EL146B\_nd287}^T = (0.411 \quad 6.457 \times 10^4 \quad 10.345 \quad 287 \quad 84 \quad 1.101 \times 10^4 \quad -6.15 \times 10^4 \quad -1.634 \times 10^4)$

$nd_{EL146B\_2} := (288)^T$

$AL_{EL146B\_nd288} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL146B\_2}, Elb\_C_o, EL)$

$AL_{EL146B\_nd288}^T = (0.447 \quad 7.016 \times 10^4 \quad 9.185 \quad 288 \quad 87 \quad 7.183 \times 10^3 \quad 6.258 \times 10^4 \quad -3.09 \times 10^4)$

Elbow 1-46C (Nodes 288 & 290)

$nd_{EL146C\_1} := (288)^T$

$AL_{EL146C\_nd288} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL146C\_1}, Elb\_C_o, EL)$

$AL_{EL146C\_nd288}{}^T = (0.447 \quad 7.016\times10^4 \quad 9.185 \quad 288 \quad 87 \quad 7.183\times10^3 \quad 6.258\times10^4 \quad -3.09\times10^4)$

$nd_{EL146C\_2} := (290)^T$

$AL_{EL146C\_nd290} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL146C\_2}, Elb\_C_o, EL)$

$AL_{EL146C\_nd290}{}^T = (0.403 \quad 6.321\times10^4 \quad 9.185 \quad 290 \quad 88 \quad -2.072\times10^4 \quad -4.82\times10^4 \quad 3.525\times10^4)$

Elbow Properties for Line 8-14A

Define pertinent elbow variables

$D_o := 10.75\,in$ — Outside Diameter [19]

$t := 0.25\,in$ — Thickness [19]

$P := 253\,psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o^4 - (D_o - 2\cdot t)^4\right]}{64}$$

$I = 113.714\,in^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$R := 1\cdot D_o$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$ Mean pipe radius

Define primary stress indices

$$h := \frac{t\cdot R}{r_m^2}$$

$h = 0.098$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4\cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4\cdot h > 0.5 \\ -0.1 + 0.4\cdot h & \text{otherwise} \end{cases}$$

$B_1 = 0$ — B_1 primary stress Index [9, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 6.137$ — B_2 primary stress Index [9, NB-3683.7]

Elbow 8-14A (Nodes 200 & 201)

$nd_{EL814A\_1} := (200)^T$

$AL_{EL814A\_nd200} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL814A\_1}, Elb\_C_o, EL\right)$

$AL_{EL814A\_nd200}{}^T = \left(0.299 \quad 5.85\times10^4 \quad 10.625 \quad 200 \quad 67 \quad -2.726\times10^3 \quad 5.832\times10^4 \quad 3.598\times10^3\right)$

$nd_{EL814A\_2} := (201)^T$

$AL_{EL814A\_nd201} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL814A\_2}, Elb\_C_o, EL\right)$

$AL_{EL814A\_nd201}{}^T = \left(0.27 \quad 5.278\times10^4 \quad 10.63 \quad 201 \quad 77 \quad -8.932\times10^3 \quad 5.197\times10^4 \quad -2.306\times10^3\right)$

Elbow Properties for Line 8-14B

Define pertinent elbow variables

$D_o := 10.75\,in$ — Outside Diameter [19]

$t := 0.25\,in$ — Thickness [19]

$P := 253\,psi$ — Internal Pressure [3, pg 23]

$I := \dfrac{\pi\cdot\left[D_o{}^4 - \left(D_o - 2\cdot t\right)^4\right]}{64}$ — Moment of inertia [8, Table 17-27, pg 17-39]

$I = 113.714\,in^4$

$R := 1.5\cdot D_o$ — Nominal bend radius of curved pipe or elbow

$r_m := \dfrac{D_o - t}{2}$ — Mean pipe radius

Define primary stress indices

$h := \dfrac{t\cdot R}{r_m{}^2}$ $\quad h = 0.146$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4\cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4\cdot h > 0.5 \\ -0.1 + 0.4\cdot h & \text{otherwise} \end{cases}$ $\quad B_1 = 0$ — B_1 primary stress Index [9, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 4.683$ B_2 primary stress Index [9, NB-3683.7]

Elbow 8-14B (Nodes 202 & 203)

$nd_{EL814B\_1} := (202)^T$

$AL_{EL814B\_nd202} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL814B\_1}, Elb\_C_o, EL)$

$AL_{EL814B\_nd202}^T = (0.175 \quad 4.486\times10^4 \quad 6.71 \quad 202 \quad 5 \quad 3.966\times10^3 \quad 4.364\times10^4 \quad -9.581\times10^3)$

$nd_{EL814B\_2} := (203)^T$

$AL_{EL814B\_nd203} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL814B\_2}, Elb\_C_o, EL)$

$AL_{EL814B\_nd203}^T = (0.155 \quad 3.96\times10^4 \quad 10.6 \quad 203 \quad 80 \quad -6.585\times10^3 \quad -3.904\times10^4 \quad 873.419)$

Writing Output Data for Elbows Associated with Lines 13 to 16, 18 to 21, and 171

$EL1A := (AL_{EL144A\_nd301}^T)$

$EL1B := (AL_{EL144A\_nd302}^T)$

$EL2A := (AL_{EL144B\_nd324}^T)$

$EL2B := (AL_{EL144B\_nd325}^T)$

$EL3A := (AL_{EL144C\_nd330}^T)$

$EL3B := (AL_{EL144C\_nd331}^T)$

$EL4A := (AL_{EL144D\_nd315}^T)$

$EL4B := (AL_{EL144D\_nd316}^T)$

$EL5A := (AL_{EL144E\_nd320}^T)$

$EL5B := (AL_{EL144E\_nd321}^T)$

$EL6A := (AL_{EL144F\_nd344}^T)$

$EL6B := (AL_{EL144F\_nd345}^T)$

$EL7A := (AL_{EL146A\_nd284}^T)$

$EL7B := (AL_{EL146A\_nd283}^T)$

$EL8A := (AL_{EL146B\_nd287}^T)$

$EL8B := (AL_{EL146B\_nd288}^T)$

$EL9A := (AL_{EL146C\_nd288}^T)$

$EL9B := (AL_{EL146C\_nd290}^T)$

$EL10A := (AL_{EL814A\_nd200}^T)$

$EL10B := (AL_{EL814A\_nd201}^T)$

$EL11A := (AL_{EL814B\_nd202}^T)$

$EL11B := (AL_{EL814B\_nd203}^T)$

vEL := (EL1A EL1B EL2A EL2B EL3A EL3B EL4A EL4B EL5A EL5B EL6A EL6B EL7A EL7B EL8A EL8B EI

ElbowLines_44_46_814 := WRITEPRN("ElbowLines_44_46_814.prn" , vEL)

FORGED TEES AND FABRICATED BRANCH TEES

Tees Strategy: *Search based on the elements comprising the tee. The input identifies which elements are associated with the pipe run and which element is associated with the branch from the run. The indices for the defined common node for all three elements is identified and the associated SRSS moment is identified for each time step. The maximum moment for the elements comprising the pipe run is found and applied as* M_r *in equation (9) of ASME III, Division I - NB - 3652 which is modified to represent tees. The maximum moment for the branch element is found and applied as* M_b *in equation (9) of ASME III, Division I - NB - 3652 [9]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$TeeDC(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_b, M_r, Z_b, Z_r, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot T_r} + B_{2b} \cdot \left[\frac{M_b \cdot (1lbf \cdot in)}{Z_b}\right] + B_{2r} \cdot \left[\frac{M_r \cdot (1lbf \cdot in)}{Z_r}\right]}{S}$$

$Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S, nf, el_R, el_B, nd_R, nd_B, C_o, EL) :=$

$ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{elR} \leftarrow match\left(el_{R_0}, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(el_R)$ if rows

$\quad ind_{elR} \leftarrow stack\left[ind_{elR}, \left(match\left(el_{R_i}, EL^{\langle 0 \rangle}\right)\right)\right]$

$EL'R_{last\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$

for $i \in 0 .. last(ind_{elR})$

$\quad EL'R_{ind_{elR_i}} \leftarrow EL_{ind_{elR_i}, 1}$

$ind_{ndR} \leftarrow match\left(nd_{R_0}, EL'R^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(nd_R)$ if r

$\quad ind_{ndR} \leftarrow stack\left[ind_{ndR}, \left(match\left(nd_{R_i}, EL'R^{\langle 0 \rangle}\right)\right)\right]$

$ind_{elB} \leftarrow match\left(el_{B_0}, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(el_B)$ if rows

$\quad ind_{elB} \leftarrow stack\left[ind_{elB}, \left(match\left(el_{B_i}, EL^{\langle 0 \rangle}\right)\right)\right]$

$EL'B_{last\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$

for $i \in 0 .. last(ind_{elB})$

$\quad EL'B_{ind_{elB_i}} \leftarrow EL_{ind_{elB_i}, 1}$

$ind_{ndB} \leftarrow match\left(nd_{B_0}, EL'B^{\langle 0 \rangle}\right)$

$\text{for } i \in 1..\text{last}(nd_B)$ $\quad$ if r

$\quad ind_{ndB} \leftarrow \text{stack}\left[ind_{ndB}, \left(\text{match}\left(nd_{B_i}, EL'B^{\langle 0\rangle}\right)\right)\right]$

$(M_R \;\; M_B \;\; Int_0) \leftarrow (0 \;\; 0 \;\; 0)$

$\text{for } i \in 0..ind_{nfo_0} - ind_{nfi_0}$

$\quad \text{for } j \in 0..\text{last}(ind_{ndR})$

$\quad\quad \text{for } k \in 0..\text{last}(ind_{ndB})$

$M_{rxgR_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{ndR_j}}$

$M_{rygR_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{ndR_j}}$

$M_{rzgR_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{ndR_j}}$

$M_{rxR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{ndR_j}} - M_{rxgR_j}\right)\cdot C$

$M_{ryR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{ndR_j}} - M_{rygR_j}\right)\cdot C$

$M_{rzR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{ndR_j}} - M_{rzgR_j}\right)\cdot C$

$M_{R_j} \leftarrow \sqrt{\left(M_{rxR_j}\right)^2 + \left(M_{ryR_j}\right)^2 + \left(M_{rzR_j}\right)^2}$

$M_{rxgB_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{ndB_k}}$

$M_{rygB_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{ndB_k}}$

$M_{rzgB_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{ndB_k}}$

$M_{rxB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{ndB_k}} - M_{rxgB_j}\right)\cdot C$

$M_{ryB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{ndB_k}} - M_{rygB_j}\right)\cdot C$

$M_{rzB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{ndB_k}} - M_{rzgB_j}\right)\cdot C$

$M_{B_j} \leftarrow \sqrt{\left(M_{rxB_j}\right)^2 + \left(M_{ryB_j}\right)^2 + \left(M_{rzB_j}\right)^2}$

$Int'_j \leftarrow \text{TeeDC}\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_{B_j}, M_R\right.$

$\text{if } Int'_j > Int_0$

$\quad Int \leftarrow \text{stack}\left(Int'_j, M_{R_j}, M_{B_j}, nf_{ind_{nfiC_{o_{0,1}}}-1+i}\right.$

$\text{Result} \leftarrow \text{stack}\left(M_{R_j}, M_{B_j}, M_{rxR_j}, M_{ryR_j}, M\right.$

$M \leftarrow M_R$

Int

Conditions applicable to forged tee

$M_{ox} := 0 \quad M_{oy} := 0 \quad M_{oz} := 0$

Defining place holding directional moment variables

$$Tee\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

TEE (Line 1-44)

Define pertinent tee variables

$P := 253psi$ — Internal Pressure [3, pg 23]

$D_o := 6.625in$ — Outside Diameter of Pipe Run [12]

$d_o := 6.625in$ — Outside Diameter of Branch [12]

$B_1 := 0.5$ — B_1 primary stress Index for tees and branches [9, NB-3683.9]

$T_r := 0.28in$ — Nominal wall thickness of designated run pipe [[12]

$$R_m := \frac{D_o - T_r}{2}$$

Mean radius of designated run pipe

$$Z_r := \pi \cdot R_m^2 \cdot T_r$$

$$Z_r = 8.8534\ in^3$$

Approximate section modulus of designated run pipe [9, NB-3683.1(d)]

$$B_{2b} := \begin{cases} 0.4 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} & \text{if } 0.4 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} > 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Index for tees and branches [9, NB-3683.9]

$$B_{2b} = 2.018$$

$T'_b := 0.28in$ — Nominal wall thickness of attached branch pipe [[12]

$$r'_m := \frac{d_o - T'_b}{2}$$

Mean radius of attached branch pipe

$$Z_b := \pi \cdot r'^2_m \cdot T'_b$$

$$Z_b = 8.853\ in^3$$

Approximate section modulus of attached branch pipe [9, NB-3683.1(d)]

$$B_{2r} := \begin{cases} 0.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} & \text{if } 0.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} > 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Index for tees and branches [9, NB-3683.9]

$$B_{2r} = 2.522$$

Tee 1-44 (Node 297)

$elR_{Tee144} := (220\ \ 221)^T$ Elements associated with pipe run

$ndR_{Tee144} := (297)^T$ Node between pipe run elements

$elB_{Tee144} := (223)^T$ Element associated with branch

$ndB_{Tee144} := (297)^T$ Node where branch intersects pipe run

$AL_{Tee144} := Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF, elR_{Tee144}, elB_{Tee144}, ndR_{Tee144}, ndB_{Tee144}, Tee\_C$

$$AL_{Tee144}^T = (0.733\ \ 6.688\times10^4\ \ 9.218\times10^4\ \ 10.32\ \ 297\ \ 17\ \ 19\ \ 23)$$

Writing Output Data for Tees Associated with Lines 1-44, 1-46, & 8-14

$Tee1 := AL_{Tee144}^T$

$Tee := (Tee1)$

TeeLines_44_46_814 := WRITEPRN("TeeLines_44_46_814.prn" , Tee)

FLANGES

Flange Strategy: *Search based on the nodes where flanges occur. Find the maximum moment combination for the node and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\mathrm{FlangeDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\,\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Flange}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(nd)$ if $\mathrm{rows}(nd) > 1$

  $ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$(M \;\; Int_0) \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \mathrm{last}(ind_{nd})$

    $M_{rxg} \leftarrow nf_{ind_{nfi}{C_o}_{0,1}+2,\, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi}{C_o}_{1,1}+2,\, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi}{C_o}_{2,1}+2,\, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi}{C_o}_{0,1}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot {C_o}_{3,0} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi}{C_o}_{1,1}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot {C_o}_{3,0} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi}{C_o}_{2,1}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot {C_o}_{3,0} + M_{rzg}$

    $M'_j \leftarrow \sqrt{{M_{rx}}^2 + {M_{ry}}^2 + {M_{rz}}^2}$

    $Int'_j \leftarrow \mathrm{FlangeDC}(P, D_o, t, I, B_1, B_2, M'_j, S)$

    if $Int'_j > Int_0$

      $Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfi}{C_o}_{0,1}-1+i,0}, EL_{ind_{nd_j},1}, ind_{nd_j}, M_{rx}, M_{ry}, M\right.$

      $Result \leftarrow M'$

Int

Conditions applicable to all flanges

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$

Defining place holding variables

$$Flange\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties of Lines 1-44

Define pertinent pipe variables

$D_o := 6.625in$ Outside Diameter [12]

$t := 0.28in$ Thickness [12]

$P := 253psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\ 4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 28.142\ in^4$

Define primary stress indices (Utilize girth weld characteristic associated with lap joint flanges in determining values)

$B_1 := 0.5$ B_1 for a girth weld [9, Table NB-3681(a)-1, pg 130]

$B_2 := 1$ B_2 for a girth weld [9, Table NB-3681(a)-1, pg 130]

Flange (Gate Valve) 1-44A (Node 299)

$nd_{FL144A} := (299)^T$

$AL_{FL144A} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL144A}, Flange\_C_o, EL\right)$

$$AL_{FL144A}^{\ T} = \begin{pmatrix} 0.166 & 6.727 \times 10^4 & 15.205 & 299 & 57 & 2.334 \times 10^4 & -5.793 \times 10^4 & -2.499 \times 10^4 \end{pmatrix}$$

Flange (Gate Valve) 1-44B (Node 298)

$nd_{FL144B} := (298)^T$

$AL_{FL144B} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL144B}, Flange\_C_o, EL\right)$

$$AL_{FL144B}^{\ T} = \begin{pmatrix} 0.122 & 4.606 \times 10^4 & 15.23 & 298 & 55 & 2.25 \times 10^4 & -4.006 \times 10^4 & 3.253 \times 10^3 \end{pmatrix}$$

Flange (Gate Valve) 1-44C (Node 296)

$nd_{FL144C} := (296)^T$

$AL_{FL144C} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL144C}, Flange\_C_o, EL)$

$AL_{FL144C}{}^T = (0.157 \quad 6.289\times10^4 \quad 6 \quad 296 \quad 112 \quad -2.913\times10^3 \quad -5.988\times10^4 \quad 1.9\times10^4)$

Flange (Gate Valve) 1-44D (Node 295)

$nd_{FL144D} := (295)^T$

$AL_{FL144D} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL144D}, Flange\_C_o, EL)$

$AL_{FL144D}{}^T = (0.142 \quad 5.556\times10^4 \quad 6.015 \quad 295 \quad 14 \quad -5.073\times10^3 \quad -5.089\times10^4 \quad 2.169\times10^4)$

Flange (Gate Valve) 1-44E (Node 317)

$nd_{FL144E} := (317)^T$

$AL_{FL144E} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL144E}, Flange\_C_o, EL)$

$AL_{FL144E}{}^T = (0.06 \quad 1.629\times10^4 \quad 6.305 \quad 317 \quad 41 \quad 7.499\times10^3 \quad -950.289 \quad 1.442\times10^4)$

Flange (Gate Valve) 1-44F (Node 318)

$nd_{FL144F} := (318)^T$

$AL_{FL144F} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL144F}, Flange\_C_o, EL)$

$AL_{FL144F}{}^T = (0.06 \quad 1.635\times10^4 \quad 6.305 \quad 318 \quad 43 \quad 7.501\times10^3 \quad -960.497 \quad 1.449\times10^4)$

Writing Output Data for Flanges Associated with Lines 1-44, 1-46, & 8-14

$F1 := \left(AL_{FL144A}{}^T\right)$

$F2 := \left(AL_{FL144B}{}^T\right)$

$F3 := \left(AL_{FL144C}{}^T\right)$

$F4 := \left(AL_{FL144D}{}^T\right)$

$F5 := \left(AL_{FL144E}{}^T\right)$

$F6 := \left(AL_{FL144F}{}^T\right)$

$F := (F1 \quad F2 \quad F3 \quad F4 \quad F5 \quad F6)$

FlangeLines_13to16_18to21_171 := WRITEPRN("FlangeLines_44_46_814.prn" , F)

Appendix C.3.6

Demand to Capacity Ratio Calculations for Components Associated with Lines 1-45 of ATR PCS Model 265

(NOTE: Values represented here are shown for one realization (Nodal Force file = LINES_45_test_R1.dat and Element/Nodal order file = EL_45.xls) and may or may not be consistent with the 80th percentile results contained in Appendix C.4)

Force Outputs from Abaqus

NF := ...\LINES_45.dat — (N)odal (F)orces for the (M)edium (L)ines of Model 3

Defined Elemental and Corresponding Nodal Order

EL := ...\EL_45(9-22-08).xls — Element and corresponding nodal order for the (M)edium (L)ines of Model 3

Time Boundaries

$t_{initial} := 1$ — Initial time for which dynamic loading is applied

$t_{final} := 21$ — Final time for which dynamic loading stops

Seismic Scale Factor (F_a)

$F_a := 1$ — Seismic scale factor [30]

Allowable Design Stress Intensity Factor (S_m): *S_m is defined below for SS304 at temperature 125ºF and SS304L at 125ºF.*

$S_{m\_125} := 20ksi$ — For SS304 at 125ºF [2, pg 316-318] [3, pg 23]

$S_{m\_125L} := 16.7ksi$ — For SS304L at 125ºF [2, pg 316-318] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Yield Strength (S_y): *S_y is defined below for SS304 at temperature 125ºF and SS304L at 125ºF.*

$S_{y\_125} := 28.35ksi$ — For SS304 at 125ºF [2, pg 646-648] [3, pg 23]

$S_{y\_125L} := 23.85ksi$ — For SS304L at 125ºF [2, pg 646-648] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Maximum Strength Applicable for Equation 9 (S): *S is defined below for SS304 at temperature 125ºF and SS304L at 125ºF.*

$S_{125} := \min(3 \cdot S_{m\_125}, 2 \cdot S_{y\_125})$ — Maximum allowable stress applied to SS304 piping [9, NB-3656]

$S_{125} = 56.7\,ksi$

$S_{125L} := \min(3 \cdot S_{m\_125L}, 2 \cdot S_{y\_125L})$ — Maximum allowable stress applied to SS304L piping [9, NB-3656]

$S_{125L} = 47.7\,ksi$

SUPPORTS

Supports Strategy: *Search based on the node for which the support acts. If this node is a termination point there will only be one node to evaluate. If this node is in line with a section of pipe there will be two representations of the same node (one for each element on each side of the node) to combine and the difference between them is the force required of the support. The D/C ratio for each support will be found by dividing the the required force found above by the support capacity.*

$$\mathrm{SupDC}(P_r, P_c) := \frac{P_r}{P_c}$$

$\mathrm{Support}(nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(nd)$ if $\mathrm{rows}(nd) > 1$

   $ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$\begin{pmatrix} Int1_5 & Int2_5 \end{pmatrix} \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

   for $j \in 0 .. \mathrm{last}(ind_{nd})$

     $P_{rg_j} \leftarrow nf_{ind_{nfi}C_{o_{0,1}} - 1,\, ind_{nd_j}}$

     $P_{r_j} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}} - 1 + i,\, ind_{nd_j}} - P_{rg_j}\right) \cdot C_{o_{2,0}} + P_{rg_j}$

   $PR_i \leftarrow \sum_{n=0}^{j} P_{r_n}$

   if $PR_i < Int1_1 \wedge C_{o_{0,0}} \neq 0$

     $Int1' \leftarrow \mathrm{SupDC}\left(\left|PR_i\right|, C_{o_{0,0}}\right)$

     $Int_1 \leftarrow \mathrm{stack}\left(Int1', PR_i, nf_{ind_{nfi}C_{o_{0,1}} - 1 + i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd}\right)$

   if $PR_i > Int2_1 \wedge C_{o_{1,0}} \neq 0$

     $Int2' \leftarrow \mathrm{SupDC}\left(\left|PR_i\right|, C_{o_{1,0}}\right)$

     $Int_2 \leftarrow \mathrm{stack}\left(Int2', PR_i, nf_{ind_{nfi}C_{o_{0,1}} - 1 + i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd}\right)$

$\begin{pmatrix} Int_1 & Int_2 \end{pmatrix}$

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U-Bolt Detail 2 Support (1x)

$P_{1\_UB2Y} := \frac{4.937 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. B.10.1]

$P_{2\_UB2Y} := \frac{4.937 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_UB2Y} := \begin{pmatrix} P_{1\_UB2Y} & 2 \\ P_{2\_UB2Y} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

$P_{1\_UB2Z} := \frac{0.143 \cdot kip}{lbf}$ ***Flexure*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_UB2Z} := \frac{0.143 \cdot kip}{lbf}$ ***Flexure*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_UB2Z} := \begin{pmatrix} P_{1\_UB2Z} & 3 \\ P_{2\_UB2Z} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

U-Bolt Detail 2 (V) (Node 1045)

U-Bolt Detail 2 supports line 1-45 at the south portion of P(1-45E) from movement in the vertical and east/west directions.

$nd1045_{UB2Y_0} := 1045$ Node associated with support

$$\left(AL1_{UB2Y\_nd1045} \;\; AL2_{UB2Y\_nd1045}\right) := Support\left(NF, nd1045_{UB2Y}, Sup\_C_{o\_UB2Y}, EL\right)$$

$$AL1_{UB2Y\_nd1045}^{T} = \left(0.094 \;\; -464.437 \;\; 5.42 \;\; 1.045 \times 10^{3} \;\; 64\right)$$

$$AL2_{UB2Y\_nd1045}^{T} = \left(0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0\right)$$

/C,demand force, occurrence time, fined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

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U-Bolt Detail 2 (EW) (Node 1045)

U-Bolt Detail 2 supports line 1-45 at the south portion of P(1-45E) from movement in the vertical and east/west directions.

$nd1045_{UB2Z_0} := 1045$ Node associated with support

$(AL1_{UB2Z\_nd1045} \;\; AL2_{UB2Z\_nd1045}) := Support(NF, nd1045_{UB2Z}, Sup\_C_{o\_UB2Z}, EL)$

$AL1_{UB2Z\_nd1045}^{T} = (0.265 \;\; -37.922 \;\; 7.965 \;\; 1.045\times10^{3} \;\; 64)$

$AL2_{UB2Z\_nd1045}^{T} = (1.014 \;\; 145.063 \;\; 9.425 \;\; 1.045\times10^{3} \;\; 64)$

/C,demand force, occurrence time, fined node, associated index for the reaction force at the selected node ing in the positive (AL1) and negative L2) directions of the global coordinate system)

Pending U-Bolt Support (1x)

$P_{1\_PUBY} := \frac{4.522 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_PUBY} := \frac{4.522 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_PUBY} := \begin{pmatrix} P_{1\_PUBY} & 2 \\ P_{2\_PUBY} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

$P_{1\_PUBZ} := \frac{0.507 \cdot kip}{lbf}$ ***Flexure*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. C.9.1]

$P_{2\_PUBZ} := \frac{0.507 \cdot kip}{lbf}$ ***Flexure*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. C.9.1]

$$Sup\_C_{o\_PUBZ} := \begin{pmatrix} P_{1\_PUBZ} & 3 \\ P_{2\_PUBZ} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

Pending U-Bolt (V) (Node 1047)

The pending U-Bolt support supports line 1-45 at the north portion of P(1-45E) from movement in the vertical and east/west directions.

$nd1047_{PUBY_0} := 1047$ Node associated with support

$\left(AL1_{PUBY\_nd1047} \;\; AL2_{PUBY\_nd1047}\right) := \text{Support}\left(NF, nd1047_{PUBY}, Sup\_C_{o\_PUBY}, EL\right)$

$AL1_{PUBY\_nd1047}^{T} = \left(0.185 \;\; -834.699 \;\; 8.535 \;\; 1.047 \times 10^{3} \;\; 62\right)$

$AL2_{PUBY\_nd1047}^{T} = (0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0)$

C,demand force, occurrence time, ned node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

Pending U-Bolt (EW) (Node 1047)

The pending U-Bolt support supports line 1-45 at the north portion of P(1-45E) from movement in the vertical and east/west directions.

$nd1047_{PUBZ_0} := 1047$ Node associated with support

$\left(AL1_{PUBZ\_nd1047} \;\; AL2_{PUBZ\_nd1047}\right) := \text{Support}\left(NF, nd1047_{PUBZ}, Sup\_C_{o\_PUBZ}, EL\right)$

$AL1_{PUBZ\_nd1047}^{T} = \left(0.46 \;\; -233.308 \;\; 8.53 \;\; 1.047 \times 10^{3} \;\; 62\right)$

$AL2_{PUBZ\_nd1047}^{T} = \left(0.322 \;\; 163.249 \;\; 6.89 \;\; 1.047 \times 10^{3} \;\; 62\right)$

D/C,demand force, occurrence time, efined node, associated index for the reaction force at the selected node eing in the positive (AL1) and negative AL2) directions of the global coordinate system)

Writing Output Data for Supports Associated with Line 45

$SA1 := AL1_{UB2Y\_nd1045}^{T}$ $SC1 := AL1_{PUBY\_nd1047}^{T}$

$SA2 := AL2_{UB2Y\_nd1045}^{T}$ $SC2 := AL2_{PUBY\_nd1047}^{T}$

$SB1 := AL1_{UB2Z\_nd1045}^{T}$ $SD1 := AL1_{PUBZ\_nd1047}^{T}$

$SB2 := AL2_{UB2Z\_nd1045}^{T}$ $SD2 := AL2_{PUBZ\_nd1047}^{T}$

$S := (SA1 \;\; SA2 \;\; SB1 \;\; SB2 \;\; SC1 \;\; SC2 \;\; SD1 \;\; SD2)$

SupportsLine_45 := WRITEPRN("SupLine_45.prn" , S)

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TERMINATION LOCATIONS

Termination Locations Strategy: *Search based on the node for which the termination location acts as well as the next node inward. The D/C ratio for each termination location will be found by dividing the the required force found above by the support capacity.*

$$\mathrm{TermDC}\left(P, D_o, t, I, B_1, B_2, M, S\right) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$$\mathrm{Term}\left(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL\right) :=$$

$$
\begin{array}{l}
ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right) \\
\text{for } i \in 1 .. \mathrm{last}(nd) \qquad \text{if } \mathrm{rows}(nd) > 1 \\
\quad ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \\
\left(M \;\; Int_0\right) \leftarrow (0 \;\; 0) \\
\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0} \\
\quad \text{for } j \in 0 .. \mathrm{last}\left(ind_{nd}\right) \\
\quad\quad M_{rxg} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{nd_j}} \\
\quad\quad M_{ryg} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{nd_j}} \\
\quad\quad M_{rzg} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{nd_j}} \\
\quad\quad M_{rx} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg} \\
\quad\quad M_{ry} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg} \\
\quad\quad M_{rz} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg} \\
\quad\quad M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2} \\
\quad\quad Int'_j \leftarrow \mathrm{TermDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right) \\
\quad\quad \text{if } Int'_j > Int_0 \\
\quad\quad\quad Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfiC_{o_{0,1}}-1}+i,0}, EL_{ind_{nd_j},1}, ind_{nd_j}, M_{rx}, M_{ry}, M_{r}\right. \\
\quad\quad\quad Result \leftarrow M' \\
Int
\end{array}
$$

Conditions applicable to all terminations

$M_{cx} := 0 \qquad M_{cy} := 0 \qquad M_{cz} := 0$

Defining place holding variables

$$Term\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Surge Tank Connection 1-45 (1x)

Define pertinent pipe variables

$D_o := 6.625in$ — Outside Diameter [33]

$t := 0.28in$ — Thickness [33]

$P := 253psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

$I = 28.142\ in^4$

Moment of inertia [8, Table 17-27, pg 17-39]

$S := S_{125}$ — Allowable design stress intensity value

Define primary stress indices

$B_1 := 0.5$

$$B_2 := \begin{vmatrix} 1.0 \ \text{ if } \ \frac{D_o}{t} \le 50 \\ \text{if } \ \frac{D_o}{t} > 50 \\ \quad \begin{vmatrix} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \frac{D_o}{t}\right) \\ Y \leftarrow 1 \\ 1.0 \cdot \frac{1}{X \cdot Y} \end{vmatrix} \end{vmatrix}$$

$B_2 = 1$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Surge Tank Connection 1-45 (Node 1006)

$nd1006_{ST145_0} := 1006$

$AL_{ST145\_nd1006} := Term\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd1006_{ST145}, Term\_C_o, EL\right)$

$AL_{ST145\_nd1006}^{T} = \left(0.067 \quad 1.969\times10^{4} \quad 6.89 \quad 1.006\times10^{3} \quad 19 \quad -1.41\times10^{3} \quad 1.911\times10^{4} \quad -4.549\times10\right.$

Writing Output Data for Terminations Associated with Line 1-45

$T1 := \left(AL_{ST145\_nd1006}^{T}\right)$ Surge Tank Connection 1-45 (Node 1006)

$T := (T1)$

TerminationsLine_45 := WRITEPRN("TermLine_45.prn" , T)

PIPE RUNS

Pipe Runs Strategy: *Search based on the nodes present in each run of pipe. Find the maximum moment combination among all of the nodes and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{PipeRunDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{PipeRun}(P, D_o, t, I, B_1, B_2, S, nf, el, C_o, EL) :=$

$$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$$

$$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$$

$$ind_{el} \leftarrow \mathrm{match}\left(el_0, EL^{\langle 0 \rangle}\right)$$

for $i \in 1 .. \mathrm{last}(el)$ if $\mathrm{rows}(el) > 1$

$$ind_{el} \leftarrow \mathrm{stack}\left[ind_{el}, \left(\mathrm{match}\left(el_i, EL^{\langle 0 \rangle}\right)\right)\right]$$

$$\left(M \quad Int_{5, \mathrm{last}(ind_{el})}\right) \leftarrow (0 \quad 0)$$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

for $j \in 0 .. \mathrm{last}(ind_{el})$

$$M_{rxg} \leftarrow nf_{ind_{nfi}C_{o_{0,1}}+2, ind_{el_j}}$$

$$M_{ryg} \leftarrow nf_{ind_{nfi}C_{o_{1,1}}+2, ind_{el_j}}$$

$$M_{rzg} \leftarrow nf_{ind_{nfi}C_{o_{2,1}}+2, ind_{el_j}}$$

$$M_{rx_j} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}}+2+i, ind_{el_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$$

$$M_{ry_j} \leftarrow \left(nf_{ind_{nfi}C_{o_{1,1}}+2+i, ind_{el_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$$

$$M_{rz_j} \leftarrow \left(nf_{ind_{nfi}C_{o_{2,1}}+2+i, ind_{el_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$$

$$M'_j \leftarrow \sqrt{\left(M_{rx_j}\right)^2 + \left(M_{ry_j}\right)^2 + \left(M_{rz_j}\right)^2}$$

$$Int'_j \leftarrow \mathrm{PipeRunDC}(P, D_o, t, I, B_1, B_2, M'_j, S)$$

if $Int'_j > Int_{0,j}$

$$H \leftarrow \left(Int'_j \quad M'_j \quad nf_{ind_{nfi}C_{o_{0,1}}-1+i, 0} \quad EL_{ind_{el_j}, 0} \quad EL_{ind_{el_j}, 1} \quad ind_{el_j} \quad M_{r} \right.$$

for $k \in 0 .. 5$

$$Int_{k,j} \leftarrow H_k$$

Int

Conditions applicable to all pipe runs

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$

Defining place holding directional moment variables

$$PipeRun\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties for Line 1-45

Define pertinent pipe variables

$D_o := 6.625\,in$ Outside Diameter [33]

$t := 0.281\,in$ Thickness [33]

$P := 253\,psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 28.23\,in^4$$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{vmatrix} 1.0 \text{ if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 \\ \quad \begin{vmatrix} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \frac{D_o}{t}\right) \\ Y \leftarrow 1.033 - 0.00033 \cdot T \\ 1.0 \cdot \frac{1}{X \cdot Y} \end{vmatrix} \end{vmatrix}$$

$B_{2PR} = 1$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-45 (Element 614)

$$el_{P145A} := (614)^T$$

$$AL_{P145A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P145A}, PipeRun\_C_o, EL\right)$$

$$AL_{P145A}^T = \begin{pmatrix} 0.057 & 1.473\times10^4 & 7.455 & 614 & 1.007\times10^3 & 7 \\ 0.057 & 1.485\times10^4 & 4.055 & 614 & 1.019\times10^3 & 8 \end{pmatrix}$$

Pipe Run 1-45B (Element 615)

$$el_{P145B} := (615)^T$$

$$AL_{P145B} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P145B}, PipeRun\_C_o, EL\right)$$

$$AL_{P145B}^T = \begin{pmatrix} 0.062 & 1.745\times10^4 & 7.455 & 615 & 1.008\times10^3 & 9 \\ 0.061 & 1.693\times10^4 & 7.455 & 615 & 1.009\times10^3 & 10 \end{pmatrix}$$

Pipe Run 1-45C (Elements 616 & 627)

$$el_{P145C} := (616 \quad 627)^T$$

$$AL_{P145C} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P145C}, PipeRun\_C_o, EL\right)$$

$$AL_{P145C}^T = \begin{pmatrix} 0.055 & 1.365\times10^4 & 7.455 & 616 & 1.01\times10^3 & 11 \\ 0.044 & 8.657\times10^3 & 4.205 & 616 & 1.032\times10^3 & 12 \\ 0.047 & 1.012\times10^4 & 10.02 & 627 & 1.015\times10^3 & 39 \\ 0.044 & 8.657\times10^3 & 4.205 & 627 & 1.032\times10^3 & 40 \end{pmatrix}$$

Pipe Run 1-45D (Elements 617 & 628)

$$el_{P145D} := (617 \quad 628)^T$$

$$AL_{P145D} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P145D}, PipeRun\_C_o, EL\right)$$

$$AL_{P145D}^T = \begin{pmatrix} 0.048 & 1.048\times10^4 & 10.02 & 617 & 1.016\times10^3 & 13 \\ 0.049 & 1.11\times10^4 & 8.53 & 617 & 1.033\times10^3 & 14 \\ 0.049 & 1.109\times10^4 & 8.53 & 628 & 1.017\times10^3 & 41 \\ 0.049 & 1.11\times10^4 & 8.53 & 628 & 1.033\times10^3 & 42 \end{pmatrix}$$

Pipe Run 1-45E (Elements 618, 629, 631, & 632)

$el_{P145E} := (618\ \ 629\ \ 631\ \ 632)^T$

$AL_{P145E} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P145E}, PipeRun\_C_o, EL\right)$

$${AL_{P145E}}^T = \begin{pmatrix} 0.048 & 1.055\times10^4 & 8.53 & 618 & 1.018\times10^3 & 15 \\ 0.047 & 9.84\times10^3 & 8.53 & 618 & 1.034\times10^3 & 16 \\ 0.047 & 9.782\times10^3 & 8.53 & 629 & 1.034\times10^3 & 43 \\ 0.039 & 6.235\times10^3 & 8.525 & 629 & 1.035\times10^3 & 44 \\ 0.039 & 6.237\times10^3 & 8.525 & 631 & 1.035\times10^3 & 45 \\ 0.057 & 1.501\times10^4 & 5.81 & 631 & 1.037\times10^3 & 46 \\ 0.049 & 1.108\times10^4 & 9.885 & 632 & 1.011\times10^3 & 47 \\ 0.057 & 1.503\times10^4 & 5.81 & 632 & 1.037\times10^3 & 48 \end{pmatrix}$$

Pipe Run 1-45F (Elements 619 & 633)

$el_{P145F} := (619\ \ 633)^T$

$AL_{P145F} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P145F}, PipeRun\_C_o, EL\right)$

$${AL_{P145F}}^T = \begin{pmatrix} 0.046 & 9.721\times10^3 & 7.455 & 619 & 1.012\times10^3 & 17 \\ 0.038 & 5.494\times10^3 & 10.01 & 619 & 1.038\times10^3 & 18 \\ 0.061 & 1.665\times10^4 & 10.015 & 633 & 1.013\times10^3 & 49 \\ 0.038 & 5.494\times10^3 & 10.01 & 633 & 1.038\times10^3 & 50 \end{pmatrix}$$

Pipe Run 1-45G (Element 620)

$el_{P145G} := (620)^T$

$AL_{P145G} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P145G}, PipeRun\_C_o, EL\right)$

$${AL_{P145G}}^T = \begin{pmatrix} 0.067 & 1.969\times10^4 & 6.89 & 620 & 1.006\times10^3 & 19 \\ 0.067 & 1.95\times10^4 & 6.89 & 620 & 1.014\times10^3 & 20 \end{pmatrix}$$

Writing Output Data for Pipe Runs Associated with Line 1-45

$PR1 := \left(AL_{P145A}^{T}\right)$

$PR2 := \left(AL_{P145B}^{T}\right)$

$PR3 := \left(AL_{P145C}^{T}\right)$

$PR4 := \left(AL_{P145D}^{T}\right)$

$PR5 := \left(AL_{P145E}^{T}\right)$

$PR6 := \left(AL_{P145F}^{T}\right)$

$PR7 := \left(AL_{P145G}^{T}\right)$

$P := (PR1 \quad PR2 \quad PR3 \quad PR4 \quad PR5 \quad PR6 \quad PR7)$

PipeRunsLine_45 := WRITEPRN("PRLine_45.prn" , P)

ELBOWS

Elbows Strategy: *Search based on the two nodes comprising the ends of each elbow. SRSS combine the three moments of each of the four node representations (one for each element connected by the nodes in question). Find the maximum of the four moment combinations and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\text{ElbowDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1 \text{lbf} \cdot \text{in})]}{S}$$

$$\text{Elbow}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$$

$$\begin{array}{l}
ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
ind_{nd} \leftarrow \text{match}\left(nd_0, EL^{\langle 1 \rangle}\right) \\
\text{for } i \in 1 .. \text{last}(nd) \qquad \text{if rows}(nd) > 1 \\
\quad ind_{nd} \leftarrow \text{stack}\left[ind_{nd}, \left(\text{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \\
(M \ \ Int_0) \leftarrow (0 \ \ 0) \\
\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0} \\
\quad \text{for } j \in 0 .. \text{last}(ind_{nd}) \\
\qquad M_{rxg} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}}+2, ind_{nd_j}} \\
\qquad M_{ryg} \leftarrow nf_{ind_{nfi_{C_{o_{1,1}}}}+2, ind_{nd_j}} \\
\qquad M_{rzg} \leftarrow nf_{ind_{nfi_{C_{o_{2,1}}}}+2, ind_{nd_j}} \\
\qquad M_{rx} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}}+2+i, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg} \\
\qquad M_{ry} \leftarrow \left(nf_{ind_{nfi_{C_{o_{1,1}}}}+2+i, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg} \\
\qquad M_{rz} \leftarrow \left(nf_{ind_{nfi_{C_{o_{2,1}}}}+2+i, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg} \\
\qquad M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2} \\
\qquad Int'_j \leftarrow \text{ElbowDC}(P, D_o, t, I, B_1, B_2, M'_j, S) \\
\qquad \text{if } Int'_j > Int_0 \\
\qquad\quad Int \leftarrow \text{stack}\left(Int'_j, M'_j, nf_{ind_{nfi_{C_{o_{0,1}}}}-1+i, 0}, EL_{ind_{nd_j}, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M \right. \\
\qquad\quad Result \leftarrow M' \\
Int
\end{array}$$

Conditions applicable to all elbows

$M_{ox} := 0 \quad M_{oy} := 0 \quad M_{oz} := 0$

Defining place holding variables

$$Elb\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Elbow Properties for Line 1-45

Define pertinent elbow variables

$D_o := 6.625\,in$ — Outside Diameter [33]

$t := 0.28\,in$ — Thickness [33]

$P := 253\,psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 28.142\,in^4$

$R := 1.5\cdot D_o$ — Nominal bend radius of curved pipe or elbow

$r_m := \frac{D_o - t}{2}$ — Mean pipe radius

Define primary stress indices

$h := \frac{t\cdot R}{r_m^{\,2}}$ $\quad h = 0.276$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4\cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4\cdot h > 0.5 \\ -0.1 + 0.4\cdot h & \text{otherwise} \end{cases}$$

$B_1 = 0.011$ — B_1 primary stress Index [9, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 3.063$ — B_2 primary stress Index [9, NB-3683.7]

Elbow 1-45A (Nodes 1007 & 1008)

$nd_{EL145A\_1} := (1007)^T$

$AL_{EL145A\_nd1007} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL145A\_1}, Elb\_C_o, EL)$

$AL_{EL145A\_nd1007}{}^T = (0.094 \quad 1.473\times10^4 \quad 7.455 \quad 1.007\times10^3 \quad 21 \quad -1.038\times10^4 \quad 1.997\times10^3 \quad -1.026$

$nd_{EL145A\_2} := (1008)^T$

$AL_{EL145A\_nd1008} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL145A\_2}, Elb\_C_o, EL)$

$AL_{EL145A\_nd1008}{}^T = (0.112 \quad 1.745\times10^4 \quad 7.455 \quad 1.008\times10^3 \quad 9 \quad -4.525\times10^3 \quad 2.8\times10^3 \quad -1.662\times1($

Elbow 1-45B (Nodes 1009 & 1010)

$nd_{EL145B\_1} := (1009)^T$

$AL_{EL145B\_nd1009} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL145B\_1}, Elb\_C_o, EL)$

$AL_{EL145B\_nd1009}{}^T = (0.108 \quad 1.693\times10^4 \quad 7.455 \quad 1.009\times10^3 \quad 24 \quad -1.154\times10^3 \quad 3.053\times10^3 \quad -1.662$

$nd_{EL145B\_2} := (1010)^T$

$AL_{EL145B\_nd1010} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL145B\_2}, Elb\_C_o, EL)$

$AL_{EL145B\_nd1010}{}^T = (0.087 \quad 1.365\times10^4 \quad 7.455 \quad 1.01\times10^3 \quad 11 \quad 3.095\times10^3 \quad 3.256\times10^3 \quad -1.289\times1$

Elbow 1-45C (Nodes 1015 & 1016)

$nd_{EL145C\_1} := (1015)^T$

$AL_{EL145C\_nd1015} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL145C\_1}, Elb\_C_o, EL)$

$AL_{EL145C\_nd1015}{}^T = (0.065 \quad 1.012\times10^4 \quad 10.02 \quad 1.015\times10^3 \quad 27 \quad 483.463 \quad -4.716\times10^3 \quad 8.946\times10$

$nd_{EL145C\_2} := (1016)^T$

$AL_{EL145C\_nd1016} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL145C\_2}, Elb\_C_o, EL)$

$AL_{EL145C\_nd1016}{}^T = (0.067 \quad 1.048\times10^4 \quad 10.02 \quad 1.016\times10^3 \quad 13 \quad 402.268 \quad -4.889\times10^3 \quad 9.256\times10$

Elbow 1-45D (Nodes 1017 & 1018)

$nd_{EL145D\_1} := (1017)^T$

$AL_{EL145D\_nd1017} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL145D\_1}, Elb\_C_o, EL)$

$AL_{EL145D\_nd1017}^T = (0.071 \quad 1.109\times10^4 \quad 8.53 \quad 1.017\times10^3 \quad 30 \quad 2.495\times10^3 \quad -4.436\times10^3 \quad 9.851\times$

$nd_{EL145D\_2} := (1018)^T$

$AL_{EL145D\_nd1018} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL145D\_2}, Elb\_C_o, EL)$

$AL_{EL145D\_nd1018}^T = (0.068 \quad 1.055\times10^4 \quad 8.53 \quad 1.018\times10^3 \quad 15 \quad 2.78\times10^3 \quad -4.699\times10^3 \quad 9.028\times1$

Elbow 1-45E (Nodes 1011 & 1012)

$nd_{EL145E\_1} := (1011)^T$

$AL_{EL145E\_nd1011} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL145E\_1}, Elb\_C_o, EL)$

$AL_{EL145E\_nd1011}^T = (0.071 \quad 1.108\times10^4 \quad 9.885 \quad 1.011\times10^3 \quad 47 \quad -2.014\times10^3 \quad -1.079\times10^4 \quad 1.56\times$

$nd_{EL145E\_2} := (1012)^T$

$AL_{EL145E\_nd1012} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL145E\_2}, Elb\_C_o, EL)$

$AL_{EL145E\_nd1012}^T = (0.062 \quad 9.722\times10^3 \quad 7.455 \quad 1.012\times10^3 \quad 34 \quad 12.487 \quad -9.718\times10^3 \quad -280.162)$

Elbow 1-45F (Nodes1013 & 1014)

$nd_{EL145F\_1} := (1013)^T$

$AL_{EL145F\_nd1013} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL145F\_1}, Elb\_C_o, EL)$

$AL_{EL145F\_nd1013}^T = (0.106 \quad 1.665\times10^4 \quad 10.015 \quad 1.013\times10^3 \quad 36 \quad -433.903 \quad 1.622\times10^4 \quad 3.728\times1$

$nd_{EL145F\_2} := (1014)^T$

$AL_{EL145F\_nd1014} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL145F\_2}, Elb\_C_o, EL)$

$AL_{EL145F\_nd1014}^T = (0.125 \quad 1.95\times10^4 \quad 6.89 \quad 1.014\times10^3 \quad 20 \quad 1.88\times10^3 \quad -1.911\times10^4 \quad 3.377\times10^3$

Writing Output Data for Elbows Associated with Line 1-45

$EL1A := \left(AL_{EL145A\_nd1007}^{T}\right)$

$EL1B := \left(AL_{EL145A\_nd1008}^{T}\right)$

$EL2A := \left(AL_{EL145B\_nd1009}^{T}\right)$

$EL2B := \left(AL_{EL145B\_nd1010}^{T}\right)$

$EL3A := \left(AL_{EL145C\_nd1015}^{T}\right)$

$EL3B := \left(AL_{EL145C\_nd1016}^{T}\right)$

$EL4A := \left(AL_{EL145D\_nd1017}^{T}\right)$

$EL4B := \left(AL_{EL145D\_nd1018}^{T}\right)$

$EL5A := \left(AL_{EL145E\_nd1011}^{T}\right)$

$EL5B := \left(AL_{EL145E\_nd1012}^{T}\right)$

$EL6A := \left(AL_{EL145F\_nd1013}^{T}\right)$

$EL6B := \left(AL_{EL145F\_nd1014}^{T}\right)$

$vEL := (EL1A\ \ EL1B\ \ EL2A\ \ EL2B\ \ EL3A\ \ EL3B\ \ EL4A\ \ EL4B\ \ EL5A\ \ EL5B\ \ EL6A\ \ EL6B)$

ElbowLine_45 := WRITEPRN("ElbowLine_45.prn" , vEL)

FORGED TEES AND FABRICATED BRANCH TEES

Tees Strategy: *Search based on the elements comprising the tee. The input identifies which elements are associated with the pipe run and which element is associated with the branch from the run. The indices for the defined common node for all three elements is identified and the associated SRSS moment is identified for each time step. The maximum moment for the elements comprising the pipe run is found and applied as M_r in equation (9) of ASME III, Division I - NB - 3652 which is modified to represent tees. The maximum moment for the branch element is found and applied as M_b in equation (9) of ASME III, Division I - NB - 3652 [9]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$TeeDC(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_b, M_r, Z_b, Z_r, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot T_r} + B_{2b} \cdot \left[\frac{M_b \cdot (1lbf \cdot in)}{Z_b}\right] + B_{2r} \cdot \left[\frac{M_r \cdot (1lbf \cdot in)}{Z_r}\right]}{S}$$

$Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S, nf, el_R, el_B, nd_R, nd_B, C_o, EL) :=$

$ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{elR} \leftarrow match\left(el_{R_0}, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(el_R)$ if rows

 $ind_{elR} \leftarrow stack\left[ind_{elR}, \left(match\left(el_{R_i}, EL^{\langle 0 \rangle}\right)\right)\right]$

$EL'R_{last\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$

for $i \in 0 .. last(ind_{elR})$

 $EL'R_{ind_{elR_i}} \leftarrow EL_{ind_{elR_i}, 1}$

$ind_{ndR} \leftarrow match\left(nd_{R_0}, EL'R^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(nd_R)$ if r

 $ind_{ndR} \leftarrow stack\left[ind_{ndR}, \left(match\left(nd_{R_i}, EL'R^{\langle 0 \rangle}\right)\right)\right]$

$ind_{elB} \leftarrow match\left(el_{B_0}, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(el_B)$ if rows

 $ind_{elB} \leftarrow stack\left[ind_{elB}, \left(match\left(el_{B_i}, EL^{\langle 0 \rangle}\right)\right)\right]$

$EL'B_{last\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$

for $i \in 0 .. last(ind_{elB})$

 $EL'B_{ind_{elB_i}} \leftarrow EL_{ind_{elB_i}, 1}$

$ind_{ndB} \leftarrow match\left(nd_{B_0}, EL'B^{\langle 0 \rangle}\right)$

for $i \in 1 .. \text{last}(nd_B)$ if r

$ind_{ndB} \leftarrow \text{stack}\left[ind_{ndB}, \left(\text{match}\left(nd_{B_i}, EL'B^{\langle 0 \rangle}\right)\right)\right]$

$(M_R \;\; M_B \;\; Int_0) \leftarrow (0 \;\; 0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

for $j \in 0 .. \text{last}(ind_{ndR})$

for $k \in 0 .. \text{last}(ind_{ndB})$

$M_{rxgR_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{ndR_j}}$

$M_{rygR_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{ndR_j}}$

$M_{rzgR_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{ndR_j}}$

$M_{rxR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{ndR_j}} - M_{rxgR_j}\right) \cdot C$

$M_{ryR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{ndR_j}} - M_{rygR_j}\right) \cdot C$

$M_{rzR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{ndR_j}} - M_{rzgR_j}\right) \cdot C$

$M_{R_j} \leftarrow \sqrt{\left(M_{rxR_j}\right)^2 + \left(M_{ryR_j}\right)^2 + \left(M_{rzR_j}\right)^2}$

$M_{rxgB_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{ndB_k}}$

$M_{rygB_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{ndB_k}}$

$M_{rzgB_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{ndB_k}}$

$M_{rxB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{ndB_k}} - M_{rxgB_j}\right) \cdot C$

$M_{ryB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{ndB_k}} - M_{rygB_j}\right) \cdot C$

$M_{rzB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{ndB_k}} - M_{rzgB_j}\right) \cdot C$

$M_{B_j} \leftarrow \sqrt{\left(M_{rxB_j}\right)^2 + \left(M_{ryB_j}\right)^2 + \left(M_{rzB_j}\right)^2}$

$Int'_j \leftarrow \text{TeeDC}\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_{B_j}, M_R\right.$

if $Int'_j > Int_0$

$Int \leftarrow \text{stack}\left(Int'_j, M_{R_j}, M_{B_j}, nf_{ind_{nfiC_{o_{0,1}}}-1+i}\right.$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** R. K. Blandford **Date:** 09/30/2008

$Result \leftarrow stack(M_{R_j}, M_{B_j}, M_{rxR_j}, M_{ryR_j}, M$

$M \leftarrow M_R$

Int

Conditions applicable to forged tee

$M_{cx} := 0$ $M_{cy} := 0$ $M_{cz} := 0$

Defining place holding directional moment variables

$$Tee\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

TEE (Line 1-45)

Define pertinent tee variables

$P := 253psi$ — Internal Pressure [3, pg 23]

$D_o := 20in$ — Outside Diameter of Pipe Run [4]

$d_o := 6.625in$ — Outside Diameter of Branch [33]

$B_1 := 0.5$ — B_1 primary stress Index for tees and branches [9, NB-3683.9]

$T_r := 0.312in$ — Nominal wall thickness of designated run pipe [4]

$$R_m := \frac{D_o - T_r}{2}$$

Mean radius of designated run pipe

$$Z_r := \pi \cdot R_m^{\,2} \cdot T_r$$

Approximate section modulus of designated run pipe [9, NB-3683.1(d)]

$$Z_r = 94.9834\ in^3$$

$T'_b := 0.28in$ — Nominal wall thickness of attached branch pipe [33]

$$r'_m := \frac{d_o - T'_b}{2}$$

Mean radius of attached branch pipe

$$Z_b := \pi \cdot r'^{\,2}_m \cdot T'_b$$

Approximate section modulus of attached branch pipe [9, NB-3683.1(d)]

$$Z_b = 8.853\ in^3$$

C_{2b} Secondary stress Index [9,NB-3683.8]

$$C_{2b} := \begin{cases} 1.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}}\cdot\left(\frac{r'_m}{R_m}\right)^{\frac{1}{2}}\cdot\left(\frac{T'_b}{T_r}\right)\cdot\left(\frac{r'_m}{\frac{d_o}{2}}\right) & \text{if } 1.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}}\cdot\left(\frac{r'_m}{R_m}\right)^{\frac{1}{2}}\cdot\left(\frac{T'_b}{T_r}\right)\cdot\left(\frac{r'_m}{\frac{d_o}{2}}\right) \ge 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$$C_{2b} = 7.308$$

C_{2r} Secondary stress Index [9,NB-3683.8]

$$t_n := T'_b$$

Wall thickness of nozzle or branch connection reinforcement associated with [9, NB-3643.4(A)-1, sketch (d)]

$$C_{2r} := \begin{cases} 1.15\cdot\left(\frac{r'_m}{t_n}\right)^{\frac{1}{4}} & \text{if } 1.15\cdot\left(\frac{r'_m}{t_n}\right)^{\frac{1}{4}} \ge 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$$C_{2r} = 2.11$$

$$B_{2b} := \begin{cases} 0.5\cdot C_{2b} & \text{if } 0.5\cdot C_{2b} \ge 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Index for branches [9, NB-3683.8]

$$B_{2b} = 3.654$$

$$B_{2r} := \begin{cases} 0.75\cdot C_{2r} & \text{if } 0.75\cdot C_{2r} \ge 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Index for branches [9, NB-3683.8]

$$B_{2r} = 1.582$$

Tee 1-45 (Nodes 122 & 1019)

$$elR_{Tee145} := (91 \quad 92)^T$$

Elements associated with pipe run

$$ndR_{Tee145} := (122)^T$$

Node between pipe run elements

$$elB_{Tee145} := (613)^T$$

Element associated with branch

$$ndB_{Tee145} := (1019)^T$$

Node where branch intersects pipe run

$$AL_{Tee145} := Tee\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF, elR_{Tee145}, elB_{Tee145}, ndR_{Tee145}, ndB_{Tee145}, Tee\_C\right.$$

$$AL_{Tee145}^{\ T} = \left(0.196 \quad 5.554\times10^{4} \quad 1.485\times10^{4} \quad 4.055 \quad 122 \quad 2 \quad 4 \quad 6\right)$$

Writing Output Data for Tees Associated with Lines 1-44, 1-46, & 8-14

$Tee1 := AL_{Tee145}^{T}$

$Tee := (Tee1)$

TeeLine_45 := WRITEPRN("TeeLine_45.prn" , Tee)

FLANGES

Flange Strategy: *Search based on the nodes where flanges occur. Find the maximum moment combination for the node and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\mathrm{FlangeDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Flange}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(nd)$ if $\mathrm{rows}(nd) > 1$

  $ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$\begin{pmatrix} M & Int_0 \end{pmatrix} \leftarrow \begin{pmatrix} 0 & 0 \end{pmatrix}$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \mathrm{last}(ind_{nd})$

    $M_{rxg} \leftarrow nf_{ind_{nfi}C_{o_{0,1}}+2,\, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi}C_{o_{1,1}}+2,\, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi}C_{o_{2,1}}+2,\, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi}C_{o_{1,1}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi}C_{o_{2,1}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow \mathrm{FlangeDC}(P, D_o, t, I, B_1, B_2, M'_j, S)$

    if $Int'_j > Int_0$

      $Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfi}C_{o_{0,1}}-1+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M\right.$

      $Result \leftarrow M'$

Int

Conditions applicable to all flanges

$M_{cx} := 0$ $M_{cy} := 0$ $M_{cz} := 0$

Defining place holding variables

$$Flange\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties of Lines 1-45

Define pertinent pipe variables

$D_o := 6.625 in$ Outside Diameter [33]

$t := 0.28 in$ Thickness [33]

$P := 253 psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^4 - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 28.142\ in^4$

Define primary stress indices (Utilize girth weld characteristic associated with lap joint flanges in determining values)

$B_1 := 0.5$ B_1 for a girth weld [9, Table NB-3681(a)-1, pg 130]

$B_2 := 1$ B_2 for a girth weld [9, Table NB-3681(a)-1, pg 130]

Flange (Gate Valve) 1-45A (Node 1006)

$nd_{FL145A} := (1006)^T$

$AL_{FL145A} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL145A}, Flange\_C_o, EL\right)$

$$AL_{FL145A}^T = \left(0.067 \quad 1.969 \times 10^4 \quad 6.89 \quad 1.006 \times 10^3 \quad 19 \quad -1.41 \times 10^3 \quad 1.911 \times 10^4 \quad -4.549 \times 10^3\right)$$

Writing Output Data for Flanges Associated with Lines 1-44, 1-46, & 8-14

$F1 := \left(AL_{FL145A}^T\right)$

$F := (F1)$

FlangeLine_45 := WRITEPRN("FlangeLine_45.prn" , F)

Appendix C.3.7

Demand to Capacity Ratio Calculations for Components Associated with Unlisted Components of ATR PCS Model 265

(NOTE: Values represented here are shown for one realization (Nodal Force file = UNLIST_COMPS_test_R1.dat and Element/Nodal order file = EL_Unlist_Comps.xls)and may or may not be consistent with the 80th percentile results contained in Appendix C.4)

Force Outputs from Abaqus

NF := ...\UNLIST_COMPS.dat

(N)odal (F)orces for the (M)edium (L)ines of Model 3

Defined Elemental and Corresponding Nodal Order

EL := ...\EL_UNLIST_COMPS(9-22-08).xls

Element and corresponding nodal order for the (M)edium (L)ines of Model 3

Time Boundaries

$t_{initial} := 1$

Initial time for which dynamic loading is applied

$t_{final} := 21$

Final time for which dynamic loading stops

Seismic Scale Factor (F_a)

$F_a := 1$

Seismic scale factor [30]

Allowable Design Stress Intensity Factor (S_m): *S_m is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{m\_125} := 20ksi$

For SS304 at 125°F [2, pg 316-318] [3, pg 23]

$S_{m\_125L} := 16.7ksi$

For SS304L at 125°F [2, pg 316-318] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Yield Strength (S_y): *S_y is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{y\_125} := 28.35ksi$

For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_125L} := 23.85ksi$

For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Maximum Strength Applicable for Equation 9 (S): *S is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{125} := \min\left(3 \cdot S_{m\_125}, 2 \cdot S_{y\_125}\right)$

$\boxed{S_{125} = 56.7\,ksi}$

Maximum allowable stress applied to SS304 piping [9, NB-3656]

$S_{125L} := \min\left(3 \cdot S_{m\_125L}, 2 \cdot S_{y\_125L}\right)$

$\boxed{S_{125L} = 47.7\,ksi}$

Maximum allowable stress applied to SS304L piping [9, NB-3656]

REDUCERS

Reducers Strategy: *Search based on the nodes comprising either end of the reducers. SRSS combine the three moments of each of the four node representations (one for each element connected by the node in question). Find the maximum of the moment combinations for each element and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. It is important to not combine the data from both nodes as the geometry for each is different and (9) must be applied for each node. The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\mathrm{ReducerDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Reducer}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(nd)$ if $\mathrm{rows}(nd) > 1$

  $ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$(M \;\; Int_0) \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \mathrm{last}(ind_{nd})$

    $M_{rxg} \leftarrow nf_{ind_{nfi}C_{o_{0,1}}+2, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi}C_{o_{1,1}}+2, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi}C_{o_{2,1}}+2, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}}+2+i, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi}C_{o_{1,1}}+2+i, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi}C_{o_{2,1}}+2+i, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow \mathrm{ReducerDC}(P, D_o, t, I, B_1, B_2, M'_j, S)$

    if $Int'_j > Int_0$

      $Int \leftarrow \mathrm{stack}\Big(Int'_j, M'_j, nf_{ind_{nfi}C_{o_{0,1}}-1+i, 0}, EL_{ind_{nd_j}, 1}, ind_{nd_j}, M_{rx}, M_{ry},$

      $Result \leftarrow M'$

Int

Conditions applicable to all reducers

$M_{cx} := 0$ $M_{cy} := 0$ $M_{cz} := 0$ Defining place holding variables

$$Reducer\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

Reducer Properties for Top of Lines 1-17 to 1-43

Define pertinent reducer variables

$D_o := (30in\ \ 10.75in)^T$ Outside Diameter [4] [11]

$t := \left(0.438in\ \ \frac{1}{4}in\right)^T$ Thickness [4] [11]

$P := (253psi\ \ 253psi)^T$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = \begin{pmatrix} 4.445 \times 10^3 \\ 113.714 \end{pmatrix} in^4$$

Define primary stress indices

$B_1 := 4.484$

$B_2 := 0.213$ with cont elements See Appendix F

Fab Red 1-17 (Nodes 63 & 225)

$nd_{FabRed117\_L} := (63)^T$ Node associated with Large end of reducer

$$AL_{FabRed117\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF, nd_{FabRed117\_L}, Reducer\_C_o, EL\right)$$

$$AL_{FabRed117\_L}^{\ T} = \left(0.688\ \ 1.85 \times 10^5\ \ 10.345\ \ 63\ \ 4\ \ 1.443 \times 10^5\ \ 4.488 \times 10^4\ \ -1.067 \times 10^5\right)$$

$nd_{FabRed117\_S} := (225)^T$ Node associated with Small end of reducer

$$AL_{FabRed117\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF, nd_{FabRed117\_S}, Reducer\_C_o, EL\right)$$

$$AL_{FabRed117\_S}^{\ T} = \left(0.465\ \ 1.967 \times 10^5\ \ 9.165\ \ 225\ \ 10\ \ -1.34 \times 10^5\ \ -7.741 \times 10^4\ \ 1.214 \times 10^5\right)$$

Writing Output Data for Fabricated Reducers Associated with Lines 1-17 and 1-43

$FRL1 := AL_{FabRed117\_L}^{\ T}$ $FRS1 := AL_{FabRed117\_S}^{\ T}$

FabReducer := WRITEPRN["FabReducer.prn" , (FRL1   FRS1)]

FORGED TEES AND FABRICATED BRANCH TEES

Tees Strategy: *Search based on the elements comprising the tee. The input identifies which elements are associated with the pipe run and which element is associated with the branch from the run. The indices for the defined common node for all three elements is identified and the associated SRSS moment is identified for each time step. The maximum moment for the elements comprising the pipe run is found and applied as* M_r *in equation (9) of ASME III, Division I - NB - 3652 which is modified to represent tees. The maximum moment for the branch element is found and applied as* M_b *in equation (9) of ASME III, Division I - NB - 3652 [9]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{TeeDC}\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_b, M_r, Z_b, Z_r, S\right) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot T_r} + B_{2b} \cdot \left[\frac{M_b \cdot (1\,\mathrm{lbf} \cdot \mathrm{in})}{Z_b}\right] + B_{2r} \cdot \left[\frac{M_r \cdot (1\,\mathrm{lbf} \cdot \mathrm{in})}{Z_r}\right]}{S}$$

$\mathrm{Tee}\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S, nf, el_R, el_B, nd_R, nd_B, C_o, EL\right) :=$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{elR} \leftarrow \mathrm{match}\left(el_{R_0}, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(el_R)$ if rows

$\quad ind_{elR} \leftarrow \mathrm{stack}\left[ind_{elR}, \left(\mathrm{match}\left(el_{R_i}, EL^{\langle 0 \rangle}\right)\right)\right]$

$EL'R_{\mathrm{last}\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$

for $i \in 0 .. \mathrm{last}(ind_{elR})$

$\quad EL'R_{ind_{elR_i}} \leftarrow EL_{ind_{elR_i}, 1}$

$ind_{ndR} \leftarrow \mathrm{match}\left(nd_{R_0}, EL'R^{\langle 0 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(nd_R)$ if r

$\quad ind_{ndR} \leftarrow \mathrm{stack}\left[ind_{ndR}, \left(\mathrm{match}\left(nd_{R_i}, EL'R^{\langle 0 \rangle}\right)\right)\right]$

$ind_{elB} \leftarrow \mathrm{match}\left(el_{B_0}, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(el_B)$ if rows

$\quad ind_{elB} \leftarrow \mathrm{stack}\left[ind_{elB}, \left(\mathrm{match}\left(el_{B_i}, EL^{\langle 0 \rangle}\right)\right)\right]$

$EL'B_{\mathrm{last}\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$

for $i \in 0 .. \mathrm{last}(ind_{elB})$

$\quad EL'B_{ind_{elB_i}} \leftarrow EL_{ind_{elB_i}, 1}$

$ind_{ndB} \leftarrow \mathrm{match}\left(nd_{B_0}, EL'B^{\langle 0 \rangle}\right)$

$$ind_{ndB} \quad \left(\quad B_0 \quad \right)$$

$$\text{for } i \in 1..\text{last}(nd_B) \qquad \text{if } r$$

$$ind_{ndB} \leftarrow \text{stack}\left[ind_{ndB}, \left(\text{match}\left(nd_{B_i}, EL'B^{\langle 0\rangle}\right)\right)\right]$$

$$\left(M_R \;\; M_B \;\; Int_0\right) \leftarrow (0 \;\; 0 \;\; 0)$$

$$\text{for } i \in 0..ind_{nfo_0} - ind_{nfi_0}$$

$$\text{for } j \in 0..\text{last}(ind_{ndR})$$

$$\text{for } k \in 0..\text{last}(ind_{ndB})$$

$$M_{rxgR_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{ndR_j}}$$

$$M_{rygR_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{ndR_j}}$$

$$M_{rzgR_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{ndR_j}}$$

$$M_{rxR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{ndR_j}} - M_{rxgR_j}\right)\cdot C$$

$$M_{ryR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{ndR_j}} - M_{rygR_j}\right)\cdot C$$

$$M_{rzR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{ndR_j}} - M_{rzgR_j}\right)\cdot C$$

$$M_{R_j} \leftarrow \sqrt{\left(M_{rxR_j}\right)^2 + \left(M_{ryR_j}\right)^2 + \left(M_{rzR_j}\right)^2}$$

$$M_{rxgB_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{ndB_k}}$$

$$M_{rygB_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{ndB_k}}$$

$$M_{rzgB_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{ndB_k}}$$

$$M_{rxB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{ndB_k}} - M_{rxgB_j}\right)\cdot C$$

$$M_{ryB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{ndB_k}} - M_{rygB_j}\right)\cdot C$$

$$M_{rzB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{ndB_k}} - M_{rzgB_j}\right)\cdot C$$

$$M_{B_j} \leftarrow \sqrt{\left(M_{rxB_j}\right)^2 + \left(M_{ryB_j}\right)^2 + \left(M_{rzB_j}\right)^2}$$

$$Int'_j \leftarrow \text{TeeDC}\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_{B_j}, M_R\right.$$

$$\text{if } Int'_j > Int_0$$

$$Int \leftarrow \text{stack}\left(Int'_j, M_{R_j}, M_{B_j}, nf_{ind_{nfiC_{o\;\;-1}}+i}\right.$$

$\text{Result} \leftarrow \text{stack}\left(M_{R_j}, M_{B_j}, M_{rxR_j}, M_{ryR_j}, M\right.$

$M \leftarrow M_R$

Int

Conditions applicable to forged tee

$M_{ox} := 0 \quad M_{oy} := 0 \quad M_{oz} := 0$

Defining place holding directional moment variables

$$Tee\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

TEE (Lines 1-30 with 8-14)

Define pertinent tee variables

$P := 253\text{psi}$ — Internal Pressure [3, pg 23]

$D_o := 16\text{in}$ — Outside Diameter of Pipe Run [7]

$d_o := 10.75\text{in}$ — Outside Diameter of Branch [19]

$B_1 := 5.122$ TOM'S CALCS — See Appendix F

$T_r := 0.25\text{in}$ — Nominal wall thickness of designated run pipe [[7]

$R_m := \dfrac{D_o - T_r}{2}$ — Mean radius of designated run pipe

$Z_r := \pi \cdot R_m^{\ 2} \cdot T_r$ — Approximate section modulus of designated run pipe [9, NB-3683.1(d)]

$Z_r = 48.707\ \text{in}^3$

$B_{2b} := 1.921$ TOM'S CALCS — See Appendix F

$T'_b := 0.25\text{in}$ — Nominal wall thickness of attached branch pipe [[19]

$r'_m := \dfrac{d_o - T'_b}{2}$ — Mean radius of attached branch pipe

$Z_b := \pi \cdot r'_m{}^{2} \cdot T'_b$ — Approximate section modulus of attached branch pipe [9, NB-3683.1(d)]

$Z_b = 21.648\ \text{in}^3$

$B_{2r} := 3.141$ TOM'S CALCS — See Appendix F

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** R. K. Blandford **Date:** 09/30/2008

Fab Branch 1-30 (Node 893 for Pipe Run (Elbow) and Node 149 for Branch)

$elR_{FabBr130} := (514 \quad 515)^T$ Elements associated with pipe run

$ndR_{FabBr130} := (893)^T$ Node between pipe run elements

$elB_{FabBr130} := (489)^T$ Element associated with branch

$ndB_{FabBr130} := (893)^T$ Node where branch intersects pipe run

$AL_{FabBr130} := Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF, elR_{FabBr130}, elB_{FabBr130}, ndR_{FabBr130}, ndB_{FabB}$

$$AL_{FabBr130}^T = (1.022 \quad 9.238 \times 10^4 \quad 1.187 \times 10^5 \quad 6.845 \quad 893 \quad 22 \quad 26 \quad 18)$$

Writing Output Data for Fabricated Branch on line 1-30

$FB := AL_{FabBr130}^T$ Fabricated Branch (Node 130)

FabBranch := WRITEPRN["FabBranch.prn" , (FB)]

Appendix C.4

80th Percentile Results of All 32 Realizations

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** B. K. Blandford **Date:** 09/30/2008

LOGIC USED TO GATHER DATA FROM ALL 32 REALIZATIONS

a := "Y:\PCS2\Automated_Evaluation\Model_265\Real"

$$\text{ReadData}(b) := \text{for } k \in 1..32$$
$$\quad d_{k-1} \leftarrow \text{READPRN}(\text{concat}(a, \text{num2str}(k), b))$$
$$\quad \text{for } j \in 0..\text{length}\left(\left(d_{k-1}\right)^T\right) - 1$$
$$\quad\quad D_{k-1,j} \leftarrow \left(d_{k-1}\right)_{0,j}$$

$$R := \text{stack}(1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32)$$

LOGIC USED TO SORT DATA BASED ON D/C RATIOS OF ALL 32 REALIZATIONS

$$\text{C\_S}(v,R) := \text{for } i \in 0..\text{cols}(v) - 1$$
$$\quad \text{for } k \in 0..\text{rows}\left(v_{0,i}\right) - 1$$
$$\quad\quad \text{for } j \in 0..\text{rows}(v) - 1$$
$$\quad\quad\quad a_{0,j} \leftarrow \left[\left(\left(v_{j,i}\right)^T\right)^{\langle k\rangle}\right]^T$$
$$\quad\quad\quad A \leftarrow a_{0,j} \text{ if } j = 0$$
$$\quad\quad\quad A \leftarrow \text{stack}\left(A, a_{0,j}\right) \text{ if } j > 0$$
$$\quad\quad b_{k,i} \leftarrow \text{stack}\left(A^T, R^T\right)^T$$
$$\quad\quad \text{Sorted}_{k,i} \leftarrow \text{reverse}\left(\text{csort}\left(b_{k,i}, 0\right)\right)$$
$$\quad \text{Sorted}$$

LOGIC USED TO JOIN RESULTS FROM EITHER END OF REDUCERS AND ELBOWS INTO ONE MATRIX

$$\text{RED\_EL}_{80th}(RE) := k \leftarrow 0$$
$$\quad \text{for } i \in 0..\frac{\text{cols}(RE) - 1}{2}$$
$$\quad\quad j \leftarrow 2 \cdot i$$
$$\quad\quad RE80TH_{i,k} \leftarrow \text{stack}\left(\left(RE_{0,j}{}^T\right)^{\langle 6\rangle T}, \left(RE_{0,j+1}{}^T\right)^{\langle 6\rangle T}\right)$$

LOGIC USED TO CONCATINATE 80TH PERCENTILE RESULTS OF PIPE RUNS INTO ONE MATRIX

$PR_{80th}(PM) :=$ for $i \in 0 .. \text{cols}(PM) - 1$

- $k_i \leftarrow 0$
- for $j \in 0 .. \text{rows}\left(PM^{\langle i \rangle}\right) - 1$
  - $k_i \leftarrow k_i + 1$ if $PM_{j,i} \neq 0$
- for $m \in 0 .. k_i - 1$
  - $PM80th_{m,i} \leftarrow \left(PM_{m,i}{}^{T}\right)^{\langle 6 \rangle T}$
- $pm80th_{0,i} \leftarrow PM80th_{0,i}$
- for $n \in 1 .. k_i - 1$
  - $pm80th_{0,i} \leftarrow \text{stack}\left(pm80th_{0,i}, PM80th_{n,i}\right)$

LOGIC USED TO DETERMINE 80TH PERCENTILE RESULTS OF SUPPORTS & TEES

$T_{80th}(T) :=$ for $i \in 0 .. \text{cols}(T) - 1$

- $T80th_{0,i} \leftarrow \left(T_{0,i}{}^{T}\right)^{\langle 6 \rangle T}$

SUPPORTS

Support output is ordered as (D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node being collinear (AL1) and apposing (AL2) the positive directionality of the global coordinate system, and realization number)

EVALUATION OF SUPPORTS ON LINES 1-13 TO 1-16, 1-18 TO 1-21, AND 1-171 FOR ALL 32 REALIZATIONS

VSA := ReadData("\SupLines_13to16_18to21_171.prn")

SA := C_S(VSA,R)

PS-20 Support (1x)

PS-20 (Node 828)

PS-20 vertically supports EL(1-171A) on line 1-171.

Compression $\left(SA_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(0.081 \quad -1.252\times 10^{4} \quad 7.455 \quad 828 \quad 108 \quad 22\right)$

Tension $\left(SA_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \left(0.657 \quad 9.25\times 10^{3} \quad 10.02 \quad 828 \quad 108 \quad 11\right)$

PS-8 Support (4x)

PS-8A (Node 829)

PS-8A vertically supports EL(1-13A) on line 1-13.

Compression $\left(SA_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \left(0.122 \quad -9.195\times 10^{3} \quad 6.14 \quad 829 \quad 106 \quad 15\right)$

Tension $\left(SA_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \left(0.409 \quad 5.754\times 10^{3} \quad 6.25 \quad 829 \quad 106 \quad 27\right)$

PS-8B (Node 830)

PS-8B vertically supports EL(1-14A) on line 1-14.

Compression $\left(SA_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \left(0.177 \quad -1.339\times 10^{4} \quad 5.23 \quad 830 \quad 104 \quad 7\right)$

Tension $\left(SA_{0,5}{}^{T}\right)^{\langle 6\rangle T} = \left(0.747 \quad 1.051\times 10^{4} \quad 4.04 \quad 830 \quad 104 \quad 19\right)$

PS-8C (Node 831)

PS-8C vertically supports EL(1-15A) on line 1-15.

Compression $\left(SA_{0,6}{}^{T}\right)^{\langle 6\rangle T} = \left(0.141 \quad -1.065\times 10^{4} \quad 10.58 \quad 831 \quad 102 \quad 19\right)$

Tension $\left(SA_{0,7}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.536 \quad 7.54\times 10^{3} \quad 6.705 \quad 831 \quad 102 \quad 7\right)$

PS-8D (Node 832)

PS-8D vertically supports EL(1-16A) on line 1-16.

Compression $\left(SA_{0,8}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.178 \quad -1.348\times 10^{4} \quad 10.26 \quad 832 \quad 100 \quad 22\right)$

Tension $\left(SA_{0,9}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.732 \quad 1.03\times 10^{4} \quad 9.12 \quad 832 \quad 100 \quad 12\right)$

EVALUATION OF SUPPORTS ON LINE 1-17 FOR ALL 32 REALIZATIONS

VSB := ReadData("\SupLine_17.prn")

SB := C_S(VSB,R)

The PR-6 Supports were softened to the point of no influence on the model due to the loading observed by initial model iterations. See main body for treatment/recommendations regarding theses supports.

PR-6 Support (7x)

PR-6A (Node 876)

PR-6A vertically supports line 1-171 just east of T from any upward movement supports EL(1-13A) on line 1-13.

Compression $\left(SB_{0,0}{}^{T}\right)^{\langle 6 \rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

Tension $\left(SB_{0,1}{}^{T}\right)^{\langle 6 \rangle T} = \left(2.76\times 10^{-4} \quad 3.106 \quad 10.04 \quad 876 \quad 86 \quad 7\right)$

PR-6B (Node 885)

PR-6B vertically supports EL(1-14A) on line 1-14.

Compression $\left(SB_{0,2}{}^{T}\right)^{\langle 6 \rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

Tension $\left(SB_{0,3}{}^{T}\right)^{\langle 6 \rangle T} = \left(2.631\times 10^{-4} \quad 2.961 \quad 4.045 \quad 885 \quad 84 \quad 2\right)$

PR-6C (Node 881)

PR-6C vertically supports EL(1-15A) on line 1-15.

Compression $\left(SB_{0,4}{}^{T}\right)^{\langle 6 \rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

Tension $\left(SB_{0,5}{}^{T}\right)^{\langle 6 \rangle T} = \left(2.458\times 10^{-4} \quad 2.767 \quad 10.06 \quad 881 \quad 82 \quad 3\right)$

PR-6D (Node 879)

PR-6D vertically supports EL(1-16A) on line 1-16.

Compression $\left(SB_{0,6}{}^{T}\right)^{\langle 6\rangle T} = (0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27)$

Tension $\left(SB_{0,7}{}^{T}\right)^{\langle 6\rangle T} = \left(2.541\times 10^{-4}\ \ 2.86\ \ 4.01\ \ 879\ \ 88\ \ 25\right)$

PR-6E (Node 865)

PR-6E vertically supports EL(1-14A) on line 1-14.

Compression $\left(SB_{0,8}{}^{T}\right)^{\langle 6\rangle T} = (0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27)$

Tension $\left(SB_{0,9}{}^{T}\right)^{\langle 6\rangle T} = \left(2.633\times 10^{-4}\ \ 2.963\ \ 4.005\ \ 865\ \ 80\ \ 25\right)$

PR-6F (Node 869)

PR-6F vertically supports EL(1-15A) on line 1-15.

Compression $\left(SB_{0,10}{}^{T}\right)^{\langle 6\rangle T} = (0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27)$

Tension $\left(SB_{0,11}{}^{T}\right)^{\langle 6\rangle T} = \left(2.655\times 10^{-4}\ \ 2.988\ \ 8.84\ \ 869\ \ 78\ \ 26\right)$

PR-6G (Node 863)

PR-6G vertically supports EL(1-16A) on line 1-16.

Compression $\left(SB_{0,12}{}^{T}\right)^{\langle 6\rangle T} = (0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27)$

Tension $\left(SB_{0,13}{}^{T}\right)^{\langle 6\rangle T} = \left(2.799\times 10^{-4}\ \ 3.151\ \ 10.41\ \ 863\ \ 76\ \ 28\right)$

EVALUATION OF SUPPORTS ON LINES 1-30 TO 1-31 AND 1-48 FOR ALL 32 REALIZATIONS

VSC := ReadData("\SupLines_30to31_48.prn")

```
truncate(VSD) := | for j ∈ 0 .. length(VSD^⟨0⟩) − 1
                 |   for k ∈ 0 .. length[(VSD^T)^⟨0⟩] − 1
                 |     | for i ∈ 0 .. 4
                 |     |   vsd_(0,i) ← (VSD_(j,k))_(0,i)
                 |     | vsdm_(j,k) ← vsd
                 | vsdm
```

Logic Used to truncate result

VSC := truncate(VSC)

SC := C_S(VSC, R)

RH-32 Support (1x)

RH-32 (Node 860)

RH-32 vertically supports line 1-30 just south of EL(1-30A) from any downward movement.

Tension $\left(SC_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(4.778\times 10^{-4}\ \ -2.272\ \ 3.875\ \ 860\ \ 80\ \ 27\right)$

Compression $\left(SC_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \left(0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27\right)$

RH-11 Support (2x)

RH-11A (Node 857)

RH-11A vertically supports line 1-30 just west of Fab Branch(1-30) from any downward movement.

Tension $\left(SC_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \left(0.513\ \ -7.656\times 10^{3}\ \ 6.85\ \ 857\ \ 82\ \ 25\right)$

Compression $\left(SC_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \left(0.329\ \ 2.388\times 10^{3}\ \ 5.365\ \ 857\ \ 82\ \ 22\right)$

RH-11B (Node 858)

RH-11B vertically supports line 1-30 between T(1-48) and T(1-31) from any downward movement.

Tension $\left(SC_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \left(0.323\ \ -4.811\times 10^{3}\ \ 5.345\ \ 858\ \ 84\ \ 27\right)$

Compression $\left(SC_{0,5}{}^{T}\right)^{\langle 6\rangle T} = \left(0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27\right)$

PS-4 Support (4x)

PS-4A (Node 849)

PS-4A vertically supports line 1-30 at FL(1-30C) from any downward movement.

Compression $\left(SC_{0,6}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.116 \quad -1.023\times 10^{4} \quad 6.62 \quad 849 \quad 74 \quad 24\right)$

Tension $\left(SC_{0,7}{}^{T}\right)^{\langle 6 \rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

PS-4B (Node 850)

PS-4B vertically supports line 1-30 at FL(1-30D) from any downward movement.

Compression $\left(SC_{0,8}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.033 \quad -2.914\times 10^{3} \quad 10.96 \quad 850 \quad 76 \quad 19\right)$

Tension $\left(SC_{0,9}{}^{T}\right)^{\langle 6 \rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

PS-4C (Node 848)

PS-4C vertically supports line 1-31 at FL(1-31A) from any downward movement.

Compression $\left(SC_{0,10}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.234 \quad -2.06\times 10^{4} \quad 4.19 \quad 848 \quad 72 \quad 28\right)$

Tension $\left(SC_{0,11}{}^{T}\right)^{\langle 6 \rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

PS-4D (Node 847)

PS-4D vertically supports line 1-31 at FL(1-31B) from any downward movement.

Compression $\left(SC_{0,12}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.093 \quad -8.166\times 10^{3} \quad 4.145 \quad 847 \quad 70 \quad 7\right)$

Tension $\left(SC_{0,13}{}^{T}\right)^{\langle 6 \rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

AIS Support (1x)

The AIS Support was released in the model due to the loading observed by initial model iterations. See main body for treatment/recommendations regarding this support.

AIS (EW) (Node 842)

AIS supports line 1-48 at top side of EL(1-48B) from horizontal movement.

Compression $\left(SC_{0,14}{}^{T}\right)^{\langle 6 \rangle T} = \left(1.426\times 10^{-4} \quad -2.628 \quad 12.62 \quad 842 \quad 119 \quad 18\right)$

Tension $\left(SC_{0,15}{}^{T}\right)^{\langle 6 \rangle T} = \left(1.897\times 10^{-4} \quad 2.514 \quad 15.06 \quad 842 \quad 119 \quad 27\right)$

AIS (NS) (Node 842)

AIS supports line 1-48 at top side of EL(1-48B) from horizontal movement.

Flexure $\left(SC_{0,16}{}^{T}\right)^{\langle 6\rangle T} = \left(1.437\times 10^{-3}\ \ -0.785\ \ 4.07\ \ 842\ \ 119\ \ 22\right)$

Flexure $\left(SC_{0,17}{}^{T}\right)^{\langle 6\rangle T} = \left(1.736\times 10^{-3}\ \ 0.948\ \ 6.84\ \ 842\ \ 119\ \ 11\right)$

RH-24 Support (2x)

RH-24A (Node 816)

RH-24A vertically supports line 1-48 just north of EL(1-48A) from any downward movement.

Tension $\left(SC_{0,18}{}^{T}\right)^{\langle 6\rangle T} = \left(0.148\ \ -1.048\times 10^{3}\ \ 5.755\ \ 816\ \ 66\ \ 16\right)$

Compression $\left(SC_{0,19}{}^{T}\right)^{\langle 6\rangle T} = (0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27)$

RH-24B (Node 815)

RH-24A vertically supports line 1-48 near the runs midpoint from any downward movement.

Tension $\left(SC_{0,20}{}^{T}\right)^{\langle 6\rangle T} = \left(0.158\ \ -1.118\times 10^{3}\ \ 6.09\ \ 815\ \ 68\ \ 19\right)$

Compression $\left(SC_{0,21}{}^{T}\right)^{\langle 6\rangle T} = (0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27)$

EVALUATION OF SUPPORTS ON LINES 1-43 AND 1-47 FOR ALL 32 REALIZATIONS

VSD := ReadData("\SupLines_43_47.prn")

SD := C_S(VSD, R)

RH-19 Support (1x)

RH-19 (Node 625)

RH-19 vertically supports line 1-43 just south of T(1-46A) from any downward movement.

Tension $\left(SD_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(1.968\ \ -1.006\times 10^{4}\ \ 5.775\ \ 625\ \ 110\ \ 22\right)$

Refer to Main Body for Recommendations Regarding this Challenged Support

Compression $\left(SD_{0,1}{}^{T}\right)^{\langle 6\rangle T} = (0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27)$

RH-17 Support (2x)

RH-17A (Node 622)

RH-17A vertically supports line 1-43 just north of EL(1-43D) from any downward movement.

Tension

$$\left(SD_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \left(0.546 \quad -6.147\times 10^{3} \quad 8.8 \quad 622 \quad 102 \quad 15\right)$$

Compression

$$\left(SD_{0,3}{}^{T}\right)^{\langle 6\rangle T} = (0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27)$$

RH-17B (Node 833)

RH-17B vertically supports line 1-43 just south of GB(1-43B) from any downward movement.

Tension

$$\left(SD_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \left(0.466 \quad -5.247\times 10^{3} \quad 4.635 \quad 833 \quad 100 \quad 7\right)$$

Compression

$$\left(SD_{0,5}{}^{T}\right)^{\langle 6\rangle T} = (0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27)$$

RH-30 Support (1x)

The RH-30 Support was released in the model due to the loading observed by initial model iterations. See main body for treatment/recommendations regarding this support.

RH-30 (NS) (Node 927)

RH-30 supports line 1-43 at the bottom portion of P(1-43G) from movement in any direction.

Tension

$$\left(SD_{0,6}{}^{T}\right)^{\langle 6\rangle T} = \left(5.175\times 10^{-4} \quad -1.796 \quad 11.49 \quad 927 \quad 165 \quad 6\right)$$

Compression

$$\left(SD_{0,7}{}^{T}\right)^{\langle 6\rangle T} = \left(5.726\times 10^{-5} \quad 1.24 \quad 12.22 \quad 927 \quad 165 \quad 17\right)$$

RH-30 (V) (Node 927)

RH-30 supports line 1-43 at the bottom portion of P(1-43G) from movement in any direction.

Downward Flexure

$$\left(SD_{0,8}{}^{T}\right)^{\langle 6\rangle T} = (0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27)$$

Upward Flexure

$$\left(SD_{0,9}{}^{T}\right)^{\langle 6\rangle T} = \left(8.265\times 10^{-5} \quad 1.789 \quad 5.27 \quad 927 \quad 165 \quad 28\right)$$

RH-30 (EW) (Node 927)

RH-30 supports line 1-43 at the bottom portion of P(1-43G) from movement in any direction.

Flexure

$$\left(SD_{0,10}{}^{T}\right)^{\langle 6\rangle T} = \left(1.324\times 10^{-3} \quad -0.86 \quad 9.9 \quad 927 \quad 165 \quad 6\right)$$

Flexure

$$\left(SD_{0,11}{}^{T}\right)^{\langle 6\rangle T} = \left(1.335\times 10^{-3} \quad 0.868 \quad 10.14 \quad 927 \quad 165 \quad 12\right)$$

RH-25 Support (2x)

RH-25A (Node 619)

RH-25A vertically supports line 1-43 between EL(1-43F) and EL(1-43G) from any downward movement.

Tension $\left(SD_{0,12}{}^{T}\right)^{\langle 6\rangle T} = \left(0.484 \quad -5.012\times 10^{3} \quad 5.815 \quad 619 \quad 98 \quad 17\right)$

Compression $\left(SD_{0,13}{}^{T}\right)^{\langle 6\rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

RH-25B (Node 617)

RH-25B vertically supports line 1-43 near the center of P(1-43J) from any downward movement.

Tension $\left(SD_{0,14}{}^{T}\right)^{\langle 6\rangle T} = \left(1.062 \quad -1.1\times 10^{4} \quad 4.795 \quad 617 \quad 96 \quad 31\right)$

This challenged support will be evaluated using a ductility factor approach. The supporting calculations for this treatment are included in Appendix E.7 for all supports for which this approach is applicable. The below function writes this information to the Appendix E.7 file.

$Duc_{RH25B} :=$ WRITEPRN("Y:\PCS2\PCS Documentation\App_E\E7 DUCTILITY CALCS\RH25B.prn" , $\left(SD_{0,14}{}^{T}\right)^{\langle 6\rangle T}$

Compression $\left(SD_{0,15}{}^{T}\right)^{\langle 6\rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

PS-10 Supports (3x)

PS-10A (Node 641)

PS-10 vertically supports 1-47 just west of EL(1-47A).

Compression $\left(SD_{0,16}{}^{T}\right)^{\langle 6\rangle T} = \left(0.89 \quad -1.967\times 10^{4} \quad 9.73 \quad 641 \quad 104 \quad 11\right)$

Tension $\left(SD_{0,17}{}^{T}\right)^{\langle 6\rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

PS-10B (Node 644)

PS-10 vertically supports 1-47 just south of FL(1-47A).

Compression $\left(SD_{0,18}{}^{T}\right)^{\langle 6\rangle T} = \left(0.843 \quad -1.864\times 10^{4} \quad 9.615 \quad 644 \quad 106 \quad 23\right)$

Tension $\left(SD_{0,19}{}^{T}\right)^{\langle 6\rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

PS-10C (Node 646)

PS-10 vertically supports 1-47 just north of FL(1-47B).

Compression $\left(SD_{0,20}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.547 \quad -1.21\times 10^{4} \quad 10.07 \quad 646 \quad 108 \quad 6\right)$

Tension $\left(SD_{0,21}{}^{T}\right)^{\langle 6 \rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

AIWS Support (1x)

AIWS (V) (Node 836)

AIWS supports line 1-43 at the bottom portion of P(1-43G) from movement in the vertical and east/west directions.

Downward Flexure $\left(SD_{0,22}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.829 \quad -1.276\times 10^{3} \quad 7.94 \quad 836 \quad 112 \quad 29\right)$

Upward Flexure $\left(SD_{0,23}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.292 \quad 449.9 \quad 10.13 \quad 836 \quad 112 \quad 19\right)$

AIWS (EW) (Node 836)

AIWS supports line 1-43 at the bottom portion of P(1-43G) from movement in the vertical and east/west directions.

Westward Flexure $\left(SD_{0,24}{}^{T}\right)^{\langle 6 \rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

Eastward Flexure $\left(SD_{0,25}{}^{T}\right)^{\langle 6 \rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

EVALUATION OF SUPPORTS ON LINES 1-44, 1-46, AND 8-14 FOR ALL 32 REALIZATIONS

VSE := ReadData("\SupLines_44_46_814.prn")

SE := C_S(VSE, R)

RH-22 Support (2x)

The RH-22 Supports were released in the model due to the loading observed by initial model iterations. See main body for treatment/recommendations regarding these supports.

RH-22 (Node 931)

RH-22 vertically supports line 1-44 just south of T(1-44) from any downward movement.

Tension $\left(SE_{0,0}{}^{T}\right)^{\langle 6 \rangle T} = \left(9.924\times 10^{-4} \quad -0.52 \quad 5.78 \quad 931 \quad 115 \quad 15\right)$

Compression $\left(SE_{0,1}{}^{T}\right)^{\langle 6 \rangle T} = \left(3.594\times 10^{-3} \quad 2.483 \quad 9.64 \quad 931 \quad 115 \quad 12\right)$

RH-22 (Node 930)

RH-22 vertically supports line 1-44 just south of EL(1-44B) from any downward movement.

Tension

$$\left(SE_{0,2}{}^{T}\right)^{\langle 6\rangle T} = (0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27)$$

Compression

$$\left(SE_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \left(2.518\times 10^{-4}\ \ 1.339\ \ 5.7\ \ 930\ \ 117\ \ 28\right)$$

PS-7 Support (1x)

PS-7 (NS) (Node 608)

PS-7 supports line 1-43 at the bottom portion of P(1-43G) from movement in the vertical and east/west directions.

Tension

$$\left(SE_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \left(0.174\ \ -1.166\times 10^{3}\ \ 4.84\ \ 608\ \ 109\ \ 7\right)$$

Compression

$$\left(SE_{0,5}{}^{T}\right)^{\langle 6\rangle T} = \left(0.351\ \ 1.182\times 10^{3}\ \ 6.005\ \ 608\ \ 109\ \ 7\right)$$

PS-7 (V) (Node 608)

PS-7 supports line 1-43 at the bottom portion of P(1-43G) from movement in the vertical and east/west directions.

Flexure

$$\left(SE_{0,6}{}^{T}\right)^{\langle 6\rangle T} = \left(1.803\ \ -3.966\times 10^{3}\ \ 5.295\ \ 608\ \ 109\ \ 12\right)$$

Flexure

$$\left(SE_{0,7}{}^{T}\right)^{\langle 6\rangle T} = (0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27)$$

The gang support and anchorage insufficiency aspects of the PS-7 support are be addressed in the main body of the report from the loads reported in Appendix E.9 for all associated lines.

PS7_N := WRITEPRN("Y:\PCS2\PCS Documentation\App_E\E9 PS-7\PS7_N_M6.prn" , $SE_{0,4}$)

PS7_S := WRITEPRN("Y:\PCS2\PCS Documentation\App_E\E9 PS-7\PS7_S_M6.prn" , $SE_{0,5}$)

PS7_D := WRITEPRN("Y:\PCS2\PCS Documentation\App_E\E9 PS-7\PS7_D_M6.prn" , $SE_{0,6}$)

PS7_U := WRITEPRN("Y:\PCS2\PCS Documentation\App_E\E9 PS-7\PS7_U_M6.prn" , $SE_{0,7}$)

RH-16 Support (2x)

RH-16A (Node 606)

RH-16A vertically supports line 1-44 just east of EL(1-44D) from any downward movement.

Tension

$$\left(SE_{0,8}{}^{T}\right)^{\langle 6\rangle T} = (0.89\ \ -931.7\ \ 5.555\ \ 606\ \ 64\ \ 30)$$

Compression

$$\left(SE_{0,9}{}^{T}\right)^{\langle 6\rangle T} = (0.988\ \ 392.4\ \ 5.3\ \ 606\ \ 64\ \ 7)$$

RH-16B was released in the model due to the loading observed by initial model iterations. See main body for treatment/recommendations regarding this support.

RH-16B (Node 605)

RH-16B vertically supports line 1-44 just south of EL(1-44E) from any downward movement.

Tension $\left(SE_{0,10}{}^{T}\right)^{\langle 6\rangle T} = (0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27)$

Compression $\left(SE_{0,11}{}^{T}\right)^{\langle 6\rangle T} = \left(8.817\times 10^{-3}\ \ 3.5\ \ 6.145\ \ 605\ \ 62\ \ 10\right)$

RH-26x Support (1x)

RH-26x (Node 222)

RH-26x vertically supports line 8-14 south of EL(8-14B) from any downward movement.

Tension $\left(SE_{0,12}{}^{T}\right)^{\langle 6\rangle T} = \left(0.04\ \ -1.132\times 10^{3}\ \ 5.26\ \ 222\ \ 65\ \ 12\right)$

This support will be evaluated in combination with RH-21x supporting lines 1-7 and 8-14. The supporting calculations for this treatment are included in Appendix E.9 for all supports for which this approach is applicable. The below function writes this information to the Appendix E.8 file.

$SRSS_{RH26x814} :=$ WRITEPRN("Y:\PCS2\PCS Documentation\App_E\E8 Common Anchorage Combinations\RH-26x814.p

Compression $\left(SE_{0,13}{}^{T}\right)^{\langle 6\rangle T} = (0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27)$

RH-13 Support (2x)

RH-13A (Node 822)

RH-13A vertically supports line 8-14 west of EL(8-14B) from any downward movement.

Tension $\left(SE_{0,14}{}^{T}\right)^{\langle 6\rangle T} = \left(0.102\ \ -1.515\times 10^{3}\ \ 5.425\ \ 822\ \ 72\ \ 23\right)$

Compression $\left(SE_{0,15}{}^{T}\right)^{\langle 6\rangle T} = (0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27)$

RH-13B (Node 820)

RH-13A vertically supports line 8-14 east of Fab Branch(1-30) from any downward movement.

Tension $\left(SE_{0,16}{}^{T}\right)^{\langle 6\rangle T} = \left(0.139\ \ -2.077\times 10^{3}\ \ 5.22\ \ 820\ \ 70\ \ 12\right)$

Compression $\left(SE_{0,17}{}^{T}\right)^{\langle 6\rangle T} = (0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27)$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** B. K. Blandford **Date:** 09/30/2008

EVALUATION OF SUPPORTS ON LINE 1-45 FOR ALL 32 REALIZATIONS

VSF := ReadData("\SupLine_45.prn")

```
truncate(VSD) := | for j ∈ 0 .. length(VSD^⟨0⟩) − 1
                 |   for k ∈ 0 .. length[((VSD^T)^⟨0⟩)] − 1
                 |     | for i ∈ 0 .. 4
                 |     |   vsd_{0,i} ← (VSD_{j,k})_{0,i}
                 |     | vsdm_{j,k} ← vsd
                 | vsdm
```

Logic Used to truncate result

VSF := truncate(VSF)

SF := C_S(VSF, R)

U-Bolt Detail 2 Support (1x)

U-Bolt Detail 2 (V) (Node 1045)

U-Bolt Detail 2 supports line 1-45 at the south portion of P(1-45E) from movement in the vertical and east/west directions.

Compression $\left(SF_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(0.12 \quad -592 \quad 4.335 \quad 1.045\times10^{3} \quad 64 \quad 24\right)$

Tension $\left(SF_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

U-Bolt Detail 2 (EW) (Node 1045)

U-Bolt Detail 2 supports line 1-45 at the south portion of P(1-45E) from movement in the vertical and east/west directions.

Flexure $\left(SF_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \left(0.38 \quad -54.33 \quad 5.82 \quad 1.045\times10^{3} \quad 64 \quad 25\right)$

Flexure $\left(SF_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \left(1.265 \quad 180.9 \quad 9.1 \quad 1.045\times10^{3} \quad 64 \quad 28\right)$

Refer to Main Body Regarding Treatment/Recommendations Related to This Support

Pending U-Bolt Support (1x)

Pending U-Bolt (V) (Node 1047)

The pending U-Bolt support supports line 1-45 at the north portion of P(1-45E) from movement in the vertical and east/west directions.

Compression $\left(SF_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \left(0.185 \quad -834.7 \quad 8.535 \quad 1.047\times10^{3} \quad 62 \quad 1\right)$

Tension $\left(SF_{0,5}{}^{T}\right)^{\langle 6\rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

Pending U-Bolt (EW) (Node 1047)

The pending U-Bolt support supports line 1-45 at the north portion of P(1-45E) from movement in the vertical and east/west directions.

Flexure $$\left(SF_{0,6}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.541 & -274.3 & 7.98 & 1.047\times10^{3} & 62 & 10 \end{pmatrix}$$

Flexure $$\left(SF_{0,7}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.346 & 175.5 & 6.89 & 1.047\times10^{3} & 62 & 7 \end{pmatrix}$$

TERMINATIONS

Termination output is ordered as (max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, index of element(s), moments about the x, y, and z axes, and realization number)

EVALUATION OF TERMINATIONS ON LINES 1-13 TO 1-16, 1-18 TO 1-21, AND 1-171 FOR ALL 32 REALIZATIONS

$VTA := ReadData("\backslash TermLines\_13to16\_18to21\_171.prn")$

$TA := C\_S(VTA, R)$

Heat Exchanger Outlet (5x)

Heat Exchanger 1-13 (Node 130)

$$\left(TA_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.125 & 2.571\times10^{5} & 10.02 & 130 & 82 & 2.397\times10^{5} & 7.194\times10^{4} & -5.877\times10^{4} & 27 \end{pmatrix}$$

Heat Exchanger 1-14 (Node 128)

$$\left(TA_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.137 & 3.193\times10^{5} & 6.7 & 128 & 84 & -3.111\times10^{5} & -5.406\times10^{4} & -4.776\times10^{4} & 7 \end{pmatrix}$$

Heat Exchanger 1-15 (Node 129)

$$\left(TA_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.137 & 3.168\times10^{5} & 6.695 & 129 & 86 & 3.119\times10^{5} & 3.775\times10^{4} & -4.089\times10^{4} & 28 \end{pmatrix}$$

Heat Exchanger 1-16 (Node 127)

$$\left(TA_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.134 & 3.051\times10^{5} & 10.12 & 127 & 88 & -3.042\times10^{5} & -1.695\times10^{4} & -1.559\times10^{4} & 12 \end{pmatrix}$$

Heat Exchanger 1-171 (Node 139)

$$\left(TA_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.107 & 1.724\times10^{5} & 10.01 & 139 & 97 & 4.067\times10^{4} & 9.161\times10^{3} & 1.673\times10^{5} & 22 \end{pmatrix}$$

Primary Pump Suction (4x)

Primary Pump 1-18 (Node 1)

$$\left(TA_{0,5}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.356 & 1.193\times10^{6} & 9.26 & 1 & 1 & 1.141\times10^{6} & 1.899\times10^{5} & -2.901\times10^{5} & 19 \end{pmatrix}$$

Primary Pump 1-19 (Node 31)

$$\left(TA_{0,6}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.362 & 1.216\times10^{6} & 4.05 & 31 & 5 & -8.179\times10^{5} & -1.49\times10^{5} & 8.875\times10^{5} & 11 \end{pmatrix}$$

Primary Pump 1-20 (Node 15)

$$\left(TA_{0,7}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.36 & 1.207\times10^{6} & 4.05 & 15 & 9 & -9.028\times10^{5} & -1.337\times10^{5} & 7.893\times10^{5} & 19 \end{pmatrix}$$

Primary Pump 1-21 (Node 22)

$$\left(TA_{0,8}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.385 & 1.31\times10^{6} & 10.26 & 22 & 13 & 1.548\times10^{5} & 6.791\times10^{4} & -1.299\times10^{6} & 28 \end{pmatrix}$$

THERE ARE NOT ANY TERMINATIONS ARE NOT PRESENTE ON LINE 1-17

EVALUATION OF TERMINATIONS ON LINES 1-30 TO 1-31 AND 1-48 FOR ALL 32 REALIZATIONS

VTC := ReadData("\TermLines_30to31_48.prn")

TC := C_S(VTC,R)

Emergency Pump Suction (2x)

Emergency Pump 1-30 (Node 160)

$$\left(TC_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.232 & 3.381\times10^{5} & 6.485 & 160 & 27 & 6.376\times10^{3} & -2.761\times10^{5} & -1.951\times10^{5} & 22 \end{pmatrix}$$

Emergency Pump 1-31 (Node 194)

$$\left(TC_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.18 & 2.335\times10^{5} & 6.335 & 194 & 41 & 1.181\times10^{5} & 1.99\times10^{5} & 3.072\times10^{4} & 11 \end{pmatrix}$$

North Wall Penetration 1-48 (1x)

North Wall Penetration 1-48 (Node 682)

$$\left(TC_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.204 & 3.327\times10^{4} & 13.09 & 682 & 151 & 8.074\times10^{3} & 3.216\times10^{4} & 2.82\times10^{3} & 25 \end{pmatrix}$$

EVALUATION OF TERMINATIONS ON LINES 1-43 AND 1-47 FOR ALL 32 REALIZATIONS

VTD := ReadData("\TermLines_43_47.prn")

TD := C_S(VTD, R)

North Wall Penetration 1-43 (1x)

North Wall Penetration 1-43 (Node 601)

$$\left(TD_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(0.289 \quad 2.888\times10^{5} \quad 4.79 \quad 601 \quad 166 \quad -4.54\times10^{4} \quad 4.97\times10^{4} \quad -2.808\times10^{5} \quad 31\right)$$

Pipe Termination 1-47 (1x)

Pipe Termination 1-47 (Node 669)

$$\left(TD_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \left(0.182 \quad 7.514\times10^{4} \quad 10.27 \quad 669 \quad 82 \quad -6.808\times10^{3} \quad -7.221\times10^{4} \quad 1.962\times10^{4} \quad 19\right)$$

EVALUATION OF TERMINATIONS ON LINES 1-44, 1-46, AND 8-14 FOR ALL 32 REALIZATIONS

VTE := ReadData("\TermLines_44_46_814.prn")

TE := C_S(VTE, R)

West Floor Penetration 1-44 (1x)

West Floor Penetration 1-44 (Node 345)

$$\left(TE_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(0.132 \quad 5.083\times10^{4} \quad 5.995 \quad 345 \quad 97 \quad -3.721\times10^{3} \quad 1.37\times10^{3} \quad 5.067\times10^{4} \quad 3\right)$$

East Ceiling Penetration 8-14 (1x)

East Ceiling Penetration 8-14 (Node 888)

$$\left(TE_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \left(0.102 \quad 6.506\times10^{4} \quad 10.63 \quad 888 \quad 68 \quad -1.293\times10^{3} \quad -6.474\times10^{4} \quad -6.306\times10^{3} \quad 19\right)$$

EVALUATION OF TERMINATIONS ON LINES 1-44, 1-46, AND 8-14 FOR ALL 32 REALIZATIONS

VTF := ReadData("\TermLine_45.prn")

TF := C_S(VTF, R)

Surge Tank Connection 1-45 (1x)

Surge Tank Connection 1-45 (Node 1006)

$$\left(TF_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(0.073 \quad 2.245\times10^{4} \quad 10.02 \quad 1.006\times10^{3} \quad 19 \quad -3.685\times10^{3} \quad -2.214\times10^{4} \quad 567.5 \quad 22\right)$$

PIPE RUNS

Termination output is ordered as (max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, indices of element(s), moments about the x, y, and z axes, and realization number)

EVALUATION OF PIPE RUNS ON LINES 1-13 TO 1-16, 1-18 TO 1-21, AND 1-171 FOR ALL 32 REALIZATIONS

VPRA := ReadData("\PRLines_13to16_18to21_171.prn")

PRA := C_S(VPRA, R)

$PRA_{80TH} := PR_{80th}(PRA)$

Pipe Properties for Line 1-13

Pipe Run 1-13A (Element 99)

$$PRA80TH_{0,0} = \begin{pmatrix} 0.121 & 2.39 \times 10^{5} & 4.05 & 99 & 123 & 81 & 19 \\ 0.125 & 2.571 \times 10^{5} & 10.02 & 99 & 130 & 82 & 27 \end{pmatrix}$$

Pipe Run 1-13B (Elements 91 & 92)

$$PRA80TH_{0,1} = \begin{pmatrix} 0.093 & 1.043 \times 10^{5} & 12.72 & 91 & 113 & 65 & 27 \\ 0.09 & 9.035 \times 10^{4} & 10.04 & 91 & 122 & 66 & 12 \\ 0.109 & 1.8 \times 10^{5} & 10.02 & 92 & 114 & 67 & 22 \\ 0.089 & 8.25 \times 10^{4} & 12.56 & 92 & 122 & 68 & 24 \end{pmatrix}$$

Pipe Run 1-13C (Elements 81 & 79)

$$PRA80TH_{0,2} = \begin{pmatrix} 0.115 & 2.069 \times 10^{5} & 9.26 & 81 & 94 & 51 & 22 \\ 0.106 & 1.65 \times 10^{5} & 9.26 & 81 & 96 & 52 & 28 \\ 0.13 & 2.804 \times 10^{5} & 9.255 & 79 & 64 & 49 & 27 \\ 0.115 & 2.07 \times 10^{5} & 9.26 & 79 & 94 & 50 & 22 \end{pmatrix}$$

Pipe Properties for Line 1-14

Pipe Run 1-14A (Element 100)

$$PRA80TH_{0,3} = \begin{pmatrix} 0.126 & 2.643 \times 10^{5} & 6.705 & 100 & 125 & 83 & 10 \\ 0.138 & 3.193 \times 10^{5} & 6.7 & 100 & 128 & 84 & 7 \end{pmatrix}$$

Pipe Run 1-14B (Elements 93 & 94)

$$PRA80TH_{0,4} = \begin{pmatrix} 0.123 & 2.481 \times 10^5 & 4.04 & 94 & 115 & 71 & 28 \\ 0.103 & 1.508 \times 10^5 & 4.05 & 94 & 121 & 72 & 19 \\ 0.102 & 1.472 \times 10^5 & 5.815 & 93 & 112 & 69 & 26 \\ 0.103 & 1.508 \times 10^5 & 4.05 & 93 & 121 & 70 & 19 \end{pmatrix}$$

Pipe Run 1-14C (Elements 84 & 82)

$$PRA80TH_{0,5} = \begin{pmatrix} 0.116 & 2.128 \times 10^5 & 5.225 & 84 & 97 & 55 & 25 \\ 0.114 & 2.037 \times 10^5 & 9.26 & 84 & 98 & 56 & 19 \\ 0.126 & 2.636 \times 10^5 & 9.26 & 82 & 65 & 53 & 22 \\ 0.114 & 2.038 \times 10^5 & 9.26 & 82 & 98 & 54 & 19 \end{pmatrix}$$

Pipe Properties for Line 1-15

Pipe Run 1-15A (Element 101)

$$PRA80TH_{0,6} = \begin{pmatrix} 0.129 & 2.76 \times 10^5 & 4.04 & 101 & 124 & 85 & 11 \\ 0.137 & 3.168 \times 10^5 & 6.695 & 101 & 129 & 86 & 28 \end{pmatrix}$$

Pipe Run 1-15B (Elements 95 & 96)

$$PRA80TH_{0,7} = \begin{pmatrix} 0.122 & 2.433 \times 10^5 & 6.695 & 96 & 116 & 75 & 28 \\ 0.098 & 1.257 \times 10^5 & 10.43 & 96 & 120 & 76 & 27 \\ 0.099 & 1.307 \times 10^5 & 6.695 & 95 & 111 & 73 & 7 \\ 0.098 & 1.257 \times 10^5 & 10.43 & 95 & 120 & 74 & 27 \end{pmatrix}$$

Pipe Run 1-15C (Elements 87 & 85)

$$PRA80TH_{0,8} = \begin{pmatrix} 0.111 & 1.904 \times 10^5 & 9.26 & 87 & 100 & 59 & 27 \\ 0.11 & 1.863 \times 10^5 & 10.6 & 87 & 102 & 60 & 19 \\ 0.125 & 2.6 \times 10^5 & 9.265 & 85 & 66 & 57 & 25 \\ 0.111 & 1.905 \times 10^5 & 9.26 & 85 & 100 & 58 & 27 \end{pmatrix}$$

Pipe Properties for Line 1-16

Pipe Run 1-16A (Element 102)

$$PRA80TH_{0,9} = \begin{pmatrix} 0.123 & 2.491\times10^{5} & 7.53 & 102 & 126 & 87 & 27 \\ 0.135 & 3.051\times10^{5} & 10.12 & 102 & 127 & 88 & 12 \end{pmatrix}$$

Pipe Run 1-16B (Elements 98 & 97)

$$PRA80TH_{0,10} = \begin{pmatrix} 0.126 & 2.638\times10^{5} & 5.06 & 98 & 117 & 79 & 24 \\ 0.102 & 1.449\times10^{5} & 10.1 & 98 & 119 & 80 & 19 \\ 0.108 & 1.767\times10^{5} & 5.8 & 97 & 110 & 77 & 13 \\ 0.102 & 1.449\times10^{5} & 10.1 & 97 & 119 & 78 & 19 \end{pmatrix}$$

Pipe Run 1-16C (Elements 90 & 88)

$$PRA80TH_{0,11} = \begin{pmatrix} 0.118 & 2.253\times10^{5} & 9.265 & 90 & 103 & 63 & 26 \\ 0.124 & 2.52\times10^{5} & 5.8 & 90 & 105 & 64 & 24 \\ 0.133 & 2.966\times10^{5} & 9.265 & 88 & 68 & 61 & 26 \\ 0.118 & 2.253\times10^{5} & 9.265 & 88 & 103 & 62 & 26 \end{pmatrix}$$

Pipe Properties for Line 1-18

Pipe Run 1-18A (Element 646 and 14)

$$PRA80TH_{0,12} = \begin{pmatrix} 0.117 & 3.766\times10^{5} & 9.26 & 646 & 4 & 162 & 27 \\ 0.118 & 3.871\times10^{5} & 10.62 & 646 & 1.048\times10^{3} & 163 & 6 \\ 0.109 & 3.157\times10^{5} & 9.265 & 14 & 3 & 19 & 19 \\ 0.109 & 3.169\times10^{5} & 9.265 & 14 & 6 & 20 & 19 \end{pmatrix}$$

Pipe Run 1-18B (Elements 655, 654, & 13)

$$PRA80TH_{0,13} = \begin{pmatrix} 0.105 & 2.831\times10^{5} & 4.05 & 655 & 7 & 172 & 25 \\ 0.118 & 3.874\times10^{5} & 4.06 & 655 & 1.057\times10^{3} & 173 & 6 \\ 0.154 & 6.869\times10^{5} & 4.205 & 654 & 1.056\times10^{3} & 170 & 28 \\ 0.118 & 3.876\times10^{5} & 4.06 & 654 & 1.057\times10^{3} & 171 & 6 \\ 0.198 & 1.056\times10^{6} & 9.26 & 13 & 30 & 17 & 19 \\ 0.154 & 6.871\times10^{5} & 4.205 & 13 & 1.056\times10^{3} & 18 & 28 \end{pmatrix}$$

Pipe Run 1-18C (Element 1)

$$PRA80TH_{0,14} = \begin{pmatrix} 0.357 & 1.193 \times 10^6 & 9.26 & 1 & 1 & 1 & 19 \\ 0.34 & 1.124 \times 10^6 & 9.26 & 1 & 29 & 2 & 19 \end{pmatrix}$$

Pipe Properties for Line 1-19

Pipe Run 1-19A (Element 647 & 23)

$$PRA80TH_{0,15} = \begin{pmatrix} 0.119 & 3.971 \times 10^5 & 9.265 & 647 & 11 & 164 & 19 \\ 0.12 & 4.056 \times 10^5 & 9.265 & 647 & 1.049 \times 10^3 & 165 & 19 \\ 0.113 & 3.426 \times 10^5 & 9.265 & 23 & 10 & 27 & 19 \\ 0.113 & 3.443 \times 10^5 & 9.265 & 23 & 13 & 28 & 19 \end{pmatrix}$$

Pipe Run 1-19B (Elements 657, 656, & 22)

$$PRA80TH_{0,16} = \begin{pmatrix} 0.104 & 2.706 \times 10^5 & 9.265 & 657 & 14 & 176 & 19 \\ 0.121 & 4.111 \times 10^5 & 4.045 & 657 & 1.059 \times 10^3 & 177 & 19 \\ 0.16 & 7.365 \times 10^5 & 4.05 & 656 & 1.058 \times 10^3 & 174 & 19 \\ 0.121 & 4.113 \times 10^5 & 4.045 & 656 & 1.059 \times 10^3 & 175 & 19 \\ 0.202 & 1.092 \times 10^6 & 4.05 & 22 & 33 & 25 & 11 \\ 0.16 & 7.369 \times 10^5 & 4.045 & 22 & 1.058 \times 10^3 & 26 & 28 \end{pmatrix}$$

Pipe Run 1-19C (Element 3)

$$PRA80TH_{0,17} = \begin{pmatrix} 0.363 & 1.216 \times 10^6 & 4.05 & 3 & 31 & 5 & 11 \\ 0.348 & 1.154 \times 10^6 & 4.05 & 3 & 32 & 6 & 11 \end{pmatrix}$$

Pipe Properties for Line 1-20

Pipe Run 1-20A (Elements 648 and 30)

$$PRA80TH_{0,18} = \begin{pmatrix} 0.117 & 3.805 \times 10^5 & 9.26 & 648 & 18 & 166 & 27 \\ 0.118 & 3.891 \times 10^5 & 9.26 & 648 & 1.05 \times 10^3 & 167 & 27 \\ 0.111 & 3.281 \times 10^5 & 9.26 & 30 & 17 & 33 & 27 \\ 0.111 & 3.298 \times 10^5 & 9.26 & 30 & 20 & 34 & 27 \end{pmatrix}$$

Pipe Run 1-20B (Elements 659, 658, & 29)

$$PRA80TH_{0,19} = \begin{pmatrix} 0.104 & 2.677\times 10^{5} & 9.265 & 659 & 21 & 180 & 26 \\ 0.119 & 3.99\times 10^{5} & 4.04 & 659 & 1.061\times 10^{3} & 181 & 19 \\ 0.158 & 7.25\times 10^{5} & 4.045 & 658 & 1.06\times 10^{3} & 178 & 19 \\ 0.119 & 3.992\times 10^{5} & 4.04 & 658 & 1.061\times 10^{3} & 179 & 19 \\ 0.201 & 1.083\times 10^{6} & 4.05 & 29 & 35 & 31 & 19 \\ 0.158 & 7.252\times 10^{5} & 4.045 & 29 & 1.06\times 10^{3} & 32 & 19 \end{pmatrix}$$

Pipe Run 1-20C (Element 5)

$$PRA80TH_{0,20} = \begin{pmatrix} 0.361 & 1.207\times 10^{6} & 4.05 & 5 & 15 & 9 & 19 \\ 0.345 & 1.145\times 10^{6} & 4.05 & 5 & 34 & 10 & 19 \end{pmatrix}$$

Pipe Properties for Line 1-21

Pipe Run 1-21A (Elements 649 & 38)

$$PRA80TH_{0,21} = \begin{pmatrix} 0.116 & 3.692\times 10^{5} & 9.26 & 649 & 25 & 168 & 27 \\ 0.117 & 3.766\times 10^{5} & 9.26 & 649 & 1.051\times 10^{3} & 169 & 27 \\ 0.111 & 3.282\times 10^{5} & 9.265 & 38 & 24 & 39 & 27 \\ 0.111 & 3.309\times 10^{5} & 9.265 & 38 & 27 & 40 & 27 \end{pmatrix}$$

Pipe Run 1-21B (Elements 33, 34, 35, 36, & 37)

$$PRA80TH_{0,22} = \begin{pmatrix} 0.105 & 2.768\times 10^{5} & 9.27 & 661 & 28 & 184 & 26 \\ 0.124 & 4.386\times 10^{5} & 10.13 & 661 & 1.063\times 10^{3} & 185 & 12 \\ 0.166 & 7.853\times 10^{5} & 10.12 & 660 & 1.062\times 10^{3} & 182 & 7 \\ 0.124 & 4.388\times 10^{5} & 10.13 & 660 & 1.063\times 10^{3} & 183 & 12 \\ 0.212 & 1.171\times 10^{6} & 10.27 & 37 & 37 & 37 & 28 \\ 0.166 & 7.855\times 10^{5} & 10.12 & 37 & 1.062\times 10^{3} & 38 & 7 \end{pmatrix}$$

Pipe Run 1-21C (Element 7)

$$PRA80TH_{0,23} = \begin{pmatrix} 0.386 & 1.31\times 10^{6} & 10.26 & 7 & 22 & 13 & 28 \\ 0.369 & 1.241\times 10^{6} & 10.27 & 7 & 36 & 14 & 28 \end{pmatrix}$$

Pipe Properties for Line 1-171

Pipe Run 1-171A (Element 109)

$$PRA80TH_{0,24} = \begin{pmatrix} 0.107 & 1.724\times10^{5} & 10.01 & 109 & 139 & 97 & 22 \\ 0.099 & 1.329\times10^{5} & 9.26 & 109 & 140 & 98 & 26 \end{pmatrix}$$

Pipe Run 1-171B (Elements 107, & 106)

$$PRA80TH_{0,25} = \begin{pmatrix} 0.108 & 1.745\times10^{5} & 10.02 & 107 & 138 & 95 & 11 \\ 0.093 & 1.058\times10^{5} & 10.04 & 107 & 141 & 96 & 27 \\ 0.091 & 9.352\times10^{4} & 3.95 & 106 & 136 & 93 & 15 \\ 0.093 & 1.058\times10^{5} & 10.04 & 106 & 141 & 94 & 27 \end{pmatrix}$$

Pipe Run 1-171C (Elements 662 & 105)

$$PRA80TH_{0,26} = \begin{pmatrix} 0.095 & 1.132\times10^{5} & 6.905 & 662 & 135 & 186 & 3 \\ 0.098 & 1.266\times10^{5} & 4.195 & 662 & 1.064\times10^{3} & 187 & 25 \\ 0.105 & 1.62\times10^{5} & 10.04 & 105 & 143 & 91 & 11 \\ 0.098 & 1.267\times10^{5} & 4.195 & 105 & 1.064\times10^{3} & 92 & 25 \end{pmatrix}$$

EVALUATION OF PIPE RUNS ON LINE 1-17 FOR ALL 32 REALIZATIONS

VPRB := ReadData("\PRLine_17.prn")

PRB := C_S(VPRB, R)

$PRB_{80TH} := PR_{80th}(PRB)$

Pipe Properties for Line 1-17

Pipe Run 1-17A (Elements 50, 54, 55, 456, & 57)

$PRB80TH_{0,0} =$

	0	1	2	3	4	5	6
0	0.109	4.879·105	4.055	50	74	17	25
1	0.11	4.991·105	4.055	50	886	18	25
2	0.093	2.477·105	3.965	54	58	21	27
3	0.098	3.258·105	3.985	54	82	22	26
4	0.098	3.259·105	3.985	55	82	23	26
5	0.106	4.347·105	3.99	55	882	24	26
6	0.105	4.17·105	6.7	456	83	71	27
7	0.106	4.348·105	3.99	456	882	72	26
8	0.109	4.887·105	6.7	57	77	25	27
9	0.105	4.172·105	6.7	57	83	26	27

Pipe Run 1-17B (Elements 66, 735, & 68)

$$PRB80TH_{0,1} = \begin{pmatrix} 0.119 & 6.315\times10^5 & 5.35 & 66 & 78 & 43 & 4 \\ 0.119 & 6.265\times10^5 & 5.35 & 66 & 1.139\times10^3 & 44 & 19 \\ 0.115 & 5.698\times10^5 & 5.35 & 735 & 85 & 97 & 19 \\ 0.119 & 6.262\times10^5 & 5.35 & 735 & 1.139\times10^3 & 98 & 19 \\ 0.113 & 5.405\times10^5 & 5.345 & 68 & 80 & 45 & 19 \\ 0.115 & 5.696\times10^5 & 5.35 & 68 & 85 & 46 & 19 \end{pmatrix}$$

Pipe Run 1-17C (Elements 71, 736, 72, & 74)

$$PRB80TH_{0,2} = \begin{pmatrix} 0.106 & 4.389\times10^5 & 4.01 & 71 & 79 & 51 & 25 \\ 0.11 & 4.968\times10^5 & 4.005 & 71 & 1.14\times10^3 & 52 & 22 \\ 0.107 & 4.531\times10^5 & 4.005 & 736 & 89 & 99 & 22 \\ 0.11 & 4.967\times10^5 & 4.005 & 736 & 1.14\times10^3 & 100 & 22 \\ 0.097 & 3.104\times10^5 & 4 & 72 & 87 & 53 & 22 \\ 0.107 & 4.53\times10^5 & 4.005 & 72 & 89 & 54 & 22 \\ 0.094 & 2.57\times10^5 & 9.7 & 74 & 81 & 55 & 19 \\ 0.097 & 3.102\times10^5 & 4 & 74 & 87 & 56 & 22 \end{pmatrix}$$

EVALUATION OF PIPE RUNS ON LINES 1-30 TO 1-31 AND 1-48 FOR ALL 32 REALIZATIONS

VPRC := ReadData("\PRLines_30to31_48.prn")

PRC := C_S(VPRC, R)

$PRC_{80TH} := PR_{80th}(PRC)$

Pipe Properties for Line 1-30

Pipe Run 1-30A (Element 653 and 111)

$$PRC80TH_{0,0} = \begin{pmatrix} 0.18 & 2.684\times10^5 & 6.34 & 653 & 67 & 131 & 28 \\ 0.194 & 3.038\times10^5 & 6.335 & 653 & 1.055\times10^3 & 132 & 28 \\ 0.163 & 2.265\times10^5 & 6.34 & 111 & 145 & 1 & 19 \\ 0.167 & 2.352\times10^5 & 6.335 & 111 & 146 & 2 & 26 \end{pmatrix}$$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** B. K. Blandford **Date:** 09/30/2008

Pipe Run 1-30B (Elements 112 & 113)

$$PRC80TH_{0,1} = \begin{pmatrix} 0.159 & 2.157\times10^5 & 6.84 & 112 & 148 & 3 & 28 \\ 0.147 & 1.877\times10^5 & 6.335 & 112 & 181 & 4 & 28 \\ 0.127 & 1.377\times10^5 & 6.345 & 113 & 164 & 5 & 6 \\ 0.147 & 1.877\times10^5 & 6.335 & 113 & 181 & 6 & 28 \end{pmatrix}$$

Pipe Run 1-30C (Elements 114, 437, & 663)

$$PRC80TH_{0,2} = \begin{pmatrix} 0.115 & 1.067\times10^5 & 10.65 & 114 & 165 & 7 & 22 \\ 0.146 & 1.852\times10^5 & 6.84 & 114 & 851 & 8 & 25 \\ 0.147 & 1.859\times10^5 & 6.84 & 437 & 851 & 77 & 25 \\ 0.152 & 1.989\times10^5 & 5.365 & 437 & 1.065\times10^3 & 78 & 28 \\ 0.181 & 2.719\times10^5 & 6.51 & 663 & 177 & 133 & 7 \\ 0.152 & 1.989\times10^5 & 5.365 & 663 & 1.065\times10^3 & 134 & 28 \end{pmatrix}$$

Pipe Run 1-30D (Elements 120, 664, 123, 665, 666, 667, & 668)

$PRC80TH_{0,3} =$

	0	1	2	3	4	5	6
0	0.211	3.454·105	6.505	120	175	13	11
1	0.219	3.644·105	6.185	120	1.066·103	14	28
2	0.221	3.689·105	6.5	664	172	135	27
3	0.219	3.643·105	6.185	664	1.066·103	136	28
4	0.221	3.688·105	6.5	123	172	15	27
5	0.214	3.522·105	6.495	123	1.067·103	16	19
6	0.214	3.522·105	6.495	665	1.067·103	137	19
7	0.199	3.149·105	6.495	665	1.068·103	138	19
8	0.199	3.149·105	6.495	666	1.068·103	139	19
9	0.178	2.641·105	6.345	666	1.069·103	140	19
10	0.178	2.64·105	6.345	667	1.069·103	141	19
11	0.168	2.376·105	6.35	667	1.07·103	142	11
12	0.155	2.079·105	10.81	668	166	143	19
13	0.168	2.377·105	6.35	668	1.07·103	144	7

Pipe Run 1-30E (Element 130, & 132)

$$PRC80TH_{0,4} = \begin{pmatrix} 0.118 & 1.15\times10^5 & 4.22 & 130 & 154 & 19 & 26 \\ 0.099 & 6.914\times10^4 & 5.695 & 130 & 162 & 20 & 28 \\ 0.141 & 1.727\times10^5 & 6.35 & 132 & 156 & 21 & 7 \\ 0.099 & 6.923\times10^4 & 5.695 & 132 & 162 & 22 & 28 \end{pmatrix}$$

Pipe Run 1-30F (Element 133)

$$PRC80TH_{0,5} = \begin{pmatrix} 0.176 & 2.59\times10^{5} & 6.35 & 133 & 157 & 23 & 7 \\ 0.179 & 2.659\times10^{5} & 6.35 & 133 & 158 & 24 & 7 \end{pmatrix}$$

Pipe Properties for Line 1-31

Pipe Run 1-31A (Elements 650, 139, & 357)

$$PRC80TH_{0,6} = \begin{pmatrix} 0.131 & 1.465\times10^{5} & 9.265 & 650 & 184 & 129 & 3 \\ 0.129 & 1.413\times10^{5} & 9.265 & 650 & 1.052\times10^{3} & 130 & 3 \\ 0.149 & 1.919\times10^{5} & 4.21 & 139 & 185 & 33 & 26 \\ 0.128 & 1.404\times10^{5} & 4.21 & 139 & 196 & 34 & 28 \\ 0.131 & 1.466\times10^{5} & 9.265 & 357 & 186 & 57 & 3 \\ 0.128 & 1.403\times10^{5} & 4.21 & 357 & 196 & 58 & 28 \end{pmatrix}$$

Pipe Run 1-31B (Elements 142 & 143)

$$PRC80TH_{0,7} = \begin{pmatrix} 0.171 & 2.464\times10^{5} & 4.22 & 142 & 188 & 35 & 22 \\ 0.228 & 3.875\times10^{5} & 4.205 & 142 & 189 & 36 & 26 \\ 0.126 & 1.347\times10^{5} & 4.21 & 143 & 190 & 37 & 27 \\ 0.125 & 1.33\times10^{5} & 10.95 & 143 & 192 & 38 & 26 \end{pmatrix}$$

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Pipe Properties for Line 1-48

Pipe Run 1-48A (Elements 672, 671, 670, 669, 317, 676, 675, 674, 673, 314, & 301)

$PRC80TH_{0,8} =$

	0	1	2	3	4	5	6
0	0.204	$3.327 \cdot 10^4$	13.09	672	682	151	25
1	0.173	$2.776 \cdot 10^4$	12.89	672	$1.074 \cdot 10^3$	152	22
2	0.148	$2.312 \cdot 10^4$	12.9	671	$1.073 \cdot 10^3$	149	19
3	0.173	$2.776 \cdot 10^4$	12.89	671	$1.074 \cdot 10^3$	150	22
4	0.126	$1.903 \cdot 10^4$	12.9	670	$1.072 \cdot 10^3$	147	17
5	0.148	$2.312 \cdot 10^4$	12.9	670	$1.073 \cdot 10^3$	148	19
6	0.107	$1.557 \cdot 10^4$	10.18	669	$1.071 \cdot 10^3$	145	22
7	0.126	$1.903 \cdot 10^4$	12.9	669	$1.072 \cdot 10^3$	146	17
8	0.092	$1.285 \cdot 10^4$	6.17	317	695	55	8
9	0.107	$1.557 \cdot 10^4$	10.18	317	$1.071 \cdot 10^3$	56	22
10	0.092	$1.285 \cdot 10^4$	6.17	676	695	159	8
11	0.083	$1.121 \cdot 10^4$	10.18	676	$1.078 \cdot 10^3$	160	22
12	0.083	$1.134 \cdot 10^4$	6.17	675	$1.077 \cdot 10^3$	157	11
13	0.083	$1.121 \cdot 10^4$	10.18	675	$1.078 \cdot 10^3$	158	22
14	0.09	$1.261 \cdot 10^4$	6.175	674	$1.076 \cdot 10^3$	155	11
15	0.083	$1.133 \cdot 10^4$	6.17	674	$1.077 \cdot 10^3$	156	11
16	0.107	$1.565 \cdot 10^4$	5.365	673	$1.075 \cdot 10^3$	153	27
17	0.09	$1.261 \cdot 10^4$	6.175	673	$1.076 \cdot 10^3$	154	11
18	0.146	$2.27 \cdot 10^4$	5.37	314	693	53	27
19	0.107	$1.565 \cdot 10^4$	5.365	314	$1.075 \cdot 10^3$	54	27
20	0.134	$2.058 \cdot 10^4$	5.86	301	681	45	22
21	0.146	$2.27 \cdot 10^4$	5.37	301	693	46	27

Pipe Run 1-48B (Elements 680, 679, 678, 677, & 310)

$PRC80TH_{0,9} =$

	0	1	2	3	4	5	6
0	0.144	$2.248 \cdot 10^4$	5.87	680	680	167	22
1	0.122	$1.836 \cdot 10^4$	5.89	680	$1.082 \cdot 10^3$	168	22
2	0.124	$1.881 \cdot 10^4$	5.9	679	$1.081 \cdot 10^3$	165	22
3	0.122	$1.835 \cdot 10^4$	5.89	679	$1.082 \cdot 10^3$	166	22
4	0.14	$2.169 \cdot 10^4$	5.9	678	$1.08 \cdot 10^3$	163	19
5	0.124	$1.88 \cdot 10^4$	5.9	678	$1.081 \cdot 10^3$	164	22
6	0.16	$2.53 \cdot 10^4$	5.89	677	$1.079 \cdot 10^3$	161	26
7	0.14	$2.169 \cdot 10^4$	5.9	677	$1.08 \cdot 10^3$	162	19
8	0.177	$2.842 \cdot 10^4$	5.885	310	678	51	26
9	0.16	$2.53 \cdot 10^4$	5.89	310	$1.079 \cdot 10^3$	52	26

Pipe Run 1-48C (Elements 684, 683, 682, 681, & 299)

$PRC80TH_{0,10} =$

	0	1	2	3	4	5	6
0	0.176	$2.823 \cdot 10^4$	5.885	684	677	175	26
1	0.153	$2.403 \cdot 10^4$	6.17	684	$1.086 \cdot 10^3$	176	19
2	0.139	$2.154 \cdot 10^4$	6.165	683	$1.085 \cdot 10^3$	173	19
3	0.153	$2.403 \cdot 10^4$	6.17	683	$1.086 \cdot 10^3$	174	19
4	0.124	$1.878 \cdot 10^4$	6.165	682	$1.084 \cdot 10^3$	171	19
5	0.139	$2.154 \cdot 10^4$	6.165	682	$1.085 \cdot 10^3$	172	19
6	0.108	$1.588 \cdot 10^4$	6.16	681	$1.083 \cdot 10^3$	169	22
7	0.124	$1.878 \cdot 10^4$	6.165	681	$1.084 \cdot 10^3$	170	19
8	0.101	$1.452 \cdot 10^4$	12.9	299	675	43	17
9	0.108	$1.589 \cdot 10^4$	6.16	299	$1.083 \cdot 10^3$	44	22

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EVALUATION OF PIPE RUNS ON LINES 1-43 AND 1-47 FOR ALL 32 REALIZATIONS

VPRD := ReadData("\PRLines_43_47.prn")

PRD := C_S(VPRD, R)

$PRD_{80TH} := PR_{80th}(PRD)$

Pipe Properties for Line 1-43 (A-J)

Pipe Run 1-43A (Element 167)

$$PRD80TH_{0,0} = \begin{pmatrix} 0.242 & 2.327\times10^{5} & 10.33 & 167 & 224 & 1 & 30 \\ 0.235 & 2.245\times10^{5} & 10.33 & 167 & 225 & 2 & 30 \end{pmatrix}$$

Pipe Run 1-43B (Elements 168 & 169)

$$PRD80TH_{0,1} = \begin{pmatrix} 0.212 & 1.968\times10^{5} & 8.88 & 168 & 226 & 3 & 30 \\ 0.187 & 1.668\times10^{5} & 8.88 & 168 & 228 & 4 & 5 \end{pmatrix}$$

Pipe Run 1-43C (Elements 172 & 174)

$$PRD80TH_{0,2} = \begin{pmatrix} 0.297 & 2.987\times10^{5} & 5.775 & 172 & 251 & 9 & 22 \\ 0.177 & 1.55\times10^{5} & 10.36 & 172 & 252 & 10 & 7 \\ 0.194 & 1.756\times10^{5} & 10.33 & 174 & 232 & 11 & 17 \\ 0.177 & 1.55\times10^{5} & 10.36 & 174 & 252 & 12 & 7 \end{pmatrix}$$

Pipe Run 1-43D (Element 175)

$$PRD80TH_{0,3} = \begin{pmatrix} 0.189 & 1.687\times10^{5} & 10.35 & 175 & 233 & 13 & 7 \\ 0.194 & 1.751\times10^{5} & 8.02 & 175 & 262 & 14 & 14 \end{pmatrix}$$

Pipe Run 1-43E (Elements 211)

$$PRD80TH_{0,4} = \begin{pmatrix} 0.14 & 1.108\times10^{5} & 5.31 & 211 & 235 & 45 & 13 \\ 0.162 & 1.37\times10^{5} & 5.305 & 211 & 281 & 46 & 7 \end{pmatrix}$$

Pipe Run 1-43F (Element 180)

$$PRD80TH_{0,5} = \begin{pmatrix} 0.192 & 1.723\times10^{5} & 5.305 & 180 & 237 & 19 & 13 \\ 0.191 & 1.72\times10^{5} & 5.295 & 180 & 620 & 20 & 6 \end{pmatrix}$$

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Pipe Run 1-43G (Elements 182, 687, 688, 689, 690, & 188)

$PRD80TH_{0,6} =$

	0	1	2	3	4	5	6
0	0.201	$1.833\cdot 10^{5}$	9.3	182	260	23	28
1	0.178	$1.562\cdot 10^{5}$	9.305	182	$1.089\cdot 10^{3}$	24	27
2	0.178	$1.562\cdot 10^{5}$	9.305	687	$1.089\cdot 10^{3}$	170	27
3	0.157	$1.306\cdot 10^{5}$	9.3	687	$1.09\cdot 10^{3}$	171	7
4	0.157	$1.306\cdot 10^{5}$	9.3	688	$1.09\cdot 10^{3}$	172	7
5	0.148	$1.204\cdot 10^{5}$	15.57	688	$1.091\cdot 10^{3}$	173	27
6	0.148	$1.204\cdot 10^{5}$	15.57	689	$1.091\cdot 10^{3}$	174	27
7	0.176	$1.535\cdot 10^{5}$	15.57	689	$1.092\cdot 10^{3}$	175	12
8	0.216	$2.013\cdot 10^{5}$	15.57	690	254	176	25
9	0.176	$1.535\cdot 10^{5}$	15.57	690	$1.092\cdot 10^{3}$	177	12
10	0.17	$1.463\cdot 10^{5}$	15.56	188	239	25	22
11	0.215	$2.008\cdot 10^{5}$	15.57	188	254	26	25

Pipe Run 1-43H (Elements 190 & 691)

$$PRD80TH_{0,7} = \begin{pmatrix} 0.169 & 1.453\times 10^{5} & 15.57 & 190 & 240 & 29 & 22 \\ 0.133 & 1.018\times 10^{5} & 15.57 & 190 & 1.093\times 10^{3} & 30 & 19 \\ 0.126 & 9.344\times 10^{4} & 9.85 & 691 & 241 & 178 & 19 \\ 0.133 & 1.018\times 10^{5} & 15.57 & 691 & 1.093\times 10^{3} & 179 & 19 \end{pmatrix}$$

Pipe Run 1-43I (Elements 192)

$$PRD80TH_{0,8} = \begin{pmatrix} 0.132 & 1.005\times 10^{5} & 9.835 & 192 & 242 & 31 & 22 \\ 0.133 & 1.017\times 10^{5} & 9.85 & 192 & 244 & 32 & 17 \end{pmatrix}$$

Pipe Run 1-43J (Elements 193, 198, 692, 693, 694, & 695)

$PRD80TH_{0,9} =$

	0	1	2	3	4	5	6
0	0.133	$1.018\cdot 10^{5}$	15.52	193	245	33	27
1	0.124	$9.156\cdot 10^{4}$	15.52	193	273	34	12
2	0.124	$9.157\cdot 10^{4}$	15.52	198	273	35	12
3	0.119	$8.553\cdot 10^{4}$	9.88	198	$1.094\cdot 10^{3}$	36	28
4	0.119	$8.554\cdot 10^{4}$	9.88	692	$1.094\cdot 10^{3}$	180	28
5	0.117	$8.227\cdot 10^{4}$	9.88	692	$1.095\cdot 10^{3}$	181	28
6	0.117	$8.228\cdot 10^{4}$	9.88	693	$1.095\cdot 10^{3}$	182	28
7	0.117	$8.25\cdot 10^{4}$	9.87	693	$1.096\cdot 10^{3}$	183	7
8	0.117	$8.251\cdot 10^{4}$	9.87	694	$1.096\cdot 10^{3}$	184	7
9	0.129	$9.746\cdot 10^{4}$	9.48	694	$1.097\cdot 10^{3}$	185	27
10	0.147	$1.189\cdot 10^{5}$	9.485	695	247	186	28
11	0.129	$9.747\cdot 10^{4}$	9.48	695	$1.097\cdot 10^{3}$	187	27

Pipe Run 1-43K (Elements 201 & 203)

$$PRD80TH_{0,10} = \begin{pmatrix} 0.135 & 1.041 \times 10^5 & 15.56 & 201 & 250 & 37 & 17 \\ 0.16 & 1.339 \times 10^5 & 9.885 & 201 & 265 & 38 & 27 \\ 0.139 & 1.095 \times 10^5 & 15.57 & 203 & 264 & 39 & 27 \\ 0.16 & 1.34 \times 10^5 & 9.885 & 203 & 265 & 40 & 27 \end{pmatrix}$$

Pipe Run 1-43L (Elements 205, 696, 697, 698, & 210)

$PRD80TH_{0,11} =$

	0	1	2	3	4	5	6
0	0.136	$1.056 \cdot 10^5$	5.29	205	263	41	7
1	0.137	$1.071 \cdot 10^5$	9.89	205	$1.098 \cdot 10^3$	42	28
2	0.137	$1.071 \cdot 10^5$	9.89	696	$1.098 \cdot 10^3$	188	28
3	0.146	$1.181 \cdot 10^5$	9.875	696	$1.099 \cdot 10^3$	189	25
4	0.146	$1.181 \cdot 10^5$	9.875	697	$1.099 \cdot 10^3$	190	25
5	0.164	$1.387 \cdot 10^5$	9.855	697	$1.1 \cdot 10^3$	191	27
6	0.185	$1.646 \cdot 10^5$	9.85	698	268	192	7
7	0.164	$1.387 \cdot 10^5$	9.855	698	$1.1 \cdot 10^3$	193	27
8	0.252	$2.441 \cdot 10^5$	4.79	210	249	43	31
9	0.185	$1.646 \cdot 10^5$	9.85	210	268	44	7

Pipe Run 1-43M (Element 607)

$$PRD80TH_{0,12} = \begin{pmatrix} 0.289 & 2.888 \times 10^5 & 4.79 & 607 & 601 & 166 & 31 \\ 0.255 & 2.479 \times 10^5 & 4.79 & 607 & 934 & 167 & 31 \end{pmatrix}$$

Pipe Properties for Line 1-43 (N-O)

Pipe Run 1-43N (Element 380)

$$PRD80TH_{0,13} = \begin{pmatrix} 0.235 & 1.006 \times 10^5 & 15.17 & 380 & 805 & 87 & 12 \\ 0.238 & 1.021 \times 10^5 & 15.17 & 380 & 1.054 \times 10^3 & 88 & 12 \end{pmatrix}$$

Pipe Run 1-43O (Element 227)

$$PRD80TH_{0,14} = \begin{pmatrix} 0.169 & 6.874 \times 10^4 & 15.2 & 227 & 299 & 51 & 17 \\ 0.201 & 8.414 \times 10^4 & 15.18 & 227 & 349 & 52 & 19 \end{pmatrix}$$

Pipe Properties for Line 1-47

Pipe Run 1-47A (Elements 272, 699, & 700)

$$PRD80TH_{0,15} = \begin{pmatrix} 0.19 & 1.698\times10^{5} & 9.585 & 272 & 626 & 59 & 17 \\ 0.119 & 8.576\times10^{4} & 9.58 & 272 & 1.101\times10^{3} & 60 & 28 \\ 0.119 & 8.576\times10^{4} & 9.58 & 699 & 1.101\times10^{3} & 194 & 28 \\ 0.09 & 4.991\times10^{4} & 8.86 & 699 & 1.102\times10^{3} & 195 & 14 \\ 0.147 & 1.184\times10^{5} & 8.03 & 700 & 629 & 196 & 25 \\ 0.09 & 4.992\times10^{4} & 8.865 & 700 & 1.102\times10^{3} & 197 & 14 \end{pmatrix}$$

Pipe Run 1-47B (Elements 273, 276,& 277)

$$PRD80TH_{0,16} = \begin{pmatrix} 0.154 & 1.266\times10^{5} & 9.79 & 273 & 630 & 61 & 19 \\ 0.17 & 1.461\times10^{5} & 9.805 & 273 & 637 & 62 & 24 \\ 0.175 & 1.527\times10^{5} & 9.79 & 276 & 637 & 67 & 19 \\ 0.12 & 8.599\times10^{4} & 9.79 & 276 & 638 & 68 & 11 \\ 0.093 & 5.383\times10^{4} & 11.04 & 277 & 632 & 69 & 22 \\ 0.12 & 8.599\times10^{4} & 9.79 & 277 & 638 & 70 & 28 \end{pmatrix}$$

Pipe Run 1-47C (Elements 274 & 281)

$$PRD80TH_{0,17} = \begin{pmatrix} 0.102 & 6.425\times10^{4} & 5.07 & 274 & 633 & 63 & 3 \\ 0.123 & 9.02\times10^{4} & 7.865 & 274 & 642 & 64 & 17 \\ 0.102 & 6.478\times10^{4} & 10.03 & 281 & 634 & 71 & 11 \\ 0.125 & 9.294\times10^{4} & 4.235 & 281 & 642 & 72 & 19 \end{pmatrix}$$

Pipe Run 1-47D (Element 275)

$$PRD80TH_{0,18} = \begin{pmatrix} 0.095 & 5.607\times10^{4} & 7.845 & 275 & 635 & 65 & 29 \\ 0.097 & 5.852\times10^{4} & 7.85 & 275 & 636 & 66 & 10 \end{pmatrix}$$

Pipe Run 1-47E (Element 284)

$$PRD80TH_{0,19} = \begin{pmatrix} 0.093 & 5.432\times10^{4} & 8.045 & 284 & 648 & 73 & 25 \\ 0.093 & 5.418\times10^{4} & 8.04 & 284 & 649 & 74 & 26 \end{pmatrix}$$

Pipe Run 1-47F (Elements 285, 701, 702, 703, 704, 705, 706, & 295)

$PRD80TH_{0,20} =$

	0	1	2	3	4	5	6
0	0.093	$5.441 \cdot 10^{4}$	8.045	285	651	75	25
1	0.095	$5.619 \cdot 10^{4}$	4.41	285	$1.103 \cdot 10^{3}$	76	19
2	0.095	$5.617 \cdot 10^{4}$	4.41	701	$1.103 \cdot 10^{3}$	198	19
3	0.094	$5.518 \cdot 10^{4}$	8.035	701	$1.104 \cdot 10^{3}$	199	10
4	0.094	$5.518 \cdot 10^{4}$	8.035	702	$1.104 \cdot 10^{3}$	200	10
5	0.092	$5.301 \cdot 10^{4}$	10.12	702	$1.105 \cdot 10^{3}$	201	18
6	0.092	$5.302 \cdot 10^{4}$	10.12	703	$1.105 \cdot 10^{3}$	202	18
7	0.091	$5.117 \cdot 10^{4}$	9.735	703	$1.106 \cdot 10^{3}$	203	32
8	0.091	$5.119 \cdot 10^{4}$	9.735	704	$1.106 \cdot 10^{3}$	204	32
9	0.085	$4.427 \cdot 10^{4}$	10.1	704	$1.107 \cdot 10^{3}$	205	27
10	0.085	$4.427 \cdot 10^{4}$	10.1	705	$1.107 \cdot 10^{3}$	206	27
11	0.08	$3.874 \cdot 10^{4}$	7.625	705	$1.108 \cdot 10^{3}$	207	3
12	0.096	$5.726 \cdot 10^{4}$	7.855	706	653	208	3
13	0.08	$3.876 \cdot 10^{4}$	7.625	706	$1.108 \cdot 10^{3}$	209	3
14	0.093	$5.41 \cdot 10^{4}$	9.45	295	653	83	11
15	0.102	$6.513 \cdot 10^{4}$	7.865	295	661	84	19

Pipe Run 1-47G (Elements 292 & 337)

$$PRD80TH_{0,21} = \begin{pmatrix} 0.1 & 6.245 \times 10^{4} & 7.87 & 292 & 662 & 77 & 11 \\ 0.086 & 4.596 \times 10^{4} & 7.855 & 292 & 703 & 78 & 25 \\ 0.074 & 3.16 \times 10^{4} & 7.845 & 337 & 665 & 85 & 28 \\ 0.086 & 4.596 \times 10^{4} & 7.855 & 337 & 703 & 86 & 25 \end{pmatrix}$$

Pipe Run 1-47H (Elements 293, 707, 708, 709, & 710)

$PRD80TH_{0,22} =$

	0	1	2	3	4	5	6
0	0.072	$2.87 \cdot 10^{4}$	7.84	293	664	79	27
1	0.069	$2.483 \cdot 10^{4}$	5.065	293	$1.109 \cdot 10^{3}$	80	4
2	0.069	$2.485 \cdot 10^{4}$	5.065	707	$1.109 \cdot 10^{3}$	210	4
3	0.071	$2.713 \cdot 10^{4}$	10.25	707	$1.11 \cdot 10^{3}$	211	24
4	0.071	$2.713 \cdot 10^{4}$	10.25	708	$1.11 \cdot 10^{3}$	212	24
5	0.079	$3.698 \cdot 10^{4}$	10.26	708	$1.111 \cdot 10^{3}$	213	27
6	0.079	$3.698 \cdot 10^{4}$	10.26	709	$1.111 \cdot 10^{3}$	214	27
7	0.092	$5.229 \cdot 10^{4}$	10.26	709	$1.112 \cdot 10^{3}$	215	7
8	0.106	$6.907 \cdot 10^{4}$	10.27	710	667	216	28
9	0.092	$5.229 \cdot 10^{4}$	10.26	710	$1.112 \cdot 10^{3}$	217	7

Pipe Run 1-47I (Element 294)

$$PRD80TH_{0,23} = \begin{pmatrix} 0.11 & 7.46 \times 10^{4} & 10.27 & 294 & 668 & 81 & 28 \\ 0.111 & 7.514 \times 10^{4} & 10.27 & 294 & 669 & 82 & 19 \end{pmatrix}$$

EVALUATION OF PIPE RUNS ON LINES 1-44, 1-46, AND 8-14 FOR ALL 32 REALIZATIONS

$VPRE := ReadData("\backslash PRLines\_44\_46\_814.prn")$

$PRE := C\_S(VPRE, R)$

$PRE_{80TH} := PR_{80th}(PRE)$

Pipe Properties for Line 1-44

Pipe Run 1-44A (Element 224)

$$PRE_{80TH_{0,0}} = \begin{pmatrix} 0.114 & 1.055 \times 10^{5} & 10.34 & 224 & 301 & 25 & 11 \\ 0.113 & 1.024 \times 10^{5} & 10.32 & 224 & 305 & 26 & 28 \end{pmatrix}$$

Pipe Run 1-44B (Elements 228, 711, 712, 713, & 263)

$PRE_{80TH_{0,1}} =$

	0	1	2	3	4	5	6
0	0.112	$1.006 \cdot 10^{5}$	10.32	228	302	27	28
1	0.105	$8.271 \cdot 10^{4}$	5.68	228	$1.113 \cdot 10^{3}$	28	25
2	0.105	$8.271 \cdot 10^{4}$	5.68	711	$1.113 \cdot 10^{3}$	120	25
3	0.099	$6.828 \cdot 10^{4}$	5.675	711	$1.114 \cdot 10^{3}$	121	13
4	0.099	$6.828 \cdot 10^{4}$	5.675	712	$1.114 \cdot 10^{3}$	122	13
5	0.098	$6.488 \cdot 10^{4}$	11.4	712	$1.115 \cdot 10^{3}$	123	7
6	0.099	$6.831 \cdot 10^{4}$	11.4	713	306	124	7
7	0.098	$6.488 \cdot 10^{4}$	11.4	713	$1.115 \cdot 10^{3}$	125	7
8	0.099	$6.838 \cdot 10^{4}$	11.4	263	306	53	7
9	0.099	$6.909 \cdot 10^{4}$	11.41	263	324	54	10

Pipe Run 1-44C (Elements 235, 714, 239, & 715)

$$PRE_{80TH_{0,2}} = \begin{pmatrix} 0.102 & 7.456 \times 10^{4} & 9.345 & 235 & 325 & 29 & 7 \\ 0.094 & 5.616 \times 10^{4} & 9.34 & 235 & 1.116 \times 10^{3} & 30 & 5 \\ 0.089 & 4.434 \times 10^{4} & 5.695 & 714 & 326 & 126 & 28 \\ 0.094 & 5.616 \times 10^{4} & 9.34 & 714 & 1.116 \times 10^{3} & 127 & 5 \\ 0.089 & 4.434 \times 10^{4} & 5.695 & 239 & 326 & 31 & 28 \\ 0.093 & 5.403 \times 10^{4} & 5.51 & 239 & 1.117 \times 10^{3} & 32 & 13 \\ 0.103 & 7.774 \times 10^{4} & 5.51 & 715 & 330 & 128 & 27 \\ 0.093 & 5.404 \times 10^{4} & 5.51 & 715 & 1.117 \times 10^{3} & 129 & 13 \end{pmatrix}$$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** B. K. Blandford **Date:** 09/30/2008

Pipe Run 1-44D (Elements 242, 243, 716, 717, 718, & 249)

$PRE80TH_{0,3} =$

	0	1	2	3	4	5	6
0	0.111	$9.751\cdot10^{4}$	9.34	242	331	33	25
1	0.132	$1.496\cdot10^{5}$	9.34	242	332	34	13
2	0.129	$1.416\cdot10^{5}$	5.69	243	332	35	13
3	0.114	$1.049\cdot10^{5}$	5.69	243	$1.118\cdot10^{3}$	36	28
4	0.114	$1.049\cdot10^{5}$	5.69	716	$1.118\cdot10^{3}$	130	28
5	0.1	$7.071\cdot10^{4}$	5.69	716	$1.119\cdot10^{3}$	131	13
6	0.1	$7.071\cdot10^{4}$	5.69	717	$1.119\cdot10^{3}$	132	13
7	0.087	$3.937\cdot10^{4}$	5.69	717	$1.12\cdot10^{3}$	133	24
8	0.079	$1.824\cdot10^{4}$	5.5	718	333	134	26
9	0.087	$3.937\cdot10^{4}$	5.69	718	$1.12\cdot10^{3}$	135	24
10	0.075	$8.077\cdot10^{3}$	6.64	249	315	37	24
11	0.079	$1.824\cdot10^{4}$	5.5	249	333	38	26

Pipe Run 1-44E (Element 250)

$$PRE80TH_{0,4} = \begin{pmatrix} 0.076 & 1.156\times10^{4} & 9.36 & 250 & 316 & 39 & 11 \\ 0.078 & 1.64\times10^{4} & 6.295 & 250 & 317 & 40 & 32 \end{pmatrix}$$

Pipe Run 1-44F (Elements 252, 719, 256, 720, & 261)

$PRE80TH_{0,5} =$

	0	1	2	3	4	5	6
0	0.078	$1.646\cdot10^{4}$	6.295	252	318	43	32
1	0.079	$1.892\cdot10^{4}$	5.355	252	$1.121\cdot10^{3}$	44	27
2	0.08	$2.055\cdot10^{4}$	6.345	719	339	136	24
3	0.079	$1.892\cdot10^{4}$	5.355	719	$1.121\cdot10^{3}$	137	27
4	0.08	$2.055\cdot10^{4}$	6.345	256	339	45	24
5	0.08	$2.113\cdot10^{4}$	5.99	256	$1.122\cdot10^{3}$	46	28
6	0.079	$1.982\cdot10^{4}$	5.995	720	602	138	19
7	0.08	$2.113\cdot10^{4}$	5.99	720	$1.122\cdot10^{3}$	139	28
8	0.079	$1.953\cdot10^{4}$	5.995	261	320	51	3
9	0.08	$2.004\cdot10^{4}$	5.995	261	602	52	19

Pipe Run 1-44G (Elements 257 & 259)

$$PRE80TH_{0,6} = \begin{pmatrix} 0.078 & 1.553\times10^{4} & 5.87 & 257 & 321 & 47 & 28 \\ 0.079 & 1.918\times10^{4} & 5.99 & 257 & 346 & 48 & 7 \\ 0.09 & 4.608\times10^{4} & 5.985 & 259 & 344 & 49 & 22 \\ 0.079 & 1.918\times10^{4} & 5.99 & 259 & 346 & 50 & 7 \end{pmatrix}$$

Pipe Properties for Line 1-46

Pipe Run 1-46A (Elements 652, 213, 721, 217, and 722)

$PRE80TH_{0,7} =$

	0	1	2	3	4	5	6
0	0.104	$8.159\cdot10^4$	10.34	652	284	118	27
1	0.109	$9.177\cdot10^4$	9.18	652	$1.053\cdot10^3$	119	6
2	0.101	$7.351\cdot10^4$	9.18	213	283	9	7
3	0.09	$4.683\cdot10^4$	5.1	213	$1.123\cdot10^3$	10	27
4	0.085	$3.4\cdot10^4$	5.695	721	291	140	22
5	0.09	$4.683\cdot10^4$	5.1	721	$1.123\cdot10^3$	141	27
6	0.085	$3.402\cdot10^4$	5.695	217	291	11	22
7	0.088	$4.151\cdot10^4$	8.825	217	$1.124\cdot10^3$	12	15
8	0.099	$6.914\cdot10^4$	10.35	722	287	142	7
9	0.088	$4.151\cdot10^4$	8.825	722	$1.124\cdot10^3$	143	15

Pipe Run 1-46B (Elements 218)

$$PRE80TH_{0,8} = \begin{pmatrix} 0.098 & 6.488\times10^4 & 9.185 & 218 & 290 & 13 & 7 \\ 0.095 & 5.907\times10^4 & 6.01 & 218 & 295 & 14 & 25 \end{pmatrix}$$

Pipe Properties for Line 8-14

Pipe Run 8-14A (Element 470)

$$PRE80TH_{0,9} = \begin{pmatrix} 0.085 & 6.497\times10^4 & 10.63 & 470 & 200 & 67 & 19 \\ 0.085 & 6.506\times10^4 & 10.63 & 470 & 888 & 68 & 19 \end{pmatrix}$$

Pipe Run 8-14B (Elements 724, 723, 165, & 160)

$$PRE80TH_{0,10} = \begin{pmatrix} 0.084 & 5.961\times10^4 & 10.95 & 724 & 201 & 146 & 22 \\ 0.081 & 4.433\times10^4 & 10.95 & 724 & 1.126\times10^3 & 147 & 28 \\ 0.078 & 3.008\times10^4 & 10.95 & 723 & 1.125\times10^3 & 144 & 19 \\ 0.081 & 4.432\times10^4 & 10.95 & 723 & 1.126\times10^3 & 145 & 19 \\ 0.079 & 3.689\times10^4 & 6.85 & 165 & 207 & 7 & 27 \\ 0.078 & 3.007\times10^4 & 10.95 & 165 & 1.125\times10^3 & 8 & 19 \\ 0.082 & 4.825\times10^4 & 10.6 & 160 & 202 & 5 & 28 \\ 0.079 & 3.688\times10^4 & 6.85 & 160 & 207 & 6 & 27 \end{pmatrix}$$

Pipe Run 8-14C (Elements 725,159,730,729,728,727,726,151,488,731,732,733, & 734)

$PRE80TH_{0,11} =$

	0	1	2	3	4	5	6
0	0.081	$4.404\cdot10^{4}$	6.715	725	203	148	24
1	0.078	$3.228\cdot10^{4}$	10.62	725	$1.127\cdot10^{3}$	149	19
2	0.08	$3.874\cdot10^{4}$	10.8	159	208	3	25
3	0.078	$3.227\cdot10^{4}$	10.62	159	$1.127\cdot10^{3}$	4	19
4	0.08	$3.909\cdot10^{4}$	10.8	730	208	158	25
5	0.083	$5.577\cdot10^{4}$	6.48	730	$1.134\cdot10^{3}$	159	25
6	0.088	$7.779\cdot10^{4}$	6.485	729	$1.133\cdot10^{3}$	156	25
7	0.083	$5.579\cdot10^{4}$	6.48	729	$1.134\cdot10^{3}$	157	25
8	0.091	$9.437\cdot10^{4}$	6.485	728	$1.132\cdot10^{3}$	154	25
9	0.088	$7.781\cdot10^{4}$	6.485	728	$1.133\cdot10^{3}$	155	25
10	0.093	$1.034\cdot10^{5}$	6.49	727	$1.131\cdot10^{3}$	152	9
11	0.091	$9.438\cdot10^{4}$	6.485	727	$1.132\cdot10^{3}$	153	25
12	0.093	$1.051\cdot10^{5}$	6.49	726	$1.13\cdot10^{3}$	150	22
13	0.093	$1.034\cdot10^{5}$	6.49	726	$1.131\cdot10^{3}$	151	9
14	0.093	$1.04\cdot10^{5}$	6.49	151	150	1	3
15	0.093	$1.051\cdot10^{5}$	6.49	151	$1.13\cdot10^{3}$	2	22

EVALUATION OF PIPE RUNS ON LINES 1-44, 1-46, AND 8-14 FOR ALL 32 REALIZATIONS

$VPRF := ReadData(\text{"\textbackslash PRLine\_45.prn"})$

$PRF := C\_S(VPRF, R)$

$PRF_{80TH} := PR_{80th}(PRF)$

Pipe Properties for Line 1-45

Pipe Run 1-45 (Element 614)

$$PRF_{80TH_{0,0}} = \begin{pmatrix} 0.06 & 1.632\times10^{4} & 6.13 & 614 & 1.007\times10^{3} & 7 & 28 \\ 0.06 & 1.646\times10^{4} & 5.42 & 614 & 1.019\times10^{3} & 8 & 14 \end{pmatrix}$$

Pipe Run 1-45B (Element 615)

$$PRF_{80TH_{0,1}} = \begin{pmatrix} 0.066 & 1.899\times10^{4} & 9.88 & 615 & 1.008\times10^{3} & 9 & 10 \\ 0.065 & 1.872\times10^{4} & 9.88 & 615 & 1.009\times10^{3} & 10 & 10 \end{pmatrix}$$

Pipe Run 1-45C (Elements 616 & 627)

$$PRF_{80TH_{0,2}} = \begin{pmatrix} 0.058 & 1.551\times10^{4} & 9.88 & 616 & 1.01\times10^{3} & 11 & 10 \\ 0.048 & 1.068\times10^{4} & 4.205 & 616 & 1.032\times10^{3} & 12 & 22 \\ 0.051 & 1.204\times10^{4} & 10.03 & 627 & 1.015\times10^{3} & 39 & 12 \\ 0.048 & 1.068\times10^{4} & 4.205 & 627 & 1.032\times10^{3} & 40 & 22 \end{pmatrix}$$

Pipe Run 1-45D (Elements 617 & 628)

$$PRF80TH_{0,3} = \begin{pmatrix} 0.052 & 1.24\times 10^{4} & 8.53 & 617 & 1.016\times 10^{3} & 13 & 15 \\ 0.05 & 1.142\times 10^{4} & 8.53 & 617 & 1.033\times 10^{3} & 14 & 14 \\ 0.05 & 1.159\times 10^{4} & 8.53 & 628 & 1.017\times 10^{3} & 41 & 14 \\ 0.05 & 1.142\times 10^{4} & 8.53 & 628 & 1.033\times 10^{3} & 42 & 14 \end{pmatrix}$$

Pipe Run 1-45E (Elements 618, 629, 631, & 632)

$$PRF80TH_{0,4} = \begin{pmatrix} 0.05 & 1.139\times 10^{4} & 8.53 & 618 & 1.018\times 10^{3} & 15 & 25 \\ 0.051 & 1.189\times 10^{4} & 6.27 & 618 & 1.034\times 10^{3} & 16 & 24 \\ 0.051 & 1.188\times 10^{4} & 6.27 & 629 & 1.034\times 10^{3} & 43 & 24 \\ 0.042 & 7.817\times 10^{3} & 5.185 & 629 & 1.035\times 10^{3} & 44 & 14 \\ 0.042 & 7.818\times 10^{3} & 5.185 & 631 & 1.035\times 10^{3} & 45 & 14 \\ 0.059 & 1.597\times 10^{4} & 10.79 & 631 & 1.037\times 10^{3} & 46 & 6 \\ 0.052 & 1.233\times 10^{4} & 7.455 & 632 & 1.011\times 10^{3} & 47 & 22 \\ 0.059 & 1.599\times 10^{4} & 10.79 & 632 & 1.037\times 10^{3} & 48 & 6 \end{pmatrix}$$

Pipe Run 1-45F (Elements 619 & 633)

$$PRF80TH_{0,5} = \begin{pmatrix} 0.049 & 1.088\times 10^{4} & 9.89 & 619 & 1.012\times 10^{3} & 17 & 28 \\ 0.039 & 6.353\times 10^{3} & 10.02 & 619 & 1.038\times 10^{3} & 18 & 25 \\ 0.066 & 1.913\times 10^{4} & 10.02 & 633 & 1.013\times 10^{3} & 49 & 22 \\ 0.039 & 6.354\times 10^{3} & 10.02 & 633 & 1.038\times 10^{3} & 50 & 25 \end{pmatrix}$$

Pipe Run 1-45G (Element 620)

$$PRF80TH_{0,6} = \begin{pmatrix} 0.073 & 2.245\times 10^{4} & 10.02 & 620 & 1.006\times 10^{3} & 19 & 22 \\ 0.073 & 2.234\times 10^{4} & 10.02 & 620 & 1.014\times 10^{3} & 20 & 22 \end{pmatrix}$$

REDUCERS

Termination output is ordered as (max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, index of element(s), moments about the x, y, and z axes, and realization number)

EVALUATION OF REDUCERS ON LINES 1-13 TO 1-16, 1-18 TO 1-21, AND 1-171 FOR ALL 32 REALIZATIONS

VRA := ReadData("\RedLines_13to16_18to21_171.prn")

RA := C_S(VRA, R)

$RA_{80TH} := RED\_EL_{80th}(RA)$

Reducer Properties for Top of Lines 1-18, 1-19, 1-20, 1-21

Reducer 1-18A (Nodes 30 & 29)

$$RA_{80TH_0} = \begin{pmatrix} 0.227 & 1.056\times10^6 & 9.26 & 30 & 21 & -1.005\times10^6 & -1.899\times10^5 & 2.616\times10^5 & 19 \\ 0.275 & 1.124\times10^6 & 9.26 & 29 & 2 & -1.073\times10^6 & -1.899\times10^5 & 2.758\times10^5 & 19 \end{pmatrix}$$

Reducer 1-19A (Nodes 33 & 32)

$$RA_{80TH_1} = \begin{pmatrix} 0.233 & 1.092\times10^6 & 4.05 & 33 & 23 & 7.198\times10^5 & 1.49\times10^5 & -8.08\times10^5 & 11 \\ 0.281 & 1.154\times10^6 & 4.05 & 32 & 6 & 7.688\times10^5 & 1.49\times10^5 & -8.478\times10^5 & 11 \end{pmatrix}$$

Reducer 1-20A (Nodes 35 & 34)

$$RA_{80TH_2} = \begin{pmatrix} 0.231 & 1.083\times10^6 & 4.05 & 35 & 29 & 7.97\times10^5 & 1.337\times10^5 & -7.211\times10^5 & 19 \\ 0.279 & 1.145\times10^6 & 4.05 & 34 & 10 & 8.499\times10^5 & 1.337\times10^5 & -7.552\times10^5 & 19 \end{pmatrix}$$

Reducer 1-21A (Nodes 37 & 36)

$$RA_{80TH_3} = \begin{pmatrix} 0.245 & 1.171\times10^6 & 10.27 & 37 & 35 & -9.913\times10^4 & -6.383\times10^4 & 1.165\times10^6 & 28 \\ 0.298 & 1.241\times10^6 & 10.27 & 36 & 14 & -1.071\times10^5 & -6.382\times10^4 & 1.234\times10^6 & 28 \end{pmatrix}$$

EVALUATION OF REDUCERS ON LINE 1-17 FOR ALL 32 REALIZATIONS

VRB := ReadData("\RedLine_17.prn")

RB := C_S(VRB, R)

$RB_{80TH} := RED\_EL_{80th}(RB)$

Reducer Properties for Lines 1-17

Reducer 1-17A (Nodes 932 & 132)

$$RB_{80TH_0} = \begin{pmatrix} 0.08 & 6 \\ 0.072 & 11 \end{pmatrix}$$

EVALUATION OF REDUCERS ON LINES 1-30 TO 1-31 AND 1-48 FOR ALL 32 REALIZATIONS

VRC := ReadData("\RedLines_30to31_48.prn")

RC := C_S(VRC, R)

$RC_{80TH} := RED\_EL_{80th}(RC)$

Reducer Properties for Lines 1-30 and 1-31

Reducer 1-30A (Nodes 159 & 160)

$$RC_{80TH_0} = \begin{pmatrix} 0.177 & 2.87\times10^{5} & 6.49 & 159 & 25 & 2.215\times10^{4} & 2.133\times10^{5} & 1.907\times10^{5} & 22 \\ 0.226 & 3.381\times10^{5} & 6.485 & 160 & 27 & 6.376\times10^{3} & -2.761\times10^{5} & -1.951\times10^{5} & 22 \end{pmatrix}$$

Reducer 1-31A (Nodes 193 & 194)

$$RC_{80TH_1} = \begin{pmatrix} 0.139 & 1.85\times10^{5} & 6.33 & 193 & 39 & -7.238\times10^{4} & -1.67\times10^{5} & -3.329\times10^{4} & 19 \\ 0.175 & 2.335\times10^{5} & 6.335 & 194 & 41 & 1.181\times10^{5} & 1.99\times10^{5} & 3.072\times10^{4} & 11 \end{pmatrix}$$

THERE ARE NOT ANY REDUCERS ON LINES 1-43 AND 1-47

THERE ARE NOT ANY REDUCERS ON LINES 1-44, 1-46, AND 8-14

THERE ARE NOT ANY REDUCERS ON LINE 1-45

ELBOWS

Elbow output is ordered as (max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, index of element(s), moments about the x, y, and z axes, and realization number)

EVALUATION OF ELBOWS ON LINES 1-13 TO 1-16, 1-18 TO 1-21, AND 1-171 FOR ALL 32 REALIZATIONS

VELA := ReadData("\ElbowLines_13to16_18to21_171.prn")

ELA := C_S(VELA, R)

$ELA_{80TH} := RED\_EL_{80th}(ELA)$

Elbow Properties for Lines 1-13, 1-14, 1-15, and 1-16

Elbow 1-13A (Nodes 123 & 114)

$$ELA_{80TH_0} = \begin{pmatrix} 0.278 & 2.39\times10^{5} & 4.05 & 123 & 81 & -1.71\times10^{5} & -8.717\times10^{4} & 1.424\times10^{5} & 19 \\ 0.21 & 1.8\times10^{5} & 10.02 & 114 & 118 & -1.008\times10^{4} & 4.205\times10^{4} & 1.747\times10^{5} & 22 \end{pmatrix}$$

Elbow 1-13B (Nodes 113 & 96)

$$ELA80TH_1 = \begin{pmatrix} 0.121 & 1.043\times10^5 & 12.72 & 113 & 65 & -7.65\times10^4 & 7.074\times10^4 & -4.189\times10^3 & 27 \\ 0.192 & 1.65\times10^5 & 9.26 & 96 & 52 & 1.616\times10^5 & 2.126\times10^4 & -2.574\times10^4 & 28 \end{pmatrix}$$

Elbow 1-14A (Nodes 125 & 115)

$$ELA80TH_2 = \begin{pmatrix} 0.308 & 2.645\times10^5 & 6.705 & 125 & 83 & 2.282\times10^5 & 2.226\times10^4 & 1.319\times10^5 & 3 \\ 0.288 & 2.477\times10^5 & 4.04 & 115 & 124 & -5.54\times10^4 & -1.094\times10^5 & 2.153\times10^5 & 19 \end{pmatrix}$$

Elbow 1-14B (Nodes 112 & 97)

$$ELA80TH_3 = \begin{pmatrix} 0.172 & 1.474\times10^5 & 4.055 & 112 & 69 & 8.613\times10^4 & -1.187\times10^5 & -1.449\times10^4 & 27 \\ 0.248 & 2.128\times10^5 & 5.225 & 97 & 55 & 1.075\times10^5 & -5.457\times10^4 & -1.754\times10^5 & 25 \end{pmatrix}$$

Elbow 1-15A (Nodes 124 & 116)

$$ELA80TH_4 = \begin{pmatrix} 0.321 & 2.76\times10^5 & 4.04 & 124 & 85 & -2.107\times10^5 & -7.678\times10^4 & 1.609\times10^5 & 11 \\ 0.283 & 2.432\times10^5 & 6.7 & 116 & 130 & 5.189\times10^3 & 9.318\times10^4 & 2.245\times10^5 & 7 \end{pmatrix}$$

Elbow 1-15B (Nodes 111 & 102)

$$ELA80TH_5 = \begin{pmatrix} 0.152 & 1.307\times10^5 & 6.695 & 111 & 135 & 4.358\times10^4 & -9.542\times10^4 & 7.801\times10^4 & 7 \\ 0.217 & 1.863\times10^5 & 10.6 & 102 & 60 & -1.479\times10^5 & 2.73\times10^4 & -1.098\times10^5 & 19 \end{pmatrix}$$

Elbow 1-16A (Nodes 126 & 117)

$$ELA80TH_6 = \begin{pmatrix} 0.29 & 2.491\times10^5 & 7.53 & 126 & 87 & -1.952\times10^5 & -2.792\times10^4 & -1.522\times10^5 & 27 \\ 0.307 & 2.64\times10^5 & 10.12 & 117 & 136 & -3.17\times10^4 & -9.497\times10^4 & 2.442\times10^5 & 12 \end{pmatrix}$$

Elbow 1-16B (Nodes 110 & 105)

$$ELA80TH_7 = \begin{pmatrix} 0.206 & 1.767\times10^5 & 5.8 & 110 & 141 & 1.001\times10^5 & -1.15\times10^5 & -8.925\times10^4 & 13 \\ 0.293 & 2.52\times10^5 & 5.8 & 105 & 140 & -1.734\times10^5 & 5.21\times10^4 & 1.752\times10^5 & 24 \end{pmatrix}$$

Elbow Properties for Lines 1-18, 1-19, 1-20, and 1-21

Elbow 1-18A (Nodes 6 & 7)

$$ELA80TH_8 = \begin{pmatrix} 0.279 & 3.169\times10^5 & 9.265 & 6 & 20 & -3.147\times10^5 & 3.483\times10^4 & -1.394\times10^4 & 19 \\ 0.249 & 2.831\times10^5 & 4.05 & 7 & 172 & -1.467\times10^5 & 1.742\times10^5 & -1.681\times10^5 & 25 \end{pmatrix}$$

Elbow 1-19A (Nodes 13 & 14)

$$ELA80TH_9 = \begin{pmatrix} 0.303 & 3.443\times10^5 & 9.265 & 13 & 28 & -3.414\times10^5 & 4.31\times10^4 & 1.146\times10^4 & 19 \\ 0.238 & 2.706\times10^5 & 9.265 & 14 & 176 & 1.789\times10^5 & -2.03\times10^5 & 2.356\times10^3 & 19 \end{pmatrix}$$

Elbow 1-20A (Nodes 20 & 21)

$$ELA80TH_{10} = \begin{pmatrix} 0.29 & 3.298\times10^5 & 9.26 & 20 & 34 & -3.268\times10^5 & 4.434\times10^4 & -361.2 & 27 \\ 0.236 & 2.677\times10^5 & 9.265 & 21 & 180 & 1.716\times10^5 & -2.041\times10^5 & -2.288\times10^4 & 26 \end{pmatrix}$$

Elbow 1-21A (Nodes 27 & 28)

$$ELA80TH_{11} = \begin{pmatrix} 0.292 & 3.309\times10^5 & 9.265 & 27 & 40 & -3.252\times10^5 & 5.642\times10^4 & 2.408\times10^4 & 27 \\ 0.244 & 2.768\times10^5 & 9.27 & 28 & 184 & 1.728\times10^5 & -2.108\times10^5 & -4.811\times10^4 & 26 \end{pmatrix}$$

Elbow Properties for Line 1-171 (Short Radius Elbow)

Elbow 1-171A (Nodes 140 & 138)

$$ELA80TH_{12} = \begin{pmatrix} 0.203 & 1.329\times10^5 & 9.26 & 140 & 98 & 8.747\times10^4 & 1\times10^5 & -2.601\times10^3 & 26 \\ 0.266 & 1.745\times10^5 & 10.02 & 138 & 109 & -4.538\times10^4 & 7.127\times10^3 & 1.684\times10^5 & 11 \end{pmatrix}$$

Elbow Properties for Line 1-171 (Long Radius Elbows)

Elbow 1-171B (Nodes 136 & 135)

$$ELA80TH_{13} = \begin{pmatrix} 0.143 & 9.352\times10^4 & 3.95 & 136 & 93 & -6.411\times10^4 & 5.07\times10^4 & 4.546\times10^4 & 15 \\ 0.173 & 1.132\times10^5 & 6.905 & 135 & 113 & -3.86\times10^4 & 878.5 & 1.064\times10^5 & 3 \end{pmatrix}$$

Elbow 1-171C (Nodes 143 & 132)

$$ELA80TH_{14} = \begin{pmatrix} 0.247 & 1.621\times10^5 & 10.04 & 143 & 117 & 3.158\times10^4 & -2.209\times10^4 & 1.574\times10^5 & 11 \\ 0.341 & 2.235\times10^5 & 10.04 & 132 & 90 & -3.392\times10^4 & 7.361\times10^3 & 2.208\times10^5 & 11 \end{pmatrix}$$

THERE ARE NOT ANY ELBOWS PRESENT ON LINE 1-17

EVALUATION OF ELBOWS ON LINES 1-30 TO 1-31 AND 1-48 FOR ALL 32 REALIZATIONS

$VELC := ReadData(\text{"\textbackslash ElbowLines\_30to31\_48.prn"})$

$ELC := C\_S(VELC, R)$

$ELC_{80TH} := RED\_EL_{80th}(ELC)$

Elbow Properties for Lines 1-30 and 1-31

Elbow 1-30A (Nodes 146 & 148)

$$ELC_{80TH_0} = \begin{pmatrix} 0.699 & 2.352\times10^5 & 6.335 & 146 & 2 & -4.631\times10^4 & 2.238\times10^5 & -5.52\times10^4 & 26 \\ 0.641 & 2.157\times10^5 & 6.84 & 148 & 87 & -5.688\times10^4 & 1.967\times10^3 & 2.08\times10^5 & 28 \end{pmatrix}$$

Elbow 1-30B (Nodes 153 & 154)

$$ELC_{80TH_1} = \begin{pmatrix} 0.421 & 1.415\times10^5 & 6.485 & 153 & 18 & 8.604\times10^4 & -9.378\times10^3 & 1.12\times10^5 & 4 \\ 0.342 & 1.15\times10^5 & 4.22 & 154 & 89 & -8.638\times10^4 & -3.237\times10^4 & 6.874\times10^4 & 26 \end{pmatrix}$$

Elbow 1-30C (Nodes 156 & 157)

$$ELC_{80TH_2} = \begin{pmatrix} 0.513 & 1.727\times10^5 & 6.35 & 156 & 97 & -4.435\times10^4 & -1.578\times10^4 & -1.662\times10^5 & 7 \\ 0.77 & 2.59\times10^5 & 6.35 & 157 & 23 & -1.357\times10^5 & -6.157\times10^4 & -2.118\times10^5 & 7 \end{pmatrix}$$

Elbow 1-31A (Nodes 184 & 185)

$$ELC_{80TH_3} = \begin{pmatrix} 0.436 & 1.466\times10^5 & 9.265 & 184 & 129 & -1.012\times10^5 & -1.056\times10^5 & 9.975\times10^3 & 26 \\ 0.571 & 1.919\times10^5 & 4.21 & 185 & 92 & -5.938\times10^4 & -1.283\times10^5 & 1.298\times10^5 & 26 \end{pmatrix}$$

Elbow 1-31B (Nodes 186 & 188)

$$ELC_{80TH_4} = \begin{pmatrix} 0.436 & 1.466\times10^5 & 9.265 & 186 & 57 & 6.52\times10^4 & -1.286\times10^5 & 2.671\times10^4 & 3 \\ 0.732 & 2.464\times10^5 & 4.22 & 188 & 95 & 6.899\times10^4 & -1.008\times10^5 & -2.14\times10^5 & 22 \end{pmatrix}$$

Elbow 1-31C (Nodes 192 & 193)

$$ELC_{80TH_5} = \begin{pmatrix} 0.396 & 1.33\times10^5 & 10.95 & 192 & 100 & 7.668\times10^4 & 9.136\times10^4 & 5.895\times10^4 & 26 \\ 0.55 & 1.85\times10^5 & 6.33 & 193 & 39 & -7.238\times10^4 & -1.67\times10^5 & -3.329\times10^4 & 19 \end{pmatrix}$$

Elbow Properties for Line 1-48

Elbow 1-48A (Nodes 681 & 680)

$$ELC_{80TH_6} = \begin{pmatrix} 0.296 & 2.058\times10^4 & 5.86 & 681 & 45 & -2.568\times10^3 & -1.234\times10^4 & 1.627\times10^4 & 22 \\ 0.323 & 2.248\times10^4 & 5.87 & 680 & 167 & 2.475\times10^3 & 1.495\times10^4 & -1.661\times10^4 & 22 \end{pmatrix}$$

Elbow 1-48B (Nodes 678 & 677)

$$ELC_{80TH_7} = \begin{pmatrix} 0.408 & 2.842\times10^4 & 5.885 & 678 & 51 & 1.602\times10^4 & -1.639\times10^4 & -1.681\times10^4 & 26 \\ 0.406 & 2.823\times10^4 & 5.885 & 677 & 126 & 1.581\times10^4 & -1.625\times10^4 & -1.682\times10^4 & 26 \end{pmatrix}$$

Elbow 1-48C (Nodes 675 & 674)

$$ELC_{80TH_8} = \begin{pmatrix} 0.209 & 1.452\times10^4 & 12.9 & 675 & 113 & 1.43\times10^4 & 1.96\times10^3 & 1.559\times10^3 & 17 \\ 0.209 & 1.446\times10^4 & 12.9 & 674 & 179 & 1.427\times10^4 & 2.064\times10^3 & 1.107\times10^3 & 17 \end{pmatrix}$$

EVALUATION OF ELBOWS ON LINES 1-43 AND 1-47 FOR ALL 32 REALIZATIONS

VELD := ReadData("\ElbowLines_43_47.prn")

ELD := C_S(VELD, R)

$ELD_{80TH} := RED\_EL_{80th}(ELD)$

Elbow Properties for Line 1-43

Elbow 1-43A (Nodes 224 & 226)

$$ELD_{80TH_0} = \begin{pmatrix} 0.909 & 2.327\times10^5 & 10.33 & 224 & 1 & 1.747\times10^5 & 8.882\times10^4 & -1.256\times10^5 & 30 \\ 0.768 & 1.968\times10^5 & 8.88 & 226 & 114 & 7.209\times10^4 & 1.541\times10^5 & -9.897\times10^4 & 30 \end{pmatrix}$$

Elbow 1-43B (Nodes 228 & 229)

$$ELD_{80TH_1} = \begin{pmatrix} 0.651 & 1.668\times10^5 & 8.88 & 228 & 116 & 5.924\times10^4 & -1.555\times10^5 & -1.223\times10^4 & 5 \\ 0.683 & 1.75\times10^5 & 10.32 & 229 & 5 & 1.506\times10^5 & -6.367\times10^4 & -6.23\times10^4 & 30 \end{pmatrix}$$

Elbow 1-43C (Nodes 232 & 233)

$$ELD_{80TH_2} = \begin{pmatrix} 0.686 & 1.756\times10^5 & 10.33 & 232 & 119 & 1.264\times10^5 & 1.113\times10^5 & 4.97\times10^4 & 17 \\ 0.659 & 1.687\times10^5 & 10.35 & 233 & 120 & -1.323\times10^5 & -9.88\times10^4 & -3.457\times10^4 & 7 \end{pmatrix}$$

Elbow 1-43D (Nodes 281 & 237)

$$ELD_{80TH_3} = \begin{pmatrix} 0.535 & 1.37\times10^5 & 5.305 & 281 & 123 & -2.622\times10^4 & -1.34\times10^5 & 1.012\times10^4 & 7 \\ 0.673 & 1.723\times10^5 & 5.3 & 237 & 122 & 5.948\times10^4 & 1.599\times10^5 & 2.394\times10^4 & 7 \end{pmatrix}$$

Elbow 1-43E (Nodes 244 & 245)

$$ELD_{80TH_4} = \begin{pmatrix} 0.397 & 1.017\times10^5 & 15.53 & 244 & 125 & -5.576\times10^4 & 7.145\times10^4 & 4.624\times10^4 & 22 \\ 0.397 & 1.018\times10^5 & 15.52 & 245 & 126 & 4.802\times10^4 & -6.956\times10^4 & -5.671\times10^4 & 27 \end{pmatrix}$$

Elbow 1-43F (Nodes 247 & 250)

$$ELD_{80TH_5} = \begin{pmatrix} 0.464 & 1.189\times10^5 & 9.485 & 247 & 128 & -1.062\times10^5 & -5.156\times10^4 & 1.454\times10^4 & 28 \\ 0.406 & 1.041\times10^5 & 15.56 & 250 & 37 & 8.559\times10^4 & 5.915\times10^4 & -2.024\times10^3 & 17 \end{pmatrix}$$

Elbow 1-43G (Nodes 264 & 263)

$$ELD_{80TH_6} = \begin{pmatrix} 0.428 & 1.095\times10^5 & 15.57 & 264 & 132 & 9.783\times10^4 & 4.761\times10^4 & -1.276\times10^4 & 27 \\ 0.412 & 1.056\times10^5 & 5.29 & 263 & 41 & 1.048\times10^5 & 1.137\times10^4 & 5.231\times10^3 & 7 \end{pmatrix}$$

Elbow Properties for Line 1-47

Elbow 1-47A (Nodes 629 & 630)

$$ELD_{80TH_7} = \begin{pmatrix} 0.754 & 1.184\times10^5 & 8.03 & 629 & 134 & -1.132\times10^5 & -2.197\times10^4 & -2.722\times10^4 & 25 \\ 0.806 & 1.266\times10^5 & 9.79 & 630 & 135 & 1.196\times10^5 & 1.886\times10^4 & 3.697\times10^4 & 19 \end{pmatrix}$$

Elbow 1-47B (Nodes 632 & 633)

$$ELD_{80TH_8} = \begin{pmatrix} 0.343 & 5.383\times10^4 & 11.04 & 632 & 69 & -1.997\times10^4 & 1.792\times10^4 & -4.666\times10^4 & 22 \\ 0.409 & 6.425\times10^4 & 5.07 & 633 & 63 & -2.502\times10^4 & -1.688\times10^4 & 5.673\times10^4 & 3 \end{pmatrix}$$

Elbow 1-47C (Nodes 636 & 648)

$$ELD_{80TH_9} = \begin{pmatrix} 0.373 & 5.852\times10^4 & 7.85 & 636 & 66 & -5.371\times10^3 & -5.824\times10^4 & -1.995\times10^3 & 10 \\ 0.346 & 5.432\times10^4 & 8.045 & 648 & 73 & -218.2 & -4.724\times10^4 & 2.681\times10^4 & 25 \end{pmatrix}$$

Elbow 1-47D (Nodes 649 & 651)

$$ELD_{80TH_{10}} = \begin{pmatrix} 0.345 & 5.418\times10^4 & 8.04 & 649 & 143 & 4.117\times10^3 & -4.453\times10^4 & 3.058\times10^4 & 26 \\ 0.347 & 5.441\times10^4 & 8.045 & 651 & 75 & 3.323\times10^3 & -4.42\times10^4 & 3.156\times10^4 & 25 \end{pmatrix}$$

Elbow 1-47E (Nodes 661 & 662)

$$ELD_{80TH_{11}} = \begin{pmatrix} 0.415 & 6.519\times10^4 & 7.86 & 661 & 152 & 7.812\times10^3 & -6.468\times10^4 & -2.291\times10^3 & 23 \\ 0.398 & 6.245\times10^4 & 7.87 & 662 & 153 & -7.578\times10^3 & 6.195\times10^4 & -2.291\times10^3 & 11 \end{pmatrix}$$

Elbow 1-47F (Nodes 665 & 664)

$$ELD_{80TH_{12}} = \begin{pmatrix} 0.202 & 3.16\times10^4 & 7.845 & 665 & 147 & -3.341\times10^3 & -3.143\times10^4 & 104.5 & 28 \\ 0.183 & 2.87\times10^4 & 7.84 & 664 & 146 & 5.157\times10^3 & 2.818\times10^4 & -1.686\times10^3 & 27 \end{pmatrix}$$

Elbow 1-47G (Nodes 667 & 668)

$$ELD_{80TH_{13}} = \begin{pmatrix} 0.44 & 6.907\times10^4 & 10.27 & 667 & 149 & 3.181\times10^3 & 6.896\times10^4 & 2.179\times10^3 & 28 \\ 0.475 & 7.46\times10^4 & 10.27 & 668 & 150 & -4.717\times10^3 & -7.415\times10^4 & 6.67\times10^3 & 28 \end{pmatrix}$$

EVALUATION OF ELBOWS ON LINES 1-44, 1-46, AND 8-14 FOR ALL 32 REALIZATIONS

$VELE := ReadData("\backslash ElbowLines\_44\_46\_814.prn")$

$ELE := C\_S(VELE, R)$

$ELE_{80TH} := RED\_EL_{80th}(ELE)$

Elbow Properties for Lines 1-44 and 1-46

Elbow 1-44A (Nodes 301 & 302)

$$ELE_{80TH_0} = \begin{pmatrix} 0.672 & 1.055 \times 10^5 & 10.34 & 301 & 25 & -3.614 \times 10^4 & -9.665 \times 10^4 & -2.207 \times 10^4 & 11 \\ 0.64 & 1.006 \times 10^5 & 5.685 & 302 & 27 & 4.785 \times 10^4 & 7.508 \times 10^4 & 4.676 \times 10^4 & 6 \end{pmatrix}$$

Elbow 1-44B (Nodes 324 & 325)

$$ELE_{80TH_1} = \begin{pmatrix} 0.44 & 6.909 \times 10^4 & 11.41 & 324 & 54 & -1.751 \times 10^4 & -1.428 \times 10^4 & -6.529 \times 10^4 & 10 \\ 0.475 & 7.453 \times 10^4 & 9.345 & 325 & 100 & -3.21 \times 10^4 & 3.098 \times 10^4 & 5.971 \times 10^4 & 3 \end{pmatrix}$$

Elbow 1-44C (Nodes 330 & 331)

$$ELE_{80TH_2} = \begin{pmatrix} 0.496 & 7.786 \times 10^4 & 5.51 & 330 & 102 & 6.302 \times 10^4 & 2.274 \times 10^4 & -3.967 \times 10^4 & 28 \\ 0.622 & 9.766 \times 10^4 & 9.34 & 331 & 33 & -6.477 \times 10^4 & -1.615 \times 10^3 & 7.307 \times 10^4 & 13 \end{pmatrix}$$

Elbow 1-44D (Nodes 315 & 316)

$$ELE_{80TH_3} = \begin{pmatrix} 0.052 & 8.078 \times 10^3 & 6.64 & 315 & 90 & 3.409 \times 10^3 & 5.326 \times 10^3 & 5.026 \times 10^3 & 24 \\ 0.074 & 1.156 \times 10^4 & 9.36 & 316 & 91 & -6.911 \times 10^3 & 1.443 \times 10^3 & -9.158 \times 10^3 & 11 \end{pmatrix}$$

Elbow 1-44E (Nodes 320 & 321)

$$ELE_{80TH_4} = \begin{pmatrix} 0.125 & 1.953 \times 10^4 & 5.995 & 320 & 51 & -6.997 \times 10^3 & 3.271 \times 10^3 & -1.794 \times 10^4 & 3 \\ 0.099 & 1.553 \times 10^4 & 5.88 & 321 & 94 & -2.988 \times 10^3 & -565.8 & 1.523 \times 10^4 & 22 \end{pmatrix}$$

Elbow 1-44F (Nodes 344 & 345)

$$ELE_{80TH_5} = \begin{pmatrix} 0.294 & 4.608 \times 10^4 & 5.985 & 344 & 96 & 5.791 \times 10^3 & -3.487 \times 10^3 & -4.558 \times 10^4 & 22 \\ 0.324 & 5.083 \times 10^4 & 5.995 & 345 & 97 & -3.721 \times 10^3 & 1.37 \times 10^3 & 5.067 \times 10^4 & 3 \end{pmatrix}$$

Elbow 1-46A (Nodes 284 & 283)

$$ELE_{80TH_6} = \begin{pmatrix} 0.519 & 8.16 \times 10^4 & 9.175 & 284 & 82 & -2.176 \times 10^4 & -7.487 \times 10^4 & -2.409 \times 10^4 & 7 \\ 0.468 & 7.351 \times 10^4 & 9.18 & 283 & 9 & -1.306 \times 10^4 & -6.688 \times 10^4 & -2.756 \times 10^4 & 7 \end{pmatrix}$$

Elbow 1-46B (Nodes 287 & 288)

$$ELE80TH_7 = \begin{pmatrix} 0.44 & 6.914\times10^4 & 10.35 & 287 & 84 & 1.147\times10^4 & -6.637\times10^4 & -1.56\times10^4 & 7 \\ 0.478 & 7.512\times10^4 & 10.35 & 288 & 87 & 2.423\times10^3 & -7.406\times10^4 & -1.237\times10^4 & 7 \end{pmatrix}$$

Elbow 1-46C (Nodes 288 & 290)

$$ELE80TH_8 = \begin{pmatrix} 0.478 & 7.512\times10^4 & 10.35 & 288 & 87 & 2.423\times10^3 & -7.406\times10^4 & -1.237\times10^4 & 7 \\ 0.413 & 6.488\times10^4 & 9.185 & 290 & 88 & -2.138\times10^4 & -4.97\times10^4 & 3.58\times10^4 & 7 \end{pmatrix}$$

Elbow Properties for Line 8-14

Elbow 8-14A (Nodes 200 & 201)

$$ELE80TH_9 = \begin{pmatrix} 0.332 & 6.497\times10^4 & 10.63 & 200 & 67 & -2.966\times10^3 & 6.481\times10^4 & 3.461\times10^3 & 19 \\ 0.305 & 5.961\times10^4 & 10.95 & 201 & 77 & -1.013\times10^4 & 5.874\times10^4 & 461.5 & 22 \end{pmatrix}$$

Elbow 8-14B (Nodes 202 & 203)

$$ELE80TH_{10} = \begin{pmatrix} 0.188 & 4.825\times10^4 & 10.6 & 202 & 79 & 1.028\times10^4 & 4.713\times10^4 & 1.05\times10^3 & 28 \\ 0.172 & 4.404\times10^4 & 6.715 & 203 & 80 & 4.92\times10^3 & 4.195\times10^4 & -1.248\times10^4 & 24 \end{pmatrix}$$

EVALUATION OF ELBOWS ON LINES 1-45 FOR ALL 32 REALIZATIONS

VELF := ReadData("\ElbowLine_45.prn")

ELF := C_S(VELF,R)

$ELF_{80TH} := RED\_EL_{80th}(ELF)$

Elbow Properties for Line 1-45

Elbow 1-45A (Nodes 1007 & 1008)

$$ELF80TH_0 = \begin{pmatrix} 0.104 & 1.632\times10^4 & 6.13 & 1.007\times10^3 & 7 & 1.233\times10^4 & -2.15\times10^3 & 1.048\times10^4 & 28 \\ 0.121 & 1.899\times10^4 & 9.88 & 1.008\times10^3 & 9 & -2.787\times10^3 & 3.788\times10^3 & -1.84\times10^4 & 10 \end{pmatrix}$$

Elbow 1-45B (Nodes 1009 & 1010)

$$ELF80TH_1 = \begin{pmatrix} 0.12 & 1.872\times10^4 & 9.88 & 1.009\times10^3 & 24 & 741 & 3.407\times10^3 & -1.839\times10^4 & 10 \\ 0.099 & 1.551\times10^4 & 9.88 & 1.01\times10^3 & 11 & 5.257\times10^3 & 2.581\times10^3 & -1.437\times10^4 & 10 \end{pmatrix}$$

Elbow 1-45C (Nodes 1015 & 1016)

$$ELF80TH_2 = \begin{pmatrix} 0.077 & 1.204\times10^4 & 10.03 & 1.015\times10^3 & 27 & -1.155\times10^3 & -6.467\times10^3 & 1.009\times10^4 & 12 \\ 0.079 & 1.24\times10^4 & 8.53 & 1.016\times10^3 & 13 & 5.596\times10^3 & -2.388\times10^3 & 1.081\times10^4 & 15 \end{pmatrix}$$

Elbow 1-45D (Nodes 1017 & 1018)

$$ELF80TH_3 = \begin{pmatrix} 0.074 & 1.159\times10^4 & 8.53 & 1.017\times10^3 & 30 & 2.315\times10^3 & -4.963\times10^3 & 1.021\times10^4 & 14 \\ 0.073 & 1.139\times10^4 & 8.53 & 1.018\times10^3 & 15 & 3.421\times10^3 & -8.075\times10^3 & 7.276\times10^3 & 25 \end{pmatrix}$$

Elbow 1-45E (Nodes 1011 & 1012)

$$ELF80TH_4 = \begin{pmatrix} 0.079 & 1.233\times10^4 & 7.455 & 1.011\times10^3 & 47 & -1.733\times10^3 & -1.21\times10^4 & 1.661\times10^3 & 22 \\ 0.07 & 1.088\times10^4 & 9.89 & 1.012\times10^3 & 34 & -67.2 & -1.088\times10^4 & 181.1 & 28 \end{pmatrix}$$

Elbow 1-45F (Nodes1013 & 1014)

$$ELF80TH_5 = \begin{pmatrix} 0.122 & 1.913\times10^4 & 10.02 & 1.013\times10^3 & 36 & -494 & 1.865\times10^4 & 4.197\times10^3 & 22 \\ 0.143 & 2.234\times10^4 & 10.02 & 1.014\times10^3 & 20 & 2.931\times10^3 & 2.214\times10^4 & 701.9 & 22 \end{pmatrix}$$

TEES

Tees output is ordered as (max D/C ratio, applied pipe run moment when D/C ratio is highest, applied branch moment when D/C ratio is highest, time when max values occur, pipe run node retrieved for calculations, indices of pipe run nodes, Index of branch node, and realization number)

THERE ARE NOT ANY TEES ON LINES 1-13 TO 1-16, 1-18 TO 1-21, AND 1-171

EVALUATION OF TEES ON LINE 1-17 FOR ALL 32 REALIZATIONS

VTeeB := ReadData("\TeeLine_17.prn")

TeeB := C_S(VTeeB, R)

TEE (Lines 1-13, 1-14, 1-15, and 1-16) attached to Line 1-17

Tee 1-13 (Node 933)

$$\left(TeeB_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.424 & 4.607\times10^5 & 2.758\times10^5 & 4.06 & 933 & 66 & 92 & 94 & 22 \end{pmatrix}$$

Tee 1-14 (Node 59)

$$\left(TeeB_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.433 & 5.185\times10^5 & 2.641\times10^5 & 4.065 & 59 & 31 & 33 & 9 & 19 \end{pmatrix}$$

Tee 1-15 (Node 61)

$$\left(TeeB_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.393 & 3.388\times10^5 & 2.83\times10^5 & 9.27 & 61 & 39 & 41 & 11 & 12 \end{pmatrix}$$

Tee 1-16 (Node 62)

$$\left(TeeB_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.446 & 4.165\times10^5 & 3.226\times10^5 & 9.265 & 62 & 57 & 59 & 13 & 26 \end{pmatrix}$$

TEE (Lines 1-18, 1-19, 1-20, and 1-21) attached to Line 1-17

Tee 1-18 (Node 5)

$$\left(TeeB_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix}0.391 & 4.325\times10^{5} & 4.203\times10^{5} & 4.055 & 5 & 19 & 73 & 1 & 25\end{pmatrix}$$

Tee 1-19 (Node 12)

$$\left(TeeB_{0,5}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix}0.419 & 5.653\times10^{5} & 3.943\times10^{5} & 4.065 & 12 & 27 & 29 & 7 & 19\end{pmatrix}$$

Tee 1-20 (Node 19)

$$\left(TeeB_{0,6}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix}0.367 & 3.758\times10^{5} & 4.04\times10^{5} & 9.265 & 19 & 47 & 49 & 3 & 22\end{pmatrix}$$

Tee 1-21 (Node 26)

$$\left(TeeB_{0,7}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix}0.391 & 4.696\times10^{5} & 3.951\times10^{5} & 9.26 & 26 & 61 & 95 & 5 & 19\end{pmatrix}$$

TEE (Lines 1-30) attached to Line 1-17

Tee 1-30 (Node 60)

$$\left(TeeB_{0,8}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix}0.839 & 6.32\times10^{5} & 3.871\times10^{5} & 6.84 & 60 & 35 & 37 & 15 & 22\end{pmatrix}$$

EVALUATION OF TEES ON LINES 1-30 TO 1-31 AND 1-48 FOR ALL 32 REALIZATIONS

VTeeC := ReadData("\TeeLines_30to31_48.prn")

TeeC := C_S(VTeeC, R)

TEE (Line 1-31)

Tee 1-31 (Node 152)

$$\left(TeeC_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix}0.601 & 1.126\times10^{5} & 1.675\times10^{5} & 4.215 & 152 & 17 & 29 & 31 & 26\end{pmatrix}$$

TEE (Line 1-48)

Tee 1-48 (Node 176 for Pipe Run and 673 for Branch (NB 3683.8)

$$\left(TeeC_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix}0.998 & 7.545\times10^{4} & 4.859\times10^{4} & 9.9 & 176 & 9 & 12 & 48 & 27\end{pmatrix}$$

Refer to main body for evaluation of this branch even though it falls below unity.

EVALUATION OF TEES ON LINES 1-43 AND 1-47 FOR ALL 32 REALIZATIONS

VTeeD := ReadData("\TeeLines_43_47.prn")

TeeD := C_S(VTeeD, R)

TEE (Line 1-43)

Tee 1-43 (Node 238)

$$\left(TeeD_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 1.263 & 1.678\times 10^{5} & 1.053\times 10^{5} & 15.17 & 238 & 21 & 55 & 49 & 12 \end{pmatrix}$$

Refer to main body for evaluation of this tee

TEE (Line 1-46) attached to Line 1-43

Tee 1-46 (Node 230)

$$\left(TeeD_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 1.205 & 1.684\times 10^{5} & 9.907\times 10^{4} & 10.35 & 230 & 6 & 7 & 47 & 7 \end{pmatrix}$$

Refer to main body for evaluation of this tee

TEE (Line 1-47)

Tee 1-47 (Node 261)

$$\left(TeeD_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 1.939 & 9.966\times 10^{4} & 1.859\times 10^{5} & 9.59 & 261 & 15 & 18 & 57 & 17 \end{pmatrix}$$

Refer to main body for evaluation of this tee

EVALUATION OF TEES ON LINES 1-44, 1-46, AND 8-14 FOR ALL 32 REALIZATIONS

VTeeE := ReadData("\TeeLines_44_46_814.prn")

TeeE := C_S(VTeeE, R)

TEE (Line 1-44)

Tee 1-44 (Node 297)

$$\left(TeeE_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.805 & 7.334\times 10^{4} & 1.021\times 10^{5} & 10.32 & 297 & 17 & 19 & 23 & 19 \end{pmatrix}$$

EVALUATION OF TEES ON LINES 1-45 FOR ALL 32 REALIZATIONS

VTeeF := ReadData("\TeeLine_45.prn")

TeeF := C_S(VTeeF, R)

TEE (Line 1-45)

Tee 1-45 (Nodes 122 & 1019)

$$\left(TeeF_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.21 & 8.63\times 10^{4} & 1.557\times 10^{4} & 10.03 & 122 & 2 & 4 & 6 & 27 \end{pmatrix}$$

FLANGES

Flange output is ordered as (max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, index of element(s), moments about the x, y, and z axes, and realization number)

EVALUATION OF FLANGES ON LINES 1-13 TO 1-16, 1-18 TO 1-21, AND 1-171 FOR ALL 32 REALIZATIONS

VFLA := ReadData("\FlangeLines_13to16_18to21_171.prn")

FLA := C_S(VFLA, R)

Pipe Properties of Line 1-13, 1-14, 1-15, and 1-16

Flange (Heat Exchanger) 1-13A (Node 130)

$$\left(FLA_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.12 & 2.571\times10^{5} & 10.02 & 130 & 82 & 2.397\times10^{5} & 7.194\times10^{4} & -5.877\times10^{4} & 27 \end{pmatrix}$$

Flange (Heat Exchanger) 1-14A (Node 128)

$$\left(FLA_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.132 & 3.193\times10^{5} & 6.7 & 128 & 84 & -3.111\times10^{5} & -5.406\times10^{4} & -4.776\times10^{4} & 7 \end{pmatrix}$$

Flange (Heat Exchanger) 1-15A (Node 129)

$$\left(FLA_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.131 & 3.168\times10^{5} & 6.695 & 129 & 86 & 3.119\times10^{5} & 3.775\times10^{4} & -4.089\times10^{4} & 28 \end{pmatrix}$$

Flange (Heat Exchanger) 1-16A (Node 127)

$$\left(FLA_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.129 & 3.051\times10^{5} & 10.12 & 127 & 88 & -3.042\times10^{5} & -1.695\times10^{4} & -1.559\times10^{4} & 12 \end{pmatrix}$$

Pipe Properties Lower Portions of Lines 1-18, 1-19, 1-20, and 1-21

Flange (Gate Valves) 1-18A (Node 4)

$$\left(FLA_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.112 & 3.764\times10^{5} & 9.26 & 4 & 162 & -3.145\times10^{5} & -1.821\times10^{5} & 9.777\times10^{4} & 19 \end{pmatrix}$$

Flange (Gate Valves) 1-18B (Node 3)

$$\left(FLA_{0,5}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.106 & 3.159\times10^{5} & 9.265 & 3 & 41 & -3.148\times10^{5} & 1.902\times10^{4} & -1.705\times10^{4} & 19 \end{pmatrix}$$

Flange (Gate Valves) 1-19A (Node 11)

$$\left(FLA_{0,6}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.115 & 3.971\times10^{5} & 9.265 & 11 & 164 & -3.416\times10^{5} & -1.84\times10^{5} & 8.43\times10^{4} & 19 \end{pmatrix}$$

Flange (Gate Valves) 1-19B (Node 10)

$$\left(FLA_{0,7}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.109 & 3.427\times10^{5} & 9.265 & 10 & 43 & -3.415\times10^{5} & 2.683\times10^{4} & 7.988\times10^{3} & 19 \end{pmatrix}$$

Flange (Gate Valves) 1-20A (Node 18)

$$\left(FLA_{0,8}{}^{T}\right)^{\langle 6\rangle T} = \left(0.113 \quad 3.805\times10^{5} \quad 9.26 \quad 18 \quad 166 \quad -3.27\times10^{5} \quad -1.778\times10^{5} \quad 7.908\times10^{4} \quad 27\right)$$

Flange (Gate Valves) 1-20B (Node 17)

$$\left(FLA_{0,9}{}^{T}\right)^{\langle 6\rangle T} = \left(0.107 \quad 3.282\times10^{5} \quad 9.26 \quad 17 \quad 45 \quad -3.269\times10^{5} \quad 2.844\times10^{4} \quad -4.842\times10^{3} \quad 27\right)$$

Flange (Gate Valves) 1-21A (Node 25)

$$\left(FLA_{0,10}{}^{T}\right)^{\langle 6\rangle T} = \left(0.112 \quad 3.692\times10^{5} \quad 9.26 \quad 25 \quad 168 \quad -3.253\times10^{5} \quad -1.62\times10^{5} \quad 6.543\times10^{4} \quad 27\right)$$

Flange (Gate Valves) 1-21B (Node 24)

$$\left(FLA_{0,11}{}^{T}\right)^{\langle 6\rangle T} = \left(0.107 \quad 3.284\times10^{5} \quad 9.265 \quad 24 \quad 47 \quad -3.253\times10^{5} \quad 4.096\times10^{4} \quad 1.739\times10^{4} \quad 27\right)$$

Pipe Properties of Upper Portion of Lines 1-18, 1-19, 1-20, and 1-21

Flange (Primary Pump) 1-18C (Node 1)

$$\left(FLA_{0,12}{}^{T}\right)^{\langle 6\rangle T} = \left(0.343 \quad 1.193\times10^{6} \quad 9.26 \quad 1 \quad 1 \quad 1.141\times10^{6} \quad 1.899\times10^{5} \quad -2.901\times10^{5} \quad 19\right)$$

Flange (Primary Pump) 1-19C (Node 31)

$$\left(FLA_{0,13}{}^{T}\right)^{\langle 6\rangle T} = \left(0.348 \quad 1.216\times10^{6} \quad 4.05 \quad 31 \quad 5 \quad -8.179\times10^{5} \quad -1.49\times10^{5} \quad 8.875\times10^{5} \quad 11\right)$$

Flange (Primary Pump) 1-20C (Node 15)

$$\left(FLA_{0,14}{}^{T}\right)^{\langle 6\rangle T} = \left(0.346 \quad 1.207\times10^{6} \quad 4.05 \quad 15 \quad 9 \quad -9.028\times10^{5} \quad -1.337\times10^{5} \quad 7.893\times10^{5} \quad 19\right)$$

Flange (Primary Pump) 1-21C (Node 22)

$$\left(FLA_{0,15}{}^{T}\right)^{\langle 6\rangle T} = \left(0.37 \quad 1.31\times10^{6} \quad 10.26 \quad 22 \quad 13 \quad 1.548\times10^{5} \quad 6.791\times10^{4} \quad -1.299\times10^{6} \quad 28\right)$$

Pipe Properties of Lines 1-171

Flange (Gate Valve) 1-171A (Node 139)

$$\left(FLA_{0,16}{}^{T}\right)^{\langle 6\rangle T} = \left(0.104 \quad 1.724\times10^{5} \quad 10.01 \quad 139 \quad 97 \quad 4.067\times10^{4} \quad 9.161\times10^{3} \quad 1.673\times10^{5} \quad 22\right)$$

THERE ARE NOT ANY FLANGES ON LINE 1-17

EVALUATION OF FLANGES ON LINES 1-30 TO 1-31 AND 1-48 FOR ALL 32 REALIZATIONS

VFLC := ReadData("\FlangeLines_30to31_48.prn")

FLC := C_S(VFLC,R)

Pipe Properties of Lines 1-30 and 1-31

Flange (Check Valve) 1-30A (Node 67)

$$\left(FLC_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.17 & 2.684\times 10^{5} & 6.34 & 67 & 131 & 1.396\times 10^{5} & 2.256\times 10^{5} & 4.044\times 10^{4} & 28 \end{pmatrix}$$

Flange (Check Valve) 1-30B (Node 145)

$$\left(FLC_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.155 & 2.265\times 10^{5} & 6.34 & 145 & 124 & 2.098\times 10^{3} & 2.248\times 10^{5} & -2.733\times 10^{4} & 19 \end{pmatrix}$$

Flange (Gate Valve) 1-30C (Node 158)

$$\left(FLC_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.169 & 2.662\times 10^{5} & 6.35 & 158 & 61 & -1.459\times 10^{5} & -6.764\times 10^{4} & -2.122\times 10^{5} & 7 \end{pmatrix}$$

Flange (Gate Valve) 1-30D (Node 159)

$$\left(FLC_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.177 & 2.87\times 10^{5} & 6.49 & 159 & 25 & 2.215\times 10^{4} & 2.133\times 10^{5} & 1.907\times 10^{5} & 22 \end{pmatrix}$$

Flange (Emergency Pump) 1-30E (Node 160)

$$\left(FLC_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.196 & 3.381\times 10^{5} & 6.485 & 160 & 27 & 6.376\times 10^{3} & -2.761\times 10^{5} & -1.951\times 10^{5} & 22 \end{pmatrix}$$

Flange (Gate Valve) 1-31A (Node 189)

$$\left(FLC_{0,5}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.214 & 3.882\times 10^{5} & 4.205 & 189 & 63 & -8.355\times 10^{4} & 6.513\times 10^{4} & 3.734\times 10^{5} & 26 \end{pmatrix}$$

Flange (Gate Valve) 1-31B (Node 190)

$$\left(FLC_{0,6}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.121 & 1.347\times 10^{5} & 4.21 & 190 & 122 & 8.295\times 10^{4} & 1.559\times 10^{4} & -1.05\times 10^{5} & 27 \end{pmatrix}$$

Flange (Emergency Pump) 1-31C (Node 194)

$$\left(FLC_{0,7}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.157 & 2.335\times10^{5} & 6.335 & 194 & 41 & 1.181\times10^{5} & 1.99\times10^{5} & 3.072\times10^{4} & 11 \end{pmatrix}$$

EVALUATION OF FLANGES ON LINES 1-43 AND 1-47 FOR ALL 32 REALIZATIONS

VFLD := ReadData("\FlangeLines_43_47.prn")

FLD := C_S(VFLD, R)

Pipe Properties of Lines 1-43

Flange (Gate Valve) 1-43A (Node 234)

$$\left(FLD_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.133 & 1.022\times10^{5} & 9.59 & 234 & 17 & -9.253\times10^{4} & -3.888\times10^{4} & -1.907\times10^{4} & 28 \end{pmatrix}$$

Flange (Gate Valve) 1-43B (Node 235)

$$\left(FLD_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.14 & 1.108\times10^{5} & 5.31 & 235 & 45 & 288.7 & -1.107\times10^{5} & 3.77\times10^{3} & 13 \end{pmatrix}$$

Flange (Gate Valve) 1-43C (Node 239)

$$\left(FLD_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.17 & 1.463\times10^{5} & 15.56 & 239 & 25 & 5.968\times10^{4} & -1.92\times10^{4} & 1.322\times10^{5} & 22 \end{pmatrix}$$

Flange (Gate Valve) 1-43D (Node 240)

$$\left(FLD_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.169 & 1.453\times10^{5} & 15.57 & 240 & 28 & 6.009\times10^{4} & -1.821\times10^{4} & 1.31\times10^{5} & 22 \end{pmatrix}$$

Flange (Gate Valve) 1-43E (Node 241)

$$\left(FLD_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.126 & 9.344\times10^{4} & 9.85 & 241 & 91 & -5.876\times10^{4} & 7.042\times10^{4} & -1.787\times10^{4} & 19 \end{pmatrix}$$

Flange (Gate Valve) 1-43F (Node 242)

$$\left(FLD_{0,5}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.132 & 1.005\times10^{5} & 9.835 & 242 & 160 & 6.039\times10^{4} & -7.887\times10^{4} & -1.54\times10^{4} & 22 \end{pmatrix}$$

Flange (Gate Valve) 1-43G (Node 249)

$$\left(FLD_{0,6}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.252 & 2.441\times10^{5} & 4.79 & 249 & 43 & -4.54\times10^{4} & 4.835\times10^{4} & -2.349\times10^{5} & 31 \end{pmatrix}$$

Flange (Gate Valve) 1-43H (Node 934)

$$\left(FLD_{0,7}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.255 & 2.479\times10^{5} & 4.79 & 934 & 54 & -4.54\times10^{4} & 4.846\times10^{4} & -2.389\times10^{5} & 31 \end{pmatrix}$$

Pipe Properties of Line 1-47

Flange (Gate Valve) 1-47A (Node 634)

$$\left(FLD_{0,8}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.161 & 6.483\times10^{4} & 10.03 & 634 & 93 & -3.652\times10^{4} & -1.322\times10^{4} & 5.191\times10^{4} & 11 \end{pmatrix}$$

Flange (Gate Valve) 1-47B (Node 635)

$$\left(FLD_{0,9}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.143 & 5.607\times10^{4} & 7.845 & 635 & 162 & 6.246\times10^{3} & -5.183\times10^{4} & 2.046\times10^{4} & 29 \end{pmatrix}$$

EVALUATION OF FLANGES ON LINES 1-44, 1-46, AND 8-14 FOR ALL 32 REALIZATIONS

VFLE := ReadData("\FlangeLines_44_46_814.prn")

FLE := C_S(VFLE,R)

Pipe Properties of Lines 1-44

Flange (Gate Valve) 1-44A (Node 299)

$$\left(FLE_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.169 & 6.874\times10^{4} & 15.2 & 299 & 57 & 2.348\times10^{4} & -5.967\times10^{4} & -2.476\times10^{4} & 17 \end{pmatrix}$$

Flange (Gate Valve) 1-44B (Node 298)

$$\left(FLE_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.129 & 4.943\times10^{4} & 10.18 & 298 & 55 & 9.852\times10^{3} & -4.539\times10^{4} & 1.692\times10^{4} & 25 \end{pmatrix}$$

Flange (Gate Valve) 1-44C (Node 296)

$$\left(FLE_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.17 & 6.921\times10^{4} & 6.01 & 296 & 112 & -3.214\times10^{3} & -6.608\times10^{4} & 2.033\times10^{4} & 19 \end{pmatrix}$$

Flange (Gate Valve) 1-44D (Node 295)

$$\left(FLE_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.149 & 5.907\times10^{4} & 6.01 & 295 & 14 & -3.315\times10^{3} & -5.451\times10^{4} & 2.25\times10^{4} & 25 \end{pmatrix}$$

Flange (Gate Valve) 1-44E (Node 317)

$$\left(FLE_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.06 & 1.64\times10^{4} & 6.295 & 317 & 41 & 7.696\times10^{3} & -181.5 & 1.449\times10^{4} & 32 \end{pmatrix}$$

Flange (Gate Valve) 1-44F (Node 318)

$$\left(FLE_{0,5}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.061 & 1.646\times10^{4} & 6.295 & 318 & 43 & 7.698\times10^{3} & -190.1 & 1.455\times10^{4} & 32 \end{pmatrix}$$

EVALUATION OF FLANGES ON LINES 1-45 FOR ALL 32 REALIZATIONS

VFLF := ReadData("\FlangeLine_45.prn")

FLF := C_S(VFLF,R)

Pipe Properties of Lines 1-45

Flange (Gate Valve) 1-45A (Node 1006)

$$\left(FLF_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.073 & 2.245\times 10^{4} & 10.02 & 1.006\times 10^{3} & 19 & -3.685\times 10^{3} & -2.214\times 10^{4} & 567.5 & 22 \end{pmatrix}$$

FABRICATED REDUCER

Support output is ordered as (max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, index of element(s), and moments about the x, y, and z axes)

EVALUATION OF FABRICATED REDUCER

$VFR := \text{ReadData}(\text{"\textbackslash FabReducer.prn"})$

$FR := C\_S(VFR, R)$

$FR_{80TH} := RED\_EL_{80th}(FR)$

Fab Red 1-17 (Nodes 63 & 224)

Fab Red 1-17 (Nodes 63 & 225)

$$FR_{80TH_0} = \begin{pmatrix} 0.688 & 2.093\times 10^{5} & 10.34 & 63 & 4 & 1.655\times 10^{5} & 5.459\times 10^{4} & -1.159\times 10^{5} & 19 \\ 0.47 & 2.241\times 10^{5} & 10.34 & 225 & 10 & 1.765\times 10^{5} & 7.582\times 10^{4} & -1.155\times 10^{5} & 7 \end{pmatrix}$$

FABRICATED BRANCH

Support output is ordered as (max D/C ratio, applied pipe run moment when D/C ratio is highest, applied branch moment when D/C ratio is highest, time when max values occur, pipe run node retrieved for calculations, indices of pipe run node, and indices of branch node)

EVALUATION OF FABRICATED BRANCH

$VFB := \text{ReadData}(\text{"\textbackslash FabBranch.prn"})$

$FB := C\_S(VFB, R)$

FABRICATED BRANCH (LINE 1-30)

Fab Br 1-30 (Node 893)

$$\left(FB_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 1.057 & 1.022\times 10^{5} & 1.339\times 10^{5} & 6.845 & 893 & 22 & 26 & 18 & 22 \end{pmatrix}$$

Refer to main body for evaluation of this branch

Appendix C.5

Spring Profiles for Supports Exibiting Nonlinear Behavior

SPRING STIFFNESS CALCULATIONS FOR SUPPORTS THAT EXHIBIT NONLINEAR BEHAVIOR (UPLIFT, GAPS, AND DIRECTIONALLY VARYING STIFFNESSES)

$E := 29000\text{ksi}$ — Modulus of Elasticity for supports (A7 steel)

Note: Photos referenced in calculations are included at the ends of the support section.

RH-24 *(Pipe allowed to slide up the threaded rod to a certain point given upward loading*

RH-24 Stiffness

Welded Beam Attachment section

$W_{RH29\_wba} := 2\text{in}$ — Width of RH-24's welded beam attachment section [24, ph-33] [M3-1-47-N49-CSUG-DSCN2775]

$T_{RH29\_wba} := \frac{1}{2}\text{in}$ — Thickness of both legs of RH-24's welded beam attachment section [24, ph-33] [M3-1-47-N49-CSUG-DSCN2775]

$A_{RH29\_wba} := W_{RH29\_wba} \cdot T_{RH29\_wba}$ — Cross sectional area of welded beam attachment

$A_{RH29\_wba} = 1\text{ in}^2$

$L_{RH29\_wba} := 2\text{in}$ — Length of welded beam attachment section [24, ph-33] scaled from [M3-1-47-N49-CSUG-DSCN2775]

$K_{RH29\_wba} := \frac{A_{RH29\_wba} \cdot E}{L_{RH29\_wba}}$ — Stiffness of welded beam attachment portion of RH-24

$K_{RH29\_wba} = 1.45 \times 10^7 \frac{\text{lbf}}{\text{in}}$

Rod section

$D_{RH29\_rod} := \frac{5}{8}\text{in}$ — Diameter of rod comprising RH-24 [20]

$A_{RH29\_rod} := \frac{\pi \cdot D_{RH29\_rod}^2}{4}$ — Cross Sectional area of rod comprising RH-24

$A_{RH29\_rod} = 0.307\text{ in}^2$

$L_{RH29\_rod} := 1\frac{3}{4}\text{in}$ — Length of rod section scaled from [M3-1-47-N49-CSUG-DSCN2775]

$$K_{RH29\_rod} := \frac{A_{RH29\_rod} \cdot E}{L_{RH29\_rod}}$$ Stiffness of rod portion of RH-24

$$K_{RH29\_rod} = 5.084 \times 10^{6} \frac{lbf}{in}$$

Adjustable Clevis section (will apply smaller cross section of the lower and upper portions of the clevis and use the distance from the pipe to where the clamp mates with the rod as the length of this cross section)

$$W_{RH29\_AC} := 1\frac{1}{4} in$$ Width of the lower section of RH-24's adjustable clevis [24, ph-12]

$$T_{RH29\_AC} := \frac{3}{16} in$$ Thickness of lower section of RH-24's adjustable clevis [24, ph-12]

$$A_{RH29\_AC} := W_{RH29\_AC} \cdot T_{RH29\_AC}$$ Cross sectional area of welded beam attachment

$$A_{RH29\_AC} = 0.234\ in^{2}$$

$$L_{RH29\_AC} := 1\frac{3}{4} in$$ Length of adjustable clevis section [24, ph-12]

$$K_{RH29\_AC} := \frac{A_{RH29\_AC} \cdot E}{L_{RH29\_AC}}$$ Stiffness of adjustable clevis portion of RH-24

$$K_{RH29\_AC} = 3.884 \times 10^{6} \frac{lbf}{in}$$

Combined stiffness of support (NOTE: springs in series combine as reciprocals)

$$K_{RH29} := \frac{1}{\frac{1}{K_{RH29\_wba}} + \frac{1}{K_{RH29\_rod}} + \frac{1}{K_{RH29\_AC}}}$$

$$K_{RH29} = 1.912 \times 10^{6} \frac{lbf}{in}$$

RH-24 Stiffness Profile

$$G_{RH29} := \frac{5}{8} in$$ RH-24 gap scaled from [M3-1-47-N49-CSUG-DSCN2775]

$$F_{RH29} := \begin{pmatrix} -10^{6} & 0 & 0 & 10^{6} \end{pmatrix}^{T} lbf$$ Force profile applied

$$Dis_{RH29} := \left[\left(\frac{F_{RH29_0}}{K_{RH29}} - G_{RH29}\right) \quad -G_{RH29} \quad 0in \quad \frac{F_{RH29_3}}{K_{RH29}}\right]^T$$

Corresponding Displacement profile to applied Force profile

$$Dis_{RH29}^T = (-1.14813 \quad -0.625 \quad 0 \quad 0.52313)\ in$$

Resulting Force Displacement profile for RH-24

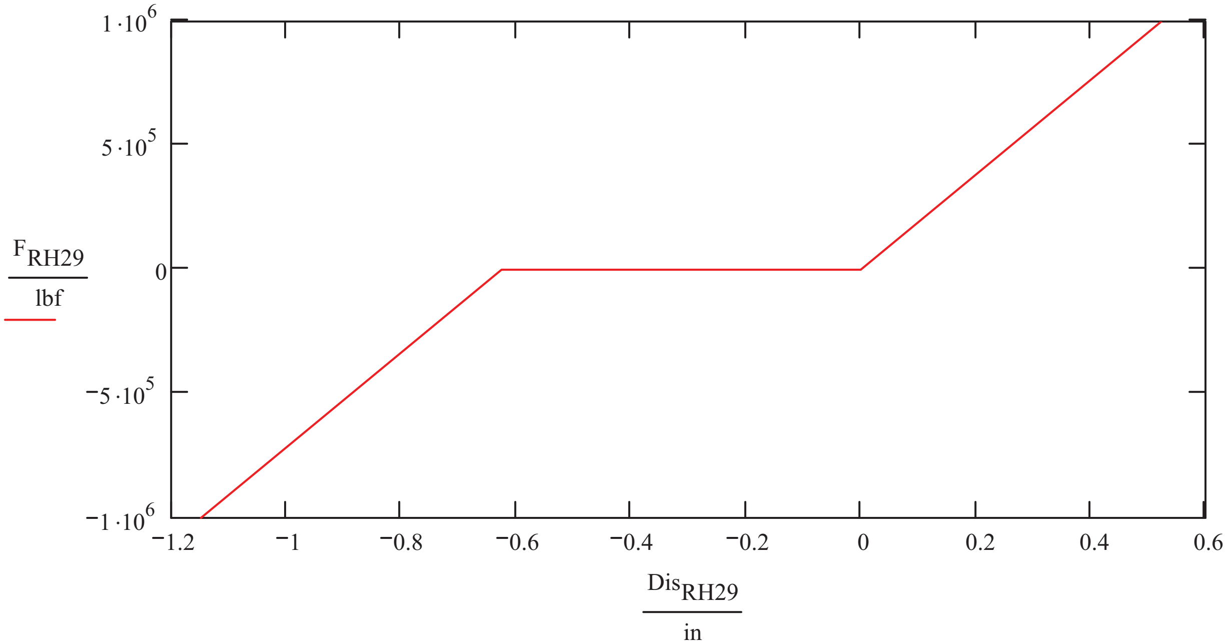


Photo [M3-1-47-N49-CSUG-DSCN2775]

PS-10 *(Doesn't resist any uplift)*

PS-10 (Doesn't resist any uplift)

PS-10 Stiffness

$A_{PS10} := 0.75in^2$ — Cross sectional area of PS-10 support [20] [8, Table 1-14 pg 1-99]

$L_{PS10} := 8in$ — Length of PS-10 support [20]

$$K_{PS10} := \frac{A_{PS10} \cdot E}{L_{PS10}}$$ Stiffness of PS-10

$$K_{PS10} = 2.719 \times 10^6 \frac{lbf}{in}$$

PS-10 Stiffness Profile

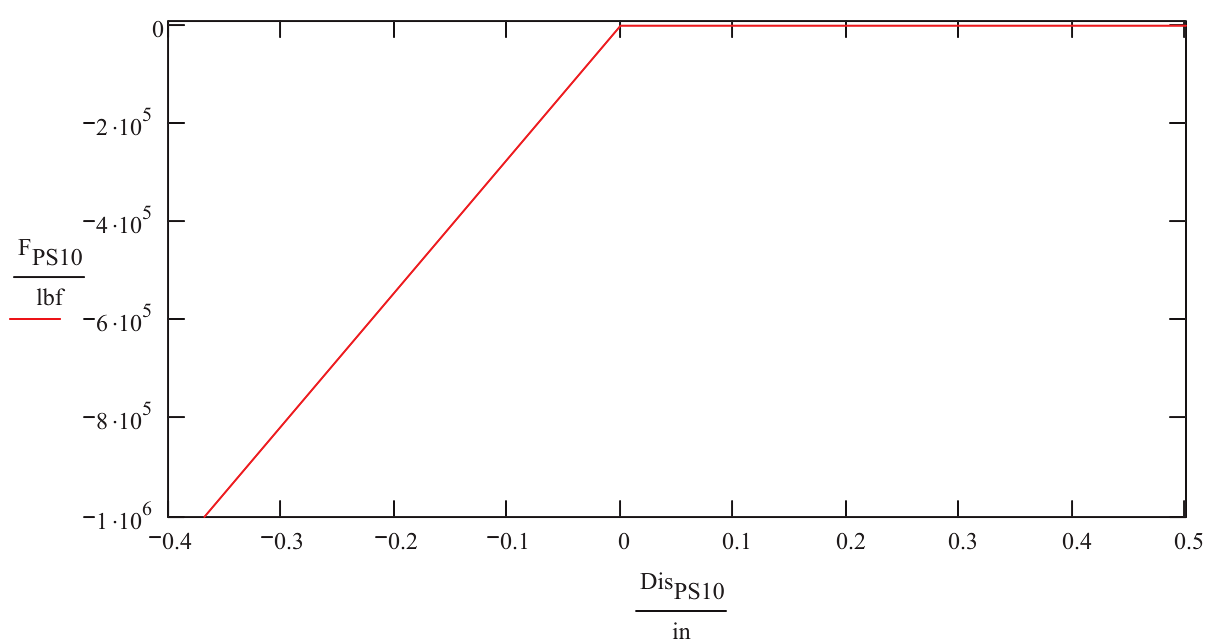
$F_{PS10} := \left(-10^6 \quad 0 \quad 0\right) lbf^T$ — Force profile applied

$$Dis_{PS10} := \left(\frac{F_{PS10_0}}{K_{PS10}} \quad 0in \quad 0.5in\right)^T$$

Corresponding Displacement profile to applied Force profile where 5in. is used to represent the uplift displacement response trend for upward force

$$Dis_{PS10}^T = (-0.36782 \quad 0 \quad 0.5)\ in$$

Resulting Force Displacement profile for PS-10



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Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** R. K. Blandford **Date:** 09/30/2008

RH-19 *(Any upward movement causes uplift for this support)*

RH-19 Stiffness

$D_{RH19} := \frac{5}{8} in$ — Diameter of rods comprising RH-19 [20]

$A_{RH19} := \frac{\pi \cdot D_{RH19}^2}{4}$ — Cross Sectional area of rods comprising RH-19

$A_{RH19} = 0.307\ in^2$

$L_{RH19} := 37.125in$ — Length between RH-19's lower connections and area ceiling (the lower connection is assumed to be even with the top of the line 1-27 pipe [26, (E8)] [25, (Det 26)]

$K_{RH19} := \frac{A_{RH19} \cdot E}{L_{RH19}}$ — Stiffness of one leg of RH-19

$K_{RH19} = 2.397 \times 10^5 \frac{lbf}{in}$

$K_{RH19\_2} := K_{RH19} + K_{RH19}$ — Stiffness of entire support (NOTE: Springs add in parallel)

$K_{RH19\_2} = 4.793 \times 10^5 \frac{lbf}{in}$

RH-19 Stiffness Profile

$F_{RH19\_2} := \begin{pmatrix} 0 & 0 & 10^6 \end{pmatrix} lbf^T$ — Force profile applied

$Dis_{RH19\_2} := \begin{pmatrix} -2in & 0in & \frac{F_{RH19\_2_2}}{K_{RH19\_2}} \end{pmatrix}^T$ — Corresponding Displacement profile to applied Force profile where 5in. is used to represent the uplift displacement response trend for upward force

$2\ Dis_{RH19\_2}^T$

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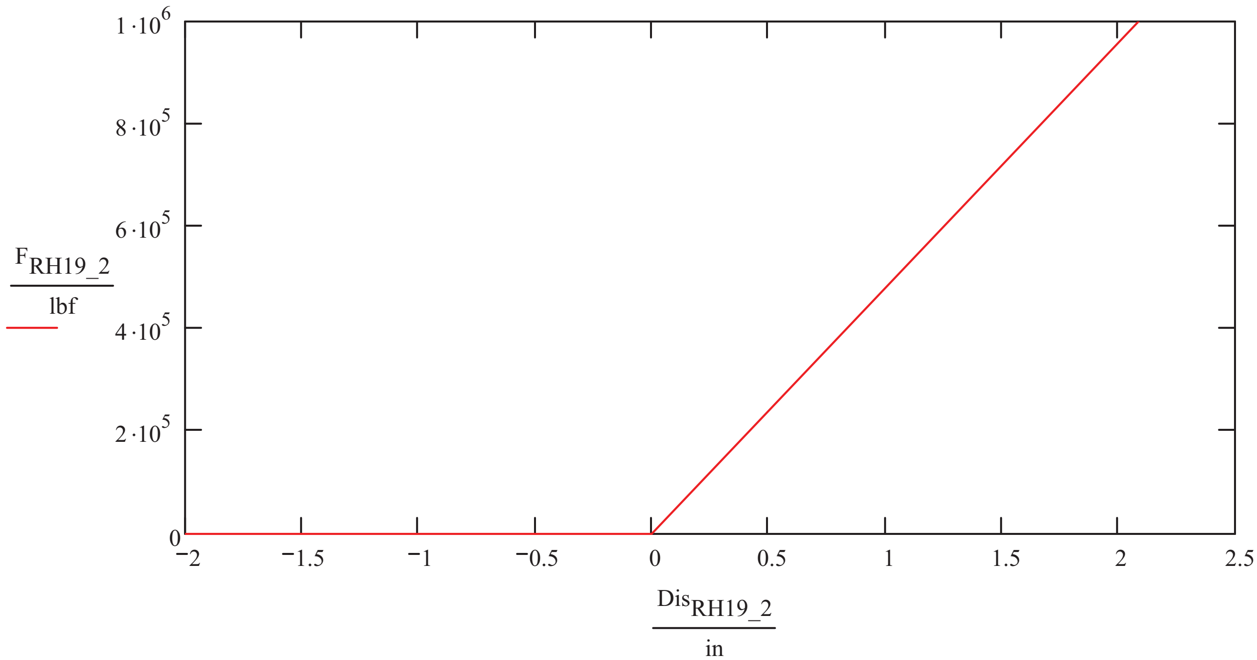
Resulting Force Displacement profile for RH-19



PS-8 *(Doesn't resist any uplift)*

PS-8 (Doesn't resist any uplift)

PS-8 Stiffness

$A_{PS8} := 2.97in^2$ — Cross sectional area of PS-8 support [22, Det 31] [8, Table 1-14 pg 1-99]

$L_{PS8} := 78in$ — Length of PS-8 support [20]

$$K_{PS8} := \frac{A_{PS8} \cdot E}{L_{PS8}}$$

Stiffness of PS-8

$$K_{PS8} = 1.104 \times 10^6 \frac{lbf}{in}$$

PS-8 Stiffness Profile

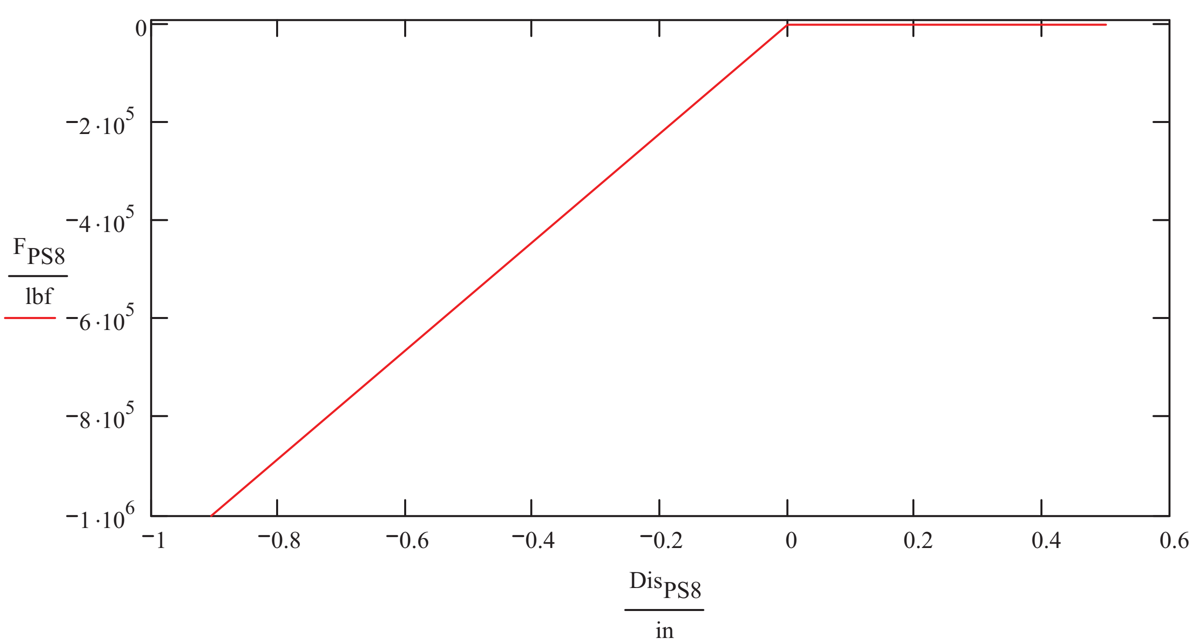
$F_{PS8} := \begin{pmatrix} -10^6 & 0 & 0 \end{pmatrix} lbf^T$ — Force profile applied

$$Dis_{PS8} := \begin{pmatrix} \frac{F_{PS8_0}}{K_{PS8}} & 0in & 0.5in \end{pmatrix}^T$$

Corresponding Displacement profile to applied Force profile where 5in. is used to represent the uplift displacement response trend for upward force

$$Dis_{PS8}^T = \begin{pmatrix} -0.90561 & 0 & 0.5 \end{pmatrix} in$$

Resulting Force Displacement profile for PS-8



PS-20 (Doesn't resist any uplift)

PS-20 (Doesn't resist any uplift)

PS-20 Stiffness

$A_{PS20} := 7.85in^2$

Cross sectional area of PS-20 support [22, Det 55] [8, Table 1-14 pg 1-99]

$L_{PS20} := 81in$

Length of PS-20 support [22, Det 55]

$K_{PS20} := \frac{A_{PS20} \cdot E}{L_{PS20}}$

Stiffness of PS-20

$K_{PS20} = 2.81 \times 10^6 \frac{lbf}{in}$

PS-20 Stiffness Profile

$F_{PS20} := \begin{pmatrix} -10^6 & 0 & 0 \end{pmatrix} lbf^T$

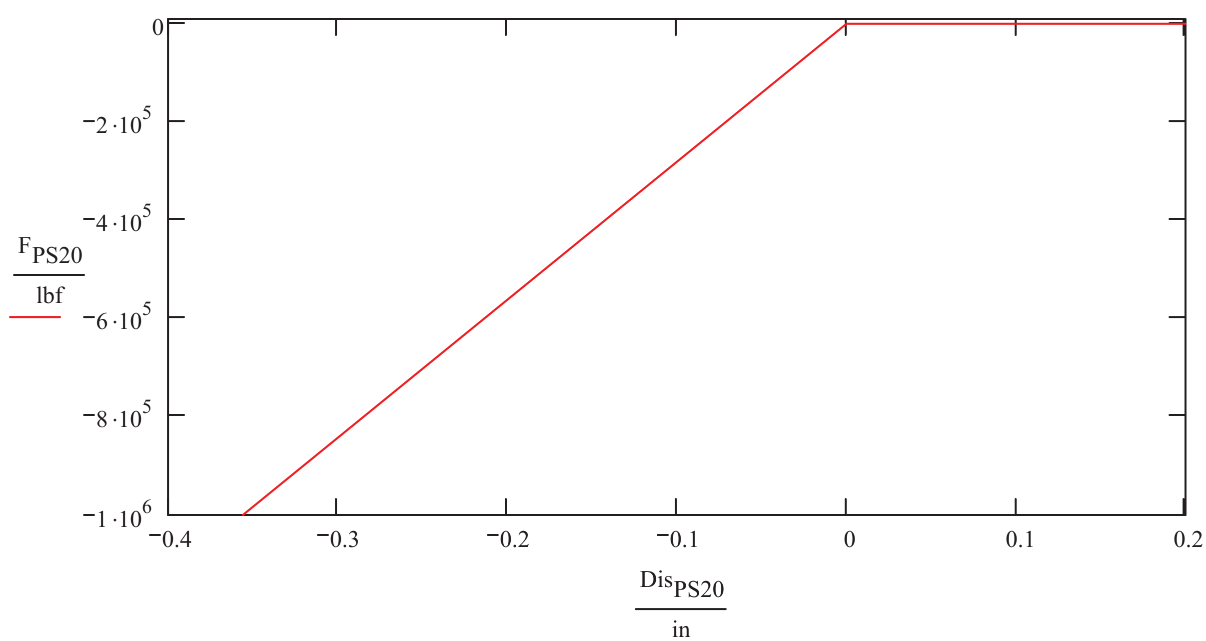
Force profile applied

$Dis_{PS20} := \begin{pmatrix} \frac{F_{PS20_0}}{K_{PS20}} & 0in & 0.2in \end{pmatrix}^T$

Corresponding Displacement profile to applied Force profile where 5in. is used to represent the uplift displacement response trend for upward force

$2\ Dis_{PS20}^T$

Resulting Force Displacement profile for PS-20



PS-4 *(Doesn't resist any uplift)*

PS-4 (Doesn't resist any uplift)

PS-4 Stiffness

$A_{PS4} := 2.97in^2$ — Cross sectional area of PS-4 support [25, Det 12] [8, Table 1-14 pg 1-99]

$L_{PS4} := 12in$ — Length of PS-4 support [20]

$$K_{PS4} := \frac{A_{PS4} \cdot E}{L_{PS4}}$$

Stiffness of PS-4

$$K_{PS4} = 7.178 \times 10^6 \frac{lbf}{in}$$

PS-4 Stiffness Profile

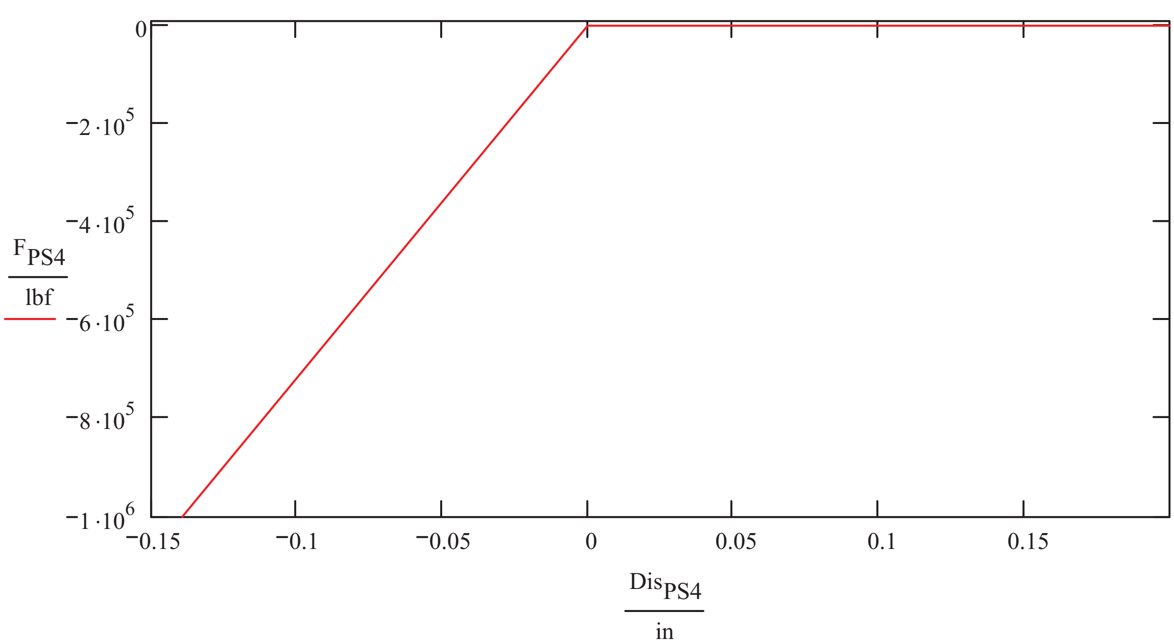
$F_{PS4} := \left(-10^6 \quad 0 \quad 0\right) lbf^T$ — Force profile applied

$$Dis_{PS4} := \left(\frac{F_{PS4_0}}{K_{PS4}} \quad 0in \quad 0.2in\right)^T$$

Corresponding Displacement profile to applied Force profile where 5in. is used to represent the uplift displacement response trend for upward force

$$Dis_{PS4}^T = (-0.13932 \quad 0 \quad 0.2)\, in$$

Resulting Force Displacement profile for PS-4



RH-26x (portion supporting 8-14) *(Any upward movement causes uplift for this support)*

RH-26x (line 8-14) Stiffness

$D_{RH26x814} := 1in$

Diameter of rods comprising RH-26x (line 8-14) [20]

$A_{RH26x814} := \frac{\pi \cdot D_{RH26x814}^{2}}{4}$

$A_{RH26x814} = 0.785\ in^2$

Cross Sectional area of rods comprising RH-26x (line 8-14)

$L_{RH26x814} := 37.125in$

Length between RH-26x (line 8-14)'s lower connections and area ceiling (the lower connection is assumed to be even with the top of the line 1-27 pipe [26, (E8)] [25, (Det 26)]

$K_{RH26x814} := \frac{A_{RH26x814} \cdot E}{L_{RH26x814}}$

Stiffness of one leg of RH-26x (line 8-14)

$K_{RH26x814} = 6.135 \times 10^5 \frac{lbf}{in}$

$K_{RH26x814\_2} := K_{RH26x814} + K_{RH26x814}$

Stiffness of entire support (NOTE: Springs add in parallel)

$K_{RH26x814\_2} = 1.227 \times 10^6 \frac{lbf}{in}$

RH-26x (line 8-14) Stiffness Profile

$F_{RH26x814\_2} := \left(0 \quad 0 \quad 10^6\right) lbf^T$

Force profile applied

$Dis_{RH26x814\_2} := \left(-2in \quad 0in \quad \frac{F_{RH26x814\_2_2}}{K_{RH26x814\_2}}\right)^T$

Corresponding Displacement profile to applied Force profile where 5in. is used to represent the uplift displacement response trend for upward force

$Dis_{RH26x814\_2}^T = (-2 \quad 0 \quad 0.81498)\ in$

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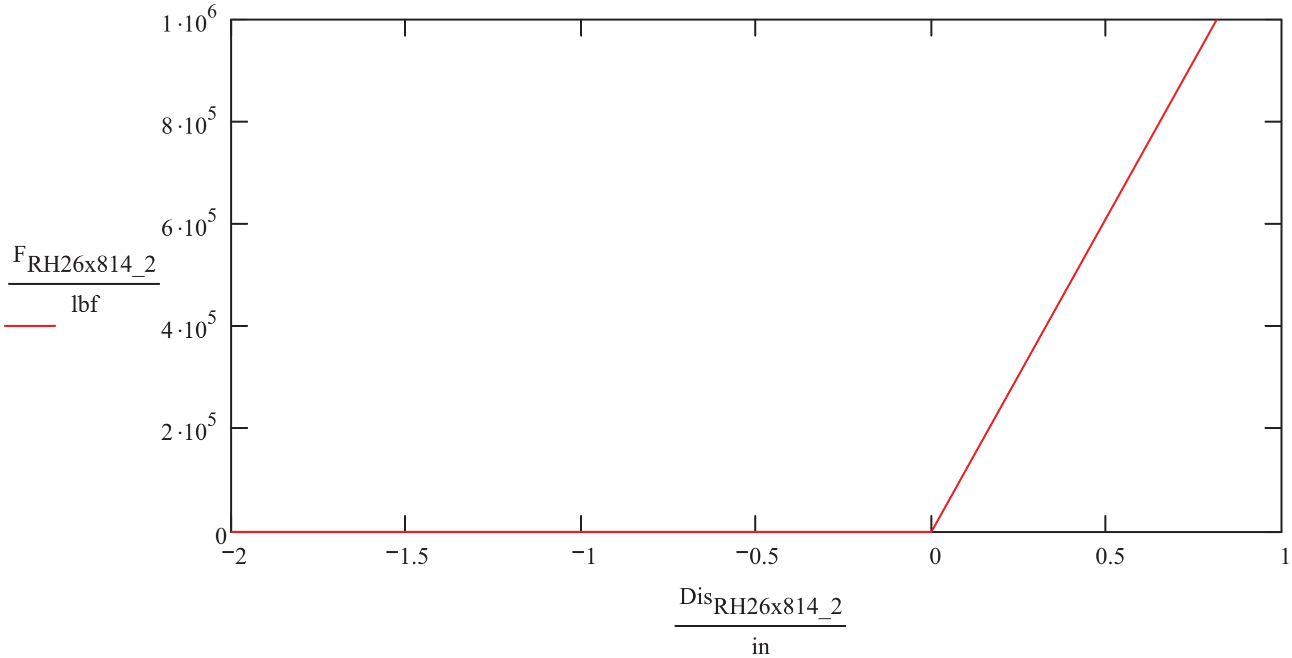
Resulting Force Displacement profile for RH-26x (line 8-14)



RH-32 (portion supporting 8-14) *(Any upward movement causes uplift for this support)*

RH-32 Stiffness

$$D_{RH32} := \frac{5}{8} in$$

Diameter of rods comprising RH-32 [20]

$$A_{RH32} := \frac{\pi \cdot D_{RH32}^2}{4}$$

Cross Sectional area of rods comprising RH-32

$$A_{RH32} = 0.307\ in^2$$

$$L_{RH32} := 39in$$

Length between RH-32's connections (the lower connection is assumed to be even with the bottom portion of the angle iron section below the pipe [22, Det 32], [7], [24, ph 33]

$$K_{RH32} := \frac{A_{RH32} \cdot E}{L_{RH32}}$$

Stiffness of one leg of RH-32

$$K_{RH32} = 2.281 \times 10^5 \frac{lbf}{in}$$

$$K_{RH32\_2} := K_{RH32} + K_{RH32}$$

$$K_{RH32\_2} = 4.563 \times 10^5 \frac{lbf}{in}$$

Stiffness of entire support (NOTE: Springs add in parallel)

RH-32 Stiffness Profile

$$F_{RH32\_2} := \begin{pmatrix} 0 & 0 & 10^6 \end{pmatrix} lbf^T$$

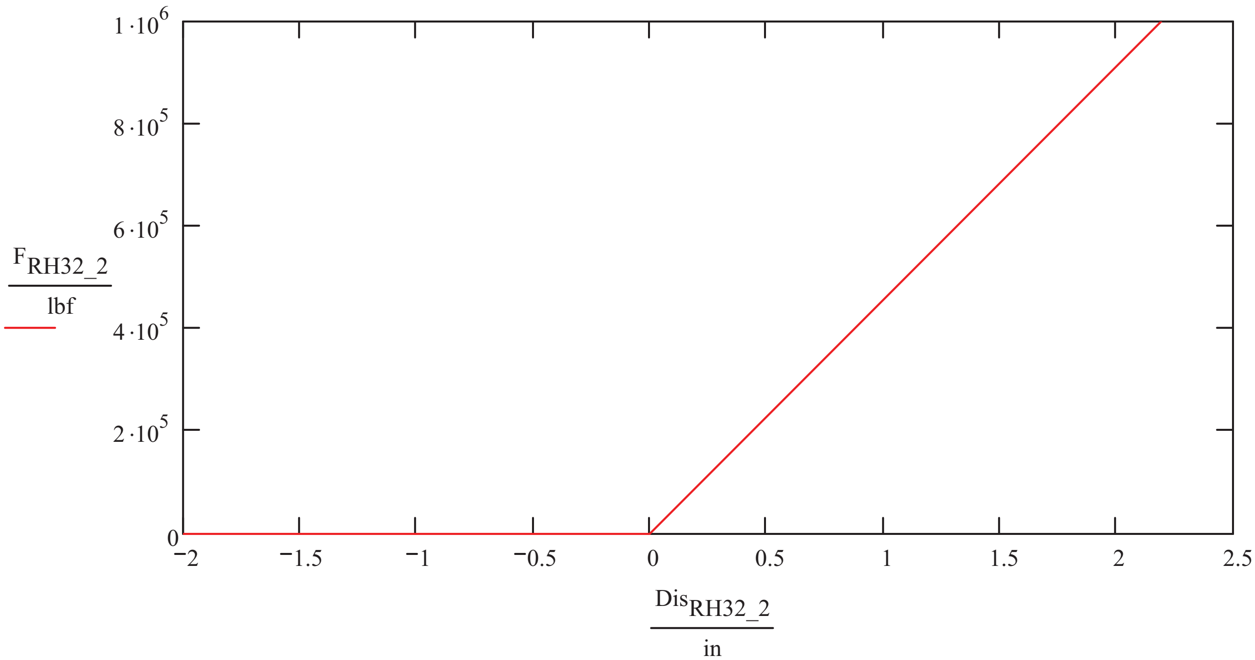
Force profile applied

$$Dis_{RH32\_2} := \begin{pmatrix} -2in & 0in & \frac{F_{RH32\_2_2}}{K_{RH32\_2}} \end{pmatrix}^T$$

Corresponding Displacement profile to applied Force profile where 5in. is used to represent the uplift displacement response trend for upward force

$$2\ Dis_{RH32\_2}^T$$

Resulting Force Displacement profile for RH-32



PR-6 *(Any downward movement is not resisted by this support)*

PR-6 Stiffness

$$D_{PR6} := \frac{5}{8} in$$

Diameter of rods comprising PR-6 [20]

$$A_{PR6} := \frac{\pi \cdot D_{PR6}^{2}}{4}$$

Cross Sectional area of rods comprising PR-6

$$A_{PR6} = 0.307\ in^2$$

$$L_{PR6} := 37.125 in$$

Length between PR-6's lower connections and area ceiling (the lower connection is assumed to be even with the top of the line 1-27 pipe [26, (E8)] [25, (Det 26)]

$$K_{PR6} := \frac{A_{PR6} \cdot E}{L_{PR6}}$$

Stiffness of one leg of PR-6

$$K_{PR6} = 2.397 \times 10^{5}\ \frac{lbf}{in}$$

$$K_{PR6\_2} := K_{PR6} + K_{PR6}$$

Stiffness of entire support (NOTE: Springs add in parallel)

$$K_{PR6\_2} = 4.793 \times 10^{5}\ \frac{lbf}{in}$$

PR-6 Stiffness Profile

$$F_{PR6\_2} := \begin{pmatrix} 0 & 0 & 10^{6} \end{pmatrix}^{T} lbf$$

Force profile applied

$$Dis_{PR6\_2} := \begin{pmatrix} -2in & 0in & \dfrac{F_{PR6\_2_{2}}}{K_{PR6\_2}} \end{pmatrix}^{T}$$

Corresponding Displacement profile to applied Force profile where 5in. is used to represent the uplift displacement response trend for upward force

$$Dis_{PR6\_2}^{T} = \begin{pmatrix} -2 & 0 & 2.08636 \end{pmatrix} in$$

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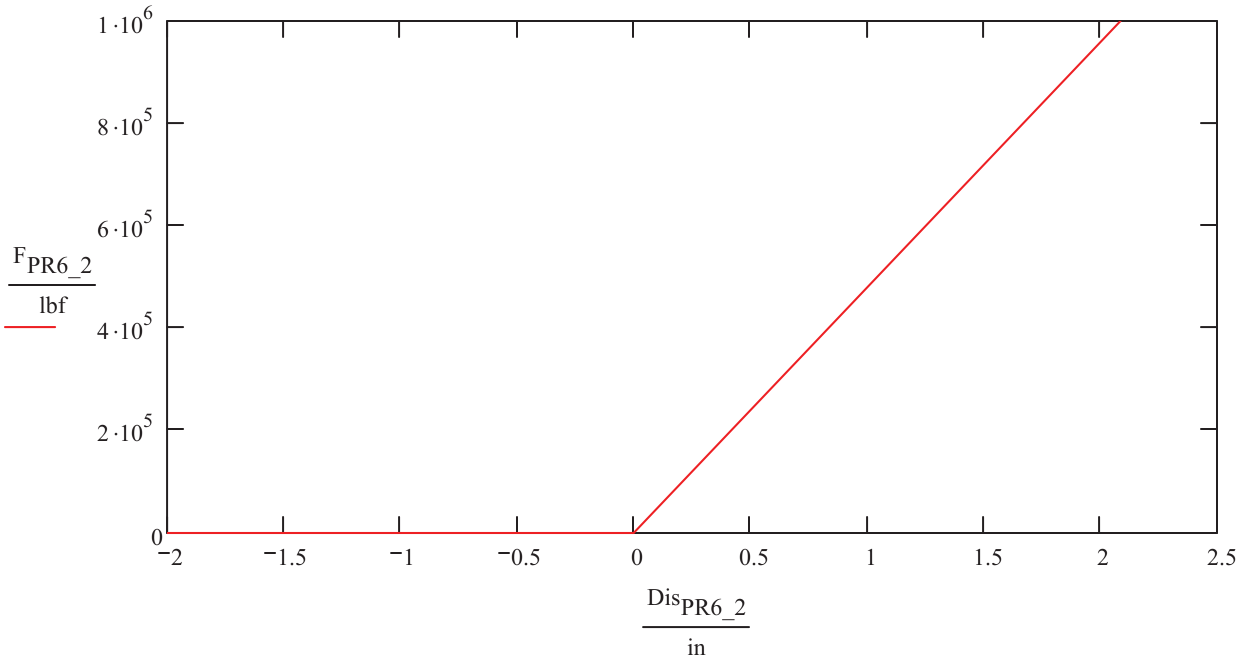
Resulting Force Displacement profile for PR-6



Appendix C.6

Dimensions Associated with Supports, Spring Hangers, Terminations, Reducers, Elbows, Tees, Fabricated Branch & Reducer, Flanges, and Valves of Model 2-6-5

(NOTE: Photos referenced in tables are included in Appendix C.9.2)

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Table 1. Dimensions Associated with Supports on Line 1-13 of Model 2-6-5

Supports (1-13)	*Dimensions*		*Reference*
PS-8A	Length from elbow top to floor	30" + 3.5" + (7'-1.5") = 119"	[22, Det 31]
	Length from connection to floor	(7'-1.5") = 85.5"	[22, Det 31]
	Nonlinear spring profile	See Appendix C.5	

Table 2. Dimensions Associated with Supports on Line 1-14 of Model 2-6-5

Supports (1-14)	*Dimensions*		*Reference*
PS-8B	Length from elbow top to floor	30" + 3.5" + (7'-1.5") = 119"	[22, Det 31]
	Length from connection to floor	(7'-1.5") = 85.5"	[22, Det 31]
	Nonlinear spring profile	See Appendix C.5	

Table 3. Dimensions Associated with Supports on Line 1-15 of Model 2-6-5

Supports (1-15)	*Dimensions*		*Reference*
PS-8C	Length from elbow top to floor	30" + 3.5" + (7'-1.5") = 119"	[22, Det 31]
	Length from connection to floor	(7'-1.5") = 85.5"	[22, Det 31]
	Nonlinear spring profile	See Appendix C.5	

Table 4. Dimensions Associated with Supports on Line 1-16 of Model 2-6-5

Supports (1-16)	*Dimensions*		*Reference*
PS-8D	Length from elbow top to floor	30" + 3.5" + (7'-1.5") = 119"	[22, Det 31]
	Length from connection to floor	(7'-1.5") = 85.5"	[22, Det 31]
	Nonlinear spring profile	See Appendix C.5	

Table 5. Dimensions Associated with Supports on Line 1-17 of Model 2-6-5

Supports (1-17)	*Dimensions*		*Reference*
PR-6A	Length connection to anchorage	5' + 30"/2 = 75"	[23]
	Distance from (Reference)	22.5" from T(1-18)	M2-1-17-N84-FSUG-DSCN2708
	Nonlinear spring profile	See Appendix C.5	
PR-6B	Length connection to anchorage	5' + 30"/2 = 75"	[23]
	Distance from (Reference)	30" east of SPS-2C	P3-M2-DSCN0003
	Nonlinear spring profile	See Appendix C.5	
PR-6C	Length connection to anchorage	5' + 30"/2 = 75"	[23]
	Distance from (Reference)	27" east of T(1-19)	P3-M2-DSCN0001
	Nonlinear spring profile	See Appendix C.5	
PR-6D	Length connection to anchorage	5' + 30"/2 = 75"	[23]
	Distance from (Reference)	53" east of SPS-5A	P2-M2-DSCN0002
	Nonlinear spring profile	See Appendix C.5	
PR-6E	Length connection to anchorage	5' + 30"/2 = 75"	[23]
	Distance from (Reference)	40" east of T(1-20)	P2-M2-DSCN0001
	Nonlinear spring profile	See Appendix C.5	
PR-6F	Length connection to anchorage	5' + 30"/2 = 75"	[23]
	Distance from (Reference)	62" west of T(1-20)	P1-M2-DSCN0004
	Nonlinear spring profile	See Appendix C.5	
PR-6G	Length connection to anchorage	5' + 30"/2 = 75"	[23]
	Distance from (Reference)	53" east of T(1-21)	P1-M2-DSCN0002-1
	Nonlinear spring profile	See Appendix C.5	

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Table 6. Dimensions Associated with Supports on Line 1-30 of Model 2-6-5

Supports (1-30)	*Dimensions*		*Reference*
RH-32	Length connection to anchorage	(2'-10") +16"/2 - 2" = 40"	[22, Det 32], [7], [24, ph 33]
	Distance from (Reference)	6.75" from EL(1-30A)	M2-1-30-N62-CSUF-DSCN2738
	Nonlinear spring profile	See Appendix C.5	
RH-11A	Length of clamp cantilever	12"	[25, Det 18]
	Size of cantilever	5" x 3" x 1/2" angle iron	[25, Det 18]
	Length connection to anchorage	(2'-10") - 10.25" - 3" = 20.75"	[12094422
	Distance from (Reference)	Located directly over line 1-24 which is 18' = 216" west of RH-13 (above line 1-23 (defined below))	[21, G8-10], M2-1-13-N30-CSUG-DSCN2764
RH-11B	Length of anchorage cantilever	12"	[25, Det 18]
	Size of cantilever	5" x 3" x 1/2" angle iron	[25, Det 18]
	Length connection to anchorage	(2'-10") - 10.25" - 3" = 20.75"	[22, Det 32], [25, Det 18]
	Distance from (Reference)	Located directly over line 1-25 which is 18' = 216" west of RH-11 (above line 1-24 (defined above))	[21, G5-7]
PS-4A	Length from flange to floor	12"	[20]
	Distance from (Reference)	At FL(1-30C)	[21, FG3-4]
	Nonlinear spring profile	See Appendix C.5	
PS-4B	Length from flange to floor	12"	[20]
	Distance from (Reference)	At FL(1-30D)	[21, FG3-4]
	Nonlinear spring profile	See Appendix C.5	

Table 7. Dimensions Associated with Supports on Line 1-31 of Model 2-6-5

Supports (1-31)	*Dimensions*		*Reference*
PS-4C	Length from flange to floor	12"	[20]
	Distance from (Reference)	At FL(1-31A)	[21, FG3-4]
	Nonlinear spring profile	See Appendix C.5	
PS-4D	Length from flange to floor	12"	[20]
	Distance from (Reference)	At FL(1-31B)	[21, FG3-4]
	Nonlinear spring profile	See Appendix C.5	

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Table 8. Dimensions Associated with Supports on Line 1-43 of Model 2-6-5

Supports (1-43)	*Dimensions*		*Reference*
RH-19	Length from bottom of pipe to ceiling connection	16.5" + 5" + 12" + 10.75"/2 - 1.75" = 37.125"	Scaled from M6-1-44-N61-CSUG-DSCN2687, [24, ph-18], [12], [11]
	Distance from (Reference)	20" from T(1-46A)	Scaled from M6-1-43-N6-CBRG-DSCN2840
	Nonlinear spring profile	See Appendix C.5	
RH-17A	Length from clamp to ceiling	16.5" + 5" + 12" - 7.4375" - 1.75" = 24.3125"	Scaled from M6-1-44-N61-CSUG-DSCN2687, [24, ph-18], [12], [11]
	Distance from (Reference)	1.5" from EL(1-43D)	Scaled from M6-1-44-N43-CSUG-DSCN2844
	Nonlinear spring profile	See Appendix C.5	
RH-17B	Length from clamp to ceiling	16.5" + 5" + 12" - 7.4375" - 1.75" = 24.3125"	Scaled from M6-1-44-N61-CSUG-DSCN2687, [24, ph-18], [12], [11]
	Distance from (Reference)	12.625" north of RH-22	[25, Det 11], [25, det 20], [25], [24, ph-18]
	Nonlinear spring profile	See Appendix C.5	
RH-30	Length from clamp to wall	4.5"	[25, Det 24]
	Conservative approximation of cantilever portion of angle	4" x 4.5" x 1/2"	[25, Det 24]
	Distance from (Reference)	30" from EL(1-43)	M6-1-43-N21-WSUG-DSCN2819
	Nonlinear spring profile	See Appendix C.5	
RH-25A	Length between connections	98' - 79' -6' -10' - 7.4375" - 1.75" = 28.5625"	[26, H15-J15], [24, ph-18, 33]
	Distance from (Reference)	28" from EL(1-43G) on P(1-43I)	[24, ph-18], Scaled from M6-1-43-N26-CSUG-DSCN2818
	Nonlinear spring profile	See Appendix C.5	
RH-25B	Length from clamp to ceiling	98' - 79' -6' -10' - 7.4375" - 1.75" = 28.5625"	[26, H15-J15], [24, ph-18, 33]
	Distance from (Reference)	31.5" from NWP(1-43)	[24, ph-18], Scaled from M6-1-43-N27-CSUG-DSC00032
	Nonlinear spring profile	See Appendix C.5	

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Table 9. Dimensions Associated with Supports on Line 1-44 of Model 2-6-5

Supports (1-44)	*Dimensions*		*Reference*
RH-22A	Length of Plate Portion of Cantilever	4"	M6-1-44-N43-CSUA-DSCN2845 [25, Detail 11]
	Length of Angle Iron Portion of Cantilever	6.625"	M6-1-44-N43-CSUA-DSCN2845 [25, Detail 11]
	Length from clamp to ceiling	14" + (2'-9") = 47"	[12], Scaled from M6-1-44-N61-CSUG-DSCN2687
	Distance from (Reference)	4" from T(1-44) toward GT(1-46B)	Scaled from M6-1-44-N43-CSUG-DSCN2844
	Nonlinear spring profile	See Appendix C.5	
RH-22B	Length Angle Iron Cantilever	10.625"	[25, Det 11]
	Length from clamp to ceiling	14"	Scaled from M6-1-44-N61-CSUG-DSCN2687
	Distance from (Reference)	21" + 18.375" - 30" = 9.375" from EL(1-44B) on P(1-44B)	[25, Det 11], [25, det 20], [25], [24, ph-18]
	Nonlinear spring profile	See Appendix C.5	
PS-7	Length connection to anchorage	18.375"	[25, Det 20]
	Support Shape	Fabricated Plate	[25, Det 20]
	Distance from (Reference)	24" from EL(1-44C)	M6-1-44-N68-WSUG-DSCN2814
RH-16A	Length between connections	98' - 79' - 6' - 7' - 5" - 1.75" = 65.25"	[27, J2-3], [24, ph-18, 33]
	Distance from (Reference)	26" from EL(1-44D) on P(1-44D)	[24, ph-18], Scaled from M6-1-44-N71-CSUG-DSCN2691
	Support rod details	0.625" diameter rod	
RH-16B	Length between connections	98' - 79' - 6' - 7' - 5" - 1.75" = 65.25"	[27, J2-3], [24, ph-18, 33]
	Distance from (Reference)	6" from EL(1-44E) on P(1-44E)	[24, ph-18], Scaled from M6-1-44-N71-CSUG-DSCN2691
	Support rod details	0.625" diameter rod	

Table 10. Dimensions Associated with Supports on Line 1-47 of Model 2-6-5

Supports (1-47)	*Dimensions*		*Reference*
PS-10A	Length from bottom of pipe to floor	8"	[28], [25, Det 8]
	Distance from (Reference)	4" from EL(1-17A)	(25, Det 8), Scaled from M6-1-47-N54-FSUG-DSCN2828
	Nonlinear spring profile	See Appendix C.5	
PS-10B	Length from bottom of pipe to floor	8"	[28], [25, Det 8]
	Distance from (Reference)	4" south from GT(1-46B)	(127036), Scaled from M6-1-47-N57-FSUG-DSCN2827
	Nonlinear spring profile	See Appendix C.5	
PS-10C	Length from bottom of pipe to floor	8"	[28], [25, Det 8]
	Distance from (Reference)	8" north from GT(1-46B)	[16], Scaled from M6-1-47-N57-FSUG-DSCN2827
	Nonlinear spring profile	See Appendix C.5	
AIWS	Dimensions of Angle Iron Structure		[25, Detail 15]
	Size of angle iron composition	1.5" x 1.5" x 3/16"	[25, Detail 15]
	Length from bottom of pipe to anchorage	8"	[25, Detail 15]
	Distance from (Reference)	40" + 2" - 6" - 9" = 27" south of EL(1-47E)	P9-M4-M6-DSCN0005, [25, Detail 15]

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Table 11. Dimensions Associated with Supports on Line 1-47 of Model 2-6-5

Supports (1-48)	*Dimensions*		*Reference*
RH-24A	Length pipe center to ceiling	9.375"	M3-1-47-N49-CSUG-DSCN2775
	Distance from (Reference)	(6'-6")+(6'-0") = 150" from EL(1-48A)	[21,CD7]
	Nonlinear spring profile	See Appendix C.5	
RH-24B	Length pipe center to ceiling	9.375"	M3-1-47-N49-CSUG-DSCN2775
	Distance from (Reference)	11" from EL(1-48A)	M2-1-48-N47-CSUG-DSCN2774
	Nonlinear spring profile	See Appendix C.5	
AIS	Cantilever properties	1.75" X 1.75" X 0.25"	M2-1-48-N44-WSUG-DSCN2773
	Length connection to anchorage	4.5" from pipe face	M2-1-48-N44-WSUG-DSCN2773
	Distance from (Reference)	At top side of EL(1-48C)	M2-1-48-N44-WSUG-DSCN2773

Table 12. Dimensions Associated with Supports on Line 8-14 of Model 2-6-5

Supports (8-14)	*Dimensions*		*Reference*
RH-26x	Length connection to anchorage	71" - EL(8-14B) = 56"	M3-1-27-N370-CSUG-DSCN2941
	Distance from (Reference)	(2'-10") - 10.25"/2 - 3" = 20.75"	[22, Det 32], [25, Det 18]
	Nonlinear spring profile	See Appendix C.5	
RH-13A	Length of anchorage cantilever	12"	[25, Det 18]
	Size of cantilever	5" x 3" x 1/2" angle iron	[25, Det 18]
	Length connection to anchorage	(2'-10") - 7.4375" - 3" = 23.5625"	[25, Det 25]
	Distance from (Reference)	Located directly over line 1-22 which is 7' east of line 1-18	[21, G12-13], M2-8-14-N7-CSUG-DSCN2742
RH-13B	Length of clamp cantilever	12"	[25, Det 18]
	Size of cantilever	5" x 3" x 1/2" angle iron	[25, Det 18]
	Length connection to anchorage	(2'-10") - 10.75"/2 - 3" = 23.5625"	[25, Det 25]
	Distance from (Reference)	Located directly over line 1-23 which is 18' = 216" west of previous RH-13 (above line 1-22)	[21,G10-12], M2-8-14-N9-CSUG-DSCN2741

Table 13. Dimensions Associated with Supports on Line 1-171 of Model 2-6-5

Supports (8-14)	*Dimensions*		*Reference*
RH-26x	Length connection to anchorage	71" - EL(8-14B) = 56"	M3-1-27-N370-CSUG-DSCN2941
	Distance from (Reference)	(2'-10") - 10.25"/2 - 3" = 20.75"	[22, Det 32], [25, Det 18]
	Nonlinear spring profile	See Appendix C.5	
RH-13A	Length of anchorage cantilever	12"	[25, Det 18]
	Size of cantilever	5" x 3" x 1/2" angle iron	[25, Det 18]
	Length connection to anchorage	(2'-10") - 7.4375" - 3" = 23.5625"	[25, Det 25]
	Distance from (Reference)	Located directly over line 1-22 which is 7' east of line 1-18	[21, G12-13], M2-8-14-N7-CSUG-DSCN2742
RH-13B	Length of clamp cantilever	12"	[25, Det 18]
	Size of cantilever	5" x 3" x 1/2" angle iron	[25, Det 18]
	Length connection to anchorage	(2'-10") - 10.75"/2 - 3" = 23.5625"	[25, Det 25]
	Distance from (Reference)	Located directly over line 1-23 which is 18' = 216" west of previous RH-13 (above line 1-22)	[21,G10-12], M2-8-14-N9-CSUG-DSCN2741

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Table 14. Dimensions Associated with Supports on Line 1-171 of Model 2-6-5

Spring Pipe Support (1-17)	*Dimensions*		*Reference*
SPS-2D	Location	Line 1-17	[20]
	Dist from Ref	4.5" west of PR-6A	M2-1-17-N84-FSUG-DSCN2708
	Load	9600	[20]
SPS-2C	Location	Line 1-17	[20]
	Dist from Ref	84" east of PR-6C	P3-M2-DSCN0002
	Load	8400	[20]
SPS-5A	Location	Line 1-17	[20]
	Dist from Ref	45" west of T(1-19)	P2-M2-DSCN0003
	Load	8700	[20]
SPS-5B	Location	Line 1-17	[20]
	Dist from Ref	28" east of PR-6E	P2-M2-DSCN0001
	Load	9000	[20]
SPS-2B	Location	Line 1-17	[20]
	Dist from Ref	13.5" east of PR-6F	P1-M2-DSCN0004
	Load	8100	[20]
SPS-2A	Location	Line 1-17	[20]
	Dist from Ref	28" west of PR-6G	P1-M2-DSCN0002-1
	Load	8900	[20]

Table 15. Dimensions Associated with Supports on Line 1-171 of Model 2-6-5

Spring Pipe Support (1-18)	*Dimensions*		*Reference*
SPS-1A	Location	Line 1-18	[21]
	Dist from Ref	At FL(1-18B)	[21, F12]
	Load	7800	[20]

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Table 16. Dimensions Associated with Spring Hangers & Spring Supports on Line 1-17 of Model 2-6-5

Spring Pipe Support (1-17)	*Dimensions*		*Reference*
SPS-2D	Location	Line 1-17	[20]
	Dist from Ref	4.5" west of PR-6A	M2-1-17-N84-FSUG-DSCN2708
	Load	9600	[20]
SPS-2C	Location	Line 1-17	[20]
	Dist from Ref	84" east of PR-6C	P3-M2-DSCN0002
	Load	8400	[20]
SPS-5A	Location	Line 1-17	[20]
	Dist from Ref	45" west of T(1-19)	P2-M2-DSCN0003
	Load	8700	[20]
SPS-5B	Location	Line 1-17	[20]
	Dist from Ref	28" east of PR-6E	P2-M2-DSCN0001
	Load	9000	[20]
SPS-2B	Location	Line 1-17	[20]
	Dist from Ref	13.5" east of PR-6F	P1-M2-DSCN0004
	Load	8100	[20]
SPS-2A	Location	Line 1-17	[20]
	Dist from Ref	28" west of PR-6G	P1-M2-DSCN0002-1
	Load	8900	[20]

Table 17. Dimensions Associated with Spring Hangers & Spring Supports on Line 1-18 of Model 2-6-5

Spring Pipe Support (1-18)	*Dimensions*		*Reference*
SPS-1A	Location	Line 1-18	[21]
	Dist from Ref	At FL(1-18B)	[21, F12]
	Load	7800	[20]

Table 18. Dimensions Associated with Spring Hangers & Spring Supports on Line 1-19 of Model 2-6-5

Spring Pipe Support (1-19)	*Dimensions*		*Reference*
SPS-1B	Location	Line 1-19	[21]
	Dist from Ref	At FL(1-19B)	[21, F10]
	Load	7200	[20]

Table 19. Dimensions Associated with Spring Hangers & Spring Supports on Line 1-20 of Model 2-6-5

Spring Pipe Support (1-20)	*Dimensions*		*Reference*
SPS-1C	Location	Line 1-20	[21]
	Dist from Ref	At FL(1-20B)	[21, F7]
	Load	7800	[20]

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Table 20. Dimensions Associated with Spring Hangers & Spring Supports on Line 1-21 of Model 2-6-5

Spring Pipe Support (1-21)	*Dimensions*		*Reference*
SPS-1D	Location	Line 1-21	[21]
	Dist from Ref	At FL(1-21B)	[21, F5]
	Load	7800	[20]

Table 21. Location Associated with Termination on Line 1-13 of Model 2-6-5

Termination (1-13)	*Dimensions*		*Reference*
HX(1-13)	Location	Where line 1-13 connects to heat exchanger	[4]

Table 22. Location Associated with Termination on Line 1-14 of Model 2-6-5

Termination (1-14)	*Dimensions*		*Reference*
HX(1-14)	Location	Where line 1-14 connects to heat exchanger	[4]

Table 23. Location Associated with Termination on Line 1-15 of Model 2-6-5

Termination (1-15)	*Dimensions*		*Reference*
HX(1-15)	Location	Where line 1-15 connects to heat exchanger	[4]

Table 24. Location Associated with Termination on Line 1-16 of Model 2-6-5

Termination (1-16)	*Dimensions*		*Reference*
HX(1-16)	Location	Where line 1-15 connects to heat exchanger	[4]

Table 25. Location Associated with Termination on Line 1-171 of Model 2-6-5

Termination (1-171)	*Dimensions*		*Reference*
HX(1-171)	Location	Where line 1-171 connects to heat exchanger	[18]

Table 26. Location Associated with Termination on Line 1-18 of Model 2-6-5

Termination (1-18)	*Dimensions*		*Reference*
PP(1-18)	Location	Where line 1-18 connects to primary pump	[5]

Table 27. Location Associated with Termination on Line 1-19 of Model 2-6-5

Termination (1-19)	*Dimensions*		*Reference*
PP(1-19)	Location	Where line 1-19 connects to primary pump	[5]

Table 28. Location Associated with Termination on Line 1-20 of Model 2-6-5

Termination (1-20)	*Dimensions*		*Reference*
PP(1-20)	Location	Where line 1-20 connects to primary pump	[5]

Table 29. Location Associated with Termination on Line 1-21 of Model 2-6-5

Termination (1-21)	*Dimensions*		*Reference*
PP(1-21)	Location	Where line 1-21 connects to primary pump	[5]

Table 30. Location Associated with Termination on Line 1-30 of Model 2-6-5

Termination (1-30)	*Dimensions*		*Reference*
EP(1-30)	Location	Where line 1-30 connects to emergency pump	[7]

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Table 31. Location Associated with Termination on Line 1-31 of Model 2-6-5

Termination (1-31)	*Dimensions*		*Reference*
EP(1-31)	Location	Where line 1-31 connects to emergency pump	[10]

Table 32. Location Associated with Termination on Line 1-43 of Model 2-6-5

Termination (1-43)	*Dimensions*		*Reference*
NWP(1-43)	Location	Where line 1-43 penetrates the north wall	[11]

Table 33. Location Associated with Termination on Line 1-44 of Model 2-6-5

Termination (1-44)	*Dimensions*		*Reference*
WFP(1-44)	Location	Where line 1-44 pentrates the floor just below west wall	[13]

Table 34. Location Associated with Termination on Line 1-47 of Model 2-6-5

Termination (1-47)	*Dimensions*		*Reference*
PT(1-47)	Location	Where line 1-47 tees into underside of pipe1-35	[16]

Table 35. Location Associated with Termination on Line 1-48 of Model 2-6-5

Termination (1-48)	*Dimensions*		*Reference*
NWP(1-48)	Location	Where line 1-48 penetrates the north wall	[17]

Table 36. Location Associated with Termination on Line 8-14 of Model 2-6-5

Termination (8-14)	*Dimensions*		*Reference*
ECP(8-14)	Location	Where line 8-14 penetrates concrete ceiling by east wall	[19]

Table 37. Location Associated with Termination on Line 1-45 of Model 2-6-5

Termination (1-45)	*Dimensions*		*Reference*
ST(1-45)	Location	Where line 1-45 connects to surge tank	[33]

Table 38. Dimensions Associated with Pipe Runs on Line 1-13 of Model 2-6-5

Pipe Run (1-13)	*Dimensions*		*Reference*
P (1-13A)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.312"	[4]
	Pipe Material	SS304	[4]
	Length between	(3'-3.25") - EL(1-13A) = 9.25"	[4]
P (1-13B)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.312"	[4]
	Pipe Material	SS304	[4]
	Length between	(9'-6") - EL(1-13A) - EL(1-13B) = 54"	[4]
P (1-13C)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.312"	[4]
	Pipe Material	SS304	[4]
	Length between	(11'-9.0625) - EL(1-13B) - T(1-13) = 86.9375"	[4]

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Table 39. Dimensions Associated with Pipe Runs on Line 1-14 of Model 2-6-5

Pipe Run (1-14)	*Dimensions*		*Reference*
P (1-14A)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.312"	[4]
	Pipe Material	SS304	[4]
	Length between	(3'-3.25") - EL(1-14A) = 9.25"	[4]
P (1-14B)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.312"	[4]
	Pipe Material	SS304	[4]
	Length between	(9'-6") - EL(1-14A) - EL(1-14B) = 54"	[4]
P (1-14C)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.312"	[4]
	Pipe Material	SS304	[4]
	Length between	(11'-9.0625) - EL(1-14B) - T(1-14) = 86.9375"	[4]

Table 40. . Dimensions Associated with Pipe Runs on Line 1-15 of Model 2-6-5

Pipe Run (1-15)	*Dimensions*		*Reference*
P (1-15A)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.312"	[4]
	Pipe Material	SS304	[4]
	Length between	(3'-3.25") - EL(1-14A) = 9.25"	[4]
P (1-15B)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.312"	[4]
	Pipe Material	SS304	[4]
	Length between	(9'-6") - EL(1-15A) - EL(1-15B) = 54"	[4]
P (1-15C)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.312"	[4]
	Pipe Material	SS304	[4]
	Length between	(11'-9.0625) - EL(1-15B) - T(1-15) = 86.9375"	[4]

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Table 41. Dimensions Associated with Pipe Runs on Line 1-16 of Model 2-6-5

Pipe Run (1-16)	*Dimensions*		*Reference*
P (1-16A)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.312"	[4]
	Pipe Material	SS304	
	Length between	(3'-3.25") - EL(1-14A) = 9.25"	[4]
P (1-16B)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.312"	[4]
	Pipe Material	SS304	[4]
	Length between	(9'-6") - EL(1-15A) - EL(1-15B) = 54"	[4]
P (1-16C)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.312"	[4]
	Pipe Material	SS304	[4]
	Length between	(11'-9.0625) - EL(1-15B) - T(1-15) = 86.9375"	[4]

Table 42. Dimensions Associated with Pipe Runs on Line 1-17 of Model 2-6-5

Pipe Run (1-17)	*Dimensions*		*Reference*
P (1-17A)	Pipe Diameter	30"	[4]
	Pipe Thickness	0.438"	[4]
	Pipe Material	SS304	[4]
	Length between	(18') -T(1-18)Leg2 - T(1-19)Leg1 = 172.5313"	[4]
P (1-17B)	Pipe Diameter	30"	[4]
	Pipe Thickness	0.438"	[4]
	Pipe Material	SS304	[4]
	Length between	(9'-8.9375") -T(1-15)Leg2 - T(1-10)Leg1 = 68.9375"	[4]
P (1-17C)	Pipe Diameter	30"	[4]
	Pipe Thickness	0.438"	[4]
	Pipe Material	SS304	[4]
	Length between	(15'-2.9375") - T(1-20)Leg2 - T(1-16)Leg1 = 139"	[4]

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Table 43. Dimensions Associated with Pipe Runs on Line 1-18 of Model 2-6-5

Pipe Run (1-18)	*Dimensions*		*Reference*
P (1-18A)	Pipe Diameter	20"	[5]
	Pipe Thickness	0.375"	[5]
	Pipe Material	SS304	[5]
	Length between GT(1-18) and EL(1-18A)	(2'-2.375") + (0.125") - EL(1-18A) = 2.5"	[5]
P (1-18B)	Pipe Diameter	20"	[5]
	Pipe Thickness	0.375"	[5]
	Pipe Material	SS304	[5]
	Length between EL(1-18A) and RED(1-18A)	(16'-9.875") - RED(1-18A) - 9" = 183.875"	[5]
P (1-18C)	Pipe Diameter	18"	[5]
	Pipe Thickness	0.3125"	[5]
	Pipe Material	SS304	[5]
	Length between RED(1-18A) and PP(1-18)	9" *	[5]

* Since [5] doesn't define the distance between the Primary Pump suction and the reducer the value was assumed to be the same as that between the Primary Pump discharge and reducer in [5].

Table 44. Dimensions Associated with Pipe Runs on Line 1-19 of Model 2-6-5

Pipe Run (1-19)	*Dimensions*		*Reference*
P (1-19A)	Pipe Diameter	20"	[5]
	Pipe Thickness	0.375"	[5]
	Pipe Material	SS304	[5]
	Length between GT(1-19) and EL(1-19A)	(2'-2.375") + (0.125") - EL(1-19A) = 2.5"	[5]
P (1-19B)	Pipe Diameter	20"	[5]
	Pipe Thickness	0.375"	[5]
	Pipe Material	SS304	[5]
	Length between EL(1-19A) and RED(1-19A)	(16'-9.875") - RED(1-19A) - 9" = 183.875"	[5]
P (1-19C)	Pipe Diameter	18"	[5]
	Pipe Thickness	0.3125"	[5]
	Pipe Material	SS304	[5]
	Length between RED(1-19A) and PP(1-19)	9" *	[5]

* Since [[5]] doesn't define the distance between the Primary Pump suction and the reducer the value was assumed to be the same as that between the Primary Pump discharge and reducer in [5]

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Table 45. Dimensions Associated with Pipe Runs on Line 1-20 of Model 2-6-5

Pipe Run (1-20)	*Dimensions*		*Reference*
P (1-20A)	Pipe Diameter	20"	[5]
	Pipe Thickness	0.375"	[5]
	Pipe Material	SS304	[5]
	Length between GT(1-20) and EL(1-20A)	(2'-2.375") + (0.125") - EL(1-20A) = 2.5"	[5]
P (1-20B)	Pipe Diameter	20"	[5]
	Pipe Thickness	0.375"	[5]
	Pipe Material	SS304	[5]
	Length between EL(1-20A) and RED(1-20A)	(16'-9.875") - RED(1-20A) - 9" = 183.875"	[5]
P (1-20C)	Pipe Diameter	18"	[5]
	Pipe Thickness	0.3125"	[5]
	Pipe Material	SS304	[5]
	Length between RED(1-20A) and PP(1-20)	9" *	[5]

* Since [[5]] doesn't define the distance between the Primary Pump suction and the reducer the value was assumed to be the same as that between the Primary Pump discharge and reducer in [5]

Table 46. Dimensions Associated with Pipe Runs on Line 1-21 of Model 2-6-5

Pipe Run (1-21)	*Dimensions*		*Reference*
P (1-21A)	Pipe Diameter	20"	[5]
	Pipe Thickness	0.375"	[5]
	Pipe Material	SS304	[5]
	Length between GT(1-21) and EL(1-21A)	(2'-2.375") + (0.125") - EL(1-21A) = 2.5"	[5]
P (1-21B)	Pipe Diameter	20"	[5]
	Pipe Thickness	0.375"	[5]
	Pipe Material	SS304	[5]
	Length between EL(1-21A) and RED(1-21A)	(16'-9.875") - RED(1-21A) - 9" = 183.875"	[5]
P (1-21C)	Pipe Diameter	18"	[5]
	Pipe Thickness	0.3125"	[5]
	Pipe Material	SS304	[5]
	Length between RED(1-21A) and PP(1-21)	9" *	[5]

* Since [[5]] doesn't define the distance between the Primary Pump suction and the reducer the value was assumed to be the same as that between the Primary Pump discharge and reducer in [5]

Table 47. Dimensions Associated with Pipe Runs on Line 1-30 of Model 2-6-5

Pipe Run (1-33)	*Dimensions*		*Reference*
P (1-33A)	Pipe Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Pipe Material	SS304	[17]
	Length between CK(1-33) and EL(1-33A)	(1'-9.125") - EL(1-33A) = 7.125"	[17]

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Table 48. Dimensions Associated with Pipe Runs on Line 1-31 of Model 2-6-5

Pipe Run (1-49)	*Dimensions*		*Reference*
P (1-49A)	Pipe Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Pipe Material	SS304	[17]
	Length between North Wall Termination and EL(1-49A)	(24'-2") - EL(1-49A) = 284"	[17]
P (1-49B)	Pipe Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Pipe Material	SS304	[17]
	Length between EL(1-49A) and EL(1-49B)	(6'-0") - EL(1-49A) - EL(1-49B) = 60"	[17]
P (1-49C)	Pipe Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Pipe Material	SS304	[17]
	Length between EL(1-49A) and EL(1-49B)	(5'-11.9375") - EL(1-49B) - EL(1-49C) = 63.4375"	[17]
P (1-49D)	Pipe Diameter	14"	[17]
	Pipe Thickness	0.25"	[17]
	Pipe Material	SS304	[17]
	Length between EL(1-49A) and FAB(1-32)	(3'-10.375") + (1'-1") - EL(1-49C) - FAB(1-32) = 49.875"	[17]

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Table 49. Dimensions Associated with Pipe Runs on Line 1-43 of Model 2-6-5

Pipe Run (1-43)	***Dimensions***		***Reference***
P (1-43A)	Pipe Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Pipe Material	SS304	[11]
	Length between	4.375"	M6-1-43-N1-PBRG-DSCN2833
P (1-43B)	Pipe Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Pipe Material	SS304	[11]
	Length between	(4'-0") - EL(1-43B) = 33"	[11]
P (1-43C)	Pipe Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Pipe Material	SS304	[11]
	Length between	(12'-6") - (3'-0.4375") -EL(1-43D) - T(1-46)Leg2 = 78.5625"	[11]
P (1-43D)	Pipe Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Pipe Material	SS304	[11]
	Length between	(6'-6.75") - (1'-6.375") - EL(1-43C) - T(1-47)Leg1 = 21.25"	[11]
P (1-43E)	Pipe Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Pipe Material	SS304	[11]
	Length between	(2'-1") - EL(1-43D) = 10"	[11]
P (1-43F)	Pipe Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Pipe Material	SS304	[11]
	Length between	(1'-11.4375") - EL(1-43D) - T(1-43)Leg2 = 2 (1.5*)	[11]
P (1-43G)	Pipe Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Pipe Material	SS304	[11]
	Length between	(18'-11.625") - (1'-11.4375") + (0.5*)- T(1-43)Leg1 = 178.6638"	[11]
P (1-43H)	Pipe Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Pipe Material	SS304	[11]
	Length between	3'-4.625"	[11]

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P (1-43I)	Pipe Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Pipe Material	SS304	[11]
	Length between	(2'-1") - EL(1-43E) = 10"	[11]

P (1-43J)	Pipe Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Pipe Material	SS304	[11]
	Length between	(18'-9") - EL(1-43E) - EL(1-43F) = 195"	[11]

P (1-43K)	Pipe Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Pipe Material	SS304	[11]
	Length between	(6'-11.4375") - EL(1-43F) - EL(1-43G) = 62.4125"	[11]

P (1-43L)	Pipe Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Pipe Material	SS304	[11]
	Length between	(14'-4") - EL(1-43G) = 165.975"	[11]

P (1-43M)	Pipe Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Pipe Material	SS304	[11]
	Length between	4"	M6-1-43-N28-WPG-DSCN2816

P (1-43N)	Pipe Diameter	6.625"	[11]
	Pipe Thickness	0.28"	[11]
	Pipe Material	SS304	[11]
	Length between	(2'-0.5") - T(1-43) -EL(1-43H) = 9.875"	[11]

P (1-43O)	Pipe Diameter	6.625"	[11]
	Pipe Thickness	0.28"	[11]
	Pipe Material	SS304	[11]
	Length between	(1'-5") - 9" + 0.125" = 8.125"	[11], [12]

*The dimensions associated with lines 1-43 (11), 1-46 (14), and 1-44 (12) appear to contradict each other by a half an inch where the most significant effect is the location of T(1-43). It is believed this is due to the inclusion of four 1/8" dimensions to accomodate the valve/flange connection which will be included in this model. Therefore based on this premise 12 places T(1-43) 0.5" closer to EL(1-43D) and reducing the 2" length of P(1-43F) calculated above.

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Table 50. Dimensions Associated with Pipe Runs on Line 1-44 of Model 2-6-5

Pipe Run (1-44)	*Dimensions*		*Reference*
P (1-44A)	Pipe Diameter	6.625"	[12]
	Pipe Thickness	0.28"	[12]
	Pipe Material	SS304	[12]
	Length between	(2'-9") - T(1-44)Branch - EL(1-44A) = 18.375"	[12]
P (1-44B)	Pipe Diameter	6.625"	[12]
	Pipe Thickness	0.28"	[12]
	Pipe Material	SS304	[12]
	Length between	(12'-9.5") - EL(1-44A) - EL(1-44B) = 114.5"	[12]
P (1-44C)	Pipe Diameter	6.625"	[12]
	Pipe Thickness	0.28"	[12]
	Pipe Material	SS304	[12]
	Length between	(14'-9") - EL(1-44B) - EL(1-44C) = 117"	[12]
P (1-44D)	Pipe Diameter	6.625"	[12]
	Pipe Thickness	0.28"	[12]
	Pipe Material	SS304	[12]
	Length between	(18'-7.375") - EL(1-44C) - EL(1-44D) = 184.375"	[12]
P (1-44E)	Pipe Diameter	6.625"	[12]
	Pipe Thickness	0.28"	[12]
	Pipe Material	SS304	[12]
	Length between	(3'-0") - EL(1-44D) = 27"	[12]
P (1-44F)	Pipe Diameter	6.625"	[12]
	Pipe Thickness	0.28"	[12]
	Pipe Material	SS304	[12]
	Length between	(10'-7.625") - EL(1-44E) = 118.625"	[12]
P (1-44G)	Pipe Diameter	6.625"	[13]
	Pipe Thickness	0.28"	[13]
	Pipe Material	SS304	[13]
	Length between	(6'-3") - EL(1-44F) = 71.25"	[13]

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Table 51. . Dimensions Associated with Pipe Runs on Line 1-46 of Model 2-6-5

Pipe Run (1-46)	*Dimensions*		*Reference*
P (1-46A)	Pipe Diameter	6.625"	[14]
	Pipe Thickness	0.28"	[14]
	Pipe Material	SS304	[14]
	Length between	(5'-7.625") + (3'-10") - EL(1-46A) - EL(1-46B) = 106.125"	[14]

P (1-46B)	Pipe Diameter	6.625"	[14]
	Pipe Thickness	0.28"	[14]
	Pipe Material	SS304	[14]
	Length between	(1'-5") + (0.125") - 9" = 8.125"	[14], [12]

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Table 52. Dimensions Associated with Pipe Runs on Line 1-47 of Model 2-6-5

Pipe Run (1-47)	*Dimensions*		*Reference*
P (1-47A)	Pipe Diameter	6.625"	[15]
	Pipe Thickness	0.28"	[15]
	Pipe Material	SS304	[15]
	Length between	(9'-3") - T(1-47) - EL(1-47A) = 90.625"	[16]
P (1-47B)	Pipe Diameter	6.625"	[15]
	Pipe Thickness	0.28"	[15]
	Pipe Material	SS304	[15]
	Length between	(6'-2.125") - EL(1-47A) - EL(1-47B) = 56.125"	[16]
P (1-47C)	Pipe Diameter	6.625"	[15]
	Pipe Thickness	0.28"	[15]
	Pipe Material	SS304	[15]
	Length between	(1'-5") - EL(1-47B) = 8"	[16]
P (1-47D)	Pipe Diameter	6.625"	[15]
	Pipe Thickness	0.28"	[15]
	Pipe Material	SS304	[15]
	Length between	(1'-5") - EL(1-47C) = 13.25"	[16]
P (1-47E)	Pipe Diameter	6.625"	[15]
	Pipe Thickness	0.28"	[15]
	Pipe Material	SS304	[15]
	Length between	(11.375")*(2^0.5) - EL(1-47C) - EL(1-47D) = 8.586679"	[16]
P (1-47F)	Pipe Diameter	6.625"	[15]
	Pipe Thickness	0.28"	[15]
	Pipe Material	SS304	[15]
	Length between	(21'-11.5") - EL(1-47D) -EL(1-47E) = 250.75"	[16]
P (1-47G)	Pipe Diameter	6.625"	[15]
	Pipe Thickness	0.28"	[15]
	Pipe Material	SS304	[15]
	Length between	(4'-5.25") - EL(1-47E) - EL(1-47F) = 40.5"	[16]
P (1-47H)	Pipe Diameter	6.625"	[15]
	Pipe Thickness	0.28"	[15]
	Pipe Material	SS304	[15]
	Length between	(13'-0.5") -EL(1-47E) - EL(1-47F) = 143.75"	[16]

Table 53. Dimensions Associated with Pipe Runs on Line 1-48 of Model 2-6-5

Pipe Run (1-48)	*Dimensions*		*Reference*
P (1-48A)	Pipe Diameter	4.5"	[17]
	Pipe Thickness	0.237	[17]
	Pipe Material	SS304	[17]
	Length between	(7'-3.5") - T(1-48) - EL(1-48C) = 73.5"	[17]
P (1-48B)	Pipe Diameter	4.5"	[17]
	Pipe Thickness	0.237	[17]
	Pipe Material	SS304	[17]
	Length between	(9'-11.5") - EL(1-48C) - EL(1-48B) = 114.5"	[17]
P (1-48C)	Pipe Diameter	4.5"	[17]
	Pipe Thickness	0.237	[17]
	Pipe Material	SS304	[17]
	Length between	(11'-9.5") - EL(1-48B) - EL(1-48A) = 133"	[17]
P (1-48D)	Pipe Diameter	4.5"	[17]
	Pipe Thickness	0.237	[17]
	Pipe Material	SS304	[17]
	Length between	(24'-2") - EL(1-48A) = 284"	[17]

Table 54. Dimensions Associated with Pipe Runs on Line 1-171 of Model 2-6-5

Pipe Run (1-171)	*Dimensions*		*Reference*
P (1-171A)	Pipe Diameter	20"	[18]
	Pipe Thickness	0.3125"	[18]
	Pipe Material	SS304	[18]
	Length between	(2'-8") - EL(1-171A) = 12"	[18]
P (1-171B)	Pipe Diameter	20"	[18]
	Pipe Thickness	0.3125"	[18]
	Pipe Material	SS304	[18]
	Length between	(9'-6") - EL(1-171A) - EL(1-171B) = 64"	[18]
P (1-171C)	Pipe Diameter	20"	[18]
	Pipe Thickness	0.3125"	[18]
	Pipe Material	SS304	[18]
	Length between	(10'-2.25") - EL(1-171B) - EL(1-171C) = 62.25"	[18]

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Table 55. Dimensions Associated with Pipe Runs on Line 8-14 of Model 2-6-5

Pipe Run (8-14)	*Dimensions*		*Reference*
P (8-14A)	Pipe Diameter	10.75"	[19]
	Pipe Thickness	0.25"	[19]
	Pipe Material	SS304	[19]
	Length between	6" between ceiling penetration and EL(8-14A)	M2-8-14-N1-CPG-DSCN2745
P (8-14B)	Pipe Diameter	10.75"	[19]
	Pipe Thickness	0.25"	[19]
	Pipe Material	SS304	[19]
	Length between	(15'-0") - EL(8-14A) - EL(8-14B) = 155"	[19]
P (8-14C)	Pipe Diameter	10.75"	[19]
	Pipe Thickness	0.25"	[19]
	Pipe Material	SS304	[19]
	Length between	(35'-1") - EL(8-14B) - FAB BRANCH(1-30) = 406"	[19]

Table 56. Dimensions Associated with Pipe Runs on Line 1-20 of Model 2-6-5

Pipe Run (1-20)	*Dimensions*		*Reference*
P (1-20A)	Pipe Diameter	20"	[5]
	Pipe Thickness	0.375"	[5]
	Pipe Material	SS304	[5]
	Length between GT(1-20) and EL(1-20A)	(2'-2.375") + (0.125") - EL(1-20A) = 2.5"	[5]
P (1-20B)	Pipe Diameter	20"	[5]
	Pipe Thickness	0.375"	[5]
	Pipe Material	SS304	[5]
	Length between EL(1-20A) and RED(1-20A)	(16'-9.875") - RED(1-20A) - 9" = 183.875"	[5]
P (1-20C)	Pipe Diameter	18"	[5]
	Pipe Thickness	0.3125"	[5]
	Pipe Material	SS304	[5]
	Length between RED(1-20A) and PP(1-20)	9" *	[5]

* Since [[5]] doesn't define the distance between the Primary Pump suction and the reducer the value was assumed to be the same as that between the Primary Pump discharge and reducer in [5]

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Table 57. Dimensions Associated with Pipe Runs on Line 1-45 of Model 2-6-5

Pipe Run (1-45)	*Dimensions*		*Reference*
P (1-45A)	Pipe Diameter	6.625"	[33]
	Pipe Thickness	0.28"	[33]
	Pipe Material	SS304	[33]
	Length between	(2'-3") - EL(1-45A) - T(1-45)(branch) = 8"	[33]
P (1-45B)	Pipe Diameter	6.625"	[33]
	Pipe Thickness	0.28"	[33]
	Pipe Material	SS304	[33]
	Length between	(2') - EL(1-45A) - EL(1-45B) = 6"	[33]
P (1-45C)	Pipe Diameter	6.625"	[33]
	Pipe Thickness	0.28"	[33]
	Pipe Material	SS304	[33]
	Length between	(4'-1") - EL(1-45B) - EL(1-45C) = 36.25"	[33]
P (1-45D)	Pipe Diameter	6.625"	[33]
	Pipe Thickness	0.28"	[33]
	Pipe Material	SS304	[33]
	Length between	(4'-3.0625") - EL(1-45C) - EL(1-45D) = 43.5"	[33]
P (1-45E)	Pipe Diameter	6.625"	[33]
	Pipe Thickness	0.28"	[33]
	Pipe Material	SS304	[33]
	Length between	(13'-0.875") - EL(1-45D) - EL(1-45E) = 144.125"	[33]
P (1-45F)	Pipe Diameter	6.625"	[33]
	Pipe Thickness	0.28"	[33]
	Pipe Material	SS304	[33]
	Length between	(7'-9") - EL(1-45E) - EL(1-45F) = 75"	[33]

Table 58. Dimensions Associated with Reducers on Line 1-22 of Model 2-6-5

Reducers (1-17)	*Dimensions*		*Reference*
RED(1-17A)	Small Diameter	20"	[18]
	Large Diameter	30"	[18]
	Length	1'-8"	[18]
	Thickness	0.5"	[18]
	Eccentric Offset	0"	[18]

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Table 59. Dimensions Associated with Reducers on Line 1-17 of Model 2-6-5

Reducers (1-18)	*Dimensions*		*Reference*
RED(1-18A)	Small Diameter	18"	[5]
	Large Diameter	20"	[5]
	Length	9" *	[6]
	Thickness	0.375"	[5]
	Eccentric Offset	0"	[5]

* Since [5] doesn't define the length of RED(1-18A) it is assumed to be of the same length as RED(1-25A) of Model 3

Table 60. Dimensions Associated with Reducers on Line 1-18 of Model 2-6-5

Reducers (1-24)	*Dimensions*		*Reference*
RED(1-24)	Small Diameter	18"	[5]
	Large Diameter	20"	[5]
	Length	9"	[5]
	Thickness	3/8"	[5]
	Eccentric Offset	0"	[5]

Table 61. Dimensions Associated with Reducers on Line 1-19 of Model 2-6-5

Reducers (1-19)	*Dimensions*		*Reference*
RED(1-19A)	Small Diameter	18"	[5]
	Large Diameter	20"	[5]
	Length	9" *	[6]
	Thickness	0.375"	[5]
	Eccentric Offset	0"	[5]

* Since [5] doesn't define the length of RED(1-19A) it is assumed to be of the same length as RED(1-25A) of Model 3

Table 62. Dimensions Associated with Reducers on Line 1-20 of Model 2-6-5

Reducers (1-20)	*Dimensions*		*Reference*
RED(1-20A)	Small Diameter	18"	[5]
	Large Diameter	20"	[5]
	Length	9" *	[6]
	Thickness	0.375"	[5]
	Eccentric Offset	0"	[5]

* Since [5] doesn't define the length of RED(1-20A) it is assumed to be of the same length as RED(1-25A) of Model 3

Table 63. Dimensions Associated with Reducers on Line 1-21 of Model 2-6-5

Reducers (1-21)	*Dimensions*		*Reference*
RED(1-21A)	Small Diameter	18"	[5]
	Large Diameter	20"	[5]
	Length	9" *	[6]
	Thickness	0.375"	[5]
	Eccentric Offset	0"	[5]

* Since [5] doesn't define the length of RED(1-21A) it is assumed to be of the same length as RED(1-25A) of Model 3

Table 64. Dimensions Associated with Reducers on Line 1-30 of Model 2-6-5

Reducers (1-30)	*Dimensions*		*Reference*
RED(1-30A)	Small Diameter	14"	[7]
	Large Diameter	16"	[7]
	Length	1'-4.5"	[7]
	Thickness	0.25"	[7]
	Eccentric Offset	1"	[7]

Table 65. Dimensions Associated with Reducers on Line 1-31 of Model 2-6-5

Reducers (1-31)	*Dimensions*		*Reference*
RED(1-31A)	Small Diameter	14"	[10]
	Large Diameter	16"	[10]
	Length	13.875"	[10]
	Thickness	0.25"	[10]
	Eccentric Offset	1"	[10]

Table 66. Dimensions Associated with Elbows on Line 1-13 of Model 2-6-5

Elbows (1-13)	*Dimensions*		*Reference*
EL (1-13A)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.312"	[4]
	Elbow Type	90º Long Radius	[4]
	Elbow Leg Lengths	30"	[29, pg 9]
EL (1-13B)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.312"	[4]
	Elbow Type	90º Long Radius	[4]
	Elbow Leg Lengths	30"	[29, pg 9]

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Table 67. Dimensions Associated with Elbows on Line 1-14 of Model 2-6-5

Elbows (1-14)	*Dimensions*		*Reference*
EL (1-14A)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.312"	[4]
	Elbow Type	90º Long Radius	[4]
	Elbow Leg Lengths	30"	[29, pg 9]
EL (1-14B)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.312"	[4]
	Elbow Type	90º Long Radius	[4]
	Elbow Leg Lengths	30"	[29, pg 9]

Table 68. . Dimensions Associated with Elbows on Line 1-15 of Model 2-6-5

Elbows (1-15)	*Dimensions*		*Reference*
EL (1-15A)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.312"	[4]
	Elbow Type	90º Long Radius	[4]
	Elbow Leg Lengths	30"	[29, pg 9]
EL (1-15B)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.312"	[4]
	Elbow Type	90º Long Radius	[4]
	Elbow Leg Lengths	30"	[29, pg 9]

Table 69. Dimensions Associated with Elbows on Line 1-16 of Model 2-6-5

Elbows (1-16)	*Dimensions*		*Reference*
EL (1-16A)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.312"	[4]
	Elbow Type	90º Long Radius	[4]
	Elbow Leg Lengths	30"	[29, pg 9]
EL (1-16B)	Pipe Diameter	20"	[4]
	Pipe Thickness	0.312"	[4]
	Elbow Type	90º Long Radius	[4]
	Elbow Leg Lengths	30"	[29, pg 9]

Table 70. Dimensions Associated with Elbows on Line 1-18 of Model 2-6-5

Elbows (1-18)	*Dimensions*		*Reference*
EL (1-18A)	Pipe Diameter	24"	[5]
	Pipe Thickness	0.375"	[5]
	Elbow Type	90º Short Radius	[5]
	Elbow Leg Lengths	24"	[29, pg 9]

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Table 71. Dimensions Associated with Elbows on Line 1-19 of Model 2-6-5

Elbows (1-19)	***Dimensions***		***Reference***
EL (1-19A)	Pipe Diameter	24"	[5]
	Pipe Thickness	0.375"	[5]
	Elbow Type	90º Short Radius	[5]
	Elbow Leg Lengths	24"	[29, pg 9]

Table 72. Dimensions Associated with Elbows on Line 1-20 of Model 2-6-5

Elbows (1-20)	***Dimensions***		***Reference***
EL (1-20A)	Pipe Diameter	24"	[5]
	Pipe Thickness	0.375"	[5]
	Elbow Type	90º Short Radius	[5]
	Elbow Leg Lengths	24"	[29, pg 9]

Table 73. Dimensions Associated with Elbows on Line 1-21 of Model 2-6-5

Elbows (1-21)	***Dimensions***		***Reference***
EL (1-21A)	Pipe Diameter	24"	[5]
	Pipe Thickness	0.375"	[5]
	Elbow Type	90º Short Radius	[5]
	Elbow Leg Lengths	24"	[29, pg 9]

Table 74. Dimensions Associated with Elbows on Line 1-30 of Model 2-6-5

Elbows (1-30)	***Dimensions***		***Reference***
EL (1-30A)	Pipe Diameter	16"	[7]
	Pipe Thickness	0.25"	[7]
	Elbow Type	90º Short Radius	[7]
	Elbow Leg Lengths	16"	[29, pg 9]
EL (1-30B)	Pipe Diameter	16"	[7]
	Pipe Thickness	0.25"	[7]
	Elbow Type	90º Short Radius	[7]
	Elbow Leg Lengths	16"	[29, pg 9]
EL (1-30C)	Pipe Diameter	16"	[7]
	Pipe Thickness	0.25"	[7]
	Elbow Type	90º Short Radius	[7]
	Elbow Leg Lengths	16"	[29, pg 9]

Table 75. Dimensions Associated with Elbows on Line 1-31 of Model 2-6-5

Elbows (1-31)	*Dimensions*		*Reference*
EL (1-31A)	Pipe Diameter	16"	[7]
	Pipe Thickness	0.25"	[7]
	Elbow Type	90º Short Radius	[7]
	Elbow Leg Lengths	16"	[29, pg 9]
EL (1-31B)	Pipe Diameter	16"	[10]
	Pipe Thickness	0.25"	[10]
	Elbow Type	90º Short Radius	[10]
	Elbow Leg Lengths	16"	[29, pg 9]
EL (1-31C)	Pipe Diameter	16"	[10]
	Pipe Thickness	0.25"	[10]
	Elbow Type	90º Short Radius	[10]
	Elbow Leg Lengths	16"	[29, pg 9]

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Table 76. Dimensions Associated with Elbows on Line 1-43 of Model 2-6-5

Elbows (1-43)	*Dimensions*		*Reference*
EL (1-43A)	Pipe Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Elbow Type	90º Long Radius	[11]
	Elbow Leg Lengths	15"	[29, pg 9]
EL (1-43B)	Pipe Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Elbow Type	90º Long Radius	[11]
	Elbow Leg Lengths	15"	[29, pg 9]
EL (1-43C)	Pipe Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Elbow Type	90º Long Radius	[11]
	Elbow Leg Lengths	15"	[29, pg 9]
EL (1-43D)	Pipe Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Elbow Type	90º Long Radius	[11]
	Elbow Leg Lengths	15"	[29, pg 9]
EL (1-43E)	Pipe Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Elbow Type	90º Long Radius	[11]
	Elbow Leg Lengths	15"	[29, pg 9]
EL (1-43F)	Pipe Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Elbow Type	90º Long Radius	[11]
	Elbow Leg Lengths	15"	[29, pg 9]
EL (1-43G)	Pipe Diameter	10.75"	[11]
	Pipe Thickness	0.28"	[11]
	Elbow Type	90º Long Radius	[11]
	Elbow Leg Lengths	6.025"	[29, pg 23]
EL (1-43H)	Pipe Diameter	6.625"	[11]
	Pipe Thickness	0.25"	[11]
	Elbow Type	90º Long Radius	[11]
	Elbow Leg Lengths	9"	[29, pg 9]

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Table 77. Dimensions Associated with Elbows on Line 1-44 of Model 2-6-5

Elbows (1-44)	*Dimensions*		*Reference*
EL (1-44A)	Pipe Diameter	6.625"	[12]
	Pipe Thickness	0.28"	[12]
	Elbow Type	90º Long Radius	[12]
	Elbow Leg Lengths	9"	[29, pg 9]
EL (1-44B)	Pipe Diameter	6.625"	[12]
	Pipe Thickness	0.28"	[12]
	Elbow Type	90º 30" Radius	[12]
	Elbow Leg Lengths	30"	[12]
EL (1-44C)	Pipe Diameter	6.625"	[12]
	Pipe Thickness	0.28"	[12]
	Elbow Type	90º 30" Radius	[12]
	Elbow Leg Lengths	30"	[12]
EL (1-44D)	Pipe Diameter	6.625"	[12]
	Pipe Thickness	0.28"	[12]
	Elbow Type	90º Long Radius	[12]
	Elbow Leg Lengths	9"	[29, pg 9]
EL (1-44E)	Pipe Diameter	6.625"	[12]
	Pipe Thickness	0.28"	[12]
	Elbow Type	90º Long Radius	[12]
	Elbow Leg Lengths	9"	[29, pg 9]
EL (1-44F)	Pipe Diameter	6.625"	[13]
	Pipe Thickness	0.28"	[13]
	Elbow Type	45º Long Radius	[13]
	Elbow Leg Lengths	3.75"	[29, pg 23]

Table 78. Dimensions Associated with Elbows on Line 1-46 of Model 2-6-5

Elbows (1-46)	*Dimensions*		*Reference*
EL (1-46A)	Pipe Diameter	6.625"	[14]
	Pipe Thickness	0.28"	[14]
	Elbow Type	45º Long Radius	[14]
	Elbow Leg Lengths	3.75"	[29, pg 23]
EL (1-46B)	Pipe Diameter	6.625"	[14]
	Pipe Thickness	0.28"	[14]
	Elbow Type	45º Long Radius	[14]
	Elbow Leg Lengths	3.75"	[29, pg 9]
EL (1-46C)	Pipe Diameter	6.625"	[14]
	Pipe Thickness	0.28"	[14]
	Elbow Type	90º Long Radius	[14]
	Elbow Leg Lengths	9"	[29, pg 23]

Table 79. Dimensions Associated with Elbows on Line 1-47 of Model 2-6-5

Elbows (1-47)	*Dimensions*		*Reference*
EL (1-47A)	Pipe Diameter	6.625"	[16]
	Pipe Thickness	0.28"	[16]
	Elbow Type	90º Long Radius	[16]
	Elbow Leg Lengths	9"	[29, pg 9]
EL (1-47B)	Pipe Diameter	6.625"	[16]
	Pipe Thickness	0.28"	[16]
	Elbow Type	90º Long Radius	[16]
	Elbow Leg Lengths	9"	[29, pg 9]
EL (1-47C)	Pipe Diameter	6.625"	[16]
	Pipe Thickness	0.28"	[16]
	Elbow Type	45º Long Radius	[16]
	Elbow Leg Lengths	3.75"	[29, pg 23]
EL (1-47D)	Pipe Diameter	6.625"	[16]
	Pipe Thickness	0.28"	[16]
	Elbow Type	45º Long Radius	[16]
	Elbow Leg Lengths	3.75"	[29, pg 23]
EL (1-47E)	Pipe Diameter	6.625"	[16]
	Pipe Thickness	0.28"	[16]
	Elbow Type	90º Long Radius	[16]
	Elbow Leg Lengths	9"	[29, pg 9]
EL (1-47F)	Pipe Diameter	6.625"	[16]
	Pipe Thickness	0.28"	[16]
	Elbow Type	90º Long Radius	[16]
	Elbow Leg Lengths	9"	[29, pg 9]
EL (1-47G)	Pipe Diameter	6.625"	[16]
	Pipe Thickness	0.28"	[16]
	Elbow Type	90º Long Radius	[16]
	Elbow Leg Lengths	9"	[29, pg 9]

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Table 80. Dimensions Associated with Elbows on Line 1-48 of Model 2-6-5

Elbows (1-48)	***Dimensions***		***Reference***
EL (1-48A)	Pipe Diameter	4.5"	[17]
	Pipe Thickness	0.237"	[17]
	Elbow Type	45º Long Radius	[17]
	Elbow Leg Lengths	2.5"	[29, pg 23]
EL (1-48B)	Pipe Diameter	4.5"	[17]
	Pipe Thickness	0.237"	[17]
	Elbow Type	45º Long Radius	[17]
	Elbow Leg Lengths	2.5"	[29, pg 23]
EL (1-48C)	Pipe Diameter	4.5"	[17]
	Pipe Thickness	0.237"	[17]
	Elbow Type	90º Long Radius	[17]
	Elbow Leg Lengths	6"	[29, pg 9]

Table 81. Dimensions Associated with Elbows on Line 1-171 of Model 2-6-5

Elbows (1-171)	***Dimensions***		***Reference***
EL (1-171A)	Pipe Diameter	20"	[18]
	Pipe Thickness	0.3125"	[18]
	Elbow Type	90º Short Radius	[18]
	Elbow Leg Lengths	20"	[29, pg 19]
EL (1-171B)	Pipe Diameter	20"	[18]
	Pipe Thickness	0.3125"	[18]
	Elbow Type	90º Long Radius	[18]
	Elbow Leg Lengths	30"	[29, pg 9]
EL (1-171C)	Pipe Diameter	20"	[18]
	Pipe Thickness	0.3125"	[18]
	Elbow Type	90º Long Radius	[18]
	Elbow Leg Lengths	30"	[29, pg 9]

Table 82. Dimensions Associated with Elbows on Line 8-14 of Model 2-6-5

Elbows (8-14)	***Dimensions***		***Reference***
EL (8-14A)	Pipe Diameter	10.75"	[19]
	Pipe Thickness	0.25"	[19]
	Elbow Type	90º Short Radius	[19]
	Elbow Leg Lengths	10"	[29, pg 19]
EL (8-14B)	Pipe Diameter	10.75"	[19]
	Pipe Thickness	0.25"	[19]
	Elbow Type	90º Long Radius	[19]
	Elbow Leg Lengths	15"	[29, pg 9]

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Table 83. Dimensions Associated with Elbows on Line 1-45 of Model 2-6-5

Elbows (1-45)	*Dimensions*		*Reference*
EL (1-45A)	Pipe Diameter	6.625"	[33]
	Pipe Thickness	0.28"	[33]
	Elbow Type	90º Long Radius	[33]
	Elbow Leg Lengths	9"	[29, pg 19]
EL (1-45B)	Pipe Diameter	6.625"	[33]
	Pipe Thickness	0.28"	[33]
	Elbow Type	90º Long Radius	[33]
	Elbow Leg Lengths	9"	[29, pg 19]
EL (1-45C)	Pipe Diameter	6.625"	[33]
	Pipe Thickness	0.28"	[33]
	Elbow Type	45º Long Radius	[33]
	Elbow Leg Lengths	3.75"	[29, pg 23]
EL (1-45D)	Pipe Diameter	6.625"	[33]
	Pipe Thickness	0.28"	[33]
	Elbow Type	45º Long Radius	[33]
	Elbow Leg Lengths	3.75"	[29, pg 23]
EL (1-45E)	Pipe Diameter	6.625"	[33]
	Pipe Thickness	0.28"	[33]
	Elbow Type	90º Long Radius	[33]
	Elbow Leg Lengths	9"	[29, pg 19]
EL (1-45F)	Pipe Diameter	6.625"	[33]
	Pipe Thickness	0.28"	[33]
	Elbow Type	90º Long Radius	[33]
	Elbow Leg Lengths	9"	[29, pg 19]

Table 84. Dimensions Associated with Tees on Line 1-13 of Model 2-6-5

Tees (1-13)	*Dimensions*		*Reference*
T(1-13)	Run Diameter	30"	[4]
	Run Thickness	0.438"	[4]
	Run Leg1 Length	22"	[4]
	Run Leg2 Length	10.4375"	Result of FE Modeling
	Branch Diameter	20"	[4]
	Branch Thickness	0.312"	[4]
	Branch Length	24.125"	Result of FE Modeling

Table 85. Dimensions Associated with Tees on Line 1-14 of Model 2-6-5

Tees (1-14)	*Dimensions*		*Reference*
T(1-14)	Run Diameter	30"	[4]
	Run Thickness	0.438"	[4]
	Run Leg1 Length	5.9375"	Result of FE Modeling
	Run Leg2 Length	12.0314"	Result of FE Modeling
	Branch Diameter	20"	[4]
	Branch Thickness	0.312"	[4]
	Branch Length	24.125"	Result of FE Modeling

Table 86. Dimensions Associated with Tees on Line 1-15 of Model 2-6-5

Tees (1-15)	*Dimensions*		*Reference*
T(1-15)	Run Diameter	30"	[4]
	Run Thickness	0.438"	[4]
	Run Leg1 Length	4.0625"	Result of FE Modeling
	Run Leg2 Length	24"	Result of FE Modeling
	Branch Diameter	20"	[4]
	Branch Thickness	0.312"	[4]
	Branch Length	24.125"	Result of FE Modeling

Table 87. Dimensions Associated with Tees on Line 1-16 of Model 2-6-5

Tees (1-16)	*Dimensions*		*Reference*
T(1-16)	Run Diameter	30"	[4]
	Run Thickness	0.438"	[4]
	Run Leg1 Length	24"	Result of FE Modeling
	Run Leg2 Length	24"	Result of FE Modeling
	Branch Diameter	20"	[4]
	Branch Thickness	0.312"	[4]
	Branch Length	24.125"	Result of FE Modeling

Table 88. Dimensions Associated with Tees on Line 1-18 of Model 2-6-5

Tees (1-18)	*Dimensions*		*Reference*
T(1-18)	Run Diameter	30"	[4]
	Run Thickness	0.438"	[4]
	Run Leg1 Length	18"	Result of FE Modeling
	Run Leg2 Length	16.46874"	Result of FE Modeling
	Branch Diameter	24"	[5]
	Branch Thickness	0.375"	[5]
	Branch Length	24.375"	[4]

Table 89. Dimensions Associated with Tees on Line 1-19 of Model 2-6-5

Tees (1-19)	*Dimensions*		*Reference*
T(1-19)	Run Diameter	30"	[4]
	Run Thickness	0.438"	[4]
	Run Leg1 Length	27"	Result of FE Modeling
	Run Leg2 Length	45"	Result of FE Modeling
	Branch Diameter	24"	[5]
	Branch Thickness	0.375"	[5]
	Branch Length	24.375"	[4]

Table 90. Dimensions Associated with Tees on Line 1-20 of Model 2-6-5

Tees (1-20)	*Dimensions*		*Reference*
T(1-20)	Run Diameter	30"	[4]
	Run Thickness	0.438"	[4]
	Run Leg1 Length	24"	Result of FE Modeling
	Run Leg2 Length	24"	Result of FE Modeling
	Branch Diameter	24"	[5]
	Branch Thickness	0.375"	[5]
	Branch Length	24.375"	[4]

Table 91. Dimensions Associated with Tees on Line 1-21 of Model 2-6-5

Tees (1-21)	*Dimensions*		*Reference*
T(1-21)	Run Diameter	30"	[4]
	Run Thickness	0.438"	[4]
	Run Leg1 Length	25"	Result of FE Modeling
	Run Leg2 Length	22"	Result of FE Modeling
	Branch Diameter	24"	[5]
	Branch Thickness	0.375"	[5]
	Branch Length	24.375"	[4]

Table 92. Dimensions Associated with Tees on Line 1-30 of Model 2-6-5

Tees (1-30)	*Dimensions*		*Reference*
T(1-30)	Run Diameter	30"	[4]
	Run Thickness	0.438"	[4]
	Run Leg1 Length	12.0311"	Result of FE Modeling
	Run Leg2 Length	20"	Result of FE Modeling
	Branch Diameter	16"	[7]
	Branch Thickness	0.25"	[7]
	Branch Length	24.75"	[4]

Table 93. Dimensions Associated with Tees on Line 1-31 of Model 2-6-5

Tees (1-31)	*Dimensions*		*Reference*
T(1-31)	Run Diameter	16"	[7]
	Run Thickness	0.25"	[7]
	Run Leg1 Length	12"	Result of FE Modeling
	Run Leg2 Length	12"	[7]
	Branch Diameter	16"	[7]
	Branch Thickness	0.25"	[7]
	Branch Length	20"	[7]

Table 94. Dimensions Associated with Tees on Line 1-43 of Model 2-6-5

Tees (1-43)	*Dimensions*		*Reference*
T(1-43)	Run Diameter	10.75"	[11]
	Run Thickness	0.25"	[11]
	Run Leg1 Length	26.02372"	Result of FE Modeling
	Run Leg2 Length	6.4375"	Result of FE Modeling
	Branch Diameter	6.625"	[11]
	Branch Thickness	0.28"	[11]
	Branch Length	5.625"	Result of FE Modeling

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Table 95. Dimensions Associated with Tees on Line 1-44 of Model 2-6-5

Tees (1-44)	Dimensions		Reference
T(1-44)	Run Diameter	6.625"	[12]
	Run Thickness	0.28"	[12]
	Run Leg1 Length	5.625"	Result of FE Modeling
	Run Leg2 Length	5.625"	Result of FE Modeling
	Branch Diameter	6.625"	[12]
	Branch Thickness	0.28"	[12]
	Branch Length	5.625"	Result of FE Modeling

Table 96. Dimensions Associated with Tees on Line 1-46 of Model 2-6-5

Tees (1-46)	Dimensions		Reference
T(1-46)	Run Diameter	10.75"	[11]
	Run Thickness	0.25"	[11]
	Run Leg1 Length	21.4375"	Result of FE Modeling
	Run Leg2 Length	20"	Result of FE Modeling
	Branch Diameter	6.625"	[14]
	Branch Thickness	0.28"	[14]
	Branch Length	13.22056"	Result of FE Modeling

Table 97. Dimensions Associated with Tees on Line 1-47 of Model 2-6-5

Tees (1-47)	Dimensions		Reference
T(1-47)	Run Diameter	10.75"	[11]
	Run Thickness	0.25"	[11]
	Run Leg1 Length	24.125"	Result of FE Modeling
	Run Leg2 Length	18.375"	[11]
	Branch Diameter	6.625"	[15]
	Branch Thickness	0.28"	[15]
	Branch Length	11.375"	Result of FE Modeling

Table 98. Dimensions Associated with Tees on Line 1-48 of Model 2-6-5

Tees (1-48)	Dimensions		Reference
T(1-48)	Run Diameter	16"	[7]
	Run Thickness	0.25"	[7]
	Run Leg1 Length	28.25"	Result of FE Modeling
	Run Leg2 Length	30.625"	Result of FE Modeling
	Branch Diameter	4.5"	[17]
	Branch Thickness	0.237"	[17]
	Branch Length	8"	Result of FE Modeling

Table 99. Dimensions Associated with Tees on Line 1-45 of Model 2-6-5

Tees (1-45)	Dimensions		Reference
T(1-45)	Run Diameter	20"	[4]
	Run Thickness	0.312"	[4]
	Run Leg1 Length	18"	Result of FE Modeling
	Run Leg2 Length	36"	Result of FE Modeling
	Branch Diameter	6.625"	[33]
	Branch Thickness	0.28"	[33]
	Branch Length	10"	Result of FE Modeling

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Table 100. Dimensions Associated with Fabricated Branch Connecting Lines 1-30 & 8-14 of Model 2-6-5

Fabricated Comp	*Dimensions*		*Reference*
FAB BRANCH (1-30 & 8-14)	Pipe Diameter	16"	[7]
	Pipe Thickness	0.25"	[7]
	Elbow Type	90º Long Radius	[7]
	Elbow Leg Lengths	24"	[29, pg 9]
	Branch Diameter	10.75"	[19]
	Branch Thickness	0.25"	[19]
	Branch Length from Centerline of Northern Elbow Leg	0" (First node) 14" (Second node)	Result of FE Modeling [7]

Table 101. Dimensions Associated with Fabricated Reducer Connecting Lines 1-17 & 1-43 of Model 2-6-5

RED(1-17 & 1-43)	Large Diameter	30"	[4]
	Large Diameter Thickness	0.438	[4]
	Small Diameter	10.75"	[4]
	Small Diameter Thickness	0.25"	[4]
	Length	11"	Result of FE Modeling
	Eccentric Offset	0"	[4]

Table 102. Dimensions Associated with Flanges on Line 1-13 of Model 2-6-5

Flanges (1-13)	*Dimensions*		*Reference*
FL (1-13A)	Location	At heat exchanger nozzel	
	Mass	Neglected due to fixation of nozzels	

Table 103. Dimensions Associated with Flanges on Line 1-14 of Model 2-6-5

Flanges (1-14)	*Dimensions*		*Reference*
FL (1-14A)	Location	At heat exchanger nozzel	
	Mass	Neglected due to fixation of nozzels	

Table 104. Dimensions Associated with Flanges on Line 1-15 of Model 2-6-5

Flanges (1-15)	*Dimensions*		*Reference*
FL (1-15A)	Location	At heat exchanger nozzel	
	Mass	Neglected due to fixation of nozzels	

Table 105. Dimensions Associated with Flanges on Line 1-16 of Model 2-6-5

Flanges (1-16)	*Dimensions*		*Reference*
FL (1-16A)	Location	At heat exchanger nozzel	
	Mass	Neglected due to fixation of nozzels	

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Table 106. Dimensions Associated with Flanges on Line 1-18 of Model 2-6-5

Flanges (1-18)	***Dimensions***		***Reference***
FL (1-18A)	Location	At point where T(1-18) and GT(1-18) meet	
	Mass	478 lbm = 1.238 lbf.s^2/in	[29, pg 99]
FL (1-18B)	Location	At point where GT(1-18) and P(1-18A) meet	
	Mass	478 lbm = 1.238 lbf.s^2/in	[29, pg 99]
FL (1-18C)	Location	At primary pump suction nozzel	
	Mass	Neglected due to fixation of nozzels	

Table 107. Dimensions Associated with Flanges on Line 1-19 of Model 2-6-5

Flanges (1-19)	***Dimensions***		***Reference***
FL (1-19A)	Location	At point where T(1-19) and GT(1-19) meet	
	Mass	478 lbm = 1.238 lbf.s^2/in	[29, pg 99]
FL (1-19B)	Location	At point where GT(1-19) and P(1-19A) meet	
	Mass	478 lbm = 1.238 lbf.s^2/in	[29, pg 99]
FL (1-19C)	Location	At primary pump suction nozzel	
	Mass	Neglected due to fixation of nozzels	

Table 108. Dimensions Associated with Flanges on Line 1-20 of Model 2-6-5

Flanges (1-20)	***Dimensions***		***Reference***
FL (1-20A)	Location	At point where T(1-20) and GT(1-20) meet	
	Mass	478 lbm = 1.238 lbf.s^2/in	[29, pg 99]
FL (1-20B)	Location	At point where GT(1-20) and P(1-20A) meet	
	Mass	478 lbm = 1.238 lbf.s^2/in	[29, pg 99]
FL (1-20C)	Location	At primary pump suction nozzel	
	Mass	Neglected due to fixation of nozzels	

Table 109. Dimensions Associated with Flanges on Line 1-21 of Model 2-6-5

Flanges (1-21)	***Dimensions***		***Reference***
FL (1-21A)	Location	At point where T(1-21) and GT(1-21) meet	
	Mass	478 lbm = 1.238 lbf.s^2/in	[29, pg 99]
FL (1-21B)	Location	At point where GT(1-21) and P(1-21A) meet	
	Mass	478 lbm = 1.238 lbf.s^2/in	[29, pg 99]
FL (1-21C)	Location	At primary pump suction nozzel	
	Mass	Neglected due to fixation of nozzels	

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Table 110. Dimensions Associated with Flanges on Line 1-30 of Model 2-6-5

Flanges (1-30)	***Dimensions***		***Reference***
FL (1-30A)	Location	At point where T(1-30) and CK(1-30) meet	
	Mass	208 lbm = 0.539 lbf.s^2/in	[29, pg 99]
FL (1-30B)	Location	At point where CK(1-30) and P(1-30A) meet	
	Mass	208 lbm = 0.539 lbf.s^2/in	[29, pg 99]
FL (1-30C)	Location	At point where P(1-30F) and GT(1-30) meet	
	Mass	208 lbm = 0.539 lbf.s^2/in	[29, pg 99]
FL (1-30D)	Location	At point where GT(1-30) and RED(1-30A) meet	
	Mass	208 lbm = 0.539 lbf.s^2/in	[29, pg 99]
FL (1-30E)	Location	At emergency pump suction nozzel	
	Mass	Neglected due to fixation of nozzels	

Table 111. Dimensions Associated with Flanges on Line 1-31 of Model 2-6-5

Flanges (1-31)	***Dimensions***		***Reference***
FL (1-31A)	Location	At point where the north side of P(1-31C) and GT(1-31) meet	
	Mass	208 lbm = 0.539 lbf.s^2/in	[29, pg 99]
FL (1-31B)	Location	At point where GT(1-31) and and the south side of P(1-31C) meet	
	Mass	208 lbm = 0.539 lbf.s^2/in	[29, pg 99]
FL (1-31C)	Location	At emergency pump suction nozzel	
	Mass	Neglected due to fixation of nozzels	

Table 112. Dimensions Associated with Flanges on Line 1-43 of Model 2-6-5

Flanges (1-43)	***Dimensions***		***Reference***
FL (1-43A)	Location	At point where P(1-43D) and GT(1-43A) meet	
	Mass	78 lbm = 0.202 lbf.s^2/in	[29, pg 99]
FL (1-43B)	Location	At point where GT(1-43A) and P(1-43E) meet	
	Mass	78 lbm = 0.202 lbf.s^2/in	[29, pg 99]
FL (1-43C)*	Location	At point where the north side of P(1-43G) ends	
	Mass	78 lbm = 0.202 lbf.s^2/in	[29, pg 99]
FL (1-43D)*	Location	At point where south side of P(1-43H) ends	
	Mass	78 lbm = 0.202 lbf.s^2/in	[29, pg 99]
FL (1-43E)	Location	At point where the north side of P(1-43G) and GB(1-43B) meet	
	Mass	78 lbm = 0.202 lbf.s^2/in	[29, pg 99]
FL (1-43F)	Location	At point where GB(1-43B) and the south side of P(1-43H) meet	
	Mass	78 lbm = 0.202 lbf.s^2/in	[29, pg 99]
FL (1-43G)	Location	At point where the north side of P(1-43L) ends	
	Mass	78 lbm = 0.202 lbf.s^2/in	[29, pg 99]
FL (1-43H)	Location	At point where GB(1-43B) and the south side of P(1-43M) ends	
	Mass	78 lbm = 0.202 lbf.s^2/in	[29, pg 99]

*Note that the distance between FL(1-43C) and FL(1-43D) is 3/8" (127030)

Table 113. Dimensions Associated with Flanges on Line 1-46 of Model 2-6-5

Flanges (1-46)	***Dimensions***		***Reference***
FL (1-44A)	Location	At point where P(1-43H) and GT(1-44A) meet	
	Mass	39 lbm = 0.101 lbf.s^2/in	[29, pg 99]
FL (1-44B)	Location	At point where GT(1-44A) and T(1-44) meet	
	Mass	39 lbm = 0.101 lbf.s^2/in	[29, pg 99]
FL (1-44C)	Location	At point where T(1-44) and GT(1-44B) meet	
	Mass	39 lbm = 0.101 lbf.s^2/in	[29, pg 99]
FL (1-44D)	Location	At point where GT(1-44B) and P(1-46B) meet	
	Mass	39 lbm = 0.101 lbf.s^2/in	[29, pg 99]
FL (1-44E)*	Location	At point where north end of P(1-44E) ends	
	Mass	41 lbm = 0.106 lbf.s^2/in (Welded Neck Flange)	[29, pg 99]
FL (1-44F)*	Location	At point where south end of P(1-44F) ends	
	Mass	41 lbm = 0.106 lbf.s^2/in (Welded Neck Flange)	[29, pg 99]

*Note that the distance between FL(1-44E) and FL(1-44F) is 3/8" (127031)

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Table 114. Dimensions Associated with Flanges on Line 1-47 of Model 2-6-5

Flanges (1-47)	*Dimensions*		*Reference*
FL (1-47A)	Location	At point where south side of P(1-47C) and GT(1-47) meet	
	Mass	39 lbm = 0.101 lbf.s^2/in	[29, pg 99]
FL (1-47B)	Location	At point where GT(1-47) and north side of P(1-47C) meet	
	Mass	39 lbm = 0.101 lbf.s^2/in	[29, pg 99]

Table 115. Dimensions Associated with Flanges on Line 1-171 of Model 2-6-5

Flanges (1-171)	*Dimensions*		*Reference*
FL (1-171A)	Location	At heat exchanger nozzel	
	Mass	Neglected due to fixation of nozzels	

Table 116. Dimensions Associated with Flanges on Line 1-45 of Model 2-6-5

Flanges (1-45)	*Dimensions*		*Reference*
FL (1-45A)	Location	At surge tank nozzel	
	Mass	Neglected due to fixation of nozzels	

Table 117. Dimensions Associated with Valves on Line 1-18 of Model 2-6-5

Valves (1-18)	*Dimensions*		*Reference*
GT (1-18)	Pipe/Valve Diameter	24"	[5]
	Pipe Thickness	0.375"	[5]
	Equiv Valve Thickness	1.258"	[5]
	Valve Lengths	3' - 9.25"	[5]
	Valve Name	GT-A-1-1-24 in.	[5], [3, pg B-2]
	Valve Mass	6715 lb = 17.392 lbf*s^2/in	[3, pg B-2]

Table 118. Dimensions Associated with Valves on Line 1-19 of Model 2-6-5

Valves (1-19)	*Dimensions*		*Reference*
GT (1-19)	Pipe/Valve Diameter	24"	[5]
	Pipe Thickness	0.375"	[5]
	Equiv Valve Thickness	1.258"	[5]
	Valve Lengths	3' - 9.25"	[5]
	Valve Name	GT-A-1-4-24 in.	[5], [3, pg B-2]
	Valve Mass	6715 lb = 17.392 lbf*s^2/in	[3, pg B-2]

Table 119. Dimensions Associated with Valves on Line 1-20 of Model 2-6-5

Valves (1-20)	*Dimensions*		*Reference*
GT (1-20)	Pipe/Valve Diameter	24"	[5]
	Pipe Thickness	0.375"	[5]
	Equiv Valve Thickness	1.258"	[5]
	Valve Lengths	3' - 9.25"	[5]
	Valve Name	GT-A-1-7-24 in.	[5], [3, pg B-2]
	Valve Mass	6715 lb = 17.392 lbf*s^2/in	[3, pg B-2]

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Table 120. Dimensions Associated with Valves on Line 1-21 of Model 2-6-5

Valves (1-21)	*Dimensions*		*Reference*
GT (1-21)	Pipe/Valve Diameter	24"	[5]
	Pipe Thickness	0.375"	[5]
	Equiv Valve Thickness	1.258"	[5]
	Valve Lengths	3' - 9.25"	[5]
	Valve Name	GT-A-1-10-24 in.	[5], [3, pg B-2]
	Valve Mass	6715 lb = 17.392 lbf*s^2/in	[3, pg B-2]

Table 121. Dimensions Associated with Valves on Line 1-30 of Model 2-6-5

Valves (1-30)	*Dimensions*		*Reference*
GT (1-30)	Pipe/Valve Diameter	16"	[7]
	Pipe Thickness	0.25"	[7]
	Equiv Valve Thickness	0.838"	App C.7
	Valve Lengths	2' - 9.25"	[7]
	Valve Name	GT-B-1-16-16 in.	[7], [3, pg B-3]
	Valve Mass	2500 lb = 6.475 lbf*s^2/in	[3, pg B-3]
CK (1-30)	Pipe/Valve Diameter	16"	[7]
	Pipe Thickness	0.25"	[7]
	Equiv Valve Thickness	0.838"	App C.7
	Valve Lengths	2' - 9.25"	[7]
	Valve Name	CK-B-1-15-16 in.	[7], [3, pg B-3]
	Valve Mass	3100 lb = 8.029 lbf*s^2/in	[3, pg B-3]

Table 122. Dimensions Associated with Valves on Line 1-31 of Model 2-6-5

Valves (1-31)	*Dimensions*		*Reference*
GT (1-31)	Pipe/Valve Diameter	16"	[10]
	Pipe Thickness	0.25"	[10]
	Equiv Valve Thickness	0.838"	App C.7
	Valve Lengths	2' - 9.25"	[10]
	Valve Name	GT-B-1-19-16 in.	[10], [3, pg B-3]
	Valve Mass	2500 lb = 6.475 lbf*s^2/in	[3, pg B-3]

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Title:	ATR Primary Coolant System Piping Seismic Evaluation				
Performer:	A. L. Crawford	**Date:** 09/30/08	**Checker:** R. K. Blandford	**Date:**	09/30/08

Table 123. Dimensions Associated with Valves on Line 1-43 of Model 2-6-5

Valves (1-43)	*Dimensions*		*Reference*
GT (1-43A)	Pipe/Valve Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Equiv Valve Thickness	0.902"	App C.7
	Valve Lengths	1' - 6.25"	[11]
	Valve Name	GT-D-1-35-10 in.	[11], [3, pg B-3]
	Valve Mass	1096 lb = 2.839 lbf*s^2/in	[3, pg B-3]
GB (1-43B)	Pipe/Valve Diameter	10.75"	[11]
	Pipe Thickness	0.25"	[11]
	Equiv Valve Thickness	0.902"	App C.7
	Valve Lengths	2' -0.75"	[11]
	Valve Name	GB-A-1-36-10 in	[11]
	Valve Mass	1.356 * 1096 lb = 3.85 lbf*s^2/in	Assumed = 1.356 * GT(1-43A) where 1.356 is the ratio between the lengths of GB(1-43B) and GT(1-43A)

Table 124. Dimensions Associated with Valves on Line 1-46 of Model 2-6-5

Valves (1-46)	*Dimensions*		*Reference*
GT (1-44A)	Pipe/Valve Diameter	6.625"	[12]
	Pipe Thickness	0.280"	[12]
	Equiv Valve Thickness	1.417"	App C.7
	Valve Lengths	1' - 4.125"	[12]
	Valve Name	GT-D-37-6 in.	[12], [3, pg 3]
	Valve Mass	491 lb = 1.272 lbf*s^2/in	[3, pg B-3]
GT (1-44B)	Pipe/Valve Diameter	6.625"	[12]
	Pipe Thickness	0.280"	[12]
	Equiv Valve Thickness	1.417"	App C.7
	Valve Lengths	1' - 4.125"	[12]
	Valve Name	-	Assumed same as GT(1-44A)
	Valve Mass	491 lb = 1.272 lbf*s^2/in	Assumed same as GT(1-44A)

Table 125. Dimensions Associated with Valves on Line 1-47 of Model 2-6-5

Valves (1-47)	*Dimensions*		*Reference*
GT (1-47)	Pipe/Valve Diameter	6.625"	[16]
	Pipe Thickness	0.280"	[16]
	Equiv Valve Thickness	1.417"	App C.7
	Valve Lengths	1' - 4.125"	[16]
	Valve Name	GT-D-33-6 in.	[16], [3, pg B-3]
	Valve Mass	491 lb = 1.272 lbf*s^2/in	[3, pg B-3]

Appendix C.7

Calculations of Pipe Thickness to Mimic Valve Behavior in Model

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** R. K. Blandford **Date:** 09/30/2008

Valve Thickness Calculations

According to Nu-Pipe the moment of inertia of the pipe valves is to be three times that of the pipe for which it is attached to. [34, 2-21]

GATE AND CHECK VALVES ASSOCIATED WITH LINES 1-18 THROUGH 1-21

GT_{1-18}, GT_{1-19}, GT_{1-20}, GT_{1-21}

The above four gate valves are located one elbow below the suction of each of the four primary coolant pumps.

$t_{PP} := 0.375in$ — Thickness of PCS pipe below primary coolant pumps [5]

$od_{PP} := 24in$ — Outer diameter of PCS pipe below primary coolant pumps [5]

$id_{PP} := od_{PP} - 2 \cdot t_{PP}$ — Inner diameter of PCS pipe below primary coolant pumps

$id_{PP} = 23.25\ in$

$$I_{PP} := \frac{\pi \cdot \left(od_{PP}^{\ 4} - id_{PP}^{\ 4}\right)}{4}$$

Moment of inertia of PCS pipe below primary coolant pumps [8, Table 17-27, pg 17-39]

$I_{PP} = 3.108 \times 10^{4}\ in^{4}$

$$T_{PP\_GT} := \left[\frac{\left[-\frac{4 \cdot (3 \cdot I_{PP})}{\pi} + od_{PP}^{\ 4}\right]^{0.25} - od_{PP}}{-2}\right]$$

Thickness of pipe representing valve if outer diameter is to remain consistent with attached pipe where equation is modification of moment of inertia equation for a pipe thickness as the output and the moment of inertia for the valve represented by 3 times the value of the moment of inertia of the pipe [8, Table 17-27, pg 17-39]

$T_{PP\_GT} = 1.258\ in$

CHECK AND GATE VALVES ASSOCIATED WITH LINES 1-30 THROUGH 1-31

GT_{1-30}, CK_{1-30} , and GT_{1-31}

GT_{1-30} is located one reducer from the emergency pump connected to line 1-30. CK_{1-30} is located immediately after the tee connecting lines 1-17 to line 1-30 on line 1-30. GT_{1-31} is located one elbow away from the emergency pump connected to line 1-31.

$t_{EP} := 0.25in$ — Thickness of PCS pipe below primary coolant pumps [10]

$od_{EP} := 16in$ — Outer diameter of PCS pipe below primary coolant pumps [10]

$id_{EP} := od_{EP} - 2 \cdot t_{EP}$ — Inner diameter of PCS pipe below primary coolant pumps

$id_{EP} = 15.5\ in$

$$I_{EP} := \frac{\pi \cdot \left(od_{EP}{}^{4} - id_{EP}{}^{4}\right)}{4}$$

Moment of inertia of PCS pipe below primary coolant pumps [8, Table 17-27, pg 17-39]

$$I_{EP} = 6.139 \times 10^{3}\,in^{4}$$

$$T_{EP\_GT} := \left[\frac{\left[-\frac{4\cdot(3\cdot I_{EP})}{\pi} + od_{EP}{}^{4}\right]^{0.25} - od_{EP}}{-2}\right]$$

Thickness of pipe representing valve if outer diameter is to remain consistent with attached pipe where equation is modification of moment of inertia equation for a pipe thickness as the output and the moment of inertia for the valve represented by 3 times the value of the moment of inertia of the pipe [8, Table 17-27, pg 17-39]

$$\boxed{T_{EP\_GT} = 0.838\,in}$$

GATE VALVES ASSOCIATED WITH LINE 1-43

$GT_{1\text{-}43A}$ and $GB_{1\text{-}43B}$

$GT_{1\text{-}43A}$ is located between $T_{1\text{-}46B}$ and $T_{1\text{-}47}$ on line 1-43. $GB_{1\text{-}43B}$ is located between $T_{1\text{-}47}$ and $EL_{1\text{-}43E}$ on line 1-43.

$$t_{NW} := 0.25in$$

Thickness of PCS pipe below primary coolant pumps [11]

$$od_{NW} := 10.75in$$

Outer diameter of PCS pipe below primary coolant pumps [11]

$$id_{NW} := od_{NW} - 2\cdot t_{NW}$$

Inner diameter of PCS pipe below primary coolant pumps

$$id_{NW} = 10.25\,in$$

$$I_{NW} := \frac{\pi \cdot \left(od_{NW}{}^{4} - id_{NW}{}^{4}\right)}{4}$$

Moment of inertia of PCS pipe below primary coolant pumps [8, Table 17-27, pg 17-39]

$$I_{NW} = 1.819 \times 10^{3}\,in^{4}$$

$$T_{NW\_GT} := \left[\frac{\left[-\frac{4\cdot(3\cdot I_{NW})}{\pi} + od_{NW}{}^{4}\right]^{0.25} - od_{NW}}{-2}\right]$$

Thickness of pipe representing valve if outer diameter is to remain consistent with attached pipe where equation is modification of moment of inertia equation for a pipe thickness as the output and the moment of inertia for the valve represented by 3 times the value of the moment of inertia of the pipe [8, Table 17-27, pg 17-39]

$$\boxed{T_{NW\_GT} = 0.902\,in}$$

GATE VALVES ASSOCIATED WITH LINES 1-44 AND 1-47

$GT_{1\text{-}44A}$, $GT_{1\text{-}44B}$, and $GT_{1\text{-}47}$

$GT_{1\text{-}44A}$ and $GT_{1\text{-}44B}$ are located on the north and south sides of $T_{1\text{-}44}$. $GT_{1\text{-}47}$ is located just north of $EL_{1\text{-}47B}$.

$t_{CL} := 0.28\,in$ — Thickness of PCS pipe below primary coolant pumps [12]

$od_{CL} := 6.625\,in$ — Outer diameter of PCS pipe below primary coolant pumps [12]

$id_{CL} := od_{CL} - 2 \cdot t_{CL}$ — Inner diameter of PCS pipe below primary coolant pumps

$id_{CL} = 6.065\,in$

$$I_{CL} := \frac{\pi \cdot \left(od_{CL}^{\,4} - id_{CL}^{\,4}\right)}{4}$$

Moment of inertia of PCS pipe below primary coolant pumps [8, Table 17-27, pg 17-39]

$I_{CL} = 450.275\,in^4$

$$T_{CL\_GT} := \left[\frac{\left[-\frac{4\cdot(3\cdot I_{CL})}{\pi} + od_{CL}^{\,4}\right]^{0.25} - od_{CL}}{-2}\right]$$

Thickness of pipe representing valve if outer diameter is to remain consistent with attached pipe where equation is modification of moment of inertia equation for a pipe thickness as the output and the moment of inertia for the valve represented by 3 times the value of the moment of inertia of the pipe [8, Table 17-27, pg 17-39]

$\boxed{T_{CL\_GT} = 1.417\,in}$

Appendix C.8

Elbow Stiffness and Water Filled Pipe Density Calculations

MATERIAL PROPERTIES USED IN ELBOW STIFFNESS CALCULATIONS

Stainless Steel Material Properties

The material properties below represent reasonable values that could be used in an analysis.

$E_s := 2.8 \cdot 10^7 \cdot psi$ — Modulus of elasticity @ 125 Fahrenheit [2, Table TM]

$\nu_s := 0.30$ — Poisson's ratio [9, NB-3683.1(b)]

$$G_s := \frac{E_s}{2 \cdot (1 + \nu_s)}$$

Shear modulus [35, Eq 2-19]

$$G_s = 1.077 \times 10^7 \, psi$$

$\rho_s := 0.28 \frac{lb}{in^3}$ — Mass density [35]

Steel Material Properties

The material properties below represent reasonable values that could be used in an analysis.

$E_c := 3.0 \cdot 10^7 \cdot psi$ — Modulus of elasticity [35, Table A-5]

$\nu_c := 0.29$ — Poisson's ratio [35]

$\rho_c := 0.282 \frac{lb}{in^3}$ — Mass density [35]

Water Material Properties

The material properties below represent reasonable values that could be used in an analysis.

$\rho_w := 62.3 \cdot \frac{lb}{ft^3}$ — Mass density [36, Table A]

$$\rho_w = 0.0361 \frac{lb}{in^3}$$

FLEXIBILITY FACTOR FUNCTION AND CALCULATIONS APPROACH

Flexibility Factor

(a) R/r is not less than 1.7 [9, NB-3686.2]

(b) center line length $R\alpha$ is greater than 2r [9, NB-3686.2]

(c) there are no flanges or other similar stiffeners within a distance r from either end of the curved section of pipe or from the ends of welding elbows. [9, NB-3686.2]

$$k(d_o, t, P, R) := \begin{array}{|l} d_i \leftarrow d_o - 2\cdot t \\ r \leftarrow \frac{1}{4}\cdot(d_o + d_i) \\ h \leftarrow t\cdot R\cdot r^{-2} \\ X_k \leftarrow 6\cdot\left(\frac{r}{t}\right)^{\frac{4}{3}}\cdot\left(\frac{R}{r}\right)^{\frac{1}{3}} \\ k_o \leftarrow 0 \\ k_o \leftarrow \frac{1.65}{h}\cdot\frac{1}{1+\left(\frac{P\cdot r}{t\cdot E_s}\right)\cdot X_k} \quad \text{if } \frac{R}{r} \geq 1.7 \\ k_o \end{array}$$

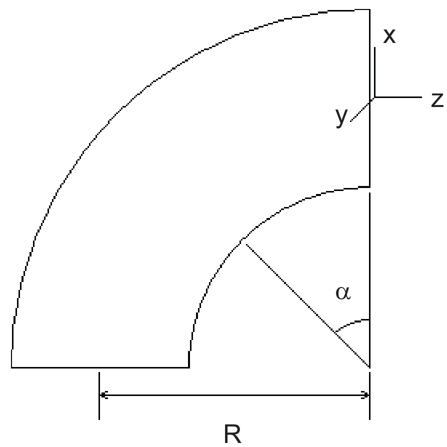
[9, NB-3686.2]

$$\theta_{nom1} = \frac{R}{E\cdot I}\cdot\int_0^{\theta} M_1\, d\alpha \qquad \theta_{ab1} = k\cdot\theta_{nom1} = \frac{k\cdot R}{E\cdot I}\cdot\int_0^{\theta} M_1\, d\alpha$$

$$\theta_{nom2} = \frac{R}{E\cdot I}\cdot\int_0^{\theta} M_2\, d\alpha \qquad \theta_{ab2} = k\cdot\theta_{nom2} = \frac{k\cdot R}{E\cdot I}\cdot\int_0^{\theta} M_2\, d\alpha$$

$$\theta_{nom3} = \frac{R}{G\cdot J}\cdot\int_0^{\theta} M_3\, d\alpha \qquad \theta_{ab3} = \theta_{nom3} = \frac{R}{G\cdot J}\cdot\int_0^{\theta} M_3\, d\alpha$$

To address the flexibility factor in the finite element model, an effective area moment of inertia will be established:



$$I_e = \frac{I}{k}$$

Therefore:

$$\theta_{ab1} = \frac{R}{E \cdot I_e} \cdot \int_0^{\theta} M_1 \, d\alpha$$

$$\theta_{ab2} = \frac{R}{E \cdot I_e} \cdot \int_0^{\theta} M_2 \, d\alpha$$

$$\theta_{ab3} = \frac{R}{G \cdot J} \cdot \int_0^{\theta} M_3 \, d\alpha$$

FLEXIBILITY FACTOR AND MOMENT OF INERTIA CALCULATIONS FOR MODEL 265

Pipe 30 Inch Diameter and 0.438 Thickness

$d_{30} := 30 \cdot in$ — Pipe outside diameter.

$t_{30} := 0.438 \cdot in$ — Pipe thickness.

$p_{253} := 253 \cdot psi$ — Internal pressure. [3]

$r_{s30} := d_{30}$ — Radius for short radius elbow.

$r_{s30} = 30\, in$

$r_{l30} := 1.5 \cdot r_{s30}$ — Radius for long radius elbow.

$r_{l30} = 45\, in$

$A_{30} := \frac{\pi}{4} \cdot \left[{d_{30}}^2 - (d_{30} - 2 \cdot t_{30})^2 \right]$ — Pipe cross section area.

$A_{30} = 40.6778\, in^2$

$A_{i30} := \frac{\pi}{4} \cdot (d_{30} - 2 \cdot t_{30})^2$ — Pipe internal area.

$A_{i30} = 666.2\, in^2$

$$\rho_{sw30} := \frac{A_{30}\cdot\rho_s + A_{i30}\cdot\rho_w}{A_{30}}$$

Mass density for the pipe with water.

$$\rho_{sw30} = 2.255\times 10^{-3}\,\frac{lbf\cdot sec^2}{in^4}$$

$$I_{30} := \frac{\pi}{64}\cdot\left[d_{30}{}^4 - \left(d_{30} - 2\cdot t_{30}\right)^4\right]$$

Pipe area moment of inertia.

$$I_{30} = 4444.58\,in^4$$

$$J_{30} := \frac{\pi}{32}\cdot\left[d_{30}{}^4 - \left(d_{30} - 2\cdot t_{30}\right)^4\right]$$

Pipe polar moment of inertia.

$$J_{30} = 8889.2\,in^4$$

$$k_{s30} := k\left(d_{30}, t_{30}, p_{253}, r_{s30}\right)$$

Flexibility factor for short radius.

$$k_{s30} = 21.902$$

$$I_{es30} := \frac{I_{30}}{k_{s30}}$$

Effective moment of inertia for short radius.

$$\boxed{I_{es30} = 202.932\,in^4}$$

$$k_{l30} := k\left(d_{30}, t_{30}, p_{253}, r_{l30}\right)$$

Flexibility factor for long radius.

$$k_{l30} = 14.187$$

$$I_{el30} := \frac{I_{30}}{k_{l30}}$$

Effective moment of inertia for long radius.

$$\boxed{I_{el30} = 313.282\,in^4}$$

Pipe 24 Inch Diameter and 0.375 Thickness

$d_{24} := 24\cdot in$ — Pipe outside diameter.

$t_{24} := 0.375\cdot in$ — Pipe thickness.

$p_{253} = 253\,psi$ — Internal pressure. [3]

$r_{s24} := d_{24}$

$r_{s24} = 24\,in$ — Radius for short radius elbow.

$r_{l24} := 1.5 \cdot r_{s24}$

$r_{l24} = 36\,in$ — Radius for long radius elbow.

$A_{24} := \frac{\pi}{4} \cdot \left[d_{24}^{\;2} - \left(d_{24} - 2 \cdot t_{24}\right)^2 \right]$

$A_{24} = 27.8325\,in^2$ — Pipe cross section area.

$A_{i24} := \frac{\pi}{4} \cdot \left(d_{24} - 2 \cdot t_{24}\right)^2$

$A_{i24} = 424.6\,in^2$ — Pipe internal area.

$\rho_{sw24} := \frac{A_{24} \cdot \rho_s + A_{i24} \cdot \rho_w}{A_{24}}$

$\rho_{sw24} = 2.15 \times 10^{-3} \frac{lbf \cdot sec^2}{in^4}$ — Mass density for the pipe with water.

$I_{24} := \frac{\pi}{64} \cdot \left[d_{24}^{\;4} - \left(d_{24} - 2 \cdot t_{24}\right)^4 \right]$

$I_{24} = 1942.30\,in^4$ — Pipe area moment of inertia.

$J_{24} := \frac{\pi}{32} \cdot \left[d_{24}^{\;4} - \left(d_{24} - 2 \cdot t_{24}\right)^4 \right]$

$J_{24} = 3884.6\,in^4$ — Pipe polar moment of inertia.

$k_{s24} := k\left(d_{24}, t_{24}, p_{253}, r_{s24}\right)$

$k_{s24} = 21.052$ — Flexibility factor for short radius.

$I_{es24} := \frac{I_{24}}{k_{s24}}$

$\boxed{I_{es24} = 92.264\,in^4}$ — Effective moment of inertia for short radius.

$k_{l24} := k\left(d_{24}, t_{24}, p_{253}, r_{l24}\right)$

Flexibility factor for long radius.

$k_{l24} = 13.684$

$I_{el24} := \dfrac{I_{24}}{k_{l24}}$

Effective moment of inertia for long radius.

$\boxed{I_{el24} = 141.942\,in^4}$

Pipe 20 Inch Diameter and 0.3125 Thickness

$d_{20} := 20 \cdot in$ Pipe outside diameter.

$t_{20} := 0.3125 \cdot in$ Pipe thickness.

$p_{253} = 253\,psi$ Internal pressure. [3]

$r_{s20} := d_{20}$

Radius for short radius elbow.

$r_{s20} = 20\,in$

$r_{l20} := 1.5 \cdot r_{s20}$

Radius for long radius elbow.

$r_{l20} = 30\,in$

$A_{20} := \dfrac{\pi}{4} \cdot \left[{d_{20}}^2 - \left(d_{20} - 2 \cdot t_{20}\right)^2 \right]$

Pipe cross section area.

$A_{20} = 19.3282\,in^2$

$A_{i20} := \dfrac{\pi}{4} \cdot \left(d_{20} - 2 \cdot t_{20}\right)^2$

Pipe internal area.

$A_{i20} = 294.8\,in^2$

$\rho_{sw20} := \dfrac{A_{20} \cdot \rho_s + A_{i20} \cdot \rho_w}{A_{20}}$

Mass density for the pipe with water.

$\rho_{sw20} = 2.15 \times 10^{-3} \dfrac{lbf \cdot sec^2}{in^4}$

$I_{20} := \frac{\pi}{64} \cdot \left[d_{20}^{\,4} - \left(d_{20} - 2 \cdot t_{20} \right)^4 \right]$ Pipe area moment of inertia.

$I_{20} = 936.68\,in^4$

$J_{20} := \frac{\pi}{32} \cdot \left[d_{20}^{\,4} - \left(d_{20} - 2 \cdot t_{20} \right)^4 \right]$ Pipe polar moment of inertia.

$J_{20} = 1873.4\,in^4$

$k_{s20} := k\left(d_{20}, t_{20}, p_{253}, r_{s20} \right)$ Flexibility factor for short radius.

$k_{s20} = 21.052$

$I_{es20} := \frac{I_{20}}{k_{s20}}$ Effective moment of inertia for short radius.

$\boxed{I_{es20} = 44.494\,in^4}$

$k_{l20} := k\left(d_{20}, t_{20}, p_{253}, r_{l20} \right)$ Flexibility factor for long radius.

$k_{l20} = 13.684$

$I_{el20} := \frac{I_{20}}{k_{l20}}$ Effective moment of inertia for long radius.

$\boxed{I_{el20} = 68.452\,in^4}$

Pipe 16 Inch Diameter and 0.25 Thickness

$d_{16} := 16 \cdot in$ Pipe outside diameter.

$t_{16} := 0.25 \cdot in$ Pipe thickness.

$p_{253} = 253\,psi$ Internal pressure. [3]

$r_{s16} := d_{16}$ Radius for short radius elbow.

$r_{s16} = 16\,in$

$r_{l16} := 1.5 \cdot r_{s16}$ Radius for long radius elbow.

$r_{l16} = 24\,in$

$A_{16} := \frac{\pi}{4} \cdot \left[d_{16}^{\;2} - \left(d_{16} - 2 \cdot t_{16}\right)^2 \right]$

Pipe cross section area.

$A_{16} = 12.37\,in^2$

$A_{i16} := \frac{\pi}{4} \cdot \left(d_{16} - 2 \cdot t_{16}\right)^2$

Pipe internal area.

$A_{i16} = 188.7\,in^2$

$\rho_{sw16} := \frac{A_{16} \cdot \rho_s + A_{i16} \cdot \rho_w}{A_{16}}$

Mass density for the pipe with water.

$\rho_{sw16} = 2.15 \times 10^{-3} \frac{lbf \cdot sec^2}{in^4}$

$I_{16} := \frac{\pi}{64} \cdot \left[d_{16}^{\;4} - \left(d_{16} - 2 \cdot t_{16}\right)^4 \right]$

Pipe area moment of inertia.

$I_{16} = 383.66\,in^4$

$J_{16} := \frac{\pi}{32} \cdot \left[d_{16}^{\;4} - \left(d_{16} - 2 \cdot t_{16}\right)^4 \right]$

Pipe polar moment of inertia.

$J_{16} = 767.3\,in^4$

$k_{s16} := k\left(d_{16}, t_{16}, p_{253}, r_{s16}\right)$

Flexibility factor for short radius.

$k_{s16} = 21.052$

$I_{es16} := \frac{I_{16}}{k_{s16}}$

Effective moment of inertia for short radius.

$\boxed{I_{es16} = 18.225\,in^4}$

$k_{l16} := k\left(d_{16}, t_{16}, p_{253}, r_{l16}\right)$

Flexibility factor for long radius.

$k_{l16} = 13.684$

$I_{el16} := \frac{I_{16}}{k_{l16}}$

Effective moment of inertia for long radius.

$I_{el16} = 28.038\,in^4$

Pipe 10 Inch Diameter (Actually 10.75 Inch OD) and 0.25 Thickness

$d_{10} := 10.75 \cdot in$ — Pipe outside diameter.

$t_{10} := 0.25 \cdot in$ — Pipe thickness.

$p_{253} = 253\,psi$ — Internal pressure. [3]

$r_{s10} := 10in$ — Radius for short radius elbow.

$r_{s10} = 10\,in$

$r_{l10} := 1.5 \cdot r_{s10}$ — Radius for long radius elbow.

$r_{l10} = 15\,in$

$A_{10} := \frac{\pi}{4} \cdot \left[d_{10}^{\;2} - \left(d_{10} - 2 \cdot t_{10} \right)^2 \right]$ — Pipe cross section area.

$A_{10} = 8.2467\,in^2$

$A_{i10} := \frac{\pi}{4} \cdot \left(d_{10} - 2 \cdot t_{10} \right)^2$ — Pipe internal area.

$A_{i10} = 82.5\,in^2$

$\rho_{sw10} := \frac{A_{10} \cdot \rho_s + A_{i10} \cdot \rho_w}{A_{10}}$ — Mass density for the pipe with water.

$\rho_{sw10} = 1.66 \times 10^{-3} \frac{lbf \cdot sec^2}{in^4}$

$I_{10} := \frac{\pi}{64} \cdot \left[d_{10}^{\;4} - \left(d_{10} - 2 \cdot t_{10} \right)^4 \right]$ — Pipe area moment of inertia.

$I_{10} = 113.71\,in^4$

$J_{10} := \frac{\pi}{32} \cdot \left[{d_{10}}^4 - \left(d_{10} - 2 \cdot t_{10} \right)^4 \right]$ Pipe polar moment of inertia.

$J_{10} = 227.4\,in^4$

$k_{s10} := k\left(d_{10}, t_{10}, p_{253}, r_{s10}\right)$ Flexibility factor for short radius.

$k_{s10} = 16.816$

$I_{es10} := \frac{I_{10}}{k_{s10}}$ Effective moment of inertia for short radius.

$I_{es10} = 6.762\,in^4$

$k_{l10} := k\left(d_{10}, t_{10}, p_{253}, r_{l10}\right)$ Flexibility factor for long radius.

$k_{l10} = 11.09$

$I_{el10} := \frac{I_{10}}{k_{l10}}$ Effective moment of inertia for long radius.

$I_{el10} = 10.254\,in^4$

Pipe 6 Inch Diameter (Actually 6.625 Inch OD) and 0.28 Thickness

$d_6 := 6.625 \cdot in$ Pipe outside diameter.

$t_6 := 0.28 \cdot in$ Pipe thickness.

$p_{253} = 253\,psi$ Internal pressure. [3]

$r_{s6} := 6in$ Radius for short radius elbow.

$r_{s6} = 6\,in$

$r_{l6} := 1.5 \cdot r_{s6}$ Radius for long radius elbow.

$r_{l6} = 9\,in$

$r_{xl6} := 30in$ Radius for 30" extra long radius elbow

$r_{xl6} = 30\,in$

$$A_6 := \frac{\pi}{4} \cdot \left[d_6^{\,2} - \left(d_6 - 2 \cdot t_6 \right)^2 \right]$$

Pipe cross section area.

$$A_6 = 5.5814\,in^2$$

$$A_{i6} := \frac{\pi}{4} \cdot \left(d_6 - 2 \cdot t_6 \right)^2$$

Pipe internal area.

$$A_{i6} = 28.9\,in^2$$

$$\rho_{sw6} := \frac{A_6 \cdot \rho_s + A_{i6} \cdot \rho_w}{A_6}$$

Mass density for the pipe with water.

$$\rho_{sw6} = 1.209 \times 10^{-3} \frac{lbf \cdot sec^2}{in^4}$$

$$I_6 := \frac{\pi}{64} \cdot \left[d_6^{\,4} - \left(d_6 - 2 \cdot t_6 \right)^4 \right]$$

Pipe area moment of inertia.

$$I_6 = 28.14\,in^4$$

$$J_6 := \frac{\pi}{32} \cdot \left[d_6^{\,4} - \left(d_6 - 2 \cdot t_6 \right)^4 \right]$$

Pipe polar moment of inertia.

$$J_6 = 56.3\,in^4$$

$$k_{s6} := k\left(d_6 , t_6 , p_{253} , r_{s6} \right)$$

Flexibility factor for short radius.

$$k_{s6} = 9.698$$

$$I_{es6} := \frac{I_6}{k_{s6}}$$

Effective moment of inertia for short radius.

$$\boxed{I_{es6} = 2.902\,in^4}$$

$$k_{l6} := k\left(d_6 , t_6 , p_{253} , r_{l6} \right)$$

Flexibility factor for long radius.

$$k_{l6} = 6.447$$

$I_{el6} := \frac{I_6}{k_{l6}}$

Effective moment of inertia for long radius.

$I_{el6} = 4.365\,in^4$

$k_{xl6} := k\left(d_6, t_6, p_{253}, r_{xl6}\right)$

Flexibility factor for 30" long radius

$k_{xl6} = 1.914$

$I_{exl6} := \frac{I_6}{k_{xl6}}$

Effective moment of inertia for 30" extra long radius.

$I_{exl6} = 14.705\,in^4$

Pipe 4 Inch Diameter (Actually 4.5 Inch OD) and 0.237 Thickness

$d_4 := 4.5 \cdot in$ — Pipe outside diameter.

$t_4 := 0.237 \cdot in$ — Pipe thickness.

$p_{376} := 376 \cdot psi$ — Internal pressure. [3]

$r_{s4} := 4in$

Radius for short radius elbow.

$r_{s4} = 4\,in$

$r_{l4} := 1.5 \cdot r_{s4}$

Radius for long radius elbow.

$r_{l4} = 6\,in$

$A_4 := \frac{\pi}{4} \cdot \left[d_4^{\,2} - \left(d_4 - 2 \cdot t_4\right)^2\right]$

Pipe cross section area.

$A_4 = 3.174\,in^2$

$A_{i4} := \frac{\pi}{4} \cdot \left(d_4 - 2 \cdot t_4\right)^2$

Pipe internal area.

$A_{i4} = 12.7\,in^2$

$$\rho_{sw4} := \frac{A_4 \cdot \rho_s + A_{i4} \cdot \rho_w}{A_4}$$

Mass density for the pipe with water.

$$\rho_{sw4} = 1.1 \times 10^{-3} \frac{lbf \cdot sec^2}{in^4}$$

$$I_4 := \frac{\pi}{64} \cdot \left[d_4^{\ 4} - \left(d_4 - 2 \cdot t_4\right)^4\right]$$

Pipe area moment of inertia.

$$I_4 = 7.23\,in^4$$

$$J_4 := \frac{\pi}{32} \cdot \left[d_4^{\ 4} - \left(d_4 - 2 \cdot t_4\right)^4\right]$$

Pipe polar moment of inertia.

$$J_4 = 14.5\,in^4$$

$$k_{s4} := k\left(d_4, t_4, p_{376}, r_{s4}\right)$$

Flexibility factor for short radius.

$$k_{s4} = 7.778$$

$$I_{es4} := \frac{I_4}{k_{s4}}$$

Effective moment of inertia for short radius.

$$\boxed{I_{es4} = 0.93\,in^4}$$

$$k_{l4} := k\left(d_4, t_4, p_{376}, r_{l4}\right)$$

Flexibility factor for long radius.

$$k_{l4} = 5.173$$

$$I_{el4} := \frac{I_4}{k_{l4}}$$

Effective moment of inertia for long radius.

$$\boxed{I_{el4} = 1.398\,in^4}$$

SUMMARY OF RESULTS

Pipe 30 Inch Diameter and 0.438 Thickness

$k_{s30} = 21.902$ Flexibility factor for short radius.

$I_{es30} = 202.932\,in^4$ Effective moment of inertia for short radius.

$k_{l30} = 14.187$ Flexibility factor for long radius.

$I_{el30} = 313.282\,in^4$ Effective moment of inertia for long radius.

Pipe 24 Inch Diameter and 0.375 Thickness

$k_{s24} = 21.052$ Flexibility factor for short radius.

$I_{es24} = 92.264\,in^4$ Effective moment of inertia for short radius.

$k_{l24} = 13.684$ Flexibility factor for long radius.

$I_{el24} = 141.942\,in^4$ Effective moment of inertia for long radius.

Pipe 20 Inch Diameter and 0.3125 Thickness

$k_{s20} = 21.052$ Flexibility factor for short radius.

$I_{es20} = 44.494\,in^4$ Effective moment of inertia for short radius.

$k_{l20} = 13.684$ Flexibility factor for long radius.

$I_{el20} = 68.452\,in^4$ Effective moment of inertia for long radius.

Pipe 16 Inch Diameter and 0.25 Thickness

$k_{s16} = 21.052$ Flexibility factor for short radius.

$I_{es16} = 18.225\,in^4$ Effective moment of inertia for short radius.

$k_{l16} = 13.684$ Flexibility factor for long radius.

$I_{el16} = 28.038\,in^4$ Effective moment of inertia for long radius.

Pipe 10 Inch Diameter (Actually 10.75 Inch OD) and 0.25 Thickness

$k_{s10} = 16.816$	Flexibility factor for short radius.
$I_{es10} = 6.762\ in^4$	Effective moment of inertia for short radius.
$k_{l10} = 11.09$	Flexibility factor for long radius.
$I_{el10} = 10.254\ in^4$	Effective moment of inertia for long radius.

Pipe 6 Inch Diameter (Actually 6.625 Inch OD) and 0.28 Thickness

$k_{s6} = 9.698$	Flexibility factor for short radius.
$I_{es6} = 2.902\ in^4$	Effective moment of inertia for short radius.
$k_{l6} = 6.447$	Flexibility factor for long radius.
$I_{el6} = 4.365\ in^4$	Effective moment of inertia for long radius.
$k_{xl6} = 1.914$	Flexibility factor for 30" long radius
$I_{exl6} = 14.705\ in^4$	Effective moment of inertia for 30" extra long radius.

Pipe 4 Inch Diameter (Actually 4.5 Inch OD) and 0.237 Thickness

$k_{s4} = 7.778$	Flexibility factor for short radius.
$I_{es4} = 0.93\ in^4$	Effective moment of inertia for short radius.
$k_{l4} = 5.173$	Flexibility factor for long radius.
$I_{el4} = 1.398\ in^4$	Effective moment of inertia for long radius.

WATER FILLED PIPE DENSITY CALCULATIONS

$$\rho_s = 0.28 \frac{lb}{in^3}$$

Mass density of Stainless Steel [54]

$$\rho_w = 0.0361 \frac{lb}{in^3}$$

Mass density of Water [55, Table A]

Pipe Sections

The density of the pipe sections will be calculated by taking the density associated with the steel and the water and multiplying the value by the cross sectional area that each will have as well as a common length variable (L). The resulting weight will be divided by the cross sectional area of the pipe section and the L multiplier. The L multiplier will cancel from the top and bottom of the equation and the result will be the density that the pipe would need to be to represent the weight of the steel and water simultaneously in the beam model.

$i := 1..8$

$j := 0..7$

Ranges used to iterate through data

$$Pipe_{Dt} := \begin{pmatrix} \text{"Diameter"} & \text{"Thickness"} \\ 30 & 0.438 \\ 24 & 0.375 \\ 20 & 0.312 \\ 18 & 0.312 \\ 16 & 0.25 \\ 10.75 & 0.25 \\ 6.625 & 0.28 \\ 4.5 & 0.237 \end{pmatrix}$$

$$Di\_p_{i-1} := \left(Pipe_{Dt_{i,0}} - 2 \cdot Pipe_{Dt_{i,1}}\right) in$$

$$Di\_p^T = (29.124 \quad 23.25 \quad 19.376 \quad 17.376 \quad 15.5 \quad 10.25 \quad 6.065 \quad 4.026)\, in$$

$$A_{w\_p_j} := \frac{\pi \cdot \left(Di\_p_j\right)^2}{4}$$

$$A_{w\_p}^T = (666.181 \quad 424.557 \quad 294.862 \quad 237.132 \quad 188.692 \quad 82.516 \quad 28.89 \quad 12.73)\, in^2$$

$$A_{s\_p_{i-1}} := \left[\frac{\pi\cdot\left(Pipe_{Dt_{i,0}}\cdot in\right)^2}{4} - A_{w\_p_{i-1}}\right]$$

$$A_{s\_p}^{T} = (40.678 \quad 27.833 \quad 19.298 \quad 17.337 \quad 12.37 \quad 8.247 \quad 5.581 \quad 3.174)\,in^2$$

$$Eq\_\rho\_p_{j,1} := \frac{\rho_s\cdot A_{s\_p_j} + \rho_w\cdot A_{w\_p_j}}{A_{s\_p_j}}$$

$$Eq\_\rho\_p^{\langle 0\rangle} := \begin{pmatrix} \text{"30 x 0.438"} \\ \text{"24 x 0.375"} \\ \text{"20 x 0.312"} \\ \text{"18 x 0.312"} \\ \text{"16 x 0.25"} \\ \text{"10.75 x 0.25"} \\ \text{"6.625 x 0.28"} \\ \text{"4.5 x 0.237"} \end{pmatrix} \qquad Eq\_\rho\_p = \begin{pmatrix} \text{"30 x 0.438"} & 2.255\times 10^{-3} \\ \text{"24 x 0.375"} & 2.15\times 10^{-3} \\ \text{"20 x 0.312"} & 2.152\times 10^{-3} \\ \text{"18 x 0.312"} & 2.002\times 10^{-3} \\ \text{"16 x 0.25"} & 2.15\times 10^{-3} \\ \text{"10.75 x 0.25"} & 1.66\times 10^{-3} \\ \text{"6.625 x 0.28"} & 1.209\times 10^{-3} \\ \text{"4.5 x 0.237"} & 1.1\times 10^{-3} \end{pmatrix} \frac{lbf\cdot s^2}{in^4}$$

Reducers

The density of the reducers will be calculated by first considering the reducer to be two beams connected in the middle of the reducer where one beam has dimensions associated with the large open end and the other beam has dimensions associated with the small open end. The method used to determine the density of each section will be the same as that for the pipe sections described above.

$i := 1..6$

$j := 0..5$

Ranges used to iterate through data

$$Red_{Dt} := \begin{pmatrix} \text{"Diameter"} & \text{"Thickness"} \\ 30 & 0.5 \\ 20 & 0.5 \\ 24 & 0.375 \\ 18 & 0.312 \\ 16 & 0.25 \\ 14 & 0.25 \end{pmatrix}$$

$$Di\_r_{i-1} := \left(Red_{Dt_{i,0}} - 2 \cdot Red_{Dt_{i,1}}\right) in$$

$$Di\_r^T = (29 \quad 19 \quad 23.25 \quad 17.376 \quad 15.5 \quad 13.5)\ in$$

$$A_{w\_r_j} := \frac{\pi \cdot (Di\_r_j)^2}{4}$$

$$A_{w\_r}^T = (660.52 \quad 283.529 \quad 424.557 \quad 237.132 \quad 188.692 \quad 143.139)\ in^2$$

$$A_{s\_r_{i-1}} := \left[\frac{\pi \cdot \left(Red_{Dt_{i,0}} \cdot in\right)^2}{4} - A_{w\_r_{i-1}}\right]$$

$$A_{s\_r}^T = (46.338 \quad 30.631 \quad 27.833 \quad 17.337 \quad 12.37 \quad 10.799)\ in^2$$

$$Eq\_\rho\_r_{j,1} := \frac{\rho_s \cdot A_{s\_r_j} + \rho_w \cdot A_{w\_r_j}}{A_{s\_r_j}}$$

$$Eq\_\rho\_r^{\langle 0 \rangle} := \begin{pmatrix} \text{"30x20 lg"} \\ \text{"30x20 sm"} \\ \text{"24x18 lg"} \\ \text{"24x18 sm"} \\ \text{"16x14 lg"} \\ \text{"16x14 sm"} \end{pmatrix} \qquad Eq\_\rho\_r = \begin{pmatrix} \text{"30x20 lg"} & 2.056 \times 10^{-3} \\ \text{"30x20 sm"} & 1.59 \times 10^{-3} \\ \text{"24x18 lg"} & 2.15 \times 10^{-3} \\ \text{"24x18 sm"} & 2.002 \times 10^{-3} \\ \text{"16x14 lg"} & 2.15 \times 10^{-3} \\ \text{"16x14 sm"} & 1.963 \times 10^{-3} \end{pmatrix} \frac{lbf \cdot s^2}{in^4}$$

Elbows

The density of the Elbows will be considered to be the same as that of the pipe with the same dimensions as an relatively close approximation.

Tees and Branches

The density of the Tees will be calculated by observing that the run and branch are both comprised of the same pipe type and one density will be associated with that pipe type. The Branches will be calculated by considering the run and branch as two separate components and a density for each will be calculated. The method used to determine the density of each section will be the same as that for the pipe sections described above.

$i := 1 .. 14$

$j := 0 .. 13$

Ranges used to iterate through data

$$T\_Br_{Dt} := \begin{pmatrix} \text{"Diameter"} & \text{"Thickness"} \\ 16 & 0.25 \\ 6.625 & 0.28 \\ 30 & 0.438 \\ 24 & 0.375 \\ 30 & 0.438 \\ 20 & 0.312 \\ 30 & 0.438 \\ 16 & 0.25 \\ 20 & 0.312 \\ 6.625 & 0.28 \\ 16 & 0.25 \\ 4.5 & 0.237 \\ 10.75 & 0.25 \\ 6.625 & 0.28 \end{pmatrix}$$

$$Di\_TB_{i-1} := \left(T\_Br_{Dt_{i,0}} - 2 \cdot T\_Br_{Dt_{i,1}}\right) in$$

$Di\_TB^T =$ (in)

	0	1	2	3	4	5	6	7	8
0	15.5	6.065	29.124	23.25	29.124	19.376	29.124	15.5	19.376

$$A_{w\_TB_j} := \frac{\pi \cdot (Di\_TB_j)^2}{4}$$

$A_{w\_TB}{}^T =$ (in²)

	0	1	2	3	4	5	6	7
0	188.692	28.89	666.181	424.557	666.181	294.862	666.181	188.692

$$A_{s\_TB_{i-1}} := \left[\frac{\pi \cdot \left(T\_Br_{Dt_{i,0}} \cdot in\right)^2}{4} - A_{w\_TB_{i-1}}\right]$$

$A_{s\_TB}{}^T =$ (in²)

	0	1	2	3	4	5	6	7	8
0	12.37	5.581	40.678	27.833	40.678	19.298	40.678	12.37	19.298

$$Eq\_\rho\_TB_{j,1} := \frac{\rho_s \cdot A_{s\_TB_j} + \rho_w \cdot A_{w\_TB_j}}{A_{s\_TB_j}}$$

$Eq\_\rho\_TB^{\langle 0 \rangle} :=$ ("T 16", "T 6", "Br 30x24_r", "Br 30x24 br", "Br 30x20 r", "Br 30x20 br", "Br 30x16 r", "Br 30x16 br", "Br 20x6 r", "Br 20x6 br", "Br 16x4 r", "Br 16x4 br", "Br 10x6 r", "Br 10x6 br")^T

$Eq\_\rho\_TB =$ ($\frac{lbf \cdot s^2}{in^4}$)

	0	1
0	"T 16"	2.15·10-3
1	"T 6"	1.209·10-3
2	"Br 30x24_r"	2.255·10-3
3	"Br 30x24 br"	2.15·10-3
4	"Br 30x20 r"	2.255·10-3
5	"Br 30x20 br"	2.152·10-3
6	"Br 30x16 r"	2.255·10-3
7	"Br 30x16 br"	2.15·10-3
8	"Br 20x6 r"	2.152·10-3
9	"Br 20x6 br"	1.209·10-3
10	"Br 16x4 r"	2.15·10-3
11	"Br 16x4 br"	1.1·10-3
12	"Br 10x6 r"	1.66·10-3
13	"Br 10x6 br"	1.209·10-3

Valves

The density of the Valves will be calculated by observing that the approach adopted by this project was to approximate the valves influence by increasing the thickness of the pipe until the moment of inertia was increased to 3 times that of the connecting pipe. However, since a lump mass representing the mass of the valve was included in the model the density of the valves will be adjusted such that it is only 10% of the mass of the pipe run that the valve intermediates.

$i := 1..4$

$j := 0..3$

Ranges used to iterate through data

$$PR_{Dt} := \begin{pmatrix} \text{"Pipe Diameter"} & \text{"Pipe Thickness"} \\ 24 & 0.375 \\ 16 & 0.25 \\ 10.75 & 0.25 \\ 6.625 & 0.28 \end{pmatrix}$$

$$Valve_{Dt} := \begin{pmatrix} \text{"Valve Diameter"} & \text{"Valve Thickness"} \\ 24 & 1.258 \\ 16 & 0.838 \\ 10.75 & 0.902 \\ 6.625 & 1.417 \end{pmatrix}$$

$$A_{s\_PR_{i-1}} := \left[\frac{\pi\cdot\left(PR_{Dt_{i,0}}\right)^2}{4} - \frac{\pi\cdot\left(PR_{Dt_{i,0}} - 2\cdot PR_{Dt_{i,1}}\right)^2}{4}\right]$$

$$A_{s\_PR}^T = \begin{pmatrix} 4.314\times10^4 & 1.917\times10^4 & 1.278\times10^4 & 8.651\times10^3 \end{pmatrix}\frac{1}{m^2}\,in^2$$

$$A_{s\_V_{i-1}} := \left[\frac{\pi\cdot\left(Valve_{Dt_{i,0}}\right)^2}{4} - \frac{\pi\cdot\left(Valve_{Dt_{i,0}} - 2\cdot Valve_{Dt_{i,1}}\right)^2}{4}\right]$$

$$A_{s\_V}^T = \begin{pmatrix} 1.393\times10^5 & 6.187\times10^4 & 4.326\times10^4 & 3.594\times10^4 \end{pmatrix}\frac{1}{m^2}\,in^2$$

$$Eq\_\rho\_V_{j,1} := \frac{0.1\cdot\rho_s\cdot A_{s\_PR_j}}{A_{s\_V_j}}$$

$$Eq\_\rho\_V^{\langle 0\rangle} := \begin{pmatrix} \text{"24in Pipe Run"} \\ \text{"16in Pipe Run"} \\ \text{"10.75in Pipe Run"} \\ \text{"6.625in Pipe Run"} \end{pmatrix}$$

$$Eq\_\rho\_V = \begin{pmatrix} \text{"24in Pipe Run"} & 2.246\times10^{-5} \\ \text{"16in Pipe Run"} & 2.247\times10^{-5} \\ \text{"10.75in Pipe Run"} & 2.143\times10^{-5} \\ \text{"6.625in Pipe Run"} & 1.746\times10^{-5} \end{pmatrix}\frac{lbf\cdot s^2}{in^4}$$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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Performer: Crawford/Clark **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

Appendix C.9

Support / Anchorage Capacities

Note: Limiting capacities for each appendix are highlighted yellow in their respective summary sections

Contents

Appendix C.9.1

Capacity Table for Supports / Anchorage Associated with Model 2-6-5

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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Performer: Crawford/Clark **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

PCS Support/Anchorage Capacities for Models 2, 6, & 5

Support	Line #	Direction	Capacity Type	Calculated Anchorage Capacity (kips)	Anchorage Reference	Calculated Support Capacity (kips)	Support Reference
PR-6A*	1-17	V (+Y)	TEN	11.256	[37, App E7]	32.094	App C.9.4
PR-6B*	1-17	V (+Y)	TEN	11.256	[37, App E7]	32.094	App C.9.4
PR-6C*	1-17	V (+Y)	TEN	11.256	[37, App E7]	32.094	App C.9.4
PR-6D*	1-17	V (+Y)	TEN	11.256	[37, App E7]	32.094	App C.9.4
PR-6E*	1-17	V (+Y)	TEN	11.256	[37, App E7]	32.094	App C.9.4
PR-6F*	1-17	V (+Y)	TEN	11.256	[37, App E7]	32.094	App C.9.4
PR-6G*	1-17	V (+Y)	TEN	11.256	[37, App E7]	32.094	App C.9.4
U-Bolt Det 2	1-45	V (+Y)	TEN	4.937	[37, App E6]	11.9	[37, App D12]
	1-45	V (-Y)	COM	4.937	[37, App E6]	5.37	[37, App D12]
	1-45	EW(Z)	LATERAL	0.143	[37, App E6]	0.853	[37, App D12]
Pending U-Bolt	1-45	V (+Y)	TEN	4.522	[37, App E6]	20.709	[37, App D5]
	1-45	V (-Y)	COM	4.522	[37, App E6]	25.434	[37, App D5]
	1-45	EW(Z)	LATERAL	0.507	[37, App E6]	0.853	[37, App D5]
PS-20	1-171	V (-Y)	COM	NA		155.021	[37, App D3]
	1-172	V(+Y)	TEN	14.07	[37, App E6]		
PS-8A	1-13A	V (-Y)	COM	NA		75.565	[37, App D3]
	1-13A	V(+Y)	TEN	14.07	[37, App E6]		
PS-8B	1-14A	V (-Y)	COM	NA		75.565	[37, App D3]
	1-14A	V(+Y)	TEN	14.07	[37, App E6]		
PS-8C	1-15A	V (-Y)	COM	NA		75.565	[37, App D3]
	1-15A	V(+Y)	TEN	14.07	[37, App E6]		
PS-8D	1-16A	V (-Y)	COM	NA		75.565	[37, App D3]
	1-16A	V(+Y)	TEN	14.07	[37, App E6]		
RH-32*	1-30	V (-Y)	TEN	4.755	[37, App E6]	20.709	[37, App D10]
RH-11A	1-30	V (-Y)	TEN	28.14	App C.9.7	14.91	App C.9.5
	1-30	V (+Y)	COM	NA		7.266	[32, App D4]
RH-11B	1-30	V (-Y)	TEN	28.14	App C.9.7	14.91	App C.9.5
	1-30	V (+Y)	COM	NA		7.266	[32, App D4]
PS-4A	1-30	V (-Y)	COM	NA		87.941	[37, App D3]
PS-4B	1-30	V (-Y)	COM	NA		87.941	[37, App D3]
PS-4C	1-30	V (-Y)	COM	NA		87.941	[37, App D3]
PS-4D	1-30	V (-Y)	COM	NA		87.941	[37, App D3]
AIS*	1-48	E (+Z)	TEN	24.16	App C.9.3	13.254	App C.9.3
	1-48	W (-Z)	COM	NA		18.435	App C.9.3
	1-48	NS (X)	FLEXURE	0.815	App C.9.3	0.815	App C.9.3
RH-24A	1-48	V (-Y)	TEN	11.25	[37, App E5]	7.069	App B.10.10
RH-24B	1-48	V (-Y)	TEN	11.25	[37, App E5]	7.069	App B.10.10
RH-19	1-43	V (-Y)	TEN	22.5	[37, App E5]	5.109	App C.9.6
RH-17A	1-43	V (-Y)	TEN	11.25	[37, App E5]	14.91	[37, App D7]
	1-43	V (+Y)	COM	NA		5.829	App C.9.5
RH-17B	1-43	V (-Y)	TEN	11.25	[37, App E5]	14.91	[37, App D7]
	1-43	V (+Y)	COM	NA		5.829	App C.9.5
RH-30*	1-43	S (-X)	TEN	3.47	[37, App E6]	19.491	[37, App D6]
	1-43	N (+X)	COM	NA		21.648	[37, App D6]
	1-43	EW (X)	FLEXURE	3.086	[37, App E6]	0.65	[37, App D6]
RH-25A	1-43	V (-Y)	TEN	11.25		10.354	[37, App D7]
RH-25B	1-43	V (-Y)	TEN	11.25		10.354	[37, App D7]
PS-10A	1-47	V (-Y)	COM	NA		22.1	[37, App D3]
PS-10B	1-47	V (-Y)	COM	NA		22.1	[37, App D3]
PS-10C	1-47	V (-Y)	COM	NA		22.1	[37, App D3]

Table continued on next page

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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Table continued from previous page

AIWS*	1-47	V (Y)	FLEXURE	2.924	[37, App E5]	1.539	[37, App D18]
	1-47	EW (X)	FLEXURE	2.275	[37, App E5]	0.853	[37, App D18]
RH-22A*	1-44	V (-Y)	TEN	1.071	[37, App E5]	0.524	[37, App D11]
	1-44	V (+Y)	COM	NA		0.691	App C.9.5
RH-22B*	1-44	V (-Y)	TEN	1.071	[37, App E5]	0.524	[37, App D11]
	1-44	V (+Y)	COM	NA		0.691	App C.9.5
PS-7	1-44	V(+Y)	FLEXURE	2.2	[37, App E6]	See Breakout Evaluation (App E.9) for Recommendations	
	1-44	V(-Y)	FLEXURE	2.2	[37, App E6]		
	1-44	N(+X)	TEN	6.686	[37, App E6]	3.37 `	App E.6
	1-44	S(-X)	COM	NA	[37, App E6]	3.37 `	App E.6
RH-16A	1-44	V (-Y)	TEN	1.047	[37, App E5]	10.354	[37, App D4]
	1-44	V (+Y)	COM	NA		0.397	App C.9.5
RH-16B*	1-44	V (-Y)	TEN	1.047	[37, App E5]	10.354	[37, App D4]
	1-44	V (+Y)	COM	NA		0.397	App C.9.5
RH-26x	8-14	V (-Y)	TEN	Combined (28.14)	[37, App E5]	52.747	App B.10.10
RH-13A	8-14	V (+Y)	TEN	NA		6.123	App C.9.5
	8-14	V (-Y)	COM	28.14	App C.9.7	14.91	[32, App D4]
RH-13B	8-14	V (+Y)	TEN	NA		6.123	App C.9.5
	8-14	V (-Y)	COM	28.14	App C.9.7	14.91	[32, App D4]

* PR-6, RH-32, AIS, RH-30, AIWS, and RH-22 were released in at least one direction or soften to the point of no influence in the model due to overloading observations from a preliminary iteration (See main body of report for treatment/recommendations regarding each of these individual components)

` U-Bolt analysis in App. E was implemented resulting in a higher u-bolt capacity and thus initiating an alternate controlling capacity component

Combined (28.14) - Indicates that the support shares a common anchorage with another support and the stated value is a place holder with the extended evaluation is shown in App E.8

Appendix C.9.2

Photos Associated with Following Supports

Project:	ATR Life-Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation				
Performer:	A. L. Crawford	**Date:**	09/30/08		
Checker:	R. K. Blandford	**Date:**	09/30/08		

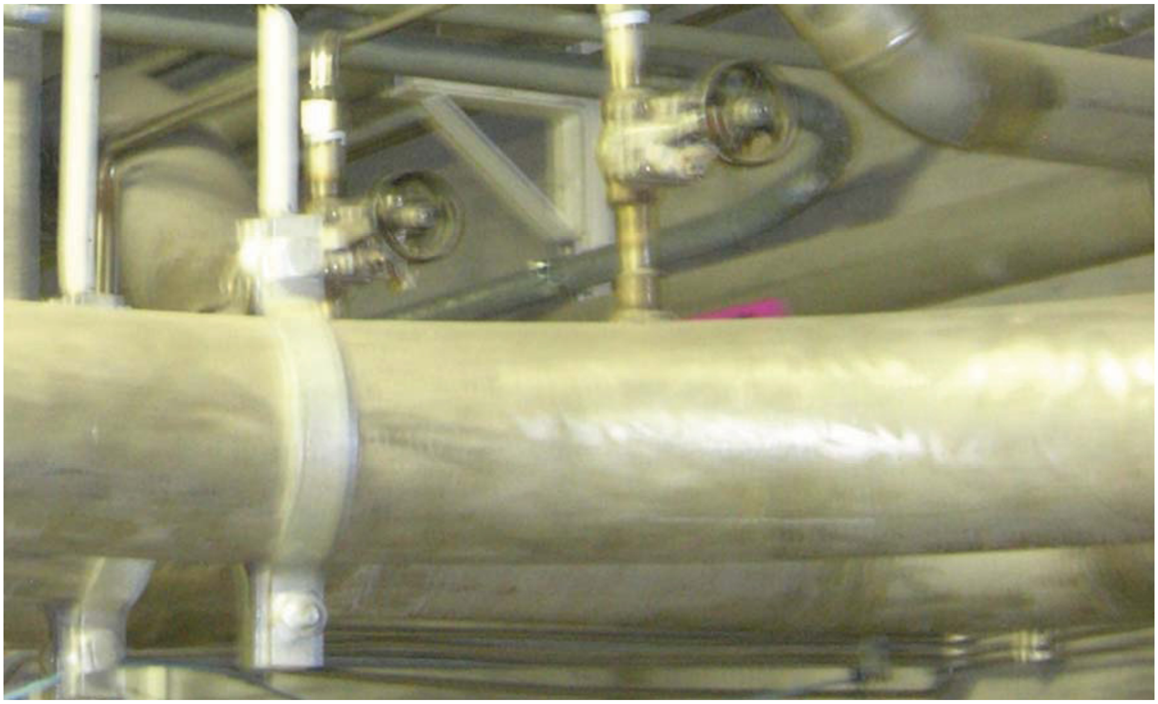

Figure C.9.2- 1. Photo M6-1-44-N71-CSUG-DSCN2691 (RH-16)

Figure C.9.2- 2. Photo M6-1-44-N74-CSUG-DSCN2807 (RH-16)

Figure C.9.2- 3. Photo M6-1-44-N68-WSUG-DSCN2814 (PS-7)

Figure C.9.2- 4. Photo M6-1-44-N43-CSUA-DSCN2848 (RH-22 & RH-17)

Figure C.9.2- 5. Photo M6-1-44-N61-CSUG-DSCN2687 (RH-22)

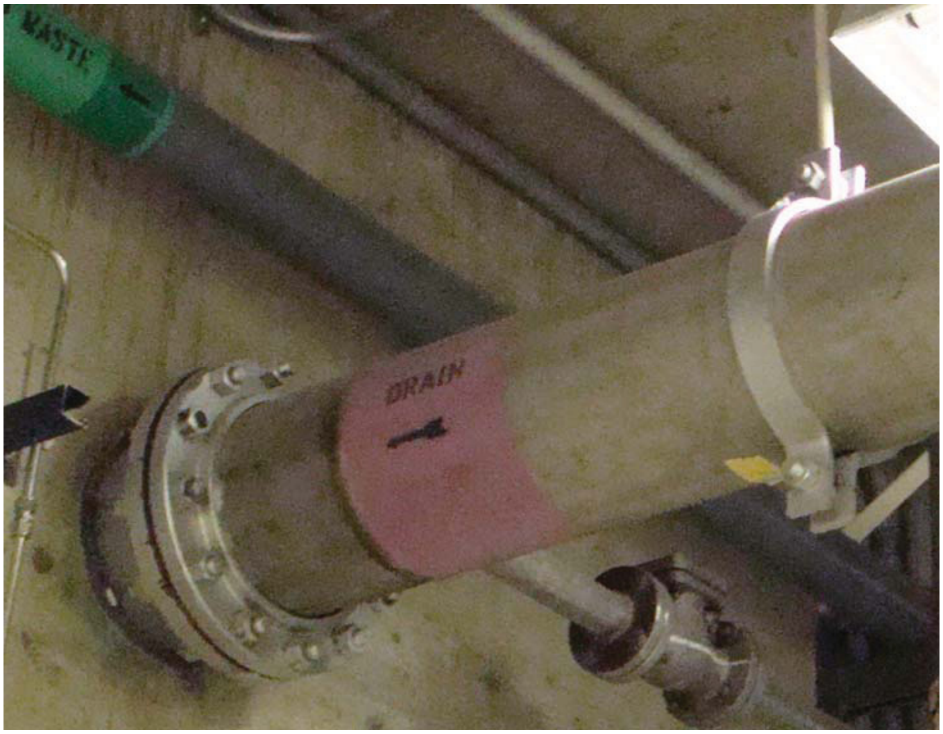

Figure C.9.2- 6. Photo M6-1-43-N27-CSUG-DSC00032 (RH-25)

Figure C.9.2- 7. Photo M6-1-44-N43-CSUG-DSCN2844 (RH-25)

Figure C.9.2- 8. Photo M6-1-43-N13-CSUG-DSCN2824 (Rh-17)

Figure C.9.2- 9. Photo M6-1-43-N6-CBRG-DSCN2840 (RH-19)

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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Figure C.9.2- 10. Photo M6-1-47-N54-FSUG-DSCN2828 (PS-10)

Figure C.9.2- 11. Photo P9-M4-M6-DSCN0002 (PS-10)

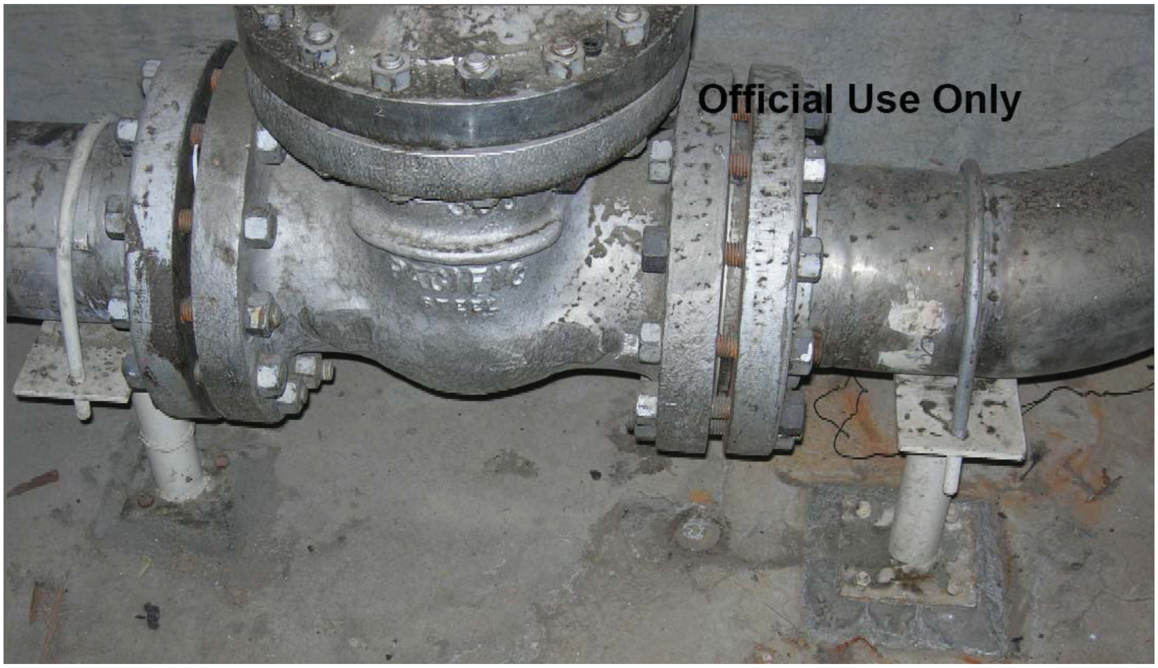

Figure C.9.2- 12. Photo M6-1-47-N57-FSUG-DSCN2827 (PS-10)

Figure C.9.2- 13. Photo P9-M4-M6-DSCN0002 (AIWS, first and second sections of wall strap spacing between GT(1-47) and AIWS (3”(strap) + 36”(concrete))

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Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

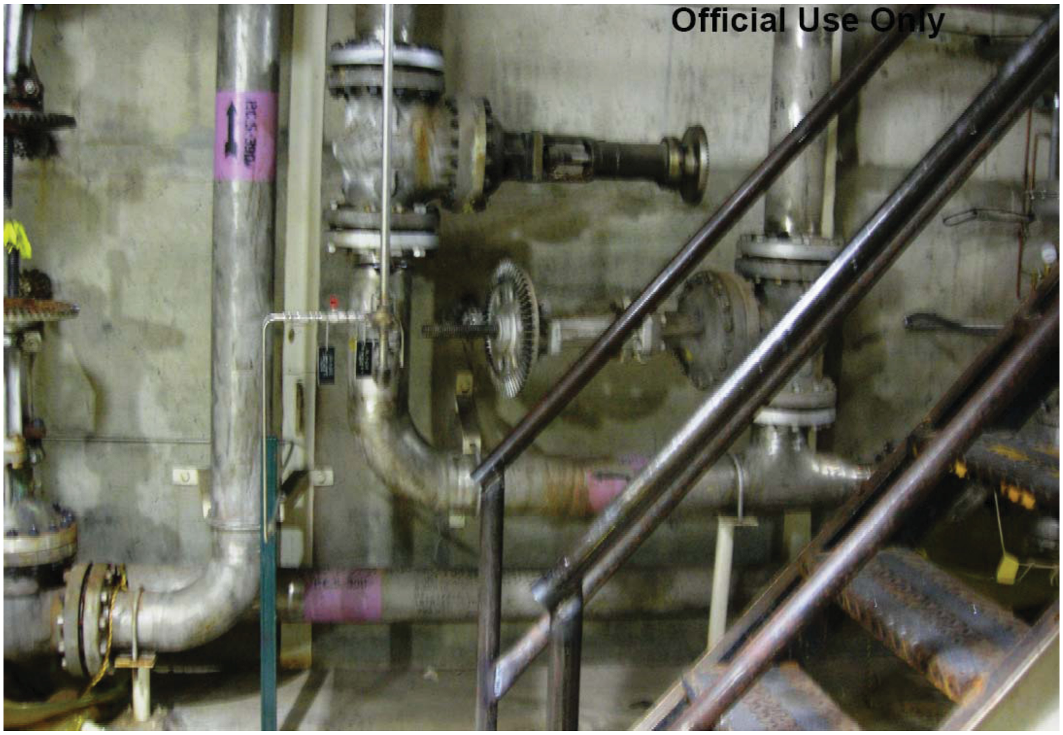

Figure C.9.2- 14. Photo P9-M4-M6-DSCN0003 (AIWS, second and third sections of wall strap spacing between GT(1-47) and AIWS (3"(strap) + 36"(concrete))

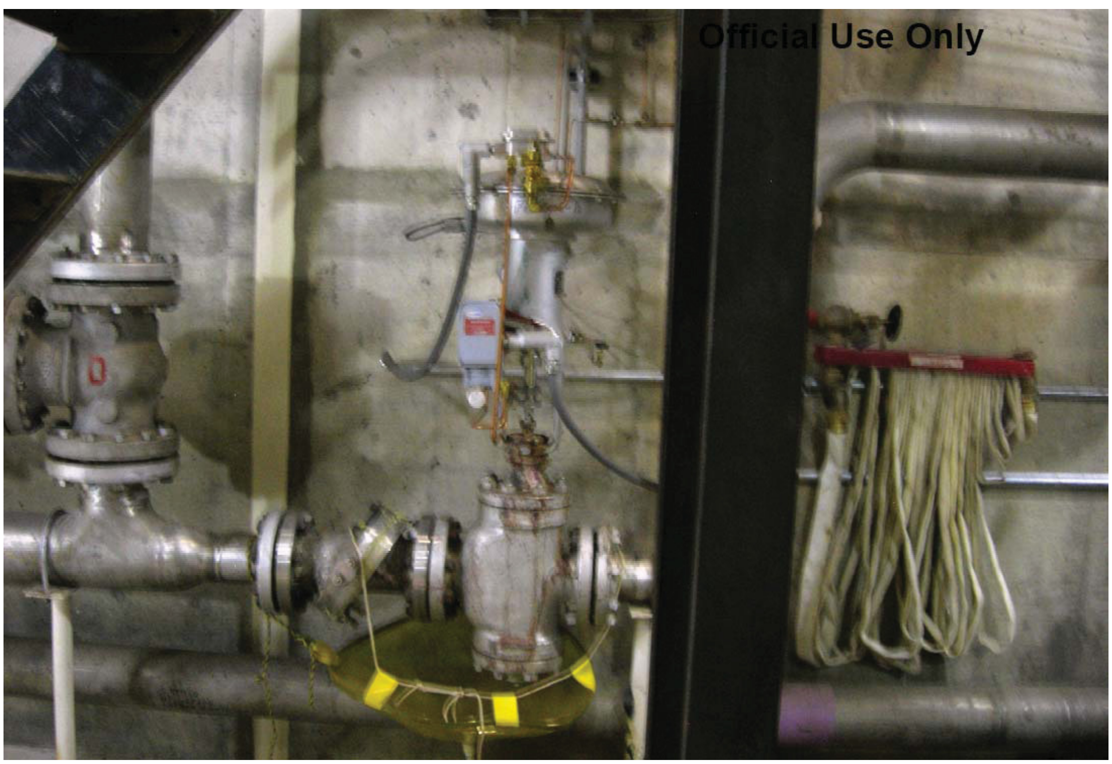

Figure C.9.2- 15. Photo P9-M4-M6-DSCN0004 (AIWS, second, third, and fourth sections of wall strap spacing between GT(1-47) and AIWS (3"(strap) + 36"(concrete))

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Figure C.9.2- 16. Photo P9-M4-M6-DSCN0005 P9-M4-M6-DSCN0004 (AIWS, third and fourth sections of wall strap spacing between GT(1-47) and AIWS (3"(strap) + 36"(concrete))

Figure C.9.2- 17. Photo M6-1-47-N1035-WSUA-DSCN2830

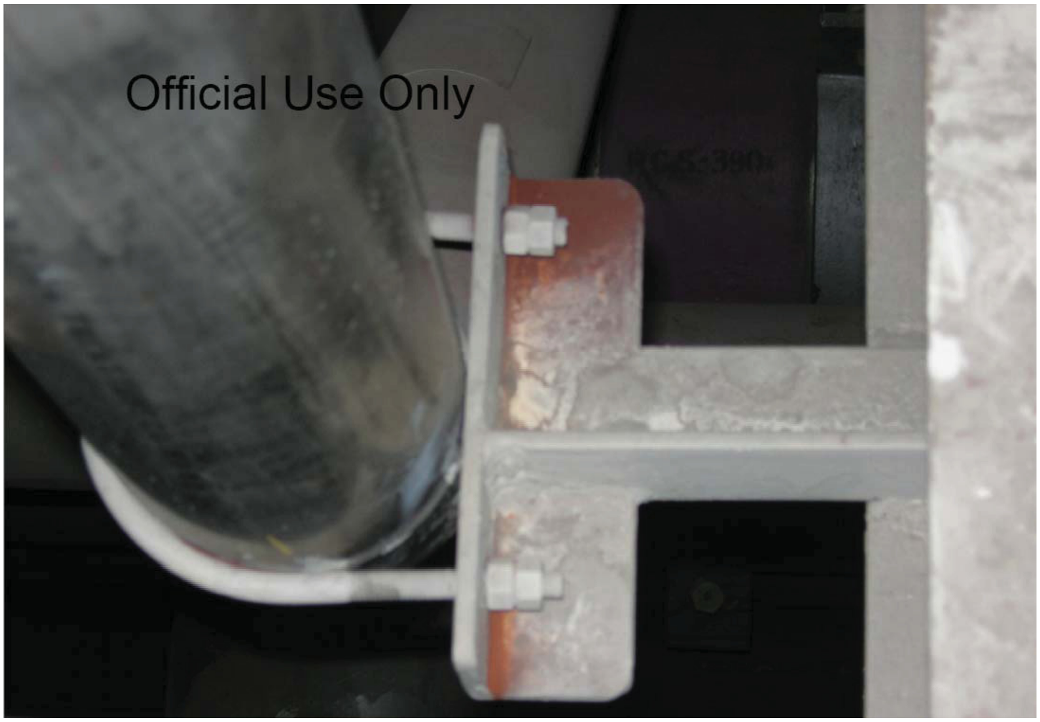

Figure C.9.2- 18. Photo M2-1-48-N44-WSUG-DSCN2773

Figure C.9.2- 19. Photo M2-1-13-N30-CSUG-DSCN2764 (RH-11)

Figure C.9.2- 20. Photo M2-1-30-N62-CSUF-DSCN2738 (RH-32)

Figure C.9.2- 21. Photo P1-M2-DSCN0002-1

Figure C.9.2- 22. Photo P1-M2-DSCN0004

Figure C.9.2- 23. Photo P2-M2-DSCN0001

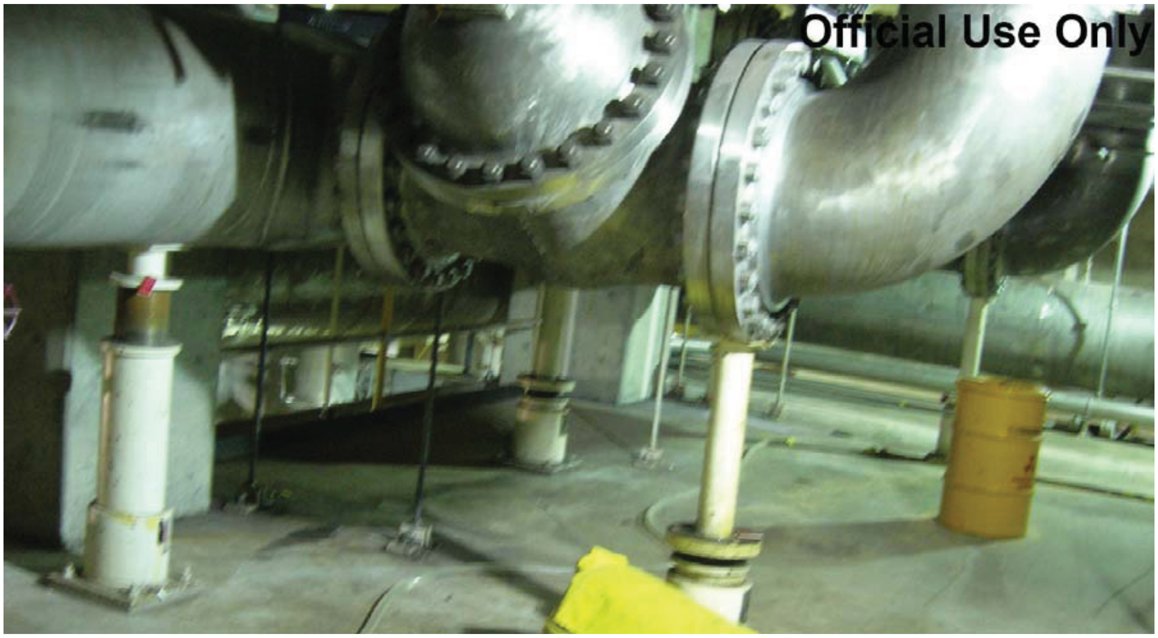

Figure C.9.2- 24. Photo P2-M2-DSCN0003

Figure C.9.2- 25. Photo P2-M2-DSCN0002

Figure C.9.2- 26. Photo P3-M2-DSCN0001

Figure C.9.2- 27. Photo P3-M2-DSCN0002

Figure C.9.2- 28. Photo P3-M2-DSCN0003

Figure C.9.2- 29. Photo M2-1-17-N84-FSUG-DSCN2708

Figure C.9.2- 30. Photo M2-8-14-N1-CPG-DSCN2745 (8-14 ceiling penetration)

Figure C.9.2- 31. Photo M2-1-48-N47-CSUG-DSCN2774

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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Figure C.9.2- 32. Photo M6-1-43-N21-WSUG-DSCN2819

Figure C.9.2- 33. Photo M6-1-44-N43-CSUA-DSCN2845

Figure C.9.2- 34. Photo M3-1-27-N370-CSUG-DSCN2941

Figure C.9.2- 35. Photo M6-1-43-N1-PBRG-DSCN2833

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** R. K. Blandford **Date:** 09/30/08

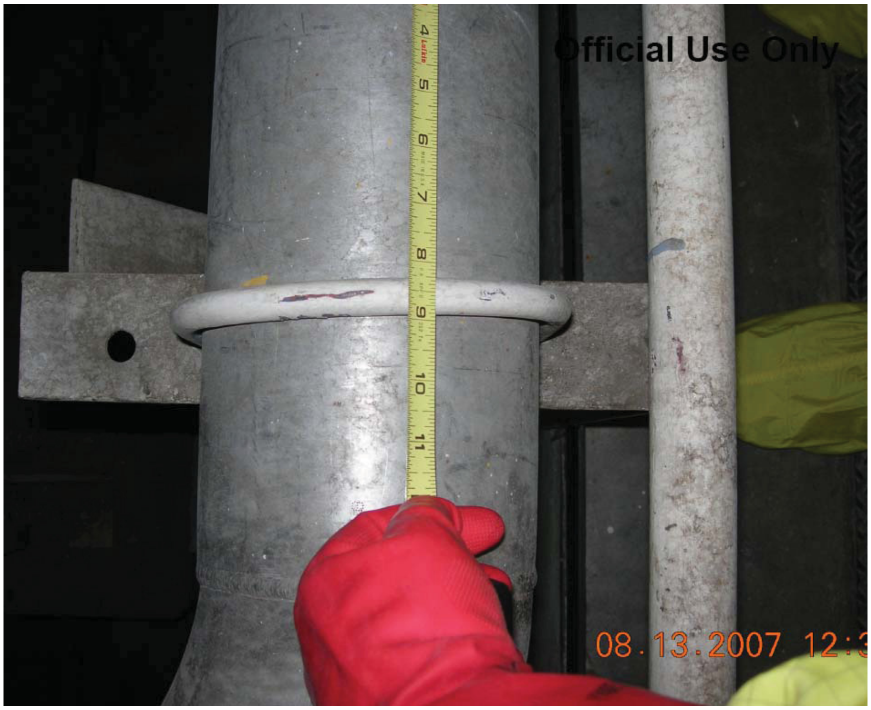

Figure C.9.2- 36. Photo M5-1-45-N8-WSUW-DSCN3298

Figure C.9.2- 37. Photo M5-1-45-N10-WSUA-DSCN3319

Figure C.9.2- 38. Photo M5-1-45-N11-PSYG-DSCN2855

Figure C.9.2- 39. Photo M1-1-2-N10-PRF-DSC00076

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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Figure C.9.2- 40. Photo M1-1-1L-N4-CSPG-DSCN2896

Figure C.9.2- 41. Photo M1-1-170-N131-CSUPC-DSC00028

Appendix C.9.3

Capacity of AIS

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

Angle Iron Support CAPACITY

The Angle Iron Support is comprised of an angle iron section horizontally protruding eastward from an I beam and is fabricated such that its geometry interlocks with the angle iron section interfacing with the vertically traveling PCS pipe. A U-bolt is attached to the interfacing angle iron section to secure the pipe. The capacities for these components and anchorage welds are shown below.

View is in the down/south direction

[M2-1-48-N44-WSUG-DSCN2773]

Component Capacity Overview:

- **Westward Loading:**
  - Compression capacity of angle iron section
- **Eastward Loading:**
  - Tension capacity of angle iron section
  - Tension capacity of u-bolt
  - ***Longitudinal shear capacity of anchorage weld***
- **Lateral (South) Loading:**
  - Flexure capacity of angle iron section
  - Shear capacity of angle iron section
  - Lateral capacity of u-bolt
  - ***Shear + Torsion capacity of weld***
- **Lateral (North) Loading:**
  - Flexure capacity of angle iron section
  - Shear capacity of angle iron section
  - Lateral capacity of u-bolt
  - ***Shear + Torsion capacity of weld***

M2-1-48-N44-WSUA-DSCN2772

(**Procedures from AISC 13th Edition (applying LRFD)**)

$i := 0$

Assigned indices corresponding to number of support types associated with these calculations

Support = 0 (U-Bolt Support)

Relationship between support and corresponding indices

Geometric and Material Properties of Support Components

ANGLE IRON SECTION [M2-1-48-N44-WSUA-DSCN2772]

Material Properties of Angle Iron Section as Defined in the Material Section of this Report:

$F_{yAngle} := 33ksi$ Yield Strength for A7 Carbon Steel

$F_{uAngle} := 60ksi$ Ultimate Strength for A7 Carbon Steel

$E_{Angle} := 29000ksi$ Modulus of Elasticity for A7 Carbon Steel

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Section Properties:

$$L1_{Angle} := \left(1\frac{3}{4}in\right)^T$$
Length of wall leg of angle section as scaled from photo [M2-1-48-N44-WSUG-DSCN2773]

$$L2_{Angle} := \left(1\frac{3}{4}in\right)^T$$
Length of protruding side leg of angle iron section as scaled from photo [M2-1-48-N44-WSUG-DSCN2773] and recognizing section to have equal size legs

$$t_{Angle} := \left(\frac{1}{4}in\right)^T$$
Thickness of angle iron section as scaled from photo [M2-1-48-N44-WSUG-DSCN2773]

$$A_{Angle_i} := \left(L1_{Angle_i} - t_{Angle_i} + L2_{Angle_i}\right) \cdot t_{Angle_i}$$

$$A_{Angle}^T = (0.812)\,in^2$$
Cross sectional area of angle iron section

$$L_{Angle} := \left(2\frac{3}{4}in\right)^T$$
Length of angle iron section from point where welc to I-beam ends to point where lower leg of horizontal angle iron section and interfacing angle iron section meet as scaled from photo [M2-1-48-N44-WSUG-DSCN2773]

$$L_{Free} := \left(L_{Angle} + L2_{Angle} + \frac{4.5in}{2} + \frac{1}{4}in\right)^T$$
Free length between pipe loading and anchorage [M2-1-48-N44-WSUG-DSCN2773] [17]

$$L_{Free_0} = (7)\,in$$

$$I_{AngleX} := \left(0.227in^4\right)^T$$
Moment of Inertia [41, pg 1-51]

$$r_{Angle\_gyration} := (0.529in)^T$$
Radius of gyration [41, 1-51]

$$y_{Angle} := (0.529in)^T$$
Distance from geometric face to neutral axis [41, 1-51]

U-BOLT (U-Bolt 4")

Note: In this analysis the tensile capacity of the u-bolt will be calculated based on the cross sectional area of both u-bolt legs straddling the pipe. Refer to Appendix E.6 for a full calculation of it lateral capacity.

Geometric Properties of U-bolt:

$$D_{ub} := (4.5in)^T$$
Diameter of pipe which the u-bolt supports [17]

$$d_{ub} := \left(\frac{1}{2}in\right)^T$$
Diameter of u-bolt rod [17] [24, Fig 137 ph-55]

ANCHORAGE WELDS

Properties of welds:

$F_{EXX} := 60ksi$ — E6013 weld material ultimate strength [43, pg I-9]

$\theta_{transverse} := \frac{\pi}{2}$ — Angle between loading and traverse welds

$F_{w\_transverse} := 0.60 \cdot F_{EXX} \cdot \left(1.0 + 0.5 \cdot \sin\left(\theta_{transverse}\right)^{1.5}\right)$ (J2-5)

$F_{w\_transverse} = 54\,ksi$ — Nominal Shear Strength of transverse welds

$\theta_{longitudinal} := 0$ — Angle between loading and traverse welds

$F_{w\_longitudinal} := 0.60 \cdot F_{EXX} \cdot \left(1.0 + 0.5 \cdot \sin\left(\theta_{longitudinal}\right)^{1.5}\right)$ (J2-5)

$F_{w\_longitudinal} = 36\,ksi$ — Nominal Shear Strength of longitudinal welds

$\omega := \left(\frac{1}{8} in\right)^{T}$ — Conservatively applied miniumum size of fillet given that thinner joined part (plate) = 1/4" [8, Table J2.4, pg 16.1-96] [M2-1-48-N44-WSUG-DSCN2773]

$L_{w\_traverse} := \left[2\left(L1_{Angle} - t_{Angle}\right) + L2_{Angle}\right]^{T}$ — Traverse length of three traverse welds [M2-1-48-N44-WSUG-DSCN2773]

$L_{w\_longitudinal} := (2 \cdot 1.5in)^{T}$ — Longitudal length of weld longitudinal welds [M2-1-48-N44-WSUG-DSCN2773]

$A_{w\_traverse_i} := L_{w\_traverse_i} \cdot 0.707\, \omega_i$ — Effective area of weld throat of traverse welds

$A_{w\_traverse} = (0.42)\, in^2$

$A_{w\_longitudinal_i} := L_{w\_longitudinal_i} \cdot 0.707\, \omega_i$ — Effective area of weld throat of traverse welds

$A_{w\_longitudinal} = (0.265)\, in^2$

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Capacities For Westward Loading

ANGLE IRON SECTION

Compression, capacity of angle iron section [8, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

$\phi_c := 0.9$ Resistance factor for compression

E2. Slenderness Limitations and Effective Length

Apply E5 to determine the slenderness ratio (KL/r) for single angles

E5. Single Angle Compression Members

The nominal compressive strength of single angle members shall be determined in accordance with Section E3 (compressive Strength for Flexural Buckling of Members Without Slender Elements) or Section E7 (Members with Slender Elements), as appropriate, for axially loaded members, as well as those subject to the slenderness modification of Section E5(a) or E5(b), provided the members meet the criteria imposed.

The effects of eccentricity on single angle members are permitted to be neglected when the members are evaluated as axially loaded compression members using on e of the effective slenderness ratios specified below, provided that : (1) members are loaded at the ends in compression through the same one leg; (2) members are attached by welding or by minimum two-bolt connections; and (3) there are not intermediate transverse loads.

Determine if supports are ***compact (1), non-compact (2),*** *or* ***slender (3)*** *to determine if it is appropriate to apply E3 or E7*

B4. Classification of sections for local buckling (See Case 15 of Table B4.1)

$$b2t_i := \frac{L1_{Angle_i}}{t_{Angle_i}}$$ Width to thickness ratio

$$b2t^T = (7)$$

Definition of λ_p and λ_r from Table B4.1 Case 6 (Flexure in legs of single angles) to be applied in classification logic. λ_p is the separation point between a compact and noncompact member. λ_r is separation point between a noncompact and slender member.

$$\lambda_p := 0.54 \cdot \sqrt{\frac{E_{Angle}}{F_{yAngle}}} \qquad \lambda_r := 0.91 \cdot \sqrt{\frac{E_{Angle}}{F_{yAngle}}}$$

$$Classification_i := \begin{cases} 1 & \text{if } b2t_i \le \lambda_p \\ 2 & \text{if } \lambda_p < b2t_i \le \lambda_r \\ 3 & \text{if } \lambda_r < b2t_i \end{cases}$$

$$Classification^T = (1)$$

Since the angle iron sections are determined to be compact E3 is applicable

(a) For equal-leg angles or unequal leg angles connected through the longer leg that are individual members or are web members of planar trusses with adjacent web members attached to the same side of the gusset plate or chord:

$$L2r_i := \frac{L_{Angle_i}}{r_{Angle\_gyration_i}}$$ Length to radius of gyration ratio

$$KLr_i := \begin{cases} 72 + 0.75 \cdot L2r_i & \text{if } L2r_i \le 80 \\ 32 + 1.25 \cdot L2r_i & \text{if } L2r_i > 80 \end{cases}$$ (E5-1) (E5-2)

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified through classification)

$$F_{e_i} := \frac{\pi^2 E_{Angle}}{\left(KLr_i\right)^2}$$ F_e is the elastic critical buckling stress (E3-4)

$$F_e^T = (49.685)\,ksi$$

Calculating the variables Limit, Op1, and Op2 to be utilized in logic to determine flexural buckling stress.

$$Limit := 4.71 \cdot \sqrt{\frac{E_{Angle}}{F_{yAngle}}}$$

$$Limit = 139.625$$

$$Op1_i := \left(0.658^{\frac{F_{yAngle}}{F_{e_i}}}\right) F_{yAngle} \qquad Op2_i := 0.877 \cdot F_{e_i}$$

$$F_{cr_i} := \begin{cases} Op1_i & \text{if } KLr_i \le Limit \\ Op2_i & \text{if } KLr_i > Limit \end{cases}$$ F_{cr} is the flexural buckling stress (E3-2) (E3-3)

$$F_{cr}^T = (24.991)\,ksi$$

$$\phi P_{n\_SL_i} := \phi_c \cdot F_{cr_i} \cdot A_{Angle_i}$$

$$\boxed{\phi P_{n\_SL}^T = (18.275)\,kip}$$ Design compressive strength

Capacities For Eastward Loading

ANGLE IRON SECTION

Tension, capacity of angle iron section [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D2. Tensile Strength

Must apply section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_Angle_i} := A_{Angle_i}$ — Gross area

2. Net Area

$A_{n\_Angle_i} := A_{g\_Angle_i}$ — Net area

3. Effective Net Area

$U_{Angle} := 0.8$ — Shear lag factor [8, Table D3.1 (case 8) pg 16.1-29]

$A_{e\_Angle_i} := A_{n\_Angle_i} \cdot U_{Angle}$ — Effective net area (D3-1)

(a) For tensile yielding in the gross section:

$P_{n\_Angle\_ty_i} := F_{yAngle} \cdot A_{g\_Angle_i}$ — Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_Angle\_ty\_UL_i} := \phi_{t\_ty} \cdot P_{n\_Angle\_ty_i}$

$\phi P_{n\_Angle\_ty\_UL}^{T} = (24.131)\ kip$ — Design tensile strength

(b) For tensile rupture in the net section:

$P_{n\_Angle\_tr_i} := F_{uAngle} \cdot A_{e\_Angle_i}$ — Nominal axial strength (P_n) (D2-2)

$\phi_{t\_tr} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_Angle\_tr\_UL_i} := \phi_{t\_tr} \cdot P_{n\_Angle\_tr_i}$

$\phi P_{n\_Angle\_tr\_UL}^{T} = (29.25)\ kip$ — Design tensile strength

U-BOLT

Tension, capacity of u-bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$A_{ub_i} := 2 \cdot \left[\pi \cdot \left(\frac{d_{ub_i}}{2} \right)^2 \right]$ — Nominal unthreaded body area for BOTH bolts in combination

$F_{nv\_ub} := 45 \text{ksi}$ — Nominal tensile stress (A307) [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment

$R_{nv\_ub_i} := F_{nv\_ub} \cdot A_{ub_i}$ — Nominal strength (R_n) (J3-1)

$\phi_{b\_sr} := 0.75$ — Resistance factor

$\phi R_{nv\_ub\_UL_i} := \phi_{b\_sr} \cdot R_{nv\_ub_i}$

$\phi R_{nv\_ub\_UL}^{T} = (13.254)\ \text{kip}$ — Design tensile strength

ANCHORAGE WELD

Shear capacity of anchorage weld [8, Ch. J pg 16.1-90 thru 121]

J2. Welds

4. Strength

$\phi_{weld} := 0.75$ — Resistance factor of weld

$R_{n\_weld_i} := \phi_{weld} \cdot \left(F_{w\_transverse} \cdot A_{w\_traverse_i} + F_{w\_longitudinal} \cdot A_{w\_longitudinal_i} \right)$ (J2-4)

$R_{n\_weld} = (24.16)\ \text{kip}$ — Nominal shear strength of weld

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Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

Capacities For Lateral (South) Loading

ANGLE IRON SECTION

Flexure, capacity of angle iron section [8, Ch. F pg 16.1-44 thru 63]

F1. General Provisions

Given resistance factor for shear

$$\phi_b := 0.9$$

Calculate the lateral-torsional buckling modification factor for a nonuniform moment loading on the beam caused by eastward loading of the pipe

$$M_{max}(F, Length) := F \cdot Length$$

Absolute value of maximum moment in the unbraced segment

$$M_A(F, Length) := \frac{3}{4} \cdot F \cdot Length$$

Absolute value of moment at quarter point of the unbraced segment

$$M_B(F, Length) := \frac{1}{2} \cdot F \cdot Length$$

Absolute value of moment at centerline of the unbraced segment

$$M_C(F, Length) := \frac{1}{4} \cdot F \cdot Length$$

Absolute value of moment at three-quarter point of the unbraced segment

$$R_m := 1.0$$

Cross-section monosymmetry parameter (value of 1.0 is assigned because it correlates to singly symmetric members subjected to single curvature bending)

$$C_b(F, Length) := \left(\frac{12.5 \cdot M_{max}(F, Length)}{2.5 \cdot M_{max}(F, Length) + 3 \cdot M_A(F, Length) + 4 \cdot M_B(F, Length) + 3 \cdot M_C(F, Length)} \cdot R_m\right)$$

$$C_b\left(F, L_{Free_i}\right) \rightarrow 1.6666666666666666667$$

F10. Single Angles

First determine value between geometric axis of rotation and extreme fiber to determine yielding moment [8, Table 17-27 pg 17-42]

$$Extreme_i := max\left[\left(L2_{Angle_i} - y_{Angle_i}\right), y_{Angle_i}\right]$$

Point farthest from the neutral axis

$$Extreme^T = (1.221)\ in$$

$$M_{y_i} := \frac{F_{yAngle} \cdot I_{AngleX_i}}{Extreme_i}$$

Equation to calculate yielding moment from moment of inertia and Extreme values [44, Equation 6-74 pg 454]

$$M_y^T = (6.135)\ kip \cdot in$$

Yielding Moment

1. Yielding

$M_{ny} := 1.5 \cdot M_y$

$M_{ny}^T = (9.203)\ kip \cdot in$ — Nominal flexural strength (F10-1)

$\phi M_{ny\_EL} := \phi_b \cdot M_{ny}$

$\phi M_{ny\_EL}^T = (8.282)\ kip \cdot in$ — Design flexural strength

$$\phi F_{ny\_EL\_Tot_i} := \frac{\phi M_{ny\_EL_i}}{L_{Angle_i} + L1_{Angle_i} + \frac{D_{ub_i}}{2}}$$

Converting flexural strength to strength at applied load by dividing the design flexural strength by the moment arm comprised of the angle iron length, the leg length of the horizontal angle iron section, and the radius of the pipe to which the clamp is connected.

$\boxed{\phi F_{ny\_EL\_Tot}^T = (1.227)\ kip}$ — Total design strength of angle iron section given flexural loading

2. Lateral-Torsional Buckling

Calculate the lateral-torsional buckling moment

(i) For bending about one of the geometric axes of an equal-leg angle with no lateral-torsional restraint

(a) With Maximum compression at the toe (applies here for eastward loading)

$C_{bLTB_i} := \min\left(C_b\left(F, L_{Angle_i}\right), 1.5\right)$ — Lateral torsional buckling modification factor with an upper limit of 1.5

$b_{F10.2_i} := L2_{Angle_i}$ — Geometric property of angle iron [8, Table B4.1 (case 6) pg 16.1-16]

$$M_{e_i} := \frac{0.66 \cdot E_{Angle} \cdot \left(b_{F10.2_i}\right)^4 \cdot t_{Angle_i} \cdot C_{bLTB_i}}{\left(L_{Angle_i}\right)^2} \left[\sqrt{1 + 0.78 \cdot \left[\frac{L_{Angle_i} \cdot t_{Angle_i}}{\left(b_{F10.2_i}\right)^2}\right]^2} - 1\right]$$

(F10-4a)

$M_e^T = (173.265)\ kip \cdot in$ — Elastic lateral-torsional buckling moment

M_y shall be taken as 0.80 times the yield moment calculated using the geometric section modulus as applied to this section.

$M_{yi_i} := 0.80 \cdot M_{y_i}$

For single angles without continuous lateral-torsional restraint along the length

(a & b) calculation

$$M_{nLTB_i} := \begin{cases} \left(0.92 - \dfrac{0.17 \cdot M_{e_i}}{M_{yi_i}}\right) \cdot M_{e_i} & \text{if } M_{e_i} \le M_{yi_i} \\ \left(1.92 - 1.17 \cdot \sqrt{\dfrac{M_{yi_i}}{M_{e_i}}}\right) \cdot M_{yi_i} & \text{if } M_{e_i} > M_{yi_i} \\ 1.5 \cdot M_{yi_i} \text{ if } 1.5 M_{yi_i} \le \left(1.92 - 1.17 \cdot \sqrt{\dfrac{M_{yi_i}}{M_{e_i}}}\right) \cdot M_{yi_i} & \text{if } M_{e_i} > M_{yi_i} \end{cases}$$

(F10-2)

(F10-3)

$M_{nLTB}^T = (7.362)\ kip \cdot in$ Nominal flexural strength

$$\phi M_{nLTB\_EL} := \phi_b \cdot M_{nLTB}$$

$\phi M_{nLTB\_EL}^T = (6.626)\ kip \cdot in$ Design flexural strength

$$\phi F_{nLTB\_EL\_Tot_i} := \frac{\phi M_{nLTB\_EL_i}}{L_{Angle_i} + L1_{Angle_i} + \dfrac{D_{ub_i}}{2}}$$

Converting flexural strength to strength at applied load by dividing the design flexural strength by the moment arm comprised of the angle iron length, the leg length of the horizontal angle iron section, and the radius of the pipe to which the clamp is connected.

$\boxed{\phi F_{nLTB\_EL\_Tot}^T = (0.982)\ kip}$ Total design strength of angle iron section given flexural loading

3. Leg Local Buckling

This mode is applicable since the toe of the leg is in compression

*Determine if supports are **compact (1), non-compact (2),** or **slender (3)***

B4. Classification of sections for local buckling (See Case 15 of Table B4.1)

$$b2t_i := \frac{b_{F10.2_i}}{t_{Angle_i}}$$

Width to thickness ratio

$$b2t^T = (7)$$

Definition of λ_p and λ_r from Table B4.1 Case 6 (Flexure in legs of single angles) to be applied in classification logic. λ_p is the separation point between a compact and noncompact member. λ_r is separation point between a noncompact and slender member.

$$\lambda_p := 0.54 \cdot \sqrt{\frac{E_{Angle}}{F_{yAngle}}} \qquad \lambda_r := 0.91 \cdot \sqrt{\frac{E_{Angle}}{F_{yAngle}}}$$

$$Classification_i := \begin{cases} 1 & \text{if } b2t_i \le \lambda_p \\ 2 & \text{if } \lambda_p < b2t_i \le \lambda_r \\ 3 & \text{if } \lambda_r < b2t_i \end{cases}$$

$$Classification^T = (1)$$

(a) For compact sections, the limit state of leg local buckling does not apply.

Shear, capacity of angle iron cross section [8, Ch. G pg 16.1-64 thru 69]

G1. General Provisions

$\phi_v := 0.9$ — Resistance factor for shear

G4. Single Angles

The nominal shear strength, V_n, of a single angle leg shall be determined using equation G2-1 with C_v = 1.0, A_w = bt where b = width of the leg resisting the shear force, in. (mm) and k_v = 1.2.

$C_v := (1 \;\; 1 \;\; 1)^T$ — Web shear coefficient

$A_{w_i} := b_{F10.2_i} \cdot t_{Angle_i}$ — Web area

$k_v := (1.2 \;\; 1.2 \;\; 1.2)$ — Web plate buckling coefficient

$$V_{n_i} := 0.6 \cdot F_{yAngle} \cdot A_{w_i} \cdot C_{v_i} \qquad \text{(G2-1)}$$

$V_n^T = (8.662)\,\text{kip}$ — Nominal shear strength

$\phi V_{n\_EL} := \phi_v \cdot V_n$

$\boxed{\phi V_{n\_EL}^T = (7.796)\,\text{kip}}$ — Design shear strength

U-BOLT

Lateral, capacity of u-bolt [Appendix E.9]

$\phi V_{nv\_ub\_SL} := 3.534\,kip$

Relationship between vertical and horizontal capacity of 6" u-bolt [Appendix E.9]

$\boxed{\phi V_{nv\_ub\_SL} = 3.534\,kip}$

Design lateral strength

ANCHORAGE WELD

- Shear & Torsion capacity of anchorage weld [42, Section 7.4]

For conservatism only the three horizontal welds were considered and two vertical welds on either side of the vertically travelling angle iron leg were neglected in this evaluation. The AISC manual was initially investigated in order to perform this calculation, however, since the table applicable for this particular loading [8, Table 8-8, pg 8-90] only applied to a maximum eccentricity of 3 times that of the north/south weld length it was unapplicable here where the eccentricy was approximately 4.5 that of the north/south weld length. A comparison was performed between that of the AISC table calculation approach [8] and that of Blodgett [42] where a maximum capacity deviation of 30% was calculated and this value will be additionally be applied to the end of this calculation to match the conservatism inherintly contained in the AISC calculations to the following Blodgett cacluations.

$b := 1.5in$

$b = 1.5\,in$

Length of horizontal east/west welds connecting angle iron to I-Beam [M2-1-48-N44-WSUG-DSCN2773]

$d := L1_{Angle}$

$d = (1.75)\,in$

Length of horizontal north/south weld connecting angle iron to I-Beam [M2-1-48-N44-WSUG-DSCN2773]

$$J_w := \frac{(2\cdot b + d)^3}{12} - \frac{b^2\cdot(b + d)^2}{2\cdot b + d}$$

Polar moment of inertia for weld forming a C shape [42, Table 5, pg 7.4-7]

$J_w = (3.928)\,in^3$

$A_w := 2\cdot b + d$

Total effective area of weld throat treated as a line

$A_w = (4.75)\,in$

$$c_v := \frac{L1_{Angle}}{2}$$

Vertical c along east/west line between east/west welds symetrically dividing weld alignment

$c_v = (0.875)\,in$

$$c_h := \frac{\left(\frac{b}{2}\right)\cdot b\cdot\omega + \left(\frac{b}{2}\right)\cdot b\cdot\omega + (b)\cdot d\cdot\omega}{b\cdot\omega + b\cdot\omega + d\cdot\omega}$$

Horizontal c calculated from point between east/west welds closest to pipe [Statics, pg 211]

$$c_h = 1.026\ \text{in}$$

$$L_{loading} := L_{Free_0} + c_h$$

Distance from load to center of gravity

$$L_{loading} = (8.026\ )\ \text{in}$$

$$f_r := \min\left(F_{w\_transverse}, F_{w\_longitudinal}\right)$$

Conservative minimum nominal stress in welds

$$f_r = 3.6 \times 10^4\ \text{psi}$$

$$\phi := 0.75$$

Resistance factor [8, pg 16.1-100]

$$\phi R_n := \frac{\phi\cdot f_r\cdot\omega}{\sqrt{\left(\frac{L_{loading}\cdot c_h}{J_w}\right)^2 + \left(\frac{L_{loading}\cdot c_v}{J_w} + \frac{1}{A_w}\right)^2}}$$

Design strength of weld [42, 7.4-11]

$$\phi R_n = 1.165 \times 10^3\ \text{lbf}$$

$$\phi R_{n\_Blog2AISC} := \phi R_n\cdot(1 - 0.30)$$

Design strength of weld considering 30% nockdown factor to acquire AISC conservatism in above Blodgett calculation.

$$\phi R_{n\_Blog2AISC} = 815.478\ \text{lbf}$$

Capacities For Lateral (North) Loading

ANGLE IRON SECTION

Flexure, capacity of angle iron section [8, Ch. F pg 16.1-44 thru 63]

F1. General Provisions

Given resistance factor for shear

$$\phi_b := 0.9$$

Calculate the lateral-torsional buckling modification factor for a nonuniform moment loading on the beam caused by westward loading of the pipe

$$M_{max}(F, Length) := F \cdot Length$$

Absolute value of maximum moment in the unbraced segment

$$M_A(F, Length) := \frac{3}{4} \cdot F \cdot Length$$

Absolute value of moment at quarter point of the unbraced segment

$$M_B(F, Length) := \frac{1}{2} \cdot F \cdot Length$$

Absolute value of moment at centerline of the unbraced segment

$$M_C(F, Length) := \frac{1}{4} \cdot F \cdot Length$$

Absolute value of moment at three-quarter point of the unbraced segment

$$R_m := 1.0$$

Cross-section monosymmetry parameter (value of 1.0 is assigned because it correlates to singly symmetric members subjected to single curvature bending)

$$C_b(F, Length) := \left(\frac{12.5 \cdot M_{max}(F, Length)}{2.5 \cdot M_{max}(F, Length) + 3 \cdot M_A(F, Length) + 4 \cdot M_B(F, Length) + 3 \cdot M_C(F, Length)} \cdot R_m \right)$$

$$C_b\left(F, L_{Free_i}\right) \rightarrow 1.6666666666666666667$$

F10. Single Angles

First determine value between geometric axis of rotation and extreme fiber to determine yielding moment [8, Table 17-27 pg 17-42]

$$Extreme_i := \max\left[\left(L2_{Angle_i} - y_{Angle_i}\right), y_{Angle_i}\right]$$

Point farthest from the neutral axis

$$Extreme^T = (1.221)\ in$$

$$M_{y_i} := \frac{F_{yAngle} \cdot I_{AngleX_i}}{Extreme_i}$$

Equation to calculate yielding moment from moment of inertia and Extreme values [Mechanics of Materials, Equation 6-74 pg 454]

$$M_y^T = (6.135)\ kip \cdot in$$

Yielding Moment

1. Yielding

$M_{ny} := 1.5 \cdot M_y$

Nominal flexural strength (F10-1)

$M_{ny}^T = (9.203)\ kip \cdot in$

$\phi M_{ny\_WL} := \phi_b \cdot M_{ny}$

Design flexural strength

$\phi M_{ny\_WL}^T = (8.282)\ kip \cdot in$

$$\phi F_{ny\_WL\_Tot_i} := \frac{\phi M_{ny\_WL_i}}{L_{Angle_i} + L1_{Angle_i} + \frac{D_{ub_i}}{2}}$$

Converting flexural strength to strength at applied load by dividing the design flexural strength by the moment arm comprised of the angle iron length, the leg length of the horizontal angle iron section, and the radius of the pipe to which the clamp is connected.

$\phi F_{ny\_WL\_Tot}^T = (1.227)\ kip$

Total design strength of angle iron section given flexural loading

2. Lateral-Torsional Buckling

Calculate the lateral-torsional buckling moment

(i) For bending about one of the geometric axes of an equal-leg angle with no lateral-torsional restraint

(a) With maximum tension at the toe (applies here for west loading)

$C_{bLTB_i} := \min\left(C_b\left(F, L_{Angle_i}\right), 1.5\right)$ Lateral torsional buckling modification factor with an upper limit of 1.5

$b_{F10.2_i} := L2_{Angle_i}$ Geometric property of angle iron [8, Table B4.1 (case 6) pg 16.1-16]

$$M_{e_i} := \frac{0.66 \cdot E_{Angle} \cdot \left(b_{F10.2_i}\right)^4 \cdot t_{Angle_i} \cdot C_{bLTB_i}}{\left(L_{Angle_i}\right)^2} \left[\sqrt{1 + 0.78 \cdot \left[\frac{L_{Angle_i} \cdot t_{Angle_i}}{\left(b_{F10.2_i}\right)^2}\right]^2} + 1\right]$$

(F10-4a)

$M_e^T = \left(1.798 \times 10^4\right) kip \cdot in$ Elastic lateral-torsional buckling moment

M_y shall be taken as 0.80 times the yield moment calculated using the geometric section modulus as applied to this section.

$M_{yi_i} := 0.80 \cdot M_{y_i}$

For single angles without continuous lateral-torsional restraint along the length

(a & b) calculation

$$M_{nLTB_i} := \begin{cases} \left(0.92 - \dfrac{0.17 \cdot M_{e_i}}{M_{yi_i}}\right) \cdot M_{e_i} & \text{if } M_{e_i} \le M_{yi_i} \\ \left(1.92 - 1.17 \cdot \sqrt{\dfrac{M_{yi_i}}{M_{e_i}}}\right) \cdot M_{yi_i} & \text{if } M_{e_i} > M_{yi_i} \\ 1.5 \cdot M_{yi_i} & \text{if } 1.5 M_{yi_i} \le \left(1.92 - 1.17 \cdot \sqrt{\dfrac{M_{yi_i}}{M_{e_i}}}\right) \cdot M_{yi_i} \text{ if } M_{e_i} > M_{yi_i} \end{cases}$$

(F10-2)

(F10-3)

$M_{nLTB}^{T} = (7.362)\ kip \cdot in$ Nominal flexural strength

$\phi M_{nLTB\_WL} := \phi_b \cdot M_{nLTB}$

$\phi M_{nLTB\_WL}^{T} = (6.626)\ kip \cdot in$ Design flexural strength

$$\phi F_{nLTB\_WL\_Tot_i} := \frac{\phi M_{nLTB\_WL_i}}{L_{Angle_i} + L1_{Angle_i} + \dfrac{D_{ub_i}}{2}}$$

Converting flexural strength to strength at applied load by dividing the design flexural strength by the moment arm comprised of the angle iron length, the leg length of the horizontal angle iron section, and the radius of the pipe to which the clamp is connected.

$\boxed{\phi F_{nLTB\_WL\_Tot}^{T} = (0.982)\ kip}$ Total design strength of angle iron section given flexural loading

Shear, capacity of angle iron cross section [8, Ch. G pg 16.1-64 thru 69]

G1. General Provisions

$\phi_v := 0.9$ Resistance factor for shear

G4. Single Angles

The nomial shear strength, V_n, of a single angle leg shall be determined using equation G2-1 with C_v = 1.0, A_w = bt where b = width of the leg resisting the shear force, in. (mm) and k_v = 1.2.

$C_v := (1\ \ 1\ \ 1)^T$ Web shear coefficient

$A_{weld_i} := b_{F10.2_i} \cdot t_{Angle_i}$ Web area

$k_v := (1.2 \;\; 1.2 \;\; 1.2)$ Web plate buckling coefficient

$V_{n_i} := 0.6 \cdot F_{yAngle} \cdot A_{weld_i} \cdot C_{v_i}$ (G2-1)

$V_n^T = (8.662)\,kip$ Nominal shear strength

$\phi V_{n\_WL} := \phi_v \cdot V_n$

$\phi V_{n\_WL}^T = (7.796)\,kip$ Design shear strength

U-BOLT

Lateral, capacity of u-bolt [Appendix E.9]

$\phi V_{nv\_ub\_NL} := 3.534 kip$ Relationship between vertical and horizontal capacity of 6" u-bolt [Appendix E.9]

$\phi V_{nv\_ub\_NL} = 3.534\,kip$ Design lateral strength

ANCHORAGE WELD

- Shear & Torsion capacity of anchorage weld [42, Section 7.4]

For conservatism only the three horizontal welds were considered and two vertical welds on either side of the vertically travelling angle iron leg were neglected in this evaluation. The AISC manual was initially investigated in order to perform this calculation, however, since the table applicable for this particular loading [8, Table 8-8, pg 8-90] only applied to a maximum eccentricity of 3 times that of the north/south weld length it was unapplicable here where the eccentricy was approximately 4.5 that of the north/south weld length. A comparison was performed between that of the AISC table calculation approach [??] and that of Blodgett [42] where a maximum capacity deviation of 30% was calculated and this value will be additionally be applied to the end of this calculation to match the conservatism inherintly contained in the AISC calculations to the following Blodgett cacluations.

$b := 1.5 in$ Length of horizontal east/west welds connecting angle iron to I-Beam [M2-1-48-N44-WSUG-DSCN2772]

$b = 1.5\,in$

$d := L1_{Angle}$ Length of horizontal north/south weld connecting angle iron to I-Beam [M2-1-48-N44-WSUG-DSCN2772]

$d = (1.75)\,in$

$$J_w := \frac{(2 \cdot b + d)^3}{12} - \frac{b^2 \cdot (b + d)^2}{2 \cdot b + d}$$ Polar moment of inertia for weld forming a C shape [42, Table 5, pg 7.4-7]

$J_w = (3.928)\,in^3$

$A_w := 2 \cdot b + d$ Total effective area of weld throat treated as a line

$A_w = (4.75)\,in$

$$c_v := \frac{L1_{Angle}}{2}$$

Vertical c along east/west line between east/west welds symetrically dividing weld alignment

$$c_v = (0.875)\ in$$

$$c_h := \frac{\left(\frac{b}{2}\right)\cdot b\cdot\omega + \left(\frac{b}{2}\right)\cdot b\cdot\omega + (b)\cdot d\cdot\omega}{b\cdot\omega + b\cdot\omega + d\cdot\omega}$$

Horizontal c calculated from point between east/west welds closest to pipe [Statics, pg 211]

$$c_h = 1.026\ in$$

$$L_{loading} := L_{Free_0} + c_h$$

Distance from load to center of gravity

$$L_{loading} = (8.026)\ in$$

$$f_r := \min\left(F_{w\_transverse}, F_{w\_longitudinal}\right)$$

Conservative minimum nominal stress in welds

$$f_r = 3.6 \times 10^4\ psi$$

$$\phi := 0.75$$

Resistance factor [8, pg 16.1-100]

$$\phi R_n := \frac{\phi\cdot f_r\cdot\omega}{\sqrt{\left(\frac{L_{loading}\cdot c_h}{J_w}\right)^2 + \left(\frac{L_{loading}\cdot c_v}{J_w} + \frac{1}{A_w}\right)^2}}$$

Design strength of weld [42, 7.4-11]

$$\phi R_n = 1.165 \times 10^3\ lbf$$

$$\phi R_{n\_Blog2AISC} := \phi R_n\cdot(1 - 0.30)$$

Design strength of weld considering 30% nockdown factor to acquire AISC conservatism in above Blodgett calculation.

$$\phi R_{n\_Blog2AISC} = 815.478\ lbf$$

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SUMMARY OF RESULTS

Capacities For Westward Loading

ANGLE IRON SECTION

Compression, capacity of angle iron section [8, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

E2. Slenderness Limitations and Effective Length

E5. Single Angle Compression Members

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified through classificatic

$$\phi P_{n\_SL}^{\ T} = (18.275)\ kip$$

Design compressive strength

Capacities For Eastward Loading

ANGLE IRON SECTION

Tension, capacity of angle iron section [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_Angle\_ty\_UL}^{\ T} = (24.131)\ kip$$

Design tensile strength

(b) For tensile rupture in the net section:

$$\phi P_{n\_Angle\_tr\_UL}^{\ T} = (29.25)\ kip$$

Design tensile strength

U-BOLT

Tension, capacity of u-bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nv\_ub\_UL}^{\ T} = (13.254)\ kip$$

Design tensile strength

ANCHORAGE WELD

Shear capacity of anchorage weld [8, Ch. J pg 16.1-90 thru 121]

$$R_{n\_weld} = (24.16)\ kip$$

Nominal shear strength of weld

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Capacities For Lateral (South) Loading

ANGLE IRON SECTION

Flexure, capacity of angle iron section [8, Ch. F pg 16.1-44 thru 63]

F1. General Provisions

F10. Single Angles

1. Yielding

$$\phi F_{ny\_EL\_Tot}^{T} = (1.227)\ kip$$

Total design strength of angle iron section given flexural loading

2. Lateral-Torsional Buckling

$$\phi F_{nLTB\_EL\_Tot}^{T} = (0.982)\ kip$$

Total design strength of angle iron section given flexural loading

3. Leg Local Buckling

(a) For compact sections, the limit state of leg local buckling does not apply.

Shear, capacity of angle iron cross section [8, Ch. G pg 16.1-64 thru 69]

G1. General Provisions

G4. Single Angles

$$\phi V_{n\_EL}^{T} = (7.796)\ kip$$

Design shear strength

U-BOLT

Lateral, capacity of u-bolt [Appendix E.9]

$$\phi V_{nv\_ub\_SL} = 3.534\ kip$$

Design lateral strength

ANCHORAGE WELD

- Shear & Torsion capacity of anchorage weld [42, Section 7.4]

$$\phi R_{n\_Blog2AISC} = 0.815\ kip$$

Design strength of weld considering 30% nockdown factor to acquire 8 conservatism in above Blodgett calculation.

Capacities For Lateral (North) Loading

ANGLE IRON SECTION

Flexure, capacity of angle iron section [8, Ch. F pg 16.1-44 thru 63]

F1. General Provisions

F10. Single Angles

1. Yielding

$$\phi F_{ny\_WL\_Tot}^{T} = (1.227)\ kip$$

Total design strength of angle iron section given flexural loading

2. Lateral-Torsional Buckling

$$\phi F_{nLTB\_WL\_Tot}^{T} = (0.982)\,kip$$

Total design strength of angle iron section given flexural loading

Shear, capacity of angle iron cross section [8, Ch. G pg 16.1-64 thru 69]

G1. General Provisions

G4. Single Angles

$$\phi V_{n\_WL}^{T} = (7.796)\,kip$$

Design shear strength

U-BOLT

Lateral, capacity of u-bolt [Appendix E.9]

$$\phi V_{nv\_ub\_NL} = 3.534\,kip$$

Design lateral strength

ANCHORAGE WELD

- Shear & Torsion capacity of anchorage weld [42, Section 7.4]

$$\phi R_{n\_Blog2AISC} = 815.478\,lbf$$

Design strength of weld considering 30% nockdown factor to acquire AISC conservatism in above Blodgett calculation.

Appendix C.9.4

Capacity of PR-6

PR-6 CAPACITY

The PR-6 supports are composed of two pairs of short angle iron sections anchored to the floor, a horizontal bolt connecting each pair to a vertically oriented eye rod, and a pair of channel iron sections spaning across the top of a horizontally travelling PCS pipe preventing upward movment. The capacities for these components are calculated below, however, are contained in [37, Appendix E7]

Component Capacity Overview:

- Upward Loading:
- Flexure capacity of channel iron sections
- Shear capacity of channel iron sections
- Tension capacity of eye rods
- Tension capacity of double angle iron tie downs
- Shear capacity of double angle iron tie downs' bolts

Procedures from AISC 13th Edition (Applying LRFD)

NOTE: These calculations encompass the 7 identical PR-6 supports.

$i := 0$ Assigned indices corresponding to number of support types associated with these calculations

Support =	0 (PR-6)

Relationship between support and corresponding indices

Geometric and Material Properties of Support Components

CHANNEL IRON SECTIONS (5 C 9.0 x 3' - 1.5" lg [23])

Material Properties of Channel Iron Sections:

$F_{y\_Ch} := 33ksi$	Yield Strength	ASTM (A7)
$F_{u\_Ch} := 60ksi$	Ultimate Strength	ASTM (A7)
$E_{Ch} := 29000ksi$	Modulus of Elasticity	AISC Symbols definition

Geometric Properties of Channel Iron Sections:

$t_{Ch\_web} := (0.325in)^T$ Thickness of channel iron section web [8, Table 1-5, pg 1-34], [23, Detail 29]

$t_{Ch\_flange} := (0.320in)^T$ Thickness of channel iron section flange [8, Table 1-5, pg 1-34], [23, Detail 29]

$w_{Ch\_flange} := (1.89in)^T$ Width of upper portion of angle iron [8, Table 1-5, pg 1-34], [23, Detail 29]

$depth_{Ch} := (5in)^T$ — Depth of channel iron sections [8, Table 1-5, pg 1-34], [23, Detail 29]

$h_{Ch\_web} := (3.5in)^T$ — Height of channel iron web [8, Table 1-5, pg 1-34], [23, Detail 29]

$A_{Ch} := \left(2.64in^2\right)^T$ — Area of channel iron sections [8, Table 1-5, pg 1-34], [23, Detail 29]

$L_{b\_Ch} := \left(31\frac{1}{2}in\right)^T$ — Length of channel iron between eye rods [23, Detail 29]

$r_{gyrationX\_Ch} := (1.83in)^T$ — Radius of gyration of channel iron sections about their horizontal axis [8, Table 1-5, pg 1-34], [23, Detail 29]

$r_{gyrationY\_Ch} := (0.486in)^T$ — Radius of gyration of channel iron sections about their vertical axis [8, Table 1-5, pg 1-34], [23, Detail 29]

$Z_{x\_Ch} := \left(4.39in^3\right)^T$ — Plastic section modulus about the x-axis [8, Table 1-5, pg 1-34], [23, Detail 29]

$S_{x\_Ch} := \left(3.56in^3\right)^T$ — Elastic section modulus about the x-axis [8, Table 1-5, pg 1-34], [23, Detail 29]

$C_{w\_Ch} := \left(2.93in^6\right)^T$ — Warping constant [8, Table 1-5, pg 1-34], [23, Detail 29]

$I_{y\_Ch} := \left(0.624in^4\right)^T$ — Moment of inertia about y axis [8, Table 1-5, pg 1-34], [23, Detail 29

$h_{o\_Ch} := (4.68in)^T$

$r_{ts\_Ch} := (0.617in)^T$

$J_{Ch} := \left(0.109in^4\right)^T$

EYE RODS (Welded Eye Rod FIG 278 1" [20])

Material Properties of Upper Eye Rod:

$F_{y\_I} := 33ksi$	Yield Strength, ksi	ASTM (A7)
$F_{u\_I} := 60ksi$	Ultimate Strength, ksi	ASTM (A7)
$E_I := 29000ksi$	Modulus of Elasticity, ksi	AISC Symbols definition

Geometric Properties of Upper Eye Rod:

$d_I := (1\,in)^T$ — Unthreaded diameter of eye rod, in. (mm) [24, Fig 278]

$Z_{I_i} := \frac{\left(d_{I_i}\right)^3}{6}$ — Plastic section modulus about the axis of bending, in.^{3} (mm^3) [24, Table 17-27]

ANGLE IRON ANCHORS (Angle Iron 3" x 4" x 3/8" [23])

Material Properties of Angle Iron:

$F_{yAngle} := 33ksi$	Yield Strength	ASTM (A7)
$F_{uAngle} := 60ksi$	Ultimate Strength	ASTM (A7)
$E_{Angle} := 29000ksi$	Modulus of Elasticity	AISC Symbols definition

Geometric Properties of Angle Iron

The holes in the angle iron sections will be conservatively treated to be 1/16" larger than that specified in drawing [23, detail 29] and the bolt will be treated as 1/8" less than that specified for 1" eye rods.

$t_{Angle} := \left(\frac{3}{8}in\right)^T$ — Scaled thickness of angle iron section

$L1_{Angle} := (3in)^T$ — Length of horizontal portion of angle iron

$L2_{Angle} := (4in)^T$ — Length of vertical portion of angle iron

$w_{Angle} := (3in)^T$ — Width of angle iron [23, detail 29]

$A_{Angle_i} := t_{Angle_i} \cdot w_{Angle_i}$

$A_{Angle} = (1.125)\,in^2$ — Cross sectional area of vertical leg of angle iron sections

$d_{Angle\_bolt} := (1in)^T$ — Conservative diameter of bolt [23, detail 29]

$d_{Angle\_hole} := \left(1\frac{1}{8}in\right)^T$ — Conservative diameter of vertical leg of angle iron section bolt hole [23, detail 29]

$a_{parrallel\_Angle} := \left(\frac{9}{16}in\right)^T$ — Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force, in. (mm) hand calculated from [23, detail 29]

$$a_{normal\_Angle_i} := \frac{w_{Angle_i} - d_{Angle\_hole_i}}{2}$$

$$a_{normal\_Angle}^{T} = (0.937)\ in$$

Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force, in. (mm) [24, Fig 212]

Capacities For Upward Loading

CHANNEL IRON SECTIONS

Flexure, capacity of channel iron sections [8, Ch. F pg 16.1-44 thru 63]

To evaluate the flexural capacity of the channel iron sections in parralel each section will be divided into two parts and treated as cantilever channel iron sections. Since this will result in four cantilever channel iron sections the resulting flexural capacity will be multiplied by a factor or 4 at the point where the moment capacity is converted into a force capacity.

F1. General Provisions

Given resistance factor for shear

$$\phi_b := 0.9$$

Calculate the lateral-torsional buckling modification factor for a nonuniform moment loading on the beam caused by downward loading of the pipe

$$M_{max}(F, Length) := F \cdot Length$$

Absolute value of maximum moment in the unbraced segment

$$M_A(F, Length) := \frac{3}{4} \cdot F \cdot Length$$

Absolute value of moment at quarter point of the unbraced segment

$$M_B(F, Length) := \frac{1}{2} \cdot F \cdot Length$$

Absolute value of moment at centerline of the unbraced segment

$$M_C(F, Length) := \frac{1}{4} \cdot F \cdot Length$$

Absolute value of moment at three-quarter point of the unbraced segment

$$R_m := 1.0$$

Cross-section monosymmetry parameter (value of 1.0 is assigned because it correlates to singly symmetric members subjected to single curvature bending)

$$C_b(F, Length) := \left(\frac{12.5 \cdot M_{max}(F, Length)}{2.5 \cdot M_{max}(F, Length) + 3 \cdot M_A(F, Length) + 4 \cdot M_B(F, Length) + 3 \cdot M_C(F, Length)} \cdot R_m \right)$$

(F1-1)

$$C_b\left(F, L_{Angle_i}\right) \rightarrow 1.6666666666666666667$$

Determine if channel FLANGES are ***compact (1), non-compact (2),*** *or* ***slender (3)***

B4. Classification of sections for local buckling (See Case 1 of Table B4.1)

$$b2t_i := \frac{w_{Ch\_flange_i}}{t_{Ch\_flange_i}}$$

Width to thickness ratio

$$b2t^T = (5.906)$$

Definition of λ_p and λ_r from Table B4.1 Case 6 (Flexure in legs of single angles) to be applied in classification logic. λ_p is the separation point between a compact and noncompact member. λ_r is separation point between a noncompact and slender member.

$$\lambda_p := 0.38 \cdot \sqrt{\frac{E_{Angle}}{F_{yAngle}}} \qquad \lambda_r := 1 \cdot \sqrt{\frac{E_{Angle}}{F_{yAngle}}}$$

$$Classification_i := \begin{cases} 1 & \text{if } b2t_i \le \lambda_p \\ 2 & \text{if } \lambda_p < b2t_i \le \lambda_r \\ 3 & \text{if } \lambda_r < b2t_i \end{cases}$$

$$Classification^T = (1)$$

Determine if channel WEBS are ***compact (1), non-compact (2),*** *or* ***slender (3)***

B4. Classification of sections for local buckling (See Case 9 of Table B4.1)

$$b2t_i := \frac{h_{Ch\_web_i}}{t_{Ch\_web_i}}$$

Width to thickness ratio

$$b2t^T = (10.769)$$

Definition of λ_p and λ_r from Table B4.1 Case 6 (Flexure in legs of single angles) to be applied in classification logic. λ_p is the separation point between a compact and noncompact member. λ_r is separation point between a noncompact and slender member.

$$\lambda_p := 3.76 \cdot \sqrt{\frac{E_{Angle}}{F_{yAngle}}} \qquad \lambda_r := 5.7 \cdot \sqrt{\frac{E_{Angle}}{F_{yAngle}}}$$

$$\text{Classification}_i := \begin{cases} 1 & \text{if } b2t_i \le \lambda_p \\ 2 & \text{if } \lambda_p < b2t_i \le \lambda_r \\ 3 & \text{if } \lambda_r < b2t_i \end{cases}$$

$$\text{Classification}^T = (1)$$

Since flanges and webs are both compact F2 is applicable

F2. Doubly Symmetric Compact I-Shaped Members and Channels Bent About Their Major Axis

1. Yielding

$$M_p := F_{y\_Ch} \cdot Z_{x\_Ch}$$

Nominal flexural strength (F2-1)

$$M_{ny} := M_p$$

$$M_{ny}^T = (144.87)\ \text{kip} \cdot \text{in}$$

$$\phi M_{ny} := \phi_b \cdot M_{ny}$$

$$\phi M_{ny}^T = (130.383)\ \text{kip} \cdot \text{in}$$

Design flexural strength

$$\phi F_{ny\_Tot_i} := 4 \cdot \left(\frac{\phi M_{ny_i}}{\frac{L_{b\_Ch}}{2}} \right)$$

Converting design flexural strength for representative member into corresponding design strength for both angle iron sections comprising total section

$$\boxed{\phi F_{ny\_Tot_i}^T = (33.113)\ \text{kip}}$$

Total design strength of angle iron section given flexural loading

2. Lateral-Torsional Buckling

Calculated length values used to distinguish between moment associated with lateral torsional buckling

L_p is the lower limit

$$L_{p\_Ch} := 1.76 \cdot r_{gyrationY\_Ch} \cdot \sqrt{\frac{E_{Ch}}{F_{y\_Ch}}}$$

(F2-2)

$$L_{p\_Ch} = (25.357)\ \text{in}$$

L_r is the upper limit

$$c_{Ch} := \frac{h_{o\_Ch}}{2} \cdot \sqrt{\frac{I_{y\_Ch}}{C_{w\_Ch}}}$$

$$L_{r\_Ch} := 1.95 \cdot r_{ts\_Ch} \cdot \frac{E_{Ch}}{0.7 \cdot F_{y\_Ch}} \cdot \sqrt{\frac{J_{Ch} \cdot c_{Ch}}{S_{x\_Ch} \cdot h_{o\_Ch}}} \cdot \sqrt{1 + \sqrt{1 + 6.76 \cdot \left(\frac{0.7 \cdot F_{y\_Ch}}{E_{Ch}} \cdot \frac{S_{x\_Ch} \cdot h_{o\_Ch}}{J_{Ch} \cdot c_{Ch}}\right)^2}}$$

$$L_{r\_Ch} = (181.424)\ in$$

$$M_{nltb} := 1.667 \cdot \left[M_p - \left(M_p - 0.7 \cdot F_{y\_Ch} \cdot S_{x\_Ch}\right) \cdot \left(\frac{L_{b\_Ch} - L_{p\_Ch}}{L_{r\_Ch} - L_{p\_Ch}}\right)\right]$$

$$M_{nltb} = (237.388)\ kip \cdot in$$

$$\phi M_{nltb} := \phi_b \cdot M_{nltb}$$

$$\phi M_{nltb}^{T} = (213.649)\ kip \cdot in$$

Design flexural strength

$$\phi F_{nltb\_Tot_i} := 4 \cdot \left(\frac{\phi M_{nltb_i}}{\frac{L_{b\_Ch}}{2}}\right)$$

Converting design flexural strength for representative member into corresponding design strength for both angle iron sections comprising total section

$$\boxed{\phi F_{nltb\_Tot_i}^{T} = (54.26)\ kip}$$

Total design strength of angle iron section given flexural loading

EYE RODS

NOTE:It was observed during inspection that all of the applicable eye rods have welded eyes even though they indicate otherwise on Drawing 120925, thus all eye rods in these calculations will be treated as welded eye rods. Since both eye rods are implemented during upward loading the tension results will be multiplied by a factor of 2 at the point where the resistance factor is implemented.

Tension, capacity of lower eye rod [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$A_{b\_I_i} := \pi \cdot \left(\frac{d_{I_i}}{2}\right)^2$$

Nominal unthreaded body area

$$F_{nt\_I} := 45ksi$$

Nominal tensile stress (A307) [8, Table J3.2] [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment

$R_{nt\_I_i} := F_{nt\_I} \cdot A_{b\_I_i}$ Nominal strength (R_n) (J3-1)

$\phi_{b\_tr} := 0.75$ Resistance factor

$\phi R_{nt\_I_i} := 2 \cdot \phi_{b\_tr} \cdot R_{nt\_I_i}$ Factor of 2 incorporated to account for both components

$\phi R_{nt\_I}^{T} = (53.014)\,kip$ Design tension strength

ANGLE IRON SECTIONS

Shear, capacity of double angle iron tie down bolts [8, Ch. J pg 16.1-90 thru 121]

Since both angle iron tie down bolts are implemented during upward loading the tension results will be multiplied by a factor of 2 at the point where the resistance factor is implemented.

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$A_{Angle\_bolt_i} := \pi \cdot \left(\frac{d_{Angle\_bolt_i}}{2}\right)^2$$ Nominal unthreaded body area

$A_{Angle\_bolt\_ds_i} := 2 \cdot A_{Angle\_bolt_i}$ Applicable area for this case since the bolt is in double shear

$F_{nv\_Angle\_bolt} := 24ksi$ Nominal shear stress in bearing type connections (A307) [8, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment and includes an allowance for threads in the shear plane

$R_{nv\_Angle\_bolt_i} := F_{nv\_Angle\_bolt} \cdot A_{Angle\_bolt\_ds_i}$ Nominal strength (R_n) (J3-1)

$\phi_{b\_sr} := 0.75$ Resistance factor

$\phi R_{nv\_Angle\_bolt_i} := 2 \cdot \phi_{b\_sr} \cdot R_{nv\_Angle\_bolt_i}$ Factor of 2 incorporated to account for both components

$\phi R_{nv\_Angle\_bolt}^{T} = (56.549)\,kip$ Design shear strength

Tension, failure of angle iron sections AISC, Ch. D pg 16.1-26 thru 31]

Since all four angle iron sections are implemented during upward loading the tension results will be multiplied by a factor of 4 at the point where the resistance factor is implemented.

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$b_{cl_i} := 2\left(t_{Angle_i}\right) + 0.63in$$

$$b_{cl}^{T} = (1.38)\ in$$

$$b_{eff\_Angle_i} := \min\left(b_{cl_i}, a_{normal\_Angle_i}\right)$$

$$b_{eff\_Angle}^{T} = (0.937)\ in$$

b_{eff} is an effective length calculated as (2t + 0.63in) which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$$P_{n\_Angle\_trp_i} := 2 \cdot t_{Angle_i} \cdot b_{eff\_Angle_i} \cdot F_{uAngle}$$ Nominal axial strength (P_n) (D5-1)

$$\phi_{n\_trp} := 0.75$$ Resistance factor for tension (ϕ_t)

$$\phi P_{n\_Angle\_trp_i} := 4 \cdot \phi_{n\_trp} \cdot P_{n\_Angle\_trp_i}$$ Factor of 4 incorporated to account for all 4 components

$$\boxed{\phi P_{n\_Angle\_trp}^{T} = (126.562)\ kip}$$ Design tensile strength

(b) For shear rupture on the effective area:

$$A_{sf\_Angle_i} := 2\left(t_{Angle_i}\right) \cdot \left(a_{parrallel\_Angle_i} + \frac{d_{Angle\_bolt_i}}{2}\right)$$

$$A_{sf\_Angle}^{T} = (0.797)\ in^2$$ Effective area

$$P_{n\_Angle\_srp_i} := 0.6 \cdot F_{uAngle} \cdot A_{sf\_Angle_i}$$ Nominal axial strength (P_n)

$$\phi_{n\_srp} := 0.75$$ Resistance factor for tension (ϕ_t)

$$\phi P_{n\_Angle\_srp_i} := 4 \cdot \phi_{n\_srp} \cdot P_{n\_Angle\_srp_i}$$ Factor of 4 incorporated to account for all 4 components (D5-2)

$$\boxed{\phi P_{n\_Angle\_srp}^{T} = (86.062)\ kip}$$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$A_{pd\_Angle_i} := d_{Angle\_bolt_i} \cdot \left(t_{Angle_i}\right)$$ Projected bearing area in.^{2} (mm^2)

$$R_{n\_Angle\_bs_i} := 1.8 \cdot F_{yAngle} \cdot A_{pd\_Angle_i}$$ Nominal bearing strength

$$\phi := 0.75$$ Resistance factor

$\phi R_{n\_Angle\_bs_i} := 4 \cdot \phi \cdot R_{n\_Angle\_bs_i}$ Factor of 4 incorporated to account for all 4 components

$\phi R_{n\_Angle\_bs}^{T} = (66.825)\ kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_Angle_i} := A_{Angle_i}$ Gross area (D3-1)

(a) For tensile yielding in the gross section:

$P_{n\_Angle\_ty_i} := F_{yAngle} \cdot A_{g\_Angle_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_Angle\_ty_i} := 4 \cdot \phi_{t\_ty} \cdot P_{n\_Angle\_ty_i}$ Factor of 4 incorporated to account for all 4 components

$\phi P_{n\_Angle\_ty}^{T} = (133.65)\ kip$ Design tensile strength

Shear, failure of channel iron cross section [8, Ch. G pg 16.1-64 thru 65]

G2. Members with Unstiffened of Stiffened Webs

$\phi_v := 1.0$ Resistance factor for shear

$h2t_{Ch_i} := \dfrac{h_{Ch\_web_i}}{t_{Ch\_web_i}}$ Ratio of web length to web thickness

$h2t_{Ch} = (10.769)$

$k_v := 5$ Given k_v value since h2t < 260

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$$C_{v_i} := \begin{cases} 1.0 & \text{if } h2t_{Ch_i} \le 1.10\sqrt{k_v \cdot \dfrac{E_{Ch}}{F_{y\_Ch}}} \\ \dfrac{1.10\sqrt{k_v \cdot \dfrac{E_{Ch}}{F_{y\_Ch}}}}{h2t_{Ch_i}} & \text{if } 1.10\sqrt{k_v \cdot \dfrac{E_{Ch}}{F_{y\_Ch}}} < h2t_{Ch_i} \le 1.37\sqrt{k_v \cdot \dfrac{E_{Ch}}{F_{y\_Ch}}} \\ \dfrac{1.51 \cdot E_{Ch} \cdot k_v}{\left(h2t_{Ch_i}\right)^2 \cdot F_{y\_Ch}} & \text{if } 1.37 \cdot \sqrt{k_v \cdot \dfrac{E_{Ch}}{F_{y\_Ch}}} < h2t_{Ch_i} \end{cases}$$

$$C_v = (1)$$

$$A_{Ch\_web_i} := depth_{Ch_i} \cdot t_{Ch\_web_i}$$

$$V_{n\_Ch_i} := 0.6 \cdot F_{y\_Ch} \cdot 2 \cdot A_{Ch\_web_i} \cdot C_{v_i}$$

$$V_{n\_Ch} = (64.35)\ \text{kip}$$

Nominal shear strength of each section of channel iron, factor of 2 incorporated in equation to account for double shear.

$$\phi V_{n\_Ch_i} := 2 \cdot \phi_v \cdot V_{n\_Ch_i}$$

$$\boxed{\phi V_{n\_Ch} = (128.7)\ \text{kip}}$$

Design shear strength, factor of 2 incorporated in equation to account for both sections

SUMMARY OF RESULTS

Capacities For Upward Loading

CHANNEL IRON SECTIONS

Flexure, capacity of channel iron sections [8, Ch. F pg 16.1-44 thru 63]

F1. General Provisions

F2. Doubly Symmetric Compact I-Shaped Members and Channels Bent About Their Major Axis

1. Yielding

$$\phi F_{ny\_Tot_i}^{\,T} = (33.113)\,kip$$

Total design strength of angle iron section given flexural loading

2. Lateral-Torsional Buckling

$$\phi F_{nltb\_Tot_i}^{\,T} = (54.26)\,kip$$

Total design strength of angle iron section given flexural loading

EYE RODS

$$\phi R_{nt\_I}^{\,T} = (53.014)\,kip$$

Design tension strength

ANGLE IRON SECTIONS

Shear, capacity of double angle iron tie down bolts [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nv\_Angle\_bolt}^{\,T} = (56.549)\,kip$$

Design shear strength

Tension, failure of angle iron sections AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_Angle\_trp}^{\,T} = (126.562)\,kip$$

Design tensile strength

(b) For shear rupture on the effective area:

$$\phi P_{n\_Angle\_srp}^{\,T} = (86.062)\,kip$$

Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\phi R_{n\_Angle\_bs}^{T} = (66.825)\ kip$$

Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_Angle\_ty}^{T} = (133.65)\ kip$$

Design tensile strength

Shear, failure of channel iron cross section [8, Ch. G pg 16.1-64 thru 65]

G2. Members with Unstiffened of Stiffened Webs

$$\phi V_{n\_Ch} = (128.7)\ kip$$

Design shear strength, factor of 2 incorporated in equation to account for both sections

Appendix C.9.5

Compression Capacity of RH-11, 13, 16, 17, 22 & PR-8

RH-11, 17, 22, 16, 13 & PR-8 COMPRESSION CAPACITY

RH-11, 17, 22, 16, and 13 primarily support the PCS piping system from downward loading and PR-8 is primarily designed to be a tie down. However, the effects of the 32 seismic events applied to the support provides some upward (downward for PR-8) loading therefore capacity in the associated compression direction is calculated below.

Component Capacity Overview:

- Upward Loading:
- Compression capacity in eye rod sections

(**Procedures from AISC 13th Edition (applying LRFD)**)

$i := 0, 1 .. 6$ — Assigned indices corresponding to number of support types associated with these calculations

Geometric and Material Properties of Support Components

PIPE SECTION

Material Properties as Defined in the Material Section of this Report:

$F_y := 33\text{ksi}$ — Yield Strength for A7 Carbon Steel

$F_u := 60\text{ksi}$ — Ultimate Strength for A7 Carbon Steel

$E := 29000\text{ksi}$ — Modulus of Elasticity for A7 Carbon Steel

$$\begin{pmatrix} RH_{11} \\ RH_{13} \\ RH_{16} \\ RH_{17} \\ RH_{22A} \\ RH_{22B} \\ RH_{24} \\ PR_8 \end{pmatrix} \quad L := \begin{pmatrix} 20.75 \\ 23.5625 \\ 65.25 \\ 24.3125 \\ 49.5 \\ 16.5 \\ 26.8125 \\ 86.5 \end{pmatrix} \text{in} \quad D := \begin{pmatrix} 0.75\text{in} \\ 0.75\text{in} \\ 0.625\text{in} \\ 0.75\text{in} \\ 0.625\text{in} \\ 0.625\text{in} \\ 0.625\text{in} \\ 1.125\text{in} \end{pmatrix} \quad r_{gyration} := \frac{D}{4} \quad A := \pi \cdot \left(\frac{D}{2}\right)^2$$

See Appendix C.6 for references related to dimensions of these supports

Capacities for Upward Loading

Compression, capacity in rod hangers [AISC, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

$\phi_c := 0.9$ — Resistance factor for compression

E2. Slenderness Limitations and Effective Length

$K := 1.0$ — Effective length in accordance with C2.b1, [AISC, comm.C2 (Table C-C2.2) (case d) pg 16.1-240] Case d was chosen because the support was allowed to rotate on the top as well as on the bottom.

The Slenderness ratio KL/r should preferably not exceed 200

$$KLr_i := \left(\frac{K \cdot L_i}{r_{gyration_i}}\right)$$

The below KLr values verify that all supports do not exceed the 200 recommended limitation

$$KLr^T = (110.667 \quad 125.667 \quad 417.6 \quad 129.667 \quad 316.8 \quad 105.6 \quad 171.6)$$

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified through classification)

$$F_{e_i} := \frac{\pi^2 E}{\left(KLr_i\right)^2}$$

F_e is the elastic critical buckling stress (E3-4)

$$F_e^T = (23.37 \quad 18.124 \quad 1.641 \quad 17.023 \quad 2.852 \quad 25.667 \quad 9.72)\ \text{ksi}$$

Calculating the variables Limit, Op1, and Op2 to be utilized in logic to determine flexural buckling stress.

$$Limit := 4.71 \cdot \sqrt{\frac{E}{F_y}} \qquad Op1_i := \left(0.658^{\frac{F_y}{F_{e_i}}}\right) F_y \qquad Op2_i := 0.877 \cdot F_{e_i}$$

$$Limit = 139.625$$

Calculating the flexural buckling stress

$$F_{cr_i} := \begin{cases} Op1_i & \text{if } KLr_i \le Limit \quad \text{(E3-2)} \\ Op2_i & \text{if } KLr_i > Limit \quad \text{(E3-3)} \end{cases}$$

$$F_{cr}^T = (18.274 \quad 15.401 \quad 1.439 \quad 14.66 \quad 2.501 \quad 19.267 \quad 8.524)\ \text{ksi}$$

$\phi P_{n_i} := \phi_c \cdot F_{cr_i} \cdot A_i$ Design compressive strength

$$\phi P_n^{\,T} = (7.266 \quad 6.123 \quad 0.397 \quad 5.829 \quad 0.691 \quad 5.32 \quad 2.354)\,\text{kip}$$

$$\phi P_n = \begin{pmatrix} 7.266 \\ 6.123 \\ 0.397 \\ 5.829 \\ 0.691 \\ 5.32 \\ 2.354 \end{pmatrix} \text{kip} \quad \begin{pmatrix} RH\_11 \\ RH\_13 \\ RH\_16 \\ RH\_17 \\ RH\_22A \\ RH\_22B \\ RH\_24 \end{pmatrix}$$

Appendix C.9.6

Capacity of RH-19

RH-19 CAPACITY

RH-19 restricts seismic motion in the downward direction of the horizontally oriented PCS piping traveling in the north/south direction. RH-19 is comprised of two welded beam attachments, two eye rods hanging from the welded beam attachments by bolts, and an angle iron section spanning between the bottom of the two eye bolts and under the PCS pipe. The anchorage assembly capacities and the associated capacities of the wall embedment are found in the anchorage and embedment portions of this report while the capacities for the remainder of the previously mentioned components are calculated below.

M6-1-43-N29-CSUG-DSCN2836

Component Capacity Overview:

- Downward Loading:

- Flexure capacity of angle iron sections
- Shear capacity of angle iron sections
- Tension capacity of eye rod
- Tension capacity of welded beam attachment
- Shear capacity of welded beam attachment's bolt

(**Procedures from AISC 13th Edition (LRFD)**)

$i := 0$ — Assigned indices corresponding to number of support types associated with these calculations

Support = 0 (RH-19)

Relationship between support and corresponding indices

Geometric and Material Properties of Support Components

ANGLE IRON ANCHOR (Angle Iron 2" x 2" x 3/8" [20])

Material Properties of Angle Iron Section as Defined in the Material Section of this Report:

$F_{yAngle} := 33ksi$ — Yield Strength for A7 Carbon Steel

$F_{uAngle} := 60ksi$ — Ultimate Strength for A7 Carbon Steel

$E_{Angle} := 29000ksi$ — Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Angle Iron:

$$t_{Angle} := \left(\frac{3}{8}in\right)^T$$

Scaled thickness of angle iron section [20]

$L1_{Angle} := (2in)^T$ Width of upper portion of angle iron [20]

$L2_{Angle} := (2.in)^T$ Width of lower portion of angle iron [20]

$A_{Angle_i} := \left(1.36in^2\right)^T$ Cross sectional area of angle iron [8, Table 1-7, pg 1-46]

$L_{Angle} := (12in)^T$ Length between rods [20]

$I_{AngleX} := \left(0.476in^4\right)^T$ Moment of inertia about the horizontal X-axis [8, Table 1-7, pg 1-46]

$r_{gyration\_AngleX} := 0.591in$ Radius of gyration about the horizontal X-axis [8, Table 1-7, pg 1-46]

$y_{Angle} := (0.632in)^T$ Distance from nuetral axis to top of angle iron [8, Table 1-7, pg 1-46]

EYE RODS (Welded Eye Rod FIG 278 5/8")

Material Properties of Welded Eye Rod as Defined in the Material Section of this Report:

$F_{y\_cl} := 33ksi$ Yield Strength for A7 Carbon Steel

$F_{u\_cl} := 60ksi$ Ultimate Strength for A7 Carbon Steel

$E_{cl} := 29000ksi$ Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Eye Rod:

$d_I := \left(\frac{5}{8}in\right)^T$ Unthreaded diameter of eye rod, in. (mm) [20] [24, Fig 278]

$Z_{I_i} := \frac{\left(d_{I_i}\right)^3}{6}$ Plastic section modulus about the axis of bending, in.^{3} (mm^3) [8, Table 17-27 pg17-39]

WELDED BEAM ATTACHMENT (Welded Beam Attachment FIG 66 5/8" Rod)

Material Properties of Welded Beam Attachment as Defined in the Material Section of this Report:

$F_{y\_wba} := 33ksi$ Yield Strength for A7 Carbon Steel

$F_{u\_wba} := 60ksi$ Ultimate Strength for A7 Carbon Steel

$E_{wba} := 29000ksi$ Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Welded Beam Attachment:

$t_{wba} := \left[2 \cdot \left(\frac{1}{4}in\right)\right]^T$ Combined thickness of welded beam attachment [24, Fig 66]

$w_{wba} := (2in)^T$ — Width of welded beam attachment [24, Fig 66]

$A_{wba_i} := t_{wba_i} \cdot w_{wba_i}$ — Cross sectional area of welded beam attachment

$A_{wba} = (1)\,in^2$

$d_{wba\_bolt} := \left(\frac{3}{4}in\right)^T$ — Diameter of welded beam attachment bolt [24, Fig 212]

$d_{wba\_hole} := \left(\frac{13}{16}in\right)^T$ — Diameter of welded beam attachment bolt hole [24, Fig 66], [8, Table J3.3]

$a_{parrallel\_wba} := \left(\frac{15}{32}in\right)^T$ — Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force, in. (mm) hand calculated from d_{wba_hole} and [24, Fig 212] data

$a_{normal\_wba_i} := \frac{w_{wba_i} - d_{wba\_hole_i}}{2}$ — Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force, in. (mm) [24, Fig 212]

$a_{normal\_wba}^T = (0.594)\,in$

Capacities For Downward Loading

ANGLE IRON SECTION

Flexure, failure of angle iron section [8, Ch. F pg 16.1-44 thru 63]

For these calculations the angle iron section will be divided into two sections based on the symmetric bending behavior about the midplane of the total section's length. This results in two sections of angle iron for which the capacity of each is equivelent. A representative section of both sections was analysed treating one end as free with a load applied to it and the other end being fixed in a local coordinate frame.

F1. General Provisions

Given resistance factor for shear

$\phi_b := 0.9$

Calculate the lateral-torsional buckling modification factor for a nonuniform moment loading on the beam caused by downward loading of the pipe

$M_{max}(F, Length) := F \cdot Length$ — Absolute value of maximum moment in the unbraced segment

$M_A(F, Length) := \frac{3}{4} \cdot F \cdot Length$ — Absolute value of moment at quarter point of the unbraced segment

$M_B(F, Length) := \frac{1}{2} \cdot F \cdot Length$ — Absolute value of moment at centerline of the unbraced segment

$M_C(F, Length) := \frac{1}{4} \cdot F \cdot Length$ — Absolute value of moment at three-quarter point of the unbraced segment

$R_m := 1.0$

Cross-section monosymmetry parameter (value of 1.0 is assigned because it correlates to singly symmetric members subjected to single curvature bending)

$$C_b(F, Length) := \left(\frac{12.5 \cdot M_{max}(F, Length)}{2.5 \cdot M_{max}(F, Length) + 3 \cdot M_A(F, Length) + 4 \cdot M_B(F, Length) + 3 \cdot M_C(F, Length)} \cdot \right.$$

(F1-1)

$$C_b\left(F, L_{Angle_i}\right) \rightarrow 1.6666666666666666667$$

F10. Single Angles

First determine value between geometric axis of rotation and extreme fiber [8, Table 17-27]

$$Extreme_i := \max\left[\left(L2_{Angle_i} - y_{Angle_i}\right), y_{Angle_i}\right]$$

Point farthest from the neutral axis

$$Extreme^T = (1.368)\ in$$

$$M_{y_i} := \frac{F_{yAngle} \cdot I_{AngleX_i}}{Extreme_i}$$

Equation to calculate yielding moment from moment of inertia and Extreme values [44, Equation 6-74]

$$M_y^T = (11.482)\ kip \cdot in$$

Yielding Moment

1. Yielding

$$M_{ny} := 1.5 \cdot M_y$$

$$M_{ny}^T = (17.224)\ kip \cdot in$$

Nominal flexural strength (F10-1)

$$\phi M_{ny} := \phi_b \cdot M_{ny}$$

$$\phi M_{ny}^T = (15.501)\ kip \cdot in$$

Design flexural strength

$$\phi F_{ny\_Tot_i} := 2 \cdot \left(\frac{\phi M_{ny_i}}{\frac{L_{Angle}}{2}} \right)$$

Converting design flexural strength for representative member into corresponding design strength for both angle iron sections comprising total section

$$\boxed{\phi F_{ny\_Tot_i}^T = (5.167)\ kip}$$

Total design strength of angle iron section given flexural loading

2. Lateral-Torsional Buckling

Calculate the lateral-torsional buckling moment

(i) For bending about one of the goemetric axes of an equal-leg angle with no lateral-torsional restraint

(a) With maximum tension at the toe (applies here for downward loading)

$$C_{bLTB_i} := \min\left(C_b\left(F, L_{Angle_i}\right), 1.5\right)$$

Lateral torsional buckling modification factor with an upper limit of 1.5

$$b_{F10.2_i} := L2_{Angle_i}$$

Geometric property of angle iron [8, Table B4.1]

$$M_{e_i} := \frac{0.66 \cdot E_{Angle} \cdot \left(b_{F10.2_i}\right)^4 \cdot t_{Angle_i} \cdot C_{bLTB_i}}{\left(L_{Angle_i}\right)^2} \left[\sqrt{1 + 0.78 \cdot \left[\frac{L_{Angle_i} \cdot t_{Angle_i}}{\left(b_{F10.2_i}\right)^2}\right.}\right.$$

(F10-4a)

$$M_e^T = \left(2.883 \times 10^3\right) \text{kip} \cdot \text{in}$$

Elastic lateral-torsional buckling moment

M_y shall be taken as 0.80 times the yield moment calculated using the geometric section modulus as applied to this section.

$$M_{yi_i} := 0.80 \cdot M_{y_i}$$

For single angles without continuous lateral-torsional restraint along the length

(a & b) calculation

$$M_{nLTB_i} := \begin{cases} \left(0.92 - \dfrac{0.17 \cdot M_{e_i}}{M_{yi_i}}\right) \cdot M_{e_i} & \text{if } M_{e_i} \le M_{yi_i} \quad \text{(F10-2)} \\ \left(1.92 - 1.17 \cdot \sqrt{\dfrac{M_{yi_i}}{M_{e_i}}}\right) \cdot M_{yi_i} & \text{if } M_{e_i} > M_{yi_i} \quad \text{(F10-3)} \\ 1.5 \cdot M_{yi_i} & \text{if } 1.5 M_{yi_i} \ge \left(1.92 - 1.17 \cdot \sqrt{\dfrac{M_{yi_i}}{M_{e_i}}}\right) \cdot M_{yi_i} \end{cases}$$

Nominal flexural strength

$$M_{nLTB}^T = (17.03)\ \text{kip} \cdot \text{in}$$

$$\phi M_{nLTB\_WL} := \phi_b \cdot M_{nLTB}$$

$$\phi M_{nLTB\_WL}{}^{T} = (15.327)\ kip \cdot in$$

Design flexural strength of the representative angle iron section

$$\phi F_{nLTB\_WL\_Tot_i} := 2 \cdot \left(\frac{\phi M_{nLTB\_WL_i}}{\frac{L_{Angle}}{2}} \right)$$

$$\boxed{\phi F_{nLTB\_WL\_Tot_i}{}^{T} = (5.109)\ kip}$$

Total design strength of angle iron section given flexural loading

Shear, failure of angle iron cross section [8, Ch. G pg 16.1-64 thru 79]

G1. General Provisions

$$\phi_v := 0.9$$

Resistance factor for shear

G4. Single Angles

The nomial shear strength, V_n, of a single angle leg shall be determined using equation G2-1 with C_v = 1.0, A_w = bt where b = width of the leg resisting the shear force, in. (mm) and k_v = 1.2.

$$C_v := (1)^T$$

Web shear coefficient

$$A_{w_i} := 2\left(b_{F10.2_i} \cdot t_{Angle_i}\right)$$

Web area (2 incorporated to account for double shear)

$$k_v := (1.2)^T$$

Web plate buckling coefficient

$$V_{n\_Angle_i} := 0.6 \cdot F_{yAngle} \cdot A_{w_i} \cdot C_{v_i} \qquad \text{(G2-1)}$$

$$V_{n\_Angle}{}^{T} = (29.7)\ kip$$

Nominal shear strength

$$\phi V_{n\_Angle} := \phi_v \cdot V_{n\_Angle}$$

$$\boxed{\phi V_{n\_Angle}{}^{T} = (26.73)\ kip}$$

Design shear strength

EYE RODS

NOTE:It was observed that all of the applicable eye rods have welded eyes even though they indicate otherwise on Drawing 20, thus all eye rods in these calculations are treated as welded eye rods

Tension, failure of eye rods [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$A_{b\_I_i} := \pi \cdot \left(\frac{d_{I_i}}{2}\right)^2$ Nominal unthreaded body area

$F_{nt\_I} := 45ksi$ Nominal tensile stress (A307) [8, Table J3.2]

$R_{nt\_I_i} := F_{nt\_I} \cdot A_{b\_I_i}$ Nominal strength (R_n) (J3-1)

$\phi_{b\_tr} := 0.75$ Resistance factor

$\phi R_{nt\_I_i} := 2 \cdot \phi_{b\_tr} \cdot R_{nt\_I_i}$ A 2 is incorporated to account for both eye rods

$\boxed{\phi R_{nt\_I}{}^T = (20.709)\,kip}$ Design tension strength

WELDED BEAM ATTACHMENT

Tension, failure of welded beam attachment [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$b_i := 2\,t_{wba_i} + 0.63in$

$b^T = (1.63)\,in$

$b_{eff_i} := \min\left(b_i, a_{normal\_wba_i}\right)$

$b_{eff}{}^T = (0.594)\,in$

b_{eff} is an effective length calculated as (2t + 0.63in) for which can not be larger than the actual distance fro the edge of the hole to the edge of th part measured in the direction normal to the applied force

$P_{n\_wba\_trp_i} := 2 \cdot t_{wba_i} \cdot b_{eff_i} \cdot F_{u\_wba}$ Nominal axial strength (P_n) (D5-1)

$\phi_{n\_trp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_wba\_trp_i} := 2 \cdot \phi_{n\_trp} \cdot P_{n\_wba\_trp_i}$ — A 2 is incorporated to account for both welded beam attachments

$\phi P_{n\_wba\_trp}^{T} = (53.438)\ kip$ — Design tensile strength

(b) For shear rupture on the effective area:

$$A_{sf\_wba_i} := 2 \cdot t_{wba_i} \cdot \left(a_{parrallel\_wba_i} + \frac{d_{wba\_hole_i}}{2} \right)$$

$A_{sf\_wba}^{T} = (0.875)\ in^2$ — Effective area

$P_{n\_wba\_srp_i} := 0.6 \cdot F_{u\_wba} \cdot A_{sf\_wba_i}$ — Nominal axial strength (P_n) (D5-2)

$\phi_{n\_srp} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_wba\_srp_i} := 2 \cdot \phi_{n\_srp} \cdot P_{n\_wba\_srp_i}$ — A 2 is incorporated to account for both welded beam attachments

$\phi P_{n\_wba\_srp}^{T} = (47.25)\ kip$ — Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_wba_i} := d_{wba\_bolt_i} \cdot t_{wba_i}$ — Projected bearing area in.^{2} (mm^2)

$R_{n\_wba\_bs_i} := 1.8 \cdot F_{y\_wba} \cdot A_{pd\_wba_i}$ — Nominal bearing strength (J7-1)

$\phi := 0.75$ — Resistance factor

$\phi R_{n\_wba\_bs_i} := 2 \cdot \phi \cdot R_{n\_wba\_bs_i}$ — A 2 is incorporated to account for both welded beam attachments

$\phi R_{n\_wba\_bs}^{T} = (33.412)\ kip$ — Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_wba_i} := A_{wba_i}$ — Gross area

(a) For tensile yielding in the gross section:

$P_{n\_wba\_ty_i} := F_{y\_wba} \cdot A_{g\_wba_i}$ — Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_wba\_ty_i} := 2 \cdot \phi_{t\_ty} \cdot P_{n\_wba\_ty_i}$ — A 2 is incorporated to account for both welded beam attachments

$\boxed{\phi P_{n\_wba\_ty}^{T} = (59.4)\ \text{kip}}$ — Design tensile strength

Shear, failure of welded beam attachment's bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$A_{wba\_bolt_i} := \pi \cdot \left(\frac{d_{wba\_bolt_i}}{2}\right)^2$$ Nominal unthreaded body area

$A_{wba\_bolt\_ds_i} := 2 \cdot A_{wba\_bolt_i}$ — Applicable area for this case since the bolt is in double shear

$F_{nv\_wba\_bolt} := 24\text{ksi}$ — Nominal shear stress in bearing type connections (A307) [8, Table J3.2]

$R_{nv\_wba\_bolt_i} := F_{nv\_wba\_bolt} \cdot A_{wba\_bolt\_ds_i}$ — Nominal strength (R_n) (J3-1)

$\phi_{b\_sr} := 0.75$ — Resistance factor

$\phi R_{nv\_wba\_bolt_i} := 2 \cdot \phi_{b\_sr} \cdot R_{nv\_wba\_bolt_i}$ — A 2 is incorporated to account for both welded beam attachment bolts

$\boxed{\phi R_{nv\_wba\_bolt}^{T} = (31.809)\ \text{kip}}$ — Design shear strength

Summary of Results

Capacities For Downward Loading

ANGLE IRON SECTION

Flexure, failure of angle iron section [8, Ch. F pg 16.1-44 thru 63]

F1. General Provisions

F10. Single Angles

1. Yielding

$$\phi F_{ny\_Tot_i}{}^{T} = (5.167)\ \text{kip}$$

Total design strength of angle iron section given flexural loading

2. Lateral-Torsional Buckling

$$\phi F_{nLTB\_WL\_Tot_i}{}^{T} = (5.109)\ \text{kip}$$

Total design strength of angle iron section given flexural loading

Shear, failure of angle iron cross section [8, Ch. G pg 16.1-64 thru 79]

G1. General Provisions

G4. Single Angles

$$\phi V_{n\_Angle}{}^{T} = (26.73)\ \text{kip}$$

Design shear strength

EYE RODS

Tension, failure of eye rods [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nt\_I}{}^{T} = (20.709)\ \text{kip}$$

Design tension strength

WELDED BEAM ATTACHMENT

Tension, failure of welded beam attachment [8, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_wba\_trp}{}^{T} = (53.438)\ \text{kip}$$

Design tensile strength

(b) For shear rupture on the effective area:

$$\phi P_{n\_wba\_srp}{}^{T} = (47.25)\ \text{kip}$$

Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\phi R_{n\_wba\_bs}^{T} = (33.412)\,kip$$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_wba\_ty}^{T} = (59.4)\,kip$$ Design tensile strength

Shear, failure of welded beam attachment's bolt [8, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$\phi R_{nv\_wba\_bolt}^{T} = (31.809)\,kip$$ Design shear strength

Appendix C.9.7

Anchorage Refinements for RH-11, RH-13, and PR-7/8 Anchor Bolts

Anchorage Refinement

The purpose of this section is to perform analysis refinement of select anchorage capacities, previously determined in a previous analysis [37, Appendix E7]. Reference numbering (shown following) corresponds to references as defined in previous analysis [37].

From previous capacity analysis [37, Appendices E4 & E7]. Will depict references as {xx}, using different brackets.

Common Weld parameters

$Fy_{cs} := 33 \cdot ksi$ $Fu_{cs} := 60 \cdot ksi$ Minimum yield and tensile strengths of ASTM A7 [1] carbon steel, used to evaluate support and anchorage structures.

$F_{exx} := 60 \cdot ksi$ E6010 & E6011 weld filler electrode ultimate strength {2}

$Fy_{a36} := 36 \cdot ksi$

$Fu_{a36} := 58 \cdot ksi$

Minimum material yield and tensile strengths of ASTM A36 {17}carbon steel, used to evaluate some anchorage structures.

$\phi_{fw} := 0.75$ Fillet weld resistance factor {3, Table J2.5]

$F_w = 0.6 \cdot F_{exx} \cdot \left(1.0 + 0.5 \cdot \sin(\theta)^{1.5}\right)$ Nominal strength of the weld metal {3, eqn J2-5]

For => $\theta := 0 \cdot deg$

$F_{wl} := \left[0.6 \cdot F_{exx} \cdot \left(1.0 + 0.5 \cdot \sin(\theta)^{1.5}\right)\right]$ $F_{wl} = 36\,ksi$ Nominal strength for longitudinal loaded fillet welds

For => $\theta := 90 \cdot deg$

$F_{wt} := \left[0.6 \cdot F_{exx} \cdot \left(1.0 + 0.5 \cdot \sin(\theta)^{1.5}\right)\right]$ $F_{wt} = 54\,ksi$ Nominal strength for transversely loaded fillet welds

$Rt_w := \frac{F_{wt}}{F_{wl}}$ $Rt_w = 1.5$ Strength capacity ratio of transverse to longitudinal welds

As indicated above, transverse welds provide 50% strength capacity increase over that of longitudinal welds.

Note - If there are combinations of longitudinal and transverse segments within the same weld pattern, Fwl (longitudinal nominal strength) will be used to determine corresponding weld capacities. Also, if the weld is loaded in differing orthogonal directions, Fwl is used to determine weld capacities.

$A_w := \frac{\sqrt{2}}{2} \cdot \frac{1}{16} \cdot in^2$ $A_w = 0.044\,in^2$ Area of 1/16-in fillet per inch of weld

Let => $Rn_w := F_{wl} \cdot A_w$ $Rn_w = 1.591\,kip$ Nominal strength of weld {3, eqn J2-4] to be used for longitudinal and mixed weld patterns.

$Vn_w := \phi_{fw} \cdot Rn_w$ $Vn_w = 1.19\,kip$ Nominal shear strength of longitudinal & mixed fillet per 1/16-in of weld per inch {3, Table J2.5]

$Vnt_w := Rt_w \cdot Vn_w$ $Vnt_w = 1.79\,kip$ Nominal shear strength of transverse fillet per 1/16-in of weld per inch {3, Table J2.5]

Steel Plate Embed parameters

$w_{emb} := 4 \cdot in$ $t_{emb} := 0.5 \cdot in$ Width and thickness of steel plate embed {4, det. 25] that anchorage welds are attached to.

When the load acts in same direction as the axis of the weld, the base metal (or steel plate embed) capacity must also be considered to determine which condition is limiting.

$\phi F_{cs} := 0.9 \cdot 0.6 \cdot Fy_{cs}$ $\phi F_{cs} = 17.82\,ksi$ Nominal shear strength of steel plate embed (or base material) {30, p. 345].

$Rn_{emb} := w_{emb} \cdot t_{emb} \cdot \phi F_{cs}$ Nominal shear strength of steel plate embed along width {30, eqn 7.23].

$Rn_{emb} = 35.64\,kip$

When the resultant load acts in differing directions (i.e., out of plane) to the weld axis, the steel plate embed anchorage governs the design strength capacity of weld. All weld resultant loads are SRSS using methods as defined by Blodgett {6, p. 7.4-7].

$\phi t_{emb} := 11.25 \cdot kip$ Design pull-out strength of steel plate embed's anchor in tension and shear, obtained from Appendix C.

$\phi s_{emb} := 12.188 \cdot kip$

$Lemb_{anc} := 1 \cdot ft$ Anchor spacing along steel plate embed

$n\phi t_{emb} := 9.38 \cdot kip$

$n\phi s_{emb} := 12.188 \cdot kip$

Design axial and shear capacity for a group of steel plate embed anchors remote from edges, obtained from Appendix C. The "n" corresponds to number of anchors overlapped.

RH-13 (Type 29) & RH-11 (Type 30) Anchorage

Anchorage for supports RH-13 and RH-11 {4, det. 18] connect to a 5 x 3 x 1/2 angle that is fillet welded along its shortened leg, to the steel plate embed. The steel plate embed is reinforced by a single channel, which supports up to three different supports.

Initially {37], it was thought that the angle cantilevers to one side and that the support's drawing detail was wrong (see following picture of RH-13B). As evaluated in this condition, these supports are loaded vertically; thus, their anchoring weld is loaded in tension and bending (due to the cantilevered angle arrangement).

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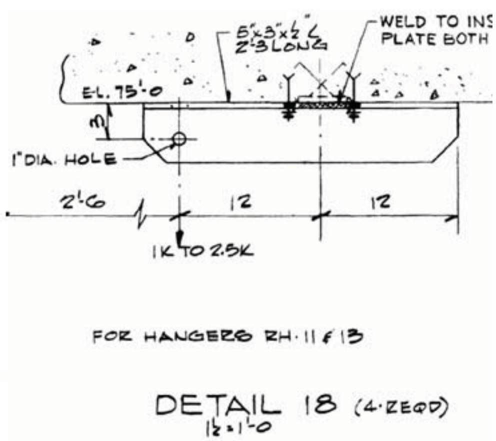

Further inspection using better equipped cameras (with greater lighting and range capabilities) indicated that RH-13 and RH-11 supports are reflective of their drawing detail {4, det. 18], however; the detail does not reflect added structural features which changes the weld anchorage evaluation approach for these supports.

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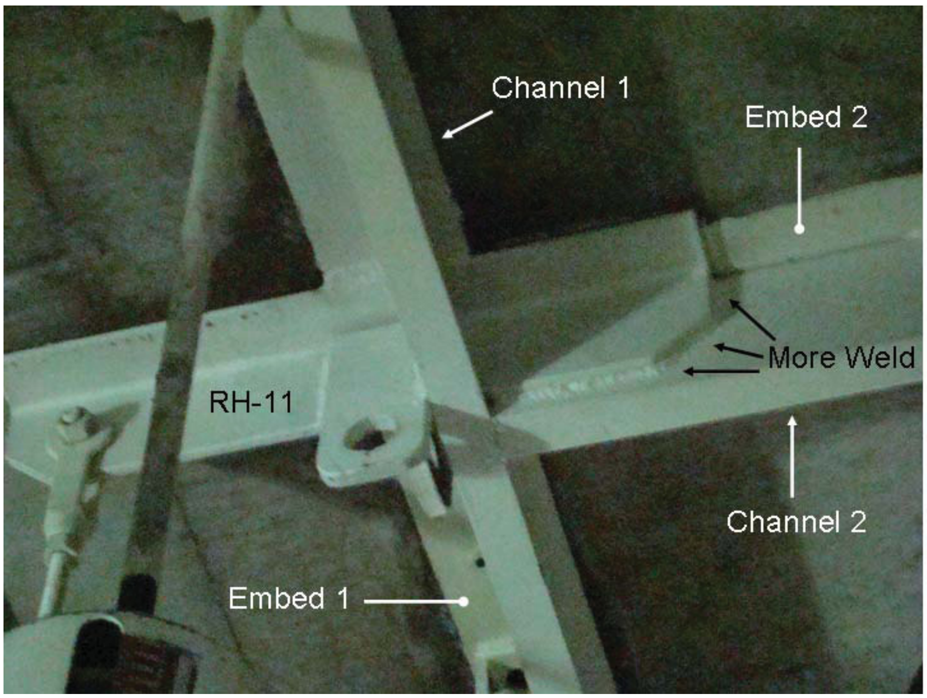
Anchorage for RH-13 and RH-11 styles are similar, but there are slight differences. As shown following, RH-11A and RH-11B are reinforced by two channels that are both skip-welded to steel embed plates.



As shown following, RH-13A and RH-13B is similar to RH-11, but with slight differences.

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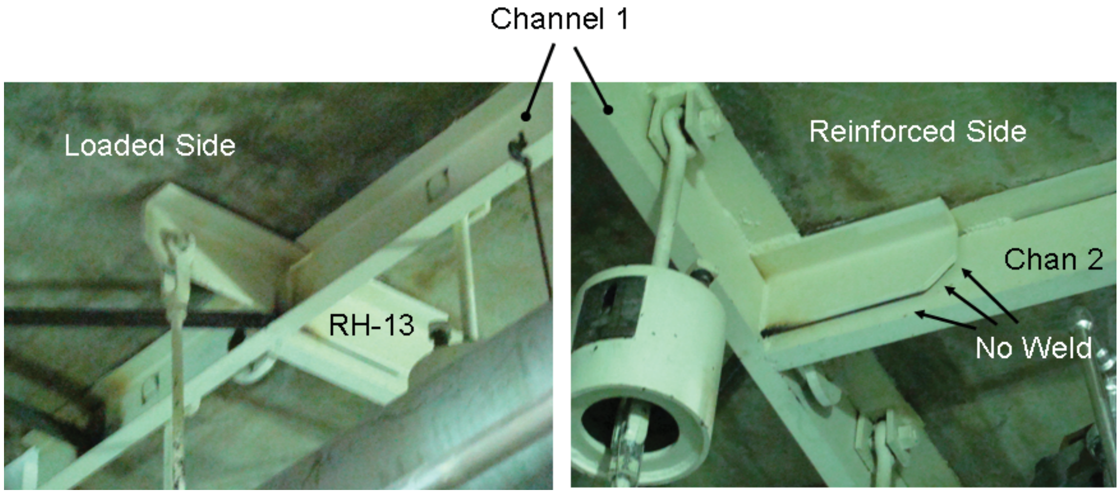

The main difference between RH-11 and RH-13 anchorage styles is that RH-11 has a little more weld on its reinforced side to Channel 2. Channel 2's estimated length is 8-ft minimum, with Channel1 significantly longer {38].

As shown following, both RH-11 and RH-13 anchorage styles are extended through Channel 1 (as one piece) and heavily welded on both sides of the Channel 1.

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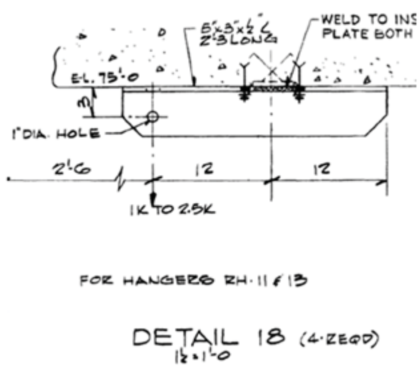
The two anchorage styles (RH-11 and RH-13) are evaluated the same. Both supports' reinforced sides are firmly supported by both channels (attached to steel embeds) and in conjunction with the channels, are pressing upward into the concrete ceiling. Hence, the supports' main weld (as shown in its drawing) acts as a pivot to a force couple and places this weld in tension only. The two supports' drawing weld {4, det. 18] is conservatively evaluated for tension, without contributions from the other channels, steel embeds, and substantial reinforced welding.



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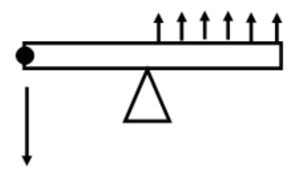
free body diagram



$t_{1311} := 0.5 \cdot in \quad d_{hole\_1311} := 1 \cdot in$ Angle thickness and hole diameter

$Lc_{1311} := 12 \cdot in \quad Le_{1311} := 2 \cdot in$ Angle cantilever length and distance from hole center to bottom edge of longer leg

$\frac{t_{1311}}{t_{emb}} = 1$ Let => $t_{s\_1311} := t_{1311}$ Fillet size for RH-13 & RN-11 weld anchorage

$$Vntw_{1311} := Rt_w \cdot Vn_w \cdot t_{s\_1311} \cdot \left(\frac{16}{in}\right) \cdot \frac{w_{emb}}{in}$$

Maximum design transverse fillet strength capacity RH-13 & RH-11 anchor welds, based on support loaded in tension

$Vntw_{1311} = 57.28\,kip$ Weld area accounts for one of two weld segments, since tension load is directly over and in-line with the single weld segment on the angle's backside.

Accounting for only one weld segment (of two segment weld) could be considered to be conservative, since both support types (RH-13 and RH-11) are held firmly between two anchored channels and transmits load to both weld segments. Will continue as is, for steel plate embeds (shown following) limit supports' weld capacity.

Let => $n_{1311} := 3$ $\quad \frac{\phi t_{emb}}{n\phi t_{emb}} = 1.199$

Based on multiple supports on channel reinforced embed, will approximate three minimum embed anchors for each support anchorage.

$\frac{Vntw_{1311}}{n_{1311} \cdot n\phi t_{emb}} = 2.035$ $\quad Vntw_{1311} := n_{1311} \cdot n\phi t_{emb}$ $\quad Vntw_{1311} = 28.14\,kip$

Maximum design shear strength capacity of these anchor welds are limited, based on steel plate embed anchors loaded in tension (vertical direction).

Determine maximum load that may be placed on weld, due to tension:

Let => $fntw_{1311} := \frac{Vntw_{1311}}{w_{emb}}$ $\quad fntw_{1311} = 7.035 \frac{kip}{in}$ Unit force capacity of weld

$Aw_{1311} := w_{emb}$ $\quad Aw_{1311} = 4\,in$ Line area of single segment weld

$\frac{Pntw_{1311}}{Aw_{1311}} = fnw_{1311}$ Tension loading (vertical direction)

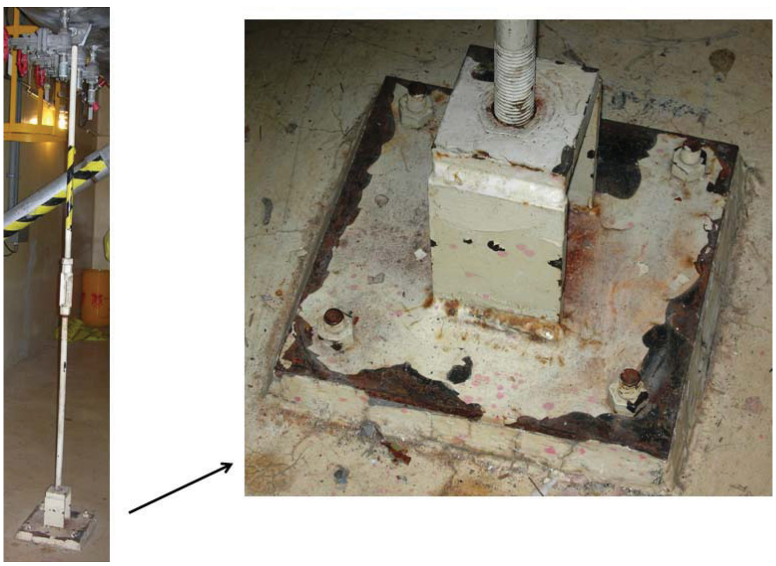
$Pntw_{1311} := fntw_{1311} \cdot Aw_{1311}$ Maximum tension capacity (vertical direction) for these supports' anchor weld

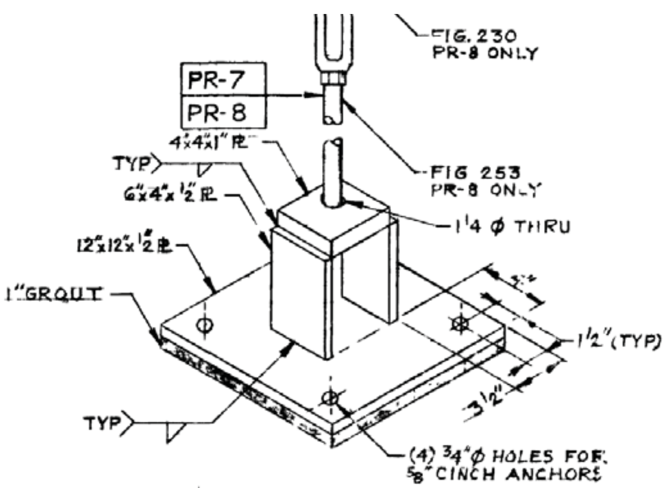
$Pntw_{1311} = 28.14\,kip$

PR-7 / PR-8 Anchorage Capacity

The purpose of this section is to determine the anchorage capacity of supports PR-7 and PR-8. Anchorage capacities for PR-7 and PR-8 were overlooked from previous capacity analysis [x1, Appendix E]. Both support anchorage are loaded in tension only. Anchorage of both supports are identical and share common results. (*Reference table is shown at bottom of calculation*)

As shown in the pictures below, PR-8 anchorage (representing both supports) consists of four anchors that extend through a 1/2-in plate [x2, det. 52], built-up grout, and into the concrete floor.





DETAIL 52
SCALE: 1 1/2" = 1'-0
REF DWG 670-P-6..

PR-8 pictures and drawing detail do not agree. The drawing calls for 1-in thick grout, but the above pictures indicate more grout as proportioned to the 1/2-in plate.

The grout thickness inaccuracy is further reaffirmed due to anchor embedment inspections, shown in Appendix B.

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From Appendix B of capacity analysis [x1], the actual anchor concrete embedment for PR-7 and PR-8 are determined.

$L7_{stud} := (3.619\ \ 3.684\ \ 3.631\ \ 3.605)^T \cdot in$ UT recorded PR-7 stud length

$L7_{surf} := (2.87\ \ 2.62\ \ 3.00\ \ 2.87)^T \cdot in$ Distance between top of stud and concrete surface

$L7_{emb} := L7_{stud} - L7_{surf}$ $L7_{emb}^T = (0.749\ \ 1.064\ \ 0.631\ \ 0.735)\,in$

$\min(L7_{emb}) = 0.631\,in$ $\frac{\sum L7_{emb}}{4} = 0.795\,in$ PR-7 minimum and average concrete anchor embedment

$L8_{stud} := (3.638\ \ 3.596\ \ 3.535\ \ 3.622)^T \cdot in$ UT recorded PR-8 stud length

$L8_{surf} := (3.12\ \ 2.62\ \ 3.25\ \ 3.06)^T \cdot in$ Distance between top of stud and concrete surface

$L8_{emb} := L8_{stud} - L8_{surf}$ $L8_{emb}^T = (0.518\ \ 0.976\ \ 0.285\ \ 0.562)\,in$

$\min(L8_{emb}) = 0.285\,in$ $\frac{\sum L8_{emb}}{4} = 0.585\,in$ PR-8 minimum and average concrete anchor embedment

From drawing, PR-7 and PR-8 use 5/8-in cinch anchors. This anchor is assumed to be a Ramset Trubolt style anchor, which is used in other areas of the PCS. A 5/8-in Ramset Trubolt expansion anchor that has a pull-out capacity of 8-kips in 4000-psi with a minimum embedment of 2.75-inches [x3]. Using DOE/EH-0545 [x4] as a guide for pull-out capacity determination, Section 6.3.3.1 defines any embedment less than 2.75-in an outliner and is outside its determination scope.

$Lemb_{min} := 2.75 \cdot in$ Minimum embedment depth

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$$\frac{\min(L8_{emb})}{\min(L7_{emb})} = 0.452 \quad < \quad \frac{\frac{\sum L8_{emb}}{4}}{\frac{\sum L7_{emb}}{4}} = 0.736$$

PR-7 and PR-8 comparative concrete anchor embedment lengths

$$\frac{\frac{\min(L8_{emb})}{\min(L7_{emb})}}{Lemb_{min}\cdot\frac{1}{in}} = 0.164 \quad < \quad \frac{\frac{\frac{\sum L8_{emb}}{4}}{\frac{\sum L7_{emb}}{4}}}{Lemb_{min}\cdot\frac{1}{in}} = 0.268 \quad < \; 1.0$$

Without anchor spacing, concrete strength, and other reduction factors considered, the PR-7 and PR-8 anchorage pull-out capacities are insignificant and for this evalaution are considered to have a pull-out capacity of zero.

x1. D. Clark and et all, ECAR EDF-8366, "ATR Primary Coolant System Piping Support and Anchorage Capacity Evaluation," Rev. 0, Sept. 27, 2007.

x2. INL drawing 120963, "Primary Coolant System Pipe Hangers, Sh 8," May, 1967.

x3. ITW Ramset/Red Head Company, Spec Data, May 1990.

x4. DOE/EH-0545, "Seismic Evaluation Procedure for Equipment in Department of Energy Facilities, March, 1997.

Appendix C.10

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Project:	ATR Life-Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation				
Performer:	Crawford/Clark/Spears	**Date:** 09/30/08	**Checker:** R. K. Blandford	**Date:**	09/30/08

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13. Drawing 127032, "Piping Spool-Primary Coolant Water Sh 2 of 2 (Line 1-44)," Revision 1, (Signature: June 1962, EDMS: February 1967).
14. Drawing 127034, "Piping Spool-Primary Coolant Water (Line 1-46)," Revision 1, (Signature: July 1962, EDMS: July 1962).
15. Drawing 127035, "Piping Spool-Primary Coolant Water Sh 1 of 2 (Line 1-47)," Revision 5, (Signature: July 1962, EDMS: January 1968).
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17. Drawing 127037, "Piping Spool-Primary Coolant Water (Line 1-48)," Revision 1, (Signature: July 1962, EDMS: January 1968).
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Engineering Calculations and Analysis Report

ATR Primary Coolant System Piping Seismic Evaluation

D. T. Clark
A. L. Crawford
K. D. Ellis
R. E. Spears

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Appendix D

Idaho National Laboratory

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Appendix D

Calculations Associated with Models 1-4 Seismic Evaluation

Contents

Appendix D.1

Identified Components Associated with Model 1-4

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Performer:	A. L. Crawford	**Date:** 09/30/08	**Checker:**	M. D. Landon		**Date:**	09/30/08

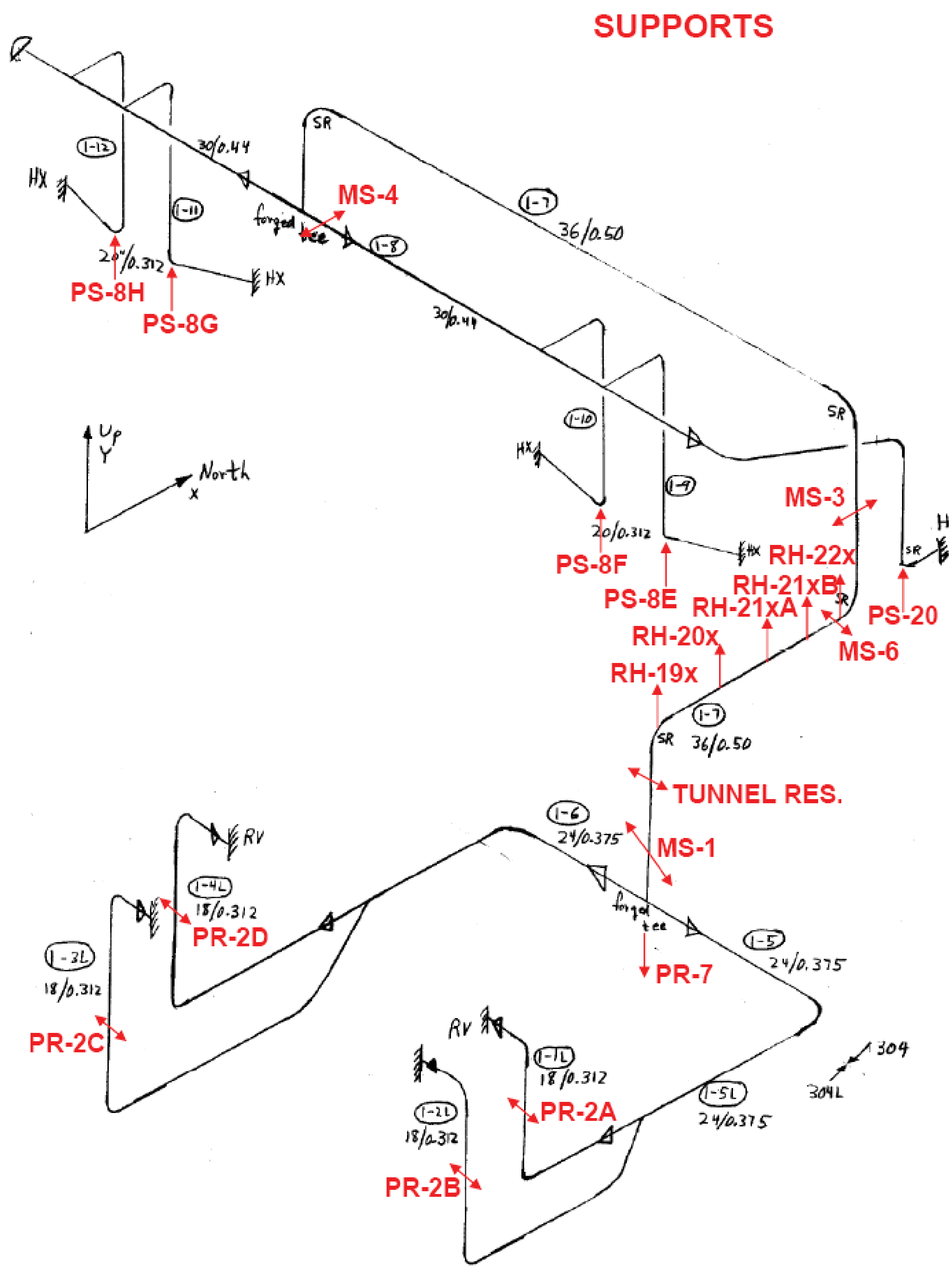

Figure D.1- 1. Supports Associated with Model 1 [1]

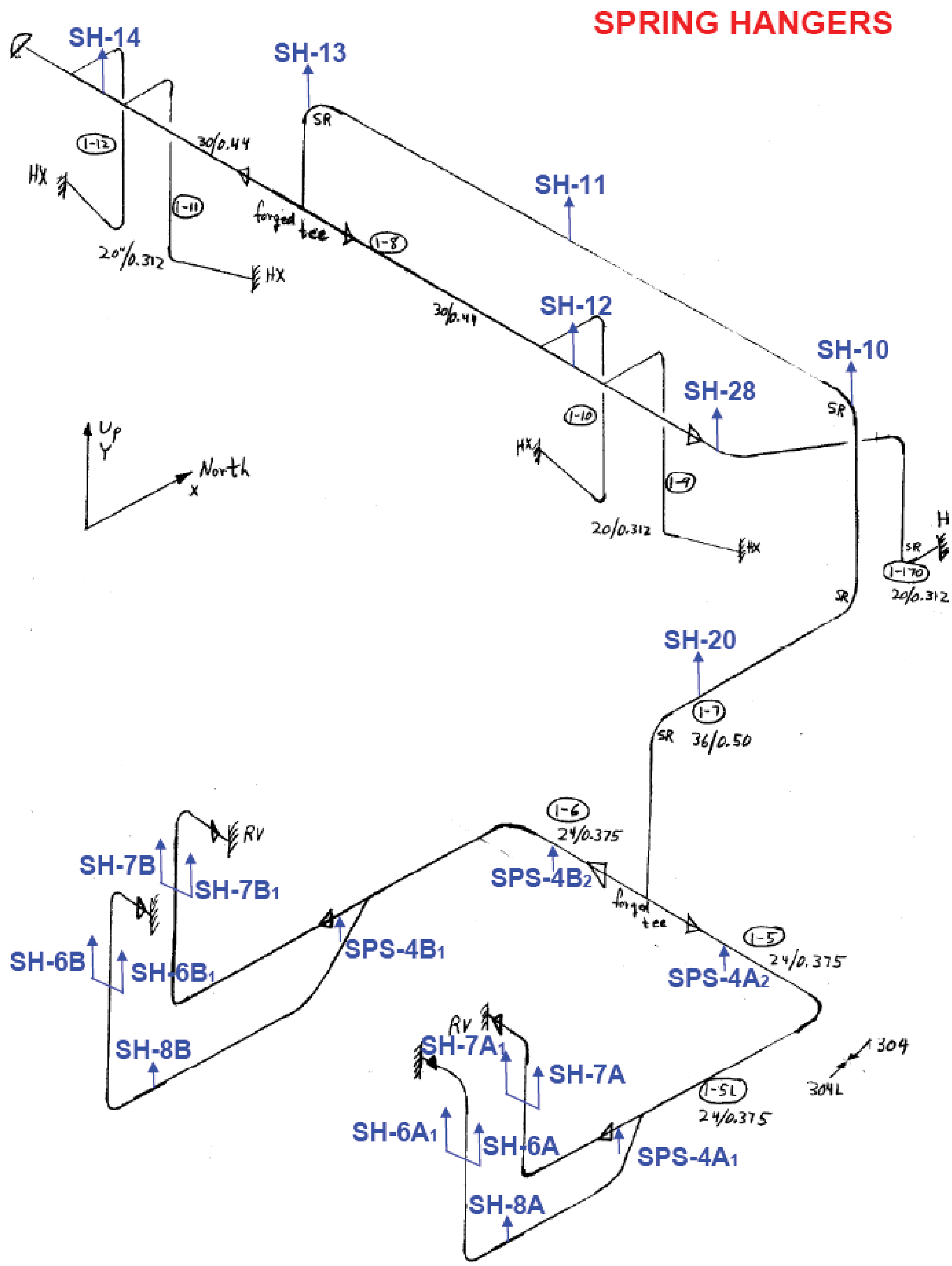

Figure D.1- 2. Spring Pipe Supports Associated with Model 1 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** M. D. Landon **Date:** 09/30/08

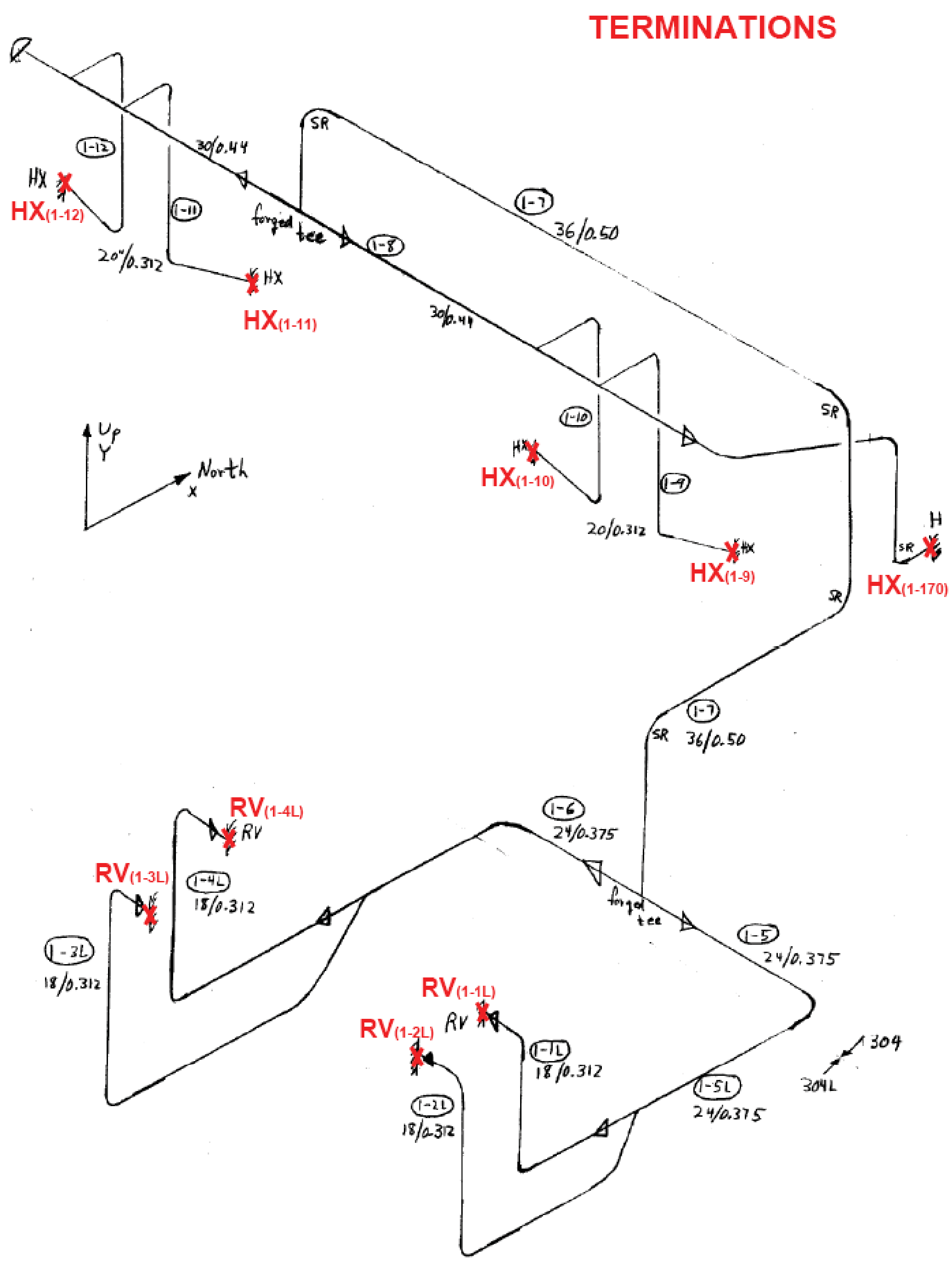

Figure D.1- 3. Terminations Associated with Model 1 [1]

Project:	ATR Life-Time Extension Project		**ECAR No.:**	ECAR-194		**Rev.:**	0
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Performer:	A. L. Crawford	**Date:** 09/30/08	**Checker:**	M. D. Landon		**Date:**	09/30/08

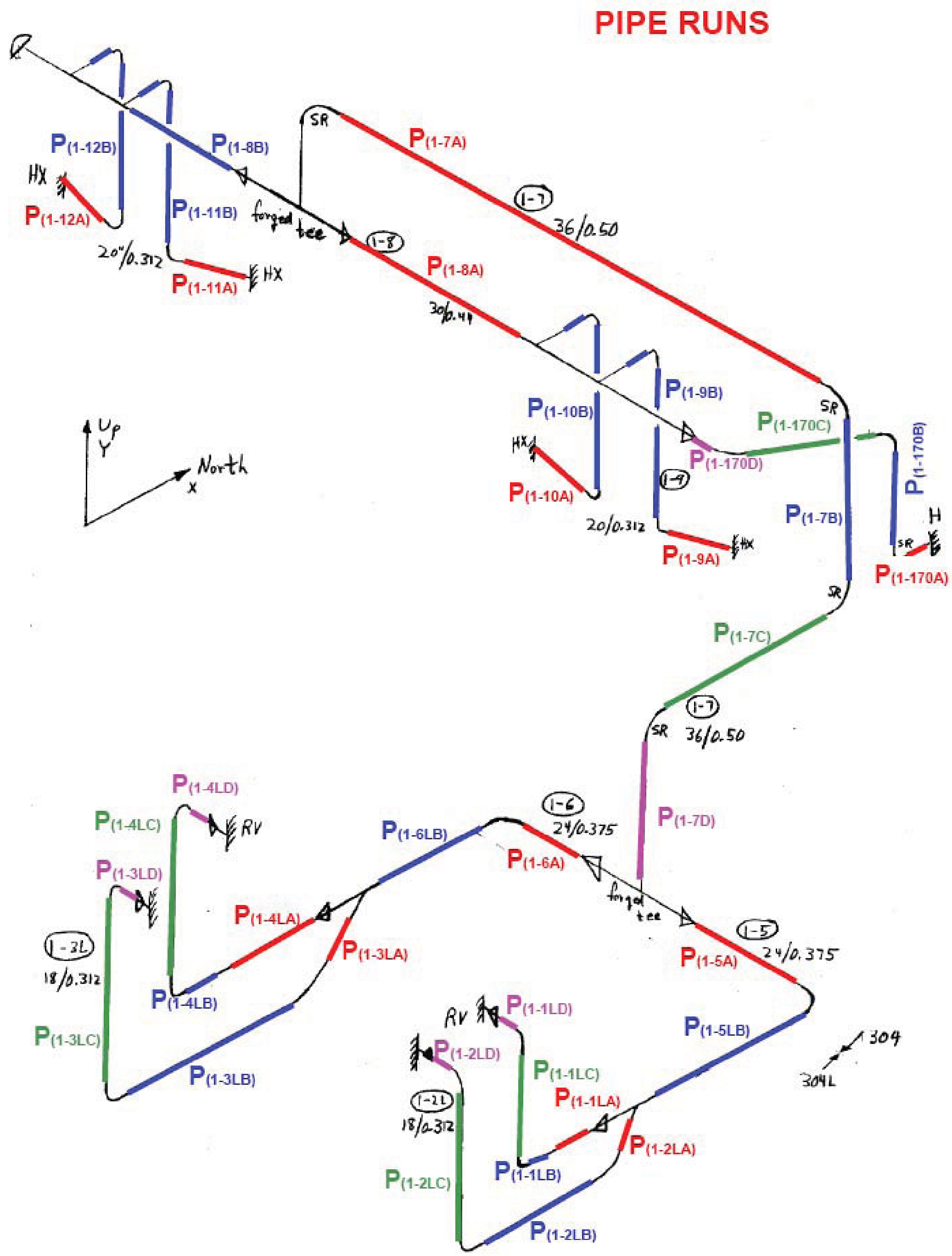

Figure D.1- 4. Pipe Runs Associated with Model 1 [1]

Project:	ATR Life-Time Extension Project			**ECAR No.:**	ECAR-194	**Rev.:**	0
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Performer:	A. L. Crawford	**Date:**	09/30/08	**Checker:**	M. D. Landon	**Date:**	09/30/08

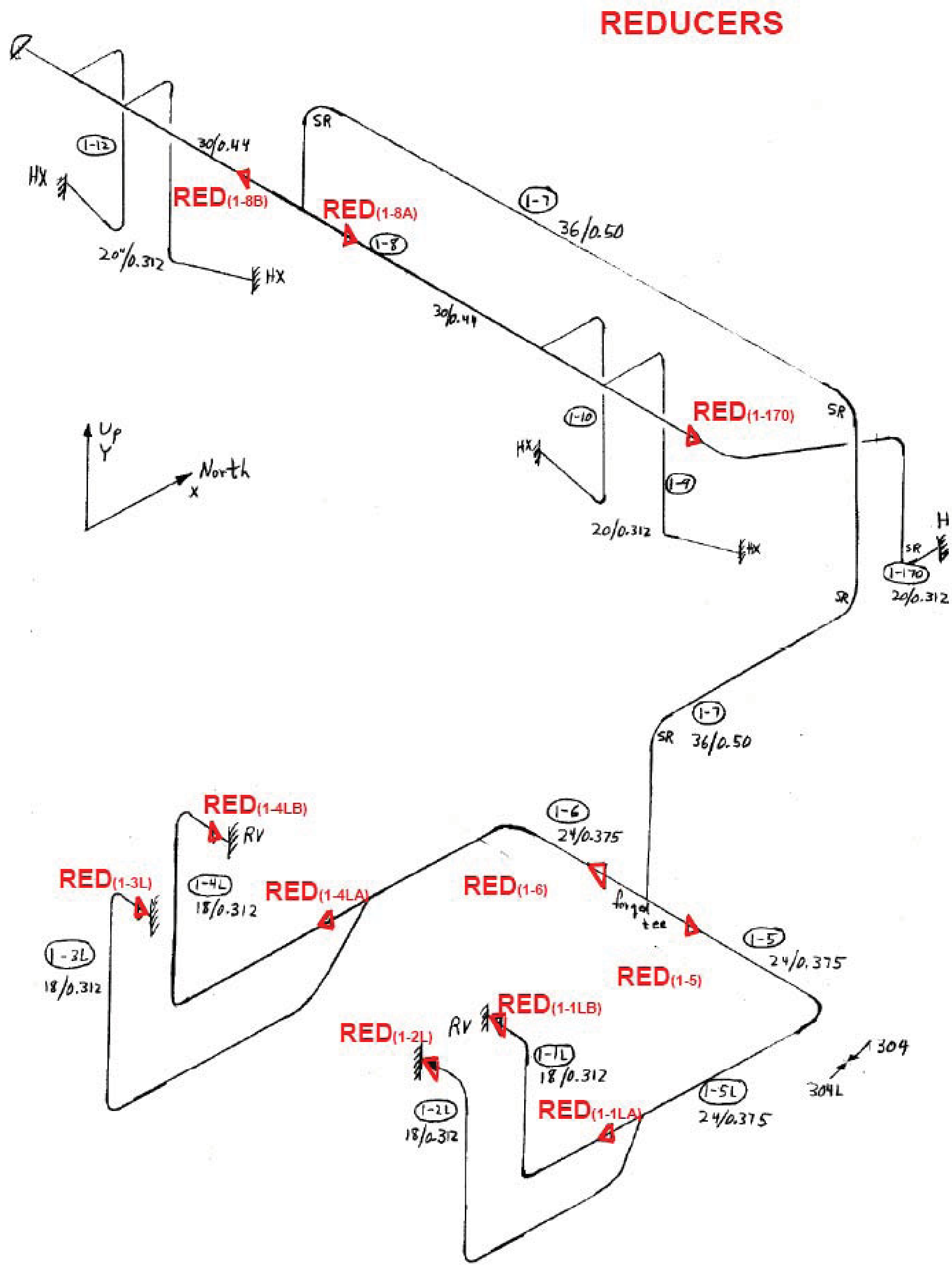

Figure D.1- 5. Reducers Associated with Model 1 [1]

Project:	ATR Life-Time Extension Project		**ECAR No.:**	ECAR-194		**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation						
Performer:	A. L. Crawford	**Date:**	09/30/08	**Checker:**	M. D. Landon	**Date:**	09/30/08

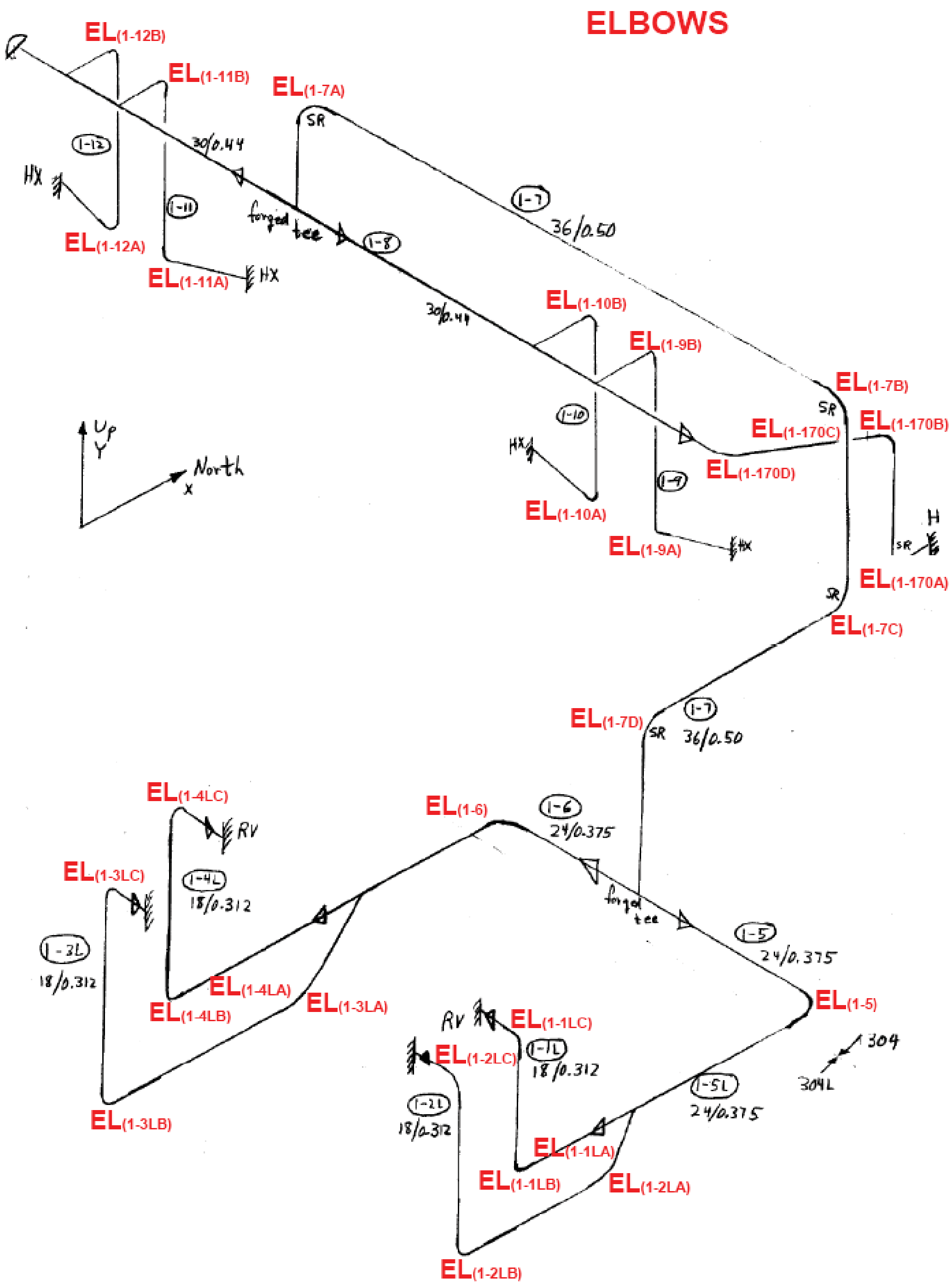

Figure D.1- 6. Elbows Associated with Model 1 [1]

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Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** M. D. Landon **Date:** 09/30/08

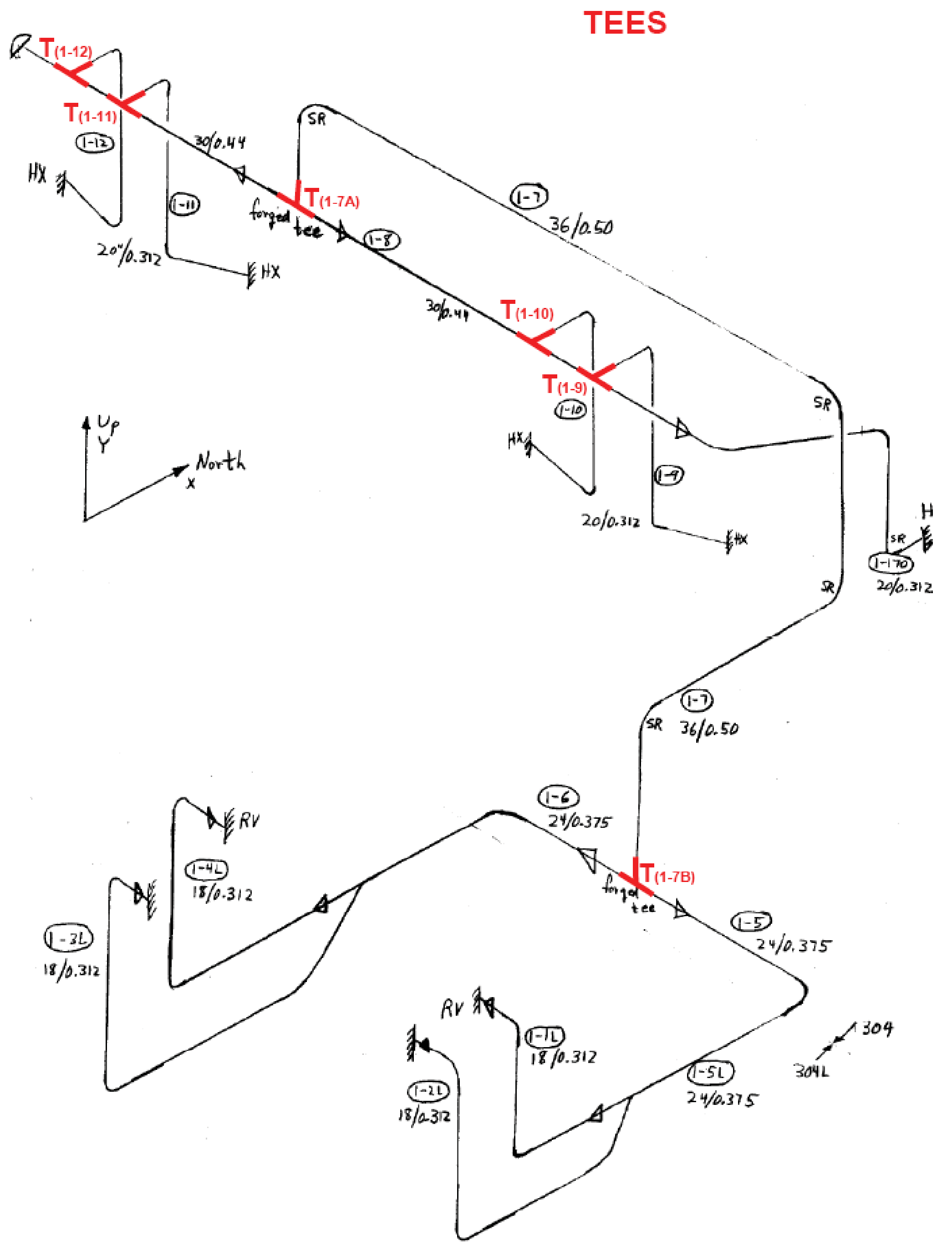

Figure D.1- 7. Tees Associated with Model 1 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
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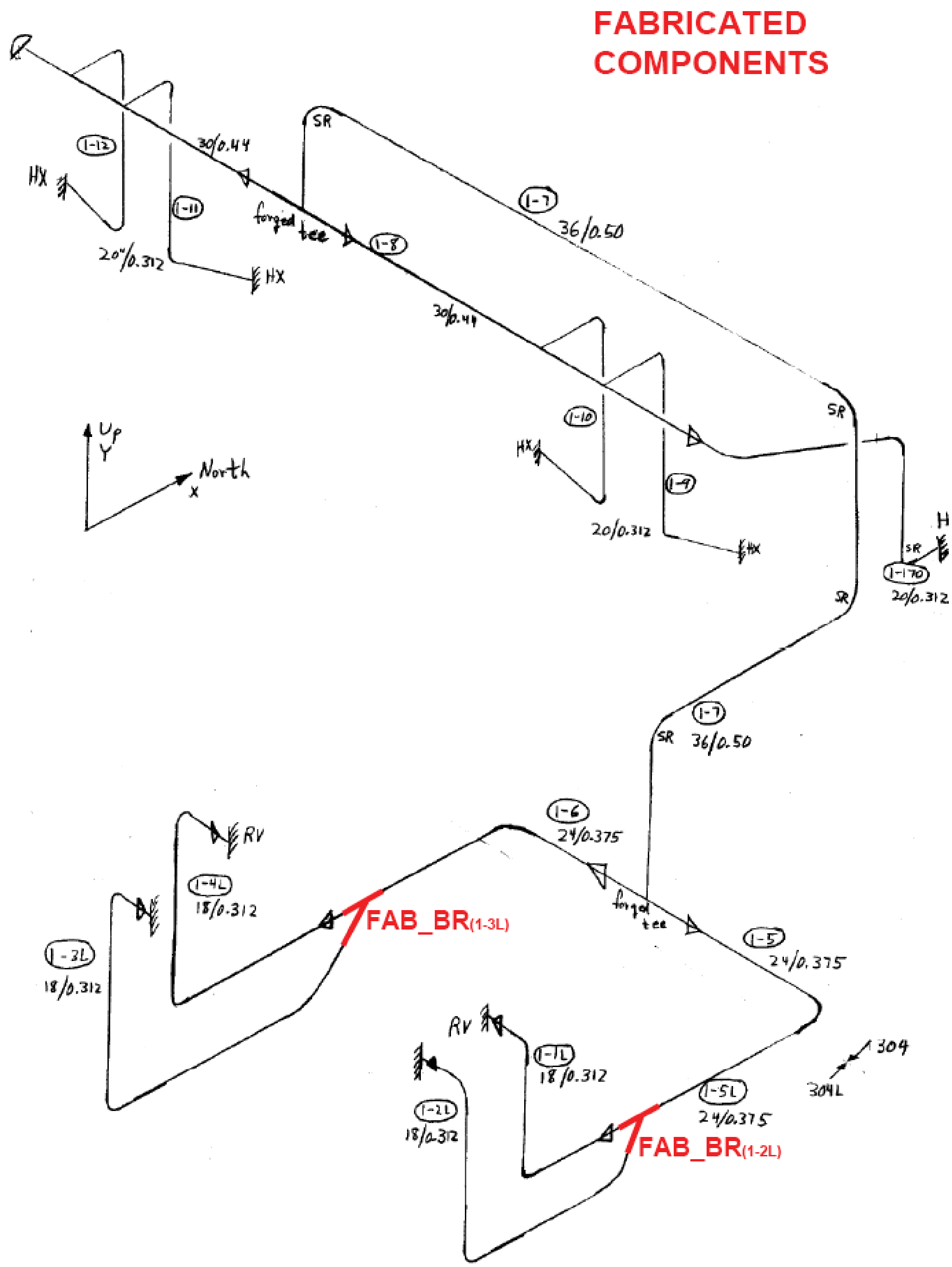

Figure D.1- 8. Fabricated Components Associated with Model 1 [1]

Project:	ATR Life-Time Extension Project	ECAR No.:	ECAR-194	Rev.:	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation				
Performer:	A. L. Crawford	Date:	09/30/08	Checker: M. D. Landon	Date: 09/30/08

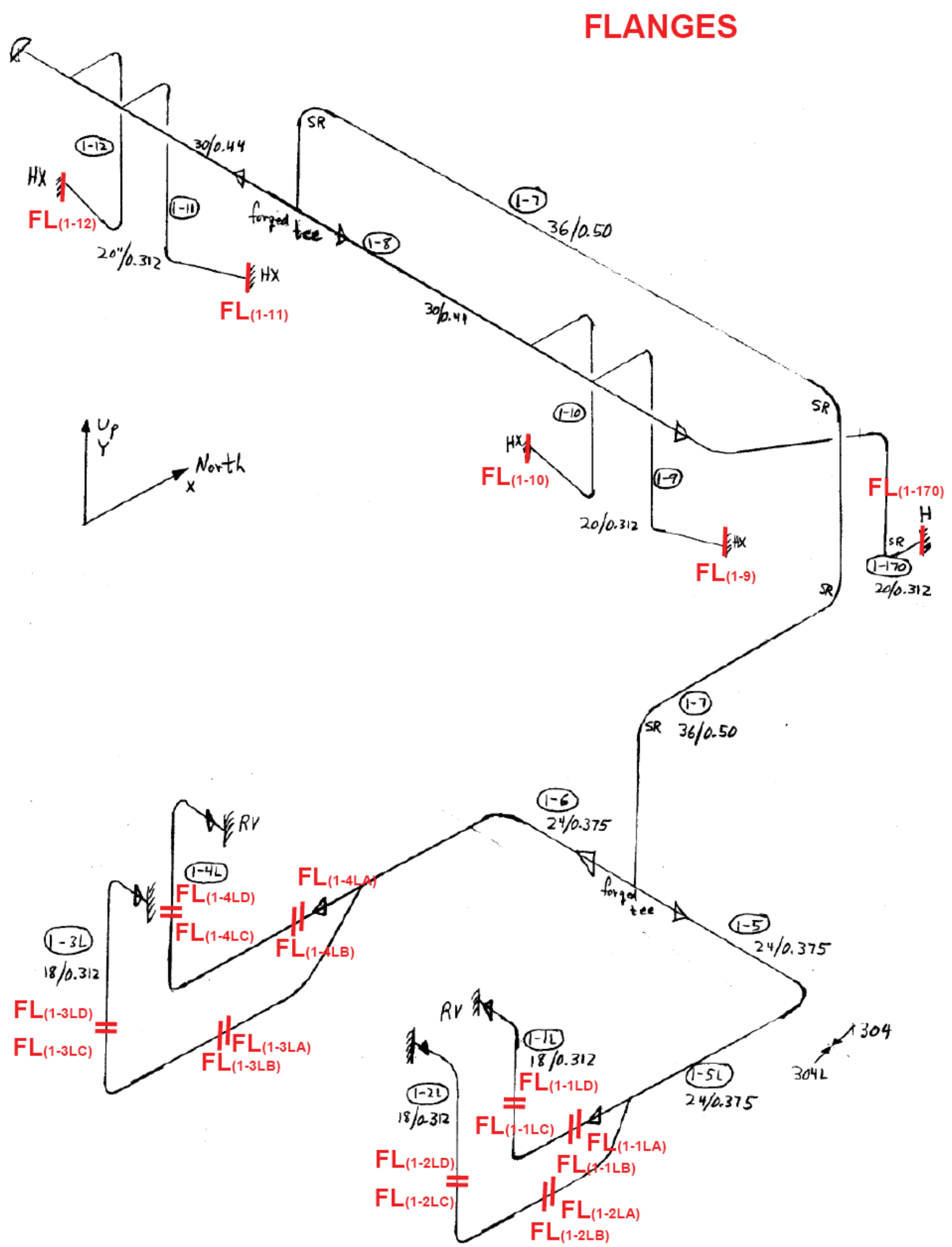

Figure D.1- 9. Flanges Associated with Model 1 [1]

Project:	ATR Life-Time Extension Project	ECAR No.:	ECAR-194	Rev.:	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation				
Performer:	A. L. Crawford	Date:	09/30/08	Checker:	M. D. Landon	Date:	09/30/08

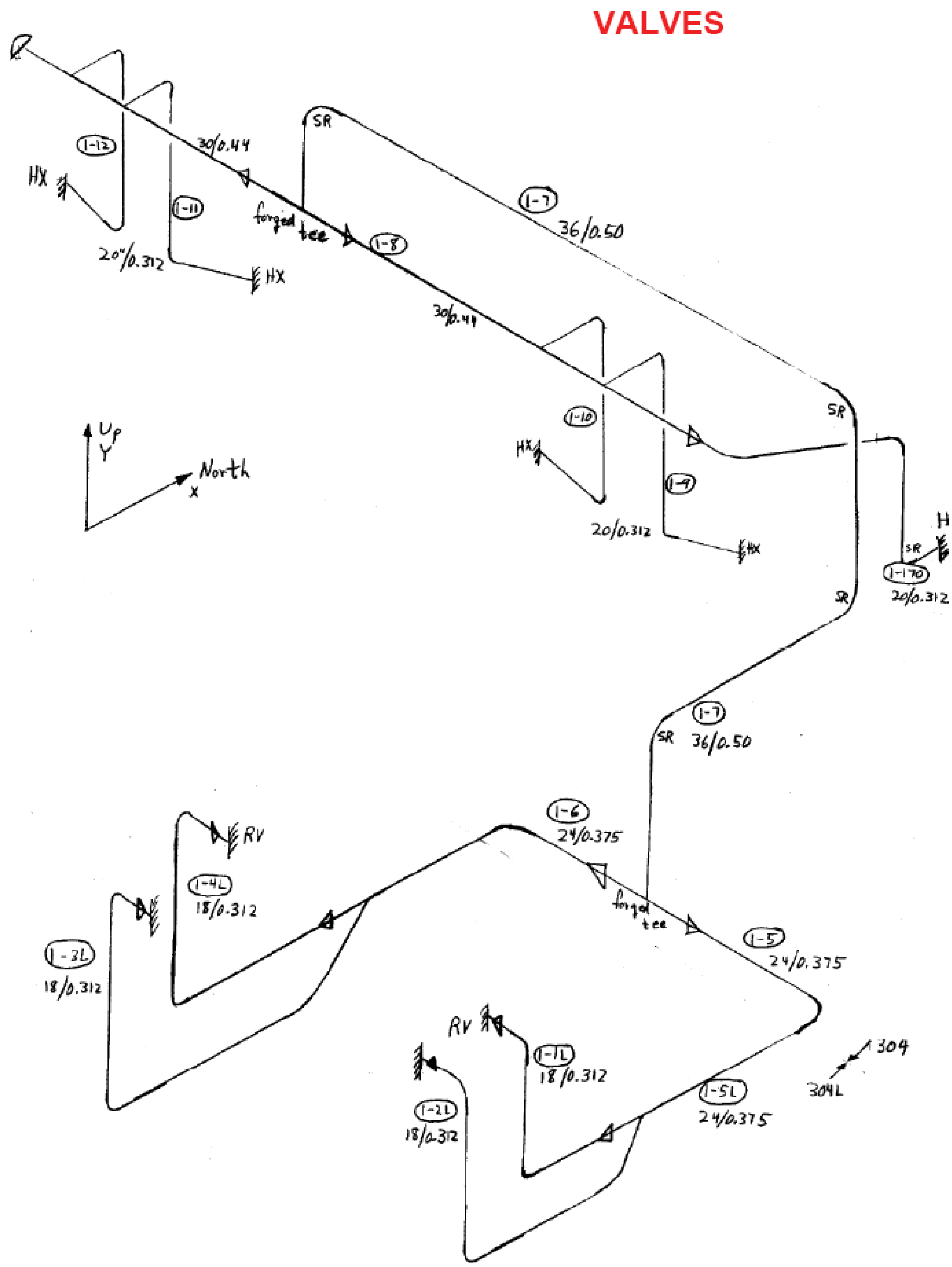

Figure D.1- 10. Valves Associated with Model 1 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** M. D. Landon **Date:** 09/30/08

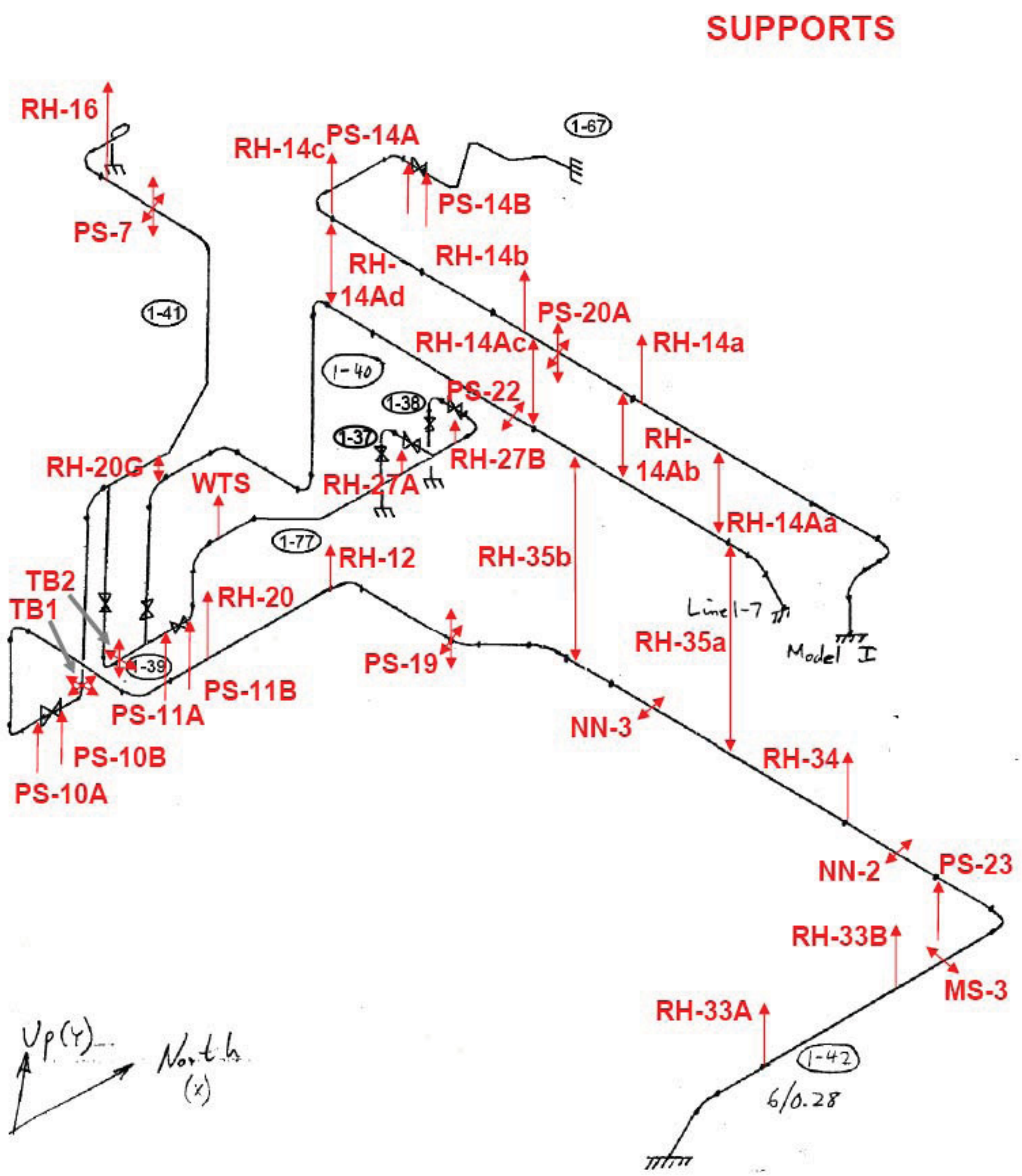

Figure D.1- 11. Supports Associated with Model 4 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** M. D. Landon **Date:** 09/30/08

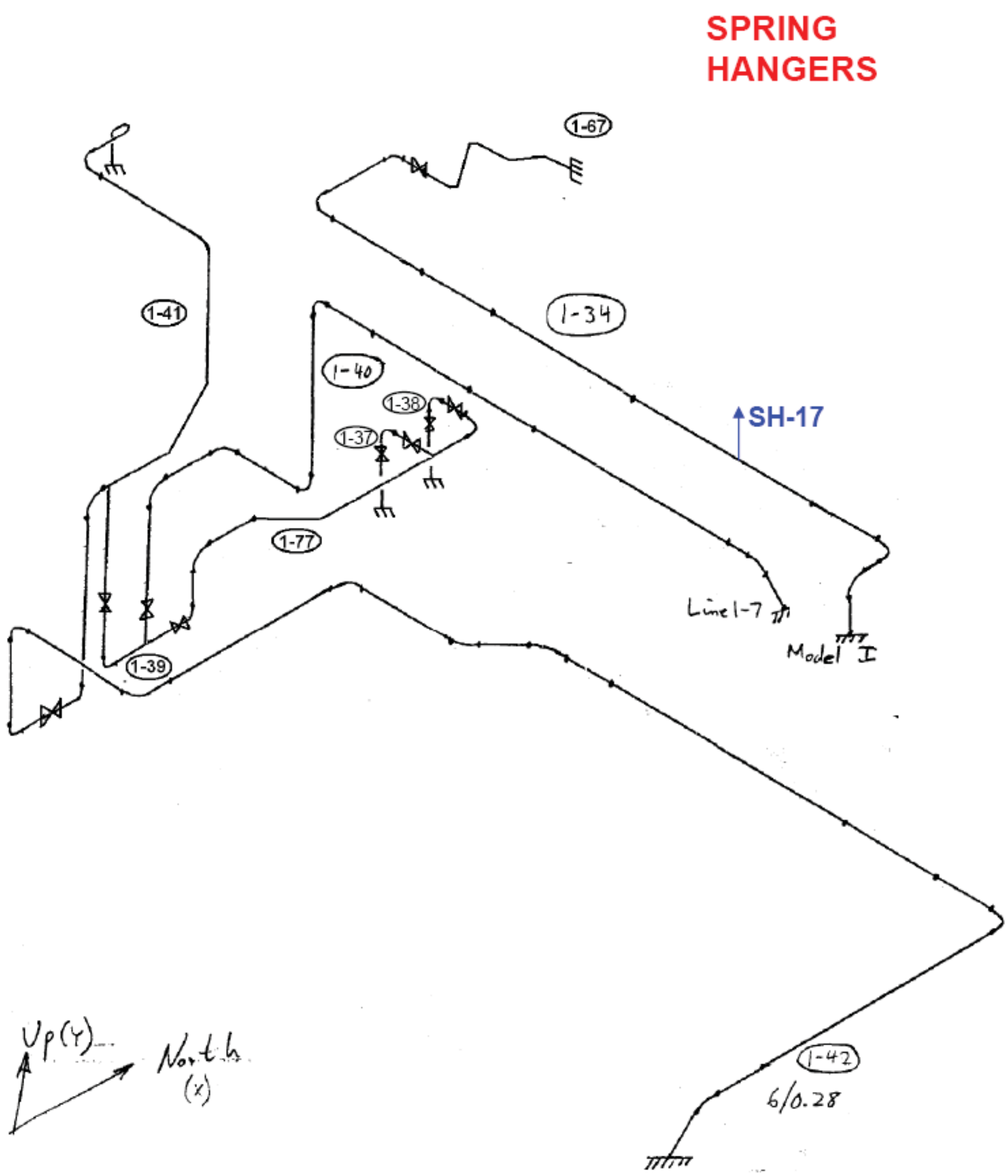

Figure D.1- 12. Spring Hangers Associated with Model 4 [1]

Project:	ATR Life-Time Extension Project		**ECAR No.:**	ECAR-194		**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation						
Performer:	A. L. Crawford	**Date:** 09/30/08	**Checker:**	M. D. Landon		**Date:**	09/30/08

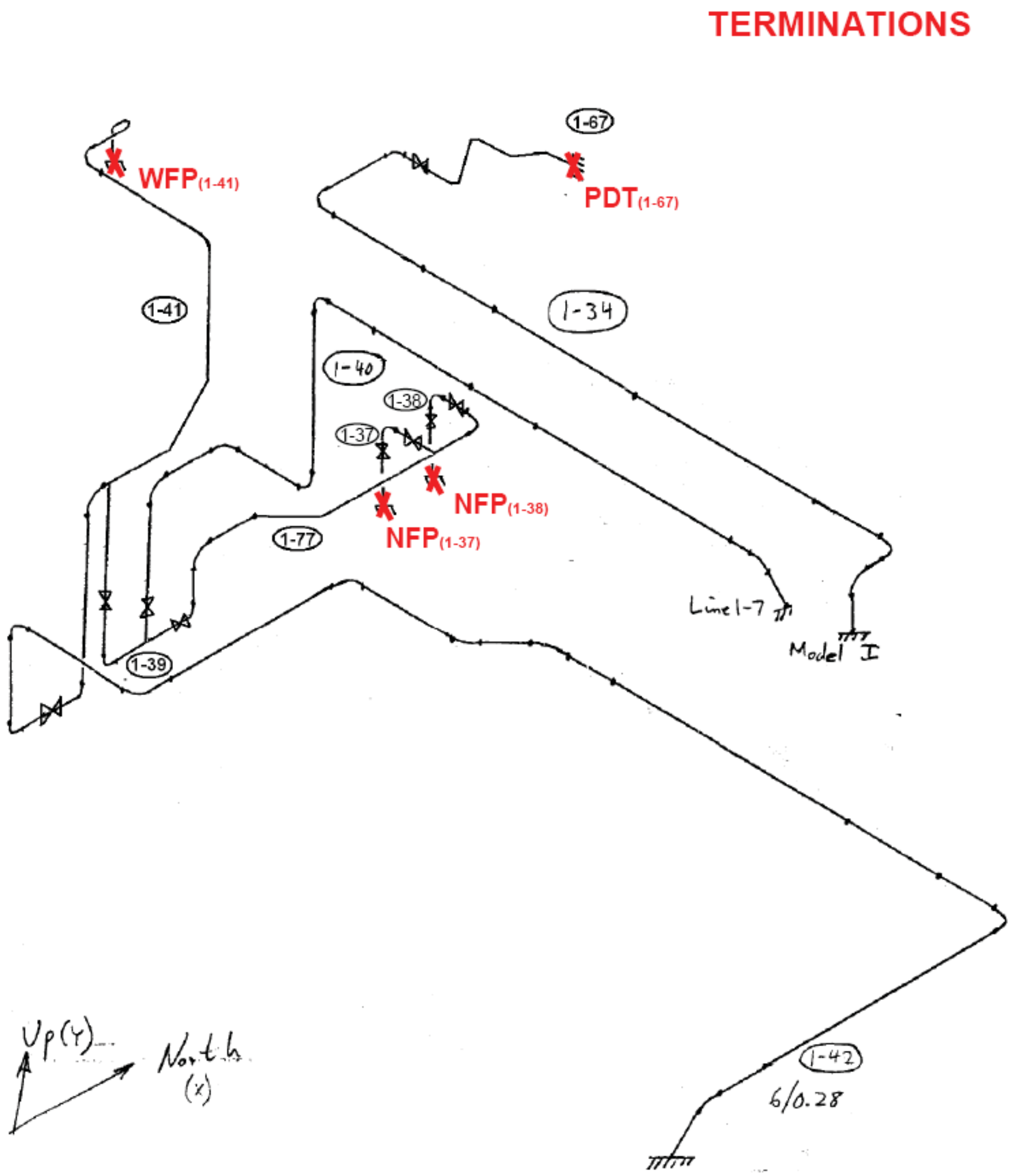

Figure D.1- 13. Terminations Associated with Model 4 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** M. D. Landon **Date:** 09/30/08

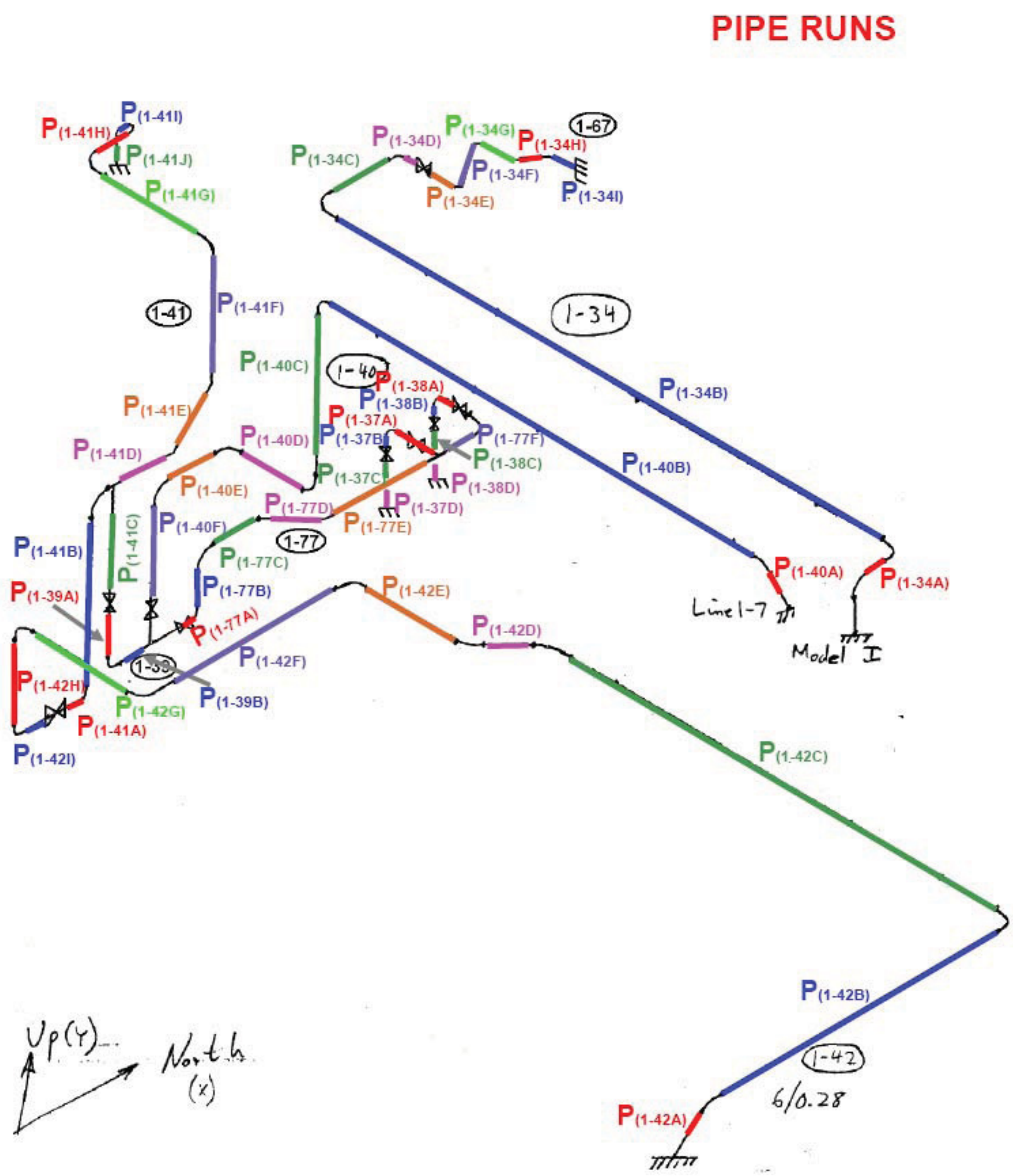

Figure D.1- 14. Pipe Runs Associated with Model 4 [1]

Project:	ATR Life-Time Extension Project		**ECAR No.:**	ECAR-194		**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation						
Performer:	A. L. Crawford	**Date:** 09/30/08	**Checker:**	M. D. Landon		**Date:**	09/30/08

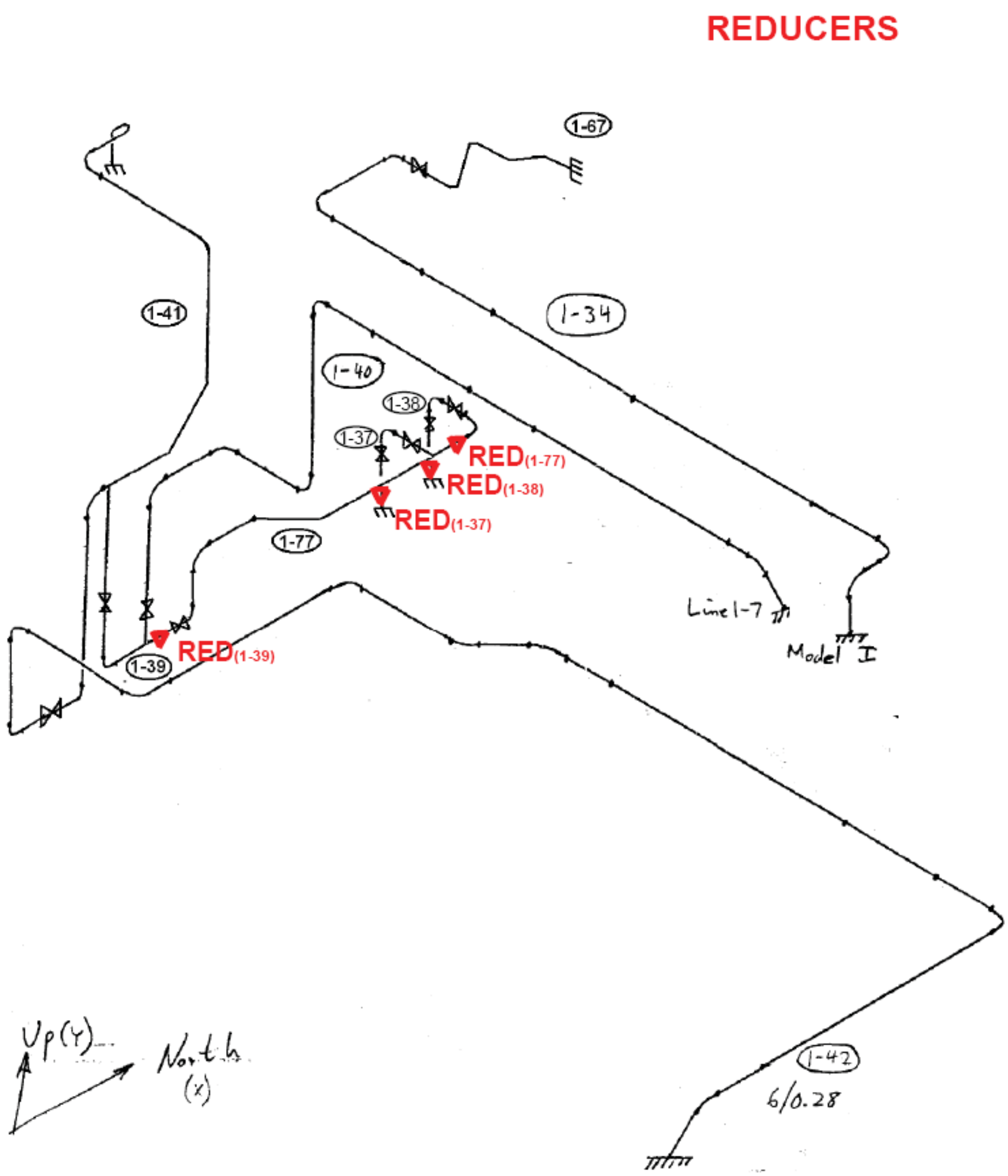

Figure D.1- 15. Reducers Associated with Model 4 [1]

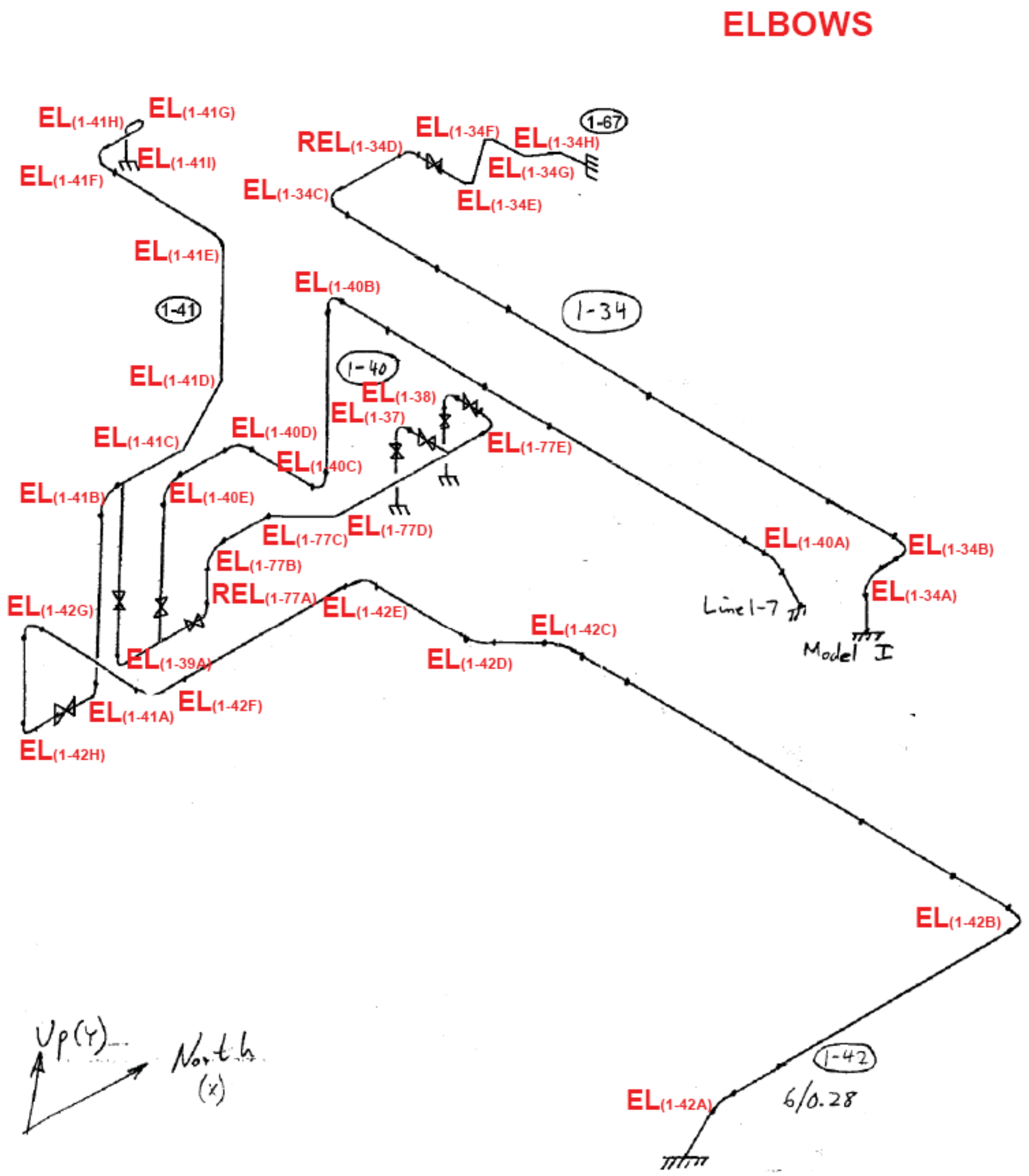

Figure D.1- 16. Elbows Associated with Model 4 [1]

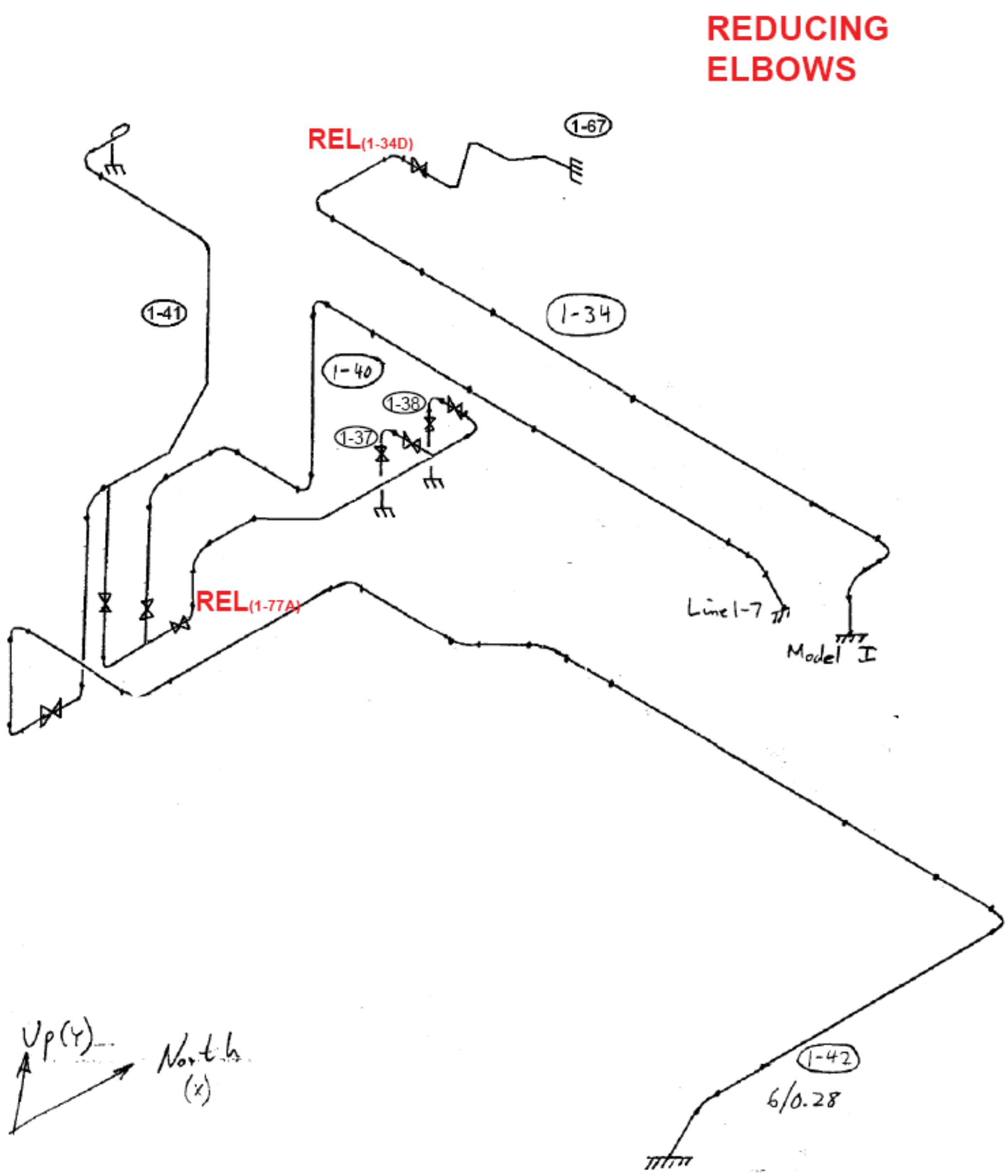

Figure D.1- 17. Reducing Elbows Associated with Model 4 [1]

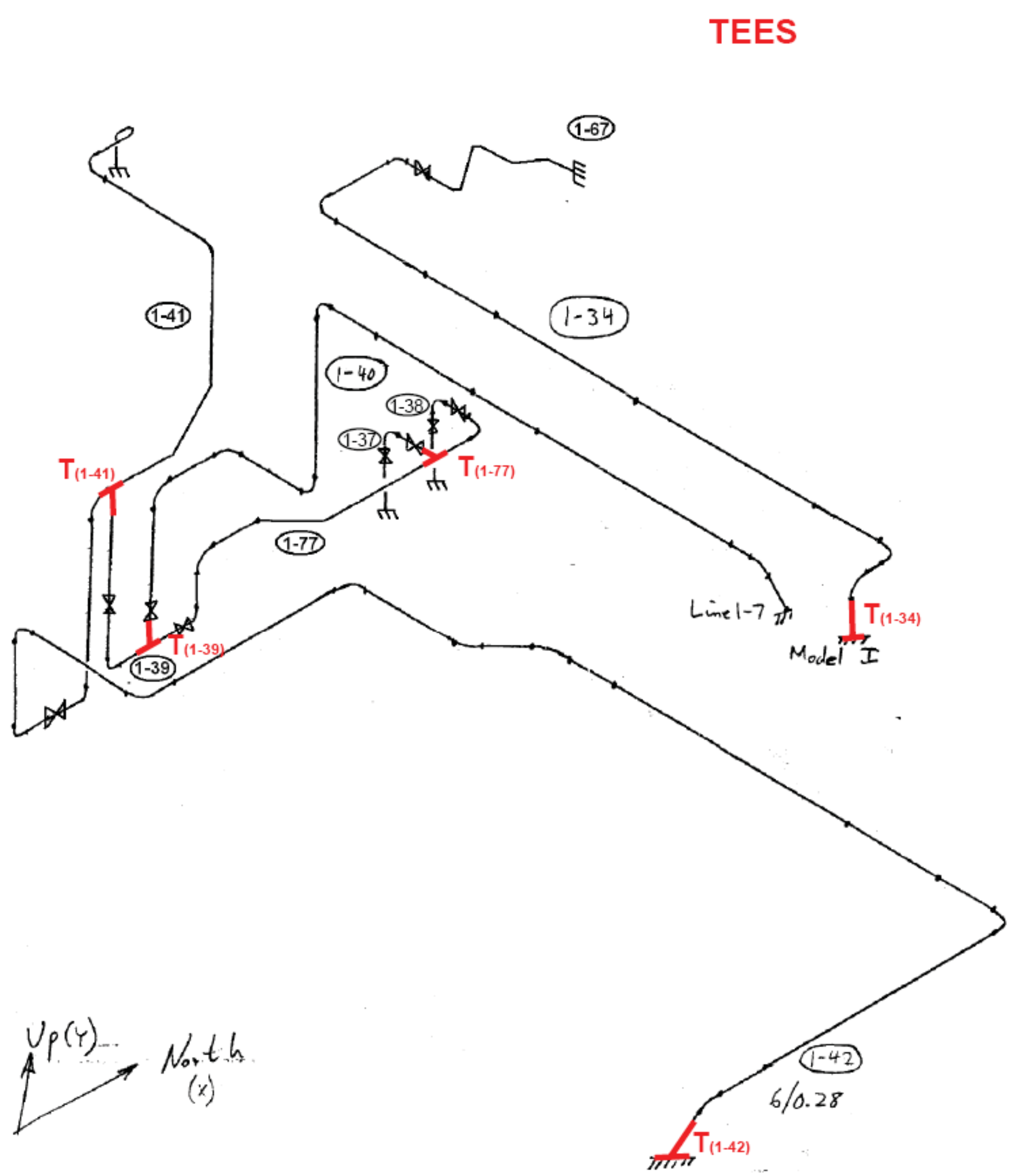

Figure D.1- 18. Tees Associated with Model 4 [1]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** M. D. Landon **Date:** 09/30/08

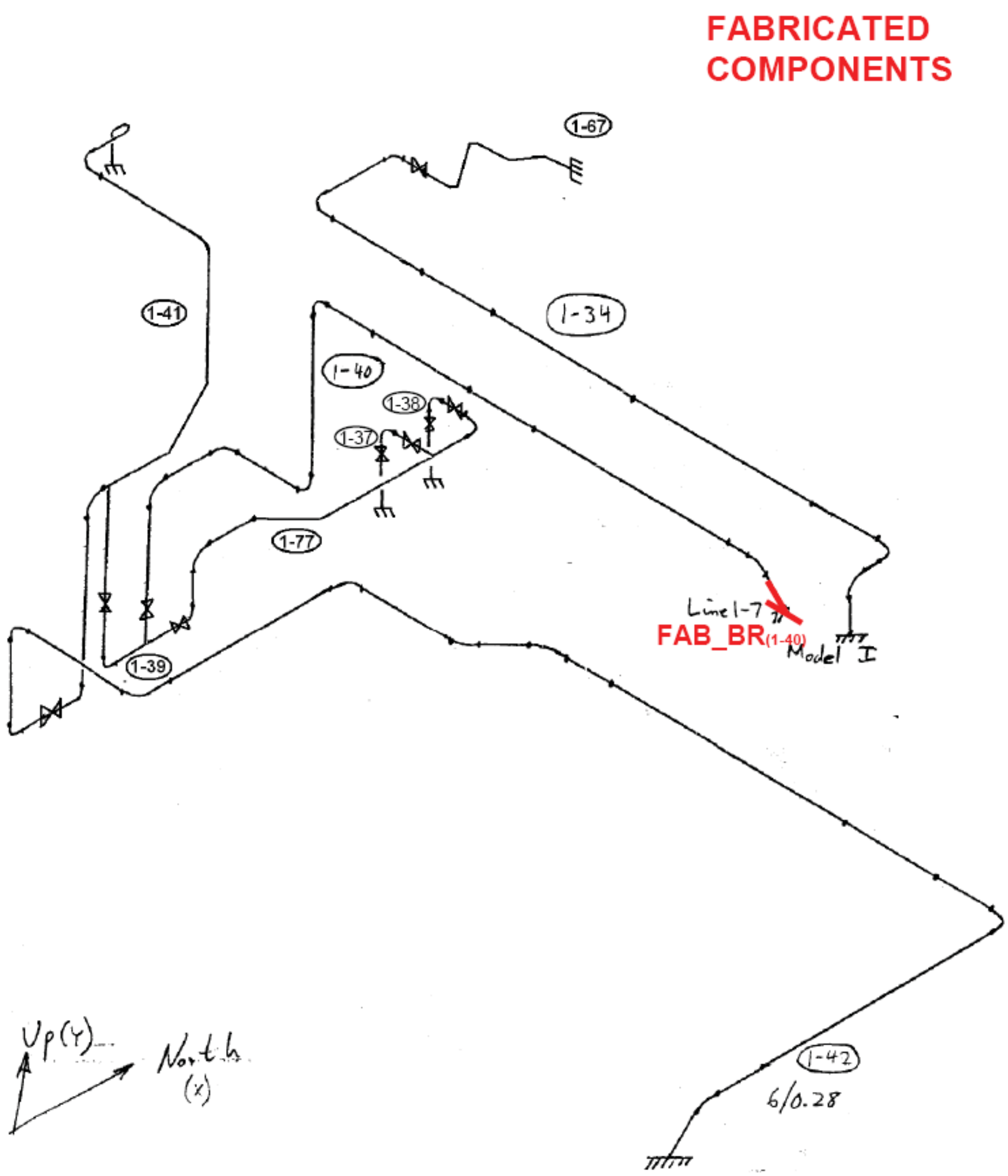

Figure D.1- 19. Fabricated Branch Associated with Model 4 [1]

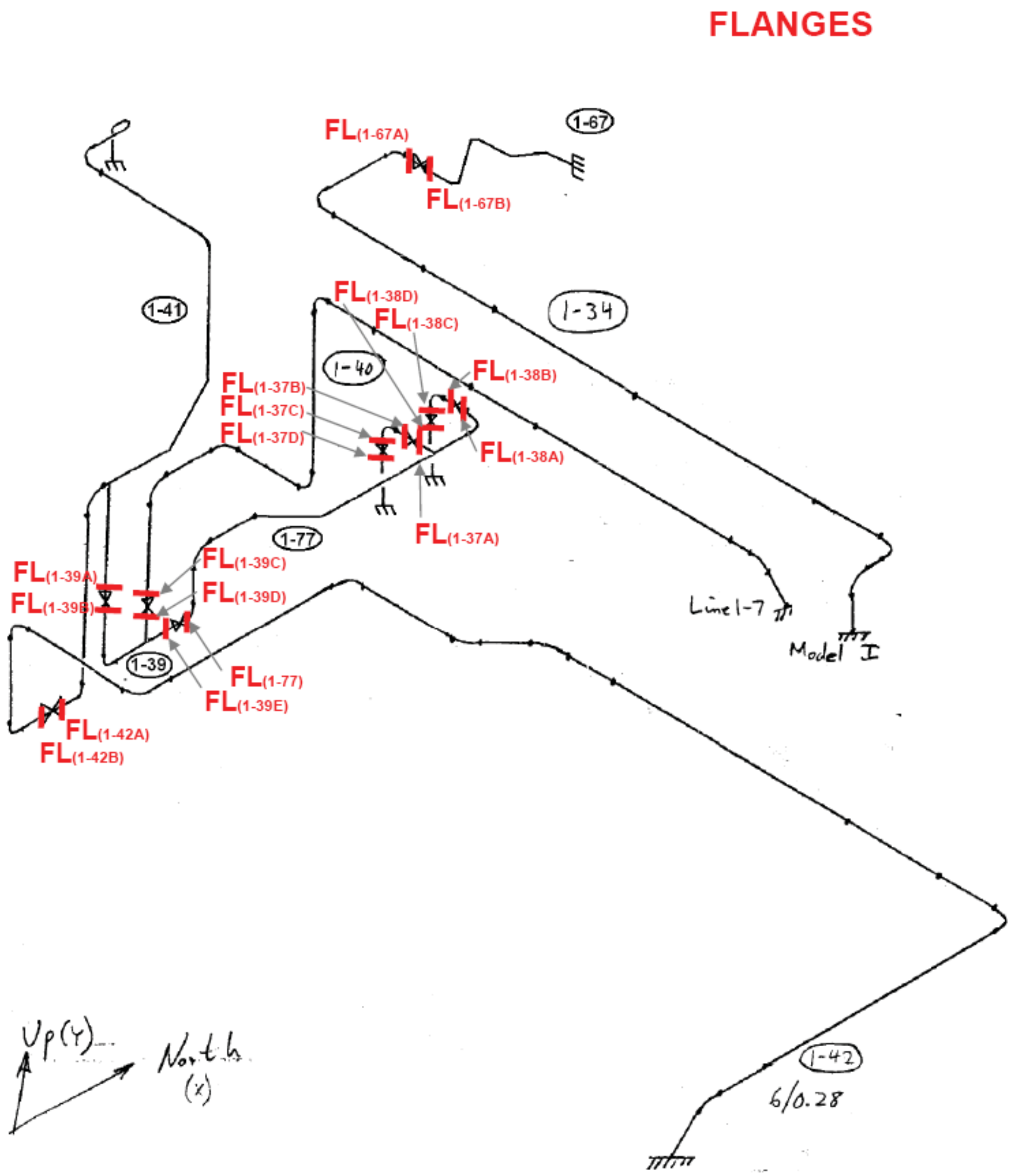

Figure D.1- 20. Flanges Associated with Model 4 [1]

Project:	ATR Life-Time Extension Project			**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation						
Performer:	A. L. Crawford	**Date:**	09/30/08	**Checker:**	M. D. Landon	**Date:**	09/30/08

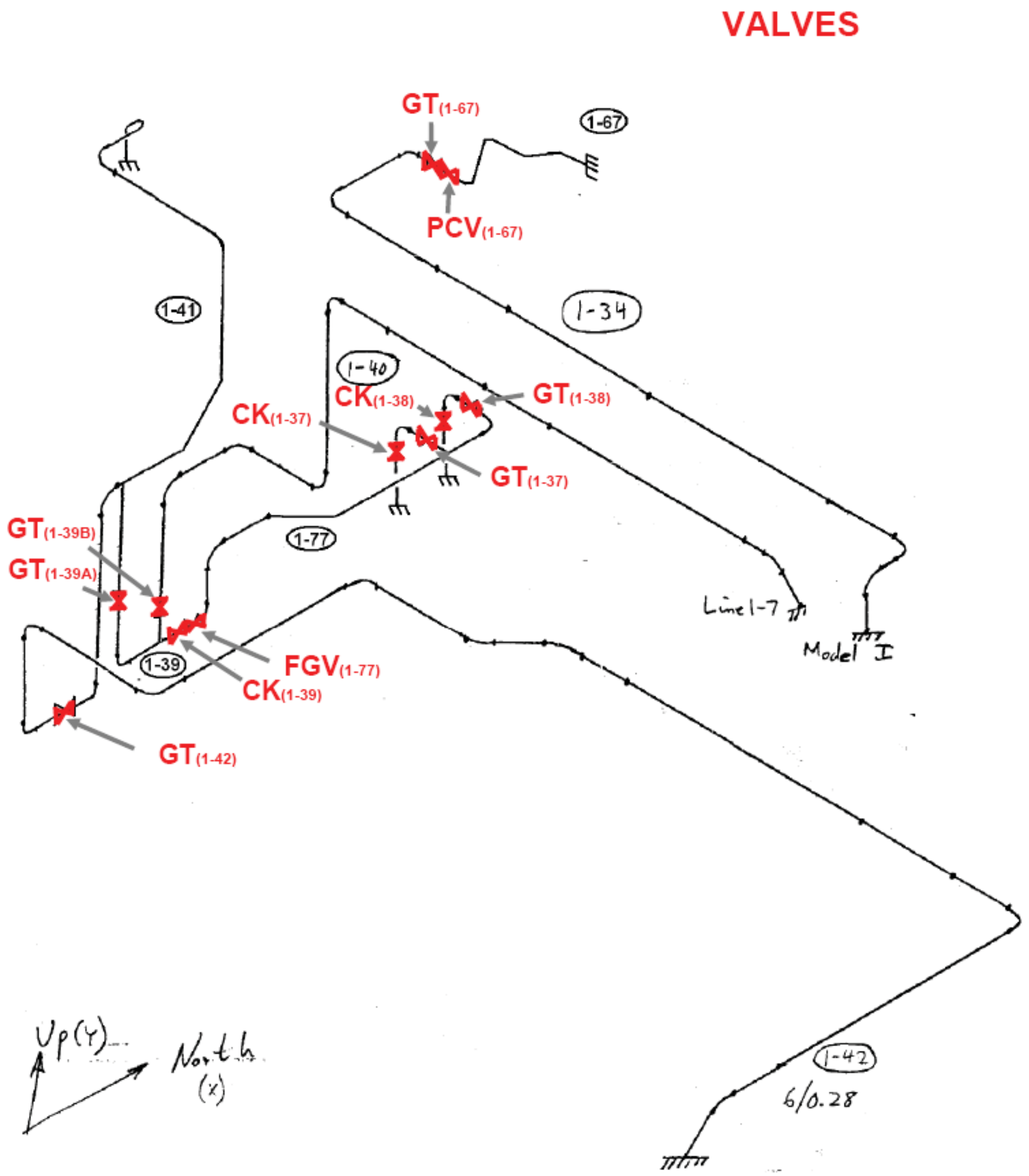

Figure D.1- 21. Valves Associated with Model 4 [1]

Appendix D.2

I-DEAS Model of Model 1-4

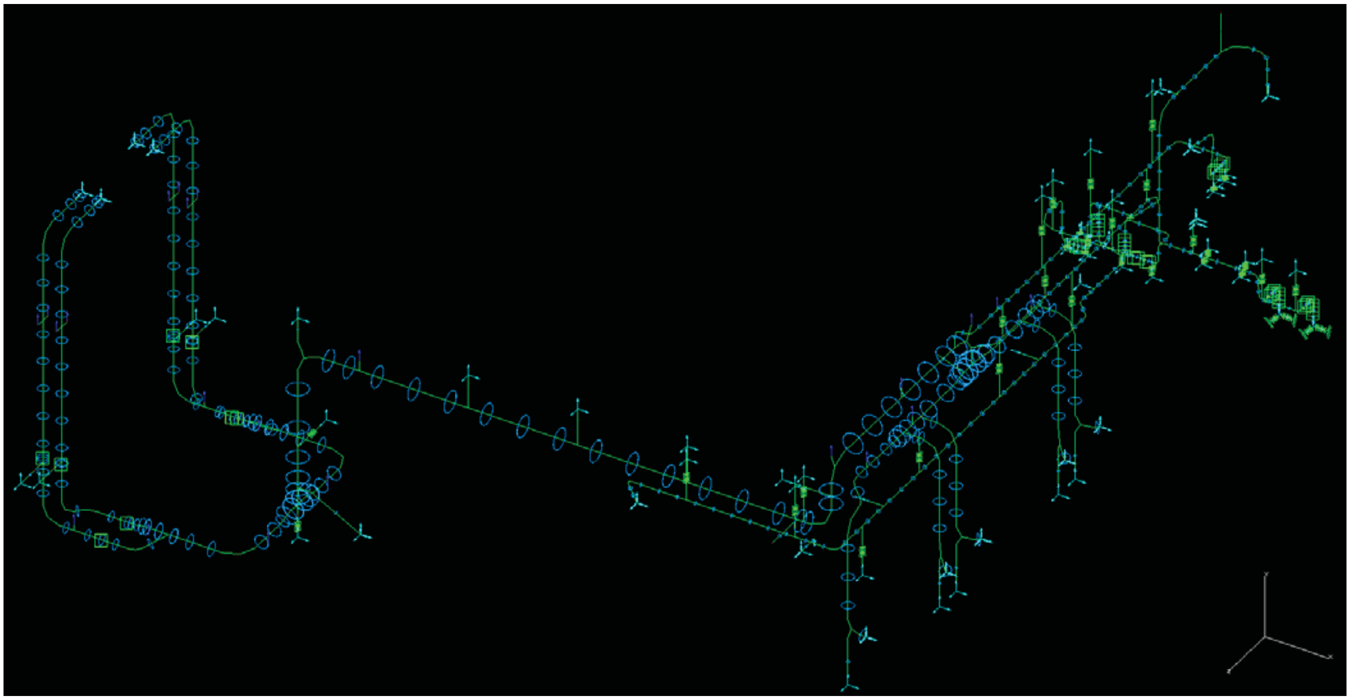

Figure D.2-1. Complete Model 1-4 Piping System

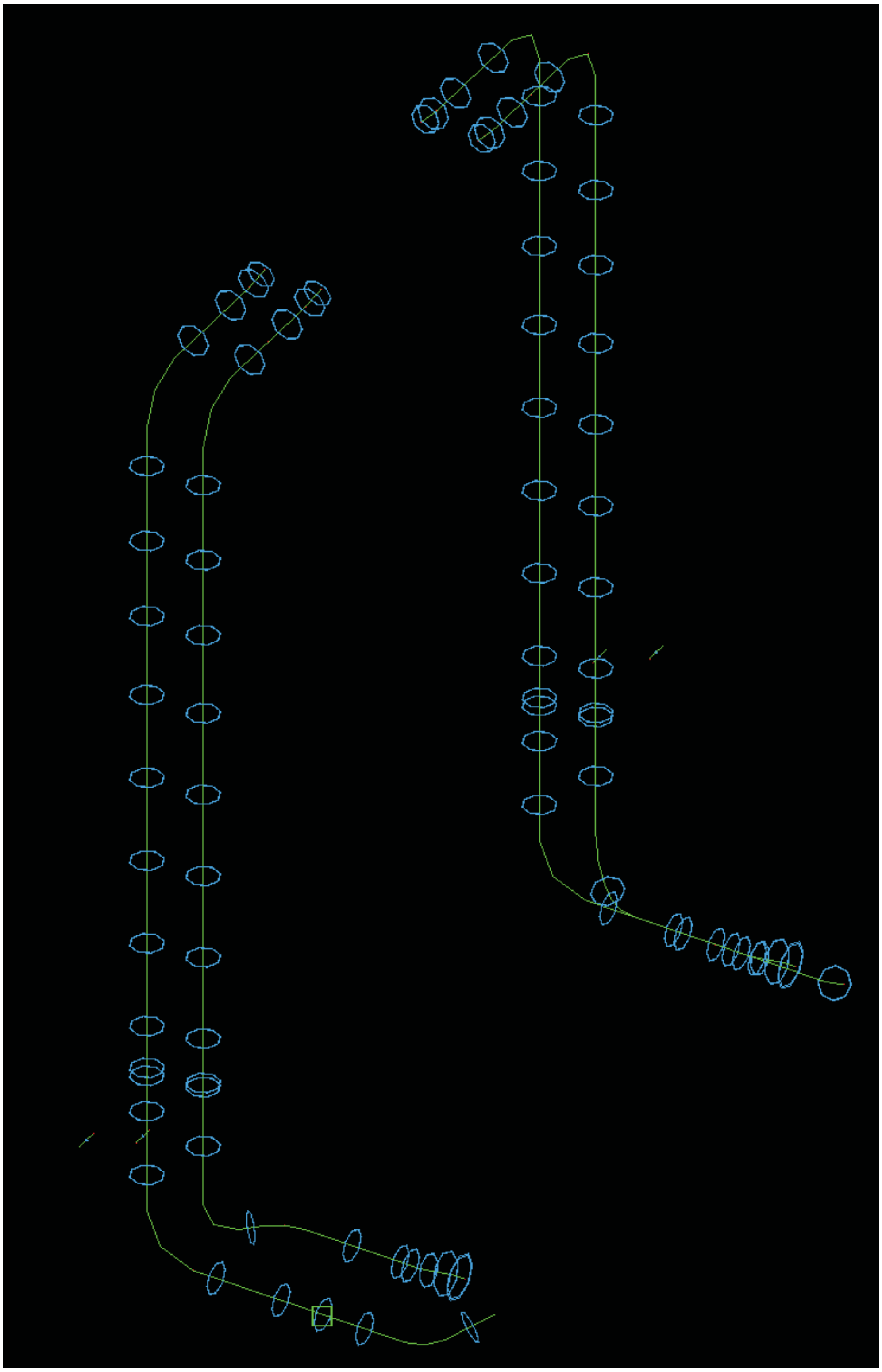

Figure D.2-2. Components Associated With Lines 1L, 2L, 3L, and 4L of Model 1

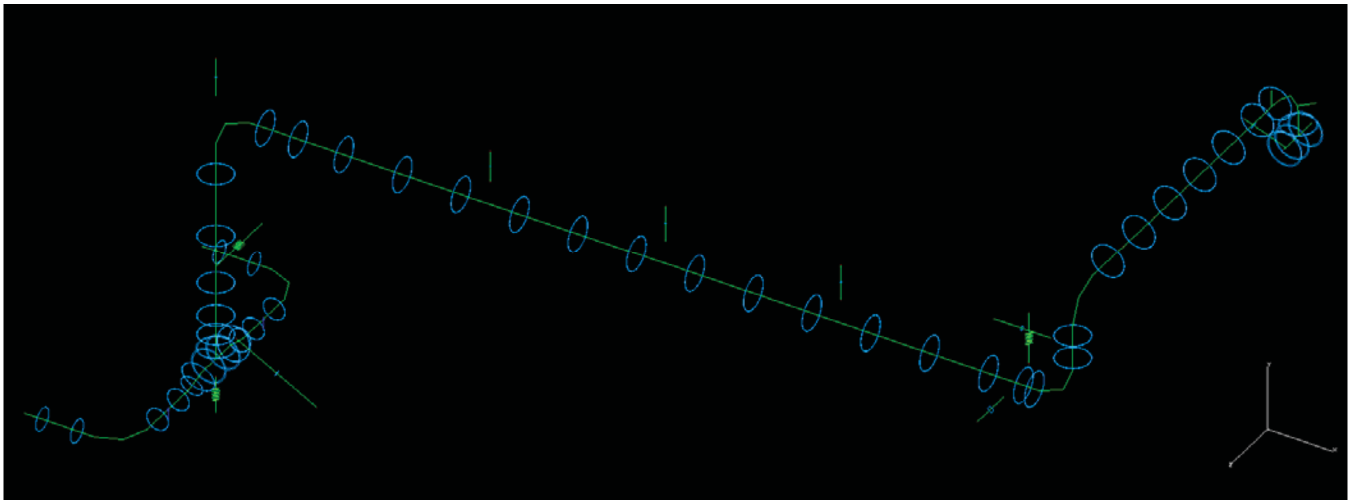

Figure D.2-3. Components Associated With Lines 5, 6, and 7 of Model 1

Project:	ATR Life-Time Extension Project			**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation						
Performer:	A. L. Crawford	**Date:**	09/30/08	**Checker:**	M. D. Landon	**Date:**	09/30/08

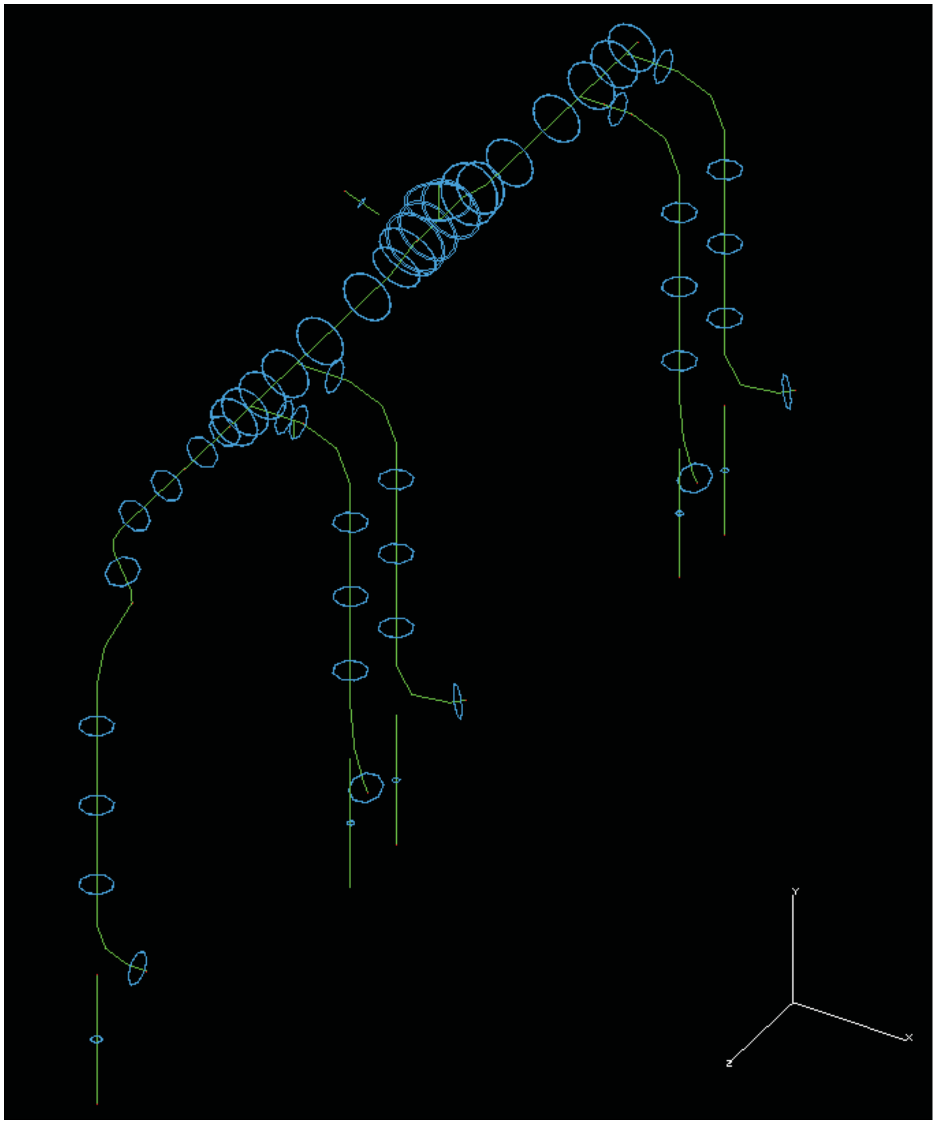

Figure D.2-4. Components Associated Lines 8, 9, 10, 11, 12, and 170 of Model 1

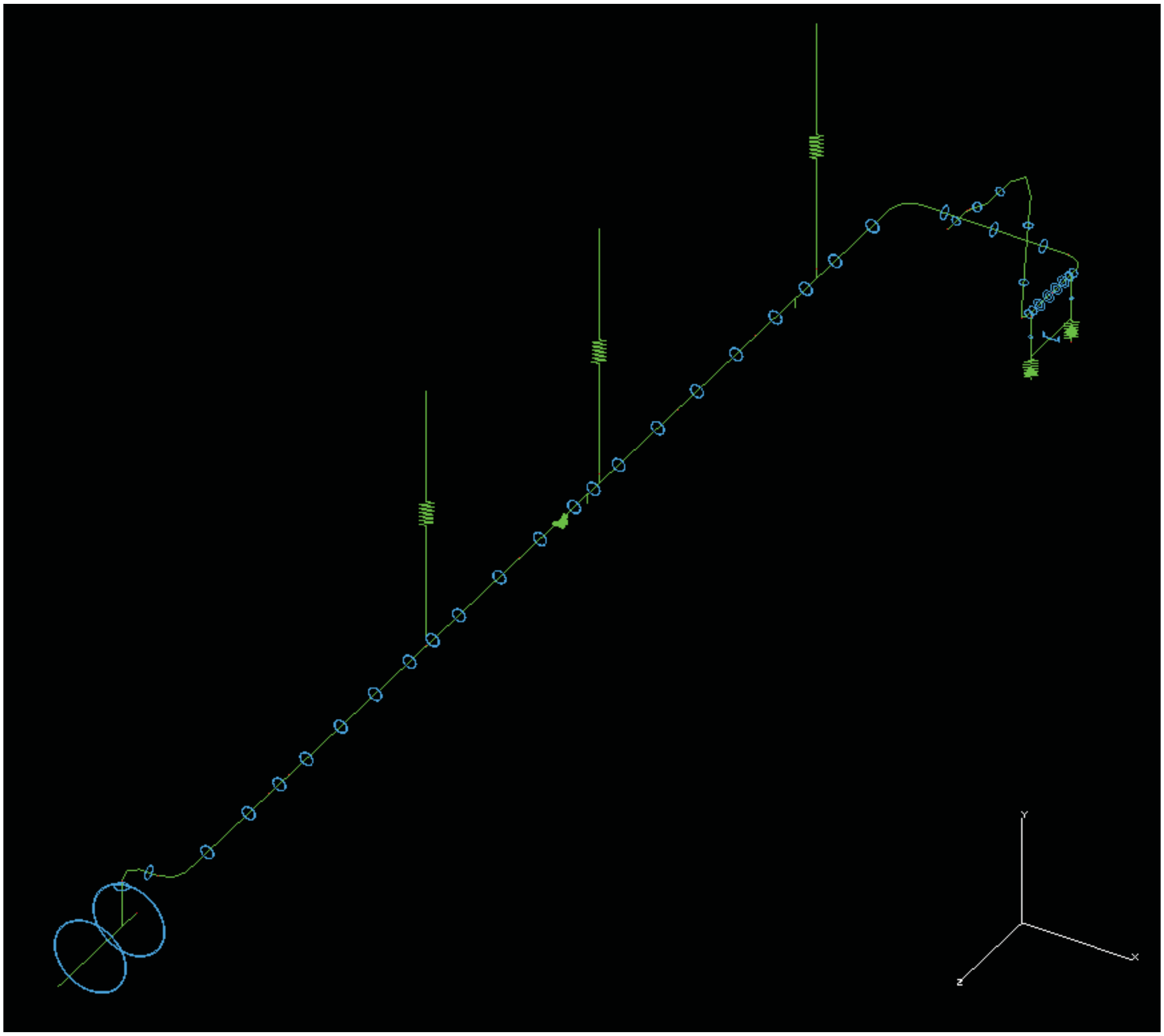

Figure D.2-5. Components Associated With Lines 34 and 67 of Model 4

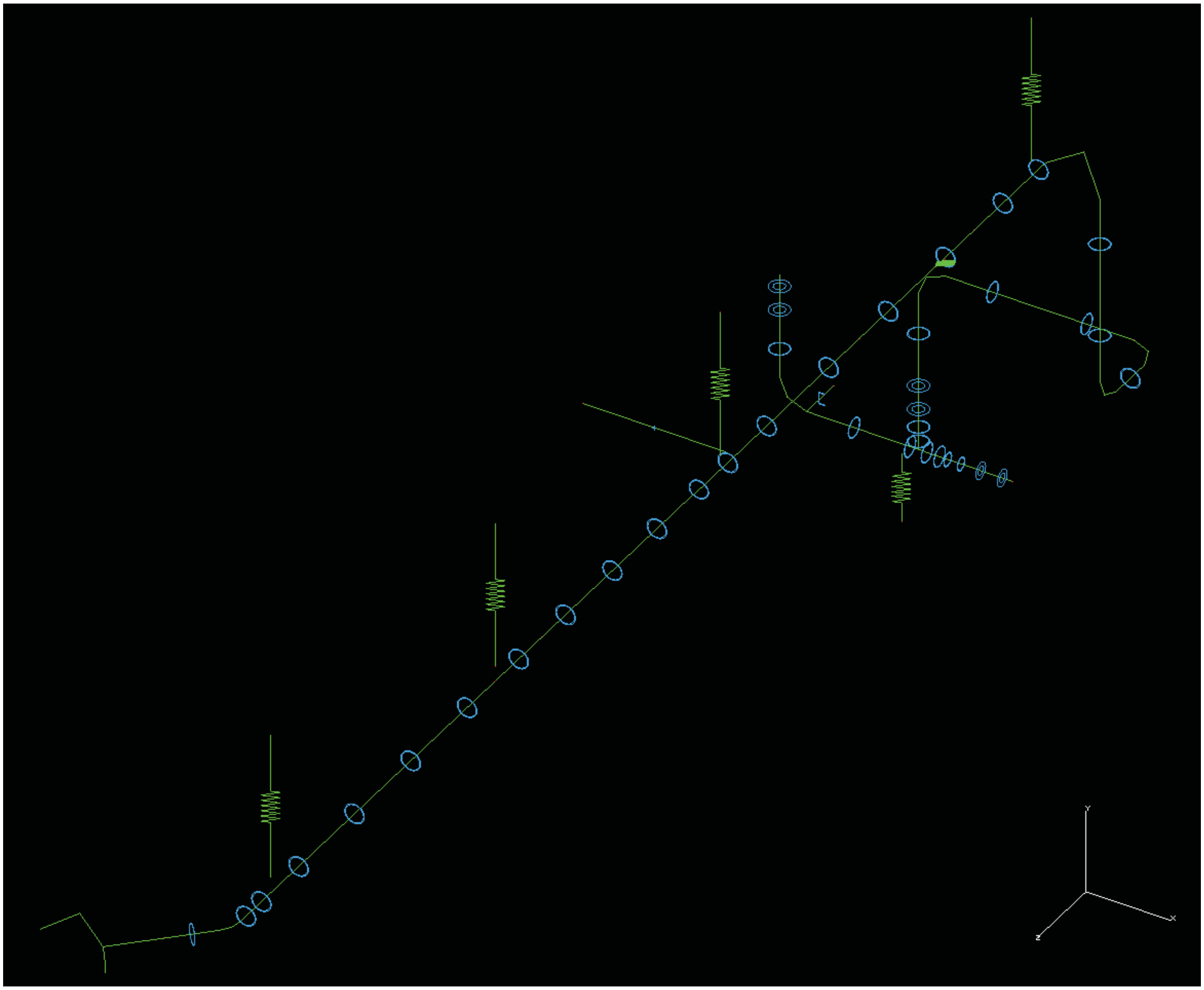

Figure D.2-6. Components Associated With Lines 39 and 40 of Model 4

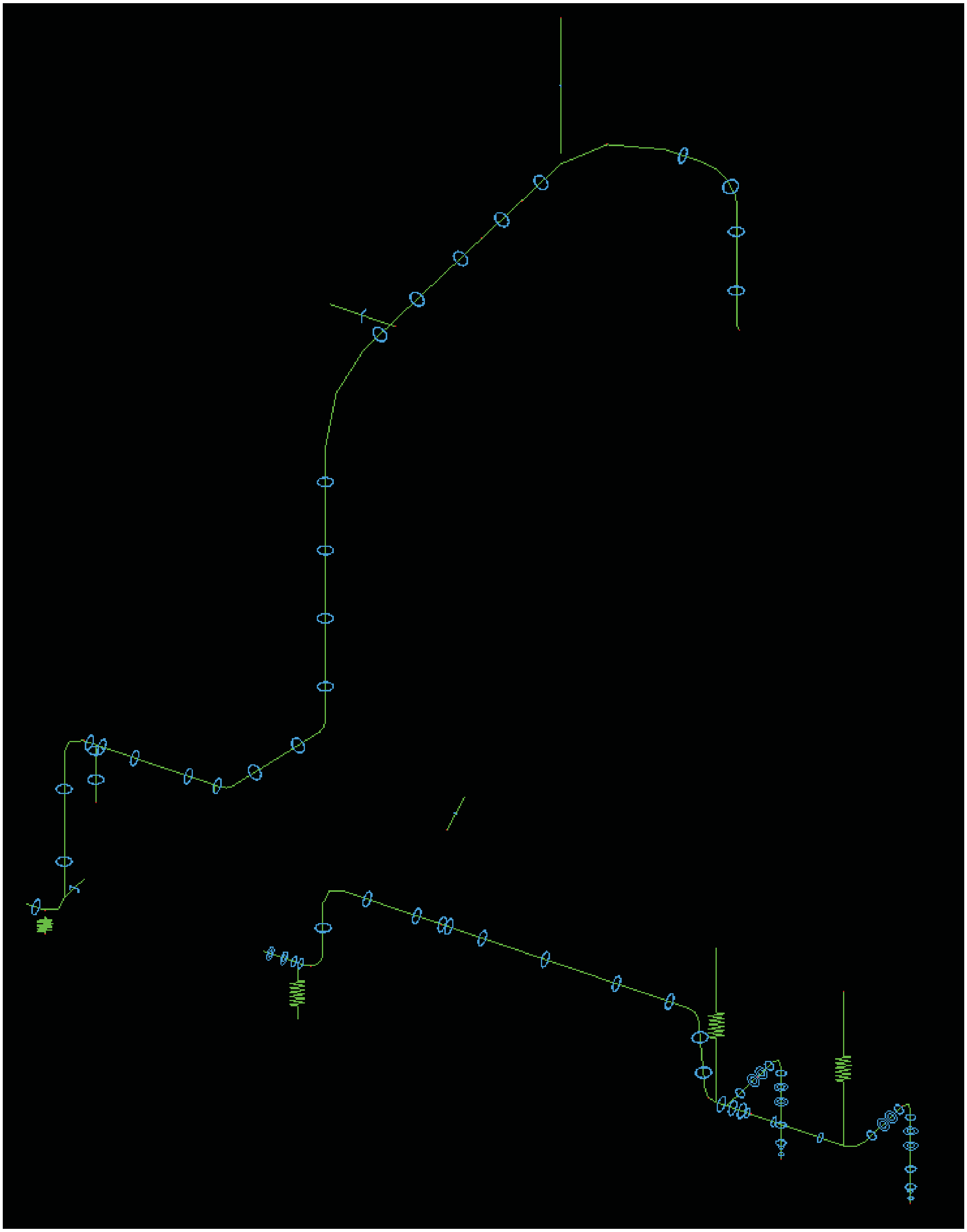

Figure D.2-7. Components Associated With Lines 41 and 77 of Model 4

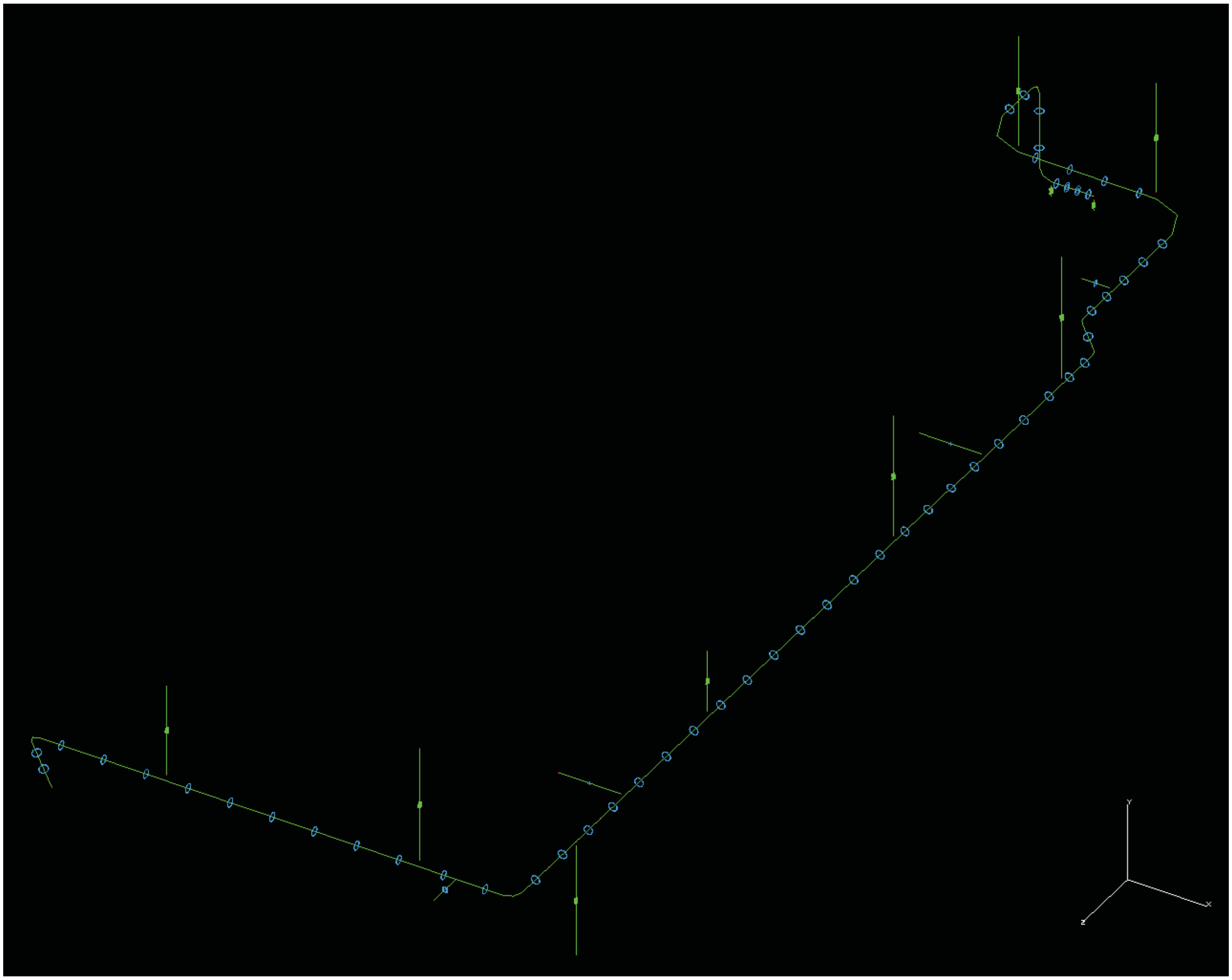

Figure D.2-8. Components Associated With Line 42 of Model 4

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** M. D. Landon **Date:** 09/30/08

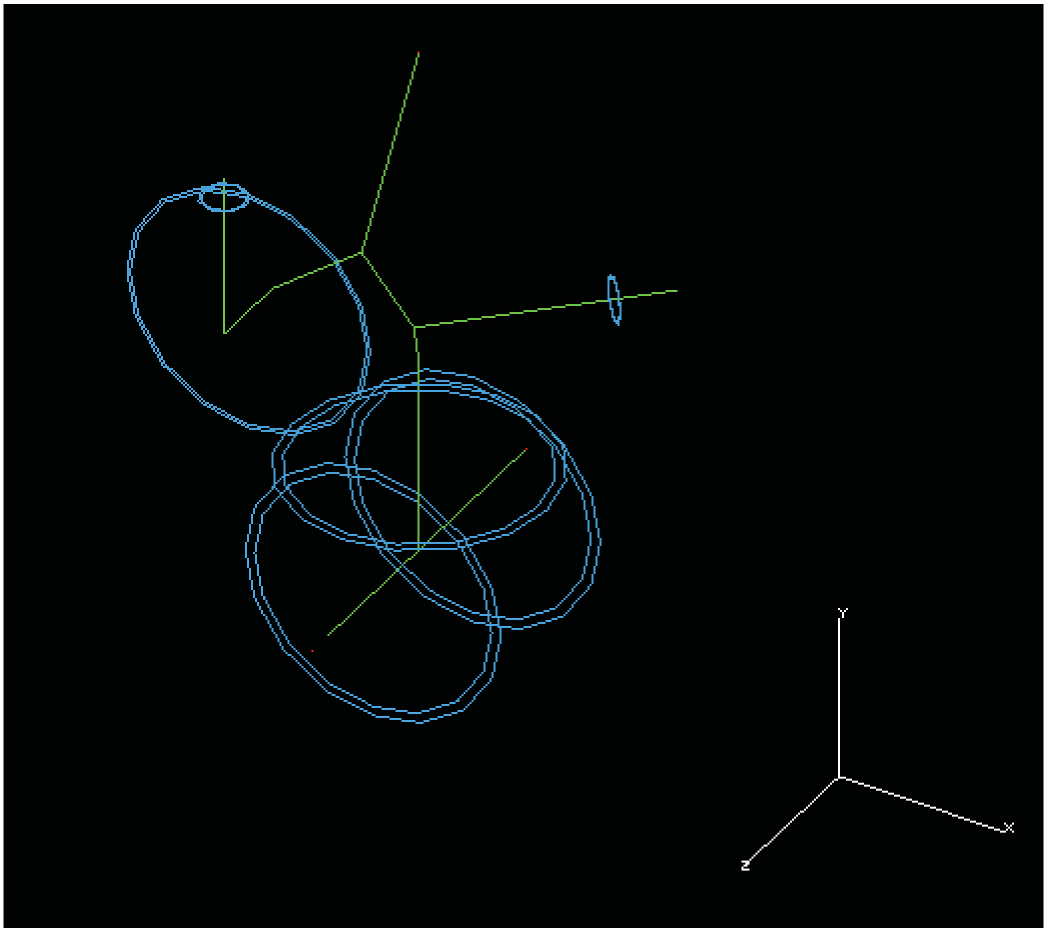

Figure D.2-9. Nonstandard Elbow of Model 1

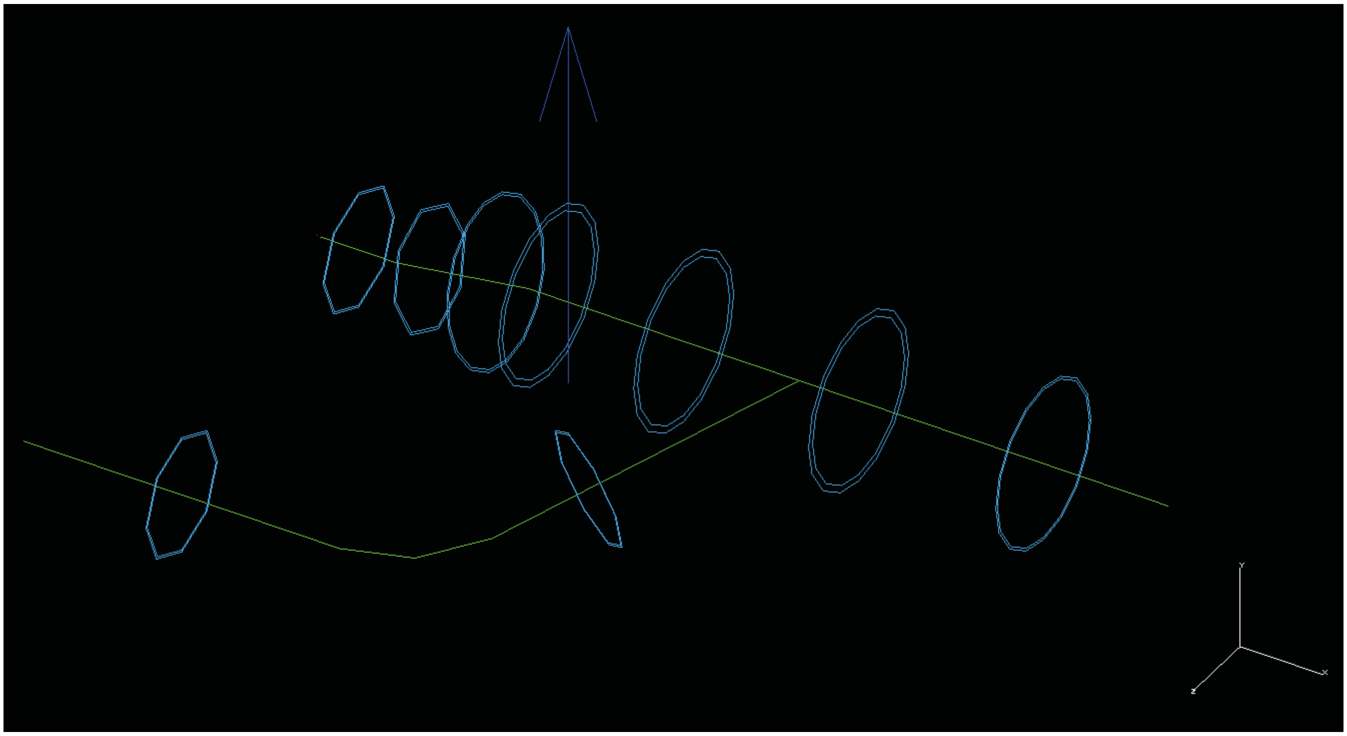

Figure D.2-10. Eastern Fabricated Branch Connecting on Model 1

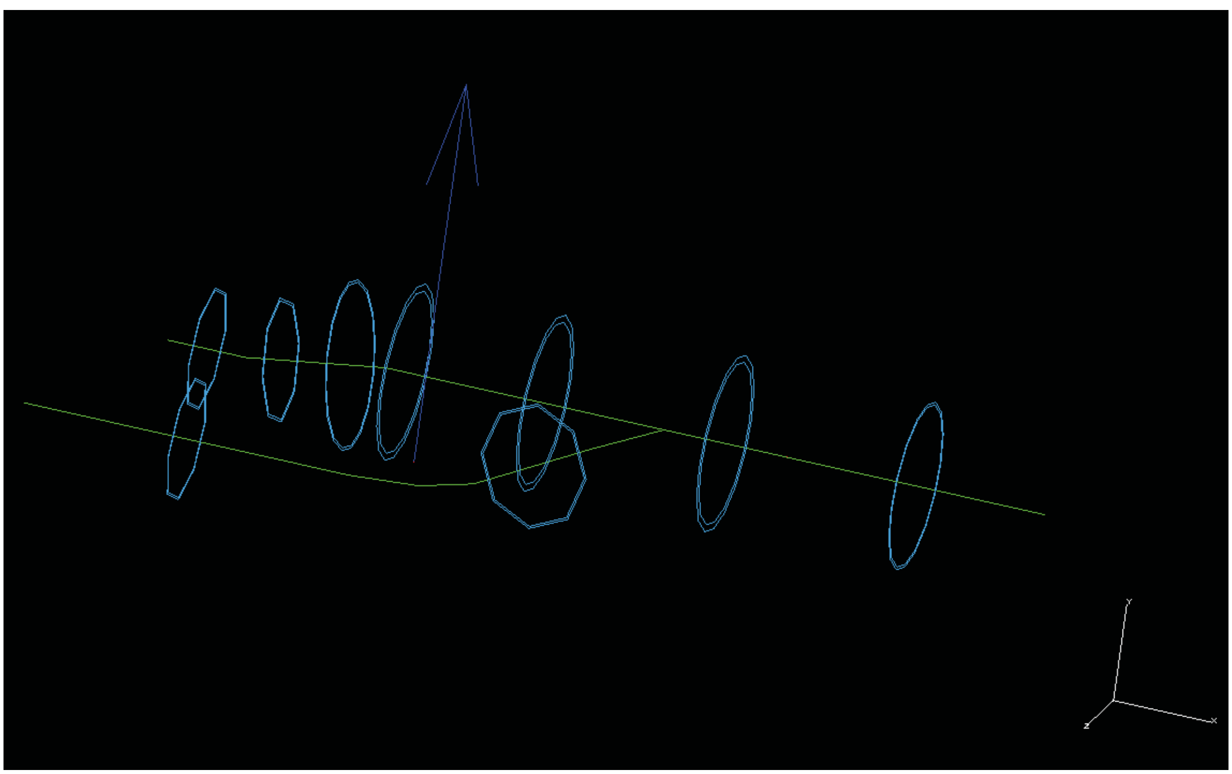

Figure D.2-11. Western Fabricated Branch Connecting on Model 1

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**%                 FEM: Model_1-4
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
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**%=========================================
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Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** M. D. Landon **Date:** 09/30/08

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    557,   1212,   1224
*ELEMENT, TYPE=B31     , ELSET=PIPE_56
    499,   1161,   1701
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    998,   1701,   1158
*ELEMENT, TYPE=B31     , ELSET=PIPE_57
    566,   1237,   1236
    568,   1238,   1235
*ELEMENT, TYPE=B31     , ELSET=PIPE_58
    567,   1236,   1223
    569,   1235,   1222
*ELEMENT, TYPE=B31     , ELSET=PIPE_59
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(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    841,   1436,    977
*ELEMENT, TYPE=B31     , ELSET=PIPE_60
    867,   1447,   1251
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    870,   1450,    668
*ELEMENT, TYPE=B31     , ELSET=PIPE_61
    102,    600,   1447
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    105,    598,   1450
*ELEMENT, TYPE=B31     , ELSET=PIPE_62
     95,    599,   1092
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    440,   1097,    599
*ELEMENT, TYPE=B31     , ELSET=PIPE_63
     98,    601,   1093
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    441,   1098,    601
*ELEMENT, TYPE=B31     , ELSET=PIPE_64
     88,    588,    590
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    922,   1496,    588
*ELEMENT, TYPE=B31     , ELSET=PIPE_65
    319,    953,    589
*ELEMENT, TYPE=B31     , ELSET=PIPE_66
    153,    588,    946
*ELEMENT, TYPE=B31     , ELSET=PIPE_67
    502,    999,   1160
    503,   1159,    999
*ELEMENT, TYPE=B31     , ELSET=PIPE_68
    871,   1451,   1211
*ELEMENT, TYPE=B31     , ELSET=PIPE_69
    556,    999,   1451
*ELEMENT, TYPE=B31     , ELSET=PIPE_70
    576,   1180,   1426
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    821,   1428,    760
*ELEMENT, TYPE=B31     , ELSET=PIPE_71
    572,   1001,   1422
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    815,   1422,   1213
*ELEMENT, TYPE=B31     , ELSET=PIPE_72
    570,   1217,   1420
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    818,   1425,    992
*ELEMENT, TYPE=B31     , ELSET=PIPE_73
    579,   1129,   1429
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    823,   1430,   1130
*ELEMENT, TYPE=B31     , ELSET=ELBOW
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    876,    961,   1642
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    941,   1644,   1303
*ELEMENT, TYPE=B31     , ELSET=ELBOW_1
    507,   1165,   1205
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    996,   1699,   1208
*ELEMENT, TYPE=B31     , ELSET=ELBOW_2
    497,    977,   1435
*ELEMENT, TYPE=B32     , ELSET=ELBOW_3
    136,    658,    706,    657
    137,    659,    708,    660
*ELEMENT, TYPE=B32     , ELSET=ELBOW_4
    138,    661,    710,    662
*ELEMENT, TYPE=B32     , ELSET=ELBOW_5
    147,    676,    732,    677
*ELEMENT, TYPE=B32     , ELSET=ELBOW_6
    151,    621,    716,    620
*ELEMENT, TYPE=B32     , ELSET=ELBOW_7
    140,    682,    738,    683
    141,    684,    740,    623
*ELEMENT, TYPE=B32     , ELSET=ELBOW_8
    142,    665,    718,    672
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    149,    667,    726,    670
*ELEMENT, TYPE=B32     , ELSET=ELBOW_9
    144,    673,    722,    679
    145,    674,    724,    678
    146,    675,    730,    680
*ELEMENT, TYPE=B32     , ELSET=ELBOW_10
    150,    623,    714,    622
*ELEMENT, TYPE=B32     , ELSET=ELBOW_11
    523,   1003,   1005,   1002
*ELEMENT, TYPE=B32     , ELSET=ELBOW_12
    524,   1010,   1013,   1011
    525,   1015,   1017,   1014
*ELEMENT, TYPE=B32     , ELSET=ELBOW_13
    526,   1007,   1009,   1006
*ELEMENT, TYPE=B32     , ELSET=ELBOW_14
    528,   1133,   1184,   1128
*ELEMENT, TYPE=B32     , ELSET=ELBOW_15
    390,    652,   1054,    655
    391,    653,   1055,    656
*ELEMENT, TYPE=B32     , ELSET=ELBOW_16
    126,    650,    742,    651
    127,    648,    744,    649
*ELEMENT, TYPE=B32     , ELSET=ELBOW_17
    122,    641,    694,    642
    123,    640,    698,    643
*ELEMENT, TYPE=B32     , ELSET=ELBOW_18
    118,    631,    686,    632
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    121,    629,    690,    635
*ELEMENT, TYPE=B32     , ELSET=ELBOW_19
    128,    638,    700,    639
    129,    636,    696,    637
*ELEMENT, TYPE=B32     , ELSET=ELBOW_20
    181,    761,    793,    762
*ELEMENT, TYPE=B32     , ELSET=ELBOW_21
    180,    765,    795,    764
*ELEMENT, TYPE=B32     , ELSET=ELBOW_22
    182,    763,    794,    756
*ELEMENT, TYPE=B32     , ELSET=ELBOW_23
    177,    783,    792,    782
*ELEMENT, TYPE=B32     , ELSET=ELBOW_24
    178,    781,    791,    780
    527,   1127,   1183,   1133
    765,    803,   1410,    802
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*ELEMENT, TYPE=B32     , ELSET=ELBOW_25
    179,    778,    790,    779
*ELEMENT, TYPE=B32     , ELSET=ELBOW_26
    172,    805,    806,    804
*ELEMENT, TYPE=B32     , ELSET=ELBOW_27
    174,    796,    800,    798
    175,    799,    801,    797
*ELEMENT, TYPE=B32     , ELSET=ELBOW_28
    173,    767,    784,    766
*ELEMENT, TYPE=B32     , ELSET=ELBOW_29
    176,    775,    788,    774
*ELEMENT, TYPE=B32     , ELSET=ELBOW_30
    187,    772,    787,    773
*ELEMENT, TYPE=B32     , ELSET=ELBOW_31
    183,    768,    785,    769
    184,    770,    786,    771
*ELEMENT, TYPE=B32     , ELSET=ELBOW_32
    185,    776,    789,    777
*ELEMENT, TYPE=B32     , ELSET=ELBOW_33
    134,    645,    702,    646
    135,    644,    704,    647
*ELEMENT, TYPE=B32     , ELSET=ELBOW_34
    517,   1034,   1037,   1035
*ELEMENT, TYPE=B32     , ELSET=ELBOW_35
    480,   1018,   1056,   1019
    534,   1038,   1041,   1039
*ELEMENT, TYPE=B32     , ELSET=ELBOW_36
    530,   1174,   1189,   1171
*ELEMENT, TYPE=B32     , ELSET=ELBOW_37
    532,   1165,   1168,   1164
    533,   1163,   1169,   1159
*ELEMENT, TYPE=B32     , ELSET=ELBOW_38
    493,   1151,   1155,   1152
*ELEMENT, TYPE=B32     , ELSET=ELBOW_39
    842,   1139,   1441,   1141
*ELEMENT, TYPE=B32     , ELSET=ELBOW_40
    495,   1022,   1025,   1023
*ELEMENT, TYPE=B32     , ELSET=ELBOW_41
    492,   1136,   1156,   1137
*ELEMENT, TYPE=B32     , ELSET=ELBOW_42
    490,   1147,   1150,   1148
    843,   1142,   1439,   1143
*ELEMENT, TYPE=B32     , ELSET=ELBOW_43
    482,   1030,   1033,   1031
*ELEMENT, TYPE=B32     , ELSET=ELBOW_44
    483,   1027,   1135,   1026
*ELEMENT, TYPE=B32     , ELSET=ELBOW_45
    531,   1158,   1192,   1157
*ELEMENT, TYPE=B32     , ELSET=ELBOW_46
    553,   1224,   1232,   1225
    554,   1227,   1231,   1226
*ELEMENT, TYPE=B32     , ELSET=ELBOW_47
    529,   1172,   1188,   1174
*ELEMENT, TYPE=B32     , ELSET=ELBOW_48
    317,    586,    951,    589
    318,    589,    952,    590
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 BEAM,   1078,    912
*MPC
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*MPC
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 BEAM,   1073,    892
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 BEAM,   1076,    892
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*MPC
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 BEAM,   1083,   1081
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 BEAM,   1085,    930
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 BEAM,   1086,    926
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 BEAM,   1087,    925
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 BEAM,   1091,    942
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 BEAM,   1089,    952
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*MPC
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 BEAM,   1101,    722
*MPC
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 BEAM,   1305,    868
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 BEAM,   1313,    960
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 BEAM,   1398,     51
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 BEAM,   1400,   1399
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 BEAM,   1412,   1411
*MPC
 BEAM,   1415,   1414
*MPC
 BEAM,   1419,   1417
*MPC
 BEAM,    961,   1443
*ELEMENT, TYPE=SPRINGA , ELSET=TUNNEL_RES_SPRING
    470,    1126,     927
*ELEMENT, TYPE=SPRINGA , ELSET=WALL PENTRATION GAP
    621,    1205,    1279
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    624,    1208,    1280
*ELEMENT, TYPE=SPRINGA , ELSET=PS10_SPRING
    692,    1353,    1351
    693,    1354,    1352
*ELEMENT, TYPE=SPRINGA , ELSET=PS-23
    696,    1247,    1345
*ELEMENT, TYPE=SPRINGA , ELSET=PS-11
    716,    1273,    1369
    717,    1275,    1368
*ELEMENT, TYPE=SPRINGA , ELSET=PS-7
    759,    1402,    1398
*ELEMENT, TYPE=SPRINGA , ELSET=PS14_BASE_SPRING
    830,    1431,    1433
    831,    1432,    1434
*ELEMENT, TYPE=SPRINGA , ELSET=PS-20AV
    727,     862,    1388
*ELEMENT, TYPE=SPRINGA , ELSET=PS-20AH
    726,     862,    1381
*ELEMENT, TYPE=SPRINGA , ELSET=RH33A_SPRING
    847,    1343,    1242
*ELEMENT, TYPE=SPRINGA , ELSET=RH33B_SPRING
    848,    1344,    1244
*ELEMENT, TYPE=SPRINGA , ELSET=RH34_SPRING
    849,    1253,    1252
*ELEMENT, TYPE=SPRINGA , ELSET=RH35_SPRING
    850,    1311,    1255
    851,    1313,    1259
*ELEMENT, TYPE=SPRINGA , ELSET=RH14A_SPRING
    852,    1302,    1304
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    855,    1288,    1289
*ELEMENT, TYPE=SPRINGA , ELSET=RH20_SPRING
    865,    1395,    1396
*ELEMENT, TYPE=SPRINGA , ELSET=RH27A_UBOLT_SPRING
    863,    1285,    1159
*ELEMENT, TYPE=SPRINGA , ELSET=RH27B_UBOLT_SPRING
    864,    1284,    1158
*ELEMENT, TYPE=SPRINGA , ELSET=RH12
    861,    1349,    1262
*ELEMENT, TYPE=SPRINGA , ELSET=WTS_SPRING
    862,    1403,    1276
*ELEMENT, TYPE=SPRINGA , ELSET=RH22X_SPRING
    866,    1120,    1119
*ELEMENT, TYPE=SPRINGA , ELSET=RH14_SPRING
    712,    1365,    1305
    713,    1363,    1294
    714,    1364,    1300
*ELEMENT, TYPE=SPRINGA , ELSET=RH-20_SPRING
    689,    1263,    1350
*ELEMENT, TYPE=SPRING1 , ELSET=ROTATIONAL SPRING60
    999,    1222
   1000,    1223
*ELEMENT, TYPE=SPRING1 , ELSET=ROTATIONAL SPRING60_1
    872,    1222
    873,    1223
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*ELEMENT, TYPE=MASS    , ELSET=LMASS18LAP
    775,    556
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    790,    576
*ELEMENT, TYPE=MASS    , ELSET=LMASS6LAP
    795,    759
    796,    760
*ELEMENT, TYPE=MASS    , ELSET=LMASS4LAP
    797,   1180
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    812,   1129
*ELEMENT, TYPE=MASS    , ELSET=LMASS6GT
    824,   1428
    825,   1427
    826,   1426
*ELEMENT, TYPE=MASS    , ELSET=LMASS4GT
    833,   1425
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    839,   1429
*ELEMENT, TYPE=MASS    , ELSET=LMASS4CK
    832,   1424
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    838,   1430
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=A7_STEEL
*ELASTIC,TYPE=ISOTROPIC
 3.00000E+07,  2.90000E-01
*DENSITY
 7.31737E-04,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE4_5X0_237
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_1,
 SECTION=PIPE
 0.22500E+01, 0.23700E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: CIRC0_625
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_2,
 SECTION=CIRC
 0.31250E+00,
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: CIRC1_25
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_3,
 SECTION=CIRC
 0.62500E+00,
-0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: CIRC1_25
**%
```

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*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_4,
 SECTION=CIRC
 0.62500E+00,
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE2_5X5
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_5,
 SECTION=PIPE
 0.14400E+01, 0.20500E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE2_5X5
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_6,
 SECTION=PIPE
 0.14400E+01, 0.20500E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: MS2
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_7,
 SECTION=CIRC
 0.30000E+01,
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: ROD1_75
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_8,
 SECTION=CIRC
 0.87500E+00,
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: ANGLENN
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_9,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.21245E+01, 0.71727E+00, 0.00000E+00, 0.27393E+01, 0.10785E+00, 0, 0.00000E+00
 0.00000E+00,-0.70710E+00,-0.70710E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00,-0.97372E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**%INFO: THE ABOVE CROSS SECTION CANNOT BE TRANSLATED TO AN
**%INFO: ABAQUS LIBRARY SECTION AND HENCE IS WRITTEN AS BEAM
**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
**%
**% I-DEAS BEAM CROSS SECTION: HSS_PS19
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_10 ,
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 SECTION=BOX
 0.30000E+01, 0.40000E+01, 0.29100E+00, 0.29100E+00, 0.29100E+00, 0.29100E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: ANGLE3_0X4_375X0_375
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_11 ,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.26401E+01, 0.11131E+01, 0.00000E+00, 0.58469E+01, 0.13202E+00, 0, 0.00000E+00
 0.00000E+00,-0.90772E+00, 0.41956E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
-0.89261E+00,-0.10186E+01
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**%INFO: THE ABOVE CROSS SECTION CANNOT BE TRANSLATED TO AN
**%INFO: ABAQUS LIBRARY SECTION AND HENCE IS WRITTEN AS BEAM
**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
**%
**% I-DEAS BEAM CROSS SECTION: HORIZONTAL_SUP3_0X4_0X0_25
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_12 ,
 SECTION=BOX
 0.30000E+01, 0.40000E+01, 0.25000E+00, 0.25000E+00, 0.25000E+00, 0.25000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: ANGLE2_5X2_5X0_25
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_13 ,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.11942E+01, 0.28548E+00, 0.00000E+00, 0.11021E+01, 0.26511E-01, 0, 0.00000E+00
 0.00000E+00,-0.70710E+00,-0.70710E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00,-0.82582E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**%INFO: THE ABOVE CROSS SECTION CANNOT BE TRANSLATED TO AN
**%INFO: ABAQUS LIBRARY SECTION AND HENCE IS WRITTEN AS BEAM
**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
**%
**% I-DEAS BEAM CROSS SECTION: ANGLE1_5X1_5X0_25
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_14 ,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.69421E+00, 0.56902E-01, 0.00000E+00, 0.21279E+00, 0.16095E-01, 0, 0.00000E+00
-0.70710E+00,-0.70710E+00, 0.00000E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00,-0.47253E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
```

```
**%INFO: THE ABOVE CROSS SECTION CANNOT BE TRANSLATED TO AN
**%INFO: ABAQUS LIBRARY SECTION AND HENCE IS WRITTEN AS BEAM
**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
**%
**% I-DEAS BEAM CROSS SECTION: ANGLE1_5X1_5X0_25
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_15 ,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.69421E+00, 0.56902E-01, 0.00000E+00, 0.21279E+00, 0.16095E-01, 0, 0.00000E+00
 0.00000E+00,-0.70710E+00,-0.70710E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00,-0.47253E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**%INFO: THE ABOVE CROSS SECTION CANNOT BE TRANSLATED TO AN
**%INFO: ABAQUS LIBRARY SECTION AND HENCE IS WRITTEN AS BEAM
**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
**%
**% I-DEAS BEAM CROSS SECTION: ANGLE1_5X1_5X0_25
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_16 ,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.69421E+00, 0.56902E-01, 0.00000E+00, 0.21279E+00, 0.16095E-01, 0, 0.00000E+00
 0.70710E+00,-0.61394E+00,-0.35082E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00,-0.47253E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**%INFO: THE ABOVE CROSS SECTION CANNOT BE TRANSLATED TO AN
**%INFO: ABAQUS LIBRARY SECTION AND HENCE IS WRITTEN AS BEAM
**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
**%
**% I-DEAS BEAM CROSS SECTION: MS6
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_17 ,
 SECTION=CIRC
 0.30000E+01,
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: MS4
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_18 ,
 SECTION=CIRC
 0.30000E+01,
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: MS3
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_19 ,
```

```
 SECTION=CIRC
 0.25000E+01,
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: CHANNEL_PS14
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_20 ,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.33590E+01, 0.15956E+01, 0.00000E+00, 0.32526E+02, 0.11065E+00, 0, 0.16155E+02
-0.10000E+01, 0.00000E+00, 0.00000E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00,-0.13299E+01
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**%INFO: THE ABOVE CROSS SECTION CANNOT BE TRANSLATED TO AN
**%INFO: ABAQUS LIBRARY SECTION AND HENCE IS WRITTEN AS BEAM
**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
**%
**% I-DEAS BEAM CROSS SECTION: PS14_PIPE_SECTION
**%
*BEAM SECTION,
 MATERIAL=A7_STEEL,
 ELSET=BEAM_21 ,
 SECTION=PIPE
 0.95000E+00, 0.14500E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: TIEBACK_APPROX
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_22 ,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.18951E+01, 0.68450E+00, 0.00000E+00, 0.44699E+01, 0.42550E-01, 0, 0.16898E+01
-0.10000E+01, 0.00000E+00, 0.00000E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00,-0.11609E+01
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**%INFO: THE ABOVE CROSS SECTION CANNOT BE TRANSLATED TO AN
**%INFO: ABAQUS LIBRARY SECTION AND HENCE IS WRITTEN AS BEAM
**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
**%
**% I-DEAS BEAM CROSS SECTION: TIEBACK_APPROX
**%
*BEAM GENERAL SECTION,
 ELSET=BEAM_23 ,
 DENSITY= 0.73174E-03,
 ZERO= 0.00000E+00
 0.18951E+01, 0.68450E+00, 0.00000E+00, 0.44699E+01, 0.42550E-01, 0, 0.16898E+01
 0.00000E+00,-0.10000E+01, 0.00000E+00
 0.30000E+08, 0.11628E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00,-0.11609E+01
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
```

```
**%INFO: THE ABOVE CROSS SECTION CANNOT BE TRANSLATED TO AN
**%INFO: ABAQUS LIBRARY SECTION AND HENCE IS WRITTEN AS BEAM
**%INFO: GENERAL SECTION (SECTION=GENERAL).
**%
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304L_24X0375 ,
 ELSET=BEAM_24 ,
 SECTION=PIPE
 0.12000E+02, 0.37500E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304L_24X0375
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.15200E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5
**%
*BEAM SECTION,
 MATERIAL=SST304_36X05,
 ELSET=PIPE,
 SECTION=PIPE
 0.18000E+02, 0.50000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_36X05
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.33900E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5
**%
*BEAM SECTION,
 MATERIAL=SST304_36X05,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.18000E+02, 0.50000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: TEE37_75X1_375
**%
*BEAM SECTION,
 MATERIAL=SST304_36X05,
 ELSET=PIPE_2,
 SECTION=PIPE
 0.18875E+02, 0.13750E+01
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304_20X0312,
 ELSET=PIPE_3,
 SECTION=PIPE
 0.10000E+02, 0.31200E+00
-0.70710E+00, 0.00000E+00,-0.70710E+00
*MATERIAL,NAME=SST304_20X0312
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.15400E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
```

```
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304_20X0312,
 ELSET=PIPE_4,
 SECTION=PIPE
 0.10000E+02, 0.31200E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304_20X0312,
 ELSET=PIPE_5,
 SECTION=PIPE
 0.10000E+02, 0.31200E+00
 0.70710E+00, 0.00000E+00,-0.70710E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304_20X0312,
 ELSET=PIPE_6,
 SECTION=PIPE
 0.10000E+02, 0.31200E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: RED20_0X0_5
**%
*BEAM SECTION,
 MATERIAL=SST304_20X0312,
 ELSET=PIPE_7,
 SECTION=PIPE
 0.10000E+02, 0.50000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE4_5X0_237
**%
*BEAM SECTION,
 MATERIAL=SST304_4X0237 ,
 ELSET=PIPE_8,
 SECTION=PIPE
 0.22500E+01, 0.23700E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_4X0237
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 1.10000E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE4_5X0_237
**%
*BEAM SECTION,
 MATERIAL=SST304_4X0237 ,
 ELSET=PIPE_9,
 SECTION=PIPE
 0.22500E+01, 0.23700E+00
 0.00000E+00, 0.93632E+00,-0.35112E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE4_5X0_237
**%
*BEAM SECTION,
 MATERIAL=SST304_4X0237 ,
 ELSET=PIPE_10 ,
 SECTION=PIPE
 0.22500E+01, 0.23700E+00
 0.17600E-02, 0.22100E-01,-0.99975E+00
```

```
**%
**% I-DEAS BEAM CROSS SECTION: PIPE4_5X0_237
**%
*BEAM SECTION,
 MATERIAL=SST304_4X0237 ,
 ELSET=PIPE_11 ,
 SECTION=PIPE
 0.22500E+01, 0.23700E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304L_RED24X0375,
 ELSET=PIPE_12 ,
 SECTION=PIPE
 0.12000E+02, 0.37500E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304L_RED24X0375
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.15200E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: BRANCH25_25X1_0
**%
*BEAM SECTION,
 MATERIAL=SST304L_RED24X0375,
 ELSET=PIPE_13 ,
 SECTION=PIPE
 0.12625E+02, 0.10000E+01
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE18_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304L_18X0312 ,
 ELSET=PIPE_14 ,
 SECTION=PIPE
 0.90000E+01, 0.31200E+00
-0.19817E+00, 0.83300E+00,-0.51655E+00
*MATERIAL,NAME=SST304L_18X0312
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.00400E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE18_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304L_18X0312 ,
 ELSET=PIPE_15 ,
 SECTION=PIPE
 0.90000E+01, 0.31200E+00
-0.43029E+00,-0.29583E+00,-0.85283E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE18_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304L_18X0312 ,
 ELSET=PIPE_16 ,
 SECTION=PIPE
 0.90000E+01, 0.31200E+00
-0.70710E+00, 0.00000E+00,-0.70710E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE18_0X0_312
```

```
**%
*BEAM SECTION,
 MATERIAL=SST304L_18X0312 ,
 ELSET=PIPE_17 ,
 SECTION=PIPE
 0.90000E+01, 0.31200E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE18_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304L_18X0312 ,
 ELSET=PIPE_18 ,
 SECTION=PIPE
 0.90000E+01, 0.31200E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE18_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304L_18X0312 ,
 ELSET=PIPE_19 ,
 SECTION=PIPE
 0.90000E+01, 0.31200E+00
 0.70710E+00, 0.00000E+00,-0.70710E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE18_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304L_18X0312 ,
 ELSET=PIPE_20 ,
 SECTION=PIPE
 0.90000E+01, 0.31200E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: BR_25_5X1_UNLISTED_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_21 ,
 DENSITY= 0.20040E-02,
 ZERO= 0.00000E+00
 0.17337E+02, 0.19894E+03, 0.00000E+00, 0.41372E+03, 0.53680E+03, 0, 0.00000E+00
-0.70688E+00, 0.48529E+00, 0.51459E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: BR_25_5X1_UNLISTED_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_22 ,
 DENSITY= 0.20040E-02,
 ZERO= 0.00000E+00
 0.17337E+02, 0.19894E+03, 0.00000E+00, 0.41372E+03, 0.53680E+03, 0, 0.00000E+00
-0.71142E+00, 0.47728E+00,-0.51582E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_4375
**%
*BEAM SECTION,
```

```
 MATERIAL=SST304_30X04375 ,
 ELSET=PIPE_23 ,
 SECTION=PIPE
 0.15000E+02, 0.43750E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_30X04375
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.25900E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_4375
**%
*BEAM SECTION,
 MATERIAL=SST304_30X04375 ,
 ELSET=PIPE_24 ,
 SECTION=PIPE
 0.15000E+02, 0.43750E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: RED30_0X0_5
**%
*BEAM SECTION,
 MATERIAL=SST304_30X04375 ,
 ELSET=PIPE_25 ,
 SECTION=PIPE
 0.15000E+02, 0.50000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6X028,
 ELSET=PIPE_26 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
-0.70710E+00, 0.00000E+00,-0.70710E+00
*MATERIAL,NAME=SST304_6X028
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 1.20900E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6X028,
 ELSET=PIPE_27 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6X028,
 ELSET=PIPE_28 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6X028,
 ELSET=PIPE_29 ,
```

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** M. D. Landon **Date:** 09/30/08

```
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.00000E+00, 0.44721E+00,-0.89442E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6X028,
 ELSET=PIPE_30 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.70710E+00, 0.00000E+00,-0.70710E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6X028,
 ELSET=PIPE_31 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: BR_36X6_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_32 ,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55810E+01, 0.87720E+01, 0.00000E+00, 0.30387E+02, 0.56284E+02, 0, 0.00000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE16_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304L_RED16X0312,
 ELSET=PIPE_33 ,
 SECTION=PIPE
 0.80000E+01, 0.31200E+00
 0.00000E+00,-0.99122E+00,-0.13216E+00
*MATERIAL,NAME=SST304L_RED16X0312
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 1.85500E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE16_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304L_RED16X0312,
 ELSET=PIPE_34 ,
 SECTION=PIPE
 0.80000E+01, 0.31200E+00
 0.00000E+00, 0.99122E+00,-0.13216E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE18_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304L_RED18X0312,
 ELSET=PIPE_35 ,
 SECTION=PIPE
 0.90000E+01, 0.31200E+00
```

```
 0.00000E+00,-0.99122E+00,-0.13216E+00
*MATERIAL,NAME=SST304L_RED18X0312
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.00400E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE18_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304L_RED18X0312,
 ELSET=PIPE_36 ,
 SECTION=PIPE
 0.90000E+01, 0.31200E+00
 0.00000E+00, 0.99122E+00,-0.13216E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE18_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304L_RED18X0375,
 ELSET=PIPE_37 ,
 SECTION=PIPE
 0.90000E+01, 0.37500E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304L_RED18X0375
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 1.77800E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304_24X0375,
 ELSET=PIPE_38 ,
 SECTION=PIPE
 0.12000E+02, 0.37500E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_24X0375
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.15200E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304_24X0375,
 ELSET=PIPE_39 ,
 SECTION=PIPE
 0.12000E+02, 0.37500E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_5
**%
*BEAM SECTION,
 MATERIAL=SST304_RED24X05 ,
 ELSET=PIPE_40 ,
 SECTION=PIPE
 0.12000E+02, 0.50000E+00
 0.00000E+00,-0.97014E+00,-0.24253E+00
*MATERIAL,NAME=SST304_RED24X05
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
```

```
 2.15200E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_5
**%
*BEAM SECTION,
 MATERIAL=SST304_RED24X05 ,
 ELSET=PIPE_41 ,
 SECTION=PIPE
 0.12000E+02, 0.50000E+00
 0.00000E+00, 0.97014E+00,-0.24253E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5
**%
*BEAM SECTION,
 MATERIAL=SST304_RED36X05 ,
 ELSET=PIPE_42 ,
 SECTION=PIPE
 0.18000E+02, 0.50000E+00
 0.00000E+00,-0.97014E+00,-0.24253E+00
*MATERIAL,NAME=SST304_RED36X05
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.33900E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5
**%
*BEAM SECTION,
 MATERIAL=SST304_RED36X05 ,
 ELSET=PIPE_43 ,
 SECTION=PIPE
 0.18000E+02, 0.50000E+00
 0.00000E+00, 0.97014E+00,-0.24253E+00
**%
**% I-DEAS BEAM CROSS SECTION: TEE37_75X1_375
**%
*BEAM SECTION,
 MATERIAL=SST304_T3775X1375 ,
 ELSET=PIPE_44 ,
 SECTION=PIPE
 0.18875E+02, 0.13750E+01
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_T3775X1375
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 1.29800E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: TEE37_75X1_375
**%
*BEAM SECTION,
 MATERIAL=SST304_T3775X1375 ,
 ELSET=PIPE_45 ,
 SECTION=PIPE
 0.18875E+02, 0.13750E+01
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: TEE37_75X1_375
**%
*BEAM SECTION,
 MATERIAL=SST304_T3775X1375 ,
 ELSET=PIPE_46 ,
 SECTION=PIPE
 0.18875E+02, 0.13750E+01
 0.10000E+01, 0.00000E+00, 0.00000E+00
```

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** M. D. Landon **Date:** 09/30/08

```
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_5
**%
*BEAM SECTION,
 MATERIAL=SST304_RED30X05 ,
 ELSET=PIPE_47 ,
 SECTION=PIPE
 0.15000E+02, 0.50000E+00
 0.00000E+00,-0.97014E+00,-0.24253E+00
*MATERIAL,NAME=SST304_RED30X05
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.05800E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_5
**%
*BEAM SECTION,
 MATERIAL=SST304_RED30X05 ,
 ELSET=PIPE_48 ,
 SECTION=PIPE
 0.15000E+02, 0.50000E+00
 0.00000E+00, 0.97014E+00,-0.24253E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6X028_125F ,
 ELSET=PIPE_49 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_6X028_125F
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 1.20900E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6X028_125F ,
 ELSET=PIPE_50 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6X028_125F ,
 ELSET=PIPE_51 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.00000E+00, 0.49954E+00,-0.86629E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6X028_125F ,
 ELSET=PIPE_52 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.75150E+00,-0.27769E+00,-0.59843E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
```

```
**%
*BEAM SECTION,
 MATERIAL=SST304_RED6X028_125F,
 ELSET=PIPE_53 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_RED6X028_125F
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.20900E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE4_5X0_237
**%
*BEAM SECTION,
 MATERIAL=SST304_RED4X0237_125F ,
 ELSET=PIPE_54 ,
 SECTION=PIPE
 0.22500E+01, 0.23700E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_RED4X0237_125F
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.10000E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE4_5X0_237
**%
*BEAM SECTION,
 MATERIAL=SST304_4X0237_125F,
 ELSET=PIPE_55 ,
 SECTION=PIPE
 0.22500E+01, 0.23700E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_4X0237_125F
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.10000E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE4_5X0_237
**%
*BEAM SECTION,
 MATERIAL=SST304_4X0237_125F,
 ELSET=PIPE_56 ,
 SECTION=PIPE
 0.22500E+01, 0.23700E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE2_375X0_154
**%
*BEAM SECTION,
 MATERIAL=SST304_RED2X0154_125F ,
 ELSET=PIPE_57 ,
 SECTION=PIPE
 0.11875E+01, 0.15400E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_RED2X0154_125F
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.01700E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
```

```
**% I-DEAS BEAM CROSS SECTION: PIPE2_375X0_154
**%
*BEAM SECTION,
 MATERIAL=SST304_2X0154_125F,
 ELSET=PIPE_58 ,
 SECTION=PIPE
 0.11875E+01, 0.15400E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_2X0154_125F
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.01700E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_T6625X028_125F ,
 ELSET=PIPE_59 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_T6625X028_125F
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.20900E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304_B20X0312_BR,
 ELSET=PIPE_60 ,
 SECTION=PIPE
 0.10000E+02, 0.31200E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_B20X0312_BR
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.15400E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: BR_30X20_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_61 ,
 DENSITY= 0.21540E-02,
 ZERO= 0.00000E+00
 0.19298E+02, 0.32379E+02, 0.00000E+00, 0.14610E+03, 0.13652E+04, 0, 0.00000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_4375
**%
*BEAM SECTION,
 MATERIAL=SST304_B30X04375_R,
 ELSET=PIPE_62 ,
 SECTION=PIPE
 0.15000E+02, 0.43750E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
```

```
*MATERIAL,NAME=SST304_B30X04375_R
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.25900E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_4375
**%
*BEAM SECTION,
 MATERIAL=SST304_B30X04375_R,
 ELSET=PIPE_63 ,
 SECTION=PIPE
 0.15000E+02, 0.43750E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5
**%
*BEAM SECTION,
 MATERIAL=SST304_B36X05_R ,
 ELSET=PIPE_64 ,
 SECTION=PIPE
 0.18000E+02, 0.50000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_B36X05_R
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.33900E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: BR_36X6_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_65 ,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55810E+01, 0.87720E+01, 0.00000E+00, 0.30387E+02, 0.56284E+02, 0, 0.00000E+00
 0.00000E+00,-0.10000E+01, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: BR_36X6_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_66 ,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55810E+01, 0.87720E+01, 0.00000E+00, 0.30387E+02, 0.56284E+02, 0, 0.00000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_B6X028_R_125F,
 ELSET=PIPE_67 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
```

```
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_B6X028_R_125F
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.20900E-03,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: PIPE4_5X0_237
**%
*BEAM SECTION,
 MATERIAL=SST304_B6X028_R_125F,
 ELSET=PIPE_68 ,
 SECTION=PIPE
 0.22500E+01, 0.23700E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: BR_6X4_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_69 ,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.31740E+01, 0.34200E+00, 0.00000E+00, 0.12020E+01, 0.14465E+02, 0, 0.00000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: VALVE6_625X1_417
**%
*BEAM SECTION,
 MATERIAL=SST304_V6_215F,
 ELSET=PIPE_70 ,
 SECTION=PIPE
 0.33125E+01, 0.14170E+01
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_V6_215F
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.74600E-05,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: VALVE_4_5_ACTUAL5_5X1_235
**%
*BEAM SECTION,
 MATERIAL=SST304_V4_215F,
 ELSET=PIPE_71 ,
 SECTION=PIPE
 0.27500E+01, 0.12350E+01
-0.10000E+01, 0.00000E+00,-0.20000E-04
*MATERIAL,NAME=SST304_V4_215F
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.39100E-05,
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: VALVE_4_5_ACTUAL5_5X1_235
**%
*BEAM SECTION,
 MATERIAL=SST304_V4_215F,
 ELSET=PIPE_72 ,
 SECTION=PIPE
```

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** M. D. Landon **Date:** 09/30/08

```
 0.27500E+01, 0.12350E+01
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: VALVE_4_5_ACTUAL5_5X1_235
**%
*BEAM SECTION,
 MATERIAL=SST304_V4_215F,
 ELSET=PIPE_73 ,
 SECTION=PIPE
 0.27500E+01, 0.12350E+01
 0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6X028,
 ELSET=ELBOW ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6X028_125F ,
 ELSET=ELBOW_1 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_T6625X028_125F ,
 ELSET=ELBOW_2 ,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW36_0X0_5R36P272
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_3 ,
 DENSITY= 0.23390E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.39820E+03, 0.00000E+00, 0.39820E+03, 0.17572E+05, 0, 0.00000E+00
-0.70710E+00, 0.70710E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW36_0X0_5R36P272
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_4 ,
 DENSITY= 0.23390E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.39820E+03, 0.00000E+00, 0.39820E+03, 0.17572E+05, 0, 0.00000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
```

```
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW20_0X0_3125R30P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_5 ,
 DENSITY= 0.21540E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.68452E+02, 0.00000E+00, 0.68452E+02, 0.17572E+05, 0, 0.00000E+00
 0.81649E+00, 0.57735E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW20_0X0_3124R20P272
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_6 ,
 DENSITY= 0.21540E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.45178E+02, 0.00000E+00, 0.45178E+02, 0.18734E+04, 0, 0.00000E+00
 0.70710E+00, 0.70710E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW20_0X0_3125R30P272
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_7 ,
 DENSITY= 0.21540E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.69625E+02, 0.00000E+00, 0.69625E+02, 0.18734E+04, 0, 0.00000E+00
 0.00000E+00, 0.10000E+01, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW20_0X0_3125R30P272
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_8 ,
 DENSITY= 0.21540E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.69625E+02, 0.00000E+00, 0.69625E+02, 0.18734E+04, 0, 0.00000E+00
 0.70710E+00, 0.70710E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW20_0X0_3125R30P272
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_9 ,
 DENSITY= 0.21540E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.69625E+02, 0.00000E+00, 0.69625E+02, 0.18734E+04, 0, 0.00000E+00
```

```
 0.81649E+00, 0.57735E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW20_0X0_3125R30P272
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_10,
 DENSITY= 0.21540E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.69625E+02, 0.00000E+00, 0.69625E+02, 0.18734E+04, 0, 0.00000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW4_5X0_237R6P272
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_11,
 DENSITY= 0.11000E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.13910E+01, 0.00000E+00, 0.13910E+01, 0.14500E+02, 0, 0.00000E+00
-0.99681E+00, 0.79740E-01, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW4_5X0_237R6P272
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_12,
 DENSITY= 0.11000E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.13910E+01, 0.00000E+00, 0.13910E+01, 0.14500E+02, 0, 0.00000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW4_5X0_237R20P272
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_13,
 DENSITY= 0.11000E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.46680E+01, 0.00000E+00, 0.46680E+01, 0.14500E+02, 0, 0.00000E+00
-0.99681E+00, 0.79740E-01, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
```

```
**% I-DEAS BEAM CROSS SECTION: ELBOW4_5X0_237R9P272
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_14,
 DENSITY= 0.11000E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.20910E+01, 0.00000E+00, 0.20910E+01, 0.14500E+02, 0, 0.00000E+00
 0.00000E+00, 0.10000E+01, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW18_0X0_3125R27P272
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_15,
 DENSITY= 0.20040E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.53542E+02, 0.00000E+00, 0.53542E+02, 0.13565E+04, 0, 0.00000E+00
-0.24227E+00, 0.97020E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW18_0X0_3125R27P272
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_16,
 DENSITY= 0.20040E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.53542E+02, 0.00000E+00, 0.53542E+02, 0.13565E+04, 0, 0.00000E+00
 0.00000E+00, 0.10000E+01, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW18_0X0_3125R27P272
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_17,
 DENSITY= 0.20040E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.53542E+02, 0.00000E+00, 0.53542E+02, 0.13565E+04, 0, 0.00000E+00
 0.70710E+00, 0.70710E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW18_0X0_3125R27P272
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_18,
 DENSITY= 0.20040E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.53542E+02, 0.00000E+00, 0.53542E+02, 0.13565E+04, 0, 0.00000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
```

```
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW18_0X0_312R18P272
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_19,
 DENSITY= 0.20040E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.34913E+02, 0.00000E+00, 0.34913E+02, 0.13565E+04, 0, 0.00000E+00
 0.81649E+00, 0.57735E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R9P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_20,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.31741E+01, 0.43650E+01, 0.00000E+00, 0.43650E+01, 0.14465E+02, 0, 0.00000E+00
 0.00000E+00,-0.10000E+01, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R9P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_21,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.31741E+01, 0.43650E+01, 0.00000E+00, 0.43650E+01, 0.14465E+02, 0, 0.00000E+00
 0.00000E+00, 0.10000E+01, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R9P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_22,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.31741E+01, 0.43650E+01, 0.00000E+00, 0.43650E+01, 0.14465E+02, 0, 0.00000E+00
 0.70710E+00,-0.70710E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R9P272
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**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_23,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.43730E+01, 0.00000E+00, 0.43730E+01, 0.56300E+02, 0, 0.00000E+00
-0.70710E+00, 0.70710E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R9P272
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_24,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.43730E+01, 0.00000E+00, 0.43730E+01, 0.56300E+02, 0, 0.00000E+00
 0.00000E+00, 0.10000E+01, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R9P272
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_25,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.43730E+01, 0.00000E+00, 0.43730E+01, 0.56300E+02, 0, 0.00000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R9P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_26,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.44110E+01, 0.00000E+00, 0.44110E+01, 0.56300E+02, 0, 0.00000E+00
-0.66667E+00, 0.74535E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R9P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_27,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.44110E+01, 0.00000E+00, 0.44110E+01, 0.56300E+02, 0, 0.00000E+00
 0.00000E+00,-0.10000E+01, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
```

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*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R9P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_28,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.44110E+01, 0.00000E+00, 0.44110E+01, 0.56300E+02, 0, 0.00000E+00
 0.00000E+00, 0.10000E+01, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R9P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_29,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.44110E+01, 0.00000E+00, 0.44110E+01, 0.56300E+02, 0, 0.00000E+00
 0.70710E+00, 0.70710E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R9P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_30,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.44110E+01, 0.00000E+00, 0.44110E+01, 0.56300E+02, 0, 0.00000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R30P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_31,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.14934E+02, 0.00000E+00, 0.14934E+02, 0.56300E+02, 0, 0.00000E+00
 0.00000E+00,-0.10000E+01, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R30P272
**%
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*BEAM GENERAL SECTION,
 ELSET=ELBOW_32,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.14741E+02, 0.00000E+00, 0.14741E+02, 0.56300E+02, 0, 0.00000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW24_0X0_375R36P272
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_33,
 DENSITY= 0.21520E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.14438E+03, 0.00000E+00, 0.14438E+03, 0.38846E+04, 0, 0.00000E+00
 0.00000E+00, 0.10000E+01, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R9P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_34,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.44110E+01, 0.00000E+00, 0.44110E+01, 0.56300E+02, 0, 0.00000E+00
-0.70710E+00,-0.70710E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R9P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_35,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.44110E+01, 0.00000E+00, 0.44110E+01, 0.56300E+02, 0, 0.00000E+00
-0.70710E+00, 0.70710E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R9P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_36,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.44110E+01, 0.00000E+00, 0.44110E+01, 0.56300E+02, 0, 0.00000E+00
-0.92387E+00, 0.38268E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
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 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R9P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_37,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.44110E+01, 0.00000E+00, 0.44110E+01, 0.56300E+02, 0, 0.00000E+00
 0.13169E+00, 0.99129E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R9P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_38,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.44110E+01, 0.00000E+00, 0.44110E+01, 0.56300E+02, 0, 0.00000E+00
 0.38268E+00,-0.92388E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R9P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_39,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.44110E+01, 0.00000E+00, 0.44110E+01, 0.56300E+02, 0, 0.00000E+00
 0.65476E+00, 0.75583E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R9P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_40,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.44110E+01, 0.00000E+00, 0.44110E+01, 0.56300E+02, 0, 0.00000E+00
 0.70710E+00,-0.70710E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R9P376
**%
*BEAM GENERAL SECTION,
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 ELSET=ELBOW_41,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.44110E+01, 0.00000E+00, 0.44110E+01, 0.56300E+02, 0, 0.00000E+00
 0.92387E+00,-0.38268E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R9P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_42,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.44110E+01, 0.00000E+00, 0.44110E+01, 0.56300E+02, 0, 0.00000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R30P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_43,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.14934E+02, 0.00000E+00, 0.14934E+02, 0.56300E+02, 0, 0.00000E+00
 0.00000E+00, 0.10000E+01, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW6_625X0_28R30P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_44,
 DENSITY= 0.12090E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.14934E+02, 0.00000E+00, 0.14934E+02, 0.56300E+02, 0, 0.00000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW4_5X0_237R6P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_45,
 DENSITY= 0.11000E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.13980E+01, 0.00000E+00, 0.13980E+01, 0.14500E+02, 0, 0.00000E+00
 0.00000E+00, 0.10000E+01, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
```

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** M. D. Landon **Date:** 09/30/08

```
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW4_5X0_237R6P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_46,
 DENSITY= 0.11000E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.13980E+01, 0.00000E+00, 0.13980E+01, 0.14500E+02, 0, 0.00000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW4_5X0_237R9P376
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_47,
 DENSITY= 0.11000E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.21030E+01, 0.00000E+00, 0.21030E+01, 0.14500E+02, 0, 0.00000E+00
-0.38268E+00, 0.92387E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW36_0X0_5R36P272
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_48,
 DENSITY= 0.23390E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.39820E+03, 0.00000E+00, 0.39820E+03, 0.17572E+05, 0, 0.00000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
*DAMPING, ALPHA=0.7026, BETA=1.711E-3
*SPRING, ELSET=TUNNEL_RES_SPRING, NONLINEAR

  -1.0000E+6, -0.2686968
   0.0000E+0, 0.0000E+0
   1.0000E+6, 0.6717423519
*SPRING, ELSET=WALL PENTRATION GAP, NONLINEAR

  -1.0000E+6, -0.9000E+0
   0.0000E+0, -0.7500E+0
   0.0000E+0, 0.7500E+0
   1.0000E+6, 0.9000E+0
*SPRING, ELSET=PS10_SPRING, NONLINEAR

  -1.0000E+6, -0.36782
   0.0000E+0, 0.0000E+0
*SPRING, ELSET=PS-23, NONLINEAR

  -1.0000E+6, -2.96552
   0.0000E+0, 0.0000E+0
*SPRING, ELSET=PS-11, NONLINEAR
```

```
  -1.0000E+6, -1.1954
   0.0000E+0, 0.0000E+0
*SPRING, ELSET=PS-7

  1.0000E+01,
*SPRING, ELSET=PS14_BASE_SPRING, NONLINEAR

  -1.0000E+6, -0.1
   0.0000E+0, 0.0000E+0
*SPRING, ELSET=PS-20AV, NONLINEAR

  -1.0000E+6, -2.26375
   0.0000E+0, 0.0000E+0
   1.0000E+6, 2.62059
*SPRING, ELSET=PS-20AH

  1.5800E+05,
*SPRING, ELSET=RH33A_SPRING, NONLINEAR

  -1.0000E+6, -13.10585
   0.0000E+0, -0.8125
   0.0000E+0, 0.0000E+0
   1.0000E+6, 12.29335
*SPRING, ELSET=RH33B_SPRING, NONLINEAR

  -1.0000E+6, -16.26699
   0.0000E+0, -0.8125
   0.0000E+0, 0.0000E+0
   1.0000E+6, 15.45449
*SPRING, ELSET=RH34_SPRING, NONLINEAR

  -1.0000E+6, -9.11929
   0.0000E+0, -0.8125
   0.0000E+0, 0.0000E+0
   1.0000E+6, 8.30679
*SPRING, ELSET=RH35_SPRING, NONLINEAR

  -1.0000E+6, -31.28514
   0.0000E+0, -1.625
   0.0000E+0, 0.0000E+0
   1.0000E+6, 29.66014
*SPRING, ELSET=RH14A_SPRING, NONLINEAR

  -1.0000E+6, -7.18862
   0.0000E+0, -1.625
   0.0000E+0, 0.0000E+0
   1.0000E+6, 5.56362
*SPRING, ELSET=RH20_SPRING, NONLINEAR

  -1.0000E+6, -1.13058
   0.0000E+0, -0.8125
   0.0000E+0, 0.0000E+0
   1.0000E+6, 0.31808
*SPRING, ELSET=RH27A_UBOLT_SPRING, NONLINEAR

  -1.0000E+6, -9.5665
   0.0000E+0, -1.625
   0.0000E+0, 0.0000E+0
   1.0000E+6, 7.9415
*SPRING, ELSET=RH27B_UBOLT_SPRING, NONLINEAR

  -1.0000E+6, -9.89403
   0.0000E+0, -1.625
   0.0000E+0, 0.0000E+0
   1.0000E+6, 8.26903
*SPRING, ELSET=RH12, NONLINEAR
```

```
  -1.0000E+6, -7.18862
   0.0000E+0, -1.625
   0.0000E+0, 0.0000E+0
   1.0000E+6, 5.56362
*SPRING, ELSET=WTS_SPRING, NONLINEAR

  -1.0000E+6, -4.40294
   0.0000E+0, -0.8125
   0.0000E+0, 0.0000E+0
   1.0000E+6, 3.59044
*SPRING, ELSET=RH22X_SPRING, NONLINEAR

   0.0000E+0, 0.0000E+0
   1.0000E+6, 7.399
*SPRING, ELSET=RH14_SPRING, NONLINEAR

  -1.0000E+6, -14.58053
   0.0000E+0, -0.25
   0.0000E+0, 0.0000E+0
   1.0000E+6, 14.33053
*SPRING, ELSET=RH-20_SPRING, NONLINEAR

  -1.0000E+6, -9.86763
   0.0000E+0, -0.1875
   0.0000E+0, 0.0000E+0
   1.0000E+6, 9.68013
*SPRING, ELSET=ROTATIONAL SPRING60, NONLINEAR
  6,
  -30970, -5.00000
  -30970, -0.005E+0
   30970, 0.005E+00
   30970, 5.00000
*SPRING, ELSET=ROTATIONAL SPRING60_1, NONLINEAR
  4,
  -30970, -5.00000
  -30970, -0.005E+0
   30970, 0.005E+00
   30970, 5.00000
*MASS, ALPHA=0.7026,
 ELSET=LMASS18LAP
  6.68000E-01,
*MASS, ALPHA=0.7026,
 ELSET=LMASS6LAP
  1.01000E-01,
*MASS, ALPHA=0.7026,
 ELSET=LMASS4LAP
  5.69700E-02,
*MASS, ALPHA=0.7026,
 ELSET=LMASS6GT
  1.27200E+00,
*MASS, ALPHA=0.7026,
 ELSET=LMASS4GT
  7.08000E-01,
*MASS, ALPHA=0.7026,
 ELSET=LMASS4CK
  5.27000E-01,
**%
*ELSET, ELSET=ALLELEMENTS
 BEAM,
 BEAM_1,
 BEAM_2,
 BEAM_3,
 BEAM_4,
 BEAM_5,
 BEAM_6,
 BEAM_7,
 BEAM_8,
 BEAM_9,
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BEAM_10 ,
BEAM_11 ,
BEAM_12 ,
BEAM_13 ,
BEAM_14 ,
BEAM_15 ,
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BEAM_17 ,
BEAM_18 ,
BEAM_19 ,
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BEAM_24 ,
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PIPE_52 ,
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ELBOW_40,
ELBOW_41,
ELBOW_42,
ELBOW_43,
ELBOW_44,
ELBOW_45,
ELBOW_46,
```

```
 ELBOW_47,
 ELBOW_48,
 LMASS18LAP,
 TUNNEL_RES_SPRING ,
 WALL PENTRATION GAP ,
 PS10_SPRING ,
 PS-23 ,
 PS-11 ,
 PS-7,
 LMASS6LAP ,
 LMASS4LAP ,
 LMASS6GT,
 PS14_BASE_SPRING,
 LMASS4GT,
 LMASS4CK,
 PS-20AV ,
 PS-20AH ,
 RH33A_SPRING,
 RH33B_SPRING,
 RH34_SPRING ,
 RH35_SPRING ,
 RH14A_SPRING,
 RH20_SPRING ,
 RH27A_UBOLT_SPRING,
 RH27B_UBOLT_SPRING,
 RH12,
 WTS_SPRING,
 RH22X_SPRING,
 RH14_SPRING ,
 ROTATIONAL SPRING60 ,
 ROTATIONAL SPRING60_1 ,
 RH-20_SPRING,
**%
*NSET,NSET=ALL
      15,      39,      51,      52,      53,      56,      57,      58,     546,     547,     548
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1698,    1699,    1700,    1701
*NSET,NSET=SUP_ELB_TEE_RED_FABBR
      15,      39,      51,      52,      53,      56,      57,      58
*NSET,NSET=ALL_NODES
      15,      39,      51,      52,      53,      56,      57,      58,     546,     547,     548
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1444,    1445,    1446
*NSET,NSET=MODEL1
      15,      39,      51,      52,      53,      56,      57,      58,     546,     547,     548
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1337,    1338,    1339,    1340,    1341,    1342,    1398,    1399,    1400,    1401,    1402
*NSET,NSET=LINE1-77
     990,     991,     992,     996,     999,    1001,    1038,    1039,    1041,    1157,    1158
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1407,    1420,    1421,    1422,    1423,    1424,    1425
*NSET,NSET=LINE1-39
     758,     983,     987,     989,     990,    1034,    1035,    1175,    1176,    1177,    1178
    1179,    1180,    1372,    1373,    1426,    1427
*NSET,NSET=LINE1-40
     586,     589,     590,     758,     776,     777,     778,     779,     780,     781,     782
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1304,    1310,    1313,    1396,    1410,    1426
*NSET,NSET=LINE1-41
     977,     983,     987,    1018,    1019,    1022,    1023,    1026,    1027,    1030,    1031
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1355,    1356,    1377,    1378,    1395,    1427
*NSET,NSET=MODEL4
     760,     977,     983,     987,     989,     990,     991,     992,     996,     999,    1001
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1231,    1232,    1233,    1234,    1235,    1236,    1237,    1238
*NSET,NSET=LINE1-42
     755,     759,     760,     766,     767,     768,     769,     770,     771,     772,     773
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     774,      775,      785,      786,      787,      788,      796,      797,      798,      799,      800
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1665,     1666,     1667,     1668,     1669,     1672,     1673,     1674,     1675,     1676,     1677
*NSET,NSET=LINE1-34_67
     588,      590,      756,      761,      762,      763,      764,      765,      793,      794,      795
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1682,     1683,     1684,     1685,     1686,     1687,     1688,     1689
*NSET,NSET=LINE1-41_77
     977,      983,      991,      992,      996,      999,     1001,     1018,     1019,     1022,     1023
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1697,     1698,     1699,     1700,     1701
*NSET,NSET=LINE1-1_2_3_4
     546,      547,      548,      549,      554,      555,      556,      557,      558,      559,      560
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1469,     1470,     1471,     1472,     1473,     1474,     1475,     1476,     1477,     1478,     1479
*NSET,NSET=LINE1-5_6_7
      15,       39,       51,       52,       53,       56,       57,       58,      586,      588,      589
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1489,     1490,     1491,     1492,     1493,     1494,     1495,     1496
*NSET,NSET=LINE1-8_9_10_11_12_170
     586,      591,      592,      593,      594,      595,      596,      597,      598,      599,      600
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1627,     1628,     1629,     1630,     1631,     1632,     1633,     1634,     1635,     1636
*NSET,NSET=LINE1-39_40
     586,      589,      590,      758,      776,      777,      778,      779,      780,      781,      782
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1642,     1643,     1644
*NSET,NSET=UNLIST_COMPS_M1-4
     568,      571,      572,      573,      579,      586,      588,      589,      590,      591,      592
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1084,     1089
*NSET,NSET=BC_NS_X_N315
     604,      607,      610,      613,      619,     1105,     1106,     1107,     1108,     1109,     1126
    1222,     1223,     1278,     1279,     1280,     1281,     1321,     1322,     1323,     1324,     1345
    1353,     1354,     1368,     1369,     1401,     1402,     1446
*NSET,NSET=BC_NS_X_N547
     974,     1148,     1284,     1285,     1406,     1407,     1431,     1432,     1433,     1434
*NSET,NSET=BC_NS_X_N552
     755,     1347,     1348,     1349,     1350,     1363,     1364,     1365,     1381,     1388,     1444
*NSET,NSET=BC_NS_X_N1340
    1355,
*NSET,NSET=BC_NS_X_N542
    1113,     1114,     1117,     1120,     1123,     1343,     1344,     1346,     1391,     1416
*NSET,NSET=BC_NS_X_N1577
     546,      547,      548,      549
*NSET,NSET=BC_V_Y_N892
    1363,     1364,     1365
*NSET,NSET=BC_V_Y_N4119
     604,      607,      610,      613,      619,     1105,     1106,     1107,     1108,     1109,     1120
    1123,     1343,     1344,     1345,     1391,     1416
*NSET,NSET=BC_V_Y_N552
     755,
*NSET,NSET=BC_V_Y_N1577
     546,      547,      548,      549,     1113,     1114,     1117,     1126,     1321,     1322,     1323
    1324,     1349,     1350,     1381,     1388,     1401,     1402
*NSET,NSET=BC_V_Y_N547
     974,     1148,     1222,     1223,     1278,     1279,     1280,     1281,     1284,     1285,     1348
    1353,     1354,     1368,     1369,     1407,     1433,     1434,     1445
*NSET,NSET=BC_EW_Z_N547
     604,      607,      610,      613,      619,      974,     1105,     1106,     1107,     1108,     1109
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
    1416,     1431,     1432,     1433,     1434
*NSET,NSET=BC_EW_Z_N1577
     546,      547,      548,      549
*NSET,NSET=BC_EW_Z_N552
     755,
*NSET,NSET=BC_EW_Z_N315
    1126,     1222,     1223,     1278,     1279,     1280,     1281,     1321,     1322,     1323,     1324
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   1353,    1354,    1368,    1369,    1401,    1402,    1445,    1446
*ELSET,ELSET=ALL, GENERATE
      55,      63,       1
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     967,     998,       1
*ELSET,ELSET=SUPPORT_RELEASE_1
     463,     464,     465,     466,     672,     673,     674,     675,     687,     746,     758
     771,
*ELSET,ELSET=SUP_ELB_TEE_RED_FABBR, GENERATE
      55,      61,       1
*ELSET,ELSET=MODEL1, GENERATE
      55,      63,       1
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     755,     759,       1
*ELSET,ELSET=LINE1-77
     498,     499,     500,     501,     502,     503,     506,     507,     508,     509,     511
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     814,     815,     816,     817,     818,     832,     833,     834,     835,     836,     837
*ELSET,ELSET=LINE1-39
     512,     513,     514,     515,     516,     517,     518,     519,     521,     522,     576
     577,     797,     798,     799,     800,     819,     820,     825,     826
*ELSET,ELSET=LINE1-40
     157,     158,     159,     160,     162,     177,     178,     179,     185,     233,     234
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     798,     819,     826
*ELSET,ELSET=LINE1-41
     479,     480,     481,     482,     483,     485,     486,     489,     490,     491,     492
     493,     494,     495,     496,     497,     521,     539,     545,     577,     612,     613
     614,     694,     695,     751,     799,     800,     820,     825
*ELSET,ELSET=MODEL4
     479,     480,     481,     482,     483,     485,     486,     489,     490,     491,     492
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     573,     574,     575,     577
*ELSET,ELSET=LINE1-42
     163,     164,     168,     169,     170,     171,     172,     173,     174,     175,     176
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     962,     963,     964,     965,     967,     968,     969,     970,     971,     972,     973
*ELSET,ELSET=LINE1-34_67
      88,     153,     154,     155,     180,     181,     182,     236,     239,     242,     243
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     986,
*ELSET,ELSET=LINE1-41_77
     479,     480,     481,     482,     483,     485,     486,     489,     490,     491,     492
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     992,     993,     994,     995,     996,     997,     998
*ELSET,ELSET=LINE1-1_2_3_4
      62,      63,      70,      71,      72,      73,      75,      78,      79,      80,      81
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     901,     902,     903,     904,     905
*ELSET,ELSET=LINE1-5_6_7
      55,      56,      57,      58,      59,      60,      61,      84,      85,      86,      87
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     917,     918,     919,     920,     921,     922
*ELSET,ELSET=LINE1-8_9_10_11_12_170
      89,      90,      91,      92,      93,      94,      95,      96,      97,      98,      99
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     928,     929,     930,     931,     932,     933
*ELSET,ELSET=LINE1-39_40
     157,     158,     159,     160,     162,     177,     178,     179,     185,     233,     234
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     940,     941
*ELSET,ELSET=UNLIST_COMPS_M1-4
      82,      83,      88,      89,      90,      91,     130,     131,     153,     162,     316
(INTERMEDIATE DATA OMITTED TO CONDENSE APPENDIX)
     425,     433
**%
<<--Replace Time History-->> (KEY PHRASE USED IN SCRIPTING PROCESS)
**%
```

```
*NSET,NSET=BS000001
1105,1106,1107,1108,1109,1113,1114,1117,1120,1123,1126,1278,1279,1280,1281
1284,1285,1321,1322,1323,1324,1343,1344,1345,1349,1350,1353,1354,1363,1364
1365,1368,1369,1381,1388,1402,1416,1433,1434
*NSET,NSET=BS000002
546,547,548,549,604,607,610,613,619,755,974,1148,1407
*RELEASE
SUPPORT_RELEASE_1, S1, M1-M2
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
**% Note: Nodes vertical is possitive z
**%       Elements vertical is possitive y
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.01
 0.005,1.0,1.0E-08,1.0
**%  STATIC PLUS SEISMIC
**%  RESTRAINT SET 3
*BOUNDARY,OP=NEW
       1346,  1,,       0.00000E+00
       1347,  1,,       0.00000E+00
       1444,  1,,       0.00000E+00
       1431,  1,,       0.00000E+00
       1431,  3,,       0.00000E+00
       1432,  1,,       0.00000E+00
       1432,  3,,       0.00000E+00
       1446,  1,,       0.00000E+00
       1446,  3,,       0.00000E+00
       1445,  2, 3,      0.00000E+00
BS000001,    1, 3,      0.00000E+00
       1222,  1, 3,      0.00000E+00
       1222,  5,,       0.00000E+00
       1223,  1, 3,      0.00000E+00
       1223,  5,,       0.00000E+00
       1401,  1, 5,      0.00000E+00
       1348,  1, 2,      0.00000E+00
       1348,  5, 6,      0.00000E+00
       1391,  1, 3,      0.00000E+00
       1391,  5, 6,      0.00000E+00
       1355,  1, 2,      0.00000E+00
       1355,  4, 6,      0.00000E+00
       1406,  1,,       0.00000E+00
       1406,  3, 6,      0.00000E+00
BS000002,    1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
       1367,    2, 8.5000E+02
       1080,    2, 2.9000E+03
       1099,    2, 3.1000E+03
       1075,    2, 3.4500E+03
       1078,    2, 3.4500E+03
       1074,    2, 3.5000E+03
       1079,    2, 3.5000E+03
       1077,    2, 3.5500E+03
       1072,    2, 3.6000E+03
       1073,    2, 3.6000E+03
       1076,    2, 3.6000E+03
       1071,    2, 3.7000E+03
       1095,    2, 4.5000E+03
       1094,    2, 5.6000E+03
       1084,    2, 5.7000E+03
       1083,    2, 6.0000E+03
       1091,    2, 6.5000E+03
       1085,    2, 9.2000E+03
       1086,    2, 9.6000E+03
       1087,    2, 9.6000E+03
       1088,    2, 1.0100E+04
```

```
       1089,    2, 1.7100E+04
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
**%OUTPUT, FIELD
**%NODE OUTPUT
**%ELEMENT OUTPUT
*OUTPUT, HISTORY,FREQUENCY=10000
**%ELEMENT OUTPUT
*NODE PRINT, TOTAL=YES
*MONITOR, NODE=589, DOF=1
*END STEP
**%
**% ====== SEISMIC WITH G-LOAD ======
**%
**% Note: Damping is address in the material properties
**%
*STEP,INC=10000000,NLGEOM
*DYNAMIC, DIRECT
 0.005,20.0,1.0E-08,0.005
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%
*BOUNDARY,OP=NEW
BS000002,    4, 6,      0.00000E+00
       1222,  5,,       0.00000E+00
       1223,  5,,       0.00000E+00
       1401,  4, 5,      0.00000E+00
       1391,  5, 6,      0.00000E+00
       1348,  5, 6,      0.00000E+00
       1355,  4, 6,      0.00000E+00
       1406,  4, 6,      0.00000E+00
*<<--H2_X_N315_TIME_HISTORY_INPUT-->>   (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_NS_X_N315, 1,,              1.0000E+00
*<<--H2_X_N547_TIME_HISTORY_INPUT-->>   (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_NS_X_N547, 1,,              1.0000E+00
*<<--H2_X_N552_TIME_HISTORY_INPUT-->>   (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_NS_X_N552, 1,,              1.0000E+00
*<<--H2_X_N1577_TIME_HISTORY_INPUT-->>  (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_NS_X_N1577, 1,,     1.0000E+00
*<<--H2_X_N542_TIME_HISTORY_INPUT-->>   (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_NS_X_N542, 1,,              1.0000E+00
*<<--V_Y_N547_TIME_HISTORY_INPUT-->>    (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_V_Y_N547, 2,,               1.0000E+00
*<<--V_Y_N552_TIME_HISTORY_INPUT-->>    (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_V_Y_N552, 2,,               1.0000E+00
*<<--V_Y_N4014_TIME_HISTORY_INPUT-->>   (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_V_Y_N4014, 2,,              1.0000E+00
*<<--V_Y_N4119_TIME_HISTORY_INPUT-->>   (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_V_Y_N4119, 2,,              1.0000E+00
*<<--V_Y_N1577_TIME_HISTORY_INPUT-->>   (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_V_Y_N1577, 2,,              1.0000E+00
*<<--H1_Z_N315_TIME_HISTORY_INPUT-->>   (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_EW_Z_N315, 3,,              1.0000E+00
*<<--H1_Z_N542_TIME_HISTORY_INPUT-->>   (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_EW_Z_N542, 3,,              1.0000E+00
*<<--H1_Z_N1577_TIME_HISTORY_INPUT-->>  (KEY PHRASE USED IN SCRIPTING PROCESS)
BC_EW_Z_N1577, 3,,     1.0000E+00
*<<--H1_Z_N319_TIME_HISTORY_INPUT-->>   (KEY PHRASE USED IN SCRIPTING PROCESS)
**%  LOAD SET 1
*CLOAD,OP=NEW
       1367,    2, 8.5000E+02
       1080,    2, 2.9000E+03
       1099,    2, 3.1000E+03
       1075,    2, 3.4500E+03
       1078,    2, 3.4500E+03
       1074,    2, 3.5000E+03
       1079,    2, 3.5000E+03
       1077,    2, 3.5500E+03
```

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Performer: A. L. Crawford **Date:** 09/30/08 **Checker:** M. D. Landon **Date:** 09/30/08

```
       1072,    2, 3.6000E+03
       1073,    2, 3.6000E+03
       1076,    2, 3.6000E+03
       1071,    2, 3.7000E+03
       1095,    2, 4.5000E+03
       1094,    2, 5.6000E+03
       1084,    2, 5.7000E+03
       1083,    2, 6.0000E+03
       1091,    2, 6.5000E+03
       1085,    2, 9.2000E+03
       1086,    2, 9.6000E+03
       1087,    2, 9.6000E+03
       1088,    2, 1.0100E+04
       1089,    2, 1.7100E+04
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT
 NFORC,SF,S
*OUTPUT, HISTORY,FREQUENCY=1
***NODE OUTPUT, NSET=CRANEND
** U,V,A
***ELEMENT OUTPUT
** UC
*NODE PRINT
*MONITOR, NODE=589, DOF=1
*END STEP
```

Project:	ATR Life-Time Extension Project			**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation						
Performer:	A. L. Crawford	**Date:**	09/30/08	**Checker:**	M. D. Landon	**Date:**	09/30/08

Appendix D.3

Calculations Associated with Model 1-4 Seismic Evaluation

Contents

Appendix D.3.1

Demand to Capacity Ratio Calculations for Components Associated with Lines 1-1, 1-2, 1-3, and 1-4 of ATR PCS Model 1-4

(NOTE: Values represented here are shown for one realization (Nodal Force file = LINE1-1_2_3_4_test_R1.dat and Element/Nodal order file = EL1-1_2_3_4_test_R1.xls) and may or may not be consistent with the 80th percentile results contained in Appendix D.4)

Force Outputs from Abaqus

NF := ...\LINE1-1_2_3_4.dat — (N)odal (F)orces for Model 1-4

Defined Elemental and Corresponding Nodal Order

EL := ..\EL_1_2_3_4(9-22-08).xls — Element and corresponding nodal order for Model 1-4

Time Boundaries

$t_{initial} := 1$ — Initial time for which dynamic loading is applied

$t_{final} := 21$ — Final time for which dynamic loading stops

Seismic Scale Factor (F_a)

$F_a := 1$ — Seismic scale factor [9]

Allowable Design Stress Intensity Factor (S_m): *S_m is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{m\_125} := 20ksi$ — For SS304 at 125°F [2, pg 316-318] [3, pg 23]

$S_{m\_125L} := 16.7ksi$ — For SS304L at 125°F [2, pg 316-318] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

$S_{m\_167} := 20ksi$ — For SS304 at 167°F [2, pg 316-318] [3, pg 23]

$S_{m\_167L} := 16.7ksi$ — For SS304L at 167°F [2, pg 316-318] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

Yield Strength (S_y): *S_y is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{y\_125} := 28.35ksi$ — For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_125L} := 23.85ksi$ — For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

$S_{y\_167} := 26.12ksi$ — For SS304 at 167°F [2, pg 646-648] [3, pg 23]

$S_{y\_167L} := 22.26ksi$ — For SS304L at 167°F [2, pg 646-648] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

Maximum Strength Applicable for Equation 9 (S): *S is defined below for SS304 at temperature 125ºF and SS304L at 125ºF.*

$S_{125} := \min(3 \cdot S_{m\_125}, 2 \cdot S_{y\_125})$

Maximum allowable stress applied to SS304 piping [4, NB-3656]

$\boxed{S_{125} = 56.7\ \mathrm{ksi}}$

$S_{125L} := \min(3 \cdot S_{m\_125L}, 2 \cdot S_{y\_125L})$

Maximum allowable stress applied to SS304L piping [4, NB-3656]

$\boxed{S_{125L} = 47.7\ \mathrm{ksi}}$

$S_{167} := \min(3 \cdot S_{m\_167}, 2 \cdot S_{y\_167})$

Maximum allowable stress applied to SS304 piping [4, NB-3656]

$\boxed{S_{167} = 52.24\ \mathrm{ksi}}$

$S_{167L} := \min(3 \cdot S_{m\_167L}, 2 \cdot S_{y\_167L})$

Maximum allowable stress applied to SS304L piping [4, NB-3656]

$\boxed{S_{167L} = 44.52\ \mathrm{ksi}}$

SUPPORTS

Supports Strategy: *Search based on the node for which the support acts. If this node is a termination point there will only be one node to evaluate. If this node is in line with a section of pipe there will be two representations of the same node (one for each element on each side of the node) to combine and the difference between them is the force required of the support. The D/C ratio for each support will be found by dividing the the required force found above by the support capacity.*

$$SupDC(P_r, P_c) := \frac{P_r}{P_c}$$

$$\begin{aligned}
Support(nf, nd, C_o, EL) := \;& ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
& ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
& ind_{nd} \leftarrow match\left(nd_0, EL^{\langle 1 \rangle}\right) \\
& \text{for } i \in 1..last(nd) \quad \text{if } rows(nd) > 1 \\
& \quad ind_{nd} \leftarrow stack\left[ind_{nd}, \left(match\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \\
& \begin{pmatrix} Int1_4 & Int2_4 \end{pmatrix} \leftarrow (0 \;\; 0) \\
& \text{for } i \in 0..ind_{nfo_0} - ind_{nfi_0} \\
& \quad \text{for } j \in 0..last\left(ind_{nd}\right) \\
& \quad\quad P_{rg_j} \leftarrow nf_{ind_{nfi}{}_{C_{o_{0,1}}-1},\, ind_{nd_j}} \\
& \quad\quad P_{r_j} \leftarrow \left(nf_{ind_{nfi}{}_{C_{o_{0,1}}-1}+i,\, ind_{nd_j}} - P_{rg_j}\right) \cdot C_{o_{2,0}} + P_{rg_j} \\
& \quad PR_i \leftarrow \sum_{n=0}^{j} P_{r_n} \\
& \quad \text{if } PR_i < Int1_1 \wedge C_{o_{0,0}} \neq 0 \\
& \quad\quad Int1' \leftarrow SupDC\left(\left|PR_i\right|, C_{o_{0,0}}\right) \\
& \quad\quad Int1 \leftarrow stack\left(Int1', PR_i, nf_{ind_{nfi}{}_{C_{o_{0,1}}-1}+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd}\right) \\
& \quad \text{if } PR_i > Int2_1 \wedge C_{o_{1,0}} \neq 0 \\
& \quad\quad Int2' \leftarrow SupDC\left(\left|PR_i\right|, C_{o_{1,0}}\right) \\
& \quad\quad Int2 \leftarrow stack\left(Int2', PR_i, nf_{ind_{nfi}{}_{C_{o_{0,1}}-1}+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd}\right) \\
& \begin{pmatrix} Int1 & Int2 \end{pmatrix}
\end{aligned}$$

PR-2A East Support

$P_{1\_PR2A\_E} := \frac{3.188 \cdot kip}{lbf}$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_PR2A\_E} := \frac{17.939 \cdot kip}{lbf}$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_PR2A\_E} := \begin{pmatrix} P_{1\_PR2A\_E} & 3 \\ P_{2\_PR2A\_E} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

PR-2A (Node 1323)

PR-2A Horizontally supports the midsection of P(1-1LC).

$nd1323_{PR2A_0} := 1323$ Node associated with support

$$\left(AL1_{PR2A\_nd1323} \;\; AL2_{PR2A\_nd1323}\right) := Support\left(NF, nd1323_{PR2A}, Sup\_C_{o\_PR2A\_E}, EL\right)$$

$$AL1_{PR2A\_nd1323}{}^T = \left(1.829 \;\; -5.83\times 10^3 \;\; 7.03 \;\; 1.323\times 10^3 \;\; 151\right)$$

$$AL2_{PR2A\_nd1323}{}^T = \left(0.267 \;\; 4.785\times 10^3 \;\; 7.13 \;\; 1.323\times 10^3 \;\; 151\right)$$

(D/C demand force, occurrence time, ...ed node, associated index for the reaction force at the selected node being in the positive (AL1) and negative directions of the global coordinate system)

PR-2B East Support

$P_{1\_PR2B\_E} := \frac{7.132 \cdot kip}{lbf}$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_PR2B\_E} := \frac{17.939 \cdot kip}{lbf}$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_PR2B\_E} := \begin{pmatrix} P_{1\_PR2B\_E} & 3 \\ P_{2\_PR2B\_E} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

PR-2B (Node 1324)

PR-2B Horizontally supports the midsection of P(1-2LC).

$nd1324_{PR2B_0} := 1324$ Node associated with support

$$\left(AL1_{PR2B\_nd1324} \;\; AL2_{PR2B\_nd1324}\right) := Support\left(NF, nd1324_{PR2B}, Sup\_C_{o\_PR2B\_E}, EL\right)$$

$$AL1_{PR2B\_nd1324}{}^T = \left(0.49 \;\; -3.495\times 10^3 \;\; 7.04 \;\; 1.324\times 10^3 \;\; 149\right)$$

$$AL2_{PR2B\_nd1324}{}^T = \left(0.15 \;\; 2.697\times 10^3 \;\; 6.93 \;\; 1.324\times 10^3 \;\; 149\right)$$

(D/C,demand force, occurrence time, ...ed node, associated index for the ...on force at the selected node being in the positive (AL1) and negative ...) directions of the global coordinate ...em)

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PR-2C West Support

$P_{1\_PR2C\_W} := \frac{17.939 \cdot kip}{lbf}$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_PR2C\_W} := \frac{7.132 \cdot kip}{lbf}$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_PR2C\_W} := \begin{pmatrix} P_{1\_PR2C\_W} & 3 \\ P_{2\_PR2C\_W} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

PR-2C (Node 1322)

PR-2C Horizontally supports the midsection of P(1-3LC).

$nd1322_{PR2C_0} := 1322$ Node associated with support

$$\left(AL1_{PR2C\_nd1322} \;\; AL2_{PR2C\_nd1322}\right) := Support\left(NF, nd1322_{PR2C}, Sup\_C_{o\_PR2C\_W}, EL\right)$$

$$AL1_{PR2C\_nd1322}{}^{T} = \left(0.165 \;\; -2.957 \times 10^{3} \;\; 7.845 \;\; 1.322 \times 10^{3} \;\; 147\right)$$

$$AL2_{PR2C\_nd1322}{}^{T} = \left(0.392 \;\; 2.796 \times 10^{3} \;\; 7.235 \;\; 1.322 \times 10^{3} \;\; 147\right)$$

...mand force, occurrence time, ...node, associated index for the reaction force at the selected node ...n the positive (AL1) and negative directions of the global coordinate system)

PR-2D West Support

$P_{1\_PR2D\_W} := \frac{17.939 \cdot kip}{lbf}$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_PR2D\_W} := \frac{3.188 \cdot kip}{lbf}$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_PR2D\_W} := \begin{pmatrix} P_{1\_PR2D\_W} & 3 \\ P_{2\_PR2D\_W} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

PR-2D (Node 1321)

PR-2D Horizontally supports the midsection of P(1-3LC).

$nd1321_{PR2D_0} := 1321$ Node associated with support

$$\left(AL1_{PR2D\_nd1321} \;\; AL2_{PR2D\_nd1321}\right) := Support\left(NF, nd1321_{PR2D}, Sup\_C_{o\_PR2D\_W}, EL\right)$$

$$AL1_{PR2D\_nd1321}{}^{T} = \left(0.254 \;\; -4.551 \times 10^{3} \;\; 7.845 \;\; 1.321 \times 10^{3} \;\; 145\right)$$

$$AL2_{PR2D\_nd1321}{}^{T} = \left(1.591 \;\; 5.074 \times 10^{3} \;\; 7.255 \;\; 1.321 \times 10^{3} \;\; 145\right)$$

(D/C demand force, occurrence time, ...node, associated index for the reaction force at the selected node being in the positive (AL1) and negative directions of the global coordinate system)

Writing Output Data for Supports Associated with Lines 1-1, 1-2, 1-3, & 1-4

$SA1 := AL1_{PR2A\_nd1323}^{T}$ PR-2A Tension

$SA2 := AL2_{PR2A\_nd1323}^{T}$ PR-2A Compression

$SB1 := AL1_{PR2B\_nd1324}^{T}$ PR-2B Tension

$SB2 := AL2_{PR2B\_nd1324}^{T}$ PR-2B Compression

$SC1 := AL1_{PR2C\_nd1322}^{T}$ PR-2C Tension

$SC2 := AL2_{PR2C\_nd1322}^{T}$ PR-2C Compression

$SD1 := AL1_{PR2D\_nd1321}^{T}$ PR-2D Tension

$SD2 := AL2_{PR2D\_nd1321}^{T}$ PR-2D Compression

$S := (SA1\ \ SA2\ \ SB1\ \ SB2\ \ SC1\ \ SC2\ \ SD1\ \ SD2)$

SupportsLines_1_2_3_4 := WRITEPRN("SupLine1-1_2_3_4.prn" , S)

TERMINATION LOCATIONS

Termination Locations Strategy: *Search based on the node for which the termination location acts as well as the next node inward. The D/C ratio for each termination location will be found by dividing the the required force found above by the support capacity.*

$$\mathrm{TermDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\,\mathrm{lbf \cdot in})]}{S}$$

$\mathrm{Term}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$$

$$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$$

$$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$$

$$\text{for } i \in 1 .. \mathrm{last}(nd) \quad \text{if } \mathrm{rows}(nd) > 1$$

$$\quad ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$$

$$\left(M \quad Int_0\right) \leftarrow (0 \quad 0)$$

$$\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$$

$$\quad \text{for } j \in 0 .. \mathrm{last}\left(ind_{nd}\right)$$

$$\quad\quad M_{rxg} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{nd_j}}$$

$$\quad\quad M_{ryg} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{nd_j}}$$

$$\quad\quad M_{rzg} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{nd_j}}$$

$$\quad\quad M_{rx} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$$

$$\quad\quad M_{ry} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$$

$$\quad\quad M_{rz} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$$

$$\quad\quad M'_j \leftarrow \sqrt{M_{rx}^{\,2} + M_{ry}^{\,2} + M_{rz}^{\,2}}$$

$$\quad\quad Int'_j \leftarrow \mathrm{TermDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$$

$$\quad\quad \text{if } Int'_j > Int_0$$

$$\quad\quad\quad Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfiC_{o_{0,1}}}-1+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M\right.$$

$$\quad\quad\quad Result \leftarrow M'$$

$$Int$$

Conditions applicable to all terminations

$M_{cx} := 0$ $M_{cy} := 0$ $M_{cz} := 0$

Defining place holding variables

$$Term\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Reactor Vessel (4x)

Define pertinent pipe variables

$D_o := 16in$ — Outside Diameter [5]

$t := 0.312in$ — Thickness [5]

$P := 272psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^4 - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

$I = 473.248\ in^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$S := S_{167L}$ — Allowable design stress intensity value

Define primary stress indices

$B_1 := 0.5$

$$B_2 := \begin{cases} 1.0 \text{ if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 \\ \quad T \leftarrow 125 \\ \quad X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \frac{D_o}{t}\right) \\ \quad Y \leftarrow 1 \\ \quad 1.0 \cdot \frac{1}{X \cdot Y} \end{cases}$$

$B_2 = 1.008$

Stress Indices are derived from [4, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [4, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Reactor Vessel 1-1L (Node 549)

$nd549_{HX11L_0} := 549$

$$AL_{HX11L\_nd549} := Term\left(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd549_{HX11L}, Term\_C_o, EL\right)$$

$$AL_{HX11L\_nd549}^T = \begin{pmatrix} 0.571 & 1.288 \times 10^6 & 7.4 & 549 & 69 & 1.286 \times 10^6 & 4.603 \times 10^4 & 3.257 \times 10^4 \end{pmatrix}$$

Reactor Vessel 1-2L (Node 548)

$nd548_{HX12L_0} := 548$

$AL_{HX12L\_nd548} := Term(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd548_{HX12L}, Term\_C_o, EL)$

$AL_{HX12L\_nd548}{}^T = (0.415 \quad 8.791\times10^5 \quad 7.39 \quad 548 \quad 71 \quad 8.392\times10^5 \quad 2.303\times10^5 \quad 1.244\times10^5)$

Reactor Vessel 1-3L (Node 547)

$nd547_{HX13L_0} := 547$

$AL_{HX13L\_nd547} := Term(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd547_{HX13L}, Term\_C_o, EL)$

$AL_{HX13L\_nd547}{}^T = (0.36 \quad 7.353\times10^5 \quad 6.67 \quad 547 \quad 75 \quad -6.637\times10^5 \quad -2.977\times10^5 \quad 1.074\times10^5)$

Reactor Vessel 1-4L (Node 546)

$nd546_{HX14L_0} := 546$

$AL_{HX14L\_nd546} := Term(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd546_{HX14L}, Term\_C_o, EL)$

$AL_{HX14L\_nd546}{}^T = (0.611 \quad 1.391\times10^6 \quad 7.4 \quad 546 \quad 73 \quad -1.385\times10^6 \quad -1.169\times10^5 \quad 6.474\times10^4)$

Writing Output Data for Terminations Associated with Lines 1-1L, 1-2L, 1-3L & 1-4L

$T1 := AL_{HX11L\_nd549}{}^T$

$T2 := AL_{HX12L\_nd548}{}^T$

$T3 := AL_{HX13L\_nd547}{}^T$

$T4 := AL_{HX14L\_nd546}{}^T$

$T := (T1 \quad T2 \quad T3 \quad T4)$

TerminationsLine1_1_2_3_4 := WRITEPRN("TermLine1-1_2_3_4.prn" , T)

PIPE RUNS

Pipe Runs Strategy: *Search based on the nodes present in each run of pipe. Find the maximum moment combination among all of the nodes and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation.*

$$\text{PipeRunDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

$\text{PipeRun}(P, D_o, t, I, B_1, B_2, S, nf, el, C_o, EL) :=$

$ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{el} \leftarrow \text{match}\left(el_0, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. \text{last}(el)$ if $\text{rows}(el) > 1$

  $ind_{el} \leftarrow \text{stack}\left[ind_{el}, \left(\text{match}\left(el_i, EL^{\langle 0 \rangle}\right)\right)\right]$

$\left(M \quad Int_{5, \text{last}(ind_{el})}\right) \leftarrow (0 \quad 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \text{last}(ind_{el})$

    $M_{rxg} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}}+2, ind_{el_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi_{C_{o_{1,1}}}}+2, ind_{el_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi_{C_{o_{2,1}}}}+2, ind_{el_j}}$

    $M_{rx_j} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}}+2+i, ind_{el_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry_j} \leftarrow \left(nf_{ind_{nfi_{C_{o_{1,1}}}}+2+i, ind_{el_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz_j} \leftarrow \left(nf_{ind_{nfi_{C_{o_{2,1}}}}+2+i, ind_{el_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{\left(M_{rx_j}\right)^2 + \left(M_{ry_j}\right)^2 + \left(M_{rz_j}\right)^2}$

    $Int'_j \leftarrow \text{PipeRunDC}(P, D_o, t, I, B_1, B_2, M'_j, S)$

    if $Int'_j > Int_{0,j}$

      $H \leftarrow \left(Int'_j \quad M'_j \quad nf_{ind_{nfi_{C_{o_{0,1}}}}-1+i, 0} \quad EL_{ind_{el_j}, 0} \quad EL_{ind_{el_j}, 1} \quad ind_{el_j} \quad M_{r}\right.$

      for $k \in 0 .. 5$

        $Int_{k, j} \leftarrow H_k$

Int

Conditions applicable to all pipe runs

$M_{ox} := 0 \quad M_{oy} := 0 \quad M_{oz} := 0$

Defining place holding directional moment variables

$$PipeRun\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties for Lines 1-1L, 2L, 3L, & 4L

Define pertinent pipe variables

$D_o := 18in$ — Outside Diameter [5,6,7]

$t := 0.312in$ — Thickness [5,6,7]

$P := 272psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^4 - (D_o - 2 \cdot t)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 678.244\ in^4$$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{array}{|l} 1.0 \ \text{ if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50 \\ \quad \begin{array}{|l} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \dfrac{D_o}{t}\right) \\ Y \leftarrow 1.033 - 0.00033 \cdot T \\ 1.0 \cdot \dfrac{1}{X \cdot Y} \end{array} \end{array}$$

$B_{2PR} = 1.057$

Stress Indices are derived from [4, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [4, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-1LA (Elements 380, 792, & 79)

$$el_{P11LA} := (380 \quad 792 \quad 79)^T$$

$$AL_{P11LA} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P11LA}, PipeRun\_C_o, EL\right)$$

$$AL_{P11LA}^{\ T} = \begin{pmatrix} 0.176 & 2.791\times10^5 & 13.42 & 380 & 571 & 93 \\ 0.182 & 2.979\times10^5 & 13.42 & 380 & 1.042\times10^3 & 94 \\ 0.176 & 2.781\times10^5 & 13.42 & 792 & 568 & 155 \\ 0.176 & 2.791\times10^5 & 13.42 & 792 & 571 & 156 \\ 0.176 & 2.781\times10^5 & 13.42 & 79 & 568 & 17 \\ 0.149 & 1.919\times10^5 & 7.385 & 79 & 649 & 18 \end{pmatrix}$$

Pipe Run 1-1LB (Elements 78)

$$el_{P11LB} := (78)^T$$

$$AL_{P11LB} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P11LB}, PipeRun\_C_o, EL\right)$$

$$AL_{P11LB}^{\ T} = \begin{pmatrix} 0.124 & 1.131\times10^5 & 7.13 & 78 & 637 & 15 \\ 0.131 & 1.376\times10^5 & 7.38 & 78 & 648 & 16 \end{pmatrix}$$

Pipe Run 1-1LC (Elements 71, 653, 664, 893, 892, 891, 890, 276, 885, 884, & 272)

$$el_{P11LC} := (71 \quad 653 \quad 664 \quad 893 \quad 892 \quad 891 \quad 890 \quad 276 \quad 885 \quad 884 \quad 272)^T$$

$$AL_{P11LC} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P11LC}, PipeRun\_C_o, EL\right)$$

$AL_{P11LC}^{\ T} =$

	0	1	2	3	4	5
0	0.202	$3.618\cdot10^5$	7.03	71	558	7
1	0.118	$9.54\cdot10^4$	9.915	71	636	8
2	0.203	$3.645\cdot10^5$	7.03	653	554	119
3	0.202	$3.619\cdot10^5$	7.03	653	558	120
4	0.203	$3.645\cdot10^5$	7.03	664	554	141
5	0.21	$3.878\cdot10^5$	7.03	664	$1.319\cdot10^3$	142
6	0.21	$3.877\cdot10^5$	7.03	893	$1.319\cdot10^3$	191
7	0.204	$3.69\cdot10^5$	7.03	893	$1.467\cdot10^3$	192
8	0.197	$3.453\cdot10^5$	7.025	892	$1.466\cdot10^3$	189
9	0.204	$3.691\cdot10^5$	7.03	892	$1.467\cdot10^3$	190
10	0.186	$3.11\cdot10^5$	6.67	891	$1.465\cdot10^3$	187
11	0.197	$3.453\cdot10^5$	7.025	891	$1.466\cdot10^3$	188
12	0.183	$3\cdot10^5$	6.665	890	$1.464\cdot10^3$	185
13	0.186	$3.11\cdot10^5$	6.67	890	$1.465\cdot10^3$	186
14	0.172	$2.673\cdot10^5$	6.665	276	902	81
15	0.183	$3\cdot10^5$	6.665	276	$1.464\cdot10^3$	82

Pipe Run 1-1LD (Elements 62 & 878)

$$el_{P11LD} := (62 \quad 878)^T$$

$$AL_{P11LD} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P11LD}, PipeRun\_C_o, EL)$$

$$AL_{P11LD}^T = \begin{pmatrix} 0.429 & 1.082 \times 10^6 & 7.4 & 62 & 625 & 1 \\ 0.276 & 5.958 \times 10^5 & 7.4 & 62 & 1.452 \times 10^3 & 2 \\ 0.144 & 1.76 \times 10^5 & 6.67 & 878 & 631 & 161 \\ 0.276 & 5.957 \times 10^5 & 7.4 & 878 & 1.452 \times 10^3 & 162 \end{pmatrix}$$

Pipe Run 1-2LA (Elements 386)

$$el_{P12LA} := (386)^T$$

$$AL_{P12LA} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P12LA}, PipeRun\_C_o, EL)$$

$$AL_{P12LA}^T = \begin{pmatrix} 0.125 & 1.179 \times 10^5 & 7.615 & 386 & 655 & 105 \\ 0.12 & 1.011 \times 10^5 & 7.455 & 386 & 1.05 \times 10^3 & 106 \end{pmatrix}$$

Pipe Run 1-2LB (Elements 82, 791, 291, & 72)

$$el_{P12LB} := (82 \quad 791 \quad 291 \quad 72)^T$$

$$AL_{P12LB} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P12LB}, PipeRun\_C_o, EL)$$

$$AL_{P12LB}^T = \begin{pmatrix} 0.135 & 1.479 \times 10^5 & 7.385 & 82 & 579 & 23 \\ 0.134 & 1.459 \times 10^5 & 7.62 & 82 & 652 & 24 \\ 0.135 & 1.475 \times 10^5 & 7.385 & 791 & 576 & 153 \\ 0.135 & 1.479 \times 10^5 & 7.385 & 791 & 579 & 154 \\ 0.135 & 1.475 \times 10^5 & 7.385 & 291 & 576 & 89 \\ 0.14 & 1.641 \times 10^5 & 7.49 & 291 & 921 & 90 \\ 0.127 & 1.241 \times 10^5 & 7.485 & 72 & 642 & 9 \\ 0.14 & 1.64 \times 10^5 & 7.49 & 72 & 921 & 10 \end{pmatrix}$$

Pipe Run 1-2LC (Elements 289, 657, 70, 654, 897, 896, 895, 894, 662, 883, 882, & 266

$el_{P12LC} := (289\ \ 657\ \ 70\ \ 654\ \ 897\ \ 896\ \ 895\ \ 894\ \ 662\ \ 883\ \ 882\ \ 266)^T$

$AL_{P12LC} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P12LC}, PipeRun\_C_o, EL)$

$AL_{P12LC}^T =$

	0	1	2	3	4	5
0	0.117	$9.029\cdot10^4$	9.905	289	641	87
1	0.142	$1.707\cdot10^5$	7.035	289	919	88
2	0.142	$1.707\cdot10^5$	7.035	657	919	127
3	0.172	$2.659\cdot10^5$	7.035	657	$1.314\cdot10^3$	128
4	0.171	$2.644\cdot10^5$	7.035	70	559	5
5	0.172	$2.66\cdot10^5$	7.035	70	$1.314\cdot10^3$	6
6	0.171	$2.643\cdot10^5$	7.035	654	555	121
7	0.171	$2.644\cdot10^5$	7.035	654	559	122
8	0.171	$2.643\cdot10^5$	7.035	897	555	199
9	0.182	$2.969\cdot10^5$	7.49	897	$1.471\cdot10^3$	200
10	0.192	$3.301\cdot10^5$	7.49	896	$1.47\cdot10^3$	197
11	0.182	$2.969\cdot10^5$	7.49	896	$1.471\cdot10^3$	198
12	0.193	$3.344\cdot10^5$	7.37	895	$1.469\cdot10^3$	195
13	0.192	$3.301\cdot10^5$	7.49	895	$1.47\cdot10^3$	196
14	0.188	$3.175\cdot10^5$	7.37	894	$1.468\cdot10^3$	193
15	0.193	$3.344\cdot10^5$	7.37	894	$1.469\cdot10^3$	194

Pipe Run 1-2LD (Elements 63 & 879)

$el_{P12LD} := (63\ \ 879)^T$

$AL_{P12LD} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P12LD}, PipeRun\_C_o, EL)$

$$AL_{P12LD}^T = \begin{pmatrix} 0.321 & 7.385\times10^5 & 7.39 & 63 & 624 & 3 \\ 0.219 & 4.163\times10^5 & 7.385 & 63 & 1.453\times10^3 & 4 \\ 0.14 & 1.647\times10^5 & 6.665 & 879 & 630 & 163 \\ 0.219 & 4.162\times10^5 & 7.385 & 879 & 1.453\times10^3 & 164 \end{pmatrix}$$

Pipe Run 1-3LA (Elements 388)

$el_{P13LA} := (388)^T$

$AL_{P13LA} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P13LA}, PipeRun\_C_o, EL)$

$$AL_{P13LA}^T = \begin{pmatrix} 0.128 & 1.256\times10^5 & 7.39 & 388 & 656 & 107 \\ 0.122 & 1.065\times10^5 & 9.89 & 388 & 1.051\times10^3 & 108 \end{pmatrix}$$

Pipe Run 1-3LB (Elements 83, 793, 292, & 75)

$$el_{P13LB} := (83 \quad 793 \quad 292 \quad 75)^{T}$$

$$AL_{P13LB} := \mathrm{PipeRun}\left(P, D_{o}, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P13LB}, PipeRun\_C_{o}, EL\right)$$

$$AL_{P13LB}{}^{T} = \begin{pmatrix} 0.136 & 1.511\times10^{5} & 7.385 & 83 & 578 & 25 \\ 0.139 & 1.607\times10^{5} & 7.385 & 83 & 653 & 26 \\ 0.136 & 1.506\times10^{5} & 7.385 & 793 & 577 & 157 \\ 0.136 & 1.511\times10^{5} & 7.385 & 793 & 578 & 158 \\ 0.136 & 1.506\times10^{5} & 7.385 & 292 & 577 & 91 \\ 0.132 & 1.408\times10^{5} & 7.485 & 292 & 922 & 92 \\ 0.123 & 1.105\times10^{5} & 7.485 & 75 & 643 & 13 \\ 0.132 & 1.408\times10^{5} & 7.485 & 75 & 922 & 14 \end{pmatrix}$$

Pipe Run 1-3LC (Elements 661, 660, 73, 656, 901, 900, 899, 898, 663, 887, 886, & 278

$$el_{P13LC} := (661 \quad 660 \quad 73 \quad 656 \quad 901 \quad 900 \quad 899 \quad 898 \quad 663 \quad 887 \quad 886 \quad 278)^{T}$$

$$AL_{P13LC} := \mathrm{PipeRun}\left(P, D_{o}, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P13LC}, PipeRun\_C_{o}, EL\right)$$

$AL_{P13LC}{}^{T} =$

	0	1	2	3	4	5
0	0.113	$8.008\cdot10^{4}$	10.235	661	640	135
1	0.131	$1.36\cdot10^{5}$	7.245	661	$1.316\cdot10^{3}$	136
2	0.158	$2.214\cdot10^{5}$	7.245	660	$1.315\cdot10^{3}$	133
3	0.131	$1.361\cdot10^{5}$	7.245	660	$1.316\cdot10^{3}$	134
4	0.159	$2.24\cdot10^{5}$	7.25	73	560	11
5	0.158	$2.215\cdot10^{5}$	7.245	73	$1.315\cdot10^{3}$	12
6	0.159	$2.242\cdot10^{5}$	7.25	656	556	125
7	0.159	$2.24\cdot10^{5}$	7.25	656	560	126
8	0.159	$2.242\cdot10^{5}$	7.25	901	556	207
9	0.173	$2.679\cdot10^{5}$	7.38	901	$1.475\cdot10^{3}$	208
10	0.184	$3.039\cdot10^{5}$	7.375	900	$1.474\cdot10^{3}$	205
11	0.173	$2.679\cdot10^{5}$	7.38	900	$1.475\cdot10^{3}$	206
12	0.186	$3.106\cdot10^{5}$	7.375	899	$1.473\cdot10^{3}$	203
13	0.184	$3.039\cdot10^{5}$	7.375	899	$1.474\cdot10^{3}$	204
14	0.178	$2.862\cdot10^{5}$	7.375	898	$1.472\cdot10^{3}$	201
15	0.186	$3.106\cdot10^{5}$	7.375	898	$1.473\cdot10^{3}$	202

Pipe Run 1-3LD (Elements 255 & 880)

$el_{P13LD} := (255 \quad 880)^T$

$AL_{P13LD} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P13LD}, PipeRun\_C_o, EL)$

$$AL_{P13LD}^T = \begin{pmatrix} 0.281 & 6.137\times10^5 & 6.67 & 255 & 626 & 57 \\ 0.194 & 3.361\times10^5 & 7.385 & 255 & 1.454\times10^3 & 58 \\ 0.135 & 1.486\times10^5 & 7.375 & 880 & 628 & 165 \\ 0.194 & 3.36\times10^5 & 7.385 & 880 & 1.454\times10^3 & 166 \end{pmatrix}$$

Pipe Run 1-4LA (Elements 381, 794, & 81)

$el_{P14LA} := (381 \quad 794 \quad 81)^T$

$AL_{P14LA} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P14LA}, PipeRun\_C_o, EL)$

$$AL_{P14LA}^T = \begin{pmatrix} 0.185 & 3.071\times10^5 & 9.52 & 381 & 570 & 95 \\ 0.191 & 3.263\times10^5 & 9.52 & 381 & 1.043\times10^3 & 96 \\ 0.185 & 3.061\times10^5 & 9.52 & 794 & 569 & 159 \\ 0.185 & 3.071\times10^5 & 9.52 & 794 & 570 & 160 \\ 0.185 & 3.061\times10^5 & 9.52 & 81 & 569 & 21 \\ 0.155 & 2.118\times10^5 & 7.38 & 81 & 651 & 22 \end{pmatrix}$$

Pipe Run 1-4LB (Elements 80)

$el_{P14LB} := (80)^T$

$AL_{P14LB} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P14LB}, PipeRun\_C_o, EL)$

$$AL_{P14LB}^T = \begin{pmatrix} 0.124 & 1.124\times10^5 & 7.365 & 80 & 639 & 19 \\ 0.138 & 1.591\times10^5 & 7.375 & 80 & 650 & 20 \end{pmatrix}$$

Pipe Run 1-4LC (Elements 658, 655, 659, 665, 902, 903, 904, 905, 889, 888, & 284)

$el_{P14LC} := (658\ \ 655\ \ 659\ \ 665\ \ 902\ \ 903\ \ 904\ \ 905\ \ 889\ \ 888\ \ 284)^T$

$AL_{P14LC} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P14LC}, PipeRun\_C_o, EL)$

$AL_{P14LC}^T =$

	0	1	2	3	4	5
0	0.183	$2.996 \cdot 10^5$	7.255	658	561	129
1	0.117	$9.067 \cdot 10^4$	9.515	658	638	130
2	0.183	$3.018 \cdot 10^5$	7.255	655	557	123
3	0.183	$2.997 \cdot 10^5$	7.255	655	561	124
4	0.183	$3.018 \cdot 10^5$	7.255	659	557	131
5	0.189	$3.206 \cdot 10^5$	7.255	659	$1.32 \cdot 10^3$	132
6	0.189	$3.205 \cdot 10^5$	7.255	665	$1.32 \cdot 10^3$	143
7	0.183	$3.02 \cdot 10^5$	7.14	665	$1.476 \cdot 10^3$	144
8	0.183	$3.02 \cdot 10^5$	7.14	902	$1.476 \cdot 10^3$	209
9	0.183	$3.008 \cdot 10^5$	7.365	902	$1.477 \cdot 10^3$	210
10	0.183	$3.009 \cdot 10^5$	7.365	903	$1.477 \cdot 10^3$	211
11	0.189	$3.206 \cdot 10^5$	7.37	903	$1.478 \cdot 10^3$	212
12	0.189	$3.207 \cdot 10^5$	7.37	904	$1.478 \cdot 10^3$	213
13	0.188	$3.165 \cdot 10^5$	7.375	904	$1.479 \cdot 10^3$	214
14	0.179	$2.886 \cdot 10^5$	7.375	905	882	215
15	0.188	$3.165 \cdot 10^5$	7.375	905	$1.479 \cdot 10^3$	216

Pipe Run 1-4LD (Elements 256 & 881)

$el_{P14LD} := (256\ \ 881)^T$

$AL_{P14LD} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P14LD}, PipeRun\_C_o, EL)$

$$AL_{P14LD}^T = \begin{pmatrix} 0.457 & 1.17 \times 10^6 & 7.4 & 256 & 627 & 59 \\ 0.293 & 6.517 \times 10^5 & 7.395 & 256 & 1.455 \times 10^3 & 60 \\ 0.144 & 1.781 \times 10^5 & 7.38 & 881 & 629 & 167 \\ 0.293 & 6.516 \times 10^5 & 7.395 & 881 & 1.455 \times 10^3 & 168 \end{pmatrix}$$

Writing Output Data for Pipe Runs Associated with Lines 1-1L, 2L, 3L, & 4L.

$PR1 := AL_{P11LA}^T$ $PR5 := AL_{P12LA}^T$ $PR9 := AL_{P13LA}^T$ $PR13 := AL_{P14LA}^T$

$PR2 := AL_{P11LB}^T$ $PR6 := AL_{P12LB}^T$ $PR10 := AL_{P13LB}^T$ $PR14 := AL_{P14LB}^T$

$PR3 := AL_{P11LC}^T$ $PR7 := AL_{P12LC}^T$ $PR11 := AL_{P13LC}^T$ $PR15 := AL_{P14LC}^T$

$PR4 := AL_{P11LD}^T$ $PR8 := AL_{P12LD}^T$ $PR12 := AL_{P13LD}^T$ $PR16 := AL_{P14LD}^T$

P := (PR1 PR2 PR3 PR4 PR5 PR6 PR7 PR8 PR9 PR10 PR11 PR12 PR13 PR14 PR15 PR16)

PipeRunsLine1_1_2_3_4 := WRITEPRN("PRLine1-1_2_3_4.prn" , P)

REDUCERS

Reducers Strategy: *Search based on the nodes comprising either end of the reducers. SRSS combine the three moments of each of the four node representations (one for each element connected by the node in question). Find the maximum of the moment combinations for each element and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. It is important to not combine the data from both nodes as the geometry for each is different and (9) must be applied for each node. The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\text{ReducerDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

$\text{Reducer}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \text{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. \text{last}(nd)$ if $\text{rows}(nd) > 1$

  $ind_{nd} \leftarrow \text{stack}\left[ind_{nd}, \left(\text{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$(M \;\; Int_0) \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \text{last}(ind_{nd})$

    $M_{rxg} \leftarrow nf_{ind_{nfi} C_{o_{0,1}} + 2, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi} C_{o_{1,1}} + 2, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi} C_{o_{2,1}} + 2, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi} C_{o_{0,1}} + 2 + i, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi} C_{o_{1,1}} + 2 + i, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi} C_{o_{2,1}} + 2 + i, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow \text{ReducerDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$

    if $Int'_j > Int_0$

      $Int \leftarrow \text{stack}\left(Int'_j, M'_j, nf_{ind_{nfi} C_{o_{0,1}} - 1 + i, 0}, EL_{ind_{nd_j}, 1}, ind_{nd_j}, M_{rx}, M_{ry},\right.$

      $\text{Result} \leftarrow M'$

Int

Conditions applicable to all reducers

$M_{cx} := 0 \quad M_{cy} := 0 \quad M_{cz} := 0$

Defining place holding variables

$$Reducer\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Reducer Properties for RED(1-1LA) & RED(1-4LA)

Define pertinent reducer variables

$D_o := (24in \ \ 18in)^T$

Outside Diameter [5]

$t := \left(\frac{3}{8}in \ \ \frac{3}{8}in\right)^T$

Thickness [5]

$P := (272psi \ \ 272psi)^T$

Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

$$I = \begin{pmatrix} 1.942 \times 10^3 \\ 806.631 \end{pmatrix} in^4$$

Moment of inertia [8, Table 17-27, pg 17-39]

Define primary stress indices

$$\alpha := atan\left(\frac{3in}{20in}\right)$$

$\alpha = 8.531\ deg$

Angular slope of reducer [5]

$$B_1 := \begin{vmatrix} 0.5 \text{ if } \alpha \le 30deg \\ 1.0 \text{ if } 30deg < \alpha \le 60deg \end{vmatrix}$$

$B_1 = 0.5$

B_1 primary stress Index [4, NB-3683.7]

$B_2 := 1.0$

B_2 primary stress Index [4, NB-3683.7]

Reducer 1-1LA (Nodes 745 & 1042)

$nd_{RD11LA\_L} := (745)^T$

Node associated with Large end of reducer

$$AL_{RD11LA\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{167L}, NF, nd_{RD11LA\_L}, Reducer\_C_o, EL\right)$$

$$AL_{RD11LA\_L}^{\ T} = \left(0.144 \ \ 3.339 \times 10^5 \ \ 9.905 \ \ 745 \ \ 101 \ \ -1.213 \times 10^5 \ \ 2.034 \times 10^5 \ \ -2.353 \times 10^5\right)$$

$nd_{RD11LA\_S} := (1042)^T$ Node associated with Small end of reducer

$AL_{RD11LA\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{167L}, NF, nd_{RD11LA\_S}, Reducer\_C_o, EL\right)$

$AL_{RD11LA\_S}^T = \left(0.148 \quad 2.979 \times 10^5 \quad 13.42 \quad 1.042 \times 10^3 \quad 94 \quad -7.429 \times 10^4 \quad 2.148 \times 10^5 \quad -1.926 \times 10^{\cdot}\right.$

Reducer 1-4LA (Nodes 746 & 1043)

$nd_{RD14LA\_L} := (746)^T$ Node associated with Large end of reducer

$AL_{RD14LA\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{167L}, NF, nd_{RD14LA\_L}, Reducer\_C_o, EL\right)$

$AL_{RD14LA\_L}^T = \left(0.148 \quad 3.611 \times 10^5 \quad 9.52 \quad 746 \quad 103 \quad 1.499 \times 10^5 \quad -1.975 \times 10^5 \quad -2.625 \times 10^5\right)$

$nd_{RD14LA\_S} := (1043)^T$ Node associated with Small end of reducer

$AL_{RD14LA\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{167L}, NF, nd_{RD14LA\_S}, Reducer\_C_o, EL\right)$

$AL_{RD14LA\_S}^T = \left(0.155 \quad 3.263 \times 10^5 \quad 9.52 \quad 1.043 \times 10^3 \quad 96 \quad 1.445 \times 10^5 \quad -1.611 \times 10^5 \quad -2.442 \times 10^5\right.$

Reducer Properties for RED(1-1LB), RED(1-4LB), RED(1-2L), & RED(1-3L)

Define pertinent reducer variables

$D_o := (18in \quad 16in)^T$ Outside Diameter [6,7]

$t := (0.312in \quad 0.312in)^T$ Thickness [6,7]

$P := (272psi \quad 272psi)^T$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\ 4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = \begin{pmatrix} 678.244 \\ 473.248 \end{pmatrix} in^4$$

Define primary stress indices

$$\alpha := atan\left(\frac{1in}{15in}\right)$$

Angular slope of reducer [6,7]

$\alpha = 3.814\,deg$

$$B_1 := \begin{cases} 0.5 & \text{if } \alpha \le 30deg \\ 1.0 & \text{if } 30deg < \alpha \le 60deg \end{cases}$$

B_1 primary stress Index [4, NB-3683.7]

$B_1 = 0.5$

$B_2 := 1.0$ B_2 primary stress Index [4, NB-3683.7]

Reducer 1-1LB (Nodes 625 & 549)

$nd_{RD11LB\_L} := (625)^T$ Node associated with Large end of reducer

$AL_{RD11LB\_L} := \text{Reducer}\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{167L}, NF, nd_{RD11LB\_L}, \text{Reducer\_C}_o, EL\right)$

$$AL_{RD11LB\_L}{}^T = \begin{pmatrix} 0.411 & 1.082\times10^6 & 7.4 & 625 & 65 & -1.081\times10^6 & -4.089\times10^4 & -3.188\times10^4 \end{pmatrix}$$

$nd_{RD11LB\_S} := (549)^T$ Node associated with Small end of reducer

$AL_{RD11LB\_S} := \text{Reducer}\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{167L}, NF, nd_{RD11LB\_S}, \text{Reducer\_C}_o, EL\right)$

$$AL_{RD11LB\_S}{}^T = \begin{pmatrix} 0.567 & 1.288\times10^6 & 7.4 & 549 & 69 & 1.286\times10^6 & 4.603\times10^4 & 3.257\times10^4 \end{pmatrix}$$

Reducer 1-2L (Nodes 624 & 548)

$nd_{RD12L\_L} := (624)^T$ Node associated with Large end of reducer

$AL_{RD12L\_L} := \text{Reducer}\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{167L}, NF, nd_{RD12L\_L}, \text{Reducer\_C}_o, EL\right)$

$$AL_{RD12L\_L}{}^T = \begin{pmatrix} 0.308 & 7.385\times10^5 & 7.39 & 624 & 67 & -7.02\times10^5 & -1.956\times10^5 & -1.198\times10^5 \end{pmatrix}$$

$nd_{RD12L\_S} := (548)^T$ Node associated with Small end of reducer

$AL_{RD12L\_S} := \text{Reducer}\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{167L}, NF, nd_{RD12L\_S}, \text{Reducer\_C}_o, EL\right)$

$$AL_{RD12L\_S}{}^T = \begin{pmatrix} 0.412 & 8.791\times10^5 & 7.39 & 548 & 71 & 8.392\times10^5 & 2.303\times10^5 & 1.244\times10^5 \end{pmatrix}$$

Reducer 1-3L (Nodes 626 & 547)

$nd_{RD13L\_L} := (626)^T$ Node associated with Large end of reducer

$AL_{RD13L\_L} := \text{Reducer}\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{167L}, NF, nd_{RD13L\_L}, \text{Reducer\_C}_o, EL\right)$

$$AL_{RD13L\_L}{}^T = \begin{pmatrix} 0.271 & 6.137\times10^5 & 6.67 & 626 & 63 & 5.5\times10^5 & 2.527\times10^5 & -1.014\times10^5 \end{pmatrix}$$

$nd_{RD13L\_S} := (547)^T$ Node associated with Small end of reducer

$AL_{RD13L\_S} := \text{Reducer}\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{167L}, NF, nd_{RD13L\_S}, \text{Reducer\_C}_o, EL\right)$

$$AL_{RD13L\_S}{}^T = \begin{pmatrix} 0.358 & 7.353\times10^5 & 6.67 & 547 & 75 & -6.637\times10^5 & -2.977\times10^5 & 1.074\times10^5 \end{pmatrix}$$

Reducer 1-4LB (Nodes 627 & 546)

$nd_{RD14LB\_L} := (627)^T$ Node associated with Large end of reducer

$AL_{RD14LB\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{167L}, NF, nd_{RD14LB\_L}, Reducer\_C_o, EL\right)$

$AL_{RD14LB\_L}{}^T = \begin{pmatrix} 0.437 & 1.17\times10^6 & 7.4 & 627 & 61 & 1.164\times10^6 & 1.027\times10^5 & -6.285\times10^4 \end{pmatrix}$

$nd_{RD14LB\_S} := (546)^T$ Node associated with Small end of reducer

$AL_{RD14LB\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{167L}, NF, nd_{RD14LB\_S}, Reducer\_C_o, EL\right)$

$AL_{RD14LB\_S}{}^T = \begin{pmatrix} 0.607 & 1.391\times10^6 & 7.4 & 546 & 73 & -1.385\times10^6 & -1.169\times10^5 & 6.474\times10^4 \end{pmatrix}$

Writing Output Data for Reducers Associated with Lines 1-1L, 1-2L, 1-3L, & 1-4L

$RL1 := AL_{RD11LA\_L}{}^T$

$RS1 := AL_{RD11LA\_S}{}^T$

$RL2 := AL_{RD14LA\_L}{}^T$

$RS2 := AL_{RD14LA\_S}{}^T$

$RL3 := AL_{RD11LB\_L}{}^T$

$RS3 := AL_{RD11LB\_S}{}^T$

$RL4 := AL_{RD12L\_L}{}^T$

$RS4 := AL_{RD12L\_S}{}^T$

$RL5 := AL_{RD13L\_L}{}^T$

$RS5 := AL_{RD13L\_S}{}^T$

$RL6 := AL_{RD14LB\_L}{}^T$

$RS6 := AL_{RD14LB\_S}{}^T$

$R := (RL1 \;\; RS1 \;\; RL2 \;\; RS2 \;\; RL3 \;\; RS3 \;\; RL4 \;\; RS4 \;\; RL5 \;\; RS5 \;\; RL6 \;\; RS6)$

ReducersLine1_1_2_3_4 := WRITEPRN("RedLine1-1_2_3_4.prn" , R)

ELBOWS

Elbows Strategy: *Search based on the two nodes comprising the ends of each elbow. SRSS combine the three moments of each of the four node representations (one for each element connected by the nodes in question). Find the maximum of the four moment combinations and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\text{ElbowDC}\left(P, D_o, t, I, B_1, B_2, M, S\right) := \frac{B_1 \cdot \dfrac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \dfrac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

$$\text{Elbow}\left(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL\right) := \left| \begin{array}{l}
ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
ind_{nd} \leftarrow \text{match}\left(nd_0, EL^{\langle 1 \rangle}\right) \\
\text{for } i \in 1 .. \text{last}(nd) \qquad\qquad\qquad\qquad \text{if rows}(nd) > 1 \\
\quad ind_{nd} \leftarrow \text{stack}\left[ind_{nd}, \left(\text{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \\
\left(M \quad Int_0\right) \leftarrow (0 \quad 0) \\
\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0} \\
\quad \text{for } j \in 0 .. \text{last}\left(ind_{nd}\right) \\
\qquad \left| \begin{array}{l}
M_{rxg} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}}+2,\, ind_{nd_j}} \\
M_{ryg} \leftarrow nf_{ind_{nfi_{C_{o_{1,1}}}}+2,\, ind_{nd_j}} \\
M_{rzg} \leftarrow nf_{ind_{nfi_{C_{o_{2,1}}}}+2,\, ind_{nd_j}} \\
M_{rx} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg} \\
M_{ry} \leftarrow \left(nf_{ind_{nfi_{C_{o_{1,1}}}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg} \\
M_{rz} \leftarrow \left(nf_{ind_{nfi_{C_{o_{2,1}}}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg} \\
M'_j \leftarrow \sqrt{M_{rx}^{\,2} + M_{ry}^{\,2} + M_{rz}^{\,2}} \\
Int'_j \leftarrow \text{ElbowDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right) \\
\text{if } Int'_j > Int_0 \\
\quad \left| \begin{array}{l}
Int \leftarrow \text{stack}\Big(Int'_j, M'_j, nf_{ind_{nfi_{C_{o_{0,1}}}}-1+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M \\
Result \leftarrow M'
\end{array} \right.
\end{array} \right. \\
Int
\end{array} \right.$$

Conditions applicable to all elbows

$M_{cx} := 0 \quad M_{cy} := 0 \quad M_{cz} := 0$ — Defining place holding variables

$$Elb\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Elbow Properties for Elbows 1-1LA, 1-1LC, 1-2LA, 1-2LB, 1-2LC, 1-3LA, 1-3LB, 1-3LC, 1-4LA, & 1-4LC

Define pertinent elbow variables

$D_o := 18in$ — Outside Diameter [5,6,7]

$t := 0.312in$ — Thickness [5,6,7]

$P := 272psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

$I = 678.244\ in^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$R := 1.5 \cdot D_o$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$ — Mean pipe radius

Define primary stress indices

$$h := \frac{t \cdot R}{r_m^{\,2}}$$ $h = 0.108$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h > 0.5 \\ -0.1 + 0.4 \cdot h & \text{otherwise} \end{cases}$$ $B_1 = 0$ — B_1 primary stress Index [4, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 5.743$ B_2 primary stress Index [4, NB-3683.7]

Elbow 1-1LA (Nodes 649 & 648)

$nd_{EL11LA\_1} := (649)^T$

$AL_{EL11LA\_nd649} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL11LA\_1}, Elb\_C_o, EL)$

$AL_{EL11LA\_nd649}^T = (0.329 \quad 1.919\times10^5 \quad 7.385 \quad 649 \quad 49 \quad -1.378\times10^5 \quad 2.251\times10^4 \quad -1.317\times10^5)$

$nd_{EL11LA\_2} := (648)^T$

$AL_{EL11LA\_nd648} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL11LA\_2}, Elb\_C_o, EL)$

$AL_{EL11LA\_nd648}^T = (0.236 \quad 1.376\times10^5 \quad 7.38 \quad 648 \quad 48 \quad 1.125\times10^5 \quad -2.297\times10^4 \quad 7.582\times10^4)$

Elbow 1-1LC (Nodes 632 & 631)

$nd_{EL11LC\_1} := (632)^T$

$AL_{EL11LC\_nd632} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL11LC\_1}, Elb\_C_o, EL)$

$AL_{EL11LC\_nd632}^T = (0.312 \quad 1.823\times10^5 \quad 7.405 \quad 632 \quad 79 \quad -1.817\times10^5 \quad 1.059\times10^3 \quad 1.501\times10^4)$

$nd_{EL11LC\_2} := (631)^T$

$AL_{EL11LC\_nd631} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL11LC\_2}, Elb\_C_o, EL)$

$AL_{EL11LC\_nd631}^T = (0.301 \quad 1.76\times10^5 \quad 6.67 \quad 631 \quad 161 \quad -1.123\times10^5 \quad -4.302\times10^4 \quad -1.285\times10^5)$

Elbow 1-2LA (Nodes 655 & 652)

$nd_{EL12LA\_1} := (655)^T$

$AL_{EL12LA\_nd655} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL12LA\_1}, Elb\_C_o, EL)$

$AL_{EL12LA\_nd655}^T = (0.202 \quad 1.18\times10^5 \quad 7.615 \quad 655 \quad 110 \quad -3.751\times10^4 \quad -7.146\times10^4 \quad -8.602\times10^4)$

$nd_{EL12LA\_2} := (652)^T$

$AL_{EL12LA\_nd652} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL12LA\_2}, Elb\_C_o, EL)$

$AL_{EL12LA\_nd652}^T = (0.25 \quad 1.459\times10^5 \quad 7.62 \quad 652 \quad 109 \quad 4.498\times10^4 \quad 8.569\times10^4 \quad 1.092\times10^5)$

Elbow 1-2LB (Nodes 642 & 641)

$nd_{EL12LB\_1} := (642)^T$

$AL_{EL12LB\_nd642} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL12LB\_1}, Elb\_C_o, EL)$

$AL_{EL12LB\_nd642}{}^T = (0.212 \;\; 1.241 \times 10^5 \;\; 7.485 \;\; 642 \;\; 9 \;\; -3.428 \times 10^4 \;\; 2.402 \times 10^4 \;\; -1.168 \times 10^5)$

$nd_{EL12LB\_2} := (641)^T$

$AL_{EL12LB\_nd641} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL12LB\_2}, Elb\_C_o, EL)$

$AL_{EL12LB\_nd641}{}^T = (0.155 \;\; 9.03 \times 10^4 \;\; 9.905 \;\; 641 \;\; 39 \;\; 6.919 \times 10^4 \;\; 4.065 \times 10^4 \;\; -4.139 \times 10^4)$

Elbow 1-2LC (Nodes 633 & 630)

$nd_{EL12LC\_1} := (633)^T$

$AL_{EL12LC\_nd633} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL12LC\_1}, Elb\_C_o, EL)$

$AL_{EL12LC\_nd633}{}^T = (0.224 \;\; 1.307 \times 10^5 \;\; 7.39 \;\; 633 \;\; 77 \;\; -1.101 \times 10^5 \;\; -3.849 \times 10^4 \;\; 5.908 \times 10^4)$

$nd_{EL12LC\_2} := (630)^T$

$AL_{EL12LC\_nd630} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL12LC\_2}, Elb\_C_o, EL)$

$AL_{EL12LC\_nd630}{}^T = (0.282 \;\; 1.647 \times 10^5 \;\; 6.665 \;\; 630 \;\; 163 \;\; -3.667 \times 10^4 \;\; -1.923 \times 10^4 \;\; -1.594 \times 10^5$

Elbow 1-3LA (Nodes 656 & 653)

$nd_{EL13LA\_1} := (656)^T$

$AL_{EL13LA\_nd656} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL13LA\_1}, Elb\_C_o, EL)$

$AL_{EL13LA\_nd656}{}^T = (0.215 \;\; 1.256 \times 10^5 \;\; 7.39 \;\; 656 \;\; 113 \;\; 4.287 \times 10^4 \;\; 3.53 \times 10^4 \;\; -1.126 \times 10^5)$

$nd_{EL13LA\_2} := (653)^T$

$AL_{EL13LA\_nd653} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL13LA\_2}, Elb\_C_o, EL)$

$AL_{EL13LA\_nd653}{}^T = (0.275 \;\; 1.607 \times 10^5 \;\; 7.385 \;\; 653 \;\; 112 \;\; -5.395 \times 10^4 \;\; -4.568 \times 10^4 \;\; 1.444 \times 10^5)$

Elbow 1-3LB (Nodes 643 & 640)

$nd_{EL13LB\_1} := (643)^T$

$AL_{EL13LB\_nd643} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL13LB\_1}, Elb\_C_o, EL)$

$AL_{EL13LB\_nd643}{}^T = (0.189 \;\; 1.105 \times 10^5 \;\; 7.485 \;\; 643 \;\; 13 \;\; 1.565 \times 10^4 \;\; -3.112 \times 10^4 \;\; -1.049 \times 10^5)$

$nd_{EL13LB\_2} := (640)^T$

$AL_{EL13LB\_nd640} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL13LB\_2}, Elb\_C_o, EL)$

$AL_{EL13LB\_nd640}{}^T = (0.137 \;\; 8.008 \times 10^4 \;\; 10.235 \;\; 640 \;\; 135 \;\; 5.743 \times 10^4 \;\; 2.634 \times 10^4 \;\; 4.92 \times 10^4)$

Elbow 1-3LC (Nodes 634 & 628)

$nd_{EL13LC\_1} := (634)^T$

$AL_{EL13LC\_nd634} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL13LC\_1}, Elb\_C_o, EL)$

$AL_{EL13LC\_nd634}^T = (0.197 \quad 1.152 \times 10^5 \quad 7.38 \quad 634 \quad 83 \quad 8.466 \times 10^4 \quad 4.383 \times 10^4 \quad 6.475 \times 10^4)$

$nd_{EL13LC\_2} := (628)^T$

$AL_{EL13LC\_nd628} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL13LC\_2}, Elb\_C_o, EL)$

$AL_{EL13LC\_nd628}^T = (0.254 \quad 1.486 \times 10^5 \quad 7.375 \quad 628 \quad 165 \quad 4.901 \times 10^4 \quad 2.926 \times 10^4 \quad -1.372 \times 10^5)$

Elbow 1-4LA (Nodes 651 & 650)

$nd_{EL11LA\_1} := (651)^T$

$AL_{EL11LA\_nd651} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL11LA\_1}, Elb\_C_o, EL)$

$AL_{EL11LA\_nd651}^T = (0.363 \quad 2.118 \times 10^5 \quad 7.38 \quad 651 \quad 22 \quad -1.589 \times 10^5 \quad 3.887 \times 10^4 \quad 1.346 \times 10^5)$

$nd_{EL11LA\_2} := (650)^T$

$AL_{EL11LA\_nd650} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL11LA\_2}, Elb\_C_o, EL)$

$AL_{EL11LA\_nd650}^T = (0.272 \quad 1.592 \times 10^5 \quad 7.375 \quad 650 \quad 45 \quad -1.353 \times 10^5 \quad 3.499 \times 10^4 \quad 7.608 \times 10^4)$

Elbow 1-4LC (Nodes 635 & 629)

$nd_{EL11LC\_1} := (635)^T$

$AL_{EL11LC\_nd635} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL11LC\_1}, Elb\_C_o, EL)$

$AL_{EL11LC\_nd635}^T = (0.339 \quad 1.981 \times 10^5 \quad 7.4 \quad 635 \quad 85 \quad 1.954 \times 10^5 \quad 461.063 \quad 3.28 \times 10^4)$

$nd_{EL11LC\_2} := (629)^T$

$AL_{EL11LC\_nd629} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL11LC\_2}, Elb\_C_o, EL)$

$AL_{EL11LC\_nd629}^T = (0.305 \quad 1.781 \times 10^5 \quad 7.38 \quad 629 \quad 167 \quad 1.41 \times 10^5 \quad 4.661 \times 10^4 \quad -9.819 \times 10^4)$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

Elbow Properties for EL(1-1LB) & EL(1-4LB)

Define pertinent elbow variables

$D_o := 18in$ — Outside Diameter [6,7]

$t := 0.312in$ — Thickness [6,7]

$P := 272psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 678.244\ in^4$

$R := 1 \cdot D_o$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$

Mean pipe radius

Define primary stress indices

$$h := \frac{t \cdot R}{r_m^{\,2}}$$

$h = 0.072$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h > 0.5 \\ -0.1 + 0.4 \cdot h & \text{otherwise} \end{cases}$$

$B_1 = 0$ — B_1 primary stress Index [4, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 7.525$ — B_2 primary stress Index [4, NB-3683.7]

Elbow 1-1LB (Nodes 637 & 636)

$nd_{EL11LB\_1} := (637)^T$

$AL_{EL11LB\_nd637} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL11LB\_1}, Elb\_C_o, EL\right)$

$AL_{EL11LB\_nd637}^{\ T} = \left(0.254 \quad 1.131 \times 10^5 \quad 7.13 \quad 637 \quad 15 \quad 1.083 \times 10^5 \quad -6.652 \times 10^3 \quad 3.18 \times 10^4\right)$

$nd_{EL11LB\_2} := (636)^T$

$AL_{EL11LB\_nd636} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL11LB\_2}, Elb\_C_o, EL\right)$

$AL_{EL11LB\_nd636}^{\ T} = \left(0.214 \quad 9.547 \times 10^4 \quad 9.915 \quad 636 \quad 54 \quad 2.673 \times 10^4 \quad 2.947 \times 10^4 \quad -8.678 \times 10^4\right)$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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Elbow 1-4LB (Nodes 639 & 638)

$nd_{EL14LB\_1} := (639)^T$

$AL_{EL14LB\_nd639} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL14LB\_1}, Elb\_C_o, EL)$

$AL_{EL14LB\_nd639}^T = (0.252 \quad 1.124\times10^5 \quad 7.365 \quad 639 \quad 19 \quad -1.036\times10^5 \quad 2.533\times10^4 \quad 3.568\times10^4)$

$nd_{EL14LB\_2} := (638)^T$

$AL_{EL14LB\_nd638} := Elbow(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{EL14LB\_2}, Elb\_C_o, EL)$

$AL_{EL14LB\_nd638}^T = (0.203 \quad 9.067\times10^4 \quad 9.515 \quad 638 \quad 130 \quad 3.795\times10^4 \quad 2.032\times10^4 \quad 7.98\times10^4)$

Writing Output Data for Elbows Associated with Lines 13 to 16, 18 to 21, and 171

$EL1A := AL_{EL11LA\_nd649}^T$

$EL1B := AL_{EL11LA\_nd648}^T$

$EL2A := AL_{EL11LC\_nd632}^T$

$EL2B := AL_{EL11LC\_nd631}^T$

$EL3A := AL_{EL12LA\_nd655}^T$

$EL3B := AL_{EL12LA\_nd652}^T$

$EL4A := AL_{EL12LB\_nd642}^T$

$EL4B := AL_{EL12LB\_nd641}^T$

$EL5A := AL_{EL12LC\_nd633}^T$

$EL5B := AL_{EL12LC\_nd630}^T$

$EL6A := AL_{EL13LA\_nd656}^T$

$EL6B := AL_{EL13LA\_nd653}^T$

$EL7A := AL_{EL13LB\_nd643}^T$

$EL7B := AL_{EL13LB\_nd640}^T$

$EL8A := AL_{EL13LC\_nd634}^T$

$EL8B := AL_{EL13LC\_nd628}^T$

$EL9A := AL_{EL11LA\_nd651}^T$

$EL9B := AL_{EL11LA\_nd650}^T$

$EL10A := AL_{EL11LC\_nd635}^T$

$EL10B := AL_{EL11LC\_nd629}^T$

$EL11A := AL_{EL11LB\_nd637}^T$

$EL11B := AL_{EL11LB\_nd636}^T$

$EL12A := AL_{EL14LB\_nd639}^T$

$EL12B := AL_{EL14LB\_nd638}^T$

vEL := (EL1A EL1B EL2A EL2B EL3A EL3B EL4A EL4B EL5A EL5B EL6A EL6B EL7A EL7B EL8A EL8B EI

ElbowLine1_1_2_3_4 := WRITEPRN("ElbowLine1-1_2_3_4.prn" , vEL)

FLANGES

Flange Strategy: *Search based on the nodes where flanges occur. Find the maximum moment combination for the node and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\mathrm{FlangeDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\,\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Flange}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(nd)$ if $\mathrm{rows}(nd) > 1$

  $ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$(M \;\; Int_0) \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \mathrm{last}(ind_{nd})$

    $M_{rxg} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}}+2,\, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi_{C_{o_{1,1}}}}+2,\, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi_{C_{o_{2,1}}}}+2,\, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi_{C_{o_{1,1}}}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi_{C_{o_{2,1}}}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow \mathrm{FlangeDC}(P, D_o, t, I, B_1, B_2, M'_j, S)$

    if $Int'_j > Int_0$

      $Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfi_{C_{o_{0,1}}}}-1+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M\right.$

      $Result \leftarrow M'$

Int

Conditions applicable to all flanges

$M_{cx} := 0 \quad M_{cy} := 0 \quad M_{cz} := 0$

Defining place holding variables

$$Flange\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties of FL(1-1L(A-D)), FL(1-2L(A-D)), FL(1-3L(A-D)), & FL(1-4L(A-D))

Define pertinent pipe variables

$D_o := 18in$ — Outside Diameter [6,7]

$t := 0.312in$ — Thickness [6,7]

$P := 272psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 678.244\ in^4$

Define primary stress indices (Utilize girth weld characteristic associated with lap joint flanges in determining values)

$B_1 := 0.5$ — B_1 for a girth weld [4, Table NB-3681(a)-1, pg 130]

$B_2 := 1$ — B_2 for a girth weld [4, Table NB-3681(a)-1, pg 130]

Flange 1-1LA (Node 571)

$nd_{FL11LA} := (571)^T$

$AL_{FL11LA} := Flange\left(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{FL11LA}, Flange\_C_o, EL\right)$

$$AL_{FL11LA}^{\ T} = \left(0.171 \quad 2.791 \times 10^5 \quad 13.42 \quad 571 \quad 156 \quad -7.431 \times 10^4 \quad 1.922 \times 10^5 \quad -1.882 \times 10^5\right)$$

Flange 1-1LB (Node 568)

$nd_{FL11LB} := (568)^T$

$AL_{FL11LB} := Flange\left(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{FL11LB}, Flange\_C_o, EL\right)$

$$AL_{FL11LB}^{\ T} = \left(0.171 \quad 2.781 \times 10^5 \quad 13.42 \quad 568 \quad 17 \quad -7.436 \times 10^4 \quad 1.912 \times 10^5 \quad -1.878 \times 10^5\right)$$

Flange 1-1LC (Node 558)

$nd_{FL11LC} := (558)^T$

$AL_{FL11LC} := \mathrm{Flange}(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{FL11LC}, Flange\_C_o, EL)$

$AL_{FL11LC}^T = (0.196 \quad 3.619 \times 10^5 \quad 7.03 \quad 558 \quad 120 \quad -3.503 \times 10^5 \quad -2.873 \times 10^4 \quad -8.638 \times 10^4)$

Flange 1-1LD (Node 554)

$nd_{FL11LD} := (554)^T$

$AL_{FL11LD} := \mathrm{Flange}(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{FL11LD}, Flange\_C_o, EL)$

$AL_{FL11LD}^T = (0.197 \quad 3.645 \times 10^5 \quad 7.03 \quad 554 \quad 141 \quad -3.528 \times 10^5 \quad -2.872 \times 10^4 \quad -8.704 \times 10^4)$

Flange 1-2LA (Node 579)

$nd_{FL12LA} := (579)^T$

$AL_{FL12LA} := \mathrm{Flange}(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{FL12LA}, Flange\_C_o, EL)$

$AL_{FL12LA}^T = (0.132 \quad 1.479 \times 10^5 \quad 7.385 \quad 579 \quad 154 \quad -6.686 \times 10^4 \quad -9.108 \times 10^3 \quad -1.316 \times 10^5)$

Flange 1-2LB (Node 576)

$nd_{FL12LB} := (576)^T$

$AL_{FL12LB} := \mathrm{Flange}(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{FL12LB}, Flange\_C_o, EL)$

$AL_{FL12LB}^T = (0.132 \quad 1.475 \times 10^5 \quad 7.385 \quad 576 \quad 89 \quad -6.687 \times 10^4 \quad -8.918 \times 10^3 \quad -1.312 \times 10^5)$

Flange 1-2LC (Node 559)

$nd_{FL12LC} := (559)^T$

$AL_{FL12LC} := \mathrm{Flange}(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{FL12LC}, Flange\_C_o, EL)$

$AL_{FL12LC}^T = (0.167 \quad 2.644 \times 10^5 \quad 7.035 \quad 559 \quad 122 \quad -2.206 \times 10^5 \quad -4.638 \times 10^4 \quad -1.381 \times 10^5)$

Flange 1-2LD (Node 555)

$nd_{FL12LD} := (555)^T$

$AL_{FL12LD} := \mathrm{Flange}(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{FL12LD}, Flange\_C_o, EL)$

$AL_{FL12LD}^T = (0.167 \quad 2.643 \times 10^5 \quad 7.035 \quad 555 \quad 199 \quad -2.201 \times 10^5 \quad -4.643 \times 10^4 \quad -1.388 \times 10^5)$

Flange 1-3LA (Node 578)

$nd_{FL13LA} := (578)^T$

$AL_{FL13LA} := Flange(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{FL13LA}, Flange\_C_o, EL)$

$AL_{FL13LA}{}^T = (0.133 \quad 1.511\times10^5 \quad 7.385 \quad 578 \quad 25 \quad -5.392\times10^4 \quad -1.375\times10^4 \quad 1.405\times10^5)$

Flange 1-3LB (Node 577)

$nd_{FL13LB} := (577)^T$

$AL_{FL13LB} := Flange(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{FL13LB}, Flange\_C_o, EL)$

$AL_{FL13LB}{}^T = (0.133 \quad 1.506\times10^5 \quad 7.385 \quad 577 \quad 157 \quad -5.393\times10^4 \quad -1.341\times10^4 \quad 1.4\times10^5)$

Flange 1-3LC (Node 560)

$nd_{FL13LC} := (560)^T$

$AL_{FL13LC} := Flange(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{FL13LC}, Flange\_C_o, EL)$

$AL_{FL13LC}{}^T = (0.155 \quad 2.24\times10^5 \quad 7.25 \quad 560 \quad 126 \quad 1.848\times10^5 \quad 4.148\times10^4 \quad -1.197\times10^5)$

Flange 1-3LD (Node 556)

$nd_{FL13LD} := (556)^T$

$AL_{FL13LD} := Flange(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{FL13LD}, Flange\_C_o, EL)$

$AL_{FL13LD}{}^T = (0.155 \quad 2.242\times10^5 \quad 7.25 \quad 556 \quad 207 \quad 1.845\times10^5 \quad 4.148\times10^4 \quad -1.204\times10^5)$

Flange 1-4LA (Node 570)

$nd_{FL14LA} := (570)^T$

$AL_{FL14LA} := Flange(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{FL14LA}, Flange\_C_o, EL)$

$AL_{FL14LA}{}^T = (0.18 \quad 3.071\times10^5 \quad 9.52 \quad 570 \quad 160 \quad 1.446\times10^5 \quad -1.401\times10^5 \quad -2.32\times10^5)$

Flange 1-4LB (Node 569)

$nd_{FL14LB} := (569)^T$

$AL_{FL14LB} := Flange(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{FL14LB}, Flange\_C_o, EL)$

$AL_{FL14LB}{}^T = (0.179 \quad 3.061\times10^5 \quad 9.52 \quad 569 \quad 21 \quad 1.446\times10^5 \quad -1.391\times10^5 \quad -2.312\times10^5)$

Flange 1-4LC (Node 561)

$nd_{FL14LC} := (561)^T$

$AL_{FL14LC} := Flange(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{FL14LC}, Flange\_C_o, EL)$

$AL_{FL14LC}{}^T = (0.177 \quad 2.997\times10^5 \quad 7.255 \quad 561 \quad 124 \quad 2.902\times10^5 \quad 2.668\times10^4 \quad -7.012\times10^4)$

Flange 1-4LD (Node 557)

$nd_{FL14LD} := (557)^T$

$AL_{FL14LD} := Flange(P, D_o, t, I, B_1, B_2, S_{167L}, NF, nd_{FL14LD}, Flange\_C_o, EL)$

$AL_{FL14LD}{}^T = (0.178 \quad 3.018\times10^5 \quad 7.255 \quad 557 \quad 131 \quad 2.922\times10^5 \quad 2.668\times10^4 \quad -7.078\times10^4)$

Writing Output Data for Flanges Associated with Lines 1-1L, 1-2L, 1-3L, & 1-4L

$F1 := AL_{FL11LA}{}^T$

$F2 := AL_{FL11LB}{}^T$

$F3 := AL_{FL11LC}{}^T$

$F4 := AL_{FL11LD}{}^T$

$F5 := AL_{FL12LA}{}^T$

$F6 := AL_{FL12LB}{}^T$

$F7 := AL_{FL12LC}{}^T$

$F8 := AL_{FL12LD}{}^T$

$F9 := AL_{FL13LA}{}^T$

$F10 := AL_{FL13LB}{}^T$

$F11 := AL_{FL13LC}{}^T$

$F12 := AL_{FL13LD}{}^T$

$F13 := AL_{FL14LA}{}^T$

$F14 := AL_{FL14LB}{}^T$

$F15 := AL_{FL14LC}{}^T$

$F16 := AL_{FL14LD}{}^T$

$F := (F1 \quad F2 \quad F3 \quad F4 \quad F5 \quad F6 \quad F7 \quad F8 \quad F9 \quad F10 \quad F11 \quad F12 \quad F13 \quad F14 \quad F15 \quad F16)$

FlangeLine1_1_2_3_4 := WRITEPRN("FlangeLine1-1_2_3_4.prn" , F)

Appendix D.3.2

Demand to Capacity Ratio Calculations for Components Associated with Lines 1-5, 1-6, and 1-7 of ATR PCS Model 1-4

(NOTE: Values represented here are shown for one realization (Nodal Force file = LINES1-5_6_7_test_R1.dat and Element/Nodal order file = EL1-5_6_7.xls) and may or may not be consistent with the 80th percentile results contained in Appendix D.4)

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Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

Force Outputs from Abaqus

NF := ...\LINE1-5_6_7.dat — (N)odal (F)orces for the (M)edium (L)ines of Model 3

Defined Elemental and Corresponding Nodal Order

EL := ..\EL_5_6_7(9-22-08).xls — Element and corresponding nodal order for the (M)edium (L)ines of Model 3

Time Boundaries

$t_{initial} := 1$ — Initial time for which dynamic loading is applied

$t_{final} := 21$ — Final time for which dynamic loading stops

Seismic Scale Factor (F_a)

$F_a := 1$ — Seismic scale factor [30]

Allowable Design Stress Intensity Factor (S_m): *S_m is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{m\_125} := 20ksi$ — For SS304 at 125°F [2, pg 316-318] [3, pg 23]

$S_{m\_125L} := 16.7ksi$ — For SS304L at 125°F [2, pg 316-318] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

$S_{m\_167} := 20ksi$ — For SS304 at 167°F [2, pg 316-318] [3, pg 23]

$S_{m\_167L} := 16.7ksi$ — For SS304L at 167°F [2, pg 316-318] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Yield Strength (S_y): *S_y is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{y\_125} := 28.35ksi$ — For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_125L} := 23.85ksi$ — For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

$S_{y\_167} := 26.12ksi$ — For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_167L} := 22.26ksi$ — For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-28 and 1-29 closest to reactor vessel [3, pg 23]

Maximum Strength Applicable for Equation 9 (S): *S is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{125} := \min(3 \cdot S_{m\_125}, 2 \cdot S_{y\_125})$

$S_{125} = 56.7\ \text{ksi}$

Maximum allowable stress applied to SS304 piping [9, NB-3656]

$S_{125L} := \min(3 \cdot S_{m\_125L}, 2 \cdot S_{y\_125L})$

$S_{125L} = 47.7\ \text{ksi}$

Maximum allowable stress applied to SS304L piping [9, NB-3656]

$S_{167} := \min(3 \cdot S_{m\_167}, 2 \cdot S_{y\_167})$

$S_{167} = 52.24\ \text{ksi}$

Maximum allowable stress applied to SS304 piping [9, NB-3656]

$S_{167L} := \min(3 \cdot S_{m\_167L}, 2 \cdot S_{y\_167L})$

$S_{167L} = 44.52\ \text{ksi}$

Maximum allowable stress applied to SS304L piping [9, NB-3656]

SUPPORTS

Supports Strategy: *Search based on the node for which the support acts. If this node is a termination point there will only be one node to evaluate. If this node is in line with a section of pipe there will be two representations of the same node (one for each element on each side of the node) to combine and the difference between them is the force required of the support. The D/C ratio for each support will be found by dividing the the required force found above by the support capacity.*

$$SupDC(P_r, P_c) := \frac{P_r}{P_c}$$

$$Support(nf, nd, C_o, EL) :=$$

$$ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right)$$
$$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right)$$
$$ind_{nd} \leftarrow match\left(nd_0, EL^{\langle 1 \rangle}\right)$$
$$\text{for } i \in 1..last(nd) \quad \text{if } rows(nd) > 1$$
$$\quad ind_{nd} \leftarrow stack\left[ind_{nd}, \left(match\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$$
$$\begin{pmatrix} Int1_4 & Int2_4 \end{pmatrix} \leftarrow (0 \quad 0)$$
$$\text{for } i \in 0..ind_{nfo_0} - ind_{nfi_0}$$
$$\quad \text{for } j \in 0..last\left(ind_{nd}\right)$$
$$\quad\quad P_{rg_j} \leftarrow nf_{ind_{nfi}{C_o}_{0,1} - 1,\, ind_{nd_j}}$$
$$\quad\quad P_{r_j} \leftarrow \left(nf_{ind_{nfi}{C_o}_{0,1} - 1 + i,\, ind_{nd_j}} - P_{rg_j}\right) \cdot {C_o}_{2,0} + P_{rg_j}$$
$$\quad PR_i \leftarrow \sum_{n=0}^{j} P_{r_n}$$
$$\quad \text{if } PR_i < Int1_1 \wedge {C_o}_{0,0} \neq 0$$
$$\quad\quad Int1' \leftarrow SupDC\left(\left|PR_i\right|, {C_o}_{0,0}\right)$$
$$\quad\quad Int_1 \leftarrow stack\left(Int1', PR_i, nf_{ind_{nfi}{C_o}_{0,1} - 1 + i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd}\right)$$
$$\quad \text{if } PR_i > Int2_1 \wedge {C_o}_{1,0} \neq 0$$
$$\quad\quad Int2' \leftarrow SupDC\left(\left|PR_i\right|, {C_o}_{1,0}\right)$$
$$\quad\quad Int_2 \leftarrow stack\left(Int2', PR_i, nf_{ind_{nfi}{C_o}_{0,1} - 1 + i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd}\right)$$
$$\begin{pmatrix} Int_1 & Int_2 \end{pmatrix}$$

PR-7 Supports (1x)

$P_{1\_PR7} := \frac{11.102 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_PR7} := \frac{0.01 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_PR7} := \begin{pmatrix} P_{1\_PR7} & 2 \\ P_{2\_PR7} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

PR-7 (Node 1402)

PR-7 vertically supports the vertical PCS pipe on line 1-7 below the tee connecting lines 1-7 to 1-5 & 1-6.

$nd1402_{PR7_0} := 1402$ Node associated with support

$$\left(AL1_{PR7\_nd1402} \quad AL2_{PR7\_nd1402}\right) := Support\left(NF, nd1402_{PR7}, Sup\_C_{o\_PR7}, EL\right)$$

$$AL1_{PR7\_nd1402}{}^{T} = \left(2.117 \times 10^{-5} \quad -0.235 \quad 7.23 \quad 1.402 \times 10^{3} \quad 97\right)$$

$$AL2_{PR7\_nd1402}{}^{T} = \left(8.763 \times 10^{-3} \quad 0.088 \quad 7.145 \quad 1.402 \times 10^{3} \quad 97\right)$$

[...]and force, occurrence time, [...]ode, associated Index for the reaction force at the selected node [...]he positive (AL1) and negative [...]ctions of the global coordinate system)

MS-1 Supports (1x)

$P_{1\_MS1\_NS} := \frac{30.55 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_MS1\_NS} := \frac{30.55 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_MS1\_NS} := \begin{pmatrix} P_{1\_MS1\_NS} & 1 \\ P_{2\_MS1\_NS} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

$P_{1\_MS1\_V} := \frac{30.55 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_MS1\_V} := \frac{30.55 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_MS1\_V} := \begin{pmatrix} P_{1\_MS1\_V} & 2 \\ P_{2\_MS1\_V} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

MS-1 North/South (Node 1401)

MS-1 vertically and laterally supports the vertical PCS pipe on line 1-7 above the tee connecting lines 1-7 to 1-5 & 1-6.

$$nd1401_{MS1\_NS_0} := 1401$$

Node associated with support

$$\left(AL1_{MS1\_NS\_nd1401} \quad AL2_{MS1\_NS\_nd1401}\right) := Support\left(NF, nd1401_{MS1\_NS}, Sup\_C_{o\_MS1\_NS}, EL\right)$$

$$AL1_{MS1\_NS\_nd1401}^{T} = \left(0.931 \quad -2.843\times10^{4} \quad 7.485 \quad 1.401\times10^{3} \quad 95\right)$$

$$AL2_{MS1\_NS\_nd1401}^{T} = \left(1.134 \quad 3.464\times10^{4} \quad 7.135 \quad 1.401\times10^{3} \quad 95\right)$$

force, occurrence time, associated Index for the reaction force at the selected node positive (AL1) and negative ons of the global coordinate system)

MS-1 Vertical (Node 1401)

MS-1 vertically and laterally supports the vertical PCS pipe on line 1-7 above the tee connecting lines 1-7 to 1-5 & 1-6.

$$nd1401_{MS1\_V_0} := 1401$$

Node associated with support

$$\left(AL1_{MS1\_V\_nd1401} \quad AL2_{MS1\_V\_nd1401}\right) := Support\left(NF, nd1401_{MS1\_V}, Sup\_C_{o\_MS1\_V}, EL\right)$$

$$AL1_{MS1\_V\_nd1401}^{T} = \left(0.6 \quad -1.834\times10^{4} \quad 7.135 \quad 1.401\times10^{3} \quad 95\right)$$

$$AL2_{MS1\_V\_nd1401}^{T} = \left(0.493 \quad 1.505\times10^{4} \quad 7.485 \quad 1.401\times10^{3} \quad 95\right)$$

and force, occurrence time, ode, associated Index for the reaction force at the selected node positive (AL1) and negative tions of the global coordinate system)

Tunnel Restraint Support (1x)

$$P_{1\_TR} := \frac{6.258\cdot kip}{lbf}$$

Eastward Compression

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$$P_{2\_TR} := \frac{85.842\cdot kip}{lbf}$$

Westward Compression

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_TR} := \begin{pmatrix} P_{1\_TR} & 3 \\ P_{2\_TR} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3

Tunnel Restraint (Node 1126)

Tunnel Restraint horizontally (E/W) restrains the vertical PCS pipe on line 1-27

$nd1126_{TR_0} := 1126$ Node associated with support

$\left(AL1_{TR\_nd1126} \;\; AL2_{TR\_nd1126}\right) := Support\left(NF, nd1126_{TR}, Sup\_C_{o\_TR}, EL\right)$

$AL1_{TR\_nd1126}{}^{T} = \left(2.144 \;\; -1.342\times10^{4} \;\; 5.915 \;\; 1.126\times10^{3} \;\; 91\right)$

$AL2_{TR\_nd1126}{}^{T} = \left(0.186 \;\; 1.6\times10^{4} \;\; 9.09 \;\; 1.126\times10^{3} \;\; 91\right)$

...and force, occurrence time, ...ode, associated index for the reaction force at the selected node ...g in the positive (AL1) and negative ...) directions of the global coordinate system)

RH-19x Support (1x)

$P_{1\_RH19x} := \dfrac{56.28 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_RH19x} := \dfrac{45.79kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$Sup\_C_{o\_RH19x} := \begin{pmatrix} P_{1\_RH19x} & 2 \\ P_{2\_RH19x} & 0 \\ F_a & 0 \end{pmatrix}$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3

RH-19x (Node 1113)

RH-19x vertically supports the vertical PCS pipe on line 1-7 traveling up from the reactor vessel area and into the tunnel

$nd1113_{RH19x_0} := 1113$ Node associated with support

$\left(AL1_{RH19x\_nd1113} \;\; AL2_{RH19x\_nd1113}\right) := Support\left(NF, nd1113_{RH19x}, Sup\_C_{o\_RH19x}, EL\right)$

$AL1_{RH19x\_nd1113}{}^{T} = \left(0.6 \;\; -3.375\times10^{4} \;\; 9.885 \;\; 1.113\times10^{3} \;\; 83\right)$

$AL2_{RH19x\_nd1113}{}^{T} = \left(0.175 \;\; 8.005\times10^{3} \;\; 7.145 \;\; 1.113\times10^{3} \;\; 83\right)$

...demand force, occurrence time, ...ed node, associated index for the reaction force at the selected node ...in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-20x Support (1x)

$P_{1\_RH20x} := \dfrac{56.28 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_RH20x} := \dfrac{53.862kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_RH20x} := \begin{pmatrix} P_{1\_RH20x} & 2 \\ P_{2\_RH20x} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3

RH-20x (Node 1114)

RH-20x vertically supports the horizontal PCS pipe on line 1-7 traveling north of RH-19x through the tunnel.

$nd1114_{RH20x_0} := 1114$ Node associated with support

$$\left(AL1_{RH20x\_nd1114} \quad AL2_{RH20x\_nd1114}\right) := Support\left(NF, nd1114_{RH20x}, Sup\_C_{o\_RH20x}, EL\right)$$

$$AL1_{RH20x\_nd1114}^{T} = \left(0.338 \quad -1.904\times 10^{4} \quad 8.545 \quad 1.114\times 10^{3} \quad 85\right)$$

$$AL2_{RH20x\_nd1114}^{T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0\right)$$

mand force, occurrence time, node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-21xA Supports (1x)

$$P_{1\_RH21xA} := \frac{56.28\cdot kip}{lbf}$$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$$P_{2\_RH21xA} := \frac{48.204kip}{lbf}$$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_RH21xA} := \begin{pmatrix} P_{1\_RH21xA} & 2 \\ P_{2\_RH21xA} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3

RH-21xA (Node 1117)

RH-21xA vertically supports the horizontal PCS pipe on line 1-7 traveling north of RH-20x through the tunnel.

$nd1117_{RH21xA_0} := 1117$ Node associated with support

$$\left(AL1_{RH21xA\_nd1117} \quad AL2_{RH21xA\_nd1117}\right) := Support\left(NF, nd1117_{RH21xA}, Sup\_C_{o\_RH21xA}, EL\right)$$

$$AL1_{RH21xA\_nd1117}^{T} = \left(0.24 \quad -1.351\times 10^{4} \quad 5.165 \quad 1.117\times 10^{3} \quad 87\right)$$

$$AL2_{RH21xA\_nd1117}^{T} = \left(6.251\times 10^{-3} \quad 301.327 \quad 8.06 \quad 1.117\times 10^{3} \quad 87\right)$$

mand force, occurrence time, node, associated index for the reaction force at the selected node e positive (AL1) and negative (AL2) directions of the global coordinate system)

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RH-21xB Supports (1x)

Capacity Result will be combined with the RH-26x support sharing the same embedment anchorage .

$P_{1\_RH21xB} := \frac{28.14 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_RH21xB} := \frac{48.204kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_RH21xB} := \begin{pmatrix} P_{1\_RH21xB} & 2 \\ P_{2\_RH21xB} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3

RH-21xB (Node 1123)

RH-21xB vertically supports the horizontal PCS pipe on line 1-7 traveling north of RH-21xA through the tunnel.

$nd1123_{RH21xB_0} := 1123$ Node associated with support

$$\left(AL1_{RH21xB\_nd1123} \;\; AL2_{RH21xB\_nd1123}\right) := Support\left(NF, nd1123_{RH21xB}, Sup\_C_{o\_RH21xB}, EL\right)$$

$$AL1_{RH21xB\_nd1123}^{\;T} = \left(0.892 \;\; -2.51\times10^{4} \;\; 8.53 \;\; 1.123\times10^{3} \;\; 89\right)$$

$$AL2_{RH21xB\_nd1123}^{\;T} = \left(0 \;\; 0 \;\; 0 \;\; 0 \;\; 0\right)$$

[d]emand force, occurrence time, [..]d node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-22x Supports (1x)

Capacity Result will be combined with the RH-26x support sharing the same embedment anchorage .

$P_{1\_RH22x} := \frac{28.14 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_RH22x} := \frac{0.01kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_RH22x} := \begin{pmatrix} P_{1\_RH22x} & 2 \\ P_{2\_RH22x} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3

RH-22x (Node 1120)

RH-22x vertically supports the horizontal PCS pipe on line 1-7 traveling north of RH-21xB through the tunnel.

$nd1120_{RH22xA_0} := 1120$ Node associated with support

$\left(AL1_{RH22xA\_nd1120} \;\; AL2_{RH22xA\_nd1120}\right) := Support\left(NF, nd1120_{RH22xA}, Sup\_C_{o\_RH22x}, EL\right)$

$AL1_{RH22xA\_nd1120}{}^{T} = \left(0.554 \;\; -1.559\times 10^{4} \;\; 5.215 \;\; 1.12\times 10^{3} \;\; 111\right)$

$AL2_{RH22xA\_nd1120}{}^{T} = \left(0 \;\; 0 \;\; 0 \;\; 0 \;\; 0\right)$

(…hand force, occurrence time, …ode, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

MS-6 Support (1x)

$P_{1\_MS6} := \frac{15 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_MS6} := \frac{15 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_MS6} := \begin{pmatrix} P_{1\_MS6} & 3 \\ P_{2\_MS6} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3

MS-6 (Node 1413)

MS-6 horizontally (E/W) supports the horizontal (N/S) PCS pipe on line 1-7 just south of RH-22x.

$nd1413_{MS6_0} := 1413$ Node associated with support

$\left(AL1_{MS6\_nd1413} \;\; AL2_{MS6\_nd1413}\right) := Support\left(NF, nd1413_{MS6}, Sup\_C_{o\_MS6}, EL\right)$

$AL1_{MS6\_nd1413}{}^{T} = \left(6.769\times 10^{-3} \;\; -101.538 \;\; 9.2 \;\; 1.413\times 10^{3} \;\; 101\right)$

$AL2_{MS6\_nd1413}{}^{T} = \left(5.398\times 10^{-3} \;\; 80.973 \;\; 8.145 \;\; 1.413\times 10^{3} \;\; 101\right)$

(…d force, occurrence time, …e, associated index for the reaction force at the selected node …positive (AL1) and negative …ons of the global coordinate system)

MS-3 Support (1x)

$P_{1\_MS3} := \dfrac{24.625 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_MS3} := \dfrac{24.625 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_MS3} := \begin{pmatrix} P_{1\_MS3} & 1 \\ P_{2\_MS3} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3

MS-3 (Node 1416)

MS-3 horizontally (N/S) supports the vertical PCS pipe on line 1-7 just north of RH-22x.

$nd1416_{MS3_0} := 1416$ Node associated with support

$$\left(AL1_{MS3\_nd1416} \;\; AL2_{MS3\_nd1416} \right) := Support\left(NF, nd1416_{MS3}, Sup\_C_{o\_MS3}, EL\right)$$

$$AL1_{MS3\_nd1416}{}^{T} = \left(0.597 \;\; -1.47 \times 10^{4} \;\; 7.85 \;\; 1.416 \times 10^{3} \;\; 105\right)$$

$$AL2_{MS3\_nd1416}{}^{T} = \left(0.517 \;\; 1.274 \times 10^{4} \;\; 10.08 \;\; 1.416 \times 10^{3} \;\; 105\right)$$

hand force, occurrence time, node, associated index for the reaction force at the selected node he positive (AL1) and negative ctions of the global coordinate system)

MS-4 Supports (1x)

$P_{1\_MS4\_NS} := \dfrac{15 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_MS4\_NS} := \dfrac{15 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_MS4\_NS} := \begin{pmatrix} P_{1\_MS4\_NS} & 1 \\ P_{2\_MS4\_NS} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

$P_{1\_MS4\_V} := \dfrac{15 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_MS4\_V} := \dfrac{15 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

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$$Sup\_C_{o\_MS4\_V} := \begin{pmatrix} P_{1\_MS4\_V} & 2 \\ P_{2\_MS4\_V} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

MS-4 North/South (Node 1418)

MS-4 laterally supports the T(1-7B) above the tee connecting line 1-7 to run 1-8.

$nd1418_{MS4\_NS_0} := 1418$ Node associated with support

$\left(AL1_{MS4\_NS\_nd1418} \;\; AL2_{MS4\_NS\_nd1418}\right) := Support\left(NF, nd1418_{MS4\_NS}, Sup\_C_{o\_MS4\_NS}, EL\right)$

$AL1_{MS4\_NS\_nd1418}^{T} = \left(1.855 \times 10^{-3} \;\; -27.832 \;\; 7.405 \;\; 1.418 \times 10^{3} \;\; 108\right)$

$AL2_{MS4\_NS\_nd1418}^{T} = \left(1.566 \times 10^{-3} \;\; 23.494 \;\; 7.74 \;\; 1.418 \times 10^{3} \;\; 108\right)$

(D/C,demand for]ce, occurrence time, [defined node, as]sociated Index for the reaction force at the selected node [po]sitive (AL1) and negative [axe]s of the global coordinate system)

MS-4 Vertical (Node 1418)

MS-4 vertically supports the T(1-7B) above the tee connecting line 1-7 to run 1-8.

$nd1418_{MS4\_V_0} := 1418$ Node associated with support

$\left(AL1_{MS4\_V\_nd1418} \;\; AL2_{MS4\_V\_nd1418}\right) := Support\left(NF, nd1418_{MS4\_V}, Sup\_C_{o\_MS4\_V}, EL\right)$

$AL1_{MS4\_V\_nd1418}^{T} = (0 \;\; 0 \;\; 0 \;\; 0 \;\; 0)$

$AL2_{MS4\_V\_nd1418}^{T} = \left(9.243 \times 10^{-3} \;\; 138.639 \;\; 8.45 \;\; 1.418 \times 10^{3} \;\; 108\right)$

(D/C,demand force, occurrence time, defined node, associated Index for the reaction force at the selected node [po]sitive (AL1) and negative [axe]s of the global coordinate system)

Writing Output Data for Supports Associated with Lines 1-5, 1-6, & 1-7

$SA1 := AL1_{PR7\_nd1402}^{T}$ $SD2 := AL2_{TR\_nd1126}^{T}$ $SH1 := AL1_{RH21xB\_nd1123}^{T}$ $SK2 := AL2_{MS3\_nd1416}^{T}$

$SA2 := AL2_{PR7\_nd1402}^{T}$ $SE1 := AL1_{RH19x\_nd1113}^{T}$ $SH2 := AL2_{RH21xB\_nd1123}^{T}$ $SL1 := AL1_{MS4\_NS\_nd1418}^{T}$

$SB1 := AL1_{MS1\_NS\_nd1401}^{T}$ $SE2 := AL2_{RH19x\_nd1113}^{T}$ $SI1 := AL1_{RH22xA\_nd1120}^{T}$ $SL2 := AL2_{MS4\_NS\_nd1418}^{T}$

$SB2 := AL2_{MS1\_NS\_nd1401}^{T}$ $SF1 := AL1_{RH20x\_nd1114}^{T}$ $SI2 := AL2_{RH22xA\_nd1120}^{T}$ $SM1 := AL1_{MS4\_V\_nd1418}^{T}$

$SC1 := AL1_{MS1\_V\_nd1401}^{T}$ $SF2 := AL2_{RH20x\_nd1114}^{T}$ $SJ1 := AL1_{MS6\_nd1413}^{T}$ $SM2 := AL2_{MS4\_V\_nd1418}^{T}$

$SC2 := AL2_{MS1\_V\_nd1401}^{T}$ $SG1 := AL1_{RH21xA\_nd1117}^{T}$ $SJ2 := AL2_{MS6\_nd1413}^{T}$

$SD1 := AL1_{TR\_nd1126}^{T}$ $SG2 := AL2_{RH21xA\_nd1117}^{T}$ $SK1 := AL1_{MS3\_nd1416}^{T}$

S := (SA1 SA2 SB1 SB2 SC1 SC2 SD1 SD2 SE1 SE2 SF1 SF2 SG1 SG2 SH1 SH2 SI1 SI2 SJ1 SJ2 SK1 SK2

SupportsLine1_5_6_7 := WRITEPRN("SupLine1-5_6_7.prn" , S)

PIPE RUNS

Pipe Runs Strategy: *Search based on the nodes present in each run of pipe. Find the maximum moment combination among all of the nodes and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{PipeRunDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\,\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

```
PipeRun(P, D_o, t, I, B_1, B_2, S, nf, el, C_o, EL) :=
  ind_nfi ← match(t_initial, nf^<0>)
  ind_nfo ← match(t_final, nf^<0>)
  ind_el ← match(el_0, EL^<0>)
  for i ∈ 1 .. last(el)                                      if rows(el) > 1
    ind_el ← stack[ind_el, (match(el_i, EL^<0>))]
  (M  Int_{5, last(ind_el)}) ← (0  0)
  for i ∈ 0 .. ind_nfo_0 − ind_nfi_0
    for j ∈ 0 .. last(ind_el)
      M_rxg ← nf_{ind_nfi_{Co_{0,1}}+2, ind_el_j}
      M_ryg ← nf_{ind_nfi_{Co_{1,1}}+2, ind_el_j}
      M_rzg ← nf_{ind_nfi_{Co_{2,1}}+2, ind_el_j}
      M_rx_j ← (nf_{ind_nfi_{Co_{0,1}}+2+i, ind_el_j} − M_rxg)·Co_{3,0} + M_rxg
      M_ry_j ← (nf_{ind_nfi_{Co_{1,1}}+2+i, ind_el_j} − M_ryg)·Co_{3,0} + M_ryg
      M_rz_j ← (nf_{ind_nfi_{Co_{2,1}}+2+i, ind_el_j} − M_rzg)·Co_{3,0} + M_rzg
      M'_j ← sqrt((M_rx_j)^2 + (M_ry_j)^2 + (M_rz_j)^2)
      Int'_j ← PipeRunDC(P, D_o, t, I, B_1, B_2, M'_j, S)
      if Int'_j > Int_{0,j}
        H ← (Int'_j  M'_j  nf_{ind_nfi_{Co_{0,1}}−1+i, 0}  EL_{ind_el_j, 0}  EL_{ind_el_j, 1}  ind_el_j  M_r
        for k ∈ 0 .. 5
          Int_{k,j} ← H_k
```

Int

Conditions applicable to all pipe runs

$M_{cx} := 0 \qquad M_{cy} := 0 \qquad M_{cz} := 0$

Defining place holding directional moment variables

$$PipeRun\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties for Lines 1-5 & 1-6

Note: Influence of SS304 vs. SS304L is accounted for in the function call

Define pertinent pipe variables

$D_o := 24in$ — Outside Diameter [4]

$t := 0.375in$ — Thickness [4]

$P := 272psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 1.942 \times 10^3 \, in^4$$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{cases} 1.0 & \text{if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 & \begin{array}{l} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \frac{D_o}{t}\right) \\ Y \leftarrow 1.033 - 0.00033 \cdot T \\ 1.0 \cdot \frac{1}{X \cdot Y} \end{array} \end{cases}$$

$B_{2PR} = 1.101$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-5A (Element 132 & 295)

$$el_{P15A} := (132 \quad 295)^T$$

$$AL_{P15A} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167}, NF, el_{P15A}, PipeRun\_C_o, EL)$$

$$AL_{P15A}^T = \begin{pmatrix} 0.142 & 4.513\times10^5 & 8.825 & 132 & 646 & 35 \\ 0.191 & 8.29\times10^5 & 7.135 & 132 & 925 & 36 \\ 0.247 & 1.255\times10^6 & 7.135 & 295 & 39 & 56 \\ 0.191 & 8.292\times10^5 & 7.135 & 295 & 925 & 57 \end{pmatrix}$$

Pipe Run 1-6A (Element 133 & 296)

$$el_{P16A} := (133 \quad 296)^T$$

$$AL_{P16A} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167}, NF, el_{P16A}, PipeRun\_C_o, EL)$$

$$AL_{P16A}^T = \begin{pmatrix} 0.146 & 4.797\times10^5 & 9.88 & 133 & 647 & 37 \\ 0.205 & 9.369\times10^5 & 7.03 & 133 & 926 & 38 \\ 0.25 & 1.283\times10^6 & 7.135 & 296 & 15 & 58 \\ 0.205 & 9.37\times10^5 & 7.03 & 296 & 926 & 59 \end{pmatrix}$$

Pipe Run 1-5B (Element 130 & 906)

$$el_{P15B} := (130 \quad 906)^T$$

$$AL_{P15B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167}, NF, el_{P15B}, PipeRun\_C_o, EL)$$

$$AL_{P15B}^T = \begin{pmatrix} 0.151 & 5.2\times10^5 & 9.895 & 130 & 748 & 31 \\ 0.149 & 5.014\times10^5 & 9.885 & 130 & 1.48\times10^3 & 32 \\ 0.145 & 4.713\times10^5 & 9.88 & 906 & 645 & 112 \\ 0.149 & 5.013\times10^5 & 9.885 & 906 & 1.48\times10^3 & 113 \end{pmatrix}$$

Pipe Run 1-6B (Element 131 & 907)

$$el_{P16B} := (131 \quad 907)^T$$

$$AL_{P16B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167}, NF, el_{P16B}, PipeRun\_C_o, EL)$$

$$AL_{P16B}^T = \begin{pmatrix} 0.149 & 5.047\times10^5 & 9.52 & 131 & 747 & 33 \\ 0.143 & 4.6\times10^5 & 9.525 & 131 & 1.481\times10^3 & 34 \\ 0.148 & 4.932\times10^5 & 8.845 & 907 & 644 & 114 \\ 0.143 & 4.599\times10^5 & 9.525 & 907 & 1.481\times10^3 & 115 \end{pmatrix}$$

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Pipe Properties for Lines 1-7

Define pertinent pipe variables

Note: Influence of SS304 vs. SS304L is accounted for in the function ca

$D_o := 36in$ Outside Diameter [4]

$t := 0.5in$ Thickness [4]

$P := 272psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$ Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 8.786 \times 10^3\, in^4$$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{cases} 1.0 \quad \text{if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50 \\ \quad \begin{array}{|l} T \leftarrow 125 \\ X \leftarrow 1.3 - 0.006\cdot\dfrac{D_o}{t} \\ Y \leftarrow 1.033 - 0.00033\cdot T \\ 1.0\cdot\dfrac{1}{X\cdot Y} \end{array} \end{cases}$$

$B_{2PR} = 1.162$

Stress Indices are derived from [9, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [9, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-7A (Elements 88, 922, 921, 315, 920, 919, & 87)

$$el_{P17A} := (88 \quad 922 \quad 921 \quad 315 \quad 920 \quad 919 \quad 87)^T$$

$$AL_{P17A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167}, NF, el_{P17A}, PipeRun\_C_o, EL\right)$$

$AL_{P17A}^{\,T} =$

	0	1	2	3	4	5
0	0.132	8.364·10^5	7.675	88	588	23
1	0.131	8.079·10^5	7.68	88	590	24
2	0.133	8.626·10^5	7.675	922	588	144
3	0.138	9.647·10^5	7.67	922	1.496·10^3	145
4	0.137	9.534·10^5	7.67	921	1.495·10^3	142
5	0.138	9.652·10^5	7.67	921	1.496·10^3	143
6	0.132	8.338·10^5	9.2	315	942	70
7	0.137	9.538·10^5	7.67	315	1.495·10^3	71
8	0.132	8.336·10^5	9.2	920	942	140
9	0.139	9.866·10^5	9.2	920	1.494·10^3	141
10	0.138	9.714·10^5	9.2	919	1.493·10^3	138
11	0.139	9.861·10^5	9.2	919	1.494·10^3	139
12	0.13	8.024·10^5	9.195	87	662	21
13	0.138	9.708·10^5	9.2	87	1.493·10^3	22

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Pipe Run 1-7B (Elements 769 & 86)

$el_{P17B} := (769 \;\; 86)^{T}$

$AL_{P17B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167}, NF, el_{P17B}, PipeRun\_C_o, EL)$

$$AL_{P17B}^{T} = \begin{pmatrix} 0.133 & 8.603\times10^{5} & 13.665 & 769 & 661 & 102 \\ 0.135 & 8.992\times10^{5} & 13.665 & 769 & 1.414\times10^{3} & 103 \\ 0.132 & 8.401\times10^{5} & 13.67 & 86 & 660 & 19 \\ 0.135 & 9.003\times10^{5} & 13.665 & 86 & 1.414\times10^{3} & 20 \end{pmatrix}$$

Pipe Run 1-7C (Elements 459, 766, 918, 917, 311, 916, 915, 308, 914, 913, 305, 912, 911, 302, 910, & 85)

$el_{P17C} := (459 \;\; 766 \;\; 918 \;\; 917 \;\; 311 \;\; 916 \;\; 915 \;\; 308 \;\; 914 \;\; 913 \;\; 305 \;\; 912 \;\; 911 \;\; 302 \;\; 910 \;\; 85)^{T}$

$AL_{P17C} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167}, NF, el_{P17C}, PipeRun\_C_o, EL)$

$AL_{P17C}^{T} =$

	0	1	2	3	4	5
0	0.144	$1.102\cdot10^{6}$	7.48	459	659	80
1	0.147	$1.169\cdot10^{6}$	7.48	459	$1.118\cdot10^{3}$	81
2	0.147	$1.17\cdot10^{6}$	7.48	766	$1.118\cdot10^{3}$	98
3	0.144	$1.1\cdot10^{6}$	7.48	766	$1.411\cdot10^{3}$	99
4	0.144	$1.105\cdot10^{6}$	7.48	918	$1.411\cdot10^{3}$	136
5	0.143	$1.089\cdot10^{6}$	10.24	918	$1.492\cdot10^{3}$	137
6	0.156	$1.362\cdot10^{6}$	10.24	917	$1.491\cdot10^{3}$	134
7	0.143	$1.09\cdot10^{6}$	10.24	917	$1.492\cdot10^{3}$	135
8	0.168	$1.625\cdot10^{6}$	10.235	311	939	68
9	0.156	$1.363\cdot10^{6}$	10.24	311	$1.491\cdot10^{3}$	69
10	0.168	$1.628\cdot10^{6}$	10.235	916	939	132
11	0.174	$1.755\cdot10^{6}$	10.235	916	$1.49\cdot10^{3}$	133
12	0.178	$1.841\cdot10^{6}$	10.235	915	$1.489\cdot10^{3}$	130
13	0.174	$1.755\cdot10^{6}$	10.235	915	$1.49\cdot10^{3}$	131
14	0.179	$1.869\cdot10^{6}$	10.23	308	936	66
15	0.178	$1.841\cdot10^{6}$	10.235	308	$1.489\cdot10^{3}$	67

Pipe Run 1-7D (Elements 909, 299, 908, 756, & 84)

$el_{P17D} := (909 \;\; 299 \;\; 908 \;\; 756 \;\; 84)^{T}$

$AL_{P17D} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167}, NF, el_{P17D}, PipeRun\_C_o, EL)$

$AL_{P17D}^{T} =$

	0	1	2	3	4	5
0	0.126	$7.045\cdot10^{5}$	13.42	909	658	118
1	0.128	$7.562\cdot10^{5}$	13.415	909	$1.483\cdot10^{3}$	119
2	0.144	$1.107\cdot10^{6}$	7.135	299	927	60
3	0.128	$7.555\cdot10^{5}$	13.415	299	$1.483\cdot10^{3}$	61
4	0.144	$1.107\cdot10^{6}$	7.135	908	927	116
5	0.157	$1.398\cdot10^{6}$	7.135	908	$1.482\cdot10^{3}$	117
6	0.171	$1.694\cdot10^{6}$	7.135	756	$1.399\cdot10^{3}$	92
7	0.157	$1.398\cdot10^{6}$	7.135	756	$1.482\cdot10^{3}$	93
8	0.146	$1.152\cdot10^{6}$	7.135	84	56	15
9	0.152	$1.283\cdot10^{6}$	7.135	84	$1.399\cdot10^{3}$	16

Writing Output Data for Pipe Runs Associated with Lines 1-5, 1-6, & 1-7

$PR1 := AL_{P15A}^{T}$

$PR2 := AL_{P16A}^{T}$

$PR3 := AL_{P15B}^{T}$

$PR4 := AL_{P16B}^{T}$

$PR5 := AL_{P17A}^{T}$

$PR6 := AL_{P17B}^{T}$

$PR7 := AL_{P17C}^{T}$

$PR8 := AL_{P17D}^{T}$

$P := (PR1\ \ PR2\ \ PR3\ \ PR4\ \ PR5\ \ PR6\ \ PR7\ \ PR8)$

PipeRunsLine1_5_6_7 := WRITEPRN("PRLine1_5_6_7.prn" , P)

REDUCERS

Reducers Strategy: *Search based on the nodes comprising either end of the reducers. SRSS combine the three moments of each of the four node representations (one for each element connected by the node in question). Find the maximum of the moment combinations for each element and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. It is important to not combine the data from both nodes as the geometry for each is different and (9) must be applied for each node. The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\text{ReducerDC}\left(P, D_o, t, I, B_1, B_2, M, S\right) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

$\text{Reducer}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \text{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. \text{last}(nd)$ if $\text{rows}(nd) > 1$

  $ind_{nd} \leftarrow \text{stack}\left[ind_{nd}, \left(\text{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$(M \ \ Int_0) \leftarrow (0 \ \ 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \text{last}(ind_{nd})$

    $M_{rxg} \leftarrow nf_{ind_{nfi}C_{o_{0,1}}+2,\, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi}C_{o_{1,1}}+2,\, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi}C_{o_{2,1}}+2,\, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi}C_{o_{1,1}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi}C_{o_{2,1}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow \text{ReducerDC}(P, D_o, t, I, B_1, B_2, M'_j, S)$

    if $Int'_j > Int_0$

      $Int \leftarrow \text{stack}\left(Int'_j, M'_j, nf_{ind_{nfi}C_{o_{0,1}}-1+i,\,0}, EL_{ind_{nd_j},\,1}, ind_{nd_j}, M_{rx}, M_{ry},\right.$

      $Result \leftarrow M'$

Int

Conditions applicable to all reducers

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$ Defining place holding variables

$$\text{Reducer\_C}_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Reducer Properties for Lines 1-5 & 1-6

$D_o := (36in \quad 24in)^T$ — Outside Diameter [5]

$t := (0.5in \quad 0.5in)^T$ — Thickness [5]

$P := (272psi \quad 272psi)^T$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - (D_o - 2\cdot t)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = \begin{pmatrix} 8.786\times10^3 \\ 2.549\times10^3 \end{pmatrix} in^4$$

Define primary stress indices

$$\alpha := \operatorname{atan}\left(\frac{6in}{24in}\right)$$

Angular slope of reducer [5]

$\alpha = 14.036\,deg$

$$B_1 := \begin{cases} 0.5 & \text{if } \alpha \le 30deg \\ 1.0 & \text{if } 30deg < \alpha \le 60deg \end{cases}$$

B_1 primary stress Index [9, NB-3683.7]

$B_1 = 0.5$

$B_2 := 1.0$ — B_2 primary stress Index [9, NB-3683.7]

Reducer 1-5 (Nodes 53 & 39)

$nd_{RD15\_L} := (53)^T$ — Node associated with Large end of reducer

$AL_{RD15\_L} := Reducer(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{167}, NF, nd_{RD15\_L}, Reducer\_C_o, EL)$

$AL_{RD15\_L}^{\;T} = (0.155 \quad 1.552\times10^6 \quad 7.135 \quad 53 \quad 5 \quad -1.274\times10^5 \quad 1.533\times10^6 \quad 2.003\times10^5)$

$nd_{RD15\_S} := (39)^T$ — Node associated with Small end of reducer

$AL_{RD15\_S} := Reducer(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{167}, NF, nd_{RD15\_S}, Reducer\_C_o, EL)$

$AL_{RD15\_S}^{\;T} = (0.176 \quad 1.255\times10^6 \quad 7.135 \quad 39 \quad 1 \quad 3.51\times10^4 \quad -1.248\times10^6 \quad -1.288\times10^5)$

Reducer 1-6 (Nodes 52 & 15)

$nd_{RD16\_L} := (52)^T$

$AL_{RD16\_L} := Reducer(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{167}, NF, nd_{RD16\_L}, Reducer\_C_o, EL)$

$AL_{RD16\_L}^{\;T} = (0.158 \quad 1.635\times10^6 \quad 7.135 \quad 52 \quad 12 \quad -3.763\times10^4 \quad 1.613\times10^6 \quad -2.614\times10^5)$

$nd_{RD16\_S} := (15)^T$

$AL_{RD16\_S} := Reducer(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{167}, NF, nd_{RD16\_S}, Reducer\_C_o, EL)$

$AL_{RD16\_S}^{\;T} = (0.178 \quad 1.283\times10^6 \quad 7.135 \quad 15 \quad 3 \quad 4.386\times10^4 \quad 1.27\times10^6 \quad -1.757\times10^5)$

Writing Output Data for Reducers Associated with Lines 1-5, 1-6, & 1-7

$RL1 := {AL_{RD15\_L}}^{T}$

$RS1 := {AL_{RD15\_S}}^{T}$

$RL2 := {AL_{RD16\_L}}^{T}$

$RS2 := {AL_{RD16\_S}}^{T}$

$R := (RL1 \ \ RS1 \ \ RL2 \ \ RS2)$

ReducersLine1_5_6_7 := WRITEPRN("RedLine1-5_6_7.prn" , R)

ELBOWS

Elbows Strategy: *Search based on the two nodes comprising the ends of each elbow. SRSS combine the three moments of each of the four node representations (one for each element connected by the nodes in question). Find the maximum of the four moment combinations and apply to equation (9) of ASME III, Division I - NB - 3652 [9]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{ElbowDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\,\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Elbow}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(nd)$ if $\mathrm{rows}(nd) > 1$

  $ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$(M \;\; Int_0) \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \mathrm{last}(ind_{nd})$

    $M_{rxg} \leftarrow nf_{ind_{nfi}{C_o}_{0,1}+2,\, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi}{C_o}_{1,1}+2,\, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi}{C_o}_{2,1}+2,\, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi}{C_o}_{0,1}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot {C_o}_{3,0} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi}{C_o}_{1,1}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot {C_o}_{3,0} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi}{C_o}_{2,1}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot {C_o}_{3,0} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow \mathrm{ElbowDC}(P, D_o, t, I, B_1, B_2, M'_j, S)$

    if $Int'_j > Int_0$

      $Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfi}{C_o}_{0,1}-1+i,0}, EL_{ind_{nd_j},1}, ind_{nd_j}, M_{rx}, M_{ry}, M\right.$

      $Result \leftarrow M'$

Int

Conditions applicable to all elbows

$M_{ox} := 0 \quad M_{oy} := 0 \quad M_{oz} := 0$

Defining place holding variables

$$Elb\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Elbow Properties for Lines 1-5 & 1-6

Define pertinent elbow variables

$D_o := 20in$ — Outside Diameter [4]

$t := 0.312in$ — Thickness [4]

$P := 272psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

$I = 935.251\ in^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$R := 1.5\cdot D_o$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$

Mean pipe radius

Define primary stress indices

$$h := \frac{t\cdot R}{r_m^{\,2}}$$

$h = 0.097$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4\cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4\cdot h > 0.5 \\ -0.1 + 0.4\cdot h & \text{otherwise} \end{cases}$$

$B_1 = 0$ — B_1 primary stress Index [9, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 6.175$ — B_2 primary stress Index [9, NB-3683.7]

Elbow 1-5 (Nodes 645 & 646)

$nd_{EL15\_1} := (645)^T$

$AL_{EL15\_nd645} := \mathrm{Elbow}\left(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL15\_1}, Elb\_C_o, EL\right)$

$AL_{EL15\_nd645}{}^T = \left(0.596 \quad 4.713\times10^5 \quad 9.88 \quad 645 \quad 112 \quad -9.354\times10^4 \quad 4.219\times10^5 \quad -1.881\times10^5\right)$

$nd_{EL15\_2} := (646)^T$

$AL_{EL15\_nd646} := \mathrm{Elbow}\left(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL15\_2}, Elb\_C_o, EL\right)$

$AL_{EL15\_nd646}{}^T = \left(0.57 \quad 4.513\times10^5 \quad 8.825 \quad 646 \quad 40 \quad 1.771\times10^5 \quad -3.503\times10^5 \quad 2.228\times10^5\right)$

Elbow 1-6 (Nodes 644 & 647)

$nd_{EL15\_1} := (644)^T$

$AL_{EL15\_nd644} := \mathrm{Elbow}\left(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL15\_1}, Elb\_C_o, EL\right)$

$AL_{EL15\_nd644}{}^T = \left(0.623 \quad 4.932\times10^5 \quad 8.845 \quad 644 \quad 42 \quad -5.808\times10^4 \quad 4.614\times10^5 \quad 1.644\times10^5\right)$

$nd_{EL15\_2} := (647)^T$

$AL_{EL15\_nd647} := \mathrm{Elbow}\left(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL15\_2}, Elb\_C_o, EL\right)$

$AL_{EL15\_nd647}{}^T = \left(0.606 \quad 4.797\times10^5 \quad 9.88 \quad 647 \quad 37 \quad 2.029\times10^5 \quad -3.411\times10^5 \quad -2.694\times10^5\right)$

Elbow Properties for Lines 1-7

Define pertinent elbow variables

$D_o := 36in$ — Outside Diameter [4]

$t := 0.5in$ — Thickness [4]

$P := 272psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o{}^4 - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 8.786\times10^3\,in^4$

$R := 1\cdot D_o$ — Nominal bend radius of curved pipe or elbow

$r_m := \dfrac{D_o - t}{2}$ — Mean pipe radius

Define primary stress indices

$h := \frac{t \cdot R}{r_m^2}$ $h = 0.057$ Characteristic bend parameter of a curved pipe or butt welding elbow

$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h > 0.5 \\ -0.1 + 0.4 \cdot h & \text{otherwise} \end{cases}$ $B_1 = 0$ B_1 primary stress Index [9, NB-3683.7]

$B_2 := \begin{cases} 1.0 & \text{if } \frac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \frac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$ $B_2 = 8.764$ B_2 primary stress Index [9, NB-3683.7]

Elbow 1-7A (Nodes 586 & 590)

This 36" elbow also has a 6" branch extending at a 45 degree angle and is also analysed as a branch in the unlisted components sub appendix.

$nd_{EL17A\_1} := (586)^T$

$AL_{EL17A\_nd586} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL17A\_1}, Elb\_C_o, EL)$

$AL_{EL17A\_nd586}^T = (0.276 \quad 8.027 \times 10^5 \quad 7.705 \quad 586 \quad 25 \quad 5.091 \times 10^4 \quad -7.516 \times 10^5 \quad 2.772 \times 10^5)$

$nd_{EL17A\_2} := (590)^T$

$AL_{EL17A\_nd590} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL17A\_2}, Elb\_C_o, EL)$

$AL_{EL17A\_nd590}^T = (0.278 \quad 8.079 \times 10^5 \quad 7.68 \quad 590 \quad 24 \quad -3.748 \times 10^5 \quad 6.817 \times 10^5 \quad -2.181 \times 10^5)$

Elbow 1-7B (Nodes 662 & 661)

$nd_{EL17B\_1} := (662)^T$

$AL_{EL17B\_nd662} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL17B\_1}, Elb\_C_o, EL)$

$AL_{EL17B\_nd662}^T = (0.276 \quad 8.024 \times 10^5 \quad 9.195 \quad 662 \quad 21 \quad 7.454 \times 10^5 \quad -1.025 \times 10^5 \quad 2.789 \times 10^5)$

$nd_{EL17B\_2} := (661)^T$

$AL_{EL17B\_nd661} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL17B\_2}, Elb\_C_o, EL)$

$AL_{EL17B\_nd661}^T = (0.296 \quad 8.603 \times 10^5 \quad 13.665 \quad 661 \quad 102 \quad 2.957 \times 10^5 \quad -6.417 \times 10^5 \quad -4.909 \times 10^5)$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

Elbow 1-7C (Nodes 660 & 659)

$nd_{EL17C\_1} := (660)^T$

$AL_{EL17C\_nd660} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL17C\_1}, Elb\_C_o, EL)$

$AL_{EL17C\_nd660}^T = (0.289 \quad 8.402\times10^5 \quad 13.67 \quad 660 \quad 49 \quad -1.809\times10^4 \quad -6.457\times10^5 \quad -5.372\times10^5)$

$nd_{EL17C\_2} := (659)^T$

$AL_{EL17C\_nd659} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL17C\_2}, Elb\_C_o, EL)$

$AL_{EL17C\_nd659}^T = (0.379 \quad 1.102\times10^6 \quad 7.48 \quad 659 \quad 80 \quad -1.478\times10^5 \quad 1.86\times10^5 \quad 1.077\times10^6)$

Elbow 1-7D (Nodes 657 & 658)

$nd_{EL17D\_1} := (657)^T$

$AL_{EL17D\_nd657} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL17D\_1}, Elb\_C_o, EL)$

$AL_{EL17D\_nd657}^T = (0.253 \quad 7.369\times10^5 \quad 8.885 \quad 657 \quad 45 \quad -4.981\times10^5 \quad 5.428\times10^5 \quad 1.532\times10^4)$

$nd_{EL17D\_2} := (658)^T$

$AL_{EL17D\_nd658} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL17D\_2}, Elb\_C_o, EL)$

$AL_{EL17D\_nd658}^T = (0.242 \quad 7.048\times10^5 \quad 13.42 \quad 658 \quad 46 \quad -2.67\times10^5 \quad 6.511\times10^5 \quad -3.891\times10^4)$

Writing Output Data for Elbows Associated with Lines 1-5, 1-6, & 1-7

$EL1A := AL_{EL15\_nd645}^T$ $\quad EL4A := AL_{EL17B\_nd662}^T$

$EL1B := AL_{EL15\_nd646}^T$ $\quad EL4B := AL_{EL17B\_nd661}^T$

$EL2A := AL_{EL15\_nd644}^T$ $\quad EL5A := AL_{EL17C\_nd660}^T$

$EL2B := AL_{EL15\_nd647}^T$ $\quad EL5B := AL_{EL17C\_nd659}^T$

$EL3A := AL_{EL17A\_nd586}^T$ $\quad EL6A := AL_{EL17D\_nd657}^T$

$EL3B := AL_{EL17A\_nd590}^T$ $\quad EL6B := AL_{EL17D\_nd658}^T$

vEL := (EL1A EL1B EL2A EL2B EL3A EL3B EL4A EL4B EL5A EL5B EL6A EL6B)

ElbowLine1_5_6_7 := WRITEPRN("ElbowLine1-5_6_7.prn" , vEL)

FORGED TEES AND FABRICATED BRANCH TEES

Tees Strategy: *Search based on the elements comprising the tee. The input identifies which elements are associated with the pipe run and which element is associated with the branch from the run. The indices for the defined common node for all three elements is identified and the associated SRSS moment is identified for each time step. The maximum moment for the elements comprising the pipe run is found and applied as M_r in equation (9) of ASME III, Division I - NB - 3652 which is modified to represent tees. The maximum moment for the branch element is found and applied as M_b in equation (9) of ASME III, Division I - NB - 3652 [9]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\text{TeeDC}(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_b, M_r, Z_b, Z_r, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot T_r} + B_{2b} \cdot \left[\frac{M_b \cdot (1\text{lbf} \cdot \text{in})}{Z_b}\right] + B_{2r} \cdot \left[\frac{M_r \cdot (1\text{lbf} \cdot \text{in})}{Z_r}\right]}{S}$$

$$\text{Tee}(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S, nf, el_R, el_B, nd_R, nd_B, C_o, EL) :=$$

$$ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$$
$$ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$$
$$ind_{elR} \leftarrow \text{match}\left(el_{R_0}, EL^{\langle 0 \rangle}\right)$$
$$\text{for } i \in 1..\text{last}(el_R) \quad \text{if rows}$$
$$\quad ind_{elR} \leftarrow \text{stack}\left[ind_{elR}, \left(\text{match}\left(el_{R_i}, EL^{\langle 0 \rangle}\right)\right)\right]$$
$$EL'R_{\text{last}\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$$
$$\text{for } i \in 0..\text{last}(ind_{elR})$$
$$\quad EL'R_{ind_{elR_i}} \leftarrow EL_{ind_{elR_i}, 1}$$
$$ind_{ndR} \leftarrow \text{match}\left(nd_{R_0}, EL'R^{\langle 0 \rangle}\right)$$
$$\text{for } i \in 1..\text{last}(nd_R) \quad \text{if r}$$
$$\quad ind_{ndR} \leftarrow \text{stack}\left[ind_{ndR}, \left(\text{match}\left(nd_{R_i}, EL'R^{\langle 0 \rangle}\right)\right)\right]$$
$$ind_{elB} \leftarrow \text{match}\left(el_{B_0}, EL^{\langle 0 \rangle}\right)$$
$$\text{for } i \in 1..\text{last}(el_B) \quad \text{if rows}$$
$$\quad ind_{elB} \leftarrow \text{stack}\left[ind_{elB}, \left(\text{match}\left(el_{B_i}, EL^{\langle 0 \rangle}\right)\right)\right]$$
$$EL'B_{\text{last}\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$$
$$\text{for } i \in 0..\text{last}(ind_{elB})$$
$$\quad EL'B_{ind_{elB_i}} \leftarrow EL_{ind_{elB_i}, 1}$$
$$ind_{ndB} \leftarrow \text{match}\left(nd_{B_0}, EL'B^{\langle 0 \rangle}\right)$$

for $i \in 1 .. \text{last}(nd_B)$ if r

$ind_{ndB} \leftarrow \text{stack}\left[ind_{ndB}, \left(\text{match}\left(nd_{B_i}, EL'B^{\langle 0 \rangle}\right)\right)\right]$

$(M_R \;\; M_B \;\; Int_0) \leftarrow (0 \;\; 0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

for $j \in 0 .. \text{last}(ind_{ndR})$

for $k \in 0 .. \text{last}(ind_{ndB})$

$M_{rxgR_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{ndR_j}}$

$M_{rygR_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{ndR_j}}$

$M_{rzgR_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{ndR_j}}$

$M_{rxR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{ndR_j}} - M_{rxgR_j}\right) \cdot C$

$M_{ryR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{ndR_j}} - M_{rygR_j}\right) \cdot C$

$M_{rzR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{ndR_j}} - M_{rzgR_j}\right) \cdot C$

$M_{R_j} \leftarrow \sqrt{\left(M_{rxR_j}\right)^2 + \left(M_{ryR_j}\right)^2 + \left(M_{rzR_j}\right)^2}$

$M_{rxgB_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{ndB_k}}$

$M_{rygB_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{ndB_k}}$

$M_{rzgB_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{ndB_k}}$

$M_{rxB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{ndB_k}} - M_{rxgB_j}\right) \cdot C$

$M_{ryB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{ndB_k}} - M_{rygB_j}\right) \cdot C$

$M_{rzB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{ndB_k}} - M_{rzgB_j}\right) \cdot C$

$M_{B_j} \leftarrow \sqrt{\left(M_{rxB_j}\right)^2 + \left(M_{ryB_j}\right)^2 + \left(M_{rzB_j}\right)^2}$

$Int'_j \leftarrow \text{TeeDC}(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_{B_j}, M_R$

if $Int'_j > Int_0$

$Int \leftarrow \text{stack}(Int'_j, M_{R_j}, M_{B_j}, nf_{ind_{nfiC_{o_{0,1}}}-1+i}$

$$\text{Result} \leftarrow \text{stack}\left(M_{R_j}, M_{B_j}, M_{rxR_j}, M_{ryR_j}, M\right.$$
$$M \leftarrow M_R$$
Int

Conditions applicable to forged tee

$M_{cx} := 0$ $M_{cy} := 0$ $M_{cz} := 0$

Defining place holding directional moment variables

$$Tee\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

FORGED TEES (LINE 1-7)

Define pertinent tee variables

$P := 272\text{psi}$ — Internal Pressure [3, pg 23]

$D_o := 36\text{in}$ — Outside Diameter [10]

$d_o := 36\text{in}$ — Outside Diameter of branch [10]

$B_1 := 0.5$ — B_1 primary stress Index for tees and branches [9, NB-3683.9]

$T_r := 1.375\text{in}$ — Nominal wall thickness of designated run pipe [14]

$$R_m := \frac{D_o - T_r}{2}$$

Mean radius of designated run pipe [10]

$$Z_r := \pi \cdot R_m^{\,2} \cdot T_r$$

Approximate section modulus of designated run pipe [9, NB-3683.1(d)]

$$Z_r = 1.2947 \times 10^3\ \text{in}^3$$

$$B_{2b} := \begin{cases} 0.4 \cdot \left(\dfrac{R_m}{T_r}\right)^{\frac{2}{3}} & \text{if } 0.4 \cdot \left(\dfrac{R_m}{T_r}\right)^{\frac{2}{3}} > 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Index for tees and branches [9, NB-3683.9]

$$B_{2b} = 2.165$$

$T'_b := 1.375\text{in}$ — Nominal wall thickness of attached branch pipe [14]

$$r'_m := \frac{d_o - T'_b}{2}$$

Mean radius of attached branch pipe [10]

$Z_b := \pi \cdot r'_m{}^2 \cdot T'_b$

Approximate section modulus of attached branch pipe [9, NB-3683.1(d)]

$Z_b = 1.295 \times 10^3\ in^3$

$$B_{2r} := \begin{cases} 0.5 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} & \text{if } 0.5 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} > 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Index for tees and branches [9, NB-3683.9]

$B_{2r} = 2.706$

Tee 1-7A (Node 591)

$elR_{Tee17A} := (90\ \ 91)^T$ Elements associated with pipe run

$ndR_{Tee17A} := (591)^T$ Node between pipe run elements

$elB_{Tee17A} := (89)^T$ Element associated with branch

$ndB_{Tee17A} := (591)^T$ Node where branch intersects pipe run

$AL_{Tee17A} := Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{167}, NF, elR_{Tee17A}, elB_{Tee17A}, ndR_{Tee17A}, ndB_{Tee17A}, Tee$

$AL_{Tee17A}{}^T = (0.1\ \ 1.033 \times 10^6\ \ 7.768 \times 10^5\ \ 9.21\ \ 591\ \ 27\ \ 29\ \ 26)$

Tee 1-7B (Node 51)

$elR_{Tee17A} := (59\ \ 60)^T$ Elements associated with pipe run

$ndR_{Tee17A} := (51)^T$ Node between pipe run elements

$elB_{Tee17A} := (61)^T$ Element associated with branch

$ndB_{Tee17A} := (51)^T$ Node where branch intersects pipe run

$AL_{Tee17A} := Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{167}, NF, elR_{Tee17A}, elB_{Tee17A}, ndR_{Tee17A}, ndB_{Tee17A}, Tee$

$AL_{Tee17A}{}^T = (0.13\ \ 2.006 \times 10^6\ \ 4.928 \times 10^5\ \ 7.135\ \ 51\ \ 9\ \ 11\ \ 13)$

Writing Output Data for Tees Associated with Lines 1-5, 1-6, & 1-7

$T1 := AL_{Tee17A}{}^T$

$T2 := AL_{Tee17A}{}^T$

$vT := (T1\ \ T2)$

TeeLine1_5_6_7 := WRITEPRN("TeeLine1-5_6_7.prn" , vT)

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

Appendix D.3.3

Demand to Capacity Ratio Calculations for Components Associated with Lines 1-8, 1-9, 1-10, 1-11, 1-12, and 1-170 of ATR PCS Model 1-4

(NOTE: Values represented here are shown for one realization (Nodal Force file = LINE1-8_9_10_11_12_170_test_R1.dat and Element/Nodal order file = EL1-8_9_10_11_12_170_.xls) and may or may not be consistent with the 80th percentile results contained in Appendix D.4)

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

Force Outputs from Abaqus

$NF :=$ ..\LINE1-8_9_10_11_12_170.da — (N)odal (F)orces for Model 1-4

Defined Elemental and Corresponding Nodal Order

$EL :=$.\EL_8_9_10_11_12_170(9-22-08).xl — Element and corresponding nodal order for Model 1-4

Time Boundaries

$t_{initial} := 1$ — Initial time for which dynamic loading is applied

$t_{final} := 21$ — Final time for which dynamic loading stops

Seismic Scale Factor (F_a)

$F_a := 1$ — Seismic scale factor [9]

Allowable Design Stress Intensity Factor (S_m): *S_m is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{m\_125} := 20ksi$ — For SS304 at 125°F [2, pg 316-318] [3, pg 23]

$S_{m\_125L} := 16.7ksi$ — For SS304L at 125°F [2, pg 316-318] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

$S_{m\_167} := 20ksi$ — For SS304 at 167°F [2, pg 316-318] [3, pg 23]

$S_{m\_167L} := 16.7ksi$ — For SS304L at 167°F [2, pg 316-318] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

Yield Strength (S_y): *S_y is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{y\_125} := 28.35ksi$ — For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_125L} := 23.85ksi$ — For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

$S_{y\_167} := 26.12ksi$ — For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_167L} := 22.26ksi$ — For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

Maximum Strength Applicable for Equation 9 (S): *S is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{125} := \min(3 \cdot S_{m\_125}, 2 \cdot S_{y\_125})$

$S_{125} = 56.7\,\text{ksi}$

Maximum allowable stress applied to SS304 piping [4, NB-3656]

$S_{125L} := \min(3 \cdot S_{m\_125L}, 2 \cdot S_{y\_125L})$

$S_{125L} = 47.7\,\text{ksi}$

Maximum allowable stress applied to SS304L piping [4, NB-3656]

$S_{167} := \min(3 \cdot S_{m\_167}, 2 \cdot S_{y\_167})$

$S_{167} = 52.24\,\text{ksi}$

Maximum allowable stress applied to SS304 piping [4, NB-3656]

$S_{167L} := \min(3 \cdot S_{m\_167L}, 2 \cdot S_{y\_167L})$

$S_{167L} = 44.52\,\text{ksi}$

Maximum allowable stress applied to SS304L piping [4, NB-3656]

SUPPORTS

Supports Strategy: *Search based on the node for which the support acts. If this node is a termination point there will only be one node to evaluate. If this node is in line with a section of pipe there will be two representations of the same node (one for each element on each side of the node) to combine and the difference between them is the force required of the support. The D/C ratio for each support will be found by dividing the the required force found above by the support capacity.*

$$\mathrm{SupDC}(P_r, P_c) := \frac{P_r}{P_c}$$

$$\mathrm{Support}(nf, nd, C_o, EL) :=$$

$$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$$

$$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$$

$$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$$

$$\text{for } i \in 1 .. \mathrm{last}(nd) \qquad \text{if } \mathrm{rows}(nd) > 1$$

$$\quad ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$$

$$\begin{pmatrix} Int1_4 & Int2_4 \end{pmatrix} \leftarrow (0 \quad 0)$$

$$\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$$

$$\quad \text{for } j \in 0 .. \mathrm{last}\left(ind_{nd}\right)$$

$$\quad\quad P_{rg_j} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}} - 1,\, ind_{nd_j}}$$

$$\quad\quad P_{r_j} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}} - 1 + i,\, ind_{nd_j}} - P_{rg_j}\right) \cdot C_{o_{2,0}} + P_{rg_j}$$

$$\quad PR_i \leftarrow \sum_{n=0}^{j} P_{r_n}$$

$$\quad \text{if } PR_i < Int1_1 \wedge C_{o_{0,0}} \neq 0$$

$$\quad\quad Int1' \leftarrow \mathrm{SupDC}\left(\left|PR_i\right|, C_{o_{0,0}}\right)$$

$$\quad\quad Int1 \leftarrow \mathrm{stack}\left(Int1', PR_i, nf_{ind_{nfi_{C_{o_{0,1}}}} - 1 + i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd}\right)$$

$$\quad \text{if } PR_i > Int2_1 \wedge C_{o_{1,0}} \neq 0$$

$$\quad\quad Int2' \leftarrow \mathrm{SupDC}\left(\left|PR_i\right|, C_{o_{1,0}}\right)$$

$$\quad\quad Int2 \leftarrow \mathrm{stack}\left(Int2', PR_i, nf_{ind_{nfi_{C_{o_{0,1}}}} - 1 + i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd}\right)$$

$$\begin{pmatrix} Int1 & Int2 \end{pmatrix}$$

PS-20b Support (1x)

$$P_{1\_PS20b} := \frac{155.021 \cdot kip}{lbf}$$

Compression

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$$P_{2\_PS20b} := \frac{14.07 \cdot kip}{lbf}$$

Tension

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_PS20b} := \begin{pmatrix} P_{1\_PS20b} & 2 \\ P_{2\_PS20b} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

PS-20b (Node 1105)

PS-20b vertically supports EL(1-170A) on line 1-170.

$$nd1105_{PS20b_0} := 1105$$

Node associated with support

$$\left(AL1_{PS20b\_nd1105} \quad AL2_{PS20b\_nd1105}\right) := Support\left(NF, nd1105_{PS20b}, Sup\_C_{o\_PS20b}, EL\right)$$

$$AL1_{PS20b\_nd1105}{}^{T} = \left(0.11 \quad -1.705 \times 10^{4} \quad 7.715 \quad 1.105 \times 10^{3} \quad 110\right)$$

$$AL2_{PS20b\_nd1105}{}^{T} = \left(0.423 \quad 5.948 \times 10^{3} \quad 13.24 \quad 1.105 \times 10^{3} \quad 110\right)$$

emand force, occurrence time, node, associated index for the reaction force at the selected node n the positive (AL1) and negative directions of the global coordinate system)

PS-8 Support (4x)

$$P_{1\_PS8} := \frac{75.565 \cdot kip}{lbf}$$

Compression

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$$P_{2\_PS8} := \frac{14.07 \cdot kip}{lbf}$$

Tension

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_PS8} := \begin{pmatrix} P_{1\_PS8} & 2 \\ P_{2\_PS8} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

PS-8E (Node 1106)

PS-8E vertically supports EL(1-9A) on line 1-9.

$$nd1106_{PS8E_0} := 1106$$

Node associated with support

$$\left(AL1_{PS8E\_nd1106} \quad AL2_{PS8E\_nd1106}\right) := Support\left(NF, nd1106_{PS8E}, Sup\_C_{o\_PS8}, EL\right)$$

$$AL1_{PS8E\_nd1106}{}^{T} = \left(0.32 \quad -2.415 \times 10^{4} \quad 13.615 \quad 1.106 \times 10^{3} \quad 112\right)$$

$$AL2_{PS8E\_nd1106}{}^{T} = \left(0.769 \quad 1.083 \times 10^{4} \quad 13.28 \quad 1.106 \times 10^{3} \quad 112\right)$$

(D/C demand force, occurrence time, node, associated index for the reaction force at the selected node being in the positive (AL1) and negative directions of the global coordinate system)

PS-8F (Node 1107)

PS-8F vertically supports EL(1-10A) on line 1-10.

$nd1107_{PS8F_0} := 1107$ Node associated with support

$\left(AL1_{PS8F\_nd1107} \;\; AL2_{PS8F\_nd1107}\right) := Support\left(NF, nd1107_{PS8F}, Sup\_C_{o\_PS8}, EL\right)$

$AL1_{PS8F\_nd1107}{}^{T} = \left(0.32 \;\; -2.416\times10^{4} \;\; 9.875 \;\; 1.107\times10^{3} \;\; 114\right)$

$AL2_{PS8F\_nd1107}{}^{T} = \left(0.707 \;\; 9.946\times10^{3} \;\; 10.19 \;\; 1.107\times10^{3} \;\; 114\right)$

lemand force, occurrence time, d node, associated index for the reaction force at the selected node in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PS-8G (Node 1108)

PS-8G vertically supports EL(1-11A) on line 1-11.

$nd1108_{PS8G_0} := 1108$ Node associated with support

$\left(AL1_{PS8G\_nd1108} \;\; AL2_{PS8G\_nd1108}\right) := Support\left(NF, nd1108_{PS8G}, Sup\_C_{o\_PS8}, EL\right)$

$AL1_{PS8G\_nd1108}{}^{T} = \left(0.383 \;\; -2.897\times10^{4} \;\; 13.62 \;\; 1.108\times10^{3} \;\; 116\right)$

$AL2_{PS8G\_nd1108}{}^{T} = \left(0.816 \;\; 1.148\times10^{4} \;\; 13.295 \;\; 1.108\times10^{3} \;\; 116\right)$

mand force, occurrence time, node, associated index for the reaction force at the selected node the positive (AL1) and negative irections of the global coordinate system)

PS-8H (Node 1109)

PS-8H vertically supports EL(1-12A) on line 1-12.

$nd1109_{PS8H_0} := 1109$ Node associated with support

$\left(AL1_{PS8H\_nd1109} \;\; AL2_{PS8H\_nd1109}\right) := Support\left(NF, nd1109_{PS8H}, Sup\_C_{o\_PS8}, EL\right)$

$AL1_{PS8H\_nd1109}{}^{T} = \left(0.311 \;\; -2.353\times10^{4} \;\; 8.405 \;\; 1.109\times10^{3} \;\; 118\right)$

$AL2_{PS8H\_nd1109}{}^{T} = \left(1.013 \;\; 1.426\times10^{4} \;\; 10.24 \;\; 1.109\times10^{3} \;\; 118\right)$

mand force, occurrence time, node, associated index for the reaction force at the selected node n the positive (AL1) and negative (AL2) directions of the global coordinate system)

MS-4 Supports (1x)

Results will be SRSS combined in compolation file in order to identify axial D/C ratios.

$P_{1\_MS4\_NS} := \frac{15 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_MS4\_NS} := \frac{15 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_MS4\_NS} := \begin{pmatrix} P_{1\_MS4\_NS} & 1 \\ P_{2\_MS4\_NS} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

$$P_{1\_MS4\_V} := \frac{15 \cdot kip}{lbf}$$

Compression

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$$P_{2\_MS4\_V} := \frac{15 \cdot kip}{lbf}$$

Tension

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_MS4\_V} := \begin{pmatrix} P_{1\_MS4\_V} & 2 \\ P_{2\_MS4\_V} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

MS-4 North/South (Node 1418)

MS-4 vertically and laterally supports the east side of T(1-7A)

$$nd1418_{MS4\_NS_0} := 1418$$

Node associated with support

$$\left(AL1_{MS4\_NS\_nd1418} \;\; AL2_{MS4\_NS\_nd1418}\right) := Support\left(NF, nd1418_{MS4\_NS}, Sup\_C_{o\_MS4\_NS}, EL\right)$$

$$AL1_{MS4\_NS\_nd1418}^{T} = \left(1.855 \times 10^{-3} \;\; -27.832 \;\; 7.405 \;\; 1.418 \times 10^{3} \;\; 123\right)$$

$$AL2_{MS4\_NS\_nd1418}^{T} = \left(1.566 \times 10^{-3} \;\; 23.494 \;\; 7.74 \;\; 1.418 \times 10^{3} \;\; 123\right)$$

ce, occurrence time, sociated Index for the reaction force at the selected node sitive (AL1) and negative s of the global coordinate system)

MS-4 Vertical (Node 1418)

MS-4 vertically and laterally supports the east side of T(1-7A)

$$nd1418_{MS4\_V_0} := 1418$$

Node associated with support

$$\left(AL1_{MS4\_V\_nd1418} \;\; AL2_{MS4\_V\_nd1418}\right) := Support\left(NF, nd1418_{MS4\_V}, Sup\_C_{o\_MS4\_V}, EL\right)$$

$$AL1_{MS4\_V\_nd1418}^{T} = \left(0 \;\; 0 \;\; 0 \;\; 0 \;\; 0\right)$$

(D/C,demand force, occurrence time, defined node, associated Index for the reaction force at the selected node

$$AL2_{MS4\_V\_nd1418}^{T} = \left(9.243 \times 10^{-3} \;\; 138.639 \;\; 8.45 \;\; 1.418 \times 10^{3} \;\; 123\right)$$

sitive (AL1) and negative s of the global coordinate system)

Writing Output Data for Supports Associated with Lines 1-8, 1-9, 1-10, 1-11, 1-12, & 1-17

$SA1 := AL1_{PS20b\_nd1105}{}^{T}$

$SA2 := AL2_{PS20b\_nd1105}{}^{T}$

$SB1 := AL1_{PS8E\_nd1106}{}^{T}$

$SB2 := AL2_{PS8E\_nd1106}{}^{T}$

$SC1 := AL1_{PS8F\_nd1107}{}^{T}$

$SC2 := AL2_{PS8F\_nd1107}{}^{T}$

$SD1 := AL1_{PS8G\_nd1108}{}^{T}$

$SD2 := AL2_{PS8G\_nd1108}{}^{T}$

$SE1 := AL1_{PS8H\_nd1109}{}^{T}$

$SE2 := AL2_{PS8H\_nd1109}{}^{T}$

$SF1 := AL1_{MS4\_NS\_nd1418}{}^{T}$

$SF2 := AL2_{MS4\_NS\_nd1418}{}^{T}$

$SG1 := AL1_{MS4\_V\_nd1418}{}^{T}$

$SG2 := AL2_{MS4\_V\_nd1418}{}^{T}$

$S := (SA1\ \ SA2\ \ SB1\ \ SB2\ \ SC1\ \ SC2\ \ SD1\ \ SD2\ \ SE1\ \ SE2\ \ SF1\ \ SF2\ \ SG1\ \ SG2)$

SupportsLine1_8_9_10_11_12_170 := WRITEPRN("SupLine1-8_9_10_11_12_170.prn" , S)

TERMINATION LOCATIONS

Termination Locations Strategy: *Search based on the node for which the termination location acts as well as the next node inward. The D/C ratio for each termination location will be found by dividing the the required force found above by the support capacity.*

$$\mathrm{TermDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Term}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

```
ind_nfi ← match(t_initial, nf^<0>)
ind_nfo ← match(t_final, nf^<0>)
ind_nd ← match(nd_0, EL^<1>)
for i ∈ 1 .. last(nd)                                     if rows(nd) > 1
   ind_nd ← stack[ind_nd, (match(nd_i, EL^<1>))]
(M  Int_0) ← (0  0)
for i ∈ 0 .. ind_nfo_0 − ind_nfi_0
   for j ∈ 0 .. last(ind_nd)
      M_rxg ← nf_(ind_nfiC_o_(0,1)+2, ind_nd_j)
      M_ryg ← nf_(ind_nfiC_o_(1,1)+2, ind_nd_j)
      M_rzg ← nf_(ind_nfiC_o_(2,1)+2, ind_nd_j)
      M_rx ← (nf_(ind_nfiC_o_(0,1)+2+i, ind_nd_j) − M_rxg)·C_o_(3,0) + M_rxg
      M_ry ← (nf_(ind_nfiC_o_(1,1)+2+i, ind_nd_j) − M_ryg)·C_o_(3,0) + M_ryg
      M_rz ← (nf_(ind_nfiC_o_(2,1)+2+i, ind_nd_j) − M_rzg)·C_o_(3,0) + M_rzg
      M'_j ← sqrt(M_rx^2 + M_ry^2 + M_rz^2)
      Int'_j ← TermDC(P, D_o, t, I, B_1, B_2, M'_j, S)
      if Int'_j > Int_0
         Int ← stack(Int'_j, M'_j, nf_(ind_nfiC_o_(0,1)−1+i, 0), EL_(ind_nd_j, 1), ind_nd_j, M_rx, M_ry, M_r
         Result ← M'
Int
```

Conditions applicable to all terminations

$M_{cx} := 0 \qquad M_{cy} := 0 \qquad M_{cz} := 0$

Defining place holding variables

$$Term\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Heat Exchanger Outlet (5x)

Define pertinent pipe variables

$D_o := 20in$ — Outside Diameter [12,13,14]

$t := 0.312in$ — Thickness [12,13,14]

$P := 272psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - (D_o - 2 \cdot t)^4\right]}{64}$$

$I = 935.251\ in^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$S := S_{167}$ — Allowable design stress intensity value

Define primary stress indices

$B_1 := 0.5$

$$B_2 := \left| \begin{array}{l} 1.0 \ \text{ if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 \\ \quad \left| \begin{array}{l} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \frac{D_o}{t}\right) \\ Y \leftarrow 1 \\ 1.0 \cdot \frac{1}{X \cdot Y} \end{array} \right. \end{array} \right.$$

$B_2 = 1.092$

Stress Indices are derived from [4, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [4, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Heat Exchanger 1-9 (Node 610)

$nd610_{HX19_0} := 610$

$AL_{HX19\_nd610} := Term(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd610_{HX19}, Term\_C_o, EL)$

$AL_{HX19\_nd610}^{\ T} = (0.199 \quad 5.174 \times 10^5 \quad 9.875 \quad 610 \quad 35 \quad 1.27 \times 10^5 \quad 1.882 \times 10^5 \quad 4.649 \times 10^5)$

Heat Exchanger 1-10 (Node 607)

$nd607_{HX110_0} := 607$

$AL_{HX110\_nd607} := Term(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd607_{HX110}, Term\_C_o, EL)$

$AL_{HX110\_nd607}{}^T = (0.203 \quad 5.364\times10^5 \quad 13.6 \quad 607 \quad 37 \quad -2.738\times10^5 \quad -1.075\times10^5 \quad 4.486\times10^5)$

Heat Exchanger 1-11 (Node 613)

$nd613_{HX111_0} := 613$

$AL_{HX111\_nd613} := Term(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd613_{HX111}, Term\_C_o, EL)$

$AL_{HX111\_nd613}{}^T = (0.202 \quad 5.311\times10^5 \quad 9.87 \quad 613 \quad 39 \quad 1.999\times10^5 \quad 1.767\times10^5 \quad 4.592\times10^5)$

Heat Exchanger 1-12 (Node 604)

$nd604_{HX112_0} := 604$

$AL_{HX112\_nd604} := Term(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd604_{HX112}, Term\_C_o, EL)$

$AL_{HX112\_nd604}{}^T = (0.227 \quad 6.429\times10^5 \quad 13.605 \quad 604 \quad 41 \quad -3.699\times10^5 \quad -8.55\times10^4 \quad 5.188\times10^5)$

Heat Exchanger 1-170 (Node 619)

$nd619_{HX1170_0} := 619$

$AL_{HX1170\_nd619} := Term(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd619_{HX1170}, Term\_C_o, EL)$

$AL_{HX1170\_nd619}{}^T = (0.189 \quad 4.724\times10^5 \quad 9.24 \quad 619 \quad 47 \quad 4.329\times10^5 \quad 8.728\times10^4 \quad 1.678\times10^5)$

Writing Output Data for Terminations Associated with Lines 1-1L, 1-2L, 1-3L & 1-4L

$T1 := AL_{HX19\_nd610}{}^T$

$T2 := AL_{HX110\_nd607}{}^T$

$T3 := AL_{HX111\_nd613}{}^T$

$T4 := AL_{HX112\_nd604}{}^T$

$T5 := AL_{HX1170\_nd619}{}^T$

$T := (T1 \quad T2 \quad T3 \quad T4 \quad T5)$

TerminationsLine1_8_9_10_11_12_170 := WRITEPRN("TermLine1-8_9_10_11_12_170.prn" , T)

PIPE RUNS

Pipe Runs Strategy: *Search based on the nodes present in each run of pipe. Find the maximum moment combination among all of the nodes and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{PipeRunDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\,\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{PipeRun}(P, D_o, t, I, B_1, B_2, S, nf, el, C_o, EL) :=$

$$
\begin{aligned}
& ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
& ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
& ind_{el} \leftarrow \mathrm{match}\left(el_0, EL^{\langle 0 \rangle}\right) \\
& \text{for } i \in 1 .. \mathrm{last}(el) \quad \text{if } \mathrm{rows}(el) > 1 \\
& \quad ind_{el} \leftarrow \mathrm{stack}\left[ind_{el}, \left(\mathrm{match}\left(el_i, EL^{\langle 0 \rangle}\right)\right)\right] \\
& \left(M \quad Int_{5, \mathrm{last}(ind_{el})}\right) \leftarrow (0 \quad 0) \\
& \text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0} \\
& \quad \text{for } j \in 0 .. \mathrm{last}(ind_{el}) \\
& \qquad M_{rxg} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}}+2,\, ind_{el_j}} \\
& \qquad M_{ryg} \leftarrow nf_{ind_{nfi_{C_{o_{1,1}}}}+2,\, ind_{el_j}} \\
& \qquad M_{rzg} \leftarrow nf_{ind_{nfi_{C_{o_{2,1}}}}+2,\, ind_{el_j}} \\
& \qquad M_{rx_j} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}}+2+i,\, ind_{el_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg} \\
& \qquad M_{ry_j} \leftarrow \left(nf_{ind_{nfi_{C_{o_{1,1}}}}+2+i,\, ind_{el_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg} \\
& \qquad M_{rz_j} \leftarrow \left(nf_{ind_{nfi_{C_{o_{2,1}}}}+2+i,\, ind_{el_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg} \\
& \qquad M'_j \leftarrow \sqrt{\left(M_{rx_j}\right)^2 + \left(M_{ry_j}\right)^2 + \left(M_{rz_j}\right)^2} \\
& \qquad Int'_j \leftarrow \mathrm{PipeRunDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right) \\
& \qquad \text{if } Int'_j > Int_{0,j} \\
& \qquad \quad H \leftarrow \left(Int'_j \quad M'_j \quad nf_{ind_{nfi_{C_{o_{0,1}}}}-1+i,\, 0} \quad EL_{ind_{el_j}, 0} \quad EL_{ind_{el_j}, 1} \quad ind_{el_j} \quad M_{r.}\right. \\
& \qquad \quad \text{for } k \in 0 .. 5 \\
& \qquad \qquad Int_{k,j} \leftarrow H_k
\end{aligned}
$$

Int

Conditions applicable to all pipe runs

$M_{ox} := 0 \quad M_{oy} := 0 \quad M_{oz} := 0$

Defining place holding directional moment variables

$$PipeRun\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties for Line 1-8

Define pertinent pipe variables

$D_o := 30in$ — Outside Diameter [11]

$t := 0.4375in$ — Thickness [11]

$P := 272psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 4.44 \times 10^3 \, in^4$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{cases} 1.0 & \text{if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 & \begin{array}{l} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \frac{D_o}{t}\right) \\ Y \leftarrow 1.033 - 0.00033 \cdot T \\ 1.0 \cdot \frac{1}{X \cdot Y} \end{array} \end{cases}$$

$B_{2PR} = 1.135$

Stress Indices are derived from [4, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [4, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-8A (Elements 97)

$el_{P18A} := (97)^T$

$AL_{P18A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P18A}, PipeRun\_C_o, EL\right)$

$$AL_{P18A}^{\ T} = \begin{pmatrix} 0.176 & 8.223 \times 10^5 & 9.205 & 97 & 595 & 17 \\ 0.147 & 4.883 \times 10^5 & 9.205 & 97 & 1.098 \times 10^3 & 18 \end{pmatrix}$$

Pipe Run 1-8B (Elements 94)

$el_{P18B} := (94)^T$

$AL_{P18B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P18B}, PipeRun\_C_o, EL)$

$$AL_{P18B}^T = \begin{pmatrix} 0.166 & 7.147\times10^5 & 7.83 & 94 & 594 & 11 \\ 0.164 & 6.897\times10^5 & 9.215 & 94 & 1.097\times10^3 & 12 \end{pmatrix}$$

Pipe Properties for Line 1-9, 1-10, 1-11, 1-12, & 1-170

Define pertinent pipe variables

$D_o := 20in$ — Outside Diameter [4]

$t := 0.312in$ — Thickness [4]

$P := 272psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o^4 - (D_o - 2\cdot t)^4\right]}{64}$$ Moment of inertia [8, Table 17-27, pg 17-39]

$I = 935.251\ in^4$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{cases} 1.0 & \text{if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 & \begin{aligned} & T \leftarrow 125 \\ & X \leftarrow \min\left(1, 1.3 - 0.006\cdot\frac{D_o}{t}\right) \\ & Y \leftarrow 1.033 - 0.00033\cdot T \\ & 1.0\cdot\frac{1}{X\cdot Y} \end{aligned} \end{cases}$$

$B_{2PR} = 1.102$

Stress Indices are derived from [4, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [4, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-9A (Elements 110)

$el_{P19A} := (110)^T$

$AL_{P19A} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P19A}, PipeRun\_C_o, EL)$

$$AL_{P19A}^T = \begin{pmatrix} 0.235 & 5.174\times10^5 & 9.875 & 110 & 610 & 35 \\ 0.219 & 4.585\times10^5 & 9.875 & 110 & 679 & 36 \end{pmatrix}$$

Pipe Run 1-9B (Elements 930, 929, & 403)

$el_{P19B} := (930 \quad 929 \quad 403)^T$

$AL_{P19B} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P19B}, PipeRun\_C_o, EL\right)$

$$AL_{P19B}^{T} = \begin{pmatrix} 0.2 & 3.875\times10^{5} & 13.6 & 930 & 673 & 147 \\ 0.157 & 2.217\times10^{5} & 13.635 & 930 & 1.633\times10^{3} & 148 \\ 0.151 & 1.998\times10^{5} & 8.45 & 929 & 1.632\times10^{3} & 145 \\ 0.157 & 2.217\times10^{5} & 13.635 & 929 & 1.633\times10^{3} & 146 \\ 0.204 & 4.022\times10^{5} & 9.215 & 403 & 672 & 91 \\ 0.151 & 1.998\times10^{5} & 8.45 & 403 & 1.632\times10^{3} & 92 \end{pmatrix}$$

Pipe Run 1-9C (Elements 592 & 867)

$el_{P19C} := (592 \quad 867)^T$

$AL_{P19C} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P19C}, PipeRun\_C_o, EL\right)$

$$AL_{P19C}^{T} = \begin{pmatrix} 0.233 & 5.117\times10^{5} & 9.215 & 592 & 665 & 119 \\ 0.234 & 5.16\times10^{5} & 9.215 & 592 & 1.251\times10^{3} & 120 \\ 0.234 & 5.162\times10^{5} & 9.215 & 867 & 1.251\times10^{3} & 125 \\ 0.239 & 5.32\times10^{5} & 9.215 & 867 & 1.447\times10^{3} & 126 \end{pmatrix}$$

Pipe Run 1-10A (Elements 111)

$el_{P110A} := (111)^T$

$AL_{P110A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P110A}, PipeRun\_C_o, EL\right)$

$$AL_{P110A}^{T} = \begin{pmatrix} 0.24 & 5.364\times10^{5} & 13.6 & 111 & 607 & 37 \\ 0.235 & 5.196\times10^{5} & 13.6 & 111 & 678 & 38 \end{pmatrix}$$

Pipe Run 1-10B (Elements 928, 927, & 401)

$el_{P110B} := (928 \quad 927 \quad 401)^T$

$AL_{P110B} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P110B}, PipeRun\_C_o, EL\right)$

$$AL_{P110B}^T = \begin{pmatrix} 0.21 & 4.228\times10^5 & 13.61 & 928 & 674 & 143 \\ 0.169 & 2.677\times10^5 & 7.69 & 928 & 1.631\times10^3 & 144 \\ 0.165 & 2.52\times10^5 & 8.44 & 927 & 1.63\times10^3 & 141 \\ 0.169 & 2.676\times10^5 & 7.69 & 927 & 1.631\times10^3 & 142 \\ 0.201 & 3.909\times10^5 & 9.88 & 401 & 671 & 89 \\ 0.165 & 2.519\times10^5 & 8.44 & 401 & 1.63\times10^3 & 90 \end{pmatrix}$$

Pipe Run 1-10C (Elements 868)

$el_{P110C} := (868)^T$

$AL_{P110C} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P110C}, PipeRun\_C_o, EL\right)$

$$AL_{P110C}^T = \begin{pmatrix} 0.231 & 5.039\times10^5 & 9.215 & 868 & 666 & 127 \\ 0.235 & 5.172\times10^5 & 9.215 & 868 & 1.448\times10^3 & 128 \end{pmatrix}$$

Pipe Run 1-11A (Elements 112)

$el_{P111A} := (112)^T$

$AL_{P111A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P111A}, PipeRun\_C_o, EL\right)$

$$AL_{P111A}^T = \begin{pmatrix} 0.238 & 5.311\times10^5 & 9.87 & 112 & 613 & 39 \\ 0.229 & 4.939\times10^5 & 9.86 & 112 & 680 & 40 \end{pmatrix}$$

Pipe Run 1-11B (Elements 924, 923, & 397)

$el_{P111B} := (924 \quad 923 \quad 397)^T$

$AL_{P111B} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P111B}, PipeRun\_C_o, EL\right)$

$$AL_{P111B}^T = \begin{pmatrix} 0.217 & 4.493\times10^5 & 13.605 & 924 & 675 & 135 \\ 0.176 & 2.964\times10^5 & 7.71 & 924 & 1.627\times10^3 & 136 \\ 0.166 & 2.577\times10^5 & 13.645 & 923 & 1.626\times10^3 & 133 \\ 0.176 & 2.964\times10^5 & 7.71 & 923 & 1.627\times10^3 & 134 \\ 0.191 & 3.531\times10^5 & 15.165 & 397 & 670 & 85 \\ 0.166 & 2.576\times10^5 & 13.645 & 397 & 1.626\times10^3 & 86 \end{pmatrix}$$

Pipe Run 1-11C (Elements 869)

$el_{P111C} := (869)^T$

$AL_{P111C} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P111C}, PipeRun\_C_o, EL\right)$

$$AL_{P111C}{}^T = \begin{pmatrix} 0.22 & 4.633\times10^5 & 15.17 & 869 & 667 & 129 \\ 0.224 & 4.761\times10^5 & 15.17 & 869 & 1.449\times10^3 & 130 \end{pmatrix}$$

Pipe Run 1-12A (Elements 113)

$el_{P112A} := (113)^T$

$AL_{P112A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P112A}, PipeRun\_C_o, EL\right)$

$$AL_{P112A}{}^T = \begin{pmatrix} 0.268 & 6.429\times10^5 & 13.605 & 113 & 604 & 41 \\ 0.265 & 6.332\times10^5 & 13.605 & 113 & 677 & 42 \end{pmatrix}$$

Pipe Run 1-12B (Elements 926, 925, & 399)

$el_{P112B} := (926 \;\; 925 \;\; 399)^T$

$AL_{P112B} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P112B}, PipeRun\_C_o, EL\right)$

$$AL_{P112B}{}^T = \begin{pmatrix} 0.237 & 5.26\times10^5 & 13.61 & 926 & 676 & 139 \\ 0.194 & 3.632\times10^5 & 7.715 & 926 & 1.629\times10^3 & 140 \\ 0.168 & 2.645\times10^5 & 13.645 & 925 & 1.628\times10^3 & 137 \\ 0.194 & 3.631\times10^5 & 7.715 & 925 & 1.629\times10^3 & 138 \\ 0.195 & 3.667\times10^5 & 10.22 & 399 & 669 & 87 \\ 0.168 & 2.645\times10^5 & 13.645 & 399 & 1.628\times10^3 & 88 \end{pmatrix}$$

Pipe Run 1-12C (Elements 870)

$el_{P112C} := (870)^T$

$AL_{P112C} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P112C}, PipeRun\_C_o, EL\right)$

$$AL_{P112C}{}^T = \begin{pmatrix} 0.218 & 4.529\times10^5 & 15.18 & 870 & 668 & 131 \\ 0.225 & 4.787\times10^5 & 15.175 & 870 & 1.45\times10^3 & 132 \end{pmatrix}$$

Pipe Run 1-170A (Elements 117)

$el_{P1170A} := (117)^T$

$AL_{P1170A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P1170A}, PipeRun\_C_o, EL\right)$

$$AL_{P1170A}{}^T = \begin{pmatrix} 0.223 & 4.724\times10^5 & 9.24 & 117 & 619 & 47 \\ 0.217 & 4.489\times10^5 & 15.165 & 117 & 620 & 48 \end{pmatrix}$$

Pipe Run 1-170B (Elements 405, 931, & 932)

$el_{P1170B} := (405 \;\; 931 \;\; 932)^T$

$AL_{P1170B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P1170B}, PipeRun\_C_o, EL)$

$$AL_{P1170B}^T = \begin{pmatrix} 0.168 & 2.652\times10^5 & 9.89 & 405 & 622 & 93 \\ 0.14 & 1.593\times10^5 & 7.655 & 405 & 1.634\times10^3 & 94 \\ 0.14 & 1.593\times10^5 & 7.655 & 931 & 1.634\times10^3 & 149 \\ 0.167 & 2.601\times10^5 & 13.605 & 931 & 1.635\times10^3 & 150 \\ 0.218 & 4.521\times10^5 & 15.16 & 932 & 621 & 151 \\ 0.167 & 2.601\times10^5 & 13.605 & 932 & 1.635\times10^3 & 152 \end{pmatrix}$$

Pipe Run 1-170C (Elements 115)

$el_{P1170C} := (115)^T$

$AL_{P1170C} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P1170C}, PipeRun\_C_o, EL)$

$$AL_{P1170C}^T = \begin{pmatrix} 0.14 & 1.576\times10^5 & 13.655 & 115 & 683 & 45 \\ 0.152 & 2.059\times10^5 & 10.285 & 115 & 684 & 46 \end{pmatrix}$$

Pipe Run 1-170D (Elements 439, 933, & 114)

$el_{P1170D} := (439 \;\; 933 \;\; 114)^T$

$AL_{P1170D} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167L}, NF, el_{P1170D}, PipeRun\_C_o, EL)$

$$AL_{P1170D}^T = \begin{pmatrix} 0.139 & 1.566\times10^5 & 13.65 & 439 & 682 & 103 \\ 0.149 & 1.948\times10^5 & 10.285 & 439 & 1.096\times10^3 & 104 \\ 0.149 & 1.948\times10^5 & 10.285 & 933 & 1.096\times10^3 & 153 \\ 0.165 & 2.537\times10^5 & 9.875 & 933 & 1.636\times10^3 & 154 \\ 0.198 & 3.78\times10^5 & 9.865 & 114 & 614 & 43 \\ 0.165 & 2.536\times10^5 & 9.875 & 114 & 1.636\times10^3 & 44 \end{pmatrix}$$

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Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

Writing Output Data for Pipe Runs Associated with Lines 1-8, 1-9, 1-10, 1-11, 1-12, & 1-17

$PR1 := AL_{P18A}^{T}$

$PR2 := AL_{P18B}^{T}$

$PR3 := AL_{P19A}^{T}$

$PR4 := AL_{P19B}^{T}$

$PR5 := AL_{P19C}^{T}$

$PR6 := AL_{P110A}^{T}$

$PR7 := AL_{P110B}^{T}$

$PR8 := AL_{P110C}^{T}$

$PR9 := AL_{P111A}^{T}$

$PR10 := AL_{P111B}^{T}$

$PR11 := AL_{P111C}^{T}$

$PR12 := AL_{P112A}^{T}$

$PR13 := AL_{P112B}^{T}$

$PR14 := AL_{P112C}^{T}$

$PR15 := AL_{P1170A}^{T}$

$PR16 := AL_{P1170B}^{T}$

$PR17 := AL_{P1170C}^{T}$

$PR18 := AL_{P1170D}^{T}$

$P := (PR1\ \ PR2\ \ PR3\ \ PR4\ \ PR5\ \ PR6\ \ PR7\ \ PR8\ \ PR9\ \ PR10\ \ PR11\ \ PR12\ \ PR13\ \ PR14\ \ PR15\ \ PR16\ \ PR17\ \ PR18)$

PipeRunsLine1_8_9_10_11_12_170 := WRITEPRN("PRLine1-8_9_10_11_12_170.prn" , P)

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REDUCERS

Reducers Strategy: *Search based on the nodes comprising either end of the reducers. SRSS combine the three moments of each of the four node representations (one for each element connected by the node in question). Find the maximum of the moment combinations for each element and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. It is important to not combine the data from both nodes as the geometry for each is different and (9) must be applied for each node. The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\mathrm{ReducerDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\,lbf \cdot in)]}{S}$$

$$\mathrm{Reducer}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$$

$$\begin{array}{l}
ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right) \\
\text{for } i \in 1 .. \mathrm{last}(nd) \quad \text{if } \mathrm{rows}(nd) > 1 \\
\quad ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \\
(M \;\; Int_0) \leftarrow (0 \;\; 0) \\
\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0} \\
\quad \text{for } j \in 0 .. \mathrm{last}(ind_{nd}) \\
\quad\quad M_{rxg} \leftarrow nf_{ind_{nfi}C_{o_{0,1}}+2,\, ind_{nd_j}} \\
\quad\quad M_{ryg} \leftarrow nf_{ind_{nfi}C_{o_{1,1}}+2,\, ind_{nd_j}} \\
\quad\quad M_{rzg} \leftarrow nf_{ind_{nfi}C_{o_{2,1}}+2,\, ind_{nd_j}} \\
\quad\quad M_{rx} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg} \\
\quad\quad M_{ry} \leftarrow \left(nf_{ind_{nfi}C_{o_{1,1}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg} \\
\quad\quad M_{rz} \leftarrow \left(nf_{ind_{nfi}C_{o_{2,1}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg} \\
\quad\quad M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2} \\
\quad\quad Int'_j \leftarrow \mathrm{ReducerDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right) \\
\quad\quad \text{if } Int'_j > Int_0 \\
\quad\quad\quad Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfi}C_{o_{0,1}}-1+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd_j}, M_{rx}, M_{ry}, \right. \\
\quad\quad\quad Result \leftarrow M'
\end{array}$$

Int

Conditions applicable to all reducers

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$ — Defining place holding variables

$$Reducer\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Reducer Properties for RED(1-8A) & RED(1-8B)

Define pertinent reducer variables

$D_o := (36in \;\; 30in)^T$ — Outside Diameter [11]

$t := (0.5in \;\; 0.5in)^T$ — Thickness [11]

$P := (272psi \;\; 272psi)^T$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = \begin{pmatrix} 8.786 \times 10^3 \\ 5.042 \times 10^3 \end{pmatrix} in^4$$

Define primary stress indices

$$\alpha := atan\left(\frac{6in}{24in}\right)$$

Angular slope of reducer [11]

$\alpha = 14.036\,deg$

$$B_1 := \begin{cases} 0.5 & \text{if } \alpha \le 30deg \\ 1.0 & \text{if } 30deg < \alpha \le 60deg \end{cases}$$

B_1 primary stress Index [4, NB-3683.7]

$B_1 = 0.5$

$B_2 := 1.0$ — B_2 primary stress Index [4, NB-3683.7]

Reducer 1-8A (Nodes 592 & 595)

$nd_{RD18A\_L} := (592)^T$ — Node associated with Large end of reducer

$$AL_{RD18A\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{167L}, NF, nd_{RD18A\_L}, Reducer\_C_o, EL\right)$$

$$AL_{RD18A\_L}^{\;T} = \left(0.152 \;\; 9.188 \times 10^5 \;\; 9.205 \;\; 592 \;\; 7 \;\; -8.844 \times 10^5 \;\; 1.118 \times 10^5 \;\; 2.227 \times 10^5\right)$$

$nd_{RD18A\_S} := (595)^T$ — Node associated with Small end of reducer

$$AL_{RD18A\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{167L}, NF, nd_{RD18A\_S}, Reducer\_C_o, EL\right)$$

$$AL_{RD18A\_S}^{\;T} = \left(0.147 \;\; 8.224 \times 10^5 \;\; 9.205 \;\; 595 \;\; 25 \;\; 7.732 \times 10^5 \;\; -1.55 \times 10^5 \;\; -2.334 \times 10^5\right)$$

Reducer 1-8B (Nodes 593 & 594)

$nd_{RD18B\_L} := (593)^T$ — Node associated with Large end of reducer

$AL_{RD18B\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{167L}, NF, nd_{RD18B\_L}, Reducer\_C_o, EL\right)$

$AL_{RD18B\_L}{}^T = \left(0.144 \quad 7.376\times10^5 \quad 13.65 \quad 593 \quad 4 \quad -5.249\times10^5 \quad 3.881\times10^5 \quad -3.433\times10^5\right)$

$nd_{RD18B\_S} := (594)^T$ — Node associated with Small end of reducer

$AL_{RD18B\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{167L}, NF, nd_{RD18B\_S}, Reducer\_C_o, EL\right)$

$AL_{RD18B\_S}{}^T = \left(0.139 \quad 7.149\times10^5 \quad 7.83 \quad 594 \quad 23 \quad -6.821\times10^5 \quad 1.263\times10^5 \quad -1.731\times10^5\right)$

Reducer Properties for RED(1-170)

Define pertinent reducer variables

$D_o := (18in \quad 16in)^T$ — Outside Diameter [14]

$t := (0.312in \quad 0.312in)^T$ — Thickness [14]

$P := (272psi \quad 272psi)^T$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o{}^4 - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = \begin{pmatrix}678.244\\473.248\end{pmatrix} in^4$$

Define primary stress indices

$$\alpha := atan\left(\frac{1in}{15in}\right)$$

Angular slope of reducer [14]

$\alpha = 3.814\,deg$

$$B_1 := \begin{cases}0.5 & \text{if } \alpha \le 30deg\\ 1.0 & \text{if } 30deg < \alpha \le 60deg\end{cases}$$

B_1 primary stress Index [4, NB-3683.7]

$B_1 = 0.5$

$B_2 := 1.0$ — B_2 primary stress Index [4, NB-3683.7]

Reducer 1-170 (Nodes 597 & 614)

$nd_{RD1170\_L} := (597)^T$ — Node associated with Large end of reducer

$AL_{RD1170\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{167L}, NF, nd_{RD1170\_L}, Reducer\_C_o, EL\right)$

$AL_{RD1170\_L}{}^T = \left(0.218 \quad 4.367\times10^5 \quad 9.865 \quad 597 \quad 21 \quad 4.335\times10^5 \quad 1.883\times10^4 \quad -4.954\times10^4\right)$

$nd_{RD1170\_S} := (614)^T$ Node associated with Small end of reducer

$AL_{RD1170\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{167L}, NF, nd_{RD1170\_S}, Reducer\_C_o, EL\right)$

$$AL_{RD1170\_S}^T = \begin{pmatrix} 0.222 & 3.78\times10^5 & 9.865 & 614 & 95 & 3.746\times10^5 & -7.532\times10^3 & -4.973\times10^4 \end{pmatrix}$$

Writing Output Data for Reducers Associated with Lines 1-1L, 1-2L, 1-3L, & 1-4L

$RL1 := AL_{RD18A\_L}^T$

$RS1 := AL_{RD18A\_S}^T$

$RL2 := AL_{RD18B\_L}^T$

$RS2 := AL_{RD18B\_S}^T$

$RL3 := AL_{RD1170\_L}^T$

$RS3 := AL_{RD1170\_S}^T$

$R := (RL1 \;\; RS1 \;\; RL2 \;\; RS2 \;\; RL3 \;\; RS3)$

ReducersLine1_8_9_10_11_12_170 := WRITEPRN("RedLine1-8_9_10_11_12_170.prn" , R)

ELBOWS

Elbows Strategy: *Search based on the two nodes comprising the ends of each elbow. SRSS combine the three moments of each of the four node representations (one for each element connected by the nodes in question). Find the maximum of the four moment combinations and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{ElbowDC}\left(P, D_o, t, I, B_1, B_2, M, S\right) := \frac{B_1 \cdot \dfrac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \dfrac{D_o}{2 \cdot I} \cdot [M \cdot (1\,\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Elbow}\left(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL\right) :=$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(nd)$ if $\mathrm{rows}(nd) > 1$

  $ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$\left(M \;\; Int_0\right) \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \mathrm{last}\left(ind_{nd}\right)$

    $M_{rxg} \leftarrow nf_{ind_{nfi} C_{o_{0,1}} + 2,\, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi} C_{o_{1,1}} + 2,\, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi} C_{o_{2,1}} + 2,\, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi} C_{o_{0,1}} + 2 + i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi} C_{o_{1,1}} + 2 + i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi} C_{o_{2,1}} + 2 + i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow \mathrm{ElbowDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$

    if $Int'_j > Int_0$

      $Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfi} C_{o_{0,1}} - 1 + i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M\right.$

      $Result \leftarrow M'$

Int

Conditions applicable to all elbows

$M_{ox} := 0 \quad M_{oy} := 0 \quad M_{oz} := 0$ — Defining place holding variables

$$Elb\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Elbow Properties for Elbows on Lines 1-9, 1-10, 1-11, 1-12, & 1-170

Define pertinent elbow variables

$D_o := 20in$ — Outside Diameter [12,13,14]

$t := 0.312in$ — Thickness [12,13,14]

$P := 272psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

$I = 935.251\ in^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$R := 1.5\cdot D_o$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$ — Mean pipe radius

Define primary stress indices

$$h := \frac{t\cdot R}{r_m^{\,2}}$$ $h = 0.097$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4\cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4\cdot h > 0.5 \\ -0.1 + 0.4\cdot h & \text{otherwise} \end{cases}$$

$B_1 = 0$ — B_1 primary stress Index [4, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 6.175$ — B_2 primary stress Index [4, NB-3683.7]

Elbow 1-9A (Nodes 679 & 673)

$nd_{EL19A\_1} := (679)^T$

$AL_{EL19A\_nd679} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL19A\_1}, Elb\_C_o, EL)$

$AL_{EL19A\_nd679}^T = (0.579 \quad 4.585\times10^5 \quad 9.875 \quad 679 \quad 36 \quad -2.219\times10^5 \quad -1.552\times10^5 \quad -3.699\times10^5)$

$nd_{EL19A\_2} := (673)^T$

$AL_{EL19A\_nd673} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL19A\_2}, Elb\_C_o, EL)$

$AL_{EL19A\_nd673}^T = (0.49 \quad 3.875\times10^5 \quad 13.6 \quad 673 \quad 61 \quad 2.721\times10^5 \quad 6.649\times10^4 \quad -2.678\times10^5)$

Elbow 1-9B (Nodes 672 & 665)

$nd_{EL19B\_1} := (672)^T$

$AL_{EL19B\_nd672} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL19B\_1}, Elb\_C_o, EL)$

$AL_{EL19B\_nd672}^T = (0.508 \quad 4.022\times10^5 \quad 9.215 \quad 672 \quad 56 \quad -3.7\times10^5 \quad 8.417\times10^4 \quad 1.333\times10^5)$

$nd_{EL19B\_2} := (665)^T$

$AL_{EL19B\_nd665} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL19B\_2}, Elb\_C_o, EL)$

$AL_{EL19B\_nd665}^T = (0.647 \quad 5.117\times10^5 \quad 9.215 \quad 665 \quad 55 \quad 5.091\times10^5 \quad 5.047\times10^4 \quad 6.086\times10^3)$

Elbow 1-10A (Nodes 678 & 674)

$nd_{EL110A\_1} := (678)^T$

$AL_{EL110A\_nd678} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL110A\_1}, Elb\_C_o, EL)$

$AL_{EL110A\_nd678}^T = (0.657 \quad 5.196\times10^5 \quad 13.6 \quad 678 \quad 38 \quad 3.193\times10^5 \quad 7.43\times10^4 \quad -4.031\times10^5)$

$nd_{EL110A\_2} := (674)^T$

$AL_{EL110A\_nd674} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL110A\_2}, Elb\_C_o, EL)$

$AL_{EL110A\_nd674}^T = (0.534 \quad 4.228\times10^5 \quad 13.61 \quad 674 \quad 64 \quad 3.404\times10^5 \quad -3.451\times10^4 \quad -2.484\times10^5)$

Elbow 1-10B (Nodes 671 & 666)

$nd_{EL110B\_1} := (671)^T$

$AL_{EL110B\_nd671} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL110B\_1}, Elb\_C_o, EL)$

$AL_{EL110B\_nd671}^T = (0.494 \quad 3.909\times10^5 \quad 9.88 \quad 671 \quad 59 \quad -3.768\times10^5 \quad 9.087\times10^4 \quad 5.033\times10^4)$

$nd_{EL110B\_2} := (666)^T$

$AL_{EL110B\_nd666} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL110B\_2}, Elb\_C_o, EL)$

$AL_{EL110B\_nd666}^T = (0.637 \quad 5.039\times10^5 \quad 9.215 \quad 666 \quad 58 \quad 5.016\times10^5 \quad 4.059\times10^4 \quad 2.581\times10^4)$

Elbow 1-11A (Nodes 680 & 675)

$nd_{EL111A\_1} := (680)^T$

$AL_{EL111A\_nd680} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL111A\_1}, Elb\_C_o, EL)$

$AL_{EL111A\_nd680}{}^T = (0.624 \;\; 4.939 \times 10^5 \;\; 9.86 \;\; 680 \;\; 40 \;\; -2.764 \times 10^5 \;\; -1.425 \times 10^5 \;\; -3.838 \times 10^5)$

$nd_{EL111A\_2} := (675)^T$

$AL_{EL111A\_nd675} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL111A\_2}, Elb\_C_o, EL)$

$AL_{EL111A\_nd675}{}^T = (0.568 \;\; 4.494 \times 10^5 \;\; 13.605 \;\; 675 \;\; 67 \;\; 2.591 \times 10^5 \;\; 8.324 \times 10^4 \;\; -3.576 \times 10^5)$

Elbow 1-11B (Nodes 670 & 667)

$nd_{EL111B\_1} := (670)^T$

$AL_{EL111B\_nd670} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL111B\_1}, Elb\_C_o, EL)$

$AL_{EL111B\_nd670}{}^T = (0.446 \;\; 3.531 \times 10^5 \;\; 15.165 \;\; 670 \;\; 77 \;\; 3.406 \times 10^5 \;\; -6.409 \times 10^4 \;\; 6.718 \times 10^4)$

$nd_{EL111B\_2} := (667)^T$

$AL_{EL111B\_nd667} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL111B\_2}, Elb\_C_o, EL)$

$AL_{EL111B\_nd667}{}^T = (0.586 \;\; 4.633 \times 10^5 \;\; 15.17 \;\; 667 \;\; 129 \;\; 4.604 \times 10^5 \;\; 5.125 \times 10^4 \;\; -1.163 \times 10^4)$

Elbow 1-12A (Nodes 677 & 676)

$nd_{EL112A\_1} := (677)^T$

$AL_{EL112A\_nd677} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL112A\_1}, Elb\_C_o, EL)$

$AL_{EL112A\_nd677}{}^T = (0.8 \;\; 6.332 \times 10^5 \;\; 13.605 \;\; 677 \;\; 71 \;\; -4.024 \times 10^5 \;\; -4.974 \times 10^4 \;\; 4.864 \times 10^5)$

$nd_{EL112A\_2} := (676)^T$

$AL_{EL112A\_nd676} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL112A\_2}, Elb\_C_o, EL)$

$AL_{EL112A\_nd676}{}^T = (0.665 \;\; 5.26 \times 10^5 \;\; 13.61 \;\; 676 \;\; 70 \;\; 3.732 \times 10^5 \;\; -6.66 \times 10^4 \;\; -3.646 \times 10^5)$

Elbow 1-12B (Nodes 669 & 668)

$nd_{EL112B\_1} := (669)^T$

$AL_{EL112B\_nd669} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL112B\_1}, Elb\_C_o, EL)$

$AL_{EL112B\_nd669}{}^T = (0.464 \;\; 3.668 \times 10^5 \;\; 10.22 \;\; 669 \;\; 74 \;\; 2.919 \times 10^5 \;\; -1.704 \times 10^5 \;\; 1.423 \times 10^5)$

$nd_{EL112B\_2} := (668)^T$

$AL_{EL112B\_nd668} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL112B\_2}, Elb\_C_o, EL)$

$AL_{EL112B\_nd668}{}^T = (0.572 \;\; 4.529 \times 10^5 \;\; 15.18 \;\; 668 \;\; 131 \;\; 4.455 \times 10^5 \;\; 8.089 \times 10^4 \;\; 9.335 \times 10^3)$

Elbow 1-170A (Nodes 620 & 621)

$nd_{EL1170A\_1} := (620)^T$

$AL_{EL1170A\_nd620} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL1170A\_1}, Elb\_C_o, EL)$

$AL_{EL1170A\_nd620}^T = (0.567 \quad 4.489\times10^5 \quad 15.165 \quad 620 \quad 82 \quad -4.488\times10^5 \quad -7.306\times10^3 \quad 967.13)$

$nd_{EL1170A\_2} := (621)^T$

$AL_{EL1170A\_nd621} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL1170A\_2}, Elb\_C_o, EL)$

$AL_{EL1170A\_nd621}^T = (0.571 \quad 4.521\times10^5 \quad 15.16 \quad 621 \quad 83 \quad 4.202\times10^5 \quad -7.681\times10^4 \quad -1.482\times10^5)$

Elbow 1-170B (Nodes 622 & 623)

$nd_{EL1170B\_1} := (622)^T$

$AL_{EL1170B\_nd622} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL1170B\_1}, Elb\_C_o, EL)$

$AL_{EL1170B\_nd622}^T = (0.335 \quad 2.652\times10^5 \quad 9.89 \quad 622 \quad 79 \quad -2.433\times10^5 \quad -4.849\times10^4 \quad 9.361\times10^4)$

$nd_{EL1170B\_2} := (623)^T$

$AL_{EL1170B\_nd623} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL1170B\_2}, Elb\_C_o, EL)$

$AL_{EL1170B\_nd623}^T = (0.307 \quad 2.433\times10^5 \quad 10.275 \quad 623 \quad 80 \quad -1.441\times10^5 \quad -1.065\times10^4 \quad 1.957\times10^5)$

Elbow 1-170C (Nodes 623 & 684)

$nd_{EL1170C\_1} := (623)^T$

$AL_{EL1170C\_nd623} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL1170C\_1}, Elb\_C_o, EL)$

$AL_{EL1170C\_nd623}^T = (0.307 \quad 2.433\times10^5 \quad 10.275 \quad 623 \quad 80 \quad -1.441\times10^5 \quad -1.065\times10^4 \quad 1.957\times10^5)$

$nd_{EL1170C\_2} := (684)^T$

$AL_{EL1170C\_nd684} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL1170C\_2}, Elb\_C_o, EL)$

$AL_{EL1170C\_nd684}^T = (0.26 \quad 2.06\times10^5 \quad 10.285 \quad 684 \quad 53 \quad -1.048\times10^5 \quad -1.199\times10^4 \quad 1.769\times10^5)$

Elbow 1-170D (Nodes 683 & 682)

$nd_{EL1170D\_1} := (683)^T$

$AL_{EL1170D\_nd683} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL1170D\_1}, Elb\_C_o, EL)$

$AL_{EL1170D\_nd683}^T = (0.199 \quad 1.576\times10^5 \quad 13.655 \quad 683 \quad 45 \quad -8.724\times10^4 \quad -7.152\times10^4 \quad -1.101\times10^5$

$nd_{EL1170D\_2} := (682)^T$

$AL_{EL1170D\_nd682} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL1170D\_2}, Elb\_C_o, EL)$

$AL_{EL1170D\_nd682}^T = (0.198 \quad 1.566\times10^5 \quad 13.65 \quad 682 \quad 49 \quad -2.203\times10^4 \quad -7.995\times10^4 \quad -1.329\times10^5)$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

Writing Output Data for Elbows Associated with Lines 1-8, 1-9, 1-10, 1-11, 1-12, & 1-70

$EL1A := AL_{EL19A\_nd679}{}^{T}$

$EL1B := AL_{EL19A\_nd673}{}^{T}$

$EL2A := AL_{EL19B\_nd672}{}^{T}$

$EL2B := AL_{EL19B\_nd665}{}^{T}$

$EL3A := AL_{EL110A\_nd678}{}^{T}$

$EL3B := AL_{EL110A\_nd674}{}^{T}$

$EL4A := AL_{EL110B\_nd671}{}^{T}$

$EL4B := AL_{EL110B\_nd666}{}^{T}$

$EL5A := AL_{EL111A\_nd680}{}^{T}$

$EL5B := AL_{EL111A\_nd675}{}^{T}$

$EL6A := AL_{EL111B\_nd670}{}^{T}$

$EL6B := AL_{EL111B\_nd667}{}^{T}$

$EL7A := AL_{EL112A\_nd677}{}^{T}$

$EL7B := AL_{EL112A\_nd676}{}^{T}$

$EL8A := AL_{EL112B\_nd669}{}^{T}$

$EL8B := AL_{EL112B\_nd668}{}^{T}$

$EL9A := AL_{EL1170A\_nd620}{}^{T}$

$EL9B := AL_{EL1170A\_nd621}{}^{T}$

$EL10A := AL_{EL1170B\_nd622}{}^{T}$

$EL10B := AL_{EL1170B\_nd623}{}^{T}$

$EL11A := AL_{EL1170C\_nd623}{}^{T}$

$EL11B := AL_{EL1170C\_nd684}{}^{T}$

$EL12A := AL_{EL1170D\_nd683}{}^{T}$

$EL12B := AL_{EL1170D\_nd682}{}^{T}$

vEL := (EL1A EL1B EL2A EL2B EL3A EL3B EL4A EL4B EL5A EL5B EL6A EL6B EL7A EL7B EL8A EL8B EI

ElbowLine1_8_9_10_11_12_170 := WRITEPRN("ElbowLine1-8_9_10_11_12_170.prn" , vEL)

FORGED TEES AND FABRICATED BRANCH TEES

Tees Strategy: *Search based on the elements comprising the tee. The input identifies which elements are associated with the pipe run and which element is associated with the branch from the run. The indices for the defined common node for all three elements is identified and the associated SRSS moment is identified for each time step. The maximum moment for the elements comprising the pipe run is found and applied as* M_r *in equation (9) of ASME III, Division I - NB - 3652 which is modified to represent tees. The maximum moment for the branch element is found and applied as* M_b *in equation (9) of ASME III, Division I - NB - 3652 [4]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$FabBrDC(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_b, M_r, Z_b, Z_r, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot T_r} + B_{2b} \cdot \left[\frac{M_b \cdot (1lbf \cdot in)}{Z_b}\right] + B_{2r} \cdot \left[\frac{M_r \cdot (1lbf \cdot in)}{Z_r}\right]}{S}$$

$FabBr(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S, nf, el_R, el_B, nd_R, nd_B, C_o, EL) :=$

$ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{elR} \leftarrow match\left(el_{R_0}, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(el_R)$ if ro

  $ind_{elR} \leftarrow stack\left[ind_{elR}, \left(match\left(el_{R_i}, EL^{\langle 0 \rangle}\right)\right)\right]$

$EL'R_{last\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$

for $i \in 0 .. last(ind_{elR})$

  $EL'R_{ind_{elR_i}} \leftarrow EL_{ind_{elR_i}, 1}$

$ind_{ndR} \leftarrow match\left(nd_{R_0}, EL'R^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(nd_R)$ if

  $ind_{ndR} \leftarrow stack\left[ind_{ndR}, \left(match\left(nd_{R_i}, EL'R^{\langle 0 \rangle}\right)\right)\right]$

$ind_{elB} \leftarrow match\left(el_{B_0}, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(el_B)$ if ro

  $ind_{elB} \leftarrow stack\left[ind_{elB}, \left(match\left(el_{B_i}, EL^{\langle 0 \rangle}\right)\right)\right]$

$EL'B_{last\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$

for $i \in 0 .. last(ind_{elB})$

  $EL'B_{ind_{elB_i}} \leftarrow EL_{ind_{elB_i}, 1}$

$ind \leftarrow match(nd \quad EL'B^{\langle 0 \rangle})$

$ind_{ndB} \leftarrow match(nd_{B_0}, EL'B ...)$

for $i \in 1..last(nd_B)$ if

$ind_{ndB} \leftarrow stack\left[ind_{ndB}, \left(match\left(nd_{B_i}, EL'B^{\langle 0 \rangle}\right)\right)\right]$

$(M_R \ \ M_B \ \ Int_0) \leftarrow (0 \ \ 0 \ \ 0)$

for $i \in 0..ind_{nfo_0} - ind_{nfi_0}$

for $j \in 0..last(ind_{ndR})$

for $k \in 0..last(ind_{ndB})$

$M_{rxgR_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2, ind_{ndR_j}}$

$M_{rygR_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2, ind_{ndR_j}}$

$M_{rzgR_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2, ind_{ndR_j}}$

$M_{rxR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i, ind_{ndR_j}} - M_{rxgR_j}\right)$

$M_{ryR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i, ind_{ndR_j}} - M_{rygR_j}\right)$

$M_{rzR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i, ind_{ndR_j}} - M_{rzgR_j}\right)$

$M_{R_j} \leftarrow \sqrt{\left(M_{rxR_j}\right)^2 + \left(M_{ryR_j}\right)^2 + \left(M_{rzR_j}\right)^2}$

$M_{rxgB_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2, ind_{ndB_k}}$

$M_{rygB_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2, ind_{ndB_k}}$

$M_{rzgB_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2, ind_{ndB_k}}$

$M_{rxB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i, ind_{ndB_k}} - M_{rxgB_j}\right)$

$M_{ryB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i, ind_{ndB_k}} - M_{rygB_j}\right)$

$M_{rzB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i, ind_{ndB_k}} - M_{rzgB_j}\right)$

$M_{B_j} \leftarrow \sqrt{\left(M_{rxB_j}\right)^2 + \left(M_{ryB_j}\right)^2 + \left(M_{rzB_j}\right)^2}$

$Int'_j \leftarrow FabBrDC\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_{B_j}\right.$

if $Int'_j > Int_0$

$Int \leftarrow stack\left(Int'_j, M_{R_j}, M_{B_j}, nf_{ind_{nfiC}}\right.$

$\text{Result} \leftarrow \text{stack}\left(M_{R_j}, M_{B_j}, M_{rxR_j}, M_{ryR_j},\right.$

$M \leftarrow M_R$

Int

Conditions applicable to forged tee

$M_{ox} := 0 \quad M_{oy} := 0 \quad M_{oz} := 0$

Defining place holding directional moment variables

$$Tee\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3 and seismic factor

Tees on Connecting Lines 1-9, 1-10, 1-11, & 1-12 to 1-8

Define pertinent tee variables

$P := 272\text{psi}$ — Internal Pressure [3, pg 23]

$D_o := 30\text{in}$ — Outside Diameter [11]

$B_1 := 0.5$ — B_1 primary stress Indice for tees and branches [4, NB-3683.9]

$T_r := 0.4375\text{in}$ — Nominal wall thickness of designated run pipe [11]

$R_m := 15\text{in}$ — Mean radius of designated run pipe [11]

$Z_r := \pi \cdot R_m^{\,2} \cdot T_r$ — Approximate section modulus of designated run pipe [4, NB-3683.1(d)]

$Z_r = 309.2505\ \text{in}^3$

$$B_{2b} := \begin{cases} 0.4 \cdot \left(\dfrac{R_m}{T_r}\right)^{\frac{2}{3}} & \text{if } 0.4 \cdot \left(\dfrac{R_m}{T_r}\right)^{\frac{2}{3}} > 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Indice for tees and branches [4, NB-3683.9]

$B_{2b} = 4.222$

$T'_b := 0.312\text{in}$ — Nominal wall thickness of attached branch pipe [11]

$r'_m := 10\text{in}$ — Mean radius of attached branch pipe [11]

$Z_b := \pi \cdot r'^{\,2}_m \cdot T'_b$ — Approximate section modulus of attached branch pipe [4, NB-3683.1(d)]

$Z_b = 98.018\ \text{in}^3$

$$B_{2r} := \begin{cases} 0.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} & \text{if } 0.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} > 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Indice for tees and branches [4, NB-3683.9]

$B_{2r} = 5.277$

Tee 1-9 (Node 600)

$elR_{Tee19} := (99\ \ 436)^T$ Elements associated with pipe run

$ndR_{Tee19} := (600)^T$ Node between pipe run elements

$elB_{Tee19} := (102)^T$ Element associated with branch

$ndB_{Tee19} := (600)^T$ Node where branch intersects pipe run

$AL_{Tee19} := FabBr(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{167}, NF, elR_{Tee19}, elB_{Tee19}, ndR_{Tee19}, ndB_{Tee19}, Tee\_C_o, E$

$$AL_{Tee19}^T = (0.704\ \ 4.615\times10^5\ \ 5.629\times10^5\ \ 9.215\ \ 600\ \ 22\ \ 101\ \ 27)$$

Tee 1-10 (Node 601)

$elR_{Tee110} := (98\ \ 441)^T$ Elements associated with pipe run

$ndR_{Tee110} := (601)^T$ Node between pipe run elements

$elB_{Tee110} := (103)^T$ Element associated with branch

$ndB_{Tee110} := (601)^T$ Node where branch intersects pipe run

$AL_{Tee110} := FabBr(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{167}, NF, elR_{Tee110}, elB_{Tee110}, ndR_{Tee110}, ndB_{Tee110}, Tee$

$$AL_{Tee110}^T = (0.673\ \ 4.334\times10^5\ \ 5.359\times10^5\ \ 9.21\ \ 601\ \ 19\ \ 107\ \ 29)$$

Tee 1-11 (Node 599)

$elR_{Tee111} := (95\ \ 440)^T$ Elements associated with pipe run

$ndR_{Tee111} := (599)^T$ Node between pipe run elements

$elB_{Tee111} := (104)^T$ Element associated with branch

$ndB_{Tee111} := (599)^T$ Node where branch intersects pipe run

$AL_{Tee111} := FabBr(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{167}, NF, elR_{Tee111}, elB_{Tee111}, ndR_{Tee111}, ndB_{Tee111}, Tee$

$$AL_{Tee111}^T = (0.739\ \ 7.764\times10^5\ \ 4.806\times10^5\ \ 9.22\ \ 599\ \ 13\ \ 105\ \ 31)$$

Tee 1-12 (Node 598)

$elR_{Tee112} := (435\ \ 96)^T$ — Elements associated with pipe run

$ndR_{Tee112} := (598)^T$ — Node between pipe run elements

$elB_{Tee112} := (105)^T$ — Element associated with branch

$ndB_{Tee112} := (598)^T$ — Node where branch intersects pipe run

$AL_{Tee112} := FabBr(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{167}, NF, elR_{Tee112}, elB_{Tee112}, ndR_{Tee112}, ndB_{Tee112}, Tee$

$$AL_{Tee112}{}^T = (0.687\ \ 5.216\times10^5\ \ 5.187\times10^5\ \ 15.175\ \ 598\ \ 16\ \ 99\ \ 33)$$

Writing Output Data for Tees Associated with Lines 1-8, 1-9, 1-10, 1-11, 1-12, & 1-170

$T1 := AL_{Tee19}{}^T$

$T2 := AL_{Tee110}{}^T$

$T3 := AL_{Tee111}{}^T$

$T4 := AL_{Tee112}{}^T$

$vT := (T1\ \ T2\ \ T3\ \ T4)$

TeeLine1_8_9_10_11_12_170 := WRITEPRN("TeeLine1-8_9_10_11_12_170.prn" , vT)

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

FLANGES

Flange Strategy: *Search based on the nodes where flanges occur. Find the maximum moment combination for the node and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\mathrm{FlangeDC}\left(P, D_o, t, I, B_1, B_2, M, S\right) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$$\mathrm{Flange}\left(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL\right) :=$$

```
ind_nfi ← match(t_initial, nf^<0>)
ind_nfo ← match(t_final, nf^<0>)
ind_nd ← match(nd_0, EL^<1>)
for i ∈ 1 .. last(nd)                                   if rows(nd) > 1
  ind_nd ← stack[ind_nd, (match(nd_i, EL^<1>))]
(M  Int_0) ← (0  0)
for i ∈ 0 .. ind_nfo_0 − ind_nfi_0
  for j ∈ 0 .. last(ind_nd)
    M_rxg ← nf_{ind_nfi_{C_o0,1}+2, ind_nd_j}
    M_ryg ← nf_{ind_nfi_{C_o1,1}+2, ind_nd_j}
    M_rzg ← nf_{ind_nfi_{C_o2,1}+2, ind_nd_j}
    M_rx ← (nf_{ind_nfi_{C_o0,1}+2+i, ind_nd_j} − M_rxg)·C_o3,0 + M_rxg
    M_ry ← (nf_{ind_nfi_{C_o1,1}+2+i, ind_nd_j} − M_ryg)·C_o3,0 + M_ryg
    M_rz ← (nf_{ind_nfi_{C_o2,1}+2+i, ind_nd_j} − M_rzg)·C_o3,0 + M_rzg
    M'_j ← sqrt(M_rx^2 + M_ry^2 + M_rz^2)
    Int'_j ← FlangeDC(P, D_o, t, I, B_1, B_2, M'_j, S)
    if Int'_j > Int_0
      Int ← stack(Int'_j, M'_j, nf_{ind_nfi_{C_o0,1}−1+i, 0}, EL_{ind_nd_j, 1}, ind_nd_j, M_rx, M_ry, M
      Result ← M'
Int
```

Conditions applicable to all flanges

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$

Defining place holding variables

$$Flange\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties of Line 1-9, 1-10, 1-11, 1-12, & 1-170

Define pertinent pipe variables

$D_o := 20in$ — Outside Diameter [12,13,14]

$t := 0.312in$ — Thickness [12,13,14]

$P := 272psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\ 4} - (D_o - 2 \cdot t)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 935.251\ in^4$

Define primary stress indices (Utilize girth weld characteristic associated with lap joint flanges in determining values)

$B_1 := 0.5$ — B_1 for a girth weld [4, Table NB-3681(a)-1, pg 130]

$B_2 := 1$ — B_2 for a girth weld [4, Table NB-3681(a)-1, pg 130]

Flange (Heat Exchanger) 1-9 (Node 610)

$nd_{FL19} := (610)^T$

$AL_{FL19} := Flange(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{FL19}, Flange\_C_o, EL)$

$$AL_{FL19}^{\ T} = \begin{pmatrix} 0.189 & 5.174 \times 10^5 & 9.875 & 610 & 35 & 1.27 \times 10^5 & 1.882 \times 10^5 & 4.649 \times 10^5 \end{pmatrix}$$

Flange (Heat Exchanger) 1-10 (Node 607)

$nd_{FL110} := (607)^T$

$AL_{FL110} := Flange(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{FL110}, Flange\_C_o, EL)$

$$AL_{FL110}^{\ T} = \begin{pmatrix} 0.193 & 5.364 \times 10^5 & 13.6 & 607 & 37 & -2.738 \times 10^5 & -1.075 \times 10^5 & 4.486 \times 10^5 \end{pmatrix}$$

Flange (Heat Exchanger) 1-11 (Node 613)

$nd_{FL111} := (613)^T$

$AL_{FL111} := Flange(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{FL111}, Flange\_C_o, EL)$

$AL_{FL111}^T = (0.192 \quad 5.311 \times 10^5 \quad 9.87 \quad 613 \quad 39 \quad 1.999 \times 10^5 \quad 1.767 \times 10^5 \quad 4.592 \times 10^5)$

Flange (Heat Exchanger) 1-12 (Node 604)

$nd_{FL112} := (604)^T$

$AL_{FL112} := Flange(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{FL112}, Flange\_C_o, EL)$

$AL_{FL112}^T = (0.215 \quad 6.429 \times 10^5 \quad 13.605 \quad 604 \quad 41 \quad -3.699 \times 10^5 \quad -8.55 \times 10^4 \quad 5.188 \times 10^5)$

Flange (Heat Exchanger) 1-170 (Node 619)

$nd_{FL1170} := (619)^T$

$AL_{FL1170} := Flange(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{FL1170}, Flange\_C_o, EL)$

$AL_{FL1170}^T = (0.18 \quad 4.724 \times 10^5 \quad 9.24 \quad 619 \quad 47 \quad 4.329 \times 10^5 \quad 8.728 \times 10^4 \quad 1.678 \times 10^5)$

Writing Output Data for Flanges Associated with Lines 1-9, 1-10, 1-11, 1-12, & 1-170

$F1 := AL_{FL19}^T$

$F2 := AL_{FL110}^T$

$F3 := AL_{FL111}^T$

$F4 := AL_{FL112}^T$

$F5 := AL_{FL1170}^T$

$F := (F1 \quad F2 \quad F3 \quad F4 \quad F5)$

FlangeLine1_8_9_10_11_12_170B := WRITEPRN("FlangeLine1-8_9_10_11_12_170.prn" , F)

Appendix D.3.4

Demand to Capacity Ratio Calculations for Components Associated with Lines 1-34 and 1-67 of ATR PCS Model 1-4

(NOTE: Values represented here are shown for one realization (Nodal Force file = LINES1-34_67_test_R1.dat and Element/Nodal order file = EL1-34_67.xls) and may or may not be consistent with the 80th percentile results contained in Appendix D.4)

Force Outputs from Abaqus

NF := ...\LINE1-34_67.dat — (N)odal (F)orces for Model 1-4

Defined Elemental and Corresponding Nodal Order

EL := ..\EL_34_67(9-22-08).xls — Element and corresponding nodal order for Model 1-4

Time Boundaries

$t_{initial} := 1$ — Initial time for which dynamic loading is applied

$t_{final} := 21$ — Final time for which dynamic loading stops

Seismic Scale Factor (F_a)

$F_a := 1$ — Seismic scale factor [9]

Allowable Design Stress Intensity Factor (S_m): *S_m is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{m\_125} := 20ksi$ — For SS304 at 125°F [2, pg 316-318] [3, pg 23]

$S_{m\_125L} := 16.7ksi$ — For SS304L at 125°F [2, pg 316-318] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

$S_{m\_167} := 20ksi$ — For SS304 at 167°F [2, pg 316-318] [3, pg 23]

$S_{m\_167L} := 16.7ksi$ — For SS304L at 167°F [2, pg 316-318] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

Yield Strength (S_y): *S_y is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{y\_125} := 28.35ksi$ — For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_125L} := 23.85ksi$ — For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

$S_{y\_167} := 26.12ksi$ — For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_167L} := 22.26ksi$ — For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

Maximum Strength Applicable for Equation 9 (S): *S is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{125} := \min\left(3 \cdot S_{m\_125}, 2 \cdot S_{y\_125}\right)$

$S_{125} = 56.7\ \text{ksi}$

Maximum allowable stress applied to SS304 piping [4, NB-3656]

$S_{125L} := \min\left(3 \cdot S_{m\_125L}, 2 \cdot S_{y\_125L}\right)$

$S_{125L} = 47.7\ \text{ksi}$

Maximum allowable stress applied to SS304L piping [4, NB-3656]

$S_{167} := \min\left(3 \cdot S_{m\_167}, 2 \cdot S_{y\_167}\right)$

$S_{167} = 52.24\ \text{ksi}$

Maximum allowable stress applied to SS304 piping [4, NB-3656]

$S_{167L} := \min\left(3 \cdot S_{m\_167L}, 2 \cdot S_{y\_167L}\right)$

$S_{167L} = 44.52\ \text{ksi}$

Maximum allowable stress applied to SS304L piping [4, NB-3656]

SUPPORTS

Supports Strategy: *Search based on the node for which the support acts. If this node is a termination point there will only be one node to evaluate. If this node is in line with a section of pipe there will be two representations of the same node (one for each element on each side of the node) to combine and the difference between them is the force required of the support. The D/C ratio for each support will be found by dividing the the required force found above by the support capacity.*

$$SupDC(P_r, P_c) := \frac{P_r}{P_c}$$

$Support(nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow match(t_{initial}, nf^{\langle 0 \rangle})$

$ind_{nfo} \leftarrow match(t_{final}, nf^{\langle 0 \rangle})$

$ind_{nd} \leftarrow match(nd_0, EL^{\langle 1 \rangle})$

for $i \in 1..last(nd)$ if $rows(nd) > 1$

  $ind_{nd} \leftarrow stack[ind_{nd}, (match(nd_i, EL^{\langle 1 \rangle}))]$

$(Int1_4 \;\; Int2_4) \leftarrow (0 \;\; 0)$

for $i \in 0..ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0..last(ind_{nd})$

    $P_{rg_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}-1}, ind_{nd_j}}$

    $P_{r_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}-1}+i, ind_{nd_j}} - P_{rg_j}\right) \cdot C_{o_{2,0}} + P_{rg_j}$

  $PR_i \leftarrow \sum_{n=0}^{j} P_{r_n}$

  if $PR_i < Int1_1 \wedge C_{o_{0,0}} \neq 0$

    $Int1' \leftarrow SupDC(|PR_i|, C_{o_{0,0}})$

    $Int_1 \leftarrow stack\left(Int1', PR_i, nf_{ind_{nfiC_{o_{0,1}}-1}+i,0}, EL_{ind_{nd_j},1}, ind_{nd}\right)$

  if $PR_i > Int2_1 \wedge C_{o_{1,0}} \neq 0$

    $Int2' \leftarrow SupDC(|PR_i|, C_{o_{1,0}})$

    $Int_2 \leftarrow stack\left(Int2', PR_i, nf_{ind_{nfiC_{o_{0,1}}-1}+i,0}, EL_{ind_{nd_j},1}, ind_{nd}\right)$

$(Int_1 \;\; Int_2)$

RH-14 Support (3x)

$P_{1\_RH14} := \frac{10.354 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_RH14} := \frac{0.104 kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_RH14} := \begin{pmatrix} P_{1\_RH14} & 2 \\ P_{2\_RH14} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3

RH-14a (Node 1363)

RH-14a vertically supports the horizontal PCS pipe on line 1-34 traveling west from EL(1-34B).

$nd1363_{RH14a_0} := 1363$ Node associated with support

$$\left(AL1_{RH14a\_nd1363} \quad AL2_{RH14a\_nd1363}\right) := Support\left(NF, nd1363_{RH14a}, Sup\_C_{o\_RH14}, EL\right)$$

$$AL1_{RH14a\_nd1363}{}^{T} = \left(0.337 \quad -3.487 \times 10^{3} \quad 13.64 \quad 1.363 \times 10^{3} \quad 83\right)$$

$$AL2_{RH14a\_nd1363}{}^{T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0\right)$$

(Demand force, occurrence time, node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-14b (Node 1364)

RH-14b vertically supports the horizontal PCS pipe on line 1-34 traveling west from RH-14a.

$nd1364_{RH14b_0} := 1364$ Node associated with support

$$\left(AL1_{RH14b\_nd1364} \quad AL2_{RH14b\_nd1364}\right) := Support\left(NF, nd1364_{RH14b}, Sup\_C_{o\_RH14}, EL\right)$$

$$AL1_{RH14b\_nd1364}{}^{T} = \left(0.581 \quad -6.013 \times 10^{3} \quad 15.17 \quad 1.364 \times 10^{3} \quad 85\right)$$

$$AL2_{RH14b\_nd1364}{}^{T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0\right)$$

(Demand force, occurrence time, node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-14c (Node 1365)

RH-14c vertically supports the horizontal PCS pipe on line 1-34 traveling west from RH-14b.

$nd1365_{RH14c_0} := 1365$ Node associated with support

$$\left(AL1_{RH14c\_nd1365} \quad AL2_{RH14c\_nd1365}\right) := Support\left(NF, nd1365_{RH14c}, Sup\_C_{o\_RH14}, EL\right)$$

$$AL1_{RH14c\_nd1365}{}^{T} = \left(0.402 \quad -4.162 \times 10^{3} \quad 8.295 \quad 1.365 \times 10^{3} \quad 81\right)$$

$$AL2_{RH14c\_nd1365}{}^{T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0\right)$$

(Demand force, occurrence time, node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate

system)

PS-20A Supports (1x)

$P_{1\_PS20A\_NS} := \frac{2.789 \cdot kip}{lbf}$ ***Flexure*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_PS20A\_NS} := \frac{2.789 \cdot kip}{lbf}$ ***Flexure*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_PS20A\_NS} := \begin{pmatrix} P_{1\_PS20A\_NS} & 1 \\ P_{2\_PS20A\_NS} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

$P_{1\_PS20A\_V} := \frac{8.518 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_PS20A\_V} := \frac{5.763 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_PS20A\_V} := \begin{pmatrix} P_{1\_PS20A\_V} & 2 \\ P_{2\_PS20A\_V} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

PS-20A North/South (Node 1381)

PS-20A vertically and laterally supports the horizontal PCS pipe on line 1-34 between RH-14a and RH-14b.

$nd1381_{PS20A\_NS_0} := 1381$ Node associated with support

$$\left(AL1_{PS20A\_NS\_nd1381} \;\; AL2_{PS20A\_NS\_nd1381}\right) := Support\left(NF, nd1381_{PS20A\_NS}, Sup\_C_{o\_PS20A\_NS}, EL\right)$$

$$AL1_{PS20A\_NS\_nd1381}^{T} = \left(0.251 \;\; -700.319 \;\; 9.875 \;\; 1.381 \times 10^{3} \;\; 87\right)$$

d force, occurrence time, e, associated Index for the reaction force at the selected node

$$AL2_{PS20A\_NS\_nd1381}^{T} = \left(0.143 \;\; 398.208 \;\; 7.325 \;\; 1.381 \times 10^{3} \;\; 87\right)$$

e positive (AL1) and negative tions of the global coordinate system)

PS-20A Vertical (Node 1388)

PS-20A vertically and laterally supports the horizontal PCS pipe on line 1-34 between RH-14a and RH-14b.

$nd1388_{PS20A\_V_0} := 1388$ Node associated with support

$$\left(AL1_{PS20A\_V\_nd1388} \;\; AL2_{PS20A\_V\_nd1388}\right) := Support\left(NF, nd1388_{PS20A\_V}, Sup\_C_{o\_PS20A\_V}, EL\right)$$

$$AL1_{PS20A\_V\_nd1388}^{T} = \left(0.162 \;\; -1.381 \times 10^{3} \;\; 10.06 \;\; 1.388 \times 10^{3} \;\; 89\right)$$

force, occurrence time, associated Index for the reaction force at the selected node

$$AL2_{PS20A\_V\_nd1388}^{T} = \left(1.089 \;\; 6.278 \times 10^{3} \;\; 15.175 \;\; 1.388 \times 10^{3} \;\; 89\right)$$

ositive (AL1) and negative ns of the global coordinate

system)

PS-14 Supports (2x)

$P_{1\_PS14} := \frac{22.106 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_PS14} := \frac{0 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_PS14} := \begin{pmatrix} P_{1\_PS14} & 2 \\ P_{2\_PS14} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

PS-14A Vertical (Node 1433)

PS-14A vertically supports the horizontal PCS pipe on line 1-34 east of REL(1-34D).

$nd1433_{PS14A_0} := 1433$ Node associated with support

$$\left(AL1_{PS14A\_nd1433} \quad AL2_{PS14A\_nd1433}\right) := Support\left(NF, nd1433_{PS14A}, Sup\_C_{o\_PS14}, EL\right)$$

$$AL1_{PS14A\_nd1433}{}^{T} = \left(0.067 \quad -1.481 \times 10^{3} \quad 5.015 \quad 1.433 \times 10^{3} \quad 101\right)$$

$$AL2_{PS14A\_nd1433}{}^{T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0\right)$$

...d force, occurrence time, ..., associated Index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PS-14B Vertical (Node 1434)

PS-14B vertically supports the horizontal PCS pipe on line 1-34 west of EL(1-34E).

$nd1444_{PS14B_0} := 1434$ Node associated with support

$$\left(AL1_{PS14B\_nd1444} \quad AL2_{PS14B\_nd1444}\right) := Support\left(NF, nd1444_{PS14B}, Sup\_C_{o\_PS14}, EL\right)$$

$$AL1_{PS14B\_nd1444}{}^{T} = \left(0.099 \quad -2.179 \times 10^{3} \quad 7.1 \quad 1.434 \times 10^{3} \quad 103\right)$$

$$AL2_{PS14B\_nd1444}{}^{T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0\right)$$

...and force, occurrence time, ...de, associated Index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

Writing Output Data for Supports Associated with Lines 1-13 to 1-16, 1-18 to 1-21, and 1-171.

$SA1 := {AL1_{RH14a\_nd1363}}^T$

$SA2 := {AL2_{RH14a\_nd1363}}^T$

$SB1 := {AL1_{RH14b\_nd1364}}^T$

$SB2 := {AL2_{RH14b\_nd1364}}^T$

$SC1 := {AL1_{RH14c\_nd1365}}^T$

$SC2 := {AL2_{RH14c\_nd1365}}^T$

$SD1 := {AL1_{PS20A\_NS\_nd1381}}^T$

$SD2 := {AL2_{PS20A\_NS\_nd1381}}^T$

$SE1 := {AL1_{PS20A\_V\_nd1388}}^T$

$SE2 := {AL2_{PS20A\_V\_nd1388}}^T$

$SF1 := {AL1_{PS14A\_nd1433}}^T$

$SF2 := {AL2_{PS14A\_nd1433}}^T$

$SG1 := {AL1_{PS14B\_nd1444}}^T$

$SG2 := {AL2_{PS14B\_nd1444}}^T$

$S := (SA1\ \ SA2\ \ SB1\ \ SB2\ \ SC1\ \ SC2\ \ SD1\ \ SD2\ \ SE1\ \ SE2\ \ SF1\ \ SF2\ \ SG1\ \ SG2)$

SupportsLine1_34_67 := WRITEPRN("SupLine1-34_67.prn" , S)

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TERMINATION LOCATIONS

Termination Locations Strategy: *Search based on the node for which the termination location acts as well as the next node inward. The D/C ratio for each termination location will be found by dividing the the required force found above by the support capacity.*

$$\text{TermDC}\left(P, D_o, t, I, B_1, B_2, M, S\right) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

$\text{Term}\left(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL\right) :=$

$$\begin{aligned}
&ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
&ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
&ind_{nd} \leftarrow \text{match}\left(nd_0, EL^{\langle 1 \rangle}\right) \\
&\text{for } i \in 1 .. \text{last}(nd) \quad \text{if rows}(nd) > 1 \\
&\quad ind_{nd} \leftarrow \text{stack}\left[ind_{nd}, \left(\text{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \\
&\left(M \;\; Int_0\right) \leftarrow (0 \;\; 0) \\
&\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0} \\
&\quad \text{for } j \in 0 .. \text{last}\left(ind_{nd}\right) \\
&\qquad M_{rxg} \leftarrow nf_{ind_{nfi}{C_o}_{0,1}+2,\, ind_{nd_j}} \\
&\qquad M_{ryg} \leftarrow nf_{ind_{nfi}{C_o}_{1,1}+2,\, ind_{nd_j}} \\
&\qquad M_{rzg} \leftarrow nf_{ind_{nfi}{C_o}_{2,1}+2,\, ind_{nd_j}} \\
&\qquad M_{rx} \leftarrow \left(nf_{ind_{nfi}{C_o}_{0,1}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot {C_o}_{3,0} + M_{rxg} \\
&\qquad M_{ry} \leftarrow \left(nf_{ind_{nfi}{C_o}_{1,1}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot {C_o}_{3,0} + M_{ryg} \\
&\qquad M_{rz} \leftarrow \left(nf_{ind_{nfi}{C_o}_{2,1}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot {C_o}_{3,0} + M_{rzg} \\
&\qquad M'_j \leftarrow \sqrt{{M_{rx}}^2 + {M_{ry}}^2 + {M_{rz}}^2} \\
&\qquad Int'_j \leftarrow \text{TermDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right) \\
&\qquad \text{if } Int'_j > Int_0 \\
&\qquad\quad Int \leftarrow \text{stack}\left(Int'_j, M'_j, nf_{ind_{nfi}{C_o}_{0,1}-1+i,0}, EL_{ind_{nd_j},1}, ind_{nd_j}, M_{rx}, M_{ry}, M_{r}\right. \\
&\qquad\quad Result \leftarrow M' \\
&Int
\end{aligned}$$

Conditions applicable to all terminations

$M_{cx} := 0$ $M_{cy} := 0$ $M_{cz} := 0$

Defining place holding variables

$$Term\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Primary Degassing Tank (1x)

Define pertinent pipe variables

$D_o := 4.5in$ — Outside Diameter [4]

$t := 0.237in$ — Thickness [4]

$P := 272psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 7.233\ in^4$

$S := S_{167}$ — Allowable design stress intensity value

Define primary stress indices

$B_1 := 0.5$

$$B_2 := \left| \begin{array}{l} 1.0 \ \text{ if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 \\ \quad \left| \begin{array}{l} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \frac{D_o}{t}\right) \\ Y \leftarrow 1 \\ 1.0 \cdot \frac{1}{X \cdot Y} \end{array} \right. \end{array} \right.$$

$B_2 = 1$

Stress Indices are derived from [4, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [4, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Primary Degassing Tank 1-67 (Node 974)

$nd974_{PDT167_0} := 974$

$AL_{PDT167\_nd974} := Term\left(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd974_{PDT167}, Term\_C_o, EL\right)$

$$AL_{PDT167\_nd974}^{T} = \left(0.169 \quad 2.42\times10^{4} \quad 8.41 \quad 974 \quad 44 \quad -5.356\times10^{3} \quad -2.356\times10^{4} \quad 1.286\times10^{3}\right)$$

Writing Output Data for Terminations Associated with Lines 1-34 & 1-67

$T1 := AL_{PDT167\_nd974}^{T}$

$T := (T1)$

TerminationsLine1_34_67 := WRITEPRN("TermLine1-34_67.prn" , T)

PIPE RUNS

Pipe Runs Strategy: *Search based on the nodes present in each run of pipe. Find the maximum moment combination among all of the nodes and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation.*

$$\text{PipeRunDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

$\text{PipeRun}(P, D_o, t, I, B_1, B_2, S, nf, el, C_o, EL) :=$

$ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{el} \leftarrow \text{match}\left(el_0, EL^{\langle 0 \rangle}\right)$

$\text{for } i \in 1..\text{last}(el)$ $\quad$ if rows(el) > 1

$\quad ind_{el} \leftarrow \text{stack}\left[ind_{el}, \left(\text{match}\left(el_i, EL^{\langle 0 \rangle}\right)\right)\right]$

$\left(M \quad Int_{5,\text{last}(ind_{el})}\right) \leftarrow (0 \quad 0)$

$\text{for } i \in 0..ind_{nfo_0} - ind_{nfi_0}$

$\quad \text{for } j \in 0..\text{last}(ind_{el})$

$\quad\quad M_{rxg} \leftarrow nf_{ind_{nfi}C_{o_{0,1}}+2,\, ind_{el_j}}$

$\quad\quad M_{ryg} \leftarrow nf_{ind_{nfi}C_{o_{1,1}}+2,\, ind_{el_j}}$

$\quad\quad M_{rzg} \leftarrow nf_{ind_{nfi}C_{o_{2,1}}+2,\, ind_{el_j}}$

$\quad\quad M_{rx_j} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}}+2+i,\, ind_{el_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

$\quad\quad M_{ry_j} \leftarrow \left(nf_{ind_{nfi}C_{o_{1,1}}+2+i,\, ind_{el_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

$\quad\quad M_{rz_j} \leftarrow \left(nf_{ind_{nfi}C_{o_{2,1}}+2+i,\, ind_{el_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

$\quad\quad M'_j \leftarrow \sqrt{\left(M_{rx_j}\right)^2 + \left(M_{ry_j}\right)^2 + \left(M_{rz_j}\right)^2}$

$\quad\quad Int'_j \leftarrow \text{PipeRunDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$

$\quad\quad \text{if } Int'_j > Int_{0,j}$

$\quad\quad\quad H \leftarrow \left(Int'_j \quad M'_j \quad nf_{ind_{nfi}C_{o_{0,1}}-1+i,\,0} \quad EL_{ind_{el_j},0} \quad EL_{ind_{el_j},1} \quad ind_{el_j} \quad M_{r}\right.$

$\quad\quad\quad \text{for } k \in 0..5$

$\quad\quad\quad\quad Int_{k,j} \leftarrow H_k$

$|\text{Int}$

Conditions applicable to all pipe runs

$M_{ox} := 0 \quad M_{oy} := 0 \quad M_{oz} := 0$

Defining place holding directional moment variables

$$PipeRun\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties for Lines 1-34(A-C)

Define pertinent pipe variables

$D_o := 6.625\,in$ — Outside Diameter [15]

$t := 0.28\,in$ — Thickness [15]

$P := 272\,psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 28.142\,in^4$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{cases} 1.0 & \text{if } \dfrac{D_o}{t} \le 50 \\ \begin{aligned} & T \leftarrow 125 \\ & X \leftarrow \min\left(1, 1.3 - 0.006\cdot\dfrac{D_o}{t}\right) \\ & Y \leftarrow 1.033 - 0.00033\cdot T \\ & 1.0\cdot\dfrac{1}{X\cdot Y} \end{aligned} & \text{if } \dfrac{D_o}{t} > 50 \end{cases}$$

$B_{2PR} = 1$

Stress Indices are derived from [4, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [4, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-34A (Elements 316 & 154)

$el_{P134A} := (316 \quad 154)^T$

$AL_{P134A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167}, NF, el_{P134A}, PipeRun\_C_o, EL\right)$

$$AL_{P134A}^{\ T} = \begin{pmatrix} 0.175 & 6.38\times10^4 & 15.17 & 316 & 756 & 30 \\ 0.19 & 7.084\times10^4 & 15.17 & 316 & 946 & 31 \\ 0.091 & 2.653\times10^4 & 7.695 & 154 & 762 & 5 \\ 0.127 & 4.27\times10^4 & 13.615 & 154 & 763 & 6 \end{pmatrix}$$

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Pipe Run 1-34B (Elements 155, 980, 236, 625, 982, 239, 981, 979, 242, 983, 984, 243, 635, 248, 974, 975, 976, 977, 640, 249, & 978)

$el_{P134B} := (155\ \ 980\ \ 236\ \ 625\ \ 982\ \ 239\ \ 981\ \ 979\ \ 242\ \ 983\ \ 984\ \ 243\ \ 635\ \ 248\ \ 974\ \ 975\ \ 976\ \ 977\ \ 640\ \ 249$

$AL_{P134B} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167}, NF, el_{P134B}, PipeRun\_C_o, EL\right)$

$AL_{P134B}^T =$

	0	1	2	3	4	5
0	0.127	$4.265\cdot10^4$	9.195	155	761	7
1	0.114	$3.714\cdot10^4$	9.885	155	$1.683\cdot10^3$	8
2	0.106	$3.351\cdot10^4$	9.88	980	854	118
3	0.114	$3.714\cdot10^4$	9.885	980	$1.683\cdot10^3$	119
4	0.106	$3.351\cdot10^4$	9.88	236	854	18
5	0.109	$3.486\cdot10^4$	9.88	236	$1.286\cdot10^3$	19
6	0.109	$3.487\cdot10^4$	9.88	625	$1.286\cdot10^3$	70
7	0.095	$2.858\cdot10^4$	9.88	625	$1.685\cdot10^3$	71
8	0.097	$2.953\cdot10^4$	9.88	982	856	122
9	0.095	$2.858\cdot10^4$	9.88	982	$1.685\cdot10^3$	123
10	0.097	$2.954\cdot10^4$	9.88	239	856	20
11	0.126	$4.204\cdot10^4$	13.62	239	$1.684\cdot10^3$	21
12	0.182	$6.725\cdot10^4$	13.63	981	859	120
13	0.126	$4.204\cdot10^4$	13.62	981	$1.684\cdot10^3$	121
14	0.183	$6.738\cdot10^4$	13.63	979	859	116
15	0.131	$4.446\cdot10^4$	13.625	979	860	117
16	0.131	$4.448\cdot10^4$	13.625	242	860	22
17	0.083	$2.303\cdot10^4$	7.68	242	$1.686\cdot10^3$	23
18	0.083	$2.303\cdot10^4$	7.68	983	$1.686\cdot10^3$	124
19	0.164	$5.93\cdot10^4$	15.18	983	$1.687\cdot10^3$	125
20	0.255	$9.95\cdot10^4$	15.18	984	862	126
21	0.164	$5.93\cdot10^4$	15.18	984	$1.687\cdot10^3$	127
22	0.255	$9.95\cdot10^4$	15.18	243	862	24
23	0.104	$3.261\cdot10^4$	13.685	243	$1.296\cdot10^3$	25
24	0.189	$7.038\cdot10^4$	9.225	635	863	72
25	0.104	$3.261\cdot10^4$	13.685	635	$1.296\cdot10^3$	73
26	0.189	$7.004\cdot10^4$	9.225	248	863	26
27	0.138	$4.766\cdot10^4$	9.88	248	$1.678\cdot10^3$	27
28	0.138	$4.766\cdot10^4$	9.88	974	$1.678\cdot10^3$	106
29	0.111	$3.538\cdot10^4$	9.88	974	$1.679\cdot10^3$	107
30	0.111	$3.538\cdot10^4$	9.88	975	$1.679\cdot10^3$	108
31	0.127	$4.27\cdot10^4$	8.405	975	$1.68\cdot10^3$	109
32	0.127	$4.27\cdot10^4$	8.405	976	$1.68\cdot10^3$	110
33	0.146	$5.135\cdot10^4$	8.405	976	$1.681\cdot10^3$	111
34	0.159	$5.681\cdot10^4$	8.405	977	$1.301\cdot10^3$	112
35	0.146	$5.134\cdot10^4$	8.405	977	$1.681\cdot10^3$	113
36	0.13	$4.419\cdot10^4$	9.25	640	868	74
37	0.159	$5.687\cdot10^4$	8.405	640	$1.301\cdot10^3$	75
38	0.13	$4.409\cdot10^4$	9.25	249	868	28
39	0.125	$4.197\cdot10^4$	15.165	249	$1.682\cdot10^3$	29
40	0.139	$4.803\cdot10^4$	15.17	978	765	114
41	0.125	$4.197\cdot10^4$	15.165	978	$1.682\cdot10^3$	115

Pipe Run 1-34C (Elements 471, 985, & 986)

$$el_{P134C} := (471 \quad 985 \quad 986)^T$$

$$AL_{P134C} := \text{PipeRun}\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167}, NF, el_{P134C}, \text{PipeRun\_C}_o, EL\right)$$

$$AL_{P134C}^{\ T} = \begin{pmatrix} 0.128 & 4.305\times10^4 & 15.17 & 471 & 764 & 32 \\ 0.089 & 2.6\times10^4 & 13.65 & 471 & 1.688\times10^3 & 33 \\ 0.089 & 2.6\times10^4 & 13.65 & 985 & 1.688\times10^3 & 128 \\ 0.066 & 1.556\times10^4 & 7.46 & 985 & 1.689\times10^3 & 129 \\ 0.084 & 2.346\times10^4 & 9.265 & 986 & 1.127\times10^3 & 130 \\ 0.066 & 1.555\times10^4 & 7.46 & 986 & 1.689\times10^3 & 131 \end{pmatrix}$$

Pipe Properties for Lines 1-34(D-I)

Define pertinent pipe variables

$D_o := 4.5in$ — Outside Diameter [15]

$t := 0.237in$ — Thickness [15]

$P := 272psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\ 4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$ — Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 7.233\ in^4$$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{cases} 1.0 \ \text{if} \ \frac{D_o}{t} \le 50 \\ \text{if} \ \frac{D_o}{t} > 50 \\ \quad T \leftarrow 125 \\ \quad X \leftarrow \min\left(1, 1.3 - 0.006\cdot\frac{D_o}{t}\right) \\ \quad Y \leftarrow 1.033 - 0.00033\cdot T \\ \quad 1.0\cdot\frac{1}{X\cdot Y} \end{cases}$$

$B_{2PR} = 1$

Stress Indices are derived from [4, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [4, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-34D (Element 472 & 645)

$el_{P134D} := (472 \quad 645)^T$

$AL_{P134D} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167}, NF, el_{P134D}, PipeRun\_C_o, EL)$

$$AL_{P134D}^T = \begin{pmatrix} 0.197 & 2.899 \times 10^4 & 9.265 & 472 & 1.128 \times 10^3 & 34 \\ 0.197 & 2.891 \times 10^4 & 9.2 & 472 & 1.306 \times 10^3 & 35 \\ 0.174 & 2.504 \times 10^4 & 9.265 & 645 & 1.129 \times 10^3 & 76 \\ 0.183 & 2.661 \times 10^4 & 9.265 & 645 & 1.306 \times 10^3 & 77 \end{pmatrix}$$

Pipe Run 1-34E (Element 473 & 646)

$el_{P134E} := (473 \quad 646)^T$

$AL_{P134E} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167}, NF, el_{P134E}, PipeRun\_C_o, EL)$

$$AL_{P134E}^T = \begin{pmatrix} 0.119 & 1.583 \times 10^4 & 9.95 & 473 & 1.13 \times 10^3 & 36 \\ 0.119 & 1.577 \times 10^4 & 9.95 & 473 & 1.307 \times 10^3 & 37 \\ 0.094 & 1.171 \times 10^4 & 5.99 & 646 & 1.003 \times 10^3 & 78 \\ 0.102 & 1.3 \times 10^4 & 5.99 & 646 & 1.307 \times 10^3 & 79 \end{pmatrix}$$

Pipe Run 1-34F (Element 474 & 581)

$el_{P134F} := (474 \quad 581)^T$

$AL_{P134F} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167}, NF, el_{P134F}, PipeRun\_C_o, EL)$

$$AL_{P134F}^T = \begin{pmatrix} 0.089 & 1.086 \times 10^4 & 9.58 & 474 & 1.002 \times 10^3 & 38 \\ 0.087 & 1.046 \times 10^4 & 9.585 & 474 & 1.24 \times 10^3 & 39 \\ 0.089 & 1.071 \times 10^4 & 8.41 & 581 & 1.007 \times 10^3 & 68 \\ 0.087 & 1.046 \times 10^4 & 9.585 & 581 & 1.24 \times 10^3 & 69 \end{pmatrix}$$

Pipe Run 1-34G (Element 475)

$el_{P134G} := (475)^T$

$AL_{P134G} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167}, NF, el_{P134G}, PipeRun\_C_o, EL)$

$$AL_{P134G}^T = \begin{pmatrix} 0.073 & 8.129 \times 10^3 & 15.14 & 475 & 1.006 \times 10^3 & 40 \\ 0.087 & 1.04 \times 10^4 & 10.155 & 475 & 1.01 \times 10^3 & 41 \end{pmatrix}$$

Pipe Run 1-34H (Element 476)

$el_{P134H} := (476)^T$

$AL_{P134H} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167}, NF, el_{P134H}, PipeRun\_C_o, EL)$

$$AL_{P134H}{}^T = \begin{pmatrix} 0.094 & 1.155\times10^4 & 10.155 & 476 & 1.011\times10^3 & 42 \\ 0.112 & 1.472\times10^4 & 10.15 & 476 & 1.015\times10^3 & 43 \end{pmatrix}$$

Pipe Run 1-34I (Element 477)

$el_{P134I} := (477)^T$

$AL_{P134I} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{167}, NF, el_{P134I}, PipeRun\_C_o, EL)$

$$AL_{P134I}{}^T = \begin{pmatrix} 0.169 & 2.42\times10^4 & 8.41 & 477 & 974 & 44 \\ 0.122 & 1.641\times10^4 & 10.15 & 477 & 1.014\times10^3 & 45 \end{pmatrix}$$

Writing Output Data for Pipe Runs Associated with Lines 1-34 & 1-67

$PR1 := AL_{P134A}{}^T$

$PR2 := AL_{P134B}{}^T$

$PR3 := AL_{P134C}{}^T$

$PR4 := AL_{P134D}{}^T$

$PR5 := AL_{P134E}{}^T$

$PR6 := AL_{P134F}{}^T$

$PR7 := AL_{P134G}{}^T$

$PR8 := AL_{P134H}{}^T$

$PR9 := AL_{P134I}{}^T$

$P := (PR1\ \ PR2\ \ PR3\ \ PR4\ \ PR5\ \ PR6\ \ PR7\ \ PR8\ \ PR9)$

PipeRunsLine1_34_67 := WRITEPRN("PRLine1-34_67.prn" , P)

ELBOWS

Elbows Strategy: *Search based on the two nodes comprising the ends of each elbow. SRSS combine the three moments of each of the four node representations (one for each element connected by the nodes in question). Find the maximum of the four moment combinations and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$ElbowDC(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1 lbf \cdot in)]}{S}$$

$Elbow(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow match\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. last(nd)$ if $rows(nd) > 1$

  $ind_{nd} \leftarrow stack\left[ind_{nd}, \left(match\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$(M \quad Int_0) \leftarrow (0 \quad 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. last(ind_{nd})$

    $M_{rxg} \leftarrow nf_{ind_{nfi C_{o_{0,1}}}+2, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi C_{o_{1,1}}}+2, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi C_{o_{2,1}}}+2, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi C_{o_{0,1}}}+2+i, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi C_{o_{1,1}}}+2+i, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi C_{o_{2,1}}}+2+i, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow ElbowDC(P, D_o, t, I, B_1, B_2, M'_j, S)$

    if $Int'_j > Int_0$

      $Int \leftarrow stack\left(Int'_j, M'_j, nf_{ind_{nfi C_{o_{0,1}}}-1+i, 0}, EL_{ind_{nd_j}, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M\right.$

      $Result \leftarrow M'$

Int

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Conditions applicable to all elbows

$M_{cx} := 0 \quad M_{cy} := 0 \quad M_{cz} := 0$

Defining place holding variables

$$Elb\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Elbow Properties for EL(1-34(A-C))

Define pertinent elbow variables

$D_o := 6.625\,in$ — Outside Diameter [15]

$t := 0.28\,in$ — Thickness [15]

$P := 272\,psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

$I = 28.142\,in^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$R := 9\,in$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$

Mean pipe radius

Define primary stress indices

$$h := \frac{t\cdot R}{r_m^{\,2}}$$

$h = 0.25$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4\cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4\cdot h > 0.5 \\ -0.1 + 0.4\cdot h & \text{otherwise} \end{cases}$$

$B_1 = 1.515 \times 10^{-4}$ — B_1 primary stress Index [4, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 3.272$ — B_2 primary stress Index [4, NB-3683.7]

Elbow 1-34A (Nodes 756 & 763)

$nd_{EL134A\_1} := (756)^T$

$AL_{EL134A\_nd756} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL134A\_1}, Elb\_C_o, EL)$

$AL_{EL134A\_nd756}^T = \begin{pmatrix} 0.433 & 6.38 \times 10^4 & 15.17 & 756 & 30 & -1.753 \times 10^4 & 6.091 \times 10^4 & 7.275 \times 10^3 \end{pmatrix}$

$nd_{EL134A\_2} := (763)^T$

$AL_{EL134A\_nd763} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL134A\_2}, Elb\_C_o, EL)$

$AL_{EL134A\_nd763}^T = \begin{pmatrix} 0.29 & 4.27 \times 10^4 & 13.615 & 763 & 16 & 1.991 \times 10^3 & 4.211 \times 10^4 & 6.827 \times 10^3 \end{pmatrix}$

Elbow 1-34B (Nodes 762 & 761)

$nd_{EL134B\_1} := (762)^T$

$AL_{EL134B\_nd762} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL134B\_1}, Elb\_C_o, EL)$

$AL_{EL134B\_nd762}^T = \begin{pmatrix} 0.18 & 2.653 \times 10^4 & 7.695 & 762 & 13 & 5.412 \times 10^3 & -2.567 \times 10^4 & -3.921 \times 10^3 \end{pmatrix}$

$nd_{EL134B\_2} := (761)^T$

$AL_{EL134B\_nd761} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL134B\_2}, Elb\_C_o, EL)$

$AL_{EL134B\_nd761}^T = \begin{pmatrix} 0.29 & 4.265 \times 10^4 & 9.195 & 761 & 7 & 1.309 \times 10^4 & -4.059 \times 10^4 & 130.023 \end{pmatrix}$

Elbow 1-34C (Nodes 765 & 764)

$nd_{EL134C\_1} := (765)^T$

$AL_{EL134C\_nd765} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL134C\_1}, Elb\_C_o, EL)$

$AL_{EL134C\_nd765}^T = \begin{pmatrix} 0.326 & 4.803 \times 10^4 & 15.17 & 765 & 114 & 4.169 \times 10^3 & 4.785 \times 10^4 & -326.482 \end{pmatrix}$

$nd_{EL134C\_2} := (764)^T$

$AL_{EL134C\_nd764} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL134C\_2}, Elb\_C_o, EL)$

$AL_{EL134C\_nd764}^T = \begin{pmatrix} 0.292 & 4.305 \times 10^4 & 15.17 & 764 & 9 & 4.21 \times 10^3 & 4.284 \times 10^4 & -239.813 \end{pmatrix}$

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Elbow Properties for REL(1-34D)

Define pertinent elbow variables

$D_{oL} := 6.625in$ — Outside Diameter of larger end segment [15]

$D_{oS} := 4.5in$ — Outside Diameter of smaller end segment [15]

$t_L := 0.28in$ — Thickness of smaller end segment [15]

$t_S := 0.237in$ — Thickness of larger end segment

$P := 272psi$ — Internal Pressure [3, pg 23]

$$I_L := \frac{\pi \cdot \left[D_{oL}^4 - \left(D_{oL} - 2 \cdot t_L\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I_L = 28.142\ in^4$$

$$I_S := \frac{\pi \cdot \left[D_{oS}^4 - \left(D_{oS} - 2 \cdot t_S\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I_S = 7.233\ in^4$$

$R_L := 9in$ — Nominal bend radius of curved pipe or elbow

$R_S := 9in$

$$r_{mL} := \frac{D_{oL} - t_L}{2}$$ Mean pipe radius

$$r_{mS} := \frac{D_{oS} - t_S}{2}$$ Mean pipe radius

Define primary stress indices for large end segment

$$h_L := \frac{t_L \cdot R_L}{r_{mL}^2} \qquad h_L = 0.25$$

Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_{1L} := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h_L < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h_L > 0.5 \\ -0.1 + 0.4 \cdot h_L & \text{otherwise} \end{cases}$$

$B_{1L} = 1.515 \times 10^{-4}$ B_1 primary stress Index [4, NB-3683.7]

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$$B_{2L} := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h_L^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h_L^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_{2L} = 3.272$ — B_2 primary stress Index [4, NB-3683.7]

Define primary stress indices for small end segment

$$h_S := \frac{t_S \cdot R_S}{r_{mS}^{\,2}}$$

$h_S = 0.469$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_{1S} := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h_S < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h_S > 0.5 \\ -0.1 + 0.4 \cdot h_S & \text{otherwise} \end{cases}$$

$B_{1S} = 0.088$ — B_1 primary stress Index [4, NB-3683.7]

$$B_{2S} := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h_S^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h_S^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_{2S} = 2.152$ — B_2 primary stress Index [4, NB-3683.7]

Reducing Elbow Large Section 1-34D (Nodes 1127 & 1133)

$nd_{REL134D\_1L} := (1127)^T$

$AL_{REL134D\_nd1127L} := Elbow(P, D_{oL}, t_L, I_L, B_{1L}, B_{2L}, S_{167}, NF, nd_{REL134D\_1L}, Elb\_C_o, EL)$

$AL_{REL134D\_nd1127L}^{\;T} = (0.173 \;\; 2.346 \times 10^4 \;\; 9.265 \;\; 1.127 \times 10^3 \;\; 58 \;\; -1.6 \times 10^3 \;\; -2.311 \times 10^4 \;\; 3.738$

$nd_{REL134D\_2L} := (1133)^T$

$AL_{REL134D\_nd1133L} := Elbow(P, D_{oL}, t_L, I_L, B_{1L}, B_{2L}, S_{167}, NF, nd_{REL134D\_2L}, Elb\_C_o, EL)$

$AL_{REL134D\_nd1133L}^{\;T} = (0.206 \;\; 2.789 \times 10^4 \;\; 9.265 \;\; 1.133 \times 10^3 \;\; 59 \;\; 1.131 \times 10^3 \;\; 2.773 \times 10^4 \;\; -2.79$

Reducing Elbow Small Section 1-34D (Nodes 1133 & 1128)

$nd_{REL134D\_1S} := (1133)^T$

$AL_{REL134D\_nd1133S} := Elbow(P, D_{oS}, t_S, I_S, B_{1S}, B_{2S}, S_{167}, NF, nd_{REL134D\_1S}, Elb\_C_o, EL)$

$AL_{REL134D\_nd1133S}^{\;T} = (0.362 \;\; 2.789 \times 10^4 \;\; 9.265 \;\; 1.133 \times 10^3 \;\; 59 \;\; 1.131 \times 10^3 \;\; 2.773 \times 10^4 \;\; -2.79$

$nd_{REL134D\_2S} := (1128)^T$

$AL_{REL134D\_nd1128S} := Elbow(P, D_{oS}, t_S, I_S, B_{1S}, B_{2S}, S_{167}, NF, nd_{REL134D\_2S}, Elb\_C_o, EL)$

$AL_{REL134D\_nd1128S}^{\;T} = (0.376 \;\; 2.899 \times 10^4 \;\; 9.265 \;\; 1.128 \times 10^3 \;\; 34 \;\; 958.866 \;\; -2.89 \times 10^4 \;\; 1.984 \times 1$

Project:	ATR Life-Time Extension Project			**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation						
Performer:	A. L. Crawford	**Date:**	09/30/2008	**Checker:**	M. D. Landon	**Date:**	09/30/2008

Elbow Properties for EL(1-34(E, G, H))

Define pertinent elbow variables

$D_o := 4.5in$ — Outside Diameter [15]

$t := 0.237in$ — Thickness [15]

$P := 272psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - (D_o - 2\cdot t)^4\right]}{64}$$

$I = 7.233\ in^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$R := 6in$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$ — Mean pipe radius

Define primary stress indices

$$h := \frac{t\cdot R}{r_m^{\,2}}$$ $h = 0.313$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4\cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4\cdot h > 0.5 \\ -0.1 + 0.4\cdot h & \text{otherwise} \end{cases}$$ $B_1 = 0.025$ — B_1 primary stress Index [4, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$ $B_2 = 2.82$ — B_2 primary stress Index [4, NB-3683.7]

Elbow 1-34E (Nodes 1003 & 1002)

$nd_{EL134E\_1} := (1003)^T$

$AL_{EL134E\_nd1003} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL134E\_1}, Elb\_C_o, EL)$

$AL_{EL134E\_nd1003}^{\ T} = (0.198\ \ 1.171\times10^4\ \ 5.99\ \ 1.003\times10^3\ \ 47\ \ 4.624\times10^3\ \ 6.157\times10^3\ \ -8.826\times 1$

$nd_{EL134E\_2} := (1002)^T$

$AL_{EL134E\_nd1002} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL134E\_2}, Elb\_C_o, EL)$

$AL_{EL134E\_nd1002}^{\ T} = (0.184\ \ 1.086\times10^4\ \ 9.58\ \ 1.002\times10^3\ \ 46\ \ 739.714\ \ -9.998\times10^3\ \ 4.165\times10^3$

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Elbow 1-34G (Nodes 1010 & 1011)

$nd_{EL134G\_1} := (1010)^T$

$AL_{EL134G\_nd1010} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL134G\_1}, Elb\_C_o, EL)$

$AL_{EL134G\_nd1010}{}^T = (0.176 \quad 1.04\times10^4 \quad 10.155 \quad 1.01\times10^3 \quad 49 \quad -1.732\times10^3 \quad 8.839\times10^3 \quad 5.207\times 1$

$nd_{EL134G\_2} := (1011)^T$

$AL_{EL134G\_nd1011} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL134G\_2}, Elb\_C_o, EL)$

$AL_{EL134G\_nd1011}{}^T = (0.195 \quad 1.155\times10^4 \quad 10.155 \quad 1.011\times10^3 \quad 42 \quad -1.073\times10^3 \quad 1.04\times10^4 \quad 4.925\times$

Elbow 1-34H (Nodes 1015 & 1014)

$nd_{EL134H\_1} := (1015)^T$

$AL_{EL134H\_nd1015} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL134H\_1}, Elb\_C_o, EL)$

$AL_{EL134H\_nd1015}{}^T = (0.248 \quad 1.472\times10^4 \quad 10.15 \quad 1.015\times10^3 \quad 53 \quad 1.245\times10^3 \quad 1.429\times10^4 \quad 3.311\times 1$

$nd_{EL134H\_2} := (1014)^T$

$AL_{EL134H\_nd1014} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL134H\_2}, Elb\_C_o, EL)$

$AL_{EL134H\_nd1014}{}^T = (0.277 \quad 1.641\times10^4 \quad 10.15 \quad 1.014\times10^3 \quad 45 \quad 2.542\times10^3 \quad 1.593\times10^4 \quad 3.015\times 1$

Elbow Properties for EL(1-34F)

Define pertinent elbow variables

$D_o := 4.5in$ — Outside Diameter [15]

$t := 0.237in$ — Thickness [15]

$P := 272psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o{}^4 - (D_o - 2\cdot t)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 7.233\ in^4$

$R := 20in$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$

Mean pipe radius

Define primary stress indices

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$h := \frac{t \cdot R}{r_m^2}$ $h = 1.043$ Characteristic bend parameter of a curved pipe or butt welding elbow

$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h > 0.5 \\ -0.1 + 0.4 \cdot h & \text{otherwise} \end{cases}$ $B_1 = 0.317$ B_1 primary stress Index [4, NB-3683.7]

$B_2 := \begin{cases} 1.0 & \text{if } \frac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \frac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$ $B_2 = 1.264$ B_2 primary stress Index [4, NB-3683.7]

Elbow 1-34F (Nodes 1007 & 1006)

$nd_{EL134E\_1} := (1007)^T$

$AL_{EL134E\_nd1007} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL134E\_1}, Elb\_C_o, EL)$

$AL_{EL134E\_nd1007}^T = (0.096 \quad 1.071\times10^4 \quad 8.41 \quad 1.007\times10^3 \quad 68 \quad -3.338\times10^3 \quad 8.828\times10^3 \quad -5.065\times$

$nd_{EL134E\_2} := (1006)^T$

$AL_{EL134E\_nd1006} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL134E\_2}, Elb\_C_o, EL)$

$AL_{EL134E\_nd1006}^T = (0.077 \quad 8.129\times10^3 \quad 15.14 \quad 1.006\times10^3 \quad 40 \quad -3.511\times10^3 \quad 5.487\times10^3 \quad 4.863\times$

Writing Output Data for Elbows Associated with Lines 13 to 16, 18 to 21, and 171

$EL1A := AL_{EL134A\_nd756}^T$

$EL1B := AL_{EL134A\_nd763}^T$

$EL2A := AL_{EL134B\_nd762}^T$

$EL2B := AL_{EL134B\_nd761}^T$

$EL3A := AL_{EL134C\_nd765}^T$

$EL3B := AL_{EL134C\_nd764}^T$

$EL4A := AL_{REL134D\_nd1127L}^T$

$EL4B := AL_{REL134D\_nd1133L}^T$

$EL5A := AL_{REL134D\_nd1133S}^T$

$EL5B := AL_{REL134D\_nd1128S}^T$

$EL6A := AL_{EL134E\_nd1003}^T$

$EL6B := AL_{EL134E\_nd1002}^T$

$EL7A := AL_{EL134G\_nd1010}^T$

$EL7B := AL_{EL134G\_nd1011}^T$

$EL8A := AL_{EL134H\_nd1015}^T$

$EL8B := AL_{EL134H\_nd1014}^T$

$EL9A := AL_{EL134E\_nd1007}^T$

$EL9B := AL_{EL134E\_nd1006}^T$

vEL := (EL1A EL1B EL2A EL2B EL3A EL3B EL4A EL4B EL5A EL5B EL6A EL6B EL7A EL7B EL8A EL8B EI

ElbowLine1_34_67 := WRITEPRN("ElbowLine1-34_67.prn" , vEL)

FABRICATED BRANCH TEES

Tees Strategy: *Search based on the elements comprising the tee. The input identifies which elements are associated with the pipe run and which element is associated with the branch from the run. The indices for the defined common node for all three elements is identified and the associated SRSS moment is identified for each time step. The maximum moment for the elements comprising the pipe run is found and applied as M_r in equation (9) of ASME III, Division I - NB - 3652 which is modified to represent tees. The maximum moment for the branch element is found and applied as M_b in equation (9) of ASME III, Division I - NB - 3652 [4]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$TeeDC(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_b, M_r, Z_b, Z_r, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot T_r} + B_{2b} \cdot \left[\frac{M_b \cdot (1 lbf \cdot in)}{Z_b}\right] + B_{2r} \cdot \left[\frac{M_r \cdot (1 lbf \cdot in)}{Z_r}\right]}{S}$$

$Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S, nf, el_R, el_B, nd_R, nd_B, C_o, EL) :=$

$ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{elR} \leftarrow match\left(el_{R_0}, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(el_R)$ if rows

$\quad ind_{elR} \leftarrow stack\left[ind_{elR}, \left(match\left(el_{R_i}, EL^{\langle 0 \rangle}\right)\right)\right]$

$EL'R_{last\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$

for $i \in 0 .. last(ind_{elR})$

$\quad EL'R_{ind_{elR_i}} \leftarrow EL_{ind_{elR_i}, 1}$

$ind_{ndR} \leftarrow match\left(nd_{R_0}, EL'R^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(nd_R)$ if r

$\quad ind_{ndR} \leftarrow stack\left[ind_{ndR}, \left(match\left(nd_{R_i}, EL'R^{\langle 0 \rangle}\right)\right)\right]$

$ind_{elB} \leftarrow match\left(el_{B_0}, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(el_B)$ if rows

$\quad ind_{elB} \leftarrow stack\left[ind_{elB}, \left(match\left(el_{B_i}, EL^{\langle 0 \rangle}\right)\right)\right]$

$EL'B_{last\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$

for $i \in 0 .. last(ind_{elB})$

$\quad EL'B_{ind_{elB_i}} \leftarrow EL_{ind_{elB_i}, 1}$

$ind_{ndB} \leftarrow match\left(nd_{B_0}, EL'B^{\langle 0 \rangle}\right)$

$ind_{ndB} \leftarrow ... \left(... B_0 ... \right)$

for $i \in 1..last(nd_B)$ ... if r

$ind_{ndB} \leftarrow stack\left[ind_{ndB}, \left(match\left(nd_{B_i}, EL'B^{\langle 0 \rangle}\right)\right)\right]$

$(M_R \;\; M_B \;\; Int_0) \leftarrow (0 \;\; 0 \;\; 0)$

for $i \in 0..ind_{nfo_0} - ind_{nfi_0}$

for $j \in 0..last(ind_{ndR})$

for $k \in 0..last(ind_{ndB})$

$M_{rxgR_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{ndR_j}}$

$M_{rygR_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{ndR_j}}$

$M_{rzgR_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{ndR_j}}$

$M_{rxR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{ndR_j}} - M_{rxgR_j}\right) \cdot C$

$M_{ryR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{ndR_j}} - M_{rygR_j}\right) \cdot C$

$M_{rzR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{ndR_j}} - M_{rzgR_j}\right) \cdot C$

$M_{R_j} \leftarrow \sqrt{\left(M_{rxR_j}\right)^2 + \left(M_{ryR_j}\right)^2 + \left(M_{rzR_j}\right)^2}$

$M_{rxgB_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{ndB_k}}$

$M_{rygB_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{ndB_k}}$

$M_{rzgB_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{ndB_k}}$

$M_{rxB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{ndB_k}} - M_{rxgB_j}\right) \cdot C$

$M_{ryB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{ndB_k}} - M_{rygB_j}\right) \cdot C$

$M_{rzB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{ndB_k}} - M_{rzgB_j}\right) \cdot C$

$M_{B_j} \leftarrow \sqrt{\left(M_{rxB_j}\right)^2 + \left(M_{ryB_j}\right)^2 + \left(M_{rzB_j}\right)^2}$

$Int'_j \leftarrow TeeDC\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_{B_j}, M_R\right.$

if $Int'_j > Int_0$

$Int \leftarrow stack\left(Int'_j, M_{R_j}, M_{B_j}, nf_{ind_{nfiC \ldots 1}+i}\right.$

$\text{Result} \leftarrow \text{stack}\left(M_{R_j}, M_{B_j}, M_{rxR_j}, M_{ryR_j}, M\right.$

$M \leftarrow M_R$

Int

Conditions applicable to forged tee

$M_{ox} := 0 \quad M_{oy} := 0 \quad M_{oz} := 0$

Defining place holding directional moment variables

$$Tee\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

FABRICATED T(1-34)

Define pertinent tee variables

$P := 272psi$ — Internal Pressure [3, pg 23]

$D_o := 36in$ — Outside Diameter of pipe run [10]

$d_o := 6.625in$ — Outside Diameter of branch [10]

$B_1 := 0.5$ — B_1 primary stress Index for tees and branches [4, Table NB-3681(a)-1]]

$T_r := 0.5in$ — Nominal wall thickness of designated run pipe [10]

$R_m := \frac{D_o - T_r}{2}$ — Mean radius of designated run pipe [10]

$Z_r := \pi \cdot R_m^{\ 2} \cdot T_r$ — Approximate section modulus of designated run pipe [4, NB-3683.1(d)]

$Z_r = 494.899\ in^3$

$T'_b := 0.28in$ — Nominal wall thickness of attached branch pipe [15]

$r'_m := \frac{d_o - T'_b}{2}$ — Mean radius of attached branch pipe [15]

$Z_b := \pi \cdot r'_m{}^{2} \cdot T'_b$ — Approximate section modulus of attached branch pipe [4, NB-3683.1(d)]

$Z_b = 8.853\ in^3$

C_{2b} Secondary stress Index [4,NB-3683.8]

$$C_{2b} := \begin{cases} 1.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}}\left(\frac{r'_m}{R_m}\right)^{\frac{1}{2}}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{\frac{d_o}{2}}\right) & \text{if } 1.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}}\left(\frac{r'_m}{R_m}\right)^{\frac{1}{2}}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{\frac{d_o}{2}}\right) \geq 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$C_{2b} = 3.674$

C_{2r} Secondary stress Index [4,NB-3683.8]

$t_n := T'_b$

Wall thickness of nozzle or branch connection reinforcement associated with [4, NB-3643.4(A)-1, sketch (d)]

$$C_{2r} := \begin{cases} 1.15\cdot\left(\frac{r'_m}{t_n}\right)^{\frac{1}{4}} & \text{if } 1.15\cdot\left(\frac{r'_m}{t_n}\right)^{\frac{1}{4}} \geq 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$C_{2r} = 2.11$

$$B_{2b} := \begin{cases} 0.5\cdot C_{2b} & \text{if } 0.5\cdot C_{2b} \geq 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Index for branches [4, NB-3683.8]

$B_{2b} = 1.837$

$$B_{2r} := \begin{cases} 0.75\cdot C_{2r} & \text{if } 0.75\cdot C_{2r} \geq 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Index for branches [4, NB-3683.8]

$B_{2r} = 1.582$

Fabricated Tee 1-34 (Node 588)

$elR_{Tee134} := (88 \quad 922)^T$ — Elements associated with pipe run

$ndR_{Tee134} := (588)^T$ — Node between pipe run elements

$elB_{Tee134} := (153)^T$ — Element associated with branch

$ndB_{Tee134} := (946)^T$ — Node where branch intersects pipe run

$AL_{Tee134} := Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{167}, NF, elR_{Tee134}, elB_{Tee134}, ndR_{Tee134}, ndB_{Tee134}, Tee\_C$

$$AL_{Tee134}{}^T = \left(0.401 \quad 7.173\times10^5 \quad 6.635\times10^4 \quad 13.62 \quad 588 \quad 1 \quad 104 \quad 4\right)$$

Writing Output Data for Tees Associated with Lines 1-34 & 1-67

$T1 := AL_{Tee134}{}^T$

$vT := (T1)$

TeeLine1_34_67 := WRITEPRN("TeeLine1-34_67.prn" , vT)

FLANGES

Flange Strategy: *Search based on the nodes where flanges occur. Find the maximum moment combination for the node and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\mathrm{FlangeDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\,\mathrm{lbf \cdot in})]}{S}$$

$\mathrm{Flange}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$$
\begin{array}{l}
ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right) \\
\text{for } i \in 1 .. \mathrm{last}(nd) \quad \text{if } \mathrm{rows}(nd) > 1 \\
\quad ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \\
(M \;\; Int_0) \leftarrow (0 \;\; 0) \\
\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0} \\
\quad \text{for } j \in 0 .. \mathrm{last}(ind_{nd}) \\
\qquad M_{rxg} \leftarrow nf_{ind_{nfi}C_{o_{0,1}}+2,\, ind_{nd_j}} \\
\qquad M_{ryg} \leftarrow nf_{ind_{nfi}C_{o_{1,1}}+2,\, ind_{nd_j}} \\
\qquad M_{rzg} \leftarrow nf_{ind_{nfi}C_{o_{2,1}}+2,\, ind_{nd_j}} \\
\qquad M_{rx} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg} \\
\qquad M_{ry} \leftarrow \left(nf_{ind_{nfi}C_{o_{1,1}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg} \\
\qquad M_{rz} \leftarrow \left(nf_{ind_{nfi}C_{o_{2,1}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg} \\
\qquad M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2} \\
\qquad Int'_j \leftarrow \mathrm{FlangeDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right) \\
\qquad \text{if } Int'_j > Int_0 \\
\qquad\quad Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfi}C_{o_{0,1}}-1+i,0}, EL_{ind_{nd_j},1}, ind_{nd_j}, M_{rx}, M_{ry}, M \right. \\
\qquad\quad Result \leftarrow M' \\
Int
\end{array}
$$

Conditions applicable to all flanges

$M_{cx} := 0$ $M_{cy} := 0$ $M_{cz} := 0$ Defining place holding variables

$$Flange\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties of Line 1-67

Define pertinent pipe variables

$D_o := 4.5in$ Outside Diameter [15]

$t := 0.237in$ Thickness [15]

$P := 272psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$ Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 7.233\ in^4$$

Define primary stress indices (Utilize girth weld characteristic associated with lap joint flanges in determining values)

$B_1 := 0.5$ B_1 for a girth weld [4, Table NB-3681(a)-1, pg 130]

$B_2 := 1$ B_2 for a girth weld [4, Table NB-3681(a)-1, pg 130]

Flange 1-67A (Node 1129)

$$nd_{FL167A} := (1129)^T$$

$$AL_{FL167A} := Flange\left(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{FL167A}, Flange\_C_o, EL\right)$$

$$AL_{FL167A}^{\ T} = \left(0.174 \quad 2.504\times10^4 \quad 9.265 \quad 1.129\times10^3 \quad 76 \quad 2.386\times10^3 \quad 2.459\times10^4 \quad 4.089\times10^3\right)$$

Flange 1-67B (Node 1130)

$$nd_{FL167B} := (1130)^T$$

$$AL_{FL167B} := Flange\left(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{FL167B}, Flange\_C_o, EL\right)$$

$$AL_{FL167B}^{\ T} = \left(0.119 \quad 1.583\times10^4 \quad 9.95 \quad 1.13\times10^3 \quad 36 \quad 6.624\times10^3 \quad -1.236\times10^4 \quad -7.349\times10^3\right)$$

Writing Output Data for Flanges Associated with Lines 1-34 & 1-67

$F1 := AL_{FL167A}^{\ T}$ $F2 := AL_{FL167B}^{\ T}$

$F := (F1 \quad F2)$

FlangeLine1_34_67 := WRITEPRN("FlangeLine1-34_67.prn" , F)

Appendix D.3.5

Demand to Capacity Ratio Calculations for Components Associated with Lines 1-39 and 1-40 of ATR PCS Model 1-4

(NOTE: Values represented here are shown for one realization (Nodal Force file = LINE1-39_40_test_R1.dat and Element/Nodal order file = EL1-39_40.xls) and may or may not be consistent with the 80th percentile results contained in Appendix D.4)

Force Outputs from Abaqus

NF := ...\LINE1-39_40.dat — (N)odal (F)orces for Model 1-4

Defined Elemental and Corresponding Nodal Order

EL := ..\EL_39_40(9-22-08).xls — Element and corresponding nodal order for Model 1-4

Time Boundaries

$t_{initial} := 1$ — Initial time for which dynamic loading is applied

$t_{final} := 21$ — Final time for which dynamic loading stops

Seismic Scale Factor (F_a)

$F_a := 1$ — Seismic scale factor [9]

Allowable Design Stress Intensity Factor (S_m): *S_m is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{m\_125} := 20ksi$ — For SS304 at 125°F [2, pg 316-318] [3, pg 23]

$S_{m\_125L} := 16.7ksi$ — For SS304L at 125°F [2, pg 316-318] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

$S_{m\_167} := 20ksi$ — For SS304 at 167°F [2, pg 316-318] [3, pg 23]

$S_{m\_167L} := 16.7ksi$ — For SS304L at 167°F [2, pg 316-318] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

Yield Strength (S_y): *S_y is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{y\_125} := 28.35ksi$ — For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_125L} := 23.85ksi$ — For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

$S_{y\_167} := 26.12ksi$ — For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_167L} := 22.26ksi$ — For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

Maximum Strength Applicable for Equation 9 (S): *S is defined below for SS304 at temperature 125ºF and SS304L at 125ºF.*

$S_{125} := \min\left(3 \cdot S_{m\_125}, 2 \cdot S_{y\_125}\right)$

Maximum allowable stress applied to SS304 piping [4, NB-3656]

$\boxed{S_{125} = 56.7\ \text{ksi}}$

$S_{125L} := \min\left(3 \cdot S_{m\_125L}, 2 \cdot S_{y\_125L}\right)$

Maximum allowable stress applied to SS304L piping [4, NB-3656]

$\boxed{S_{125L} = 47.7\ \text{ksi}}$

$S_{167} := \min\left(3 \cdot S_{m\_167}, 2 \cdot S_{y\_167}\right)$

Maximum allowable stress applied to SS304 piping [4, NB-3656]

$\boxed{S_{167} = 52.24\ \text{ksi}}$

$S_{167L} := \min\left(3 \cdot S_{m\_167L}, 2 \cdot S_{y\_167L}\right)$

Maximum allowable stress applied to SS304L piping [4, NB-3656]

$\boxed{S_{167L} = 44.52\ \text{ksi}}$

SUPPORTS

Supports Strategy: *Search based on the node for which the support acts. If this node is a termination point there will only be one node to evaluate. If this node is in line with a section of pipe there will be two representations of the same node (one for each element on each side of the node) to combine and the difference between them is the force required of the support. The D/C ratio for each support will be found by dividing the the required force found above by the support capacity.*

$$SupDC(P_r, P_c) := \frac{P_r}{P_c}$$

$$\begin{aligned}
Support(nf, nd, C_o, EL) :=\ & ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
& ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
& ind_{nd} \leftarrow match\left(nd_0, EL^{\langle 1 \rangle}\right) \\
& \text{for } i \in 1..last(nd) \quad \text{if } rows(nd) > 1 \\
& \quad ind_{nd} \leftarrow stack\left[ind_{nd}, \left(match\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \\
& \begin{pmatrix} Int1_4 & Int2_4 \end{pmatrix} \leftarrow (0 \quad 0) \\
& \text{for } i \in 0..ind_{nfo_0} - ind_{nfi_0} \\
& \quad \text{for } j \in 0..last\left(ind_{nd}\right) \\
& \quad\quad P_{rg_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}-1}, ind_{nd_j}} \\
& \quad\quad P_{r_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}-1}+i, ind_{nd_j}} - P_{rg_j}\right) \cdot C_{o_{2,0}} + P_{rg_j} \\
& \quad PR_i \leftarrow \sum_{n=0}^{j} P_{r_n} \\
& \quad \text{if } PR_i < Int1_1 \wedge C_{o_{0,0}} \neq 0 \\
& \quad\quad Int1' \leftarrow SupDC\left(\left|PR_i\right|, C_{o_{0,0}}\right) \\
& \quad\quad Int_1 \leftarrow stack\left(Int1', PR_i, nf_{ind_{nfiC_{o_{0,1}}-1}+i,0}, EL_{ind_{nd_j},1}, ind_{nd}\right) \\
& \quad \text{if } PR_i > Int2_1 \wedge C_{o_{1,0}} \neq 0 \\
& \quad\quad Int2' \leftarrow SupDC\left(\left|PR_i\right|, C_{o_{1,0}}\right) \\
& \quad\quad Int_2 \leftarrow stack\left(Int2', PR_i, nf_{ind_{nfiC_{o_{0,1}}-1}+i,0}, EL_{ind_{nd_j},1}, ind_{nd}\right) \\
& \begin{pmatrix} Int_1 & Int_2 \end{pmatrix}
\end{aligned}$$

Tieback2 Support (1x)

$P_{1\_TB2\_EW} := \frac{5.577 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_TB2\_EW} := \frac{1.528 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_TB2\_EW} := \begin{pmatrix} P_{1\_TB2\_EW} & 3 \\ P_{2\_TB2\_EW} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

$P_{1\_TB2\_V} := \frac{0.908 \cdot kip}{lbf}$ ***Flexure*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_TB2\_V} := \frac{0.908 \cdot kip}{lbf}$ ***Flexure*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_TB2\_V} := \begin{pmatrix} P_{1\_TB2\_V} & 2 \\ P_{2\_TB2\_V} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

Tieback2 East/West (Node 1445)

Tieback2 vertically and laterally supports the horizontal PCS pipe on line 1-39 at north side of EL(1-39A).

$nd1445_{TB2\_EW_0} := 1445$ Node associated with support

$$\left(AL1_{TB2\_EW\_nd1445} \;\; AL2_{TB2\_EW\_nd1445}\right) := Support\left(NF, nd1445_{TB2\_EW}, Sup\_C_{o\_TB2\_EW}, EL\right)$$

$$AL1_{TB2\_EW\_nd1445}{}^{T} = \left(0.196 \;\; -1.095 \times 10^{3} \;\; 5.875 \;\; 1.445 \times 10^{3} \;\; 100\right)$$

$$AL2_{TB2\_EW\_nd1445}{}^{T} = \left(1.155 \;\; 1.765 \times 10^{3} \;\; 10.69 \;\; 1.445 \times 10^{3} \;\; 100\right)$$

orce, occurrence time, ssociated Index for the reaction force at the selected node sitive (AL1) and negative s of the global coordinate system)

Tieback2 Vertical (Node 1445)

Tieback2 vertically and laterally supports the horizontal PCS pipe on line 1-34 between RH-14a and RH-14b.

$nd1445_{TB2\_V_0} := 1445$ Node associated with support

$$\left(AL1_{TB2\_V\_nd1445} \;\; AL2_{TB2\_V\_nd1445}\right) := Support\left(NF, nd1445_{TB2\_V}, Sup\_C_{o\_TB2\_V}, EL\right)$$

$$AL1_{TB2\_V\_nd1445}{}^{T} = \left(2.436 \;\; -2.212 \times 10^{3} \;\; 10.23 \;\; 1.445 \times 10^{3} \;\; 100\right)$$

$$AL2_{TB2\_V\_nd1445}{}^{T} = \left(0 \;\; 0 \;\; 0 \;\; 0 \;\; 0\right)$$

force, occurrence time, , associated Index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

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PS-11A Support (1x)

$P_{1\_PS11A} := \frac{20.496 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_PS11A} := \frac{0 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_PS11A} := \begin{pmatrix} P_{1\_PS11A} & 2 \\ P_{2\_PS11A} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

PS-11A (Node 1369)

PS-11A vertically supports T(1-39) south of CK(1-39).

$nd1369_{PS11A_0} := 1369$ Node associated with support

$$\left(AL1_{PS11A\_nd1369} \quad AL2_{PS11A\_nd1369}\right) := Support\left(NF, nd1369_{PS11A}, Sup\_C_{o\_PS11A}, EL\right)$$

$$AL1_{PS11A\_nd1369}{}^{T} = \left(0.486 \quad -9.968 \times 10^{3} \quad 1.115 \quad 1.369 \times 10^{3} \quad 79\right)$$

$$AL2_{PS11A\_nd1369}{}^{T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0\right)$$

...mand force, occurrence time, ... node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-14A Support (4x)

$P_{1\_RH14A} := \frac{7.069 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_RH14A} := \frac{0.691 kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_RH14A} := \begin{pmatrix} P_{1\_RH14A} & 2 \\ P_{2\_RH14A} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3

RH-14Aa (Node 1288)

RH-14Aa vertically supports the horizontal PCS pipe on line 1-40 traveling west from EL(1-40A).

$nd1288_{RH14Aa_0} := 1288$ Node associated with support

$$\left(AL1_{RH14Aa\_nd1288} \quad AL2_{RH14Aa\_nd1288}\right) := Support\left(NF, nd1288_{RH14Aa}, Sup\_C_{o\_RH14A}, EL\right)$$

$$AL1_{RH14Aa\_nd1288}{}^{T} = \left(0.214 \quad -1.515 \times 10^{3} \quad 13.645 \quad 1.288 \times 10^{3} \quad 97\right)$$

$$AL2_{RH14Aa\_nd1288}{}^{T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0\right)$$

...and force, occurrence time, ...ode, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate

system)

RH-14Ab (Node 1291)

RH-14Ab vertically supports the horizontal PCS pipe on line 1-40 traveling west from RH-14Aa.

$nd1291_{RH14Ab_0} := 1291$ Node associated with support

$\left(AL1_{RH14Ab\_nd1291}\ \ AL2_{RH14Ab\_nd1291}\right) := Support\left(NF, nd1291_{RH14Ab}, Sup\_C_{o\_RH14A}, EL\right)$

$AL1_{RH14Ab\_nd1291}^{T} = \left(0.183\ \ -1.292\times10^{3}\ \ 7.675\ \ 1.291\times10^{3}\ \ 95\right)$

$AL2_{RH14Ab\_nd1291}^{T} = \left(0\ \ 0\ \ 0\ \ 0\ \ 0\right)$

...hand force, occurrence time, ...ode, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-14Ac (Node 1297)

RH-14Ac vertically supports the horizontal PCS pipe on line 1-40 traveling west from RH-14Ab.

$nd1297_{RH14Ac_0} := 1297$ Node associated with support

$\left(AL1_{RH14Ac\_nd1297}\ \ AL2_{RH14Ac\_nd1297}\right) := Support\left(NF, nd1297_{RH14Ac}, Sup\_C_{o\_RH14A}, EL\right)$

$AL1_{RH14Ac\_nd1297}^{T} = \left(0.176\ \ -1.248\times10^{3}\ \ 5.775\ \ 1.297\times10^{3}\ \ 93\right)$

$AL2_{RH14Ac\_nd1297}^{T} = \left(0\ \ 0\ \ 0\ \ 0\ \ 0\right)$

...hand force, occurrence time, ...ode, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-14Ad (Node 1302)

RH-14Ad vertically supports the horizontal PCS pipe on line 1-40 traveling west from RH-14Ac.

$nd1302_{RH14Ad_0} := 1302$ Node associated with support

$\left(AL1_{RH14Ad\_nd1302}\ \ AL2_{RH14Ad\_nd1302}\right) := Support\left(NF, nd1302_{RH14Ad}, Sup\_C_{o\_RH14A}, EL\right)$

$AL1_{RH14Ad\_nd1302}^{T} = \left(0.569\ \ -4.021\times10^{3}\ \ 5.71\ \ 1.302\times10^{3}\ \ 91\right)$

$AL2_{RH14Ad\_nd1302}^{T} = \left(0\ \ 0\ \ 0\ \ 0\ \ 0\right)$

...mand force, occurrence time, ...node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-20G Support (1x)

$P_{1\_RH20} := \frac{7.069 \cdot kip}{lbf}$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_RH20} := \frac{7.069 \cdot kip}{lbf}$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system

See main body for further discussion of this support

$$Sup\_C_{o\_RH20} := \begin{pmatrix} P_{1\_RH20} & 2 \\ P_{2\_RH20} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3

RH-20G (Node 1395)

RH-20 vertically supports the horizontal PCS pipe on line 1-40 at north end of EL(1-40E).

$nd1395_{RH20_0} := 1395$ Node associated with support

$$\left(AL1_{RH20\_nd1395} \;\; AL2_{RH20\_nd1395}\right) := Support\left(NF, nd1395_{RH20}, Sup\_C_{o\_RH20}, EL\right)$$

$$AL1_{RH20\_nd1395}{}^T = (0 \;\; 0 \;\; 0 \;\; 0 \;\; 0)$$

$$AL2_{RH20\_nd1395}{}^T = \left(0.53 \;\; 3.747 \times 10^3 \;\; 5.295 \;\; 1.395 \times 10^3 \;\; 101\right)$$

(D/C,demand force, occurrence time, defined node, associated index for the reaction force at the selected node in the positive (AL1) and negative (AL2) directions of the global coordinate system)

PS-22 Support (North/South)

$P_{1\_PS22} := \frac{5.658 \cdot kip}{lbf}$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_PS22} := \frac{11.25 \cdot kip}{lbf}$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_PS22} := \begin{pmatrix} P_{1\_PS22} & 1 \\ P_{2\_PS22} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

PS-22 Axial (NS) (Node 1444)

PS-22 horizontally (N/S) supports the horizontal(E/W) PCS pipe on line 1-40 just west of RH-14Ac

$nd1444_{PS22_0} := 1444$ Node associated with support

$$\left(AL1_{PS22\_nd1444} \;\; AL2_{PS22\_nd1444}\right) := Support\left(NF, nd1444_{PS22}, Sup\_C_{o\_PS22}, EL\right)$$

$$AL1_{PS22\_nd1444}{}^T = \left(0.172 \;\; -973.894 \;\; 5.44 \;\; 1.444 \times 10^3 \;\; 90\right)$$

$$AL2_{PS22\_nd1444}{}^T = \left(0.102 \;\; 1.145 \times 10^3 \;\; 10.205 \;\; 1.444 \times 10^3 \;\; 90\right)$$

(D/C, demand force, occurrence time, defined node, associated index for the reaction force at the selected node in the positive (AL1) and negative (AL2) directions of the global coordinate system)

Writing Output Data for Supports Associated with Lines 1-13 to 1-16, 1-18 to 1-21, and 1-171.

$SA1 := AL1_{TB2\_EW\_nd1445}{}^T$

$SA2 := AL2_{TB2\_EW\_nd1445}{}^T$

$SB1 := AL1_{TB2\_V\_nd1445}{}^T$

$SB2 := AL2_{TB2\_V\_nd1445}{}^T$

$SC1 := AL1_{PS11A\_nd1369}{}^T$

$SC2 := AL2_{PS11A\_nd1369}{}^T$

$SD1 := AL1_{RH14Aa\_nd1288}{}^T$

$SD2 := AL2_{RH14Aa\_nd1288}{}^T$

$SE1 := AL1_{RH14Ab\_nd1291}{}^T$

$SE2 := AL2_{RH14Ab\_nd1291}{}^T$

$SF1 := AL1_{RH14Ac\_nd1297}{}^T$

$SF2 := AL2_{RH14Ac\_nd1297}{}^T$

$SG1 := AL1_{RH14Ad\_nd1302}{}^T$

$SG2 := AL2_{RH14Ad\_nd1302}{}^T$

$SH1 := AL1_{RH20\_nd1395}{}^T$

$SH2 := AL2_{RH20\_nd1395}{}^T$

$SI1 := AL1_{PS22\_nd1444}{}^T$

$SI2 := AL2_{PS22\_nd1444}{}^T$

$S := (SA1\ \ SA2\ \ SB1\ \ SB2\ \ SC1\ \ SC2\ \ SD1\ \ SD2\ \ SE1\ \ SE2\ \ SF1\ \ SF2\ \ SG1\ \ SG2\ \ SH1\ \ SH2\ \ SI1\ \ SI2)$

SupportsLine1_39_40 := WRITEPRN("SupLine1-39_40.prn" , S)

TERMINATION LOCATIONS (NONE)

PIPE RUNS

Pipe Runs Strategy: *Search based on the nodes present in each run of pipe. Find the maximum moment combination among all of the nodes and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation.*

$$\text{PipeRunDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

$$\text{PipeRun}(P, D_o, t, I, B_1, B_2, S, nf, el, C_o, EL) :=$$

```
ind_nfi ← match(t_initial, nf^<0>)
ind_nfo ← match(t_final, nf^<0>)
ind_el ← match(el_0, EL^<0>)
for i ∈ 1 .. last(el)                                   if rows(el) > 1
   ind_el ← stack[ind_el, (match(el_i, EL^<0>))]
(M  Int_{5, last(ind_el)}) ← (0  0)
for i ∈ 0 .. ind_nfo_0 − ind_nfi_0
   for j ∈ 0 .. last(ind_el)
      M_rxg ← nf_{ind_nfiC_o_{0,1}+2, ind_el_j}
      M_ryg ← nf_{ind_nfiC_o_{1,1}+2, ind_el_j}
      M_rzg ← nf_{ind_nfiC_o_{2,1}+2, ind_el_j}
      M_rx_j ← (nf_{ind_nfiC_o_{0,1}+2+i, ind_el_j} − M_rxg)·C_o_{3,0} + M_rxg
      M_ry_j ← (nf_{ind_nfiC_o_{1,1}+2+i, ind_el_j} − M_ryg)·C_o_{3,0} + M_ryg
      M_rz_j ← (nf_{ind_nfiC_o_{2,1}+2+i, ind_el_j} − M_rzg)·C_o_{3,0} + M_rzg
      M'_j ← sqrt((M_rx_j)^2 + (M_ry_j)^2 + (M_rz_j)^2)
      Int'_j ← PipeRunDC(P, D_o, t, I, B_1, B_2, M'_j, S)
      if Int'_j > Int_{0, j}
         H ← (Int'_j  M'_j  nf_{ind_nfiC_o_{0,1}−1+i, 0}  EL_{ind_el_j, 0}  EL_{ind_el_j, 1}  ind_el_j  M_r
         for k ∈ 0 .. 5
            Int_{k, j} ← H_k
```

Int

Conditions applicable to all pipe runs

$M_{cx} := 0 \quad M_{cy} := 0 \quad M_{cz} := 0$

Defining place holding directional moment variables

$$PipeRun\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties for Line 1-39

Define pertinent pipe variables

$D_o := 6.625in$ — Outside Diameter [16]

$t := 0.28in$ — Thickness [16]

$P := 376psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 28.142\ in^4$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{vmatrix} 1.0 \ \text{ if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50 \\ \quad \begin{vmatrix} T \leftarrow 125 \\ X \leftarrow 1.3 - 0.006 \cdot \dfrac{D_o}{t} \\ Y \leftarrow 1.033 - 0.00033 \cdot T \\ 1.0 \cdot \dfrac{1}{X \cdot Y} \end{vmatrix} \end{vmatrix}$$

$B_{2PR} = 1$

Stress Indices are derived from [4, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [4, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-39A (Element 521)

$el_{P139A} := (521)^T$

$AL_{P139A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P139A}, PipeRun\_C_o, EL\right)$

$$AL_{P139A}^{\ T} = \begin{pmatrix} 0.245 & 9.891 \times 10^4 & 8.5 & 521 & 987 & 58 \\ 0.281 & 1.163 \times 10^5 & 4.98 & 521 & 1.035 \times 10^3 & 59 \end{pmatrix}$$

Pipe Run 1-39B (Element 516)

$el_{P139B} := (516)^T$

$AL_{P139B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P139B}, PipeRun\_C_o, EL)$

$$AL_{P139B}{}^T = \begin{pmatrix} 0.22 & 8.708 \times 10^4 & 4.975 & 516 & 1.034 \times 10^3 & 49 \\ 0.298 & 1.248 \times 10^5 & 4.255 & 516 & 1.176 \times 10^3 & 50 \end{pmatrix}$$

Pipe Properties for Line 1-40

Define pertinent pipe variables

$D_o := 6.625in$ — Outside Diameter [17]

$t := 0.28in$ — Thickness [17]

$P := 272psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o{}^4 - (D_o - 2 \cdot t)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 28.142\,in^4$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \left| \begin{array}{l} 1.0 \text{ if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 \\ \quad \left| \begin{array}{l} T \leftarrow 125 \\ X \leftarrow 1.3 - 0.006 \cdot \frac{D_o}{t} \\ Y \leftarrow 1.033 - 0.00033 \cdot T \\ 1.0 \cdot \frac{1}{X \cdot Y} \end{array} \right. \end{array} \right.$$

$B_{2PR} = 1$

Stress Indices are derived from [4, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [4, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-40A (Element 162)

$el_{P140A} := (162)^T$

$AL_{P140A} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P140A}, PipeRun\_C_o, EL)$

$$AL_{P140A}{}^T = \begin{pmatrix} 0.117 & 4.28 \times 10^4 & 8.415 & 162 & 803 & 9 \\ 0.136 & 5.198 \times 10^4 & 10.18 & 162 & 953 & 10 \end{pmatrix}$$

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Pipe Run 1-40B (Element 320, 649, 626, 935, 324, 934, 937, 936, 651, 327, 938, 636, 876, 939, 877, 940, 941, & 641)

$el_{P140B} := (320\ \ 649\ \ 626\ \ 935\ \ 324\ \ 934\ \ 937\ \ 936\ \ 651\ \ 327\ \ 938\ \ 636\ \ 876\ \ 939\ \ 877\ \ 940\ \ 941\ \ 641$

$AL_{P140B} := \text{PipeRun}\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P140B}, \text{PipeRun\_C}_o, EL\right)$

$AL_{P140B}{}^{T} =$

	0	1	2	3	4	5
0	0.111	$3.984 \cdot 10^4$	8.415	320	802	35
1	0.103	$3.616 \cdot 10^4$	8.415	320	$1.31 \cdot 10^3$	36
2	0.092	$3.063 \cdot 10^4$	7.73	649	$1.287 \cdot 10^3$	74
3	0.103	$3.616 \cdot 10^4$	8.415	649	$1.31 \cdot 10^3$	75
4	0.092	$3.06 \cdot 10^4$	7.73	626	$1.287 \cdot 10^3$	68
5	0.089	$2.922 \cdot 10^4$	7.74	626	$1.638 \cdot 10^3$	69
6	0.091	$3.03 \cdot 10^4$	7.765	935	954	109
7	0.089	$2.922 \cdot 10^4$	7.74	935	$1.638 \cdot 10^3$	110
8	0.091	$3.03 \cdot 10^4$	7.765	324	954	37
9	0.101	$3.492 \cdot 10^4$	7.78	324	$1.637 \cdot 10^3$	38
10	0.118	$4.32 \cdot 10^4$	7.8	934	959	107
11	0.101	$3.492 \cdot 10^4$	7.78	934	$1.637 \cdot 10^3$	108
12	0.118	$4.318 \cdot 10^4$	7.8	937	959	113
13	0.135	$5.115 \cdot 10^4$	10.175	937	$1.64 \cdot 10^3$	114
14	0.159	$6.305 \cdot 10^4$	10.175	936	$1.639 \cdot 10^3$	111
15	0.135	$5.115 \cdot 10^4$	10.175	936	$1.64 \cdot 10^3$	112
16	0.183	$7.45 \cdot 10^4$	10.18	651	960	76
17	0.159	$6.305 \cdot 10^4$	10.175	651	$1.639 \cdot 10^3$	77
18	0.183	$7.451 \cdot 10^4$	10.18	327	960	39
19	0.195	$8.038 \cdot 10^4$	10.185	327	$1.641 \cdot 10^3$	40
20	0.209	$8.721 \cdot 10^4$	10.19	938	$1.298 \cdot 10^3$	115
21	0.195	$8.038 \cdot 10^4$	10.185	938	$1.641 \cdot 10^3$	116
22	0.215	$9.011 \cdot 10^4$	10.195	636	961	70
23	0.209	$8.721 \cdot 10^4$	10.19	636	$1.298 \cdot 10^3$	71
24	0.216	$9.035 \cdot 10^4$	10.195	876	961	103
25	0.161	$6.395 \cdot 10^4$	10.195	876	$1.642 \cdot 10^3$	104
26	0.116	$4.218 \cdot 10^4$	10.2	939	963	117
27	0.161	$6.395 \cdot 10^4$	10.195	939	$1.642 \cdot 10^3$	118
28	0.116	$4.218 \cdot 10^4$	10.2	877	963	105
29	0.13	$4.905 \cdot 10^4$	5.715	877	$1.643 \cdot 10^3$	106
30	0.13	$4.905 \cdot 10^4$	5.715	940	$1.643 \cdot 10^3$	119
31	0.171	$6.849 \cdot 10^4$	5.715	940	$1.644 \cdot 10^3$	120
32	0.219	$9.186 \cdot 10^4$	5.71	941	$1.303 \cdot 10^3$	121
33	0.171	$6.849 \cdot 10^4$	5.715	941	$1.644 \cdot 10^3$	122
34	0.169	$6.763 \cdot 10^4$	5.71	641	776	72
35	0.22	$9.209 \cdot 10^4$	5.71	641	$1.303 \cdot 10^3$	73

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Pipe Run 1-40C (Element 233 & 160)

$$el_{P140C} := (233 \quad 160)^T$$

$$AL_{P140C} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P140C}, PipeRun\_C_o, EL\right)$$

$$AL_{P140C}{}^T = \begin{pmatrix} 0.138 & 5.271 \times 10^4 & 9.9 & 233 & 777 & 23 \\ 0.123 & 4.569 \times 10^4 & 10.18 & 233 & 852 & 24 \\ 0.141 & 5.437 \times 10^4 & 10.18 & 160 & 778 & 7 \\ 0.123 & 4.569 \times 10^4 & 10.18 & 160 & 852 & 8 \end{pmatrix}$$

Pipe Run 1-40D (Element 159)

$$el_{P140D} := (159)^T$$

$$AL_{P140D} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P140D}, PipeRun\_C_o, EL\right)$$

$$AL_{P140D}{}^T = \begin{pmatrix} 0.144 & 5.572 \times 10^4 & 9.445 & 159 & 779 & 5 \\ 0.143 & 5.515 \times 10^4 & 4.245 & 159 & 780 & 6 \end{pmatrix}$$

Pipe Run 1-40E (Element 234 & 158)

$$el_{P140E} := (234 \quad 158)^T$$

$$AL_{P140E} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P140E}, PipeRun\_C_o, EL\right)$$

$$AL_{P140E}{}^T = \begin{pmatrix} 0.139 & 5.319 \times 10^4 & 9.2 & 234 & 781 & 25 \\ 0.112 & 4.034 \times 10^4 & 10.68 & 234 & 853 & 26 \\ 0.115 & 4.168 \times 10^4 & 10.67 & 158 & 782 & 3 \\ 0.112 & 4.034 \times 10^4 & 10.68 & 158 & 853 & 4 \end{pmatrix}$$

Pipe Run 1-40F (Element 157)

$$el_{P140F} := (157)^T$$

$$AL_{P140F} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P140F}, PipeRun\_C_o, EL\right)$$

$$AL_{P140F}{}^T = \begin{pmatrix} 0.164 & 6.538 \times 10^4 & 5.67 & 157 & 758 & 1 \\ 0.124 & 4.626 \times 10^4 & 5.715 & 157 & 783 & 2 \end{pmatrix}$$

Writing Output Data for Pipe Runs Associated with Lines 1-39 & 1-40

$PR1 := AL_{P139A}^{T}$

$PR2 := AL_{P139B}^{T}$

$PR3 := AL_{P140A}^{T}$

$PR4 := AL_{P140B}^{T}$

$PR5 := AL_{P140C}^{T}$

$PR6 := AL_{P140D}^{T}$

$PR7 := AL_{P140E}^{T}$

$PR8 := AL_{P140F}^{T}$

$P := (PR1 \quad PR2 \quad PR3 \quad PR4 \quad PR5 \quad PR6 \quad PR7 \quad PR8)$

PipeRunsLine1_39_40 := WRITEPRN("PRLine1-39_40.prn" , P)

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REDUCERS

Reducers Strategy: *Search based on the nodes comprising either end of the reducers. SRSS combine the three moments of each of the four node representations (one for each element connected by the node in question). Find the maximum of the moment combinations for each element and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. It is important to not combine the data from both nodes as the geometry for each is different and (9) must be applied for each node. The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\text{ReducerDC}\left(P, D_o, t, I, B_1, B_2, M, S\right) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

$$\text{Reducer}\left(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL\right) :=$$

$$\begin{array}{l}
ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
ind_{nd} \leftarrow \text{match}\left(nd_0, EL^{\langle 1 \rangle}\right) \\
\text{for } i \in 1 .. \text{last}(nd) \quad \text{if rows}(nd) > 1 \\
\quad ind_{nd} \leftarrow \text{stack}\left[ind_{nd}, \left(\text{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \\
\left(M \quad Int_0\right) \leftarrow (0 \quad 0) \\
\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0} \\
\quad \text{for } j \in 0 .. \text{last}\left(ind_{nd}\right) \\
\quad\quad M_{rxg} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}}+2,\, ind_{nd_j}} \\
\quad\quad M_{ryg} \leftarrow nf_{ind_{nfi_{C_{o_{1,1}}}}+2,\, ind_{nd_j}} \\
\quad\quad M_{rzg} \leftarrow nf_{ind_{nfi_{C_{o_{2,1}}}}+2,\, ind_{nd_j}} \\
\quad\quad M_{rx} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg} \\
\quad\quad M_{ry} \leftarrow \left(nf_{ind_{nfi_{C_{o_{1,1}}}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg} \\
\quad\quad M_{rz} \leftarrow \left(nf_{ind_{nfi_{C_{o_{2,1}}}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg} \\
\quad\quad M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2} \\
\quad\quad Int'_j \leftarrow \text{ReducerDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right) \\
\quad\quad \text{if } Int'_j > Int_0 \\
\quad\quad\quad Int \leftarrow \text{stack}\left(Int'_j, M'_j, nf_{ind_{nfi_{C_{o_{0,1}}}-1}+i,0}, EL_{ind_{nd_j},1}, ind_{nd_j}, M_{rx}, M_{ry},\right. \\
\quad\quad\quad Result \leftarrow M'
\end{array}$$

Int

Conditions applicable to all reducers

$M_{ox} := 0 \quad M_{oy} := 0 \quad M_{oz} := 0$ — Defining place holding variables

$$Reducer\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Reducer Properties for Line 1-39

Define pertinent reducer variables

$D_o := (6.625in \;\; 4.5in)^T$ — Outside Diameter [16]

$t := (0.28in \;\; 0.237in)^T$ — Thickness [16]

$P := (376psi \;\; 376psi)^T$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = \begin{pmatrix} 28.142 \\ 7.233 \end{pmatrix} in^4$$

Define primary stress indices

$$\alpha := atan\left(\frac{1.0625in}{5.5in}\right)$$

Angular slope of reducer [16]

$\alpha = 10.934\,deg$

$$B_1 := \begin{vmatrix} 0.5 \text{ if } \alpha \le 30deg \\ 1.0 \text{ if } 30deg < \alpha \le 60deg \end{vmatrix}$$

$B_1 = 0.5$ — B_1 primary stress Index [4, NB-3683.7]

$B_2 := 1.0$ — B_2 primary stress Index [4, NB-3683.7]

Reducer 1-39 (Nodes 1175 & 1178)

$nd_{RD139\_L} := (1175)^T$ — Node associated with Large end of reducer

$$AL_{RD139\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF, nd_{RD139\_L}, Reducer\_C_o, EL\right)$$

$$AL_{RD139\_L}^{\;T} = \left(0.168 \;\; 6.18\times10^4 \;\; 5.345 \;\; 1.175\times10^3 \;\; 46 \;\; 2.309\times10^3 \;\; -5.009\times10^3 \;\; 6.155\times10^4\right)$$

$nd_{RD139\_S} := (1178)^T$ — Node associated with Small end of reducer

$$AL_{RD139\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF, nd_{RD139\_S}, Reducer\_C_o, EL\right)$$

$$AL_{RD139\_S}^{\;T} = \left(0.334 \;\; 5.519\times10^4 \;\; 5.345 \;\; 1.178\times10^3 \;\; 54 \;\; 2.338\times10^3 \;\; -5.843\times10^3 \;\; 5.482\times10^4\right)$$

Writing Output Data for Reducers Associated with Line 1-39 & 1-40

$RL1 := AL_{RD139\_L}^{T}$

$RS1 := AL_{RD139\_S}^{T}$

$R := (RL1 \quad RS1)$

ReducersLine1_39_40 := WRITEPRN("RedLine1-39_40.prn" , R)

ELBOWS

Elbows Strategy: *Search based on the two nodes comprising the ends of each elbow. SRSS combine the three moments of each of the four node representations (one for each element connected by the nodes in question). Find the maximum of the four moment combinations and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{ElbowDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Elbow}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(nd)$ if $\mathrm{rows}(nd) > 1$

  $ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$(M \;\; Int_0) \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \mathrm{last}(ind_{nd})$

    $M_{rxg} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}}+2, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi_{C_{o_{1,1}}}}+2, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi_{C_{o_{2,1}}}}+2, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}}+2+i, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi_{C_{o_{1,1}}}}+2+i, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi_{C_{o_{2,1}}}}+2+i, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow \mathrm{ElbowDC}(P, D_o, t, I, B_1, B_2, M'_j, S)$

    if $Int'_j > Int_0$

      $Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfi_{C_{o_{0,1}}}}-1+i, 0}, EL_{ind_{nd_j}, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M\right.$

      $Result \leftarrow M'$

Int

Conditions applicable to all elbows

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$ — Defining place holding variables

$$Elb\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Elbow Properties for EL(1-39)

Define pertinent elbow variables

$D_o := 6.625\text{in}$ — Outside Diameter [16]

$t := 0.28\text{in}$ — Thickness [16]

$P := 376\text{psi}$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

$$I = 28.142\,\text{in}^4$$

Moment of inertia [8, Table 17-27, pg 17-39]

$R := 9\text{in}$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$

Mean pipe radius

Define primary stress indices

$$h := \frac{t \cdot R}{r_m^{\,2}}$$

$h = 0.25$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4\cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4\cdot h > 0.5 \\ -0.1 + 0.4\cdot h & \text{otherwise} \end{cases}$$

$B_1 = 1.515 \times 10^{-4}$ — B_1 primary stress Index [4, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 3.272$ — B_2 primary stress Index [4, NB-3683.7]

Elbow 1-39 (Nodes 1034 & 1035)

$nd_{EL139\_1} := (1034)^T$

$AL_{EL139\_nd1034} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL139\_1}, Elb\_C_o, EL\right)$

$AL_{EL139\_nd1034}{}^T = \left(0.592 \quad 8.708\times10^4 \quad 4.975 \quad 1.034\times10^3 \quad 49 \quad -1.944\times10^4 \quad 1.936\times10^4 \quad 8.264\times 1\right.$

$nd_{EL139\_2} := (1035)^T$

$AL_{EL139\_nd1035} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL139\_2}, Elb\_C_o, EL\right)$

$AL_{EL139\_nd1035}{}^T = \left(0.79 \quad 1.163\times10^5 \quad 4.98 \quad 1.035\times10^3 \quad 52 \quad 8.186\times10^3 \quad 1.893\times10^4 \quad 1.145\times10^5\right)$

Elbow Properties for EL(1-40(A, C, D, & E))

Define pertinent elbow variables

$D_o := 6.625\,in$ — Outside Diameter [17]

$t := 0.28in$ — Thickness [17]

$P := 272psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o{}^4 - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 28.142\,in^4$

$R := 9in$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$

Mean pipe radius

Define primary stress indices

$$h := \frac{t\cdot R}{r_m{}^2}$$

$h = 0.25$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4\cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4\cdot h > 0.5 \\ -0.1 + 0.4\cdot h & \text{otherwise} \end{cases}$$

$B_1 = 1.515\times10^{-4}$ — B_1 primary stress Index [4, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 3.272$ — B_2 primary stress Index [4, NB-3683.7]

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Elbow 1-40A (Nodes 803 & 802)

$nd_{EL140A\_1} := (803)^T$

$AL_{EL140A\_nd803} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL140A\_1}, Elb\_C_o, EL)$

$AL_{EL140A\_nd803}{}^T = (0.316 \quad 4.28\times10^4 \quad 8.415 \quad 803 \quad 9 \quad -2.031\times10^4 \quad 3.671\times10^4 \quad 8.46\times10^3)$

$nd_{EL140A\_2} := (802)^T$

$AL_{EL140A\_nd802} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL140A\_2}, Elb\_C_o, EL)$

$AL_{EL140A\_nd802}{}^T = (0.294 \quad 3.984\times10^4 \quad 8.415 \quad 802 \quad 80 \quad -1.864\times10^4 \quad 3.403\times10^4 \quad 9.036\times10^3)$

Elbow 1-40C (Nodes 778 & 779)

$nd_{EL140C\_1} := (778)^T$

$AL_{EL140C\_nd778} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL140C\_1}, Elb\_C_o, EL)$

$AL_{EL140C\_nd778}{}^T = (0.401 \quad 5.437\times10^4 \quad 10.18 \quad 778 \quad 7 \quad 6.629\times10^3 \quad -4.465\times10^4 \quad -3.032\times10^4)$

$nd_{EL140C\_2} := (779)^T$

$AL_{EL140C\_nd779} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL140C\_2}, Elb\_C_o, EL)$

$AL_{EL140C\_nd779}{}^T = (0.411 \quad 5.572\times10^4 \quad 9.445 \quad 779 \quad 5 \quad 2.356\times10^4 \quad -1.407\times10^4 \quad -4.85\times10^4)$

Elbow 1-40D (Nodes 780 & 781)

$nd_{EL140D\_1} := (780)^T$

$AL_{EL140D\_nd780} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL140D\_1}, Elb\_C_o, EL)$

$AL_{EL140D\_nd780}{}^T = (0.407 \quad 5.515\times10^4 \quad 4.245 \quad 780 \quad 14 \quad 1.72\times10^4 \quad 3.178\times10^3 \quad 5.231\times10^4)$

$nd_{EL140D\_2} := (781)^T$

$AL_{EL140D\_nd781} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL140D\_2}, Elb\_C_o, EL)$

$AL_{EL140D\_nd781}{}^T = (0.392 \quad 5.319\times10^4 \quad 9.2 \quad 781 \quad 15 \quad -3.2\times10^4 \quad 2.501\times10^4 \quad -3.435\times10^4)$

Elbow 1-40E (Nodes 782 & 783)

$nd_{EL140E\_1} := (782)^T$

$AL_{EL140E\_nd782} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL140E\_1}, Elb\_C_o, EL)$

$AL_{EL140E\_nd782}{}^T = (0.307 \quad 4.168\times10^4 \quad 10.67 \quad 782 \quad 3 \quad -3.745\times10^4 \quad -1.384\times10^4 \quad -1.194\times10^4)$

$nd_{EL140E\_2} := (783)^T$

$AL_{EL140E\_nd783} := Elbow(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL140E\_2}, Elb\_C_o, EL)$

$AL_{EL140E\_nd783}{}^T = (0.341 \quad 4.626\times10^4 \quad 5.715 \quad 783 \quad 2 \quad 2.586\times10^4 \quad 6.663\times10^3 \quad 3.778\times10^4)$

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Elbow Properties for EL(1-40B)

Define pertinent elbow variables

$D_o := 6.625\,in$ — Outside Diameter [17]

$t := 0.28\,in$ — Thickness [17]

$P := 272\,psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 28.142\,in^4$

$R := 30\,in$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$

Mean pipe radius

Define primary stress indices

$$h := \frac{t \cdot R}{r_m^{\,2}}$$

$h = 0.835$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h > 0.5 \\ -0.1 + 0.4 \cdot h & \text{otherwise} \end{cases}$$

$B_1 = 0.234$ — B_1 primary stress Index [4, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 1.467$ — B_2 primary stress Index [4, NB-3683.7]

Elbow 1-40B (Nodes 776 & 777)

$nd_{EL140B\_1} := (776)^T$

$AL_{EL140B\_nd776} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL140B\_1}, Elb\_C_o, EL\right)$

$$AL_{EL140B\_nd776}^{\;T} = \begin{pmatrix} 0.238 & 6.763 \times 10^4 & 5.71 & 776 & 72 & 6.586 \times 10^4 & -1.078 \times 10^4 & 1.099 \times 10^4 \end{pmatrix}$$

$nd_{EL140B\_2} := (777)^T$

$AL_{EL140B\_nd777} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{EL140B\_2}, Elb\_C_o, EL\right)$

$$AL_{EL140B\_nd777}^{\;T} = \begin{pmatrix} 0.189 & 5.271 \times 10^4 & 9.9 & 777 & 21 & -4.132 \times 10^4 & 3.263 \times 10^4 & -2.617 \times 10^3 \end{pmatrix}$$

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Writing Output Data for Elbows Associated with Lines 1-39 and 1-40

$EL1A := AL_{EL139\_nd1034}^{T}$

$EL1B := AL_{EL139\_nd1035}^{T}$

$EL2A := AL_{EL140A\_nd803}^{T}$

$EL2B := AL_{EL140A\_nd802}^{T}$

$EL3A := AL_{EL140C\_nd778}^{T}$

$EL3B := AL_{EL140C\_nd779}^{T}$

$EL4A := AL_{EL140D\_nd780}^{T}$

$EL4B := AL_{EL140D\_nd781}^{T}$

$EL5A := AL_{EL140E\_nd782}^{T}$

$EL5B := AL_{EL140E\_nd783}^{T}$

$EL6A := AL_{EL140B\_nd776}^{T}$

$EL6B := AL_{EL140B\_nd777}^{T}$

vEL := (EL1A EL1B EL2A EL2B EL3A EL3B EL4A EL4B EL5A EL5B EL6A EL6B)

ElbowLine1_39_40 := WRITEPRN("ElbowLine1-39_40.prn" , vEL)

FORGED TEES AND FABRICATED BRANCH TEES

Tees Strategy: *Search based on the elements comprising the tee. The input identifies which elements are associated with the pipe run and which element is associated with the branch from the run. The indices for the defined common node for all three elements is identified and the associated SRSS moment is identified for each time step. The maximum moment for the elements comprising the pipe run is found and applied as* M_r *in equation (9) of ASME III, Division I - NB - 3652 which is modified to represent tees. The maximum moment for the branch element is found and applied as* M_b *in equation (9) of ASME III, Division I - NB - 3652 [4]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\text{TeeDC}\left(P,D_o,T_r,B_1,B_{2b},B_{2r},M_b,M_r,Z_b,Z_r,S\right) := \frac{B_1\cdot\frac{P\cdot D_o}{2\cdot T_r}+B_{2b}\cdot\left[\frac{M_b\cdot(1\text{lbf}\cdot\text{in})}{Z_b}\right]+B_{2r}\cdot\left[\frac{M_r\cdot(1\text{lbf}\cdot\text{in})}{Z_r}\right]}{S}$$

$\text{Tee}\left(P,D_o,T_r,B_1,B_{2b},B_{2r},Z_b,Z_r,S,nf,el_R,el_B,nd_R,nd_B,C_o,EL\right) :=$

```
ind_nfi ← match(t_initial, nf^<0>)
ind_nfo ← match(t_final, nf^<0>)
ind_elR ← match(el_R_0, EL^<0>)
for i ∈ 1 .. last(el_R)                                              if rows
    ind_elR ← stack[ind_elR, (match(el_R_i, EL^<0>))]
EL'R_last(EL^<0>) ← 0
for i ∈ 0 .. last(ind_elR)
    EL'R_(ind_elR_i) ← EL_(ind_elR_i, 1)
ind_ndR ← match(nd_R_0, EL'R^<0>)
for i ∈ 1 .. last(nd_R)                                              if r
    ind_ndR ← stack[ind_ndR, (match(nd_R_i, EL'R^<0>))]
ind_elB ← match(el_B_0, EL^<0>)
for i ∈ 1 .. last(el_B)                                              if rows
    ind_elB ← stack[ind_elB, (match(el_B_i, EL^<0>))]
EL'B_last(EL^<0>) ← 0
for i ∈ 0 .. last(ind_elB)
    EL'B_(ind_elB_i) ← EL_(ind_elB_i, 1)
ind_ndB ← match(nd_B_0, EL'B^<0>)
```

for $i \in 1..\text{last}(nd_B)$ if r

$ind_{ndB} \leftarrow \text{stack}\left[ind_{ndB}, \left(\text{match}\left(nd_{B_i}, EL'B^{\langle 0 \rangle}\right)\right)\right]$

$(M_R \;\; M_B \;\; Int_0) \leftarrow (0 \;\; 0 \;\; 0)$

for $i \in 0..ind_{nfo_0} - ind_{nfi_0}$

for $j \in 0..\text{last}(ind_{ndR})$

for $k \in 0..\text{last}(ind_{ndB})$

$M_{rxgR_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2, ind_{ndR_j}}$

$M_{rygR_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2, ind_{ndR_j}}$

$M_{rzgR_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2, ind_{ndR_j}}$

$M_{rxR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i, ind_{ndR_j}} - M_{rxgR_j}\right)\cdot C$

$M_{ryR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i, ind_{ndR_j}} - M_{rygR_j}\right)\cdot C$

$M_{rzR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i, ind_{ndR_j}} - M_{rzgR_j}\right)\cdot C$

$M_{R_j} \leftarrow \sqrt{\left(M_{rxR_j}\right)^2 + \left(M_{ryR_j}\right)^2 + \left(M_{rzR_j}\right)^2}$

$M_{rxgB_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2, ind_{ndB_k}}$

$M_{rygB_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2, ind_{ndB_k}}$

$M_{rzgB_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2, ind_{ndB_k}}$

$M_{rxB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i, ind_{ndB_k}} - M_{rxgB_j}\right)\cdot C$

$M_{ryB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i, ind_{ndB_k}} - M_{rygB_j}\right)\cdot C$

$M_{rzB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i, ind_{ndB_k}} - M_{rzgB_j}\right)\cdot C$

$M_{B_j} \leftarrow \sqrt{\left(M_{rxB_j}\right)^2 + \left(M_{ryB_j}\right)^2 + \left(M_{rzB_j}\right)^2}$

$Int'_j \leftarrow \text{TeeDC}\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_{B_j}, M_R\right.$

if $Int'_j > Int_0$

$Int \leftarrow \text{stack}\left(Int'_j, M_{R_j}, M_{B_j}, nf_{ind_{nfiC_{o_{0,1}}}-1+i}\right.$

$$\text{Result} \leftarrow \text{stack}\left(M_{R_j}, M_{B_j}, M_{rxR_j}, M_{ryR_j}, M\right.$$
$$M \leftarrow M_R$$
Int

Conditions applicable to forged tee

$M_{ox} := 0 \quad M_{oy} := 0 \quad M_{oz} := 0$ — Defining place holding directional moment variables

$$Tee\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

FORGED TEES (LINE 1-39)

Define pertinent tee variables

$P := 376\text{psi}$ — Internal Pressure [16, pg 23]

$D_o := 6.625\text{in}$ — Outside Diameter [16]

$d_o := 6.625\text{in}$ — Outside Diameter of branch [16]

$B_1 := 0.5$ — B_1 primary stress Index for tees and branches [4, NB-3683.9]

$T_r := 0.28\text{in}$ — Nominal wall thickness of designated run pipe [16]

$$R_m := \frac{D_o - T_r}{2}$$ — Mean radius of designated run pipe [16]

$$Z_r := \pi \cdot R_m^{\;2} \cdot T_r$$ — Approximate section modulus of designated run pipe [4, NB-3683.1(d)]

$$Z_r = 8.8534\ \text{in}^3$$

$$B_{2b} := \begin{cases} 0.4 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} & \text{if } 0.4 \cdot \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} > 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Index for tees and branches [4, NB-3683.9]

$$B_{2b} = 2.018$$

$T'_b := 0.28\text{in}$ — Nominal wall thickness of attached branch pipe [16]

$$r'_m := \frac{d_o - T'_b}{2}$$ — Mean radius of attached branch pipe [16]

$$Z_b := \pi \cdot r'^{\;2}_m \cdot T'_b$$ — Approximate section modulus of attached branch pipe [4, NB-3683.1(d)]

$$Z_b = 8.853\ \text{in}^3$$

$$B_{2r} := \begin{cases} 0.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} & \text{if } 0.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} > 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Index for tees and branches [4, NB-3683.9]

$B_{2r} = 2.522$

Tee 1-39 (Node 989)

$elR_{Tee139} := (513\ \ 514)^T$ — Elements associated with pipe run

$ndR_{Tee139} := (989)^T$ — Node between pipe run elements

$elB_{Tee139} := (512)^T$ — Element associated with branch

$ndB_{Tee139} := (989)^T$ — Node where branch intersects pipe run

$AL_{Tee139} := Tee\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF, elR_{Tee139}, elB_{Tee139}, ndR_{Tee139}, ndB_{Tee139}, Tee\_C\right.$

$$AL_{Tee139}^T = \left(1.023\quad 1.176\times10^5\quad 9.761\times10^4\quad 4.25\quad 989\quad 43\quad 45\quad 41\right)$$

Writing Output Data for Tees Associated with Lines 1-39 & 1-40

$T1 := AL_{Tee139}^T$

$vT := (T1)$

TeeLine1_39_40 := WRITEPRN("TeeLine1-39_40.prn" , vT)

FLANGES

Flange Strategy: *Search based on the nodes where flanges occur. Find the maximum moment combination for the node and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\mathrm{FlangeDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Flange}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(nd)$ if $\mathrm{rows}(nd) > 1$

  $ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$(M \;\; Int_0) \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \mathrm{last}(ind_{nd})$

    $M_{rxg} \leftarrow nf_{ind_{nfi}C_{o_{0,1}}+2,\, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi}C_{o_{1,1}}+2,\, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi}C_{o_{2,1}}+2,\, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi}C_{o_{1,1}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi}C_{o_{2,1}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow \mathrm{FlangeDC}(P, D_o, t, I, B_1, B_2, M'_j, S)$

    if $Int'_j > Int_0$

      $Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfi}C_{o_{0,1}}-1+i,0}, EL_{ind_{nd_j},1}, ind_{nd_j}, M_{rx}, M_{ry}, M\right.$

      $Result \leftarrow M'$

Int

Conditions applicable to all flanges

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$ — Defining place holding variables

$$Flange\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties of FL(1-39(A-D))

Define pertinent pipe variables

$D_o := 6.625in$ — Outside Diameter [16]

$t := 0.28in$ — Thickness [16]

$P := 376psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\ 4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$ — Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 28.142\ in^4$$

Define primary stress indices (Utilize girth weld characteristic associated with lap joint flanges in determining values)

$B_1 := 0.5$ — B_1 for a girth weld [4, Table NB-3681(a)-1, pg 130]

$B_2 := 1$ — B_2 for a girth weld [4, Table NB-3681(a)-1, pg 130]

Flange 1-39A (Node 983)

$$nd_{FL139A} := (983)^T$$

$$AL_{FL139A} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL139A}, Flange\_C_o, EL\right)$$

$$AL_{FL139A}^{\ T} = \begin{pmatrix} 0.277 & 1.146 \times 10^5 & 4.245 & 983 & 87 & 628.656 & -1.405 \times 10^4 & 1.137 \times 10^5 \end{pmatrix}$$

Flange 1-39B (Node 987)

$$nd_{FL139B} := (987)^T$$

$$AL_{FL139B} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL139B}, Flange\_C_o, EL\right)$$

$$AL_{FL139B}^{\ T} = \begin{pmatrix} 0.245 & 9.891 \times 10^4 & 8.5 & 987 & 58 & 2.333 \times 10^4 & -2.425 \times 10^4 & 9.301 \times 10^4 \end{pmatrix}$$

Flange 1-39C (Node 758)

$$nd_{FL139C} := (758)^T$$

$$AL_{FL139C} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL139C}, Flange\_C_o, EL\right)$$

$$AL_{FL139C}^{\ T} = \begin{pmatrix} 0.175 & 6.538 \times 10^4 & 5.67 & 758 & 85 & 1.711 \times 10^4 & 6.819 \times 10^3 & 6.273 \times 10^4 \end{pmatrix}$$

Flange 1-39D (Node 1180)

$nd_{FL139D} := (1180)^T$

$AL_{FL139D} := \text{Flange}(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL139D}, \text{Flange\_C}_o, EL)$

$AL_{FL139D}^{\ T} = (0.227 \quad 9.053\times10^4 \quad 10.185 \quad 1.18\times10^3 \quad 64 \quad -1.664\times10^4 \quad -1.642\times10^4 \quad -8.746\times10^4)$

Pipe Properties of FL(1-39E)

Define pertinent pipe variables

$D_o := 4.5in$ — Outside Diameter [4]

$t := 0.237in$ — Thickness [4]

$P := 376psi$ — Internal Pressure [3, pg 23]

$I := \frac{\pi\cdot\left[D_o^{\ 4} - (D_o - 2\cdot t)^4\right]}{64}$ — Moment of inertia [8, Table 17-27, pg 17-39]

$I = 7.233\ in^4$

Define primary stress indices (Utilize girth weld characteristic associated with lap joint flanges in determining values)

$B_1 := 0.5$ — B_1 for a girth weld [4, Table NB-3681(a)-1, pg 130]

$B_2 := 1$ — B_2 for a girth weld [4, Table NB-3681(a)-1, pg 130]

Flange 1-39E (Node 990)

$nd_{FL139E} := (990)^T$

$AL_{FL139E} := \text{Flange}(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL139E}, \text{Flange\_C}_o, EL)$

$AL_{FL139E}^{\ T} = (0.299 \quad 4.885\times10^4 \quad 5.35 \quad 990 \quad 56 \quad 1.666\times10^3 \quad -5.789\times10^3 \quad 4.847\times10^4)$

Writing Output Data for Flanges Associated with Lines 1-39 & 1-40

$F1 := AL_{FL139A}^{\ T}$

$F2 := AL_{FL139B}^{\ T}$

$F3 := AL_{FL139C}^{\ T}$

$F4 := AL_{FL139D}^{\ T}$

$F5 := AL_{FL139E}^{\ T}$

$F := (F1 \quad F2 \quad F3 \quad F4 \quad F5)$

FlangeLine1_39_40 := WRITEPRN("FlangeLine1-39_40.prn" , F)

Appendix D.3.6

Demand to Capacity Ratio Calculations for Components Associated with Lines 1-41, 1-77, 1-37, and 1-38 of ATR PCS Model 1-4

(NOTE: Values represented here are shown for one realization (Nodal Force file = LINE1-41_77_test_R1.dat and Element/Nodal order file = EL1-41_77.xls) and may or may not be consistent with the 80th percentile results contained in Appendix D.4)

Force Outputs from Abaqus

NF := ...\LINE1-41_77.dat — (N)odal (F)orces for Model 1-4

Defined Elemental and Corresponding Nodal Order

EL := ..\EL_41_77(9-22-08).xls — Element and corresponding nodal order for Model 1-4

Time Boundaries

$t_{initial} := 1$ — Initial time for which dynamic loading is applied

$t_{final} := 21$ — Final time for which dynamic loading stops

Seismic Scale Factor (F_a)

$F_a := 1$ — Seismic scale factor [9]

Allowable Design Stress Intensity Factor (S_m): *S_m is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{m\_125} := 20ksi$ — For SS304 at 125°F [2, pg 316-318] [3, pg 23]

$S_{m\_125L} := 16.7ksi$ — For SS304L at 125°F [2, pg 316-318] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

$S_{m\_167} := 20ksi$ — For SS304 at 167°F [2, pg 316-318] [3, pg 23]

$S_{m\_167L} := 16.7ksi$ — For SS304L at 167°F [2, pg 316-318] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

Yield Strength (S_y): *S_y is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{y\_125} := 28.35ksi$ — For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_125L} := 23.85ksi$ — For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

$S_{y\_167} := 26.12ksi$ — For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_167L} := 22.26ksi$ — For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

Maximum Strength Applicable for Equation 9 (S): *S is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{125} := \min(3 \cdot S_{m\_125}, 2 \cdot S_{y\_125})$

Maximum allowable stress applied to SS304 piping [4, NB-3656]

$S_{125} = 56.7\,ksi$

$2S_{y\_125} = 56.7\,ksi$

$S_{125L} := \min(3 \cdot S_{m\_125L}, 2 \cdot S_{y\_125L})$

Maximum allowable stress applied to SS304L piping [4, NB-3656]

$S_{125L} = 47.7\,ksi$

$S_{167} := \min(3 \cdot S_{m\_167}, 2 \cdot S_{y\_167})$

Maximum allowable stress applied to SS304 piping [4, NB-3656]

$S_{167} = 52.24\,ksi$

$S_{167L} := \min(3 \cdot S_{m\_167L}, 2 \cdot S_{y\_167L})$

Maximum allowable stress applied to SS304L piping [4, NB-3656]

$S_{167L} = 44.52\,ksi$

SUPPORTS

Supports Strategy: *Search based on the node for which the support acts. If this node is a termination point there will only be one node to evaluate. If this node is in line with a section of pipe there will be two representations of the same node (one for each element on each side of the node) to combine and the difference between them is the force required of the support. The D/C ratio for each support will be found by dividing the the required force found above by the support capacity.*

$$SupDC(P_r, P_c) := \frac{P_r}{P_c}$$

$$
\begin{aligned}
Support(nf, nd, C_o, EL) := \quad & ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
& ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
& ind_{nd} \leftarrow match\left(nd_0, EL^{\langle 1 \rangle}\right) \\
& \text{for } i \in 1..last(nd) \quad \text{if } rows(nd) > 1 \\
& \quad ind_{nd} \leftarrow stack\left[ind_{nd}, \left(match\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \\
& \begin{pmatrix} Int1_4 & Int2_4 \end{pmatrix} \leftarrow (0 \quad 0) \\
& \text{for } i \in 0..ind_{nfo_0} - ind_{nfi_0} \\
& \quad \text{for } j \in 0..last\left(ind_{nd}\right) \\
& \quad\quad P_{rg_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}-1}, ind_{nd_j}} \\
& \quad\quad P_{r_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}-1}+i, ind_{nd_j}} - P_{rg_j}\right) \cdot C_{o_{2,0}} + P_{rg_j} \\
& \quad PR_i \leftarrow \sum_{n=0}^{j} P_{r_n} \\
& \quad \text{if } PR_i < Int1_1 \wedge C_{o_{0,0}} \neq 0 \\
& \quad\quad Int1' \leftarrow SupDC\left(\left|PR_i\right|, C_{o_{0,0}}\right) \\
& \quad\quad Int1 \leftarrow stack\left(Int1', PR_i, nf_{ind_{nfiC_{o_{0,1}}-1}+i,0}, EL_{ind_{nd_j},1}, ind_{nd}\right) \\
& \quad \text{if } PR_i > Int2_1 \wedge C_{o_{1,0}} \neq 0 \\
& \quad\quad Int2' \leftarrow SupDC\left(\left|PR_i\right|, C_{o_{1,0}}\right) \\
& \quad\quad Int2 \leftarrow stack\left(Int2', PR_i, nf_{ind_{nfiC_{o_{0,1}}-1}+i,0}, EL_{ind_{nd_j},1}, ind_{nd}\right) \\
& \begin{pmatrix} Int1 & Int2 \end{pmatrix}
\end{aligned}
$$

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PS-10 Support (1x)

$P_{1\_PS10} := \frac{22.1 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_PS10} := \frac{0 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$Sup\_C_{o\_PS10} := \begin{pmatrix} P_{1\_PS10} & 2 \\ P_{2\_PS10} & 0 \\ F_a & 0 \end{pmatrix}$ Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

PS-10B (Node 1353)

PS-10B vertically supports line 1-42 at the south side of EL(1-42I).

$nd1353_{PS10B_0} := 1353$ Node associated with support

$\left(AL1_{PS10B\_nd1353} \quad AL2_{PS10B\_nd1353}\right) := Support\left(NF, nd1353_{PS10B}, Sup\_C_{o\_PS10}, EL\right)$

$AL1_{PS10B\_nd1353}{}^{T} = \left(0.13 \quad -2.876 \times 10^{3} \quad 5.35 \quad 1.353 \times 10^{3} \quad 141\right)$

$AL2_{PS10B\_nd1353}{}^{T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0\right)$

…demand force, occurrence time, …d node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

Tieback1 Support (1x)

$P_{1\_TB1\_EW} := \frac{5.577 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_TB1\_EW} := \frac{1.528 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$Sup\_C_{o\_TB1\_EW} := \begin{pmatrix} P_{1\_TB1\_EW} & 3 \\ P_{2\_TB1\_EW} & 0 \\ F_a & 0 \end{pmatrix}$ Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

$P_{1\_TB1\_NS} := \frac{0.908 \cdot kip}{lbf}$ ***Flexure*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_TB1\_NS} := \frac{0.908 \cdot kip}{lbf}$ ***Flexure*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

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$$Sup\_C_{o\_TB1\_NS} := \begin{pmatrix} P_{1\_TB1\_NS} & 1 \\ P_{2\_TB1\_NS} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

Tieback1 East/West (Node 1446)

Tieback1 laterally supports the vertical PCS pipe on line 1-41 at the top side of EL(1-41A).

$$nd1446_{TB1\_EW_0} := 1446$$

Node associated with support

$$\left(AL1_{TB1\_EW\_nd1446} \quad AL2_{TB1\_EW\_nd1446}\right) := Support\left(NF, nd1446_{TB1\_EW}, Sup\_C_{o\_TB1\_EW}, EL\right)$$

$$AL1_{TB1\_EW\_nd1446}^{T} = \left(0.175 \quad -978.579 \quad 9.915 \quad 1.446\times10^{3} \quad 171\right)$$

$$AL2_{TB1\_EW\_nd1446}^{T} = \left(0.576 \quad 880.155 \quad 9.75 \quad 1.446\times10^{3} \quad 171\right)$$

...d force, occurrence time, ...e, associated Index for the reaction force at the selected node ...he positive (AL1) and negative ...ections of the global coordinate system)

Tieback1 North/South (Node 1446)

Tieback1 laterally supports the vertical PCS pipe on line 1-41 at the top side of EL(1-41A).

$$nd1446_{TB1\_NS_0} := 1446$$

Node associated with support

$$\left(AL1_{TB1\_NS\_nd1446} \quad AL2_{TB1\_NS\_nd1446}\right) := Support\left(NF, nd1446_{TB1\_NS}, Sup\_C_{o\_TB1\_NS}, EL\right)$$

$$AL1_{TB1\_NS\_nd1446}^{T} = \left(2.934 \quad -2.664\times10^{3} \quad 4.9 \quad 1.446\times10^{3} \quad 171\right)$$

$$AL2_{TB1\_NS\_nd1446}^{T} = \left(2.494 \quad 2.265\times10^{3} \quad 5.645 \quad 1.446\times10^{3} \quad 171\right)$$

...d force, occurrence time, ...e, associated Index for the reaction force at the selected node ...ositive (AL1) and negative ...ns of the global coordinate system)

PS-7 Support (1x)

$$P_{1\_PS7\_NS} := \frac{6.686\cdot kip}{lbf}$$

Tension

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$$P_{2\_PS7\_NS} := \frac{3.37\cdot kip}{lbf}$$

Compression

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_PS7\_NS} := \begin{pmatrix} P_{1\_PS7\_NS} & 1 \\ P_{2\_PS7\_NS} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

$$P_{1\_PS7\_V} := \frac{2.2\cdot kip}{lbf}$$

Flexure

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$$P_{2\_PS7\_V} := \frac{2.2\cdot kip}{lbf}$$

Flexure

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_PS7\_V} := \begin{pmatrix} P_{1\_PS7\_V} & 2 \\ P_{2\_PS7\_V} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

PS-7 North/South (Node 1355)

PS-7 supports line 1-41 at the eastern portion of P(1-41G) from movement in the vertical and east/west directions.

$nd1355_{PS7\_NS_0} := 1355$ Node associated with support

$$\left(AL1_{PS7\_NS\_nd1355} \;\; AL2_{PS7\_NS\_nd1355}\right) := Support\left(NF, nd1355_{PS7\_NS}, Sup\_C_{o\_PS7\_NS}, EL\right)$$

$$AL1_{PS7\_NS\_nd1355}^{T} = \begin{pmatrix} 0.184 & -1.231 \times 10^{3} & 1.01 & 1.355 \times 10^{3} & 143 \end{pmatrix}$$

$$AL2_{PS7\_NS\_nd1355}^{T} = \begin{pmatrix} 0.494 & 1.664 \times 10^{3} & 1.165 & 1.355 \times 10^{3} & 143 \end{pmatrix}$$

hand force, occurrence time, node, associated index for the reaction force at the selected node the positive (AL1) and negative ections of the global coordinate system)

PS-7 Vertical (Node 1355)

PS-7 supports line 1-41 at the eastern portion of P(1-41G) from movement in the vertical and east/west directions.

$nd1355_{PS7\_V_0} := 1355$ Node associated with support

$$\left(AL1_{PS7\_V\_nd1355} \;\; AL2_{PS7\_V\_nd1355}\right) := Support\left(NF, nd1355_{PS7\_V}, Sup\_C_{o\_PS7\_V}, EL\right)$$

$$AL1_{PS7\_V\_nd1355}^{T} = \begin{pmatrix} 1.115 & -2.454 \times 10^{3} & 1 & 1.355 \times 10^{3} & 143 \end{pmatrix}$$

$$AL2_{PS7\_V\_nd1355}^{T} = \begin{pmatrix} 0.802 & 1.764 \times 10^{3} & 1.005 & 1.355 \times 10^{3} & 143 \end{pmatrix}$$

,demand force, occurrence time, ed node, associated index for the reaction force at the selected node the positive (AL1) and negative irections of the global coordinate system)

RH-16 Support (1x)

$$P_{1\_RH16} := \frac{1.047 \cdot kip}{lbf}$$

Tension

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$$P_{2\_RH16} := \frac{0.397 \cdot kip}{lbf}$$

Compression

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_RH16} := \begin{pmatrix} P_{1\_RH16} & 2 \\ P_{2\_RH16} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

RH-16C (Node 1356)

RH-16C vertically supports line 1-41 just east of EL(1-41F) from any downward movement.

$nd1356_{RH16C_0} := 1356$ Node associated with support

$\left(AL1_{RH16C\_nd1356} \;\; AL2_{RH16C\_nd1356}\right) := \text{Support}\left(NF, nd1356_{RH16C}, Sup\_C_{o\_RH16}, EL\right)$

$AL1_{RH16C\_nd1356}{}^{T} = \left(1.985 \times 10^{-3} \;\; -2.078 \;\; 1.015 \;\; 1.356 \times 10^{3} \;\; 145\right)$

$AL2_{RH16C\_nd1356}{}^{T} = \left(0.012 \;\; 4.889 \;\; 1.025 \;\; 1.356 \times 10^{3} \;\; 145\right)$

nd force, occurrence time, de, associated index for the reaction force at the selected node ing in the positive (AL1) and negative L2) directions of the global coordinate system)

PS-11B Support (1x)

$P_{1\_PS11} := \dfrac{20.496 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_PS11} := \dfrac{0 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$Sup\_C_{o\_PS11} := \begin{pmatrix} P_{1\_PS11} & 2 \\ P_{2\_PS11} & 0 \\ F_a & 0 \end{pmatrix}$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

PS-11B (Node 1368)

PS-11B vertically supports line 1-77 just south of REL(1-77A).

$nd1368_{PS11B_0} := 1368$ Node associated with support

$\left(AL1_{PS11B\_nd1368} \;\; AL2_{PS11B\_nd1368}\right) := \text{Support}\left(NF, nd1368_{PS11B}, Sup\_C_{o\_PS11}, EL\right)$

$AL1_{PS11B\_nd1368}{}^{T} = \left(0.133 \;\; -2.729 \times 10^{3} \;\; 4.075 \;\; 1.368 \times 10^{3} \;\; 147\right)$

$AL2_{PS11B\_nd1368}{}^{T} = \left(0 \;\; 0 \;\; 0 \;\; 0 \;\; 0\right)$

nand force, occurrence time, node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

WTS Support (1x)

$P_{1\_WTS} := \dfrac{0.59 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_WTS} := \dfrac{0.01 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_WTS} := \begin{pmatrix} P_{1\_WTS} & 2 \\ P_{2\_WTS} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

WTS (Node 1407)

WTS vertically supports line 1-77 just north of EL(1-77B) from any downward movement.

$$nd1407_{WTSC_0} := 1407$$

Node associated with support

$$\left(AL1_{WTSC\_nd1407}\ \ AL2_{WTSC\_nd1407}\right) := Support\left(NF, nd1407_{WTSC}, Sup\_C_{o\_WTS}, EL\right)$$

$$AL1_{WTSC\_nd1407}^{T} = \left(2.846\ \ -1.679\times 10^{3}\ \ 4.93\ \ 1.407\times 10^{3}\ \ 149\right)$$

$$AL2_{WTSC\_nd1407}^{T} = \left(0\ \ 0\ \ 0\ \ 0\ \ 0\right)$$

...mand force, occurrence time, ... node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-27 Support (1x)

$$P_{1\_RH27} := \frac{7.069\cdot kip}{lbf}$$

Tension

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$$P_{2\_RH27} := \frac{0\cdot kip}{lbf}$$

Compression

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_RH27} := \begin{pmatrix} P_{1\_RH27} & 2 \\ P_{2\_RH27} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

RH-27A (Node 1285)

RH-27A vertically supports line 1-77 just north of EL(1-77D) from any downward movement.

$$nd1285_{RH27A_0} := 1285$$

Node associated with support

$$\left(AL1_{RH27A\_nd1285}\ \ AL2_{RH27A\_nd1285}\right) := Support\left(NF, nd1285_{RH27A}, Sup\_C_{o\_RH27}, EL\right)$$

$$AL1_{RH27A\_nd1285}^{T} = \left(0.299\ \ -2.111\times 10^{3}\ \ 10.34\ \ 1.285\times 10^{3}\ \ 173\right)$$

$$AL2_{RH27A\_nd1285}^{T} = \left(0\ \ 0\ \ 0\ \ 0\ \ 0\right)$$

...and force, occurrence time, ...ode, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-27B (Node 1284)

RH-27B vertically supports line 1-77 just south of EL(1-77E) from any downward movement.

$nd1284_{RH27B_0} := 1284$ Node associated with support

$\left(AL1_{RH27B\_nd1284} \;\; AL2_{RH27B\_nd1284}\right) := Support\left(NF, nd1284_{RH27B}, Sup\_C_{o\_RH27}, EL\right)$

$AL1_{RH27B\_nd1284}{}^{T} = \left(0.304 \;\; -2.146\times10^{3} \;\; 10.555 \;\; 1.284\times10^{3} \;\; 175\right)$

$AL2_{RH27B\_nd1284}{}^{T} = (0 \;\; 0 \;\; 0 \;\; 0 \;\; 0)$

...and force, occurrence time, ...de, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

Writing Output Data for Supports Associated with Lines 1-13 to 1-16, 1-18 to 1-21, and 1-171.

$SA1 := AL1_{PS10B\_nd1353}{}^{T}$

$SA2 := AL2_{PS10B\_nd1353}{}^{T}$

$SB1 := AL1_{TB1\_EW\_nd1446}{}^{T}$

$SB2 := AL2_{TB1\_EW\_nd1446}{}^{T}$

$SC1 := AL1_{TB1\_NS\_nd1446}{}^{T}$

$SC2 := AL2_{TB1\_NS\_nd1446}{}^{T}$

$SD1 := AL1_{PS7\_NS\_nd1355}{}^{T}$

$SD2 := AL2_{PS7\_NS\_nd1355}{}^{T}$

$SE1 := AL1_{PS7\_V\_nd1355}{}^{T}$

$SE2 := AL2_{PS7\_V\_nd1355}{}^{T}$

$SF1 := AL1_{RH16C\_nd1356}{}^{T}$

$SF2 := AL2_{RH16C\_nd1356}{}^{T}$

$SG1 := AL1_{PS11B\_nd1368}{}^{T}$

$SG2 := AL2_{PS11B\_nd1368}{}^{T}$

$SH1 := AL1_{WTSC\_nd1407}{}^{T}$

$SH2 := AL2_{WTSC\_nd1407}{}^{T}$

$SI1 := AL1_{RH27A\_nd1285}{}^{T}$

$SI2 := AL2_{RH27A\_nd1285}{}^{T}$

$SJ1 := AL1_{RH27B\_nd1284}{}^{T}$

$SJ2 := AL2_{RH27B\_nd1284}{}^{T}$

$S := (SA1 \;\; SA2 \;\; SB1 \;\; SB2 \;\; SC1 \;\; SC2 \;\; SD1 \;\; SD2 \;\; SE1 \;\; SE2 \;\; SF1 \;\; SF2 \;\; SG1 \;\; SG2 \;\; SH1 \;\; SH2 \;\; SI1 \;\; SI2 \;\; SJ1 \;\; SJ2)$

SupportsLine1_41_77 := WRITEPRN("SupLine1-41_77.prn" , S)

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

TERMINATION LOCATIONS

Termination Locations Strategy: *Search based on the node for which the termination location acts as well as the next node inward. The D/C ratio for each termination location will be found by dividing the the required force found above by the support capacity.*

$$\mathrm{TermDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1 \mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Term}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

```
ind_nfi ← match(t_initial, nf^<0>)
ind_nfo ← match(t_final, nf^<0>)
ind_nd ← match(nd_0, EL^<1>)
for i ∈ 1 .. last(nd)                                        if rows(nd) > 1
    ind_nd ← stack[ind_nd, (match(nd_i, EL^<1>))]
(M  Int_0) ← (0  0)
for i ∈ 0 .. ind_nfo_0 − ind_nfi_0
    for j ∈ 0 .. last(ind_nd)
        M_rxg ← nf_(ind_nfi_(Co_0,1)+2, ind_nd_j)
        M_ryg ← nf_(ind_nfi_(Co_1,1)+2, ind_nd_j)
        M_rzg ← nf_(ind_nfi_(Co_2,1)+2, ind_nd_j)
        M_rx ← (nf_(ind_nfi_(Co_0,1)+2+i, ind_nd_j) − M_rxg)·Co_3,0 + M_rxg
        M_ry ← (nf_(ind_nfi_(Co_1,1)+2+i, ind_nd_j) − M_ryg)·Co_3,0 + M_ryg
        M_rz ← (nf_(ind_nfi_(Co_2,1)+2+i, ind_nd_j) − M_rzg)·Co_3,0 + M_rzg
        M'_j ← sqrt(M_rx^2 + M_ry^2 + M_rz^2)
        Int'_j ← TermDC(P, D_o, t, I, B_1, B_2, M'_j, S)
        if Int'_j > Int_0
            Int ← stack(Int'_j, M'_j, nf_(ind_nfi_(Co_0,1)−1+i, 0), EL_(ind_nd_j, 1), ind_nd_j, M_rx, M_ry, M_1
            Result ← M'
Int
```

Conditions applicable to all terminations

$M_{cx} := 0$ $M_{cy} := 0$ $M_{cz} := 0$

Defining place holding variables

$$Term\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

North Floor Pentration (2x)

Define pertinent pipe variables

$D_o := 2.375 in$

Outside Diameter [18]

$t := 0.154 in$

Thickness [18]

$P := 376 psi$

Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

$I = 0.666\ in^4$

Moment of inertia [8, Table 17-27, pg 17-39]

$S := S_{125}$

Allowable design stress intensity value

Define primary stress indices

$B_1 := 0.5$

$$B_2 := \left| \begin{array}{l} 1.0 \ \text{ if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50 \\ \quad \left| \begin{array}{l} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \dfrac{D_o}{t}\right) \\ Y \leftarrow 1 \\ 1.0 \cdot \dfrac{1}{X \cdot Y} \end{array} \right. \end{array} \right.$$

$B_2 = 1$

Stress Indices are derived from [4, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [4, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

North Floor Penetration 1-37 (Node 1222)

$nd1222_{NFP137_0} := 1222$

$AL_{NFP137\_nd1222} := Term(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd1222_{NFP137}, Term\_C_o, EL)$

$AL_{NFP137\_nd1222}{}^T = (1.233 \quad 3.838 \times 10^4 \quad 4.95 \quad 1.222 \times 10^3 \quad 120 \quad -1.881 \times 10^4 \quad -1.265 \times 10^4 \quad 3.097$

North Floor Penetration 1-38 (Node 1223)

$nd1223_{NFP138_0} := 1223$

$AL_{NFP138\_nd1223} := Term(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd1223_{NFP138}, Term\_C_o, EL)$

$AL_{NFP138\_nd1223}{}^T = (1.141 \quad 3.545 \times 10^4 \quad 4.95 \quad 1.223 \times 10^3 \quad 116 \quad -7.622 \times 10^3 \quad -1.548 \times 10^4 \quad 3.097$

West Floor Pentration (1x)

Define pertinent pipe variables

$D_o := 6.625 in$ — Outside Diameter [19]

$t := 0.28 in$ — Thickness [19]

$P := 376 psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o{}^4 - (D_o - 2 \cdot t)^4\right]}{64}$$

$I = 28.142\, in^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$S := S_{125}$ — Allowable design stress intensity value

Define primary stress indices

$B_1 := 0.5$

$$B_2 := \begin{cases} 1.0 \text{ if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 \\ \quad T \leftarrow 125 \\ \quad X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \frac{D_o}{t}\right) \\ \quad Y \leftarrow 1 \\ \quad 1.0 \cdot \frac{1}{X \cdot Y} \end{cases}$$

$B_2 = 1$

Stress Indices are derived from [4, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [4, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

West Floor Penetration 1-41 (Node 1148)

$nd1148_{WFP141_0} := 1148$

$AL_{WFP141\_nd1148} := Term(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd1148_{WFP141}, Term\_C_o, EL)$

$AL_{WFP141\_nd1148}{}^T = (0.273 \quad 1.126 \times 10^5 \quad 1.5 \quad 1.148 \times 10^3 \quad 21 \quad 555.718 \quad -698.946 \quad 1.126 \times 10^5)$

Writing Output Data for Terminations Associated with Lines 1-41 and 1-77

$T1 := AL_{NFP137\_nd1222}{}^T$

$T2 := AL_{NFP138\_nd1223}{}^T$

$T3 := AL_{WFP141\_nd1148}{}^T$

$T := (T1 \quad T2 \quad T3)$

TerminationsLine1_41_77 := WRITEPRN("TermLine1-41_77.prn" , T)

PIPE RUNS

Pipe Runs Strategy: *Search based on the nodes present in each run of pipe. Find the maximum moment combination among all of the nodes and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{PipeRunDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{PipeRun}(P, D_o, t, I, B_1, B_2, S, nf, el, C_o, EL) :=$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{el} \leftarrow \mathrm{match}\left(el_0, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(el)$ if $\mathrm{rows}(el) > 1$

  $ind_{el} \leftarrow \mathrm{stack}\left[ind_{el}, \left(\mathrm{match}\left(el_i, EL^{\langle 0 \rangle}\right)\right)\right]$

$\left(M \quad Int_{5, \mathrm{last}(ind_{el})}\right) \leftarrow (0 \quad 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \mathrm{last}(ind_{el})$

$M_{rxg} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}}+2, ind_{el_j}}$

$M_{ryg} \leftarrow nf_{ind_{nfi_{C_{o_{1,1}}}}+2, ind_{el_j}}$

$M_{rzg} \leftarrow nf_{ind_{nfi_{C_{o_{2,1}}}}+2, ind_{el_j}}$

$M_{rx_j} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}}+2+i, ind_{el_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

$M_{ry_j} \leftarrow \left(nf_{ind_{nfi_{C_{o_{1,1}}}}+2+i, ind_{el_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

$M_{rz_j} \leftarrow \left(nf_{ind_{nfi_{C_{o_{2,1}}}}+2+i, ind_{el_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

$M'_j \leftarrow \sqrt{\left(M_{rx_j}\right)^2 + \left(M_{ry_j}\right)^2 + \left(M_{rz_j}\right)^2}$

$Int'_j \leftarrow \mathrm{PipeRunDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$

if $Int'_j > Int_{0,j}$

  $H \leftarrow \left(Int'_j \quad M'_j \quad nf_{ind_{nfi_{C_{o_{0,1}}}}-1+i, 0} \quad EL_{ind_{el_j}, 0} \quad EL_{ind_{el_j}, 1} \quad ind_{el_j} \quad M_{r.}\right.$

  for $k \in 0 .. 5$

    $Int_{k,j} \leftarrow H_k$

Int

Conditions applicable to all pipe runs

$M_{cx} := 0 \quad M_{cy} := 0 \quad M_{cz} := 0$

Defining place holding directional moment variables

$$PipeRun\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties for Line 1-41

Define pertinent pipe variables

$D_o := 6.625\,in$ — Outside Diameter [18]

$t := 0.28\,in$ — Thickness [18]

$P := 376\,psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^4 - (D_o - 2\cdot t)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 28.142\,in^4$$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{cases} 1.0 & \text{if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 & \begin{cases} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006\cdot\frac{D_o}{t}\right) \\ Y \leftarrow 1.033 - 0.00033\cdot T \\ 1.0\cdot\frac{1}{X\cdot Y} \end{cases} \end{cases}$$

$B_{2PR} = 1$

Stress Indices are derived from [4, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [4, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-41A (Element 606)

$el_{P141A} := (606)^T$

$AL_{P141A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P141A}, PipeRun\_C_o, EL\right)$

$$AL_{P141A}^T = \begin{pmatrix} 0.166 & 6.087\times10^4 & 10.185 & 606 & 760 & 132 \\ 0.194 & 7.467\times10^4 & 10.185 & 606 & 1.018\times10^3 & 133 \end{pmatrix}$$

Pipe Run 1-41B (Element 479 & 987)

$$el_{P141B} := (479\ \ 987)^T$$

$$AL_{P141B} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P141B}, PipeRun\_C_o, EL\right)$$

$$AL_{P141B}^T = \begin{pmatrix} 0.201 & 7.777 \times 10^4 & 5.62 & 479 & 1.019 \times 10^3 & 1 \\ 0.165 & 6.065 \times 10^4 & 4.96 & 479 & 1.69 \times 10^3 & 2 \\ 0.312 & 1.313 \times 10^5 & 4.95 & 987 & 1.023 \times 10^3 & 182 \\ 0.165 & 6.065 \times 10^4 & 4.96 & 987 & 1.69 \times 10^3 & 183 \end{pmatrix}$$

Pipe Run 1-41C (Element 840)

$$el_{P141C} := (840)^T$$

$$AL_{P141C} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P141C}, PipeRun\_C_o, EL\right)$$

$$AL_{P141C}^T = \begin{pmatrix} 0.277 & 1.146 \times 10^5 & 4.245 & 840 & 983 & 160 \\ 0.359 & 1.541 \times 10^5 & 4.235 & 840 & 1.435 \times 10^3 & 161 \end{pmatrix}$$

Pipe Run 1-41D (Element 988, 545, & 494)

$$el_{P141D} := (988\ \ 545\ \ 494)^T$$

$$AL_{P141D} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P141D}, PipeRun\_C_o, EL\right)$$

$$AL_{P141D}^T = \begin{pmatrix} 0.367 & 1.577 \times 10^5 & 5 & 988 & 1.436 \times 10^3 & 184 \\ 0.205 & 7.965 \times 10^4 & 5.31 & 988 & 1.691 \times 10^3 & 185 \\ 0.121 & 3.95 \times 10^4 & 1.135 & 545 & 1.203 \times 10^3 & 84 \\ 0.205 & 7.964 \times 10^4 & 5.31 & 545 & 1.691 \times 10^3 & 85 \\ 0.111 & 3.474 \times 10^4 & 1.135 & 494 & 1.152 \times 10^3 & 31 \\ 0.127 & 4.23 \times 10^4 & 1.135 & 494 & 1.203 \times 10^3 & 32 \end{pmatrix}$$

Pipe Run 1-41E (Element 989 & 491)

$$el_{P141E} := (989\ \ 491)^T$$

$$AL_{P141E} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P141E}, PipeRun\_C_o, EL\right)$$

$$AL_{P141E}^T = \begin{pmatrix} 0.135 & 4.608 \times 10^4 & 5.35 & 989 & 1.151 \times 10^3 & 186 \\ 0.207 & 8.06 \times 10^4 & 4.995 & 989 & 1.692 \times 10^3 & 187 \\ 0.333 & 1.416 \times 10^5 & 1.14 & 491 & 1.137 \times 10^3 & 23 \\ 0.207 & 8.06 \times 10^4 & 4.995 & 491 & 1.692 \times 10^3 & 24 \end{pmatrix}$$

Pipe Run 1-41F (Element 991, 875, 990, & 874)

$$el_{P141F} := (991\ \ 875\ \ 990\ \ 874)^T$$

$$AL_{P141F} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P141F}, PipeRun\_C_o, EL\right)$$

$$AL_{P141F}{}^T = \begin{pmatrix} 0.344 & 1.468\times10^5 & 1.14 & 991 & 1.136\times10^3 & 190 \\ 0.289 & 1.204\times10^5 & 1.135 & 991 & 1.694\times10^3 & 191 \\ 0.228 & 9.1\times10^4 & 1.135 & 875 & 1.199\times10^3 & 180 \\ 0.289 & 1.204\times10^5 & 1.135 & 875 & 1.694\times10^3 & 181 \\ 0.228 & 9.1\times10^4 & 1.135 & 990 & 1.199\times10^3 & 188 \\ 0.154 & 5.542\times10^4 & 1.135 & 990 & 1.693\times10^3 & 189 \\ 0.105 & 3.168\times10^4 & 9.96 & 874 & 1.026\times10^3 & 178 \\ 0.154 & 5.541\times10^4 & 1.135 & 874 & 1.693\times10^3 & 179 \end{pmatrix}$$

Pipe Run 1-41G (Element 481, 612, 993, 539, & 992)

$$el_{P141G} := (481\ \ 612\ \ 993\ \ 539\ \ 992)^T$$

$$AL_{P141G} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P141G}, PipeRun\_C_o, EL\right)$$

$AL_{P141G}{}^T =$

	0	1	2	3	4	5
0	0.149	$5.305\cdot10^4$	1.14	481	$1.027\cdot10^3$	6
1	0.206	$8.029\cdot10^4$	1.16	481	$1.269\cdot10^3$	7
2	0.164	$6.031\cdot10^4$	1	612	$1.269\cdot10^3$	134
3	0.164	$6\cdot10^4$	1.155	612	$1.696\cdot10^3$	135
4	0.158	$5.741\cdot10^4$	1.16	993	$1.194\cdot10^3$	194
5	0.164	$6.001\cdot10^4$	1.155	993	$1.696\cdot10^3$	195
6	0.158	$5.741\cdot10^4$	1.16	539	$1.194\cdot10^3$	82
7	0.152	$5.452\cdot10^4$	1.18	539	$1.695\cdot10^3$	83
8	0.158	$5.738\cdot10^4$	1.5	992	$1.03\cdot10^3$	192
9	0.152	$5.452\cdot10^4$	1.18	992	$1.695\cdot10^3$	193

Pipe Run 1-41H (Element 485)

$$el_{P141H} := (485)^T$$

$$AL_{P141H} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P141H}, PipeRun\_C_o, EL\right)$$

$$AL_{P141H}{}^T = \begin{pmatrix} 0.098 & 2.828\times10^4 & 1.505 & 485 & 1.031\times10^3 & 14 \\ 0.152 & 5.424\times10^4 & 5.03 & 485 & 1.139\times10^3 & 15 \end{pmatrix}$$

Pipe Run 1-41I (Element 486)

$el_{P141I} := (486)^T$

$AL_{P141I} := \mathrm{PipeRun}(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P141I}, \mathrm{PipeRun\_C_o}, EL)$

$$AL_{P141I}^T = \begin{pmatrix} 0.187 & 7.102\times10^4 & 5.03 & 486 & 1.141\times10^3 & 16 \\ 0.184 & 6.966\times10^4 & 5.03 & 486 & 1.142\times10^3 & 17 \end{pmatrix}$$

Pipe Run 1-41J (Element 489 & 994)

$el_{P141J} := (489 \quad 994)^T$

$AL_{P141J} := \mathrm{PipeRun}(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P141J}, \mathrm{PipeRun\_C_o}, EL)$

$$AL_{P141J}^T = \begin{pmatrix} 0.181 & 6.849\times10^4 & 9.925 & 489 & 1.143\times10^3 & 18 \\ 0.207 & 8.062\times10^4 & 1.505 & 489 & 1.697\times10^3 & 19 \\ 0.261 & 1.066\times10^5 & 1.5 & 994 & 1.147\times10^3 & 196 \\ 0.207 & 8.062\times10^4 & 1.505 & 994 & 1.697\times10^3 & 197 \end{pmatrix}$$

Pipe Properties for Line 1-77A, 1-77F, 1-37(A-C), & 1-38(A-C)

Define pertinent pipe variables

$D_o := 4.5\text{in}$ — Outside Diameter [20,21]

$t := 0.237\text{in}$ — Thickness [20,21]

$P := 376\text{psi}$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - (D_o - 2\cdot t)^4\right]}{64}$$ — Moment of inertia [8, Table 17-27, pg 17-39]

$I = 7.233\ \text{in}^4$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{cases} 1.0 & \text{if } \dfrac{D_o}{t} \le 50 \\ \text{if } \dfrac{D_o}{t} > 50 & \left| \begin{array}{l} T \leftarrow 125 \\ X \leftarrow \min\left(1, 1.3 - 0.006\cdot\dfrac{D_o}{t}\right) \\ Y \leftarrow 1.033 - 0.00033\cdot T \\ 1.0\cdot\dfrac{1}{X\cdot Y} \end{array} \right. \end{cases}$$

$B_{2PR} = 1$

Stress Indices are derived from [4, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [4, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-77A (Element 520 & 617)

$el_{P177A} := (520 \quad 617)^T$

$AL_{P177A} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P177A}, PipeRun\_C_o, EL)$

$AL_{P177A}^T =$

0.251	4.003×10^4	10.695	520	992	62
0.254	4.06×10^4	10.695	520	1.274×10^3	63
0.258	4.123×10^4	10.695	617	1.172×10^3	136
0.254	4.059×10^4	10.695	617	1.274×10^3	137

Pipe Run 1-77F (Element 499, 998, & 498)

$el_{P177F} := (499 \quad 998 \quad 498)^T$

$AL_{P177F} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P177F}, PipeRun\_C_o, EL)$

$AL_{P177F}^T =$

0.172	2.559×10^4	10.39	499	1.161×10^3	42
0.146	2.08×10^4	4.945	499	1.701×10^3	43
0.23	3.627×10^4	4.95	998	1.158×10^3	204
0.146	2.08×10^4	4.945	998	1.701×10^3	205
0.201	3.086×10^4	3.96	498	1.001×10^3	40
0.232	3.657×10^4	4.95	498	1.157×10^3	41

Pipe Run 1-37A (Element 557 and 871)

$el_{P137A} := (557 \quad 871)^T$

$AL_{P137A} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P137A}, PipeRun\_C_o, EL)$

$AL_{P137A}^T =$

0.298	4.852×10^4	4.95	557	1.212×10^3	100
0.315	5.174×10^4	4.95	557	1.224×10^3	101
0.299	4.884×10^4	4.945	871	1.211×10^3	176
0.349	5.788×10^4	4.925	871	1.451×10^3	177

Pipe Run 1-37B (Element 558)

$el_{P137B} := (558)^T$

$AL_{P137B} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P137B}, PipeRun\_C_o, EL)$

$AL_{P137B}^T =$

0.235	3.711×10^4	4.95	558	1.216×10^3	102
0.291	4.721×10^4	4.95	558	1.225×10^3	103

Pipe Run 1-37C (Element 560)

$el_{P137C} := (560)^T$

$AL_{P137C} := \text{PipeRun}(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P137C}, \text{PipeRun\_C}_o, EL)$

$$AL_{P137C}^T = \begin{pmatrix} 0.118 & 1.584\times 10^4 & 4.925 & 560 & 1.219\times 10^3 & 106 \\ 0.161 & 2.354\times 10^4 & 4.915 & 560 & 1.234\times 10^3 & 107 \end{pmatrix}$$

Pipe Run 1-38A (Element 555)

$el_{P138A} := (555)^T$

$AL_{P138A} := \text{PipeRun}(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P138A}, \text{PipeRun\_C}_o, EL)$

$$AL_{P138A}^T = \begin{pmatrix} 0.205 & 3.167\times 10^4 & 3.965 & 555 & 1.213\times 10^3 & 96 \\ 0.22 & 3.428\times 10^4 & 3.97 & 555 & 1.227\times 10^3 & 97 \end{pmatrix}$$

Pipe Run 1-38B (Element 559)

$el_{P138B} := (559)^T$

$AL_{P138B} := \text{PipeRun}(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P138B}, \text{PipeRun\_C}_o, EL)$

$$AL_{P138B}^T = \begin{pmatrix} 0.176 & 2.632\times 10^4 & 3.975 & 559 & 1.217\times 10^3 & 104 \\ 0.207 & 3.201\times 10^4 & 3.975 & 559 & 1.226\times 10^3 & 105 \end{pmatrix}$$

Pipe Run 1-38C (Element 562)

$el_{P138C} := (562)^T$

$AL_{P138C} := \text{PipeRun}(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P138C}, \text{PipeRun\_C}_o, EL)$

$$AL_{P138C}^T = \begin{pmatrix} 0.135 & 1.886\times 10^4 & 4.945 & 562 & 1.218\times 10^3 & 108 \\ 0.179 & 2.681\times 10^4 & 4.95 & 562 & 1.233\times 10^3 & 109 \end{pmatrix}$$

Pipe Properties for Line 1-77(B-E)

Define pertinent pipe variables

$D_o := 6.625\,in$ Outside Diameter [20]

$t := 0.28\,in$ Thickness [20]

$P := 376\,psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^4 - (D_o - 2\cdot t)^4\right]}{64}$$ Moment of inertia [8, Table 17-27, pg 17-39]

$I = 28.142\,in^4$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{cases} 1.0 \text{ if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 \\ \quad T \leftarrow 125 \\ \quad X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \frac{D_o}{t}\right) \\ \quad Y \leftarrow 1.033 - 0.00033 \cdot T \\ \quad 1.0 \cdot \frac{1}{X \cdot Y} \end{cases}$$

$B_{2PR} = 1$

Stress Indices are derived from [4, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [4, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-77B (Element 511)

$el_{P177B} := (511)^T$

$AL_{P177B} := \text{PipeRun}(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P177B}, \text{PipeRun\_C}_o, EL)$

$$AL_{P177B}^T = \begin{pmatrix} 0.126 & 4.194 \times 10^4 & 10.69 & 511 & 1.038 \times 10^3 & 60 \\ 0.127 & 4.248 \times 10^4 & 10.695 & 511 & 1.171 \times 10^3 & 61 \end{pmatrix}$$

Pipe Run 1-77C (Element 995, 509, 508, 619, 550, 996, 548, & 507)

$el_{P177C} := (995 \quad 509 \quad 508 \quad 619 \quad 550 \quad 996 \quad 548 \quad 507)^T$

$AL_{P177C} := \text{PipeRun}(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P177C}, \text{PipeRun\_C}_o, EL)$

$AL_{P177C}^T =$

	0	1	2	3	4	5
0	0.124	$4.064 \cdot 10^4$	10.685	995	$1.039 \cdot 10^3$	198
1	0.11	$3.389 \cdot 10^4$	10.69	995	$1.698 \cdot 10^3$	199
2	0.095	$2.707 \cdot 10^4$	10.695	509	$1.17 \cdot 10^3$	58
3	0.11	$3.389 \cdot 10^4$	10.69	509	$1.698 \cdot 10^3$	59
4	0.095	$2.696 \cdot 10^4$	10.695	508	996	56
5	0.095	$2.707 \cdot 10^4$	10.695	508	$1.17 \cdot 10^3$	57
6	0.095	$2.696 \cdot 10^4$	10.695	619	996	138
7	0.092	$2.523 \cdot 10^4$	10.695	619	$1.276 \cdot 10^3$	139
8	0.09	$2.436 \cdot 10^4$	10.22	550	$1.208 \cdot 10^3$	88
9	0.092	$2.523 \cdot 10^4$	10.695	550	$1.276 \cdot 10^3$	89
10	0.09	$2.436 \cdot 10^4$	10.22	996	$1.208 \cdot 10^3$	200
11	0.097	$2.763 \cdot 10^4$	10.36	996	$1.699 \cdot 10^3$	201
12	0.108	$3.289 \cdot 10^4$	10.375	548	$1.205 \cdot 10^3$	86
13	0.097	$2.763 \cdot 10^4$	10.36	548	$1.699 \cdot 10^3$	87
14	0.121	$3.919 \cdot 10^4$	4.95	507	$1.165 \cdot 10^3$	54
15	0.107	$3.288 \cdot 10^4$	10.375	507	$1.205 \cdot 10^3$	55

Pipe Run 1-77D (Element 506 & 997)

$el_{P177D} := (506 \quad 997)^T$

$AL_{P177D} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P177D}, PipeRun\_C_o, EL)$

$$AL_{P177D}^T = \begin{pmatrix} 0.117 & 3.763\times10^4 & 4.95 & 506 & 1.164\times10^3 & 52 \\ 0.104 & 3.121\times10^4 & 4.95 & 506 & 1.7\times10^3 & 53 \\ 0.139 & 4.816\times10^4 & 10.4 & 997 & 1.163\times10^3 & 202 \\ 0.104 & 3.121\times10^4 & 4.95 & 997 & 1.7\times10^3 & 203 \end{pmatrix}$$

Pipe Run 1-77E

Elements associated with run P(1-77E) is also part of T(1-77) and will be calculated as T(1-77)

Pipe Properties for Line 1-37D & 1-38D

Define pertinent pipe variables

$D_o := 2.375\,in$ Outside Diameter [21]

$t := 0.154\,in$ Thickness [21]

$P := 376\,psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o^4 - \left(D_o - 2\cdot t\right)^4\right]}{64}$$ Moment of inertia [8, Table 17-27, pg 17-39]

$I = 0.666\,in^4$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{array}{|l} 1.0 \ \text{ if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 \\ \quad \begin{array}{|l} T \leftarrow 125 \\ X \leftarrow 1.3 - 0.006\cdot\frac{D_o}{t} \\ Y \leftarrow 1.033 - 0.00033\cdot T \\ 1.0\cdot\frac{1}{X\cdot Y} \end{array} \end{array}$$

$B_{2PR} = 1$

Stress Indices are derived from [4, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [4, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

Pipe Run 1-37D (Element 569)

$el_{P137D} := (569)^T$

$AL_{P137D} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P137D}, PipeRun\_C_o, EL\right)$

$$AL_{P137D}^T = \begin{pmatrix} 1.233 & 3.838\times10^4 & 4.95 & 569 & 1.222\times10^3 & 120 \\ 0.963 & 2.979\times10^4 & 4.945 & 569 & 1.235\times10^3 & 121 \end{pmatrix}$$

Pipe Run 1-38D (Element 567)

$el_{P138D} := (567)^T$

$AL_{P138D} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P138D}, PipeRun\_C_o, EL\right)$

$$AL_{P138D}^T = \begin{pmatrix} 1.141 & 3.545\times10^4 & 4.95 & 567 & 1.223\times10^3 & 116 \\ 0.984 & 3.047\times10^4 & 4.95 & 567 & 1.236\times10^3 & 117 \end{pmatrix}$$

Writing Output Data for Pipe Runs Associated with Lines 1-41 & 1-77

$PR1 := AL_{P141A}^T$

$PR2 := AL_{P141B}^T$

$PR3 := AL_{P141C}^T$

$PR4 := AL_{P141D}^T$

$PR5 := AL_{P141E}^T$

$PR6 := AL_{P141F}^T$

$PR7 := AL_{P141G}^T$

$PR8 := AL_{P141H}^T$

$PR9 := AL_{P141I}^T$

$PR10 := AL_{P141J}^T$

$PR11 := AL_{P177A}^T$

$PR12 := AL_{P177F}^T$

$PR13 := AL_{P137A}^T$

$PR14 := AL_{P137B}^T$

$PR15 := AL_{P137C}^T$

$PR16 := AL_{P138A}^T$

$PR17 := AL_{P138B}^T$

$PR18 := AL_{P138C}^T$

$PR19 := AL_{P177B}^T$

$PR20 := AL_{P177C}^T$

$PR21 := AL_{P177D}^T$

$PR22 := AL_{P137D}^T$

$PR23 := AL_{P138D}^T$

P := (PR1 PR2 PR3 PR4 PR5 PR6 PR7 PR8 PR9 PR10 PR11 PR12 PR13 PR14 PR15 PR16 PR17 PR18 PR19 I

PipeRunsLine1_41_77 := WRITEPRN("PRLine1-41_77.prn" , P)

REDUCERS

Reducers Strategy: *Search based on the nodes comprising either end of the reducers. SRSS combine the three moments of each of the four node representations (one for each element connected by the node in question). Find the maximum of the moment combinations for each element and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. It is important to not combine the data from both nodes as the geometry for each is different and (9) must be applied for each node. The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\mathrm{ReducerDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

```
Reducer(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=
  ind_nfi ← match(t_initial, nf^<0>)
  ind_nfo ← match(t_final, nf^<0>)
  ind_nd ← match(nd_0, EL^<1>)
  for i ∈ 1 .. last(nd)                                         if rows(nd) > 1
    ind_nd ← stack[ind_nd, (match(nd_i, EL^<1>))]
  (M  Int_0) ← (0  0)
  for i ∈ 0 .. ind_nfo_0 − ind_nfi_0
    for j ∈ 0 .. last(ind_nd)
      M_rxg ← nf_{ind_nfi_{C_o_{0,1}}+2, ind_nd_j}
      M_ryg ← nf_{ind_nfi_{C_o_{1,1}}+2, ind_nd_j}
      M_rzg ← nf_{ind_nfi_{C_o_{2,1}}+2, ind_nd_j}
      M_rx ← (nf_{ind_nfi_{C_o_{0,1}}+2+i, ind_nd_j} − M_rxg)·C_o_{3,0} + M_rxg
      M_ry ← (nf_{ind_nfi_{C_o_{1,1}}+2+i, ind_nd_j} − M_ryg)·C_o_{3,0} + M_ryg
      M_rz ← (nf_{ind_nfi_{C_o_{2,1}}+2+i, ind_nd_j} − M_rzg)·C_o_{3,0} + M_rzg
      M'_j ← sqrt(M_rx^2 + M_ry^2 + M_rz^2)
      Int'_j ← ReducerDC(P, D_o, t, I, B_1, B_2, M'_j, S)
      if Int'_j > Int_0
        Int ← stack(Int'_j, M'_j, nf_{ind_nfi_{C_o_{0,1}}−1+i, 0}, EL_{ind_nd_j, 1}, ind_nd_j, M_rx, M_ry,
        Result ← M'
  Int
```

Conditions applicable to all reducers

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$

Defining place holding variables

$$Reducer\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Reducer Properties for Line 1-77

Define pertinent reducer variables

$D_o := (6.625in \;\; 4.5in)^T$ Outside Diameter [20]

$t := (0.28in \;\; 0.237in)^T$ Thickness [20]

$P := (376psi \;\; 376psi)^T$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o{}^4 - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = \begin{pmatrix} 28.142 \\ 7.233 \end{pmatrix} in^4$$

Define primary stress indices

$$\alpha := atan\left(\frac{1.0625in}{5.5in}\right)$$

Angular slope of reducer [20]

$\alpha = 10.934\,deg$

$$B_1 := \begin{vmatrix} 0.5 \;\; \text{if} \;\; \alpha \le 30deg \\ 1.0 \;\; \text{if} \;\; 30deg < \alpha \le 60deg \end{vmatrix}$$

B_1 primary stress Index [4, NB-3683.7]

$B_1 = 0.5$

$B_2 := 1.0$ B_2 primary stress Index [4, NB-3683.7]

Reducer 1-77 (Nodes 1160 & 1161)

$nd_{RD177\_L} := (1160)^T$ Node associated with Large end of reducer

$AL_{RD177\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF, nd_{RD177\_L}, Reducer\_C_o, EL\right)$

$$AL_{RD177\_L}{}^T = \left(0.1 \;\; 2.941 \times 10^4 \;\; 10.395 \;\; 1.16 \times 10^3 \;\; 49 \;\; 8.012 \times 10^3 \;\; 1.162 \times 10^4 \;\; 2.58 \times 10^4\right)$$

$nd_{RD177\_S} := (1161)^T$ Node associated with Small end of reducer

$AL_{RD177\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF, nd_{RD177\_S}, Reducer\_C_o, EL\right)$

$$AL_{RD177\_S}{}^T = \left(0.172 \;\; 2.559 \times 10^4 \;\; 10.39 \;\; 1.161 \times 10^3 \;\; 44 \;\; 7.774 \times 10^3 \;\; 1.334 \times 10^4 \;\; 2.04 \times 10^4\right)$$

Reducer Properties for Lines 1-37 & 1-38

Define pertinent reducer variables

$D_o := (4.5in \;\; 2.375in)^T$ — Outside Diameter [21]

$t := (0.237in \;\; 0.154in)^T$ — Thickness [21]

$P := (376psi \;\; 376psi)^T$ — Internal Pressure [3, pg 23]

$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$ — Moment of inertia [8, Table 17-27, pg 17-39]

$I = \begin{pmatrix} 7.233 \\ 0.666 \end{pmatrix} in^4$

Define primary stress indices

$\alpha := atan\left(\frac{1.0625in}{4in}\right)$ — Angular slope of reducer [5]

$\alpha = 14.876\,deg$

$B_1 := \begin{vmatrix} 0.5 \;\; if \;\; \alpha \le 30deg \\ 1.0 \;\; if \;\; 30deg < \alpha \le 60deg \end{vmatrix}$ — B_1 primary stress Index [4, NB-3683.7]

$B_1 = 0.5$

$B_2 := 1.0$ — B_2 primary stress Index [4, NB-3683.7]

Reducer 1-37 (Nodes 1234 & 1235)

$nd_{RD137\_L} := (1234)^T$ — Node associated with Large end of reducer

$AL_{RD137\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF, nd_{RD137\_L}, Reducer\_C_o, EL\right)$

$AL_{RD137\_L}^{\;T} = \left(0.161 \;\; 2.354\times10^4 \;\; 4.915 \;\; 1.234\times10^3 \;\; 112 \;\; 7.555\times10^3 \;\; 1.367\times10^4 \;\; -1.762\times10^4\right)$

$nd_{RD137\_S} := (1235)^T$ — Node associated with Small end of reducer

$AL_{RD137\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF, nd_{RD137\_S}, Reducer\_C_o, EL\right)$

$AL_{RD137\_S}^{\;T} = \left(0.963 \;\; 2.979\times10^4 \;\; 4.945 \;\; 1.235\times10^3 \;\; 118 \;\; -1.349\times10^4 \;\; -1.273\times10^4 \;\; 2.332\times10^4\right)$

Reducer 1-38 (Nodes 1233 & 1236)

$nd_{RD138\_L} := (1233)^T$ — Node associated with Large end of reducer

$AL_{RD138\_L} := Reducer\left(P_0, D_{o_0}, t_0, I_0, B_1, B_2, S_{125}, NF, nd_{RD138\_L}, Reducer\_C_o, EL\right)$

$AL_{RD138\_L}^{\;T} = \left(0.179 \;\; 2.681\times10^4 \;\; 4.95 \;\; 1.233\times10^3 \;\; 110 \;\; 8.551\times10^3 \;\; 1.553\times10^4 \;\; -2.011\times10^4\right)$

$nd_{RD138\_S} := (1236)^T$ Node associated with Small end of reducer

$AL_{RD138\_S} := Reducer\left(P_1, D_{o_1}, t_1, I_1, B_1, B_2, S_{125}, NF, nd_{RD138\_S}, Reducer\_C_o, EL\right)$

$AL_{RD138\_S}^{\ T} = \left(0.984 \quad 3.047\times10^4 \quad 4.95 \quad 1.236\times10^3 \quad 114 \quad -8.138\times10^3 \quad -1.55\times10^4 \quad 2.493\times10^4\right)$

Writing Output Data for Reducers Associated with Lines 1-41 & 1-77

$RL1 := AL_{RD177\_L}^{\ T}$

$RS1 := AL_{RD177\_S}^{\ T}$

$RL2 := AL_{RD137\_L}^{\ T}$

$RS2 := AL_{RD137\_S}^{\ T}$

$RL3 := AL_{RD138\_L}^{\ T}$

$RS3 := AL_{RD138\_S}^{\ T}$

$R := (RL1 \quad RS1 \quad RL2 \quad RS2 \quad RL3 \quad RS3)$

ReducersLine1_41_77 := WRITEPRN("RedLine1-41_77.prn" , R)

ELBOWS

Elbows Strategy: *Search based on the two nodes comprising the ends of each elbow. SRSS combine the three moments of each of the four node representations (one for each element connected by the nodes in question). Find the maximum of the four moment combinations and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{ElbowDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Elbow}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. \mathrm{last}(nd)$ if $\mathrm{rows}(nd) > 1$

  $ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$(M \;\; Int_0) \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \mathrm{last}\left(ind_{nd}\right)$

    $M_{rxg} \leftarrow nf_{ind_{nfi}C_{o_{0,1}}+2,\, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi}C_{o_{1,1}}+2,\, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi}C_{o_{2,1}}+2,\, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi}C_{o_{1,1}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi}C_{o_{2,1}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow \mathrm{ElbowDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$

    if $Int'_j > Int_0$

      $Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfi}C_{o_{0,1}}-1+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M\right.$

      $Result \leftarrow M'$

Int

Conditions applicable to all elbows

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$ Defining place holding variables

$$Elb\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Elbow Properties for EL(1-41(A-D,G-H) & EL(1-77(B-D))

Define pertinent elbow variables

$D_o := 6.625in$ Outside Diameter [20,21]

$t := 0.28in$ Thickness [20,21]

$P := 376psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

$I = 28.142\ in^4$ Moment of inertia [8, Table 17-27, pg 17-39]

$R := 9in$ Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$ Mean pipe radius

Define primary stress indices

$$h := \frac{t \cdot R}{r_m^{\,2}}$$ $h = 0.25$ Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h > 0.5 \\ -0.1 + 0.4 \cdot h & \text{otherwise} \end{cases}$$

$B_1 = 1.515 \times 10^{-4}$ B_1 primary stress Index [4, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 3.272$ B_2 primary stress Index [4, NB-3683.7]

Elbow 1-41A (Nodes 1018 & 1019)

$nd_{EL141A\_1} := (1018)^T$

$AL_{EL141A\_nd1018} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL141A\_1}, Elb\_C_o, EL\right)$

$AL_{EL141A\_nd1018}^{\ \ T} = (0.508 \quad 7.475 \times 10^4 \quad 10.185 \quad 1.018 \times 10^3 \quad 3 \quad 3.055 \times 10^3 \quad 9.376 \times 10^3 \quad -7.41 \times 1$

$nd_{EL141A\_2} := (1019)^T$

$AL_{EL141A\_nd1019} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL141A\_2}, Elb\_C_o, EL)$

$AL_{EL141A\_nd1019}^T = (0.561 \;\; 8.265 \times 10^4 \;\; 5.62 \;\; 1.019 \times 10^3 \;\; 4 \;\; -1.479 \times 10^4 \;\; -2.805 \times 10^4 \;\; 7.632 \times$

Elbow 1-41B (Nodes 1023 & 1022)

$nd_{EL141B\_1} := (1023)^T$

$AL_{EL141B\_nd1023} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL141B\_1}, Elb\_C_o, EL)$

$AL_{EL141B\_nd1023}^T = (0.892 \;\; 1.313 \times 10^5 \;\; 4.95 \;\; 1.023 \times 10^3 \;\; 182 \;\; -5.032 \times 10^3 \;\; -4.086 \times 10^4 \;\; 1.247$

$nd_{EL141B\_2} := (1022)^T$

$AL_{EL141B\_nd1022} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL141B\_2}, Elb\_C_o, EL)$

$AL_{EL141B\_nd1022}^T = (1.031 \;\; 1.517 \times 10^5 \;\; 4.955 \;\; 1.022 \times 10^3 \;\; 33 \;\; -4.805 \times 10^3 \;\; -4.074 \times 10^4 \;\; 1.46 \times$

Elbow 1-41C (Nodes 1152 & 1151)

$nd_{EL141C\_1} := (1152)^T$

$AL_{EL141C\_nd1152} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL141C\_1}, Elb\_C_o, EL)$

$AL_{EL141C\_nd1152}^T = (0.236 \;\; 3.474 \times 10^4 \;\; 1.135 \;\; 1.152 \times 10^3 \;\; 31 \;\; 1.767 \times 10^4 \;\; -1.432 \times 10^4 \;\; 2.626 \times$

$nd_{EL141C\_2} := (1151)^T$

$AL_{EL141C\_nd1151} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL141C\_2}, Elb\_C_o, EL)$

$AL_{EL141C\_nd1151}^T = (0.313 \;\; 4.608 \times 10^4 \;\; 5.35 \;\; 1.151 \times 10^3 \;\; 28 \;\; 8.355 \times 10^3 \;\; -1.745 \times 10^4 \;\; -4.183 \times$

Elbow 1-41D (Nodes 1136 & 1137)

$nd_{EL141D\_1} := (1136)^T$

$AL_{EL141D\_nd1136} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL141D\_1}, Elb\_C_o, EL)$

$AL_{EL141D\_nd1136}^T = (0.998 \;\; 1.468 \times 10^5 \;\; 1.14 \;\; 1.136 \times 10^3 \;\; 25 \;\; 1.713 \times 10^4 \;\; -1.386 \times 10^4 \;\; -1.452 \times$

$nd_{EL141D\_2} := (1137)^T$

$AL_{EL141D\_nd1137} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL141D\_2}, Elb\_C_o, EL)$

$AL_{EL141D\_nd1137}^T = (0.962 \;\; 1.416 \times 10^5 \;\; 1.14 \;\; 1.137 \times 10^3 \;\; 23 \;\; 1.745 \times 10^4 \;\; -1.396 \times 10^4 \;\; -1.399 \times$

Elbow 1-41G (Nodes 1139 & 1141)

$nd_{EL141G\_1} := (1139)^T$

$AL_{EL141G\_nd1139} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL141G\_1}, Elb\_C_o, EL)$

$AL_{EL141G\_nd1139}^T = (0.368 \quad 5.424 \times 10^4 \quad 5.03 \quad 1.139 \times 10^3 \quad 164 \quad -2.115 \times 10^4 \quad 2.297 \times 10^3 \quad -4.989$

$nd_{EL141G\_2} := (1141)^T$

$AL_{EL141G\_nd1141} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL141G\_2}, Elb\_C_o, EL)$

$AL_{EL141G\_nd1141}^T = (0.483 \quad 7.102 \times 10^4 \quad 5.03 \quad 1.141 \times 10^3 \quad 165 \quad 2.761 \times 10^4 \quad -4.358 \times 10^3 \quad 6.529 \times$

Elbow 1-41H (Nodes 1142 & 1143)

$nd_{EL141H\_1} := (1142)^T$

$AL_{EL141H\_nd1142} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL141H\_1}, Elb\_C_o, EL)$

$AL_{EL141H\_nd1142}^T = (0.473 \quad 6.966 \times 10^4 \quad 5.03 \quad 1.142 \times 10^3 \quad 17 \quad 3.771 \times 10^4 \quad -377.361 \quad 5.857 \times 10^4$

$nd_{EL141H\_2} := (1143)^T$

$AL_{EL141H\_nd1143} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL141H\_2}, Elb\_C_o, EL)$

$AL_{EL141H\_nd1143}^T = (0.465 \quad 6.849 \times 10^4 \quad 9.925 \quad 1.143 \times 10^3 \quad 18 \quad -3.68 \times 10^4 \quad -3.828 \times 10^3 \quad -5.763$

Elbow 1-77B (Nodes 1038 & 1039)

$nd_{EL177B\_1} := (1038)^T$

$AL_{EL177B\_nd1038} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL177B\_1}, Elb\_C_o, EL)$

$AL_{EL177B\_nd1038}^T = (0.285 \quad 4.194 \times 10^4 \quad 10.69 \quad 1.038 \times 10^3 \quad 60 \quad 6.424 \times 10^3 \quad -4.108 \times 10^4 \quad 5.453 \times$

$nd_{EL177B\_2} := (1039)^T$

$AL_{EL177B\_nd1039} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL177B\_2}, Elb\_C_o, EL)$

$AL_{EL177B\_nd1039}^T = (0.276 \quad 4.064 \times 10^4 \quad 10.685 \quad 1.039 \times 10^3 \quad 80 \quad 5.131 \times 10^3 \quad -3.899 \times 10^4 \quad 1.022$

Elbow 1-77C (Nodes 1165 & 1164)

$nd_{EL177C\_1} := (1165)^T$

$AL_{EL177C\_nd1165} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL177C\_1}, Elb\_C_o, EL)$

$AL_{EL177C\_nd1165}^T = (0.266 \quad 3.919 \times 10^4 \quad 4.95 \quad 1.165 \times 10^3 \quad 74 \quad -4.979 \times 10^3 \quad 1.802 \times 10^4 \quad 3.444 \times 1$

$nd_{EL177C\_2} := (1164)^T$

$AL_{EL177C\_nd1164} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL177C\_2}, Elb\_C_o, EL)$

$AL_{EL177C\_nd1164}^T = (0.256 \quad 3.763 \times 10^4 \quad 4.95 \quad 1.164 \times 10^3 \quad 73 \quad 5.497 \times 10^3 \quad -1.355 \times 10^4 \quad -3.467 \times$

Elbow 1-77D (Nodes 1163 & 1159)

$nd_{EL177D\_1} := (1163)^T$

$AL_{EL177D\_nd1163} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL177D\_1}, Elb\_C_o, EL)$

$AL_{EL177D\_nd1163}^T = (0.327 \quad 4.816\times10^4 \quad 10.4 \quad 1.163\times10^3 \quad 202 \quad 1.807\times10^3 \quad 4.704\times10^4 \quad -1.021\times$

$nd_{EL177D\_2} := (1159)^T$

$AL_{EL177D\_nd1159} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL177D\_2}, Elb\_C_o, EL)$

$AL_{EL177D\_nd1159}^T = (0.369 \quad 5.43\times10^4 \quad 10.395 \quad 1.159\times10^3 \quad 76 \quad 742.04 \quad 5.4\times10^4 \quad -5.59\times10^3)$

Elbow Properties for EL(1-41E & F)

Define pertinent elbow variables

$D_o := 6.625in$ Outside Diameter [18,19]

$t := 0.28in$ Thickness [18,19]

$P := 376psi$ Internal Pressure [3, pg 23]

$I := \frac{\pi \cdot \left[D_o^4 - (D_o - 2\cdot t)^4\right]}{64}$ Moment of inertia [8, Table 17-27, pg 17-39]

$I = 28.142\,in^4$

$R := 30in$ Nominal bend radius of curved pipe or elbow

$r_m := \frac{D_o - t}{2}$ Mean pipe radius

Define primary stress indices

$h := \frac{t\cdot R}{r_m^2}$ $h = 0.835$ Characteristic bend parameter of a curved pipe or butt welding elbow

$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4\cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4\cdot h > 0.5 \\ -0.1 + 0.4\cdot h & \text{otherwise} \end{cases}$ $B_1 = 0.234$ B_1 primary stress Index [4, NB-3683.7]

$B_2 := \begin{cases} 1.0 & \text{if } \frac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \frac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$ $B_2 = 1.467$ B_2 primary stress Index [4, NB-3683.7]

Elbow 1-41E (Nodes 1026 & 1027)

$nd_{EL141E\_1} := (1026)^T$

$AL_{EL141E\_nd1026} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL141E\_1}, Elb\_C_o, EL)$

$AL_{EL141E\_nd1026}^T = (0.115 \quad 3.168\times10^4 \quad 9.96 \quad 1.026\times10^3 \quad 178 \quad -1.065\times10^4 \quad -1.825\times10^4 \quad -2.36$

$nd_{EL141E\_2} := (1027)^T$

$AL_{EL141E\_nd1027} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL141E\_2}, Elb\_C_o, EL)$

$AL_{EL141E\_nd1027}^T = (0.18 \quad 5.305\times10^4 \quad 1.14 \quad 1.027\times10^3 \quad 6 \quad 4.307\times10^4 \quad -2.057\times10^4 \quad -2.316\times10$

Elbow 1-41F (Nodes 1030 & 1031)

$nd_{EL141F\_1} := (1030)^T$

$AL_{EL141F\_nd1030} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL141F\_1}, Elb\_C_o, EL)$

$AL_{EL141F\_nd1030}^T = (0.193 \quad 5.746\times10^4 \quad 1.5 \quad 1.03\times10^3 \quad 8 \quad 9.569\times10^3 \quad -4.024\times10^4 \quad 3.989\times10^4)$

$nd_{EL141F\_2} := (1031)^T$

$AL_{EL141F\_nd1031} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL141F\_2}, Elb\_C_o, EL)$

$AL_{EL141F\_nd1031}^T = (0.104 \quad 2.828\times10^4 \quad 1.505 \quad 1.031\times10^3 \quad 9 \quad 1.24\times10^4 \quad 2.415\times10^4 \quad -7.932\times10$

Elbow Properties for EL(1-37), EL(1-38), & EL(1-77E)

Define pertinent elbow variables

$D_o := 4.5in$ — Outside Diameter [20,21]

$t := 0.237in$ — Thickness [20,21]

$P := 376psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o^4 - (D_o - 2\cdot t)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 7.233\ in^4$

$R := 6in$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$

Mean pipe radius

Define primary stress indices

$$h := \frac{t\cdot R}{r_m^2}$$

$h = 0.313$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4\cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4\cdot h > 0.5 \\ -0.1 + 0.4\cdot h & \text{otherwise} \end{cases}$$

$B_1 = 0.025$ — B_1 primary stress Index [4, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 2.82$ B_2 primary stress Index [4, NB-3683.7]

Elbow 1-37 (Nodes 1224 & 1225)

$nd_{EL137\_1} := (1224)^T$

$AL_{EL137\_nd1224} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL137\_1}, Elb\_C_o, EL)$

$AL_{EL137\_nd1224}^T = (0.802 \quad 5.174\times10^4 \quad 4.95 \quad 1.224\times10^3 \quad 101 \quad 2.569\times10^4 \quad -4.224\times10^3 \quad -4.471\times$

$nd_{EL137\_2} := (1225)^T$

$AL_{EL137\_nd1225} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL137\_2}, Elb\_C_o, EL)$

$AL_{EL137\_nd1225}^T = (0.732 \quad 4.721\times10^4 \quad 4.95 \quad 1.225\times10^3 \quad 91 \quad 2.759\times10^4 \quad -1.234\times10^4 \quad -3.627\times 1$

Elbow 1-38 (Nodes 1227 & 1226)

$nd_{EL138\_1} := (1227)^T$

$AL_{EL138\_nd1227} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL138\_1}, Elb\_C_o, EL)$

$AL_{EL138\_nd1227}^T = (0.532 \quad 3.428\times10^4 \quad 3.97 \quad 1.227\times10^3 \quad 97 \quad -1.636\times10^4 \quad -8.677\times10^3 \quad -2.885\times$

$nd_{EL138\_2} := (1226)^T$

$AL_{EL138\_nd1226} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL138\_2}, Elb\_C_o, EL)$

$AL_{EL138\_nd1226}^T = (0.497 \quad 3.201\times10^4 \quad 3.975 \quad 1.226\times10^3 \quad 93 \quad -1.74\times10^4 \quad -1.515\times10^4 \quad -2.219\times$

Elbow 1-77E (Nodes 1158 & 1157)

$nd_{EL177E\_1} := (1158)^T$

$AL_{EL177E\_nd1158} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL177E\_1}, Elb\_C_o, EL)$

$AL_{EL177E\_nd1158}^T = (0.563 \quad 3.627\times10^4 \quad 4.95 \quad 1.158\times10^3 \quad 204 \quad 1.506\times10^4 \quad 2.294\times10^4 \quad -2.371\times$

$nd_{EL177E\_2} := (1157)^T$

$AL_{EL177E\_nd1157} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL177E\_2}, Elb\_C_o, EL)$

$AL_{EL177E\_nd1157}^T = (0.567 \quad 3.657\times10^4 \quad 4.95 \quad 1.157\times10^3 \quad 70 \quad 1.013\times10^4 \quad 2.011\times10^4 \quad -2.882\times 1$

Elbow Properties for REL(1-41E)

Define pertinent elbow variables

$D_{oL} := 6.625\,in$ — Outside Diameter of larger end segment [19]

$D_{oS} := 4.5\,in$ — Outside Diameter of smaller end segment [19]

$t_L := 0.28\,in$ — Thickness of smaller end segment [19]

$t_S := 0.237\,in$ — Thickness of larger end segment

$P := 376\,psi$ — Internal Pressure [3, pg 23]

$$I_L := \frac{\pi \cdot \left[D_{oL}^4 - \left(D_{oL} - 2 \cdot t_L\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I_L = 28.142\,in^4$$

$$I_S := \frac{\pi \cdot \left[D_{oS}^4 - \left(D_{oS} - 2 \cdot t_S\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I_S = 7.233\,in^4$$

$R_L := 9\,in$ — Nominal bend radius of curved pipe or elbow

$R_S := 9\,in$

$$r_{mL} := \frac{D_{oL} - t_L}{2}$$

Mean pipe radius

$$r_{mS} := \frac{D_{oS} - t_S}{2}$$

Mean pipe radius

Define primary stress indices for large end segment

$$h_L := \frac{t_L \cdot R_L}{r_{mL}^2} \qquad h_L = 0.25$$

Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_{1L} := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h_L < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h_L > 0.5 \\ -0.1 + 0.4 \cdot h_L & \text{otherwise} \end{cases}$$

$B_{1L} = 1.515 \times 10^{-4}$ B_1 primary stress Index [4, NB-3683.7]

$$B_{2L} := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h_L^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h_L^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_{2L} = 3.272$ — B_2 primary stress Index [4, NB-3683.7]

Define primary stress indices for small end segment

$$h_S := \frac{t_S \cdot R_S}{r_{mS}^2}$$

$h_S = 0.469$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_{1S} := \begin{cases} 0 & \text{if } -0.1 + 0.4 \cdot h_S < 0 \\ 0.5 & \text{if } -0.1 + 0.4 \cdot h_S > 0.5 \\ -0.1 + 0.4 \cdot h_S & \text{otherwise} \end{cases}$$

$B_{1S} = 0.088$ — B_1 primary stress Index [4, NB-3683.7]

$$B_{2S} := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h_S^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h_S^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_{2S} = 2.152$ — B_2 primary stress Index [4, NB-3683.7]

Reducing Elbow Large Section 1-77A (Nodes 1174 & 1171)

$nd_{REL177A\_1L} := (1171)^T$

$AL_{REL177A\_nd1171L} := Elbow(P, D_{oL}, t_L, I_L, B_{1L}, B_{2L}, S_{167}, NF, nd_{REL177A\_1L}, Elb\_C_o, EL)$

$AL_{REL177A\_nd1171L}^T = (0.313 \quad 4.248 \times 10^4 \quad 10.695 \quad 1.171 \times 10^3 \quad 61 \quad -7.873 \times 10^3 \quad 4.116 \times 10^4 \quad 6.9$

$nd_{REL177A\_2L} := (1174)^T$

$AL_{REL177A\_nd1174L} := Elbow(P, D_{oL}, t_L, I_L, B_{1L}, B_{2L}, S_{167}, NF, nd_{REL177A\_2L}, Elb\_C_o, EL)$

$AL_{REL177A\_nd1174L}^T = (0.314 \quad 4.26 \times 10^4 \quad 10.69 \quad 1.174 \times 10^3 \quad 68 \quad -7.453 \times 10^3 \quad 4.095 \times 10^4 \quad 9.062$

Reducing Elbow Small Section 1-77A (Nodes 1172 & 1174)

$nd_{REL177A\_1S} := (1174)^T$

$AL_{REL177A\_nd1174S} := Elbow(P, D_{oS}, t_S, I_S, B_{1S}, B_{2S}, S_{167}, NF, nd_{REL177A\_1S}, Elb\_C_o, EL)$

$AL_{REL177A\_nd1174S}^T = (0.552 \quad 4.26 \times 10^4 \quad 10.69 \quad 1.174 \times 10^3 \quad 68 \quad -7.453 \times 10^3 \quad 4.095 \times 10^4 \quad 9.062$

$nd_{REL177A\_2S} := (1172)^T$

$AL_{REL177A\_nd1172S} := Elbow(P, D_{oS}, t_S, I_S, B_{1S}, B_{2S}, S_{167}, NF, nd_{REL177A\_2S}, Elb\_C_o, EL)$

$AL_{REL177A\_nd1172S}^T = (0.534 \quad 4.123 \times 10^4 \quad 10.695 \quad 1.172 \times 10^3 \quad 64 \quad -7.525 \times 10^3 \quad 4.035 \times 10^4 \quad 3.8$

Writing Output Data for Elbows Associated with Lines 1-41 & 1-77

$EL1A := AL_{EL141A\_nd1018}^T$

$EL1B := AL_{EL141A\_nd1019}^T$

$EL2A := AL_{EL141B\_nd1023}^T$

$EL2B := AL_{EL141B\_nd1022}^T$

$EL3A := AL_{EL141C\_nd1152}^T$

$EL3B := AL_{EL141C\_nd1151}^T$

$EL4A := AL_{EL141D\_nd1136}^T$

$EL4B := AL_{EL141D\_nd1137}^T$

$EL5A := AL_{EL141F\_nd1030}^T$

$EL5B := AL_{EL141F\_nd1031}^T$

$EL6A := AL_{EL141G\_nd1139}^T$

$EL6B := AL_{EL141G\_nd1141}^T$

$EL7A := AL_{EL141H\_nd1142}^T$

$EL7B := AL_{EL141H\_nd1143}^T$

$EL8A := AL_{EL177B\_nd1038}^T$

$EL8B := AL_{EL177B\_nd1039}^T$

$EL9A := AL_{EL177C\_nd1165}^T$

$EL9B := AL_{EL177C\_nd1164}^T$

$EL10A := AL_{EL177D\_nd1163}^T$

$EL10B := AL_{EL177D\_nd1159}^T$

$EL11A := AL_{EL141E\_nd1026}^T$

$EL11B := AL_{EL141E\_nd1027}^T$

$EL12A := AL_{EL137\_nd1224}^T$

$EL12B := AL_{EL137\_nd1225}^T$

$EL13A := AL_{EL138\_nd1227}^T$

$EL13B := AL_{EL138\_nd1226}^T$

$EL14A := AL_{EL177E\_nd1158}^T$

$EL14B := AL_{EL177E\_nd1157}^T$

$EL15A := AL_{REL177A\_nd1171L}^T$

$EL15B := AL_{REL177A\_nd1174L}^T$

$EL16A := AL_{REL177A\_nd1174S}^T$

$EL16B := AL_{REL177A\_nd1172S}^T$

vEL := (EL1A EL1B EL2A EL2B EL3A EL3B EL4A EL4B EL5A EL5B EL6A EL6B EL7A EL7B EL8A EL8B EI

ElbowLine1_41_77 := WRITEPRN("ElbowLine1-41_77.prn" , vEL)

FORGED TEES AND FABRICATED BRANCH TEES

Tees Strategy: *Search based on the elements comprising the tee. The input identifies which elements are associated with the pipe run and which element is associated with the branch from the run. The indices for the defined common node for all three elements is identified and the associated SRSS moment is identified for each time step. The maximum moment for the elements comprising the pipe run is found and applied as* M_r *in equation (9) of ASME III, Division I - NB - 3652 which is modified to represent tees. The maximum moment for the branch element is found and applied as* M_b *in equation (9) of ASME III, Division I - NB - 3652 [4]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\text{TeeDC}\left(P,D_o,T_r,B_1,B_{2b},B_{2r},M_b,M_r,Z_b,Z_r,S\right) := \frac{B_1\cdot\frac{P\cdot D_o}{2\cdot T_r} + B_{2b}\cdot\left[\frac{M_b\cdot(1\text{lbf}\cdot\text{in})}{Z_b}\right] + B_{2r}\cdot\left[\frac{M_r\cdot(1\text{lbf}\cdot\text{in})}{Z_r}\right]}{S}$$

$$\text{Tee}\left(P,D_o,T_r,B_1,B_{2b},B_{2r},Z_b,Z_r,S,nf,el_R,el_B,nd_R,nd_B,C_o,EL\right) :=$$

$$\begin{array}{l}
ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0\rangle}\right)\\
ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0\rangle}\right)\\
ind_{elR} \leftarrow \text{match}\left(el_{R_0}, EL^{\langle 0\rangle}\right)\\
\text{for } i \in 1..\text{last}(el_R) \qquad \text{if rows}\\
\quad ind_{elR} \leftarrow \text{stack}\left[ind_{elR}, \left(\text{match}\left(el_{R_i}, EL^{\langle 0\rangle}\right)\right)\right]\\
EL'R_{\text{last}\left(EL^{\langle 0\rangle}\right)} \leftarrow 0\\
\text{for } i \in 0..\text{last}(ind_{elR})\\
\quad EL'R_{ind_{elR_i}} \leftarrow EL_{ind_{elR_i},1}\\
ind_{ndR} \leftarrow \text{match}\left(nd_{R_0}, EL'R^{\langle 0\rangle}\right)\\
\text{for } i \in 1..\text{last}(nd_R) \qquad \text{if r}\\
\quad ind_{ndR} \leftarrow \text{stack}\left[ind_{ndR}, \left(\text{match}\left(nd_{R_i}, EL'R^{\langle 0\rangle}\right)\right)\right]\\
ind_{elB} \leftarrow \text{match}\left(el_{B_0}, EL^{\langle 0\rangle}\right)\\
\text{for } i \in 1..\text{last}(el_B) \qquad \text{if rows}\\
\quad ind_{elB} \leftarrow \text{stack}\left[ind_{elB}, \left(\text{match}\left(el_{B_i}, EL^{\langle 0\rangle}\right)\right)\right]\\
EL'B_{\text{last}\left(EL^{\langle 0\rangle}\right)} \leftarrow 0\\
\text{for } i \in 0..\text{last}(ind_{elB})\\
\quad EL'B_{ind_{elB_i}} \leftarrow EL_{ind_{elB_i},1}\\
ind_{ndB} \leftarrow \text{match}\left(nd_{B_0}, EL'B^{\langle 0\rangle}\right)
\end{array}$$

for $i \in 1 .. \text{last}(nd_B)$ if r

$ind_{ndB} \leftarrow \text{stack}\left[ind_{ndB}, \left(\text{match}\left(nd_{B_i}, EL'B^{\langle 0 \rangle}\right)\right)\right]$

$(M_R \;\; M_B \;\; Int_0) \leftarrow (0 \;\; 0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

for $j \in 0 .. \text{last}(ind_{ndR})$

for $k \in 0 .. \text{last}(ind_{ndB})$

$M_{rxgR_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{ndR_j}}$

$M_{rygR_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{ndR_j}}$

$M_{rzgR_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{ndR_j}}$

$M_{rxR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{ndR_j}} - M_{rxgR_j}\right)\cdot C$

$M_{ryR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{ndR_j}} - M_{rygR_j}\right)\cdot C$

$M_{rzR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{ndR_j}} - M_{rzgR_j}\right)\cdot C$

$M_{R_j} \leftarrow \sqrt{\left(M_{rxR_j}\right)^2 + \left(M_{ryR_j}\right)^2 + \left(M_{rzR_j}\right)^2}$

$M_{rxgB_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2,\, ind_{ndB_k}}$

$M_{rygB_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2,\, ind_{ndB_k}}$

$M_{rzgB_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2,\, ind_{ndB_k}}$

$M_{rxB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i,\, ind_{ndB_k}} - M_{rxgB_j}\right)\cdot C$

$M_{ryB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i,\, ind_{ndB_k}} - M_{rygB_j}\right)\cdot C$

$M_{rzB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i,\, ind_{ndB_k}} - M_{rzgB_j}\right)\cdot C$

$M_{B_j} \leftarrow \sqrt{\left(M_{rxB_j}\right)^2 + \left(M_{ryB_j}\right)^2 + \left(M_{rzB_j}\right)^2}$

$Int'_j \leftarrow \text{TeeDC}\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_{B_j}, M_R\right.$

if $Int'_j > Int_0$

$Int \leftarrow \text{stack}\left(Int'_j, M_{R_j}, M_{B_j}, nf_{ind_{nfiC_{o_{0,1}}}-1+i}\right.$

$\text{Result} \leftarrow \text{stack}\left(M_{R_j}, M_{B_j}, M_{rxR_j}, M_{ryR_j}, M\right.$

$M \leftarrow M_R$

Int

Conditions applicable to forged tee

$M_{ox} := 0 \quad M_{oy} := 0 \quad M_{oz} := 0$

Defining place holding directional moment variables

$$Tee\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

FORGED TEES (LINE 1-41)

Define pertinent tee variables

$P := 376\text{psi}$ — Internal Pressure [3, pg 23]

$D_o := 6.625\text{in}$ — Outside Diameter [19]

$d_o := 6.625\text{in}$ — Outside Diameter of branch [19]

$B_1 := 0.5$ — B_1 primary stress Index for tees and branches [4, NB-3683.9]

$T_r := 0.28\text{in}$ — Nominal wall thickness of designated run pipe [19]

$R_m := \dfrac{D_o - T_r}{2}$ — Mean radius of designated run pipe [19]

$Z_r := \pi \cdot R_m^{\,2} \cdot T_r$ — Approximate section modulus of designated run pipe [4, NB-3683.1(d)]

$Z_r = 8.8534\,\text{in}^3$

$$B_{2b} := \begin{cases} 0.4\cdot\left(\dfrac{R_m}{T_r}\right)^{\frac{2}{3}} & \text{if } 0.4\cdot\left(\dfrac{R_m}{T_r}\right)^{\frac{2}{3}} > 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Index for tees and branches [4, NB-3683.9]

$B_{2b} = 2.018$

$T'_b := 0.28\text{in}$ — Nominal wall thickness of attached branch pipe [19]

$r'_m := \dfrac{d_o - T'_b}{2}$ — Mean radius of attached branch pipe [19]

$Z_b := \pi \cdot r'^{\,2}_m \cdot T'_b$ — Approximate section modulus of attached branch pipe [4, NB-3683.1(d)]

$Z_b = 8.853\,\text{in}^3$

$$B_{2r} := \begin{cases} 0.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} & \text{if } 0.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} > 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Index for tees and branches [4, NB-3683.9]

$B_{2r} = 2.522$

Tee 1-41 (Node 977)

$elR_{Tee141} := (496\ \ 841)^T$ — Elements associated with pipe run

$ndR_{Tee141} := (977)^T$ — Node between pipe run elements

$elB_{Tee141} := (497)^T$ — Element associated with branch

$ndB_{Tee141} := (977)^T$ — Node where branch intersects pipe run

$AL_{Tee141} := Tee(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF, elR_{Tee141}, elB_{Tee141}, ndR_{Tee141}, ndB_{Tee141}, Tee\_C$

$$AL_{Tee141}^T = (1.428\ \ 1.459\times10^5\ \ 1.632\times10^5\ \ 4.245\ \ 977\ \ 36\ \ 162\ \ 38)$$

FABRICATED T(1-77)

Define pertinent tee variables

$P := 376psi$ — Internal Pressure [3, pg 23]

$D_o := 6.625in$ — Outside Diameter of pipe run [20]

$d_o := 4.5in$ — Outside Diameter of branch [20]

$B_1 := 0.5$ — B_1 primary stress Index for tees and branches [4, Table NB-3681(a)-1]]

$T_r := 0.28in$ — Nominal wall thickness of designated run pipe [20]

$R_m := \frac{D_o - T_r}{2}$ — Mean radius of designated run pipe [20]

$Z_r := \pi\cdot R_m^2\cdot T_r$ — Approximate section modulus of designated run pipe [4, NB-3683.1(d)]

$Z_r = 8.8534\ in^3$

$T'_b := 0.237in$ — Nominal wall thickness of attached branch pipe [20]

$r'_m := \frac{d_o - T'_b}{2}$ — Mean radius of attached branch pipe [20]

$Z_b := \pi\cdot r'_m{}^2\cdot T'_b$ — Approximate section modulus of attached branch pipe [4, NB-3683.1(d)]

$Z_b = 3.383\ in^3$

C_{2b} Secondary stress Index [4,NB-3683.8]

$$C_{2b} := \begin{cases} 1.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}}\left(\frac{r'_m}{R_m}\right)^{\frac{1}{2}}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{\frac{d_o}{2}}\right) & \text{if } 1.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}}\left(\frac{r'_m}{R_m}\right)^{\frac{1}{2}}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{\frac{d_o}{2}}\right) \ge 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$$C_{2b} = 4.973$$

C_{2r} Secondary stress Index [4,NB-3683.8]

$$t_n := T'_b$$

Wall thickness of nozzle or branch connection reinforcement associated with [4, NB-3643.4(A)-1, sketch (d)]

$$C_{2r} := \begin{cases} 1.15\cdot\left(\frac{r'_m}{t_n}\right)^{\frac{1}{4}} & \text{if } 1.15\cdot\left(\frac{r'_m}{t_n}\right)^{\frac{1}{4}} \ge 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$$C_{2r} = 1.992$$

$$B_{2b} := \begin{cases} 0.5\cdot C_{2b} & \text{if } 0.5\cdot C_{2b} \ge 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Index for branches [4, NB-3683.8]

$$B_{2b} = 2.487$$

$$B_{2r} := \begin{cases} 0.75\cdot C_{2r} & \text{if } 0.75\cdot C_{2r} \ge 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Index for branches [4, NB-3683.8]

$$B_{2r} = 1.494$$

Fabricated Tee 1-77 (Node 999)

$$elR_{Tee177} := (502\ \ 503)^T$$

Elements associated with pipe run

$$ndR_{Tee177} := (999)^T$$

Node between pipe run elements

$$elB_{Tee177} := (556)^T$$

Element associated with branch

$$ndB_{Tee177} := (999)^T$$

Node where branch intersects pipe run

$$AL_{Tee177} := Tee\big(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{167}, NF, elR_{Tee177}, elB_{Tee177}, ndR_{Tee177}, ndB_{Tee177}, Tee\_C$$

$$AL_{Tee177}^T = \left(1.057\quad 5.344\times10^4\quad 5.981\times10^4\quad 10.405\quad 999\quad 48\quad 50\quad 98\right)$$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

Writing Output Data for Tees Associated with Lines 1-41 & 1-77

$T1 := AL_{Tee141}^{T}$

$T2 := AL_{Tee177}^{T}$

$vT := (T1 \quad T2)$

TeeLine1_41_77 := WRITEPRN("TeeLine1-41_77.prn" , vT)

FLANGES

Flange Strategy: *Search based on the nodes where flanges occur. Find the maximum moment combination for the node and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\mathrm{FlangeDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Flange}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

$$
\begin{array}{l}
ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right) \\
\text{for } i \in 1 .. \mathrm{last}(nd) \qquad \text{if } \mathrm{rows}(nd) > 1 \\
\quad ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right] \\
(M \quad Int_0) \leftarrow (0 \quad 0) \\
\text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0} \\
\quad \text{for } j \in 0 .. \mathrm{last}(ind_{nd}) \\
\quad\quad M_{rxg} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}}+2,\, ind_{nd_j}} \\
\quad\quad M_{ryg} \leftarrow nf_{ind_{nfi_{C_{o_{1,1}}}}+2,\, ind_{nd_j}} \\
\quad\quad M_{rzg} \leftarrow nf_{ind_{nfi_{C_{o_{2,1}}}}+2,\, ind_{nd_j}} \\
\quad\quad M_{rx} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg} \\
\quad\quad M_{ry} \leftarrow \left(nf_{ind_{nfi_{C_{o_{1,1}}}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg} \\
\quad\quad M_{rz} \leftarrow \left(nf_{ind_{nfi_{C_{o_{2,1}}}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg} \\
\quad\quad M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2} \\
\quad\quad Int'_j \leftarrow \mathrm{FlangeDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right) \\
\quad\quad \text{if } Int'_j > Int_0 \\
\quad\quad\quad Int \leftarrow \mathrm{stack}\left(Int'_j, M'_j, nf_{ind_{nfi_{C_{o_{0,1}}}}-1+i,\, 0}, EL_{ind_{nd_j}, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M\right. \\
\quad\quad\quad Result \leftarrow M' \\
Int
\end{array}
$$

Conditions applicable to all flanges

$M_{ox} := 0$ $M_{oy} := 0$ $M_{oz} := 0$ — Defining place holding variables

$$Flange\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties of Line 1-77, 1-37, & 1-38

Define pertinent pipe variables

$D_o := 4.5in$ — Outside Diameter [20,21]

$t := 0.237in$ — Thickness [20,21]

$P := 376psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o{}^4 - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$ — Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 7.233\ in^4$$

Define primary stress indices (Utilize girth weld characteristic associated with lap joint flanges in determining values)

$B_1 := 0.5$ — B_1 for a girth weld [4, Table NB-3681(a)-1, pg 130]

$B_2 := 1$ — B_2 for a girth weld [4, Table NB-3681(a)-1, pg 130]

Flange 1-77 (Node 992)

$nd_{FL177} := (992)^T$

$AL_{FL177} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL177}, Flange\_C_o, EL\right)$

$$AL_{FL177}{}^T = \begin{pmatrix} 0.251 & 4.003 \times 10^4 & 10.695 & 992 & 62 & -7.583 \times 10^3 & 3.927 \times 10^4 & 1.748 \times 10^3 \end{pmatrix}$$

Flange 1-37A (Node 1211)

$nd_{FL137A} := (1211)^T$

$AL_{FL137A} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL137A}, Flange\_C_o, EL\right)$

$$AL_{FL137A}{}^T = \begin{pmatrix} 0.299 & 4.884 \times 10^4 & 4.945 & 1.211 \times 10^3 & 176 & 5.395 \times 10^3 & 1.844 \times 10^4 & -4.49 \times 10^4 \end{pmatrix}$$

Flange 1-37B (Node 1212)

$nd_{FL137B} := (1212)^T$

$AL_{FL137B} := Flange\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL137B}, Flange\_C_o, EL\right)$

$$AL_{FL137B}{}^T = \begin{pmatrix} 0.298 & 4.852 \times 10^4 & 4.95 & 1.212 \times 10^3 & 156 & 1.836 \times 10^4 & 3.551 \times 10^3 & -4.477 \times 10^4 \end{pmatrix}$$

Flange 1-37C (Node 1216)

$nd_{FL137C} := (1216)^T$

$AL_{FL137C} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL137C}, Flange\_C_o, EL)$

$AL_{FL137C}^T = (0.235 \;\; 3.711\times10^4 \;\; 4.95 \;\; 1.216\times10^3 \;\; 102 \;\; 2.149\times10^4 \;\; -1.238\times10^4 \;\; -2.76\times10^4)$

Flange 1-37D (Node 1219)

$nd_{FL137D} := (1219)^T$

$AL_{FL137D} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL137D}, Flange\_C_o, EL)$

$AL_{FL137D}^T = (0.118 \;\; 1.584\times10^4 \;\; 4.925 \;\; 1.219\times10^3 \;\; 106 \;\; -6.394\times10^3 \;\; 1.33\times10^4 \;\; 5.762\times10^3)$

Flange 1-38A (Node 1001)

$nd_{FL138A} := (1001)^T$

$AL_{FL138A} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL138A}, Flange\_C_o, EL)$

$AL_{FL138A}^T = (0.201 \;\; 3.086\times10^4 \;\; 3.96 \;\; 1.001\times10^3 \;\; 40 \;\; -4.114\times10^3 \;\; 9.64\times10^3 \;\; -2.903\times10^4)$

Flange 1-38B (Node 1213)

$nd_{FL138B} := (1213)^T$

$AL_{FL138B} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL138B}, Flange\_C_o, EL)$

$AL_{FL138B}^T = (0.205 \;\; 3.167\times10^4 \;\; 3.965 \;\; 1.213\times10^3 \;\; 154 \;\; -1.254\times10^4 \;\; -2.296\times10^3 \;\; -2.899\times10^4$

Flange 1-38C (Node 1217)

$nd_{FL138C} := (1217)^T$

$AL_{FL138C} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL138C}, Flange\_C_o, EL)$

$AL_{FL138C}^T = (0.176 \;\; 2.632\times10^4 \;\; 3.975 \;\; 1.217\times10^3 \;\; 104 \;\; -1.489\times10^4 \;\; -1.511\times10^4 \;\; -1.558\times10^4$

Flange 1-38D (Node 1218)

$nd_{FL138D} := (1218)^T$

$AL_{FL138D} := Flange(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{FL138D}, Flange\_C_o, EL)$

$AL_{FL138D}^T = (0.135 \;\; 1.886\times10^4 \;\; 4.945 \;\; 1.218\times10^3 \;\; 108 \;\; 1.02\times10^4 \;\; 1.578\times10^4 \;\; -1.608\times10^3)$

Writing Output Data for Flanges Associated with Lines 1-77, 1-37, & 1-38

$F1 := {AL_{FL177}}^T$

$F2 := {AL_{FL137A}}^T$

$F3 := {AL_{FL137B}}^T$

$F4 := {AL_{FL137C}}^T$

$F5 := {AL_{FL137D}}^T$

$F6 := {AL_{FL138A}}^T$

$F7 := {AL_{FL138B}}^T$

$F8 := {AL_{FL138C}}^T$

$F9 := {AL_{FL138D}}^T$

$F := (F1 \quad F2 \quad F3 \quad F4 \quad F5 \quad F6 \quad F7 \quad F8 \quad F9)$

FlangeLine1_41_77 := WRITEPRN("FlangeLine1-41_77.prn" , F)

Appendix D.3.7

Demand to Capacity Ratio Calculations for Components Associated with Line 1-42 of ATR PCS Model 1-4

(NOTE: Values represented here are shown for one realization (Nodal Force file = LINE1-42_test_R1.dat and Element/Nodal order file = EL1-42.xls) and may or may not be consistent with the 80th percentile results contained in Appendix D.4)

Force Outputs from Abaqus

NF := ...\LINE1-42.dat — (N)odal (F)orces for Model 1-4

Defined Elemental and Corresponding Nodal Order

EL := ...\EL_42(9-22-08).xls — Element and corresponding nodal order for Model 1-4

Time Boundaries

$t_{initial} := 1$ — Initial time for which dynamic loading is applied

$t_{final} := 21$ — Final time for which dynamic loading stops

Seismic Scale Factor (F_a)

$F_a := 1$ — Seismic scale factor [9]

Allowable Design Stress Intensity Factor (S_m): *S_m is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{m\_125} := 20ksi$ — For SS304 at 125°F [2, pg 316-318] [3, pg 23]

$S_{m\_125L} := 16.7ksi$ — For SS304L at 125°F [2, pg 316-318] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

$S_{m\_167} := 20ksi$ — For SS304 at 167°F [2, pg 316-318] [3, pg 23]

$S_{m\_167L} := 16.7ksi$ — For SS304L at 167°F [2, pg 316-318] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

Yield Strength (S_y): *S_y is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{y\_125} := 28.35ksi$ — For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_125L} := 23.85ksi$ — For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

$S_{y\_167} := 26.12ksi$ — For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_167L} := 22.26ksi$ — For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

Maximum Strength Applicable for Equation 9 (S): *S is defined below for SS304 at temperature 125^{o}F and SS304L at 125^{o}F.*

$S_{125} := \min\left(3 \cdot S_{m\_125}, 2 \cdot S_{y\_125}\right)$

$S_{125} = 56.7\,\mathrm{ksi}$

Maximum allowable stress applied to SS304 piping [4, NB-3656]

$S_{125L} := \min\left(3 \cdot S_{m\_125L}, 2 \cdot S_{y\_125L}\right)$

$S_{125L} = 47.7\,\mathrm{ksi}$

Maximum allowable stress applied to SS304L piping [4, NB-3656]

$S_{167} := \min\left(3 \cdot S_{m\_167}, 2 \cdot S_{y\_167}\right)$

$S_{167} = 52.24\,\mathrm{ksi}$

Maximum allowable stress applied to SS304 piping [4, NB-3656]

$S_{167L} := \min\left(3 \cdot S_{m\_167L}, 2 \cdot S_{y\_167L}\right)$

$S_{167L} = 44.52\,\mathrm{ksi}$

Maximum allowable stress applied to SS304L piping [4, NB-3656]

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SUPPORTS

Supports Strategy: *Search based on the node for which the support acts. If this node is a termination point there will only be one node to evaluate. If this node is in line with a section of pipe there will be two representations of the same node (one for each element on each side of the node) to combine and the difference between them is the force required of the support. The D/C ratio for each support will be found by dividing the the required force found above by the support capacity.*

$$\mathrm{SupDC}(P_r, P_c) := \frac{P_r}{P_c}$$

$$\mathrm{Support}(nf, nd, C_o, EL) :=$$

$$ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$$

$$ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$$

$$ind_{nd} \leftarrow \mathrm{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$$

$$\text{for } i \in 1..\mathrm{last}(nd) \quad \text{if } \mathrm{rows}(nd) > 1$$

$$\quad ind_{nd} \leftarrow \mathrm{stack}\left[ind_{nd}, \left(\mathrm{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$$

$$\begin{pmatrix} Int_{1_4} & Int_{2_4} \end{pmatrix} \leftarrow \begin{pmatrix} 0 & 0 \end{pmatrix}$$

$$\text{for } i \in 0..ind_{nfo_0} - ind_{nfi_0}$$

$$\quad \text{for } j \in 0..\mathrm{last}(ind_{nd})$$

$$\quad\quad P_{rg_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}-1},\, ind_{nd_j}}$$

$$\quad\quad P_{r_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}-1}+i,\, ind_{nd_j}} - P_{rg_j}\right) \cdot C_{o_{2,0}} + P_{rg_j}$$

$$\quad PR_i \leftarrow \sum_{n=0}^{j} P_{r_n}$$

$$\quad \text{if } PR_i < Int_{1_1} \wedge C_{o_{0,0}} \neq 0$$

$$\quad\quad Int_{1'} \leftarrow \mathrm{SupDC}\left(\left|PR_i\right|, C_{o_{0,0}}\right)$$

$$\quad\quad Int_1 \leftarrow \mathrm{stack}\left(Int_{1'}, PR_i, nf_{ind_{nfiC_{o_{0,1}}-1}+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd}\right)$$

$$\quad \text{if } PR_i > Int_{2_1} \wedge C_{o_{1,0}} \neq 0$$

$$\quad\quad Int_{2'} \leftarrow \mathrm{SupDC}\left(\left|PR_i\right|, C_{o_{1,0}}\right)$$

$$\quad\quad Int_2 \leftarrow \mathrm{stack}\left(Int_{2'}, PR_i, nf_{ind_{nfiC_{o_{0,1}}-1}+i,\, 0}, EL_{ind_{nd_j},\, 1}, ind_{nd}\right)$$

$$\begin{pmatrix} Int_1 & Int_2 \end{pmatrix}$$

RH-35 Support (1x)

$P_{1\_RH35} := \frac{3.728 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_RH35} := \frac{0.228 kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_RH35} := \begin{pmatrix} P_{1\_RH35} & 2 \\ P_{2\_RH35} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3

RH-35a (Node 1311)

RH-35a vertically supports the horizontal PCS pipe on line 1-42 traveling west from RH-34).

$nd1311_{RH35a_0} := 1311$ Node associated with support

$$\left(AL1_{RH35a\_nd1311} \quad AL2_{RH35a\_nd1311}\right) := Support\left(NF, nd1311_{RH35a}, Sup\_C_{o\_RH35}, EL\right)$$

$$AL1_{RH35a\_nd1311}{}^{T} = \left(0.253 \quad -941.712 \quad 5.51 \quad 1.311 \times 10^{3} \quad 96\right)$$

$$AL2_{RH35a\_nd1311}{}^{T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0\right)$$

C,demand force, occurrence time, ined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-35b (Node 1313)

RH-35b vertically supports the horizontal PCS pipe on line 1-42 traveling west from NN2).

$nd1313_{RH35b_0} := 1313$ Node associated with support

$$\left(AL1_{RH35b\_nd1313} \quad AL2_{RH35b\_nd1313}\right) := Support\left(NF, nd1313_{RH35b}, Sup\_C_{o\_RH35}, EL\right)$$

$$AL1_{RH35b\_nd1313}{}^{T} = \left(0.283 \quad -1.055 \times 10^{3} \quad 5.785 \quad 1.313 \times 10^{3} \quad 98\right)$$

$$AL2_{RH35b\_nd1313}{}^{T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0\right)$$

mand force, occurrence time, node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-33A Support (1x)

$P_{1\_RH33A} := \frac{4.117 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_RH33A} := \frac{0.024 kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_RH33A} := \begin{pmatrix} P_{1\_RH33A} & 2 \\ P_{2\_RH33A} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3

RH-33A (Node 1343)

RH-33A vertically supports the horizontal PCS pipe on line 1-42 traveling north from EL(1-42A).

$nd1343_{RH33Aa_0} := 1343$ Node associated with support

$$\begin{pmatrix} AL1_{RH33Aa\_nd1343} & AL2_{RH33Aa\_nd1343} \end{pmatrix} := Support\left(NF, nd1343_{RH33Aa}, Sup\_C_{o\_RH33A}, EL\right)$$

$$AL1_{RH33Aa\_nd1343}^{T} = \begin{pmatrix} 0.173 & -713.71 & 8.47 & 1.343\times10^{3} & 90 \end{pmatrix}$$

$$AL2_{RH33Aa\_nd1343}^{T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

C,demand force, occurrence time, ned node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-33B Support (1x)

$$P_{1\_RH33B} := \frac{3.47\cdot kip}{lbf}$$ ***Tension***

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$$P_{2\_RH33B} := \frac{0.024kip}{lbf}$$ ***Compression***

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_RH33B} := \begin{pmatrix} P_{1\_RH33B} & 2 \\ P_{2\_RH33B} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3

RH-33B (Node 1344)

RH-33B vertically supports the horizontal PCS pipe on line 1-42 traveling north from RH-33B.

$nd1344_{RH33Ba_0} := 1344$ Node associated with support

$$\begin{pmatrix} AL1_{RH33Ba\_nd1344} & AL2_{RH33Ba\_nd1344} \end{pmatrix} := Support\left(NF, nd1344_{RH33Ba}, Sup\_C_{o\_RH33B}, EL\right)$$

$$AL1_{RH33Ba\_nd1344}^{T} = \begin{pmatrix} 0.424 & -1.471\times10^{3} & 5.47 & 1.344\times10^{3} & 92 \end{pmatrix}$$

$$AL2_{RH33Ba\_nd1344}^{T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

mand force, occurrence time, node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

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Horizontal Support (1x)

$P_{1\_HS} := \frac{8.342 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_HS} := \frac{8.467 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_HS} := \begin{pmatrix} P_{1\_HS} & 3 \\ P_{2\_HS} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3

Horizontal Support (Node 1391)

The horizontal support horizontally (E/W) supports the horizontal (N/S) PCS pipe on line 1-42 just north of RH-33B.

$nd1391_{HS_0} := 1391$ Node associated with support

$$\left(AL1_{HS\_nd1391} \;\; AL2_{HS\_nd1391}\right) := Support\left(NF, nd1391_{HS}, Sup\_C_{o\_HS}, EL\right)$$

$$AL1_{HS\_nd1391}{}^{T} = \left(0.2 \;\; -1.669 \times 10^{3} \;\; 7.86 \;\; 1.391 \times 10^{3} \;\; 83\right)$$

$$AL2_{HS\_nd1391}{}^{T} = \left(0.2 \;\; 1.696 \times 10^{3} \;\; 10.1 \;\; 1.391 \times 10^{3} \;\; 83\right)$$

,demand force, occurrence time, ed node, associated index for the reaction force at the selected node ng in the positive (AL1) and negative 2) directions of the global coordinate system)

PS-23 Support (1x)

$P_{1\_PS23} := \frac{16.789 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_PS23} := \frac{0 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_PS23} := \begin{pmatrix} P_{1\_PS23} & 2 \\ P_{2\_PS23} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

PS-23 (Node 1345)

PS-23 vertically supports line 1-42 west of EL(1-42B).

$nd1345_{PS23_0} := 1345$ Node associated with support

$$\left(AL1_{PS23\_nd1345} \;\; AL2_{PS23\_nd1345}\right) := Support\left(NF, nd1345_{PS23}, Sup\_C_{o\_PS23}, EL\right)$$

$$AL1_{PS23\_nd1345}{}^{T} = \left(0.074 \;\; -1.234 \times 10^{3} \;\; 8.4 \;\; 1.345 \times 10^{3} \;\; 82\right)$$

$$AL2_{PS23\_nd1345}{}^{T} = \left(0 \;\; 0 \;\; 0 \;\; 0 \;\; 0\right)$$

C,demand force, occurrence time, ned node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate

system)

NN Supports (2x)

$P_{1\_NN\_NS} := \frac{11.25 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_NN\_NS} := \frac{35.487 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_NN\_NS} := \begin{pmatrix} P_{1\_NN\_NS} & 1 \\ P_{2\_NN\_NS} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

NN2 North/South (Node 1346)

NN2 vertically and laterally supports the horizontal PCS pipe on line 1-42 between PS-23 and RH-34.

$nd1346_{NN2\_NS_0} := 1346$ Node associated with support

$$\left(AL1_{NN2\_NS\_nd1346} \quad AL2_{NN2\_NS\_nd1346}\right) := Support\left(NF, nd1346_{NN2\_NS}, Sup\_C_{o\_NN\_NS}, EL\right)$$

$$AL1_{NN2\_NS\_nd1346}^{T} = \begin{pmatrix} 0.045 & -507.848 & 5.95 & 1.346 \times 10^{3} & 70 \end{pmatrix}$$

$$AL2_{NN2\_NS\_nd1346}^{T} = \begin{pmatrix} 0.012 & 429.902 & 7.145 & 1.346 \times 10^{3} & 70 \end{pmatrix}$$

hand force, occurrence time, ode, associated Index for the reaction force at the selected node he positive (AL1) and negative ections of the global coordinate system)

NN3 North/South (Node 1347)

NN3 vertically and laterally supports the horizontal PCS pipe on line 1-42 between PS-23 and RH-34.

$nd1347_{NN3\_NS_0} := 1347$ Node associated with support

$$\left(AL1_{NN3\_NS\_nd1347} \quad AL2_{NN3\_NS\_nd1347}\right) := Support\left(NF, nd1347_{NN3\_NS}, Sup\_C_{o\_NN\_NS}, EL\right)$$

$$AL1_{NN3\_NS\_nd1347}^{T} = \begin{pmatrix} 0.039 & -443.888 & 5.725 & 1.347 \times 10^{3} & 72 \end{pmatrix}$$

$$AL2_{NN3\_NS\_nd1347}^{T} = \begin{pmatrix} 0.016 & 558.776 & 5.87 & 1.347 \times 10^{3} & 72 \end{pmatrix}$$

nd force, occurrence time, de, associated Index for the reaction force at the selected node the positive (AL1) and negative rections of the global coordinate system)

PS-19 Supports (2x)

$P_{1\_PS19\_NS} := \frac{11.25 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_PS19\_NS} := \frac{96.792 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_PS19\_NS} := \begin{pmatrix} P_{1\_PS19\_NS} & 1 \\ P_{2\_PS19\_NS} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

$$P_{1\_PS19\_V} := \frac{0.546 \cdot kip}{lbf}$$

Flexure

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$$P_{2\_PS19\_V} := \frac{0.546 \cdot kip}{lbf}$$

Flexure

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_PS19\_V} := \begin{pmatrix} P_{1\_PS19\_V} & 2 \\ P_{2\_PS19\_V} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(North), y(Up), and z(East) correspond to positive 1, 2, and 3

PS-19 North/South (Node 1348)

PS-19 vertically and laterally supports the horizontal PCS pipe on line 1-42 between PS-23 and RH-34.

$$nd1348_{PS19\_NS_0} := 1348$$

Node associated with support

$$\begin{pmatrix} AL1_{PS19\_NS\_nd1348} & AL2_{PS19\_NS\_nd1348} \end{pmatrix} := Support\left(NF, nd1348_{PS19\_NS}, Sup\_C_{o\_PS19\_NS}, EL\right)$$

$$AL1_{PS19\_NS\_nd1348}{}^{T} = \begin{pmatrix} 0.111 & -1.253 \times 10^{3} & 6.915 & 1.348 \times 10^{3} & 74 \end{pmatrix}$$

$$AL2_{PS19\_NS\_nd1348}{}^{T} = \begin{pmatrix} 0.012 & 1.169 \times 10^{3} & 10.105 & 1.348 \times 10^{3} & 74 \end{pmatrix}$$

force, occurrence time, associated Index for the reaction force at the selected node ositive (AL1) and negative ns of the global coordinate system)

PS-19 Vertical (Node 1348)

PS-19 vertically and laterally supports the horizontal PCS pipe on line 1-42 between PS-23 and RH-34.

$$nd1348_{PS19\_V_0} := 1348$$

Node associated with support

$$\begin{pmatrix} AL1_{PS19\_V\_nd1348} & AL2_{PS19\_V\_nd1348} \end{pmatrix} := Support\left(NF, nd1348_{PS19\_V}, Sup\_C_{o\_PS19\_V}, EL\right)$$

$$AL1_{PS19\_V\_nd1348}{}^{T} = \begin{pmatrix} 1.798 & -981.527 & 5.79 & 1.348 \times 10^{3} & 74 \end{pmatrix}$$

$$AL2_{PS19\_V\_nd1348}{}^{T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

nand force, occurrence time, node, associated Index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-12 Support (1x)

$$P_{1\_RH12} := \frac{3.976 \cdot kip}{lbf}$$

Tension

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$$P_{2\_RH12} := \frac{0.228 kip}{lbf}$$

Compression

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_RH12} := \begin{pmatrix} P_{1\_RH12} & 2 \\ P_{2\_RH12} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3

RH-12 (Node 1349)

RH-12 vertically supports the horizontal PCS pipe on line 1-42 at the south side of EL(1-42E).

$$nd1349_{RH12_0} := 1349$$

Node associated with support

$$\left(AL1_{RH12\_nd1349} \quad AL2_{RH12\_nd1349}\right) := Support\left(NF, nd1349_{RH12}, Sup\_C_{o\_RH12}, EL\right)$$

$$AL1_{RH12\_nd1349}^{T} = \left(0.472 \quad -1.876\times10^{3} \quad 8.555 \quad 1.349\times10^{3} \quad 100\right)$$

$$AL2_{RH12\_nd1349}^{T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0\right)$$

mand force, occurrence time, node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-20 Support (1x)

$$P_{1\_RH20} := \frac{10.354 \cdot kip}{lbf}$$

Tension

Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$$P_{2\_RH20} := \frac{0.228 kip}{lbf}$$

Compression

Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_RH20} := \begin{pmatrix} P_{1\_RH20} & 2 \\ P_{2\_RH20} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3

RH-20 (Node 1350)

RH-20 vertically supports the horizontal PCS pipe on line 1-42 at the north side of EL(1-42F).

$$nd1350_{RH20_0} := 1350$$

Node associated with support

$$\left(AL1_{RH20\_nd1350} \quad AL2_{RH20\_nd1350}\right) := Support\left(NF, nd1350_{RH20}, Sup\_C_{o\_RH20}, EL\right)$$

$$AL1_{RH20\_nd1350}^{T} = \left(0.215 \quad -2.221\times10^{3} \quad 3.865 \quad 1.35\times10^{3} \quad 76\right)$$

$$AL2_{RH20\_nd1350}^{T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0\right)$$

demand force, occurrence time, ed node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

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PS-10 Support (1x)

$P_{1\_PS10} := \frac{22.1 \cdot kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_PS10} := \frac{0 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_PS10} := \begin{pmatrix} P_{1\_PS10} & 2 \\ P_{2\_PS10} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3

PS-10A (Node 1354)

PS-10A vertically supports line 1-42 at the north side of EL(1-42H).

$nd1354_{PS10A_0} := 1354$ Node associated with support

$$\left(AL1_{PS10A\_nd1354} \quad AL2_{PS10A\_nd1354}\right) := Support\left(NF, nd1354_{PS10A}, Sup\_C_{o\_PS10}, EL\right)$$

$$AL1_{PS10A\_nd1354}^{T} = \left(0.574 \quad -1.268 \times 10^{4} \quad 3.85 \quad 1.354 \times 10^{3} \quad 80\right)$$

$$AL2_{PS10A\_nd1354}^{T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0\right)$$

[...]emand force, occurrence time, [...]d node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate system)

RH-34 Support (1x)

$P_{1\_RH34} := \frac{7.069 \cdot kip}{lbf}$ ***Tension*** Capacity of support if the reaction force provided at the node of interest is in the positive direction of the global coordinate system [App. D.9.1]

$P_{2\_RH34} := \frac{0.307kip}{lbf}$ ***Compression*** Capacity of support if the reaction force provided at the node of interest is in the negative direction of the global coordinate system [App. D.9.1]

$$Sup\_C_{o\_RH34} := \begin{pmatrix} P_{1\_RH34} & 2 \\ P_{2\_RH34} & 0 \\ F_a & 0 \end{pmatrix}$$

Constants associated with support capacity and seismic scale factor in first column and direction of support's capacity at top of section column where x(NS), y(Vertical), and z(EW) correspond to 1, 2, and 3

RH-34 (Node 1253)

RH-35a vertically supports the horizontal PCS pipe on line 1-42 traveling west from RH-34).

$nd1253_{RH34_0} := 1253$ Node associated with support

$$\left(AL1_{RH34\_nd1253} \quad AL2_{RH34\_nd1253}\right) := Support\left(NF, nd1253_{RH34}, Sup\_C_{o\_RH34}, EL\right)$$

$$AL1_{RH34\_nd1253}^{T} = \left(0.092 \quad -653.749 \quad 5.28 \quad 1.253 \times 10^{3} \quad 94\right)$$

$$AL2_{RH34\_nd1253}^{T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0\right)$$

[...]/C,demand force, occurrence time, [...]fined node, associated index for the reaction force at the selected node being in the positive (AL1) and negative (AL2) directions of the global coordinate

system)

Writing Output Data for Supports Associated with Line 1-42

$SA1 := AL1_{RH35a\_nd1311}^T$

$SA2 := AL2_{RH35a\_nd1311}^T$

$SB1 := AL1_{RH35b\_nd1313}^T$

$SB2 := AL2_{RH35b\_nd1313}^T$

$SC1 := AL1_{RH33Aa\_nd1343}^T$

$SC2 := AL2_{RH33Aa\_nd1343}^T$

$SD1 := AL1_{RH33Ba\_nd1344}^T$

$SD2 := AL2_{RH33Ba\_nd1344}^T$

$SE1 := AL1_{HS\_nd1391}^T$

$SE2 := AL2_{HS\_nd1391}^T$

$SF1 := AL1_{PS23\_nd1345}^T$

$SF2 := AL2_{PS23\_nd1345}^T$

$SG1 := AL1_{NN2\_NS\_nd1346}^T$

$SG2 := AL2_{NN2\_NS\_nd1346}^T$

$SH1 := AL1_{NN3\_NS\_nd1347}^T$

$SH2 := AL2_{NN3\_NS\_nd1347}^T$

$SI1 := AL1_{PS19\_NS\_nd1348}^T$

$SI2 := AL2_{PS19\_NS\_nd1348}^T$

$SJ1 := AL1_{PS19\_V\_nd1348}^T$

$SJ2 := AL2_{PS19\_V\_nd1348}^T$

$SK1 := AL1_{RH12\_nd1349}^T$

$SK2 := AL2_{RH12\_nd1349}^T$

$SL1 := AL1_{RH20\_nd1350}^T$

$SL2 := AL2_{RH20\_nd1350}^T$

$SM1 := AL1_{PS10A\_nd1354}^T$

$SM2 := AL2_{PS10A\_nd1354}^T$

$SN1 := AL1_{RH34\_nd1253}^T$

$SN2 := AL2_{RH34\_nd1253}^T$

S := (SA1 SA2 SB1 SB2 SC1 SC2 SD1 SD2 SE1 SE2 SF1 SF2 SG1 SG2 SH1 SH2 SI1 SI2 SJ1 SJ2 SK1 SK2

SupportsLine1_42 := WRITEPRN("SupLine1_42.prn" , S)

TERMINATION LOCATIONS (NONE)

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PIPE RUNS

Pipe Runs Strategy: *Search based on the nodes present in each run of pipe. Find the maximum moment combination among all of the nodes and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{PipeRunDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$$\mathrm{PipeRun}(P, D_o, t, I, B_1, B_2, S, nf, el, C_o, EL) :=$$

$$\begin{aligned}
& ind_{nfi} \leftarrow \mathrm{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right) \\
& ind_{nfo} \leftarrow \mathrm{match}\left(t_{final}, nf^{\langle 0 \rangle}\right) \\
& ind_{el} \leftarrow \mathrm{match}\left(el_0, EL^{\langle 0 \rangle}\right) \\
& \text{for } i \in 1 .. \mathrm{last}(el) \quad \text{if } \mathrm{rows}(el) > 1 \\
& \quad ind_{el} \leftarrow \mathrm{stack}\left[ind_{el}, \left(\mathrm{match}\left(el_i, EL^{\langle 0 \rangle}\right)\right)\right] \\
& \left(M \quad Int_{5, \mathrm{last}(ind_{el})}\right) \leftarrow (0 \quad 0) \\
& \text{for } i \in 0 .. ind_{nfo_0} - ind_{nfi_0} \\
& \quad \text{for } j \in 0 .. \mathrm{last}(ind_{el}) \\
& \qquad M_{rxg} \leftarrow nf_{ind_{nfi_{C_{o_{0,1}}}}+2,\, ind_{el_j}} \\
& \qquad M_{ryg} \leftarrow nf_{ind_{nfi_{C_{o_{1,1}}}}+2,\, ind_{el_j}} \\
& \qquad M_{rzg} \leftarrow nf_{ind_{nfi_{C_{o_{2,1}}}}+2,\, ind_{el_j}} \\
& \qquad M_{rx_j} \leftarrow \left(nf_{ind_{nfi_{C_{o_{0,1}}}}+2+i,\, ind_{el_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg} \\
& \qquad M_{ry_j} \leftarrow \left(nf_{ind_{nfi_{C_{o_{1,1}}}}+2+i,\, ind_{el_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg} \\
& \qquad M_{rz_j} \leftarrow \left(nf_{ind_{nfi_{C_{o_{2,1}}}}+2+i,\, ind_{el_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg} \\
& \qquad M'_j \leftarrow \sqrt{\left(M_{rx_j}\right)^2 + \left(M_{ry_j}\right)^2 + \left(M_{rz_j}\right)^2} \\
& \qquad Int'_j \leftarrow \mathrm{PipeRunDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right) \\
& \qquad \text{if } Int'_j > Int_{0,j} \\
& \qquad\quad H \leftarrow \left(Int'_j \quad M'_j \quad nf_{ind_{nfi_{C_{o_{0,1}}}}-1+i,\, 0} \quad EL_{ind_{el_j},\, 0} \quad EL_{ind_{el_j},\, 1} \quad ind_{el_j} \quad M_{r\ldots}\right. \\
& \qquad\quad \text{for } k \in 0 .. 5 \\
& \qquad\qquad Int_{k,j} \leftarrow H_k
\end{aligned}$$

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Int

Conditions applicable to all pipe runs

$M_{cx} := 0 \quad M_{cy} := 0 \quad M_{cz} := 0$

Defining place holding directional moment variables

$$PipeRun\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties for Line 1-42

Define pertinent pipe variables

$D_o := 6.625\text{in}$ — Outside Diameter [22]

$t := 0.28\text{in}$ — Thickness [22]

$P := 376\text{psi}$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^4 - (D_o - 2 \cdot t)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$$I = 28.142\ \text{in}^4$$

Define primary stress indices

$B_{1PR} := 0.5$

$$B_{2PR} := \begin{cases} 1.0 & \text{if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50 & \begin{aligned} & T \leftarrow 125 \\ & X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \frac{D_o}{t}\right) \\ & Y \leftarrow 1.033 - 0.00033 \cdot T \\ & 1.0 \cdot \frac{1}{X \cdot Y} \end{aligned} \end{cases}$$

$B_{2PR} = 1$

Stress Indices are derived from [4, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [4, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

Pipe Run 1-42A (Elements 197 & 171)

$el_{P142A} := (197 \quad 171)^T$

$AL_{P142A} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P142A}, PipeRun\_C_o, EL\right)$

$$AL_{P142A}^T = \begin{pmatrix} 0.094 & 2.661 \times 10^4 & 8.235 & 197 & 816 & 43 \\ 0.112 & 3.497 \times 10^4 & 8.235 & 197 & 1.442 \times 10^3 & 44 \\ 0.061 & 1.053 \times 10^4 & 13.18 & 171 & 805 & 11 \\ 0.094 & 2.661 \times 10^4 & 8.235 & 171 & 816 & 12 \end{pmatrix}$$

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Pipe Run 1-42B (Element 943, 942, 192, 948, 947, 946, 945, 944, 194, 193, & 170)

$$el_{P142B} := (943\ \ 942\ \ 192\ \ 948\ \ 947\ \ 946\ \ 945\ \ 944\ \ 194\ \ 193\ \ 170)^T$$

$$AL_{P142B} := PipeRun\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P142B}, PipeRun\_C_o, EL\right)$$

$AL_{P142B}{}^T =$

	0	1	2	3	4	5
0	0.06	$9.908 \cdot 10^3$	9.005	943	804	103
1	0.055	$7.637 \cdot 10^3$	5.49	943	$1.646 \cdot 10^3$	104
2	0.062	$1.086 \cdot 10^4$	13.185	942	$1.645 \cdot 10^3$	101
3	0.055	$7.636 \cdot 10^3$	5.49	942	$1.646 \cdot 10^3$	102
4	0.074	$1.686 \cdot 10^4$	13.095	192	811	37
5	0.062	$1.087 \cdot 10^4$	13.185	192	$1.645 \cdot 10^3$	38
6	0.074	$1.686 \cdot 10^4$	13.095	948	811	113
7	0.077	$1.84 \cdot 10^4$	13.18	948	$1.651 \cdot 10^3$	114
8	0.079	$1.896 \cdot 10^4$	13.18	947	$1.65 \cdot 10^3$	111
9	0.077	$1.84 \cdot 10^4$	13.18	947	$1.651 \cdot 10^3$	112
10	0.073	$1.649 \cdot 10^4$	13.18	946	$1.649 \cdot 10^3$	109
11	0.079	$1.896 \cdot 10^4$	13.18	946	$1.65 \cdot 10^3$	110
12	0.078	$1.885 \cdot 10^4$	5.45	945	$1.648 \cdot 10^3$	107
13	0.073	$1.649 \cdot 10^4$	13.18	945	$1.649 \cdot 10^3$	108
14	0.096	$2.738 \cdot 10^4$	10.105	944	$1.647 \cdot 10^3$	105
15	0.078	$1.885 \cdot 10^4$	5.45	944	$1.648 \cdot 10^3$	106
16	0.122	$3.995 \cdot 10^4$	10.105	194	813	41
17	0.096	$2.738 \cdot 10^4$	10.105	194	$1.647 \cdot 10^3$	42
18	0.101	$2.976 \cdot 10^4$	9.03	193	812	39
19	0.122	$3.997 \cdot 10^4$	10.105	193	813	40
20	0.063	$1.135 \cdot 10^4$	5.33	170	767	9
21	0.114	$3.602 \cdot 10^4$	9.035	170	812	10

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Pipe Run 1-42C (Element 949, 216, 950, 589, 952, 951, 213, 958, 957, 956, 955, 954, 953, 595, 961, 960, 959, 200, 963, 962, 597, 964, & 169)

$el_{P142C} := (949\ \ 216\ \ 950\ \ 589\ \ 952\ \ 951\ \ 213\ \ 958\ \ 957\ \ 956\ \ 955\ \ 954\ \ 953\ \ 595\ \ 961\ \ 960\ \ 959\ \ 200\ \ 963\ \ 962\ \ 597$

$$AL_{P142C} := \text{PipeRun}\left(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P142C}, \text{PipeRun\_C}_o, EL\right)$$

$AL_{P142C}{}^{T} =$

	0	1	2	3	4	5
0	0.083	$2.098\cdot10^{4}$	10.095	949	766	115
1	0.086	$2.259\cdot10^{4}$	8.395	949	$1.652\cdot10^{3}$	116
2	0.132	$4.452\cdot10^{4}$	8.395	216	833	49
3	0.086	$2.26\cdot10^{4}$	8.395	216	$1.652\cdot10^{3}$	50
4	0.132	$4.453\cdot10^{4}$	8.395	950	833	117
5	0.102	$3.011\cdot10^{4}$	8.395	950	$1.653\cdot10^{3}$	118
6	0.08	$1.958\cdot10^{4}$	8.395	589	$1.248\cdot10^{3}$	59
7	0.102	$3.011\cdot10^{4}$	8.395	589	$1.653\cdot10^{3}$	60
8	0.08	$1.96\cdot10^{4}$	8.395	952	$1.248\cdot10^{3}$	121
9	0.064	$1.182\cdot10^{4}$	5.955	952	$1.655\cdot10^{3}$	122
10	0.056	$8.309\cdot10^{3}$	10.095	951	$1.654\cdot10^{3}$	119
11	0.064	$1.182\cdot10^{4}$	5.955	951	$1.655\cdot10^{3}$	120
12	0.068	$1.393\cdot10^{4}$	7.49	213	823	47
13	0.056	$8.309\cdot10^{3}$	10.095	213	$1.654\cdot10^{3}$	48
14	0.068	$1.392\cdot10^{4}$	7.49	958	823	133
15	0.059	$9.737\cdot10^{3}$	8.395	958	$1.661\cdot10^{3}$	134
16	0.074	$1.652\cdot10^{4}$	9.04	957	$1.66\cdot10^{3}$	131
17	0.059	$9.737\cdot10^{3}$	8.395	957	$1.661\cdot10^{3}$	132
18	0.08	$1.97\cdot10^{4}$	9.04	956	$1.659\cdot10^{3}$	129
19	0.074	$1.652\cdot10^{4}$	9.04	956	$1.66\cdot10^{3}$	130
20	0.081	$1.993\cdot10^{4}$	6.18	955	$1.658\cdot10^{3}$	127
21	0.08	$1.97\cdot10^{4}$	9.04	955	$1.659\cdot10^{3}$	128
22	0.075	$1.713\cdot10^{4}$	6.175	954	$1.657\cdot10^{3}$	125
23	0.081	$1.993\cdot10^{4}$	6.18	954	$1.658\cdot10^{3}$	126
24	0.067	$1.335\cdot10^{4}$	6.715	953	$1.656\cdot10^{3}$	123
25	0.075	$1.713\cdot10^{4}$	6.175	953	$1.657\cdot10^{3}$	124
26	0.084	$2.172\cdot10^{4}$	8.075	595	$1.254\cdot10^{3}$	61
27	0.067	$1.335\cdot10^{4}$	6.715	595	$1.656\cdot10^{3}$	62
28	0.084	$2.168\cdot10^{4}$	8.075	961	$1.254\cdot10^{3}$	139
29	0.063	$1.154\cdot10^{4}$	8.715	961	$1.665\cdot10^{3}$	140
30	0.061	$1.047\cdot10^{4}$	5.875	960	$1.664\cdot10^{3}$	137
31	0.063	$1.154\cdot10^{4}$	8.715	960	$1.665\cdot10^{3}$	138
32	0.073	$1.606\cdot10^{4}$	5.875	959	$1.663\cdot10^{3}$	135
33	0.061	$1.047\cdot10^{4}$	5.875	959	$1.664\cdot10^{3}$	136
34	0.084	$2.176\cdot10^{4}$	5.87	200	819	45
35	0.073	$1.606\cdot10^{4}$	5.875	200	$1.663\cdot10^{3}$	46
36	0.085	$2.183\cdot10^{4}$	5.87	963	819	143
37	0.064	$1.186\cdot10^{4}$	5.98	963	$1.667\cdot10^{3}$	144
38	0.066	$1.292\cdot10^{4}$	6.71	962	$1.666\cdot10^{3}$	141
39	0.064	$1.186\cdot10^{4}$	5.98	962	$1.667\cdot10^{3}$	142
40	0.085	$2.203\cdot10^{4}$	7.67	597	$1.256\cdot10^{3}$	63
41	0.066	$1.292\cdot10^{4}$	6.71	597	$1.666\cdot10^{3}$	64
42	0.085	$2.201\cdot10^{4}$	7.67	964	$1.256\cdot10^{3}$	145
43	0.084	$2.176\cdot10^{4}$	6.71	964	$1.668\cdot10^{3}$	146
44	0.089	$2.403\cdot10^{4}$	8.375	169	796	7

44	0.089	$2.403\cdot10^4$	8.375	169	796	7
45	0.084	$2.176\cdot10^4$	6.71	169	$1.668\cdot10^3$	8

Pipe Run 1-42D (Element 168)

$el_{P142D} := (168)^T$

$AL_{P142D} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P142D}, PipeRun\_C_o, EL)$

$$AL_{P142D}^{\ T} = \begin{pmatrix} 0.09 & 2.455\times10^4 & 6.715 & 168 & 798 & 5 \\ 0.107 & 3.241\times10^4 & 6.92 & 168 & 799 & 6 \end{pmatrix}$$

Pipe Run 1-42E (Element 965, 967, 969, 968, & 334)

$el_{P142E} := (965\ \ 967\ \ 969\ \ 968\ \ 334)^T$

$AL_{P142E} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P142E}, PipeRun\_C_o, EL)$

$AL_{P142E}^{\ T} =$

	0	1	2	3	4	5
0	0.11	$3.411\cdot10^4$	6.92	965	797	147
1	0.116	$3.713\cdot10^4$	6.92	965	$1.669\cdot10^3$	148
2	0.123	$4.058\cdot10^4$	6.92	967	967	149
3	0.116	$3.713\cdot10^4$	6.92	967	$1.669\cdot10^3$	150
4	0.123	$4.054\cdot10^4$	6.92	969	967	153
5	0.074	$1.67\cdot10^4$	6.98	969	$1.673\cdot10^3$	154
6	0.078	$1.879\cdot10^4$	9.93	968	$1.672\cdot10^3$	151
7	0.074	$1.67\cdot10^4$	6.98	968	$1.673\cdot10^3$	152
8	0.127	$4.217\cdot10^4$	6.74	334	768	55
9	0.078	$1.879\cdot10^4$	9.93	334	$1.672\cdot10^3$	56

Pipe Run 1-42F (Element 163, 970, 220, & 971)

$el_{P142F} := (163\ \ 970\ \ 220\ \ 971)^T$

$AL_{P142F} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P142F}, PipeRun\_C_o, EL)$

$$AL_{P142F}^{\ T} = \begin{pmatrix} 0.16 & 5.837\times10^4 & 6.915 & 163 & 769 & 1 \\ 0.133 & 4.522\times10^4 & 6.735 & 163 & 1.674\times10^3 & 2 \\ 0.112 & 3.496\times10^4 & 6.73 & 970 & 838 & 155 \\ 0.133 & 4.522\times10^4 & 6.735 & 970 & 1.674\times10^3 & 156 \\ 0.112 & 3.496\times10^4 & 6.73 & 220 & 838 & 51 \\ 0.124 & 4.1\times10^4 & 9.435 & 220 & 1.675\times10^3 & 52 \\ 0.148 & 5.22\times10^4 & 9.76 & 971 & 770 & 157 \\ 0.124 & 4.1\times10^4 & 9.435 & 971 & 1.675\times10^3 & 158 \end{pmatrix}$$

Pipe Run 1-42G (Element 164 & 972)

$el_{P142G} := (164 \quad 972)^T$

$AL_{P142G} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P142G}, PipeRun\_C_o, EL)$

$AL_{P142G}^T =$

0.096	2.726×10^4	9.76	164	771	3
0.107	3.269×10^4	9.435	164	1.676×10^3	4
0.122	3.988×10^4	9.44	972	772	159
0.107	3.268×10^4	9.435	972	1.676×10^3	160

Pipe Run 1-42H (Element 221 & 973)

$el_{P142H} := (221 \quad 973)^T$

$AL_{P142H} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P142H}, PipeRun\_C_o, EL)$

$AL_{P142H}^T =$

0.12	3.913×10^4	9.935	221	773	53
0.104	3.115×10^4	9.92	221	1.677×10^3	54
0.134	4.557×10^4	9.935	973	775	161
0.104	3.114×10^4	9.92	973	1.677×10^3	162

Pipe Run 1-42I (Element 605)

$el_{P142I} := (605)^T$

$AL_{P142I} := PipeRun(P, D_o, t, I, B_{1PR}, B_{2PR}, S_{125}, NF, el_{P142I}, PipeRun\_C_o, EL)$

$AL_{P142I}^T =$

0.135	4.611×10^4	10.66	605	759	65
0.178	6.666×10^4	3.85	605	774	66

Writing Output Data for Pipe Runs Associated with Line 1-42

$PR1 := AL_{P142A}^T$ $PR6 := AL_{P142F}^T$

$PR2 := AL_{P142B}^T$ $PR7 := AL_{P142G}^T$

$PR3 := AL_{P142C}^T$ $PR8 := AL_{P142H}^T$

$PR4 := AL_{P142D}^T$ $PR9 := AL_{P142I}^T$

$PR5 := AL_{P142E}^T$

$P := (PR1 \quad PR2 \quad PR3 \quad PR4 \quad PR5 \quad PR6 \quad PR7 \quad PR8 \quad PR9)$

PipeRunsLine1_42 := WRITEPRN("PRLine1-42.prn" , P)

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

ELBOWS

Elbows Strategy: *Search based on the two nodes comprising the ends of each elbow. SRSS combine the three moments of each of the four node representations (one for each element connected by the nodes in question). Find the maximum of the four moment combinations and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\mathrm{ElbowDC}(P, D_o, t, I, B_1, B_2, M, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\,\mathrm{lbf} \cdot \mathrm{in})]}{S}$$

$\mathrm{Elbow}(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL) :=$

```
ind_nfi ← match(t_initial, nf^<0>)
ind_nfo ← match(t_final, nf^<0>)
ind_nd ← match(nd_0, EL^<1>)
for i ∈ 1 .. last(nd)                                         if rows(nd) > 1
   ind_nd ← stack[ind_nd, (match(nd_i, EL^<1>))]
(M  Int_0) ← (0  0)
for i ∈ 0 .. ind_nfo_0 − ind_nfi_0
   for j ∈ 0 .. last(ind_nd)
      M_rxg ← nf_(ind_nfi_(C_o_(0,1)) + 2, ind_nd_j)
      M_ryg ← nf_(ind_nfi_(C_o_(1,1)) + 2, ind_nd_j)
      M_rzg ← nf_(ind_nfi_(C_o_(2,1)) + 2, ind_nd_j)
      M_rx ← (nf_(ind_nfi_(C_o_(0,1)) + 2 + i, ind_nd_j) − M_rxg)·C_o_(3,0) + M_rxg
      M_ry ← (nf_(ind_nfi_(C_o_(1,1)) + 2 + i, ind_nd_j) − M_ryg)·C_o_(3,0) + M_ryg
      M_rz ← (nf_(ind_nfi_(C_o_(2,1)) + 2 + i, ind_nd_j) − M_rzg)·C_o_(3,0) + M_rzg
      M'_j ← sqrt(M_rx^2 + M_ry^2 + M_rz^2)
      Int'_j ← ElbowDC(P, D_o, t, I, B_1, B_2, M'_j, S)
      if Int'_j > Int_0
         Int ← stack(Int'_j, M'_j, nf_(ind_nfi_(C_o_(0,1)) − 1 + i, 0), EL_(ind_nd_j, 1), ind_nd_j, M_rx, M_ry, M
         Result ← M'
Int
```

Conditions applicable to all elbows

$M_{cx} := 0 \quad M_{cy} := 0 \quad M_{cz} := 0$ — Defining place holding variables

$$Elb\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Elbow Properties for EL(1-42(A-D, H))

Define pertinent elbow variables

$D_o := 6.625\text{in}$ — Outside Diameter [22]

$t := 0.28\text{in}$ — Thickness [22]

$P := 376\text{psi}$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\,4} - \left(D_o - 2\cdot t\right)^4\right]}{64}$$

$I = 28.142\,\text{in}^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$R := 9\text{in}$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$ — Mean pipe radius

Define primary stress indices

$$h := \frac{t\cdot R}{r_m^{\,2}}$$ $h = 0.25$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4\cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4\cdot h > 0.5 \\ -0.1 + 0.4\cdot h & \text{otherwise} \end{cases}$$

$B_1 = 1.515 \times 10^{-4}$ — B_1 primary stress Index [4, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 3.272$ — B_2 primary stress Index [4, NB-3683.7]

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

Elbow 1-42A (Nodes 805 & 804)

$nd_{EL142A\_1} := (805)^T$

$AL_{EL142A\_nd805} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL142A\_1}, Elb\_C_o, EL\right)$

$AL_{EL142A\_nd805}{}^T = \begin{pmatrix} 0.072 & 1.053 \times 10^4 & 13.18 & 805 & 11 & -481.827 & -1.048 \times 10^4 & 938.886 \end{pmatrix}$

$nd_{EL142A\_2} := (804)^T$

$AL_{EL142A\_nd804} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL142A\_2}, Elb\_C_o, EL\right)$

$AL_{EL142A\_nd804}{}^T = \begin{pmatrix} 0.067 & 9.908 \times 10^3 & 9.005 & 804 & 103 & -735.288 & -3.086 \times 10^3 & 9.387 \times 10^3 \end{pmatrix}$

Elbow 1-42B (Nodes 767 & 766)

$nd_{EL142B\_1} := (767)^T$

$AL_{EL142B\_nd767} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL142B\_1}, Elb\_C_o, EL\right)$

$AL_{EL142B\_nd767}{}^T = \begin{pmatrix} 0.077 & 1.135 \times 10^4 & 5.33 & 767 & 17 & -1.044 \times 10^3 & -1.126 \times 10^4 & -972.551 \end{pmatrix}$

$nd_{EL142B\_2} := (766)^T$

$AL_{EL142B\_nd766} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL142B\_2}, Elb\_C_o, EL\right)$

$AL_{EL142B\_nd766}{}^T = \begin{pmatrix} 0.143 & 2.098 \times 10^4 & 10.095 & 766 & 115 & -1.031 \times 10^3 & 2.094 \times 10^4 & 898.77 \end{pmatrix}$

Elbow 1-42C (Nodes 796 & 798)

$nd_{EL142C\_1} := (796)^T$

$AL_{EL142C\_nd796} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL142C\_1}, Elb\_C_o, EL\right)$

$AL_{EL142C\_nd796}{}^T = \begin{pmatrix} 0.163 & 2.403 \times 10^4 & 8.375 & 796 & 7 & 2.6 \times 10^3 & -2.389 \times 10^4 & 462.015 \end{pmatrix}$

$nd_{EL142C\_2} := (798)^T$

$AL_{EL142C\_nd798} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL142C\_2}, Elb\_C_o, EL\right)$

$AL_{EL142C\_nd798}{}^T = \begin{pmatrix} 0.167 & 2.455 \times 10^4 & 6.715 & 798 & 20 & -767.224 & 2.452 \times 10^4 & 994.836 \end{pmatrix}$

Elbow 1-42D (Nodes 799 & 797)

$nd_{EL142D\_1} := (799)^T$

$AL_{EL142D\_nd799} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL142D\_1}, Elb\_C_o, EL\right)$

$AL_{EL142D\_nd799}{}^T = \begin{pmatrix} 0.22 & 3.241 \times 10^4 & 6.92 & 799 & 6 & -397.704 & -3.239 \times 10^4 & 1.058 \times 10^3 \end{pmatrix}$

$nd_{EL142D\_2} := (797)^T$

$AL_{EL142D\_nd797} := Elbow\left(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL142D\_2}, Elb\_C_o, EL\right)$

$AL_{EL142D\_nd797}{}^T = \begin{pmatrix} 0.232 & 3.411 \times 10^4 & 6.92 & 797 & 22 & 248.066 & -3.41 \times 10^4 & 866.604 \end{pmatrix}$

Elbow 1-42G (Nodes 772 & 773)

$nd_{EL142G\_1} := (772)^T$

$AL_{EL142G\_nd772} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL142G\_1}, Elb\_C_o, EL)$

$AL_{EL142G\_nd772}{}^T = (0.271 \quad 3.988\times10^4 \quad 9.44 \quad 772 \quad 159 \quad -3.781\times10^4 \quad -9.122\times10^3 \quad -8.84\times10^3)$

$nd_{EL142G\_2} := (773)^T$

$AL_{EL142G\_nd773} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL142G\_2}, Elb\_C_o, EL)$

$AL_{EL142G\_nd773}{}^T = (0.266 \quad 3.913\times10^4 \quad 9.935 \quad 773 \quad 35 \quad 1.922\times10^4 \quad 3.003\times10^4 \quad 1.612\times10^4)$

Elbow 1-42H (Nodes 775 & 774)

$nd_{EL142H\_1} := (775)^T$

$AL_{EL142H\_nd775} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL142H\_1}, Elb\_C_o, EL)$

$AL_{EL142H\_nd775}{}^T = (0.31 \quad 4.557\times10^4 \quad 9.935 \quad 775 \quad 161 \quad -1.785\times10^4 \quad 3.002\times10^4 \quad -2.926\times10^4)$

$nd_{EL142H\_2} := (774)^T$

$AL_{EL142H\_nd774} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL142H\_2}, Elb\_C_o, EL)$

$AL_{EL142H\_nd774}{}^T = (0.453 \quad 6.673\times10^4 \quad 3.85 \quad 774 \quad 25 \quad 7.439\times10^3 \quad -3.985\times10^3 \quad 6.62\times10^4)$

Elbow Properties for EL(1-42(E-F))

Define pertinent elbow variables

$D_o := 6.625in$ — Outside Diameter [22]

$t := 0.28in$ — Thickness [22]

$P := 376psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi\cdot\left[D_o{}^4 - (D_o - 2\cdot t)^4\right]}{64}$$

$I = 28.142\,in^4$ — Moment of inertia [8, Table 17-27, pg 17-39]

$R := 30in$ — Nominal bend radius of curved pipe or elbow

$$r_m := \frac{D_o - t}{2}$$ — Mean pipe radius

Define primary stress indices

$$h := \frac{t\cdot R}{r_m{}^2}$$ $h = 0.835$ — Characteristic bend parameter of a curved pipe or butt welding elbow

$$B_1 := \begin{cases} 0 & \text{if } -0.1 + 0.4\cdot h < 0 \\ 0.5 & \text{if } -0.1 + 0.4\cdot h > 0.5 \\ -0.1 + 0.4\cdot h & \text{otherwise} \end{cases}$$

$B_1 = 0.234$ — B_1 primary stress Index [4, NB-3683.7]

$$B_2 := \begin{cases} 1.0 & \text{if } \dfrac{1.3}{h^{\frac{2}{3}}} \le 1.0 \\ \dfrac{1.3}{h^{\frac{2}{3}}} & \text{otherwise} \end{cases}$$

$B_2 = 1.467$ — B_2 primary stress Index [4, NB-3683.7]

Elbow 1-42E (Nodes 768 & 769)

$nd_{EL142E\_1} := (768)^T$

$AL_{EL142E\_nd768} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL142E\_1}, Elb\_C_o, EL)$

$$AL_{EL142E\_nd768}^T = \begin{pmatrix} 0.147 & 4.217 \times 10^4 & 6.74 & 768 & 28 & 7.296 \times 10^3 & 4.145 \times 10^4 & 2.598 \times 10^3 \end{pmatrix}$$

$nd_{EL142E\_2} := (769)^T$

$AL_{EL142E\_nd769} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL142E\_2}, Elb\_C_o, EL)$

$$AL_{EL142E\_nd769}^T = \begin{pmatrix} 0.196 & 5.837 \times 10^4 & 6.915 & 769 & 1 & -1.112 \times 10^3 & -5.536 \times 10^4 & 1.848 \times 10^4 \end{pmatrix}$$

Elbow 1-42F (Nodes 770 & 771)

$nd_{EL142F\_1} := (770)^T$

$AL_{EL142F\_nd770} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL142F\_1}, Elb\_C_o, EL)$

$$AL_{EL142F\_nd770}^T = \begin{pmatrix} 0.177 & 5.224 \times 10^4 & 9.76 & 770 & 31 & -1.525 \times 10^3 & -1.93 \times 10^4 & 4.852 \times 10^4 \end{pmatrix}$$

$nd_{EL142F\_2} := (771)^T$

$AL_{EL142F\_nd771} := Elbow(P, D_o, t, I, B_1, B_2, S_{125}, NF, nd_{EL142F\_2}, Elb\_C_o, EL)$

$$AL_{EL142F\_nd771}^T = \begin{pmatrix} 0.101 & 2.726 \times 10^4 & 9.76 & 771 & 32 & -2.361 \times 10^4 & 5.742 \times 10^3 & -1.236 \times 10^4 \end{pmatrix}$$

Writing Output Data for Elbows Associated with Line 1-42

$EL1A := AL_{EL142A\_nd805}^T$

$EL1B := AL_{EL142A\_nd804}^T$

$EL2A := AL_{EL142B\_nd767}^T$

$EL2B := AL_{EL142B\_nd766}^T$

$EL3A := AL_{EL142C\_nd796}^T$

$EL3B := AL_{EL142C\_nd798}^T$

$EL4A := AL_{EL142D\_nd799}^T$

$EL4B := AL_{EL142D\_nd797}^T$

$EL5A := AL_{EL142G\_nd772}^T$

$EL5B := AL_{EL142G\_nd773}^T$

$EL6A := AL_{EL142H\_nd775}^T$

$EL6B := AL_{EL142H\_nd774}^T$

$EL7A := AL_{EL142E\_nd768}^T$

$EL7B := AL_{EL142E\_nd769}^T$

$EL8A := AL_{EL142F\_nd770}^T$

$EL8B := AL_{EL142F\_nd771}^T$

vEL := (EL1A EL1B EL2A EL2B EL3A EL3B EL4A EL4B EL5A EL5B EL6A EL6B EL7A EL7B EL8A EL8B)

ElbowLine1_42 := WRITEPRN("ElbowLine1-42.prn" , vEL)

FLANGES

Flange Strategy: *Search based on the nodes where flanges occur. Find the maximum moment combination for the node and apply to equation (9) of ASME III, Division I - NB - 3652 [4]. Use the geometry of the pipe when applying (9). The D/C ratio for each node will be determined by dividing the left side of the equation by the right side of the equation and taking the max of the result.*

$$\text{FlangeDC}\left(P, D_o, t, I, B_1, B_2, M, S\right) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot [M \cdot (1\text{lbf} \cdot \text{in})]}{S}$$

$$\text{Flange}\left(P, D_o, t, I, B_1, B_2, S, nf, nd, C_o, EL\right) :=$$

$ind_{nfi} \leftarrow \text{match}\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow \text{match}\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{nd} \leftarrow \text{match}\left(nd_0, EL^{\langle 1 \rangle}\right)$

for $i \in 1 .. \text{last}(nd)$ if $\text{rows}(nd) > 1$

  $ind_{nd} \leftarrow \text{stack}\left[ind_{nd}, \left(\text{match}\left(nd_i, EL^{\langle 1 \rangle}\right)\right)\right]$

$\left(M \;\; Int_0\right) \leftarrow (0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. \text{last}\left(ind_{nd}\right)$

    $M_{rxg} \leftarrow nf_{ind_{nfi}C_{o_{0,1}}+2,\, ind_{nd_j}}$

    $M_{ryg} \leftarrow nf_{ind_{nfi}C_{o_{1,1}}+2,\, ind_{nd_j}}$

    $M_{rzg} \leftarrow nf_{ind_{nfi}C_{o_{2,1}}+2,\, ind_{nd_j}}$

    $M_{rx} \leftarrow \left(nf_{ind_{nfi}C_{o_{0,1}}+2+i,\, ind_{nd_j}} - M_{rxg}\right) \cdot C_{o_{3,0}} + M_{rxg}$

    $M_{ry} \leftarrow \left(nf_{ind_{nfi}C_{o_{1,1}}+2+i,\, ind_{nd_j}} - M_{ryg}\right) \cdot C_{o_{3,0}} + M_{ryg}$

    $M_{rz} \leftarrow \left(nf_{ind_{nfi}C_{o_{2,1}}+2+i,\, ind_{nd_j}} - M_{rzg}\right) \cdot C_{o_{3,0}} + M_{rzg}$

    $M'_j \leftarrow \sqrt{M_{rx}^2 + M_{ry}^2 + M_{rz}^2}$

    $Int'_j \leftarrow \text{FlangeDC}\left(P, D_o, t, I, B_1, B_2, M'_j, S\right)$

    if $Int'_j > Int_0$

      $Int \leftarrow \text{stack}\left(Int'_j, M'_j, nf_{ind_{nfi}C_{o_{0,1}-1}+i,\, 0}, EL_{ind_{nd_j}, 1}, ind_{nd_j}, M_{rx}, M_{ry}, M\right.$

      $Result \leftarrow M'$

Int

Conditions applicable to all flanges

$M_{cx} := 0 \qquad M_{cy} := 0 \qquad M_{cz} := 0$ Defining place holding variables

$$Flange\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(NS), y(Vertical), and z(EW) correspond to positive 1, 2, and 3 and seismic factor

Pipe Properties of Line 1-42

Define pertinent pipe variables

$D_o := 6.625in$ Outside Diameter [22]

$t := 0.28in$ Thickness [22]

$P := 376psi$ Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\ 4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

Moment of inertia [8, Table 17-27, pg 17-39]

$I = 28.142\ in^4$

Define primary stress indices (Utilize girth weld characteristic associated with lap joint flanges in determining values)

$B_1 := 0.5$ B_1 for a girth weld [4, Table NB-3681(a)-1, pg 130]

$B_2 := 1$ B_2 for a girth weld [4, Table NB-3681(a)-1, pg 130]

Flange 1-42A (Node 759)

$nd_{FL142A} := (759)^T$

$AL_{FL142A} := Flange\left(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{FL142A}, Flange\_C_o, EL\right)$

$$AL_{FL142A}^{\ T} = \left(0.146 \quad 4.611 \times 10^4 \quad 10.66 \quad 759 \quad 65 \quad 1.219 \times 10^4 \quad -6.791 \times 10^3 \quad 4.394 \times 10^4\right)$$

Flange 1-42B (Node 760)

$nd_{FL142B} := (760)^T$

$AL_{FL142B} := Flange\left(P, D_o, t, I, B_1, B_2, S_{167}, NF, nd_{FL142B}, Flange\_C_o, EL\right)$

$$AL_{FL142B}^{\ T} = \left(0.18 \quad 6.087 \times 10^4 \quad 10.185 \quad 760 \quad 85 \quad -3.14 \times 10^3 \quad -1.024 \times 10^4 \quad 5.992 \times 10^4\right)$$

Writing Output Data for Flanges Associated with Line 1-42

$F1 := AL_{FL142A}^{\ T} \qquad F2 := AL_{FL142B}^{\ T}$

$F := (F1 \quad F2)$

FlangeLine1_42 := WRITEPRN("FlangeLine1-42.prn" , F)

Appendix D.3.8

Demand to Capacity Ratio Calculations for Components Associated with Unlisted Components of ATR PCS Model 1-4

(NOTE: Values represented here are shown for one realization (Nodal Force file = UNLIST_COMPS_M1-4_test_R1.dat and Element/Nodal order file = EL_UNLIST_COMPS_m14.xls) and may or may not be consistent with the 80th percentile results contained in Appendix D.4)

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

Force Outputs from Abaqus

NF := ...\UNLIST_COMPS_M1-4.dat — (N)odal (F)orces for Model 1-4

Defined Elemental and Corresponding Nodal Order

EL := ...\EL_UNLIST_COMPS_M1-4(9-22-08).xls — Element and corresponding nodal order for Model 1-4

Time Boundaries

$t_{initial} := 1$ — Initial time for which dynamic loading is applied

$t_{final} := 21$ — Final time for which dynamic loading stops

Seismic Scale Factor (F_a)

$F_a := 1$ — Seismic scale factor [9]

Allowable Design Stress Intensity Factor (S_m): *S_m is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{m\_125} := 20ksi$ — For SS304 at 125°F [2, pg 316-318] [3, pg 23]

$S_{m\_125L} := 16.7ksi$ — For SS304L at 125°F [2, pg 316-318] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

$S_{m\_167} := 20ksi$ — For SS304 at 167°F [2, pg 316-318] [3, pg 23]

$S_{m\_167L} := 16.7ksi$ — For SS304L at 167°F [2, pg 316-318] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

Yield Strength (S_y): *S_y is defined below for SS304 at temperature 125°F and SS304L at 125°F.*

$S_{y\_125} := 28.35ksi$ — For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_125L} := 23.85ksi$ — For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

$S_{y\_167} := 26.12ksi$ — For SS304 at 125°F [2, pg 646-648] [3, pg 23]

$S_{y\_167L} := 22.26ksi$ — For SS304L at 125°F [2, pg 646-648] Applicable only for portions of lines 1-1, 1-2, 1-3, 1-4, 1-5, and 1-6 closest to reactor vessel [3, pg 23]

Maximum Strength Applicable for Equation 9 (S): *S is defined below for SS304 at temperature 125^{o}F and SS304L at 125^{o}F.*

$S_{125} := \min\left(3 \cdot S_{m\_125}, 2 \cdot S_{y\_125}\right)$

$\boxed{S_{125} = 56.7\,\text{ksi}}$

Maximum allowable stress applied to SS304 piping [4, NB-3656]

$S_{125L} := \min\left(3 \cdot S_{m\_125L}, 2 \cdot S_{y\_125L}\right)$

$\boxed{S_{125L} = 47.7\,\text{ksi}}$

Maximum allowable stress applied to SS304L piping [4, NB-3656]

$S_{167} := \min\left(3 \cdot S_{m\_167}, 2 \cdot S_{y\_167}\right)$

$\boxed{S_{167} = 52.24\,\text{ksi}}$

Maximum allowable stress applied to SS304 piping [4, NB-3656]

$S_{167L} := \min\left(3 \cdot S_{m\_167L}, 2 \cdot S_{y\_167L}\right)$

$\boxed{S_{167L} = 44.52\,\text{ksi}}$

Maximum allowable stress applied to SS304L piping [4, NB-3656]

FABRICATED BRANCH TEES

Tees Strategy: *Search based on the elements comprising the tee. The input identifies which elements are associated with the pipe run and which element is associated with the branch from the run. The indices for the defined common node for all three elements is identified and the associated SRSS moment is identified for each time step. The maximum moment for the elements comprising the pipe run is found and applied as M_r in equation (9) of ASME III, Division I - NB - 3652 which is modified to represent tees. The maximum moment for the branch element is found and applied as M_b in equation (9) of ASME III, Division I - NB - 3652 [4]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$FabBrDC(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_b, M_r, Z_b, Z_r, S) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot T_r} + B_{2b} \cdot \left[\frac{M_b \cdot (1 lbf \cdot in)}{Z_b}\right] + B_{2r} \cdot \left[\frac{M_r \cdot (1 lbf \cdot in)}{Z_r}\right]}{S}$$

$FabBr(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S, nf, el_R, el_B, nd_R, nd_B, C_o, EL) :=$

$ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0 \rangle}\right)$

$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0 \rangle}\right)$

$ind_{elR} \leftarrow match\left(el_{R_0}, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(el_R)$ if ro

$\quad ind_{elR} \leftarrow stack\left[ind_{elR}, \left(match\left(el_{R_i}, EL^{\langle 0 \rangle}\right)\right)\right]$

$EL'R_{last\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$

for $i \in 0 .. last(ind_{elR})$

$\quad EL'R_{ind_{elR_i}} \leftarrow EL_{ind_{elR_i}, 1}$

$ind_{ndR} \leftarrow match\left(nd_{R_0}, EL'R^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(nd_R)$ if

$\quad ind_{ndR} \leftarrow stack\left[ind_{ndR}, \left(match\left(nd_{R_i}, EL'R^{\langle 0 \rangle}\right)\right)\right]$

$ind_{elB} \leftarrow match\left(el_{B_0}, EL^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(el_B)$ if ro

$\quad ind_{elB} \leftarrow stack\left[ind_{elB}, \left(match\left(el_{B_i}, EL^{\langle 0 \rangle}\right)\right)\right]$

$EL'B_{last\left(EL^{\langle 0 \rangle}\right)} \leftarrow 0$

for $i \in 0 .. last(ind_{elB})$

$\quad EL'B_{ind_{elB_i}} \leftarrow EL_{ind_{elB_i}, 1}$

$ind_{ndB} \leftarrow match\left(nd_{B_0}, EL'B^{\langle 0 \rangle}\right)$

for $i \in 1 .. last(nd_B)$ if

$ind_{ndB} \leftarrow stack\left[ind_{ndB}, \left(match\left(nd_{B_i}, EL'B^{\langle 0 \rangle}\right)\right)\right]$

$(M_R \;\; M_B \;\; Int_0) \leftarrow (0 \;\; 0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

for $j \in 0 .. last(ind_{ndR})$

for $k \in 0 .. last(ind_{ndB})$

$M_{rxgR_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2, ind_{ndR_j}}$

$M_{rygR_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2, ind_{ndR_j}}$

$M_{rzgR_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2, ind_{ndR_j}}$

$M_{rxR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i, ind_{ndR_j}} - M_{rxgR_j}\right)$

$M_{ryR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i, ind_{ndR_j}} - M_{rygR_j}\right)$

$M_{rzR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i, ind_{ndR_j}} - M_{rzgR_j}\right)$

$M_{R_j} \leftarrow \sqrt{\left(M_{rxR_j}\right)^2 + \left(M_{ryR_j}\right)^2 + \left(M_{rzR_j}\right)^2}$

$M_{rxgB_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2, ind_{ndB_k}}$

$M_{rygB_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}}+2, ind_{ndB_k}}$

$M_{rzgB_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}}+2, ind_{ndB_k}}$

$M_{rxB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}}+2+i, ind_{ndB_k}} - M_{rxgB_j}\right)$

$M_{ryB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}}+2+i, ind_{ndB_k}} - M_{rygB_j}\right)$

$M_{rzB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}}+2+i, ind_{ndB_k}} - M_{rzgB_j}\right)$

$M_{B_j} \leftarrow \sqrt{\left(M_{rxB_j}\right)^2 + \left(M_{ryB_j}\right)^2 + \left(M_{rzB_j}\right)^2}$

$Int'_j \leftarrow FabBrDC\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_{B_j}\right.$

if $Int'_j > Int_0$

$Int \leftarrow stack\left(Int'_j, M_{R_j}, M_{B_j}, nf_{ind_{nfiC_{o\ldots}}} - \right.$

$\text{Result} \leftarrow \text{stack}\left(M_{R_j}, M_{B_j}, M_{rxR_j}, M_{ryR_j},\right.$

$M \leftarrow M_R$

Int

Conditions applicable to forged tee

$M_{cx} := 0 \quad M_{cy} := 0 \quad M_{cz} := 0$

Defining place holding directional moment variables

$$FabBr\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

FABRICATED WYES

Define pertinent tee variables

$P := 272\text{psi}$ — Internal Pressure [3, pg 23]

$D_o := 25.25\text{in}$ — Outside Diameter of pipe run [6,7,23]

$d_o := 18\text{in}$ — Outside Diameter of branch [6,7,23]

$B_1 := 0.5$ — B_1 primary stress Index for tees and branches [4, Table NB-3681(a)-1]]

B1 value actually applied via results of App F.3.3 evaluation

$B_1 := 15.805$

$T_r := 1.0\text{in}$ — Nominal wall thickness of designated run pipe [6,7,23]

$R_m := \dfrac{D_o - T_r}{2}$ — Mean radius of designated run pipe [6,7,23]

$Z_r := \pi \cdot R_m^{\ 2} \cdot T_r$ — Approximate section modulus of designated run pipe [4, NB-3683.1(d)]

$Z_r = 461.8632\ \text{in}^3$

$T'_b := 0.312\text{in}$ — Nominal wall thickness of attached branch pipe [6,7,23]

$r'_m := \dfrac{d_o - T'_b}{2}$ — Mean radius of attached branch pipe [6,7,23]

$Z_b := \pi \cdot r'_m{}^2 \cdot T'_b$

Approximate section modulus of attached branch pipe [4, NB-3683.1(d)]

$Z_b = 76.666\ in^3$

C_{2b} Secondary stress Index [4,NB-3683.8]

$$C_{2b} := \begin{cases} 1.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}}\cdot\left(\frac{r'_m}{R_m}\right)^{\frac{1}{2}}\cdot\left(\frac{T'_b}{T_r}\right)\cdot\left(\frac{r'_m}{\frac{d_o}{2}}\right) & \text{if } 1.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}}\cdot\left(\frac{r'_m}{R_m}\right)^{\frac{1}{2}}\cdot\left(\frac{T'_b}{T_r}\right)\cdot\left(\frac{r'_m}{\frac{d_o}{2}}\right) \ge 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$C_{2b} = 2.073$

C_{2r} Secondary stress Index [4,NB-3683.8]

$t_n := T'_b$

Wall thickness of nozzle or branch connection reinforcement associated with [4, NB-3643.4(A)-1, sketch (d)]

$$C_{2r} := \begin{cases} 1.15\cdot\left(\frac{r'_m}{t_n}\right)^{\frac{1}{4}} & \text{if } 1.15\cdot\left(\frac{r'_m}{t_n}\right)^{\frac{1}{4}} \ge 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$C_{2r} = 2.654$

$$B_{2b} := \begin{cases} 0.5\cdot C_{2b} & \text{if } 0.5\cdot C_{2b} \ge 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Index for branches [4, NB-3683.8]

$B_{2b} = 1.036$

B2b value actually applied via results of App F.3.3 evaluation

$B_{2b} := 1.752$

$$B_{2r} := \begin{cases} 0.75\cdot C_{2r} & \text{if } 0.75\cdot C_{2r} \ge 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Index for branches [4, NB-3683.8]

$B_{2r} = 1.99$

B2r value actually applied via results of App F.3.3 evaluation

$B_{2r} := 7.059$

Fabricated Branch 1-2L (Node 572)

$elR_{FabBr12L} := (393\ \ 422)^T$ Elements associated with pipe run

$ndR_{FabBr12L} := (572)^T$ Node between pipe run elements

$elB_{FabBr12L} := (387)^T$ Element associated with branch

$ndB_{FabBr12L} := (572)^T$ Node where branch intersects pipe run

$AL_{FabBr12L} := FabBr\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{167L}, NF, elR_{FabBr12L}, elB_{FabBr12L}, ndR_{FabBr12L}, ndB_{I}\right.$

$$AL_{FabBr12L}^T = \left(1.429\quad 5.082\times10^5\quad 6.919\times10^4\quad 9.885\quad 572\quad 59\quad 65\quad 45\right)$$

Fabricated Branch 1-3L (Node 573)

$elR_{FabBr13L} := (395\ \ 423)^T$ Elements associated with pipe run

$ndR_{FabBr13L} := (573)^T$ Node between pipe run elements

$elB_{FabBr13L} := (389)^T$ Element associated with branch

$ndB_{FabBr13L} := (573)^T$ Node where branch intersects pipe run

$AL_{FabBr13L} := FabBr\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{167L}, NF, elR_{FabBr13L}, elB_{FabBr13L}, ndR_{FabBr13L}, ndB_{I}\right.$

$$AL_{FabBr13L}^T = \left(1.424\quad 5.096\times10^5\quad 5.842\times10^4\quad 9.525\quad 573\quad 63\quad 67\quad 49\right)$$

FABRICATED ELBOW BRANCH

Define pertinent tee variables

$P := 272\text{psi}$ — Internal Pressure [3, pg 23]

$D_o := 36\text{in}$ — Outside Diameter of pipe run [10,17]

$d_o := 6.625\text{in}$ — Outside Diameter of branch [10,17]

$B_1 := 0.5$ — B_1 primary stress Index for tees and branches [4, Table NB-3681(a)-1]]

$T_r := 0.5\text{in}$ — Nominal wall thickness of designated run pipe [10,17]

$R_m := \dfrac{D_o - T_r}{2}$ — Mean radius of designated run pipe [10,17]

$Z_r := \pi \cdot R_m^{\ 2} \cdot T_r$ — Approximate section modulus of designated run pipe [4, NB-3683.1(d)]

$Z_r = 494.899\ \text{in}^3$

$T'_b := 0.28\text{in}$ — Nominal wall thickness of attached branch pipe [10,17]

$r'_m := \dfrac{d_o - T'_b}{2}$ — Mean radius of attached branch pipe [10,17]

$Z_b := \pi \cdot r'^{\ 2}_m \cdot T'_b$ — Approximate section modulus of attached branch pipe [4, NB-3683.1(d)]

$Z_b = 8.853\ \text{in}^3$

C_{2b} Secondary stress Index [4,NB-3683.8]

$$C_{2b} := \begin{cases} 1.5\cdot\left(\dfrac{R_m}{T_r}\right)^{\frac{2}{3}}\left(\dfrac{r'_m}{R_m}\right)^{\frac{1}{2}}\left(\dfrac{T'_b}{T_r}\right)\left(\dfrac{r'_m}{\frac{d_o}{2}}\right) & \text{if } 1.5\cdot\left(\dfrac{R_m}{T_r}\right)^{\frac{2}{3}}\left(\dfrac{r'_m}{R_m}\right)^{\frac{1}{2}}\left(\dfrac{T'_b}{T_r}\right)\left(\dfrac{r'_m}{\frac{d_o}{2}}\right) \ge 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$C_{2b} = 3.674$

C_{2r} Secondary stress Index [4,NB-3683.8]

$t_n := T'_b$ — Wall thickness of nozzle or branch connection reinforcement associated with [4, NB-3643.4(A)-1, sketch (d)]

$$C_{2r} := \begin{cases} 1.15\cdot\left(\frac{r'_m}{t_n}\right)^{\frac{1}{4}} & \text{if } 1.15\cdot\left(\frac{r'_m}{t_n}\right)^{\frac{1}{4}} \geq 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$C_{2r} = 2.11$

$$B_{2b} := \begin{cases} 0.5\cdot C_{2b} & \text{if } 0.5\cdot C_{2b} \geq 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Index for branches [4, NB-3683.8]

$B_{2b} = 1.837$

$$B_{2r} := \begin{cases} 0.75\cdot C_{2r} & \text{if } 0.75\cdot C_{2r} \geq 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Index for branches [4, NB-3683.8]

$B_{2r} = 1.582$

Fabricated Branch 1-42 (Node 589)

$elR_{FabBr142} := (318 \quad 317)^T$ — Elements associated with pipe run

$ndR_{FabBr142} := (589)^T$ — Node between pipe run elements

$elB_{FabBr142} := (319)^T$ — Element associated with branch

$ndB_{FabBr142} := (953)^T$ — Node where branch intersects pipe run

$AL_{FabBr142} := FabBr(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{167}, NF, elR_{FabBr142}, elB_{FabBr142}, ndR_{FabBr142}, ndB_{Fa}$

$$AL_{FabBr142}{}^T = \left(0.323 \quad 6.336\times10^5 \quad 4.797\times10^4 \quad 8.42 \quad 589 \quad 24 \quad 26 \quad 30\right)$$

Writing Output Data for Fabricated Branches

$FB1 := AL_{FabBr12L}{}^T$

$FB2 := AL_{FabBr13L}{}^T$

$FB3 := AL_{FabBr142}{}^T$

$vFB := (FB1 \quad FB2 \quad FB3)$

FabBrLine_UNLIST_COMP := WRITEPRN("FabBrLine_UNLIST_COMP.prn" , vFB)

Appendix D.4

80th Percentile Results of All 32 Realizations

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

LOGIC USED TO GATHER DATA FROM ALL 32 REALIZATIONS

a := "Y:\PCS2\Automated_Evaluation\Model_14\Real"

```
ReadData(b) := for k ∈ 1 .. 32
                  d_{k-1} ← READPRN(concat(a, num2str(k), b))
                  for j ∈ 0 .. length((d_{k-1})^T) - 1
                    D_{k-1, j} ← (d_{k-1})_{0, j}
```

R := stack(1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32)

LOGIC USED TO SORT DATA BASED ON D/C RATIOS OF ALL 32 REALIZATIONS

```
C_S(v,R) := for i ∈ 0 .. cols(v) - 1
              for k ∈ 0 .. rows(v_{0,i}) - 1
                for j ∈ 0 .. rows(v) - 1
                  a_{0,j} ← [((v_{j,i})^T)^<k>]^T
                  A ← a_{0,j} if j = 0
                  A ← stack(A, a_{0,j}) if j > 0
                b_{k,i} ← stack(A^T, R^T)^T
                Sorted_{k,i} ← reverse(csort(b_{k,i}, 0))
            Sorted
```

LOGIC USED TO JOIN RESULTS FROM EITHER END OF REDUCERS AND ELBOWS INTO ONE MATRIX

```
RED_EL_80th(RE) := k ← 0
                   for i ∈ 0 .. (cols(RE) - 1)/2
                     j ← 2·i
                     RE80TH_{i,k} ← stack(((RE_{0,j})^T)^<6>^T, ((RE_{0,j+1})^T)^<6>^T)
```

LOGIC USED TO CONCATINATE 80TH PERCENTILE RESULTS OF PIPE RUNS INTO ONE MATRIX

$PR_{80th}(PM) :=$ for $i \in 0 .. cols(PM) - 1$

- $k_i \leftarrow 0$
- for $j \in 0 .. rows\left(PM^{\langle i \rangle}\right) - 1$
  - $k_i \leftarrow k_i + 1$ if $PM_{j,i} \neq 0$
- for $m \in 0 .. k_i - 1$
  - $PM80th_{m,i} \leftarrow \left(\left(PM_{m,i}\right)^T\right)^{\langle 6 \rangle T}$
- $pm80th_{0,i} \leftarrow PM80th_{0,i}$
- for $n \in 1 .. k_i - 1$
  - $pm80th_{0,i} \leftarrow stack\left(pm80th_{0,i}, PM80th_{n,i}\right)$

LOGIC USED TO DETERMINE 80TH PERCENTILE RESULTS OF SUPPORTS & TEES

$T_{80th}(T) :=$ for $i \in 0 .. cols(T) - 1$

$$T80th_{0,i} \leftarrow \left(\left(T_{0,i}\right)^T\right)^{\langle 6 \rangle T}$$

SUPPORTS

Support output is ordered as (D/C,demand force, occurance time, defined node, associated index for the reaction force at the selected node being colinear (AL1) and apposing (AL2) the positive directionality of the global coordinate system, and realization number)

EVALUATION OF SUPPORTS ON LINES 1-1L, 1-2L, 1-3L, & 1-4L FOR ALL 32 REALIZATI

VSA := ReadData("\SupLine1-1_2_3_4.prn")

SA := C_S(VSA,R)

PR-2 East Support (2x)

PR-2A (Node 1323)

PR-2A Horizontally supports the midsection of P(1-1LC).

Tension $\left(SA_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(1.811 \quad -5.774\times10^{3} \quad 9.18 \quad 1.323\times10^{3} \quad 151 \quad 7\right)$

This challenged support will be evaluated in a breakout analysis in Appendix E.4 where its loading will be applied simutaneously with that of the appropriate PR-1 support for which it shares a common anchorage structure. The below function writes this information to the Appendix E.4 file.

PR2_E_T := WRITEPRN("Y:\PCS2\Automated_Evaluation\PR-1&2_Combo_Evaluation\PR2A_E_Tension.prn" , $SA_{0,0}$)

PR2_E_C := WRITEPRN("Y:\PCS2\Automated_Evaluation\PR-1&2_Combo_Evaluation\PR2A_E_Compression.prn" , $SA_{0,}$

Compression $\left(SA_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \left(0.248 \quad 4.444\times10^{3} \quad 6.935 \quad 1.323\times10^{3} \quad 151 \quad 9\right)$

PR-2B (Node 1324)

PR-2B Horizontally supports the midsection of P(1-2LC).

Tension $\left(SA_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \left(0.49 \quad -3.495\times10^{3} \quad 7.04 \quad 1.324\times10^{3} \quad 149 \quad 1\right)$

Compression $\left(SA_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \left(0.15 \quad 2.695\times10^{3} \quad 6.93 \quad 1.324\times10^{3} \quad 149 \quad 9\right)$

PR-2 West Support (2x)

PR-2C (Node 1322)

PR-2C Horizontally supports the midsection of P(1-3LC).

Compression $\left(SA_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \left(0.172 \quad -3.088\times10^{3} \quad 7.85 \quad 1.322\times10^{3} \quad 147 \quad 12\right)$

Tension $\left(SA_{0,5}{}^{T}\right)^{\langle 6\rangle T} = \left(0.435 \quad 3.104\times10^{3} \quad 7.23 \quad 1.322\times10^{3} \quad 147 \quad 22\right)$

PR-2D (Node)

PR-2D Horizontally supports the midsection of P(1-4LC).

Compression $\left(SA_{0,6}{}^{T}\right)^{\langle 6\rangle T} = \left(0.287 \quad -5.145\times10^{3} \quad 8.535 \quad 1.321\times10^{3} \quad 145 \quad 25\right)$

Tension $\left(SA_{0,7}{}^{T}\right)^{\langle 6\rangle T} = \left(1.782 \quad 5.682\times10^{3} \quad 7.255 \quad 1.321\times10^{3} \quad 145 \quad 30\right)$

This challenged support will be evaluated in a breakout analysis in Appendix E.4 where its loading will be applied simutaneously with that of the appropriate PR-1 support for which it shares a common anchorage structure. The below function writes this information to the Appendix E.4 file.

PR2_W_C := WRITEPRN("Y:\PCS2\Automated_Evaluation\PR-1&2_Combo_Evaluation\PR2D_W_Compression.prn" ,SA(

PR2_W_T := WRITEPRN("Y:\PCS2\Automated_Evaluation\PR-1&2_Combo_Evaluation\PR2D_W_Tension.prn" ,$SA_{0,7}$)

EVALUATION OF SUPPORTS ON LINES 1-5, 1-6, & 1-7 FOR ALL 32 REALIZATIONS

VSB := ReadData("\SupLine1-5_6_7.prn")

SB := C_S(VSB,R)

```
truncate(VSD) := | for j ∈ 0 .. length(VSD^<0>) − 1
                 |   for k ∈ 0 .. length[(VSD^T)^<0>] − 1
                 |     | for i ∈ 0 .. 4
                 |     |   vsd_(0,i) ← (VSD_(j,k))_(0,i)
                 |     | vsdm_(j,k) ← vsd
                 | vsdm
```

Logic Used to truncate result

SB := C_S(VSB,R)

PR-7 Supports (1x)

The PR-7 was softened to the point of no influence on the model due to the loading observed by initial model iterations. See main body for treatment/recommendations regarding theses supports.

PR-7 (Node 1402)

PR-7 vertically supports the vertical PCS pipe on line 1-7 below the tee connecting lines 1-7 to 1-5 & 1-6.

Compression $\left(SB_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(2.326\times10^{-5} \quad 30\right)$

Tension $\left(SB_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \left(8.495\times10^{-3} \quad 0.085 \quad 7.145 \quad 1.402\times10^{3} \quad 97 \quad 16\right)$

MS-1 Supports (1x)

MS-1 North/South (Node 1401)

MS-1 vertically and laterally supports the vertical PCS pipe on line 1-7 above the tee connecting lines 1-7 to 1-5 & 1-6.

Tension $\left(SB_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.912 & -2.787\times10^{4} & 7.02 & 1.401\times10^{3} & 95 & 17 \end{pmatrix}$

Compression $\left(SB_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 1.065 & 3.253\times10^{4} & 6.66 & 1.401\times10^{3} & 95 & 26 \end{pmatrix}$

MS-1 Vertical (Node 1401)

Compression $\left(SB_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.564 & -1.723\times10^{4} & 6.66 & 1.401\times10^{3} & 95 & 26 \end{pmatrix}$

Tension $\left(SB_{0,5}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.483 & 1.474\times10^{4} & 7.02 & 1.401\times10^{3} & 95 & 17 \end{pmatrix}$

MS-1 Axial Via SSRS Combination (Node 1401)

$$SRSS(A,B) := \left(A^{2} + B^{2}\right)^{0.5}$$

Tension

$$T_{MS1} := \left[SRSS\left[\left(SB_{0,2}\right)_{6,0},\left(SB_{0,5}\right)_{6,0}\right]\ \ SRSS\left[\left(SB_{0,2}\right)_{6,1},\left(SB_{0,5}\right)_{6,1}\right]\ \ \left(SB_{0,2}\right)_{6,2}\ \ \left(SB_{0,2}\right)_{6,3}\ \ \left(SB_{0,2}\right)_{6,4}\ \ \left(SB_{0,\right.$$

$$T_{MS1} = \begin{pmatrix} 1.032 & 3.153\times10^{4} & 7.02 & 1.401\times10^{3} & 95 & 17 \end{pmatrix}$$

Refer to Main Body Regarding the Treatment of this Support

Compression

$$C_{MS1} := \left[SRSS\left[\left(SB_{0,3}\right)_{6,0},\left(SB_{0,4}\right)_{6,0}\right]\ \ SRSS\left[\left(SB_{0,3}\right)_{6,1},\left(SB_{0,4}\right)_{6,1}\right]\ \ \left(SB_{0,3}\right)_{6,2}\ \ \left(SB_{0,3}\right)_{6,3}\ \ \left(SB_{0,3}\right)_{6,4}\ \ \left(SB_{0,\right.$$

$$C_{MS1} = \begin{pmatrix} 1.205 & 3.681\times10^{4} & 6.66 & 1.401\times10^{3} & 95 & 26 \end{pmatrix}$$

Refer to Main Body Regarding the Treatment of this Support

Tunnel Restraint Support (1x)

Tunnel Restraint (Node 1126)

Tunnel Restraint horizontally (E/W) restrains the vertical PCS pipe on line 1-27

Eastward Compression $\left(SB_{0,6}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 2.012 & -1.259\times10^{4} & 5.92 & 1.126\times10^{3} & 91 & 17 \end{pmatrix}$

Refer to Main Body Regarding the Treatment of this Support

Westward Compression $\left(SB_{0,7}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.197 & 1.692\times10^{4} & 5.405 & 1.126\times10^{3} & 91 & 25 \end{pmatrix}$

RH-19x Support (1x)

RH-19x (Node 1113)

RH-19x vertically supports the vertical PCS pipe on line 1-7 traveling up from the reactor vessel area and into the tunnel

Tension $\left(SB_{0,8}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix}0.641 & -3.607\times 10^{4} & 9.885 & 1.113\times 10^{3} & 83 & 27\end{pmatrix}$

Compression $\left(SB_{0,9}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix}0.174 & 7.974\times 10^{3} & 7.145 & 1.113\times 10^{3} & 83 & 13\end{pmatrix}$

RH-20x Support (1x)

RH-20x (Node 1114)

RH-20x vertically supports the horizontal PCS pipe on line 1-7 traveling north of RH-19x through the tunnel.

Tension $\left(SB_{0,10}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix}0.404 & -2.275\times 10^{4} & 6.23 & 1.114\times 10^{3} & 85 & 24\end{pmatrix}$

Compression $\left(SB_{0,11}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix}0.039 & 2.097\times 10^{3} & 7.025 & 1.114\times 10^{3} & 85 & 2\end{pmatrix}$

RH-21xA & B Supports (2x)

RH-21xA (Node 1117)

RH-21xA vertically supports the horizontal PCS pipe on line 1-7 traveling north of RH-20x through the tunnel.

Tension $\left(SB_{0,12}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix}0.601 & -3.38\times 10^{4} & 4.815 & 1.117\times 10^{3} & 87 & 18\end{pmatrix}$

Compression $\left(SB_{0,13}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix}0.319 & 1.538\times 10^{4} & 7.88 & 1.117\times 10^{3} & 87 & 29\end{pmatrix}$

RH-21xB (Node 1123)

RH-21xB vertically supports the horizontal PCS pipe on line 1-7 traveling north of RH-21xA through the tunnel.

Tension $\left(SB_{0,14}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix}1.316 & -3.704\times 10^{4} & 7.805 & 1.123\times 10^{3} & 89 & 29\end{pmatrix}$

This challenged support will be evaluated in combination with RH-26x supporting lines 1-27 and 8-14. The supporting calculations for this treatment are included in Appendix E.8 for all supports for which this approach is applicable. Below function writes this information to the Appendix E.8 file.

$SRSS_{RH21x}$:= WRITEPRN("Y:\PCS2\PCS Documentation\App_E\E8 Common Anchorage Combinations\RH-21x.prn" ,(

Compression $\left(SB_{0,15}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix}0.232 & 1.12\times 10^{4} & 4.805 & 1.123\times 10^{3} & 89 & 18\end{pmatrix}$

RH-22x Supports (1x)

RH-22x (Node 1120)

RH-22x vertically supports the horizontal PCS pipe on line 1-7 traveling north of RH-21xB through the tunnel.

Tension $\left(SB_{0,16}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.754 \quad -2.121 \times 10^{4} \quad 5.24 \quad 1.12 \times 10^{3} \quad 111 \quad 5\right)$

This support will be evaluated in combination with RH-27x supporting line 1-27. The supporting calculations for this treatment are included in Appendix E.8 for all supports for which this approach is applicable. Below function writes this information to the Appendix E.8 file.

$SRSS_{RH22x}$:= WRITEPRN("Y:\PCS2\PCS Documentation\App_E\E8 Common Anchorage Combinations\RH-22x.prn" ,(S

Compression $\left(SB_{0,17}{}^{T}\right)^{\langle 6 \rangle T} = (0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27)$

MS-6 Support (1x)

MS-6 (Node 1413)

MS-6 horizontally (E/W) supports the horizontal (N/S) PCS pipe on line 1-7 just south of RH-22x.

Compression $\left(SB_{0,18}{}^{T}\right)^{\langle 6 \rangle T} = \left(7.057 \times 10^{-3} \quad -105.9 \quad 13.23 \quad 1.413 \times 10^{3} \quad 101 \quad 26\right)$

Tension $\left(SB_{0,19}{}^{T}\right)^{\langle 6 \rangle T} = \left(5.981 \times 10^{-3} \quad 89.71 \quad 4.99 \quad 1.413 \times 10^{3} \quad 101 \quad 31\right)$

MS-3 Support (1x)

MS-3 (Node 1416)

MS-3 horizontally (N/S) supports the vertical PCS pipe on line 1-7 just north of RH-33B.

Tension $\left(SB_{0,20}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.694 \quad -1.709 \times 10^{4} \quad 7.84 \quad 1.416 \times 10^{3} \quad 105 \quad 32\right)$

Compression $\left(SB_{0,21}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.651 \quad 1.604 \times 10^{4} \quad 8.51 \quad 1.416 \times 10^{3} \quad 105 \quad 20\right)$

EVALUATION OF SUPPORTS ON LINES 1-8, 1-9, 1-10, 1-11, 1-12, & 1-170 FOR ALL 32 REALIZATIONS

VSC := ReadData("\SupLine1-8_9_10_11_12_170.prn")

VSC := truncate(VSC)

SC := C_S(VSC, R)

PS-20 Support (1x)

PS-20b (Node 1105)

PS-20b vertically supports EL(1-170A) on line 1-170.

Compression $\left(SC_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(0.112 \quad -1.73\times10^{4} \quad 7.725 \quad 1.105\times10^{3} \quad 110 \quad 28\right)$

Tension $\left(SC_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \left(0.459 \quad 6.463\times10^{3} \quad 13.23 \quad 1.105\times10^{3} \quad 110 \quad 13\right)$

PS-8 Support (4x)

PS-8E (Node 829)

PS-8E vertically supports EL(1-9A) on line 1-9.

Compression $\left(SC_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \left(0.323 \quad -2.439\times10^{4} \quad 13.62 \quad 1.106\times10^{3} \quad 112 \quad 13\right)$

Tension $\left(SC_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \left(0.787 \quad 1.107\times10^{4} \quad 13.28 \quad 1.106\times10^{3} \quad 112 \quad 25\right)$

PS-8F (Node 830)

PS-8F vertically supports EL(1-10A) on line 1-10.

Compression $\left(SC_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \left(0.327 \quad -2.471\times10^{4} \quad 9.87 \quad 1.107\times10^{3} \quad 114 \quad 5\right)$

Tension $\left(SC_{0,5}{}^{T}\right)^{\langle 6\rangle T} = \left(0.739 \quad 1.039\times10^{4} \quad 10.16 \quad 1.107\times10^{3} \quad 114 \quad 25\right)$

PS-8G (Node 831)

PS-8G vertically supports EL(1-11A) on line 1-11.

Compression $\left(SC_{0,6}{}^{T}\right)^{\langle 6\rangle T} = \left(0.387 \quad -2.926\times10^{4} \quad 13.62 \quad 1.108\times10^{3} \quad 116 \quad 17\right)$

Tension $\left(SC_{0,7}{}^{T}\right)^{\langle 6\rangle T} = \left(0.838 \quad 1.179\times10^{4} \quad 13.29 \quad 1.108\times10^{3} \quad 116 \quad 4\right)$

PS-8H (Node 832)

PS-8H vertically supports EL(1-12A) on line 1-12.

Compression $\left(SC_{0,8}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.317 & -2.398\times 10^{4} & 8.405 & 1.109\times 10^{3} & 118 & 29 \end{pmatrix}$

Tension $\left(SC_{0,9}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 1.046 & 1.472\times 10^{4} & 10.21 & 1.109\times 10^{3} & 118 & 12 \end{pmatrix}$

MS-4 Supports (1x)

MS-4 North/South (Node 1418)

MS-4 vertically and laterally supports the east side of T(1-7A)

Compression $\left(SC_{0,10}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 2.094\times 10^{-3} & -31.41 & 7.395 & 1.418\times 10^{3} & 123 & 27 \end{pmatrix}$

Tension $\left(SC_{0,11}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 1.916\times 10^{-3} & 28.74 & 7.745 & 1.418\times 10^{3} & 123 & 23 \end{pmatrix}$

MS-4 Vertical (Node 1418)

MS-4 vertically and laterally supports the east side of T(1-7A)

Compression $\left(SC_{0,12}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 27 \end{pmatrix}$

Tension $\left(SC_{0,13}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.01 & 157.3 & 6.89 & 1.418\times 10^{3} & 123 & 24 \end{pmatrix}$

EVALUATION OF SUPPORTS ON LINES 1-34 AND 1-67 FOR ALL 32 REALIZATIONS

VSD := ReadData("\SupLine1-34_67.prn")

SD := C_S(VSD,R)

RH-14 Support (3x)

RH-14a (Node 1363)

RH-14a vertically supports the horizontal PCS pipe on line 1-34 traveling west from EL(1-34B).

Tension $\left(SD_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.362 & -3.745\times 10^{3} & 9.86 & 1.363\times 10^{3} & 83 & 10 \end{pmatrix}$

Compression $\left(SD_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 27 \end{pmatrix}$

RH-14b (Node 1364)

RH-14b vertically supports the horizontal PCS pipe on line 1-34 traveling west from RH-14a.

Tension $\left(SD_{0,2}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.67 \quad -6.936\times 10^{3} \quad 9.225 \quad 1.364\times 10^{3} \quad 85 \quad 28\right)$

Compression $\left(SD_{0,3}{}^{T}\right)^{\langle 6 \rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

RH-14c (Node 1365)

RH-14c vertically supports the horizontal PCS pipe on line 1-34 traveling west from RH-14b.

Tension $\left(SD_{0,4}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.421 \quad -4.363\times 10^{3} \quad 6.16 \quad 1.365\times 10^{3} \quad 81 \quad 30\right)$

Compression $\left(SD_{0,5}{}^{T}\right)^{\langle 6 \rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$

PS-20A Supports (1x)

PS-20A North/South (Node 1381)

PS-20A vertically and laterally supports the horizontal PCS pipe on line 1-34 between RH-14a and RH-14b.

Flexure $\left(SD_{0,6}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.295 \quad -822.5 \quad 9.2 \quad 1.381\times 10^{3} \quad 87 \quad 15\right)$

Flexure $\left(SD_{0,7}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.169 \quad 471.6 \quad 7.33 \quad 1.381\times 10^{3} \quad 87 \quad 2\right)$

PS-20A Vertical (Node 1388)

PS-20A vertically and laterally supports the horizontal PCS pipe on line 1-34 between RH-14a and RH-14b.

Compression $\left(SD_{0,8}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.255 \quad -2.176\times 10^{3} \quad 10.85 \quad 1.388\times 10^{3} \quad 89 \quad 26\right)$

Tension $\left(SD_{0,9}{}^{T}\right)^{\langle 6 \rangle T} = \left(1.272 \quad 7.329\times 10^{3} \quad 9.22 \quad 1.388\times 10^{3} \quad 89 \quad 28\right)$

This challenged support will be evaluated using a ductility factor approach. The supporting calculations for this treatment are included in Appendix E.7 for all supports for which this approach is applicable. Below function writes this information to the Appendix E.7 file.

$Duc_{PS20} := \text{WRITEPRN}\left(\text{"Y:\textbackslash PCS2\textbackslash PCS Documentation\textbackslash App\_E\textbackslash E7 DUCTILITY CALCS\textbackslash PS20A.prn"}, \left(SD_{0,9}{}^{T}\right)^{\langle 6 \rangle T}\right)$

PS-14 Supports (2x)

PS-14A Vertical (Node 1433)

PS-14A vertically supports the horizontal PCS pipe on line 1-34 east of REL(1-34D).

Compression $\left(SD_{0,10}{}^{T}\right)^{\langle 6\rangle T} = \left(0.088\ \ -1.944\times 10^{3}\ \ 7.285\ \ 1.433\times 10^{3}\ \ 101\ \ 32\right)$

Tension $\left(SD_{0,11}{}^{T}\right)^{\langle 6\rangle T} = \left(0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27\right)$

PS-14B Vertical (Node 1444)

PS-14B vertically supports the horizontal PCS pipe on line 1-34 west of EL(1-34E).

Compression $\left(SD_{0,12}{}^{T}\right)^{\langle 6\rangle T} = \left(0.101\ \ -2.238\times 10^{3}\ \ 7.095\ \ 1.434\times 10^{3}\ \ 103\ \ 29\right)$

Tension $\left(SD_{0,13}{}^{T}\right)^{\langle 6\rangle T} = \left(0\ \ 0\ \ 0\ \ 0\ \ 0\ \ 27\right)$

EVALUATION OF SUPPORTS ON LINES 1-39 AND 1-40 FOR ALL 32 REALIZATIONS

VSE := ReadData("\SupLine1-39_40.prn")

SE := C_S(VSE, R)

Tieback2 Support (1x)

Tieback2 East/West (Node 1445)

Tieback2 vertically and laterally supports the horizontal PCS pipe on line 1-39 at north side of EL(1-39A).

Compression $\left(SE_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(0.215\ \ -1.202\times 10^{3}\ \ 5.875\ \ 1.445\times 10^{3}\ \ 100\ \ 13\right)$

Tension $\left(SE_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \left(1.336\ \ 2.041\times 10^{3}\ \ 10.69\ \ 1.445\times 10^{3}\ \ 100\ \ 30\right)$

Refer to main body of report for discussion of this component

Tieback2 Vertical (Node 1445)

Tieback2 vertically and laterally supports the horizontal PCS pipe on line 1-34 between RH-14a and RH-14b.

Flexure $\left(SE_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \left(2.551\ \ -2.317\times 10^{3}\ \ 10.23\ \ 1.445\times 10^{3}\ \ 100\ \ 27\right)$

Flexure $\left(SE_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \left(0.051\ \ 46.64\ \ 9.76\ \ 1.445\times 10^{3}\ \ 100\ \ 12\right)$

Refer to main body of report for discussion of this component

PS-11A Support (1x)

PS-11A (Node 1369)

PS-11A vertically supports T(1-39) south of CK(1-39).

Compression $$\left(SE_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \left(0.575 \quad -1.179\times10^{4} \quad 5.295 \quad 1.369\times10^{3} \quad 79 \quad 20\right)$$

Tension $$\left(SE_{0,5}{}^{T}\right)^{\langle 6\rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$$

RH-14A Support (4x)

RH-14Aa (Node 1360)

RH-14Aa vertically supports the horizontal PCS pipe on line 1-40 traveling west from EL(1-40A).

Tension $$\left(SE_{0,6}{}^{T}\right)^{\langle 6\rangle T} = \left(0.218 \quad -1.54\times10^{3} \quad 13.65 \quad 1.288\times10^{3} \quad 97 \quad 7\right)$$

Compression $$\left(SE_{0,7}{}^{T}\right)^{\langle 6\rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$$

RH-14Ab (Node 1361)

RH-14Ab vertically supports the horizontal PCS pipe on line 1-40 traveling west from RH-14Aa.

Tension $$\left(SE_{0,8}{}^{T}\right)^{\langle 6\rangle T} = \left(0.203 \quad -1.437\times10^{3} \quad 9.025 \quad 1.291\times10^{3} \quad 95 \quad 22\right)$$

Compression $$\left(SE_{0,9}{}^{T}\right)^{\langle 6\rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$$

RH-14Ac (Node 1362)

RH-14Ac vertically supports the horizontal PCS pipe on line 1-40 traveling west from RH-14Ab.

Tension $$\left(SE_{0,10}{}^{T}\right)^{\langle 6\rangle T} = \left(0.168 \quad -1.19\times10^{3} \quad 5.775 \quad 1.297\times10^{3} \quad 93 \quad 7\right)$$

Compression $$\left(SE_{0,11}{}^{T}\right)^{\langle 6\rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$$

RH-14Ad (Node 1366)

RH-14Ad vertically supports the horizontal PCS pipe on line 1-40 traveling west from RH-14Ac.

Tension $$\left(SE_{0,12}{}^{T}\right)^{\langle 6\rangle T} = \left(0.605 \quad -4.273\times10^{3} \quad 8.735 \quad 1.302\times10^{3} \quad 91 \quad 27\right)$$

Compression $$\left(SE_{0,13}{}^{T}\right)^{\langle 6\rangle T} = \left(0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27\right)$$

RH-20G Support (1x)

See main body for further discussion of this support

RH-20G (Node 1397)

RH-20 vertically supports the horizontal PCS pipe on line 1-40 at north end of EL(1-40E).

Tension $$\left(SE_{0,14}{}^{T}\right)^{\langle 6\rangle T} = (0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27)$$

Compression $$\left(SE_{0,15}{}^{T}\right)^{\langle 6\rangle T} = \left(0.827 \quad 5.846 \times 10^{3} \quad 5.29 \quad 1.395 \times 10^{3} \quad 101 \quad 30\right)$$

PS-22 Support (North/South)

PS-22 Axial (NS) (Node 1444)

PS-22 horizontally (N/S) supports the horizontal(E/W) PCS pipe on line 1-40 just west of RH-14Ac

Compression $$\left(SE_{0,16}{}^{T}\right)^{\langle 6\rangle T} = \left(0.191 \quad -1.08 \times 10^{3} \quad 4.97 \quad 1.444 \times 10^{3} \quad 90 \quad 6\right)$$

Tension $$\left(SE_{0,17}{}^{T}\right)^{\langle 6\rangle T} = \left(0.106 \quad 1.188 \times 10^{3} \quad 10.2 \quad 1.444 \times 10^{3} \quad 90 \quad 19\right)$$

EVALUATION OF SUPPORTS ON LINES 1-41 AND 1-77 FOR ALL 32 REALIZATIONS

$$VSF := ReadData(\text{"\textbackslash SupLine1-41\_77.prn"})$$

$$SF := C\_S(VSF, R)$$

PS-10 Support (1x)

PS-10B (Node 1353)

PS-10B vertically supports line 1-42 at the south side of EL(1-42I).

Compression $$\left(SF_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(0.192 \quad -4.233 \times 10^{3} \quad 5.35 \quad 1.353 \times 10^{3} \quad 141 \quad 16\right)$$

Tension $$\left(SF_{0,1}{}^{T}\right)^{\langle 6\rangle T} = (0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 27)$$

Tieback1 Support (1x)

Tieback1 East/West (Node 1019)

Tieback1 laterally supports the vertical PCS pipe on line 1-41 at the top side of EL(1-41A).

Compression $$\left(SF_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \left(0.213 \quad -1.185 \times 10^{3} \quad 9.915 \quad 1.446 \times 10^{3} \quad 171 \quad 19\right)$$

Tension $$\left(SF_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \left(0.747 \quad 1.141 \times 10^{3} \quad 5.125 \quad 1.446 \times 10^{3} \quad 171 \quad 2\right)$$

Tieback1 North/South (Node 1019)

Tieback1 laterally supports the vertical PCS pipe on line 1-41 at the top side of EL(1-41A).

Lateral $$\left(SF_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 3.05 & -2.77\times 10^{3} & 4.905 & 1.446\times 10^{3} & 171 & 26 \end{pmatrix}$$

Lateral $$\left(SF_{0,5}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 2.537 & 2.304\times 10^{3} & 7.795 & 1.446\times 10^{3} & 171 & 13 \end{pmatrix}$$

Refer to main body of report for discussion of this component

PS-7 Support (1x)

PS-7 North/South (Node 1355)

PS-7 supports line 1-41 at the eastern portion of P(1-41G) from movement in the vertical and east/west directions.

Tension $$\left(SF_{0,6}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.184 & -1.231\times 10^{3} & 1.01 & 1.355\times 10^{3} & 143 & 1 \end{pmatrix}$$

Compression $$\left(SF_{0,7}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.5 & 1.685\times 10^{3} & 1.165 & 1.355\times 10^{3} & 143 & 16 \end{pmatrix}$$

PS-7 Vertical (Node 1355)

PS-7 supports line 1-41 at the eastern portion of P(1-41G) from movement in the vertical and east/west directions.

Flexure $$\left(SF_{0,8}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 1.115 & -2.454\times 10^{3} & 1 & 1.355\times 10^{3} & 143 & 27 \end{pmatrix}$$

Flexure $$\left(SF_{0,9}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.802 & 1.764\times 10^{3} & 1.005 & 1.355\times 10^{3} & 143 & 27 \end{pmatrix}$$

The gang support and anchorage insufficiency aspects of the PS-7 support are to be evaluated in Appendix E.9.

PS7_N := WRITEPRN("Y:\PCS2\PCS Documentation\App_E\E9 PS-7\PS7_N_M4.prn" , $SF_{0,6}$)

PS7_S := WRITEPRN("Y:\PCS2\PCS Documentation\App_E\E9 PS-7\PS7_S_M4.prn" , $SF_{0,7}$)

PS7_D := WRITEPRN("Y:\PCS2\PCS Documentation\App_E\E9 PS-7\PS7_D_M4.prn" , $SF_{0,8}$)

PS7_U := WRITEPRN("Y:\PCS2\PCS Documentation\App_E\E9 PS-7\PS7_U_M4.prn" , $SF_{0,9}$)

RH-16 Support (1x)

RH-16C (Node 1356)

RH-16C vertically supports line 1-41 just east of EL(1-41F) from any downward movement.

Tension $$\left(SF_{0,10}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 1.986\times 10^{-3} & -2.079 & 1.015 & 1.356\times 10^{3} & 145 & 27 \end{pmatrix}$$

Compression $$\left(SF_{0,11}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.012 & 4.89 & 1.025 & 1.356\times 10^{3} & 145 & 9 \end{pmatrix}$$

PS-11B Support (1x)

PS-11B (Node 1368)

PS-11B vertically supports line 1-77 just south of REL(1-77A).

Compression $$\left(SF_{0,12}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.199 & -4.083\times 10^{3} & 5.415 & 1.368\times 10^{3} & 147 & 29 \end{pmatrix}$$

Tension $$\left(SF_{0,13}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 27 \end{pmatrix}$$

Wall Triangle Support (1x)

Wall Triangle Support (Node 1407)

Wall Triangle Support vertically supports line 1-77 just north of EL(1-77B) from any downward movement.

Tension $$\left(SF_{0,14}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 2.886 & -1.703\times 10^{3} & 4.93 & 1.407\times 10^{3} & 149 & 30 \end{pmatrix}$$

Capacity values of support anchorage associated with this support are still pending

Compression $$\left(SF_{0,15}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 27 \end{pmatrix}$$

RH-27 Support (1x)

RH-27A (Node 1285)

RH-27A vertically supports line 1-77 just north of EL(1-77D) from any downward movement.

Tension $$\left(SF_{0,16}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.313 & -2.211\times 10^{3} & 10.3 & 1.285\times 10^{3} & 173 & 28 \end{pmatrix}$$

Compression $$\left(SF_{0,17}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 27 \end{pmatrix}$$

RH-27B (Node 1284)

RH-27B vertically supports line 1-77 just south of EL(1-77E) from any downward movement.

Tension $$\left(SF_{0,18}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.279 & -1.973\times 10^{3} & 10.55 & 1.284\times 10^{3} & 175 & 17 \end{pmatrix}$$

Compression $$\left(SF_{0,19}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 27 \end{pmatrix}$$

EVALUATION OF SUPPORTS ON LINE 1-42 FOR ALL 32 REALIZATIONS

$VSG := ReadData(\text{"\textbackslash SupLine1\_42.prn"})$

$SG := C\_S(VSG, R)$

RH-35 Support (1x)

RH-35a (Node 1358)

RH-35a vertically supports the horizontal PCS pipe on line 1-42 traveling west from RH-34).

Tension $$\left(SG_{0,0}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0.278 & -1.037 \times 10^{3} & 5.885 & 1.311 \times 10^{3} & 96 & 29 \end{pmatrix}$$

Compression $$\left(SG_{0,1}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 27 \end{pmatrix}$$

RH-35b (Node 1359)

RH-35b vertically supports the horizontal PCS pipe on line 1-42 traveling west from NN2).

Tension $$\left(SG_{0,2}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0.31 & -1.155 \times 10^{3} & 5.77 & 1.313 \times 10^{3} & 98 & 13 \end{pmatrix}$$

Compression $$\left(SG_{0,3}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 27 \end{pmatrix}$$

RH-33A Support (1x)

RH-33A (Node 1343)

RH-33A vertically supports the horizontal PCS pipe on line 1-42 traveling north from EL(1-42A).

Tension $$\left(SG_{0,4}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0.21 & -862.9 & 5.565 & 1.343 \times 10^{3} & 90 & 22 \end{pmatrix}$$

Compression $$\left(SG_{0,5}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 27 \end{pmatrix}$$

RH-33B Support (1x)

RH-33B (Node 1344)

RH-33B vertically supports the horizontal PCS pipe on line 1-42 traveling north from RH-33B.

Tension $$\left(SG_{0,6}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0.406 & -1.411 \times 10^{3} & 8.395 & 1.344 \times 10^{3} & 92 & 2 \end{pmatrix}$$

Compression $$\left(SG_{0,7}{}^{T}\right)^{\langle 6 \rangle T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 27 \end{pmatrix}$$

Horizontal Support (1x)

Horizontal Support (Node 1391)

The horizontal support horizontally (E/W) supports the horizontal (N/S) PCS pipe on line 1-7 just south of RH-22x.

Tension $\left(SG_{0,8}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.211 & -1.762\times 10^{3} & 9.24 & 1.391\times 10^{3} & 83 & 17 \end{pmatrix}$

Compression $\left(SG_{0,9}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.221 & 1.873\times 10^{3} & 5.45 & 1.391\times 10^{3} & 83 & 25 \end{pmatrix}$

PS-23 Support (1x)

PS-23 (Node 1345)

PS-23 vertically supports line 1-42 west of EL(1-42B).

Compression $\left(SG_{0,10}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.073 & -1.233\times 10^{3} & 8.4 & 1.345\times 10^{3} & 82 & 15 \end{pmatrix}$

Tension $\left(SG_{0,11}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 27 \end{pmatrix}$

NN Supports (2x)

NN2 North/South (Node 1346)

NN2 vertically and laterally supports the horizontal PCS pipe on line 1-42 between PS-23 and RH-34.

Compression $\left(SG_{0,12}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.051 & -579 & 5.96 & 1.346\times 10^{3} & 70 & 3 \end{pmatrix}$

Tension $\left(SG_{0,13}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.013 & 466.2 & 7.135 & 1.346\times 10^{3} & 70 & 16 \end{pmatrix}$

NN3 North/South (Node 1347)

NN3 vertically and laterally supports the horizontal PCS pipe on line 1-42 between PS-23 and RH-34.

Compression $\left(SG_{0,14}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.047 & -529.9 & 5.725 & 1.347\times 10^{3} & 72 & 11 \end{pmatrix}$

Tension $\left(SG_{0,15}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.019 & 678.6 & 5.855 & 1.347\times 10^{3} & 72 & 30 \end{pmatrix}$

PS-19 Supports (2x)

PS-19 North/South (Node 1348)

PS-19 vertically and laterally supports the horizontal PCS pipe on line 1-42 between PS-23 and RH-34.

Compression $\left(SG_{0,16}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.129 & -1.455\times 10^{3} & 6.925 & 1.348\times 10^{3} & 74 & 27 \end{pmatrix}$

Tension $\left(SG_{0,17}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.015 & 1.446\times 10^{3} & 6.755 & 1.348\times 10^{3} & 74 & 23 \end{pmatrix}$

PS-19 Vertical (Node 1348)

PS-19 vertically and laterally supports the horizontal PCS pipe on line 1-42 between PS-23 and RH-34.

Flexure $$\left(SG_{0,18}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 2.128 & -1.162\times 10^{3} & 9.855 & 1.348\times 10^{3} & 74 & 10 \end{pmatrix}$$

Refer to main body of report for discussion of this component

Flexure $$\left(SG_{0,19}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 27 \end{pmatrix}$$

RH-12 Support (1x)

RH-12 (Node 1349)

RH-12 vertically supports the horizontal PCS pipe on line 1-42 at the south side of EL(1-42E).

Tension $$\left(SG_{0,20}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.526 & -2.091\times 10^{3} & 5.655 & 1.349\times 10^{3} & 100 & 10 \end{pmatrix}$$

Compression $$\left(SG_{0,21}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 27 \end{pmatrix}$$

RH-20 Support (1x)

RH-20 (Node 1350)

RH-20 vertically supports the horizontal PCS pipe on line 1-42 at the north side of EL(1-42F).

Tension $$\left(SG_{0,22}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.263 & -2.727\times 10^{3} & 5.905 & 1.35\times 10^{3} & 76 & 7 \end{pmatrix}$$

Compression $$\left(SG_{0,23}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 27 \end{pmatrix}$$

PS-10 Support (1x)

PS-10A (Node 1354)

PS-10A vertically supports line 1-42 at the north side of EL(1-42H).

Compression $$\left(SG_{0,24}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.705 & -1.558\times 10^{4} & 5.865 & 1.354\times 10^{3} & 80 & 6 \end{pmatrix}$$

Tension $$\left(SG_{0,25}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 27 \end{pmatrix}$$

RH-34 Support (1x)

RH-34 (Node 1357)

RH-34 vertically supports the horizontal PCS pipe on line 1-42 traveling west from NN-2).

Tension $$\left(SG_{0,26}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.105 & -742.3 & 5.28 & 1.253\times 10^{3} & 94 & 14 \end{pmatrix}$$

Compression $$\left(SG_{0,27}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 27 \end{pmatrix}$$

TERMINATIONS

Termination output is ordered as (max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, indicie of element(s), moments about the x, y, and z axes, and realization number)

EVALUATION OF TERMINATIONS ON LINES 1-1L, 1-2L, 1-3L, & 1-4L FOR ALL 32 REALIZATIONS

VTA := ReadData("\TermLine1-1_2_3_4.prn")

TA := C_S(VTA, R)

Reactor Vessel (4x)

Reactor Vessel 1-1L (Node 549)

$$\left(TA_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(0.545 \quad 1.219\times10^{6} \quad 7.405 \quad 549 \quad 69 \quad 1.217\times10^{6} \quad 6.655\times10^{4} \quad 4.054\times10^{4} \quad 7\right)$$

Reactor Vessel 1-2L (Node 548)

$$\left(TA_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \left(0.415 \quad 8.791\times10^{5} \quad 7.39 \quad 548 \quad 71 \quad 8.392\times10^{5} \quad 2.303\times10^{5} \quad 1.244\times10^{5} \quad 1\right)$$

Reactor Vessel 1-3L (Node 547)

$$\left(TA_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \left(0.371 \quad 7.635\times10^{5} \quad 6.665 \quad 547 \quad 75 \quad -6.834\times10^{5} \quad -3.21\times10^{5} \quad 1.138\times10^{5} \quad 26\right)$$

Reactor Vessel 1-4L (Node 546)

$$\left(TA_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \left(0.612 \quad 1.395\times10^{6} \quad 7.405 \quad 546 \quad 73 \quad -1.389\times10^{6} \quad -1.03\times10^{5} \quad 6.277\times10^{4} \quad 9\right)$$

THERE ARE NOT ANY TERMINATIONS ARE NOT PRESENT ON LINES 1-5, 1-6, & 1-7

EVALUATION OF TERMINATIONS ON LINES 1-8, 1-9, 1-10, 1-11, 1-12, & 1-170 FOR ALL 32 REALIZATIONS

VTC := ReadData("\TermLine1-8_9_10_11_12_170.prn")

TC := C_S(VTC, R)

Heat Exchanger Outlet (5x)

Heat Exchanger 1-9 (Node 610)

$$\left(TC_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(0.203 \quad 5.336\times10^{5} \quad 9.87 \quad 610 \quad 35 \quad 1.363\times10^{5} \quad 1.961\times10^{5} \quad 4.772\times10^{5} \quad 5\right)$$

Heat Exchanger 1-10 (Node 607)

$$\left(TC_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \left(0.207 \quad 5.544\times10^{5} \quad 13.6 \quad 607 \quad 37 \quad -3.022\times10^{5} \quad -1.21\times10^{5} \quad 4.488\times10^{5} \quad 11\right)$$

Heat Exchanger 1-11 (Node 613)

$$\left(TC_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \left(0.206 \quad 5.485\times10^{5} \quad 9.865 \quad 613 \quad 39 \quad 2.101\times10^{5} \quad 1.827\times10^{5} \quad 4.726\times10^{5} \quad 25\right)$$

Heat Exchanger 1-12 (Node 604)

$$\left(TC_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \left(0.232 \quad 6.636\times10^{5} \quad 13.6 \quad 604 \quad 41 \quad -3.931\times10^{5} \quad -8.767\times10^{4} \quad 5.274\times10^{5} \quad 25\right)$$

Heat Exchanger 1-170 (Node 619)

$$\left(TC_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \left(0.192 \quad 4.865\times10^{5} \quad 9.235 \quad 619 \quad 47 \quad 4.456\times10^{5} \quad 8.379\times10^{4} \quad 1.764\times10^{5} \quad 30\right)$$

EVALUATION OF TERMINATIONS ON LINES 1-34 AND 1-67 FOR ALL 32 REALIZATIONS

VTD := ReadData("\TermLine1-34_67.prn")

TD := C_S(VTD,R)

Primary Degassing Tank (1x)

Primary Degassing Tank 1-67 (Node 974)

$$\left(TD_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(0.174 \quad 2.503\times10^{4} \quad 8.415 \quad 974 \quad 44 \quad -4.886\times10^{3} \quad -2.451\times10^{4} \quad 1.381\times10^{3} \quad 27\right)$$

THERE ARE NOT ANY TERMINATIONS ARE NOT PRESENT ON LINES 1-5, 1-6, & 1-7

EVALUATION OF TERMINATIONS ON LINES 1-41 AND 1-77 FOR ALL 32 REALIZATIONS

VTF := ReadData("\TermLine1-41_77.prn")

TF := C_S(VTF,R)

North Floor Pentration (2x)

North Floor Penetration 1-37 (Node 1222)

$$\left(TF_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(1.253 \quad 3.901\times10^{4} \quad 4.945 \quad 1.222\times10^{3} \quad 120 \quad -1.984\times10^{4} \quad -1.3\times10^{4} \quad 3.097\times10^{4} \quad 1\right.$$

Refer to main body of report for discussion of this component

North Floor Penetration 1-38 (Node 1223)

$$\left(TF_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \left(1.151 \quad 3.579\times10^{4} \quad 4.94 \quad 1.223\times10^{3} \quad 116 \quad -6.784\times10^{3} \quad -1.66\times10^{4} \quad 3.097\times10^{4} \quad 4\right.$$

Refer to main body of report for discussion of this component

West Floor Pentration (1x)

West Floor Penetration 1-41 (Node 1148)

$$\left(TF_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.275 & 1.134\times 10^{5} & 1.5 & 1.148\times 10^{3} & 21 & 302.4 & -595 & 1.134\times 10^{5} & 13 \end{pmatrix}$$

THERE ARE NOT ANY TERMINATIONS ARE NOT PRESENT ON LINE 1-42

PIPE RUNS

Termination output is ordered as (max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, indicies of element(s), moments about the x, y, and z axes, and realization number)

EVALUATION OF PIPE RUNS ON LINES 1-1, 1-2, 1-3, AND 1-4 FOR ALL 32 REALIZATIONS

$VPRA := ReadData("\backslash PRLine1\text{-}1\_2\_3\_4.prn")$

$PRA := C\_S(VPRA, R)$

$PRA_{80TH} := PR_{80th}(PRA)$

Pipe Properties for Lines 1-1L, 2L, 3L, & 4L

Pipe Run 1-1LA (Elements 380, 792, & 79)

$$PRA_{80TH_{0,0}} = \begin{pmatrix} 0.183 & 3.01\times 10^{5} & 9.91 & 380 & 571 & 93 & 11 \\ 0.19 & 3.244\times 10^{5} & 9.91 & 380 & 1.042\times 10^{3} & 94 & 11 \\ 0.183 & 2.998\times 10^{5} & 9.91 & 792 & 568 & 155 & 11 \\ 0.183 & 3.01\times 10^{5} & 9.91 & 792 & 571 & 156 & 11 \\ 0.183 & 2.999\times 10^{5} & 9.91 & 79 & 568 & 17 & 11 \\ 0.149 & 1.919\times 10^{5} & 7.385 & 79 & 649 & 18 & 26 \end{pmatrix}$$

Pipe Run 1-1LB (Elements 78)

$$PRA_{80TH_{0,1}} = \begin{pmatrix} 0.125 & 1.159\times 10^{5} & 7.13 & 78 & 637 & 15 & 17 \\ 0.133 & 1.409\times 10^{5} & 7.385 & 78 & 648 & 16 & 12 \end{pmatrix}$$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

Pipe Run 1-1LC (Elements 71, 653, 664, 893, 892, 891, 890, 276, 885, 884, & 272)

$PRA80TH_{0,2} =$

	0	1	2	3	4	5	6
0	0.199	$3.528 \cdot 10^5$	7.04	71	558	7	10
1	0.118	$9.54 \cdot 10^4$	9.915	71	636	8	1
2	0.2	$3.555 \cdot 10^5$	7.04	653	554	119	10
3	0.199	$3.529 \cdot 10^5$	7.04	653	558	120	10
4	0.2	$3.555 \cdot 10^5$	7.04	664	554	141	10
5	0.207	$3.787 \cdot 10^5$	7.04	664	$1.319 \cdot 10^3$	142	10
6	0.207	$3.785 \cdot 10^5$	7.04	893	$1.319 \cdot 10^3$	191	10
7	0.203	$3.661 \cdot 10^5$	7.03	893	$1.467 \cdot 10^3$	192	5
8	0.197	$3.46 \cdot 10^5$	7.13	892	$1.466 \cdot 10^3$	189	9
9	0.203	$3.662 \cdot 10^5$	7.03	892	$1.467 \cdot 10^3$	190	5
10	0.192	$3.297 \cdot 10^5$	7.375	891	$1.465 \cdot 10^3$	187	22
11	0.197	$3.46 \cdot 10^5$	7.13	891	$1.466 \cdot 10^3$	188	9
12	0.185	$3.066 \cdot 10^5$	7.14	890	$1.464 \cdot 10^3$	185	5
13	0.192	$3.298 \cdot 10^5$	7.375	890	$1.465 \cdot 10^3$	186	22
14	0.169	$2.571 \cdot 10^5$	7.145	276	902	81	30
15	0.185	$3.066 \cdot 10^5$	7.14	276	$1.464 \cdot 10^3$	82	5
16	0.17	$2.588 \cdot 10^5$	7.145	885	902	175	30
17	0.155	$2.119 \cdot 10^5$	6.89	885	$1.459 \cdot 10^3$	176	26
18	0.144	$1.78 \cdot 10^5$	7.4	884	$1.458 \cdot 10^3$	173	11
19	0.155	$2.118 \cdot 10^5$	6.89	884	$1.459 \cdot 10^3$	174	26
20	0.145	$1.82 \cdot 10^5$	9.91	272	632	79	7
21	0.144	$1.779 \cdot 10^5$	7.4	272	$1.458 \cdot 10^3$	80	11

Pipe Run 1-1LD (Elements 62 & 878)

$$PRA80TH_{0,3} = \begin{pmatrix} 0.411 & 1.023 \times 10^6 & 7.405 & 62 & 625 & 1 & 7 \\ 0.266 & 5.651 \times 10^5 & 7.4 & 62 & 1.452 \times 10^3 & 2 & 23 \\ 0.142 & 1.714 \times 10^5 & 6.67 & 878 & 631 & 161 & 27 \\ 0.266 & 5.65 \times 10^5 & 7.4 & 878 & 1.452 \times 10^3 & 162 & 23 \end{pmatrix}$$

Pipe Run 1-2LA (Elements 386)

$$PRA80TH_{0,4} = \begin{pmatrix} 0.125 & 1.179 \times 10^5 & 7.615 & 386 & 655 & 105 & 1 \\ 0.12 & 1.015 \times 10^5 & 7.455 & 386 & 1.05 \times 10^3 & 106 & 27 \end{pmatrix}$$

Pipe Run 1-2LB (Elements 82, 791, 291, & 72)

$$PRA80TH_{0,5} = \begin{pmatrix} 0.133 & 1.429\times10^{5} & 7.395 & 82 & 579 & 23 & 10 \\ 0.135 & 1.501\times10^{5} & 7.62 & 82 & 652 & 24 & 17 \\ 0.133 & 1.426\times10^{5} & 7.395 & 791 & 576 & 153 & 10 \\ 0.133 & 1.429\times10^{5} & 7.395 & 791 & 579 & 154 & 10 \\ 0.133 & 1.426\times10^{5} & 7.395 & 291 & 576 & 89 & 10 \\ 0.141 & 1.674\times10^{5} & 7.49 & 291 & 921 & 90 & 17 \\ 0.13 & 1.325\times10^{5} & 7.485 & 72 & 642 & 9 & 25 \\ 0.141 & 1.674\times10^{5} & 7.49 & 72 & 921 & 10 & 17 \end{pmatrix}$$

Pipe Run 1-2LC (Elements 289, 657, 70, 654, 897, 896, 895, 894, 662, 883, 882, & 266

$PRA80TH_{0,6} =$

	0	1	2	3	4	5	6
0	0.118	$9.556\cdot10^{4}$	9.905	289	641	87	7
1	0.14	$1.659\cdot10^{5}$	7.035	289	919	88	27
2	0.14	$1.66\cdot10^{5}$	7.035	657	919	127	27
3	0.17	$2.599\cdot10^{5}$	7.035	657	$1.314\cdot10^{3}$	128	27
4	0.169	$2.577\cdot10^{5}$	9.175	70	559	5	24
5	0.17	$2.6\cdot10^{5}$	7.035	70	$1.314\cdot10^{3}$	6	26
6	0.169	$2.571\cdot10^{5}$	9.175	654	555	121	24
7	0.169	$2.577\cdot10^{5}$	9.175	654	559	122	24
8	0.169	$2.571\cdot10^{5}$	9.175	897	555	199	24
9	0.186	$3.092\cdot10^{5}$	7.49	897	$1.471\cdot10^{3}$	200	27
10	0.199	$3.529\cdot10^{5}$	7.49	896	$1.47\cdot10^{3}$	197	27
11	0.186	$3.093\cdot10^{5}$	7.49	896	$1.471\cdot10^{3}$	198	27
12	0.202	$3.601\cdot10^{5}$	7.495	895	$1.469\cdot10^{3}$	195	27
13	0.199	$3.53\cdot10^{5}$	7.49	895	$1.47\cdot10^{3}$	196	27
14	0.192	$3.288\cdot10^{5}$	7.495	894	$1.468\cdot10^{3}$	193	27
15	0.202	$3.601\cdot10^{5}$	7.495	894	$1.469\cdot10^{3}$	194	27
16	0.171	$2.614\cdot10^{5}$	7.495	662	912	137	12
17	0.192	$3.287\cdot10^{5}$	7.495	662	$1.468\cdot10^{3}$	138	27
18	0.17	$2.609\cdot10^{5}$	7.495	883	912	171	12
19	0.149	$1.942\cdot10^{5}$	7.38	883	$1.457\cdot10^{3}$	172	25
20	0.131	$1.357\cdot10^{5}$	7.38	882	$1.456\cdot10^{3}$	169	26
21	0.149	$1.941\cdot10^{5}$	7.38	882	$1.457\cdot10^{3}$	170	25
22	0.131	$1.356\cdot10^{5}$	6.68	266	633	77	27
23	0.131	$1.355\cdot10^{5}$	7.38	266	$1.456\cdot10^{3}$	78	26

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Pipe Run 1-2LD (Elements 63 & 879)

$$PRA80TH_{0,7} = \begin{pmatrix} 0.321 & 7.385\times10^{5} & 7.39 & 63 & 624 & 3 & 1 \\ 0.219 & 4.166\times10^{5} & 7.39 & 63 & 1.453\times10^{3} & 4 & 11 \\ 0.141 & 1.691\times10^{5} & 6.675 & 879 & 630 & 163 & 4 \\ 0.219 & 4.165\times10^{5} & 7.39 & 879 & 1.453\times10^{3} & 164 & 11 \end{pmatrix}$$

Pipe Run 1-3LA (Elements 388)

$$PRA80TH_{0,8} = \begin{pmatrix} 0.127 & 1.228\times10^{5} & 7.4 & 388 & 656 & 107 & 3 \\ 0.123 & 1.102\times10^{5} & 9.885 & 388 & 1.051\times10^{3} & 108 & 31 \end{pmatrix}$$

Pipe Run 1-3LB (Elements 83, 793, 292, & 75)

$$PRA80TH_{0,9} = \begin{pmatrix} 0.135 & 1.482\times10^{5} & 7.385 & 83 & 578 & 25 & 26 \\ 0.138 & 1.575\times10^{5} & 7.375 & 83 & 653 & 26 & 28 \\ 0.135 & 1.478\times10^{5} & 7.385 & 793 & 577 & 157 & 26 \\ 0.135 & 1.482\times10^{5} & 7.385 & 793 & 578 & 158 & 26 \\ 0.135 & 1.477\times10^{5} & 7.385 & 292 & 577 & 91 & 26 \\ 0.133 & 1.419\times10^{5} & 7.49 & 292 & 922 & 92 & 12 \\ 0.124 & 1.13\times10^{5} & 7.495 & 75 & 643 & 13 & 25 \\ 0.133 & 1.418\times10^{5} & 7.49 & 75 & 922 & 14 & 12 \end{pmatrix}$$

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Pipe Run 1-3LC (Elements 661, 660, 73, 656, 901, 900, 899, 898, 663, 887, 886, & 27

$PRA80TH_{0,10} =$

	0	1	2	3	4	5	6
0	0.114	$8.057\cdot10^{4}$	9.51	661	640	135	17
1	0.135	$1.497\cdot10^{5}$	7.245	661	$1.316\cdot10^{3}$	136	9
2	0.163	$2.38\cdot10^{5}$	7.245	660	$1.315\cdot10^{3}$	133	10
3	0.135	$1.497\cdot10^{5}$	7.245	660	$1.316\cdot10^{3}$	134	9
4	0.163	$2.372\cdot10^{5}$	7.245	73	560	11	10
5	0.163	$2.381\cdot10^{5}$	7.245	73	$1.315\cdot10^{3}$	12	10
6	0.163	$2.371\cdot10^{5}$	7.245	656	556	125	10
7	0.163	$2.372\cdot10^{5}$	7.245	656	560	126	10
8	0.163	$2.372\cdot10^{5}$	7.245	901	556	207	10
9	0.172	$2.679\cdot10^{5}$	7.38	901	$1.475\cdot10^{3}$	208	1
10	0.185	$3.071\cdot10^{5}$	7.495	900	$1.474\cdot10^{3}$	205	12
11	0.172	$2.679\cdot10^{5}$	7.38	900	$1.475\cdot10^{3}$	206	1
12	0.189	$3.195\cdot10^{5}$	7.495	899	$1.473\cdot10^{3}$	203	27
13	0.185	$3.072\cdot10^{5}$	7.495	899	$1.474\cdot10^{3}$	204	12
14	0.182	$2.969\cdot10^{5}$	7.495	898	$1.472\cdot10^{3}$	201	27
15	0.189	$3.196\cdot10^{5}$	7.495	898	$1.473\cdot10^{3}$	202	27
16	0.164	$2.392\cdot10^{5}$	7.495	663	892	139	27
17	0.182	$2.968\cdot10^{5}$	7.495	663	$1.472\cdot10^{3}$	140	27
18	0.164	$2.391\cdot10^{5}$	7.495	887	892	179	27
19	0.14	$1.654\cdot10^{5}$	6.66	887	$1.461\cdot10^{3}$	180	23
20	0.123	$1.095\cdot10^{5}$	7.39	886	$1.46\cdot10^{3}$	177	12
21	0.14	$1.653\cdot10^{5}$	6.66	886	$1.461\cdot10^{3}$	178	23
22	0.126	$1.207\cdot10^{5}$	8.485	278	634	83	4
23	0.123	$1.093\cdot10^{5}$	7.39	278	$1.46\cdot10^{3}$	84	12

Pipe Run 1-3LD (Elements 255 & 880)

$$PRA80TH_{0,11} = \begin{pmatrix} 0.289 & 6.374\times10^{5} & 6.665 & 255 & 626 & 57 & 26 \\ 0.2 & 3.546\times10^{5} & 7.39 & 255 & 1.454\times10^{3} & 58 & 9 \\ 0.135 & 1.482\times10^{5} & 7.385 & 880 & 628 & 165 & 12 \\ 0.2 & 3.545\times10^{5} & 7.39 & 880 & 1.454\times10^{3} & 166 & 9 \end{pmatrix}$$

Pipe Run 1-4LA (Elements 381, 794, & 81)

$$PRA80TH_{0,12} = \begin{pmatrix} 0.19 & 3.228\times10^{5} & 9.52 & 381 & 570 & 95 & 2 \\ 0.195 & 3.396\times10^{5} & 7.85 & 381 & 1.043\times10^{3} & 96 & 28 \\ 0.19 & 3.217\times10^{5} & 9.52 & 794 & 569 & 159 & 2 \\ 0.19 & 3.228\times10^{5} & 9.52 & 794 & 570 & 160 & 2 \\ 0.19 & 3.217\times10^{5} & 9.52 & 81 & 569 & 21 & 2 \\ 0.154 & 2.089\times10^{5} & 7.385 & 81 & 651 & 22 & 9 \end{pmatrix}$$

Pipe Run 1-4LB (Elements 80)

$$PRA80TH_{0,13} = \begin{pmatrix} 0.123 & 1.122\times 10^{5} & 7.375 & 80 & 639 & 19 & 9 \\ 0.138 & 1.572\times 10^{5} & 7.385 & 80 & 650 & 20 & 9 \end{pmatrix}$$

Pipe Run 1-4LC (Elements 658, 655, 659, 665, 902, 903, 904, 905, 889, 888, & 284)

$PRA80TH_{0,14} =$

	0	1	2	3	4	5	6
0	0.193	$3.318\cdot 10^{5}$	7.255	658	561	129	28
1	0.119	$9.668\cdot 10^{4}$	9.52	658	638	130	12
2	0.193	$3.341\cdot 10^{5}$	7.255	655	557	123	28
3	0.193	$3.319\cdot 10^{5}$	7.255	655	561	124	28
4	0.193	$3.341\cdot 10^{5}$	7.255	659	557	131	28
5	0.2	$3.547\cdot 10^{5}$	7.255	659	$1.32\cdot 10^{3}$	132	28
6	0.2	$3.545\cdot 10^{5}$	7.255	665	$1.32\cdot 10^{3}$	143	28
7	0.192	$3.303\cdot 10^{5}$	7.145	665	$1.476\cdot 10^{3}$	144	25
8	0.192	$3.304\cdot 10^{5}$	7.145	902	$1.476\cdot 10^{3}$	209	25
9	0.191	$3.271\cdot 10^{5}$	7.135	902	$1.477\cdot 10^{3}$	210	12
10	0.191	$3.271\cdot 10^{5}$	7.135	903	$1.477\cdot 10^{3}$	211	12
11	0.189	$3.196\cdot 10^{5}$	7.38	903	$1.478\cdot 10^{3}$	212	22
12	0.189	$3.196\cdot 10^{5}$	7.38	904	$1.478\cdot 10^{3}$	213	22
13	0.186	$3.114\cdot 10^{5}$	7.13	904	$1.479\cdot 10^{3}$	214	10
14	0.177	$2.821\cdot 10^{5}$	7.38	905	882	215	15
15	0.186	$3.114\cdot 10^{5}$	7.13	905	$1.479\cdot 10^{3}$	216	10
16	0.177	$2.815\cdot 10^{5}$	7.38	889	882	183	15
17	0.167	$2.491\cdot 10^{5}$	7.39	889	$1.463\cdot 10^{3}$	184	25
18	0.156	$2.148\cdot 10^{5}$	7.4	888	$1.462\cdot 10^{3}$	181	3
19	0.167	$2.491\cdot 10^{5}$	7.39	888	$1.463\cdot 10^{3}$	182	25
20	0.152	$2.033\cdot 10^{5}$	7.405	284	635	85	12
21	0.156	$2.148\cdot 10^{5}$	7.4	284	$1.462\cdot 10^{3}$	86	3

Pipe Run 1-4LD (Elements 256 & 881)

$$PRA80TH_{0,15} = \begin{pmatrix} 0.457 & 1.172\times 10^{6} & 7.405 & 256 & 627 & 59 & 9 \\ 0.293 & 6.517\times 10^{5} & 7.395 & 256 & 1.455\times 10^{3} & 60 & 1 \\ 0.143 & 1.743\times 10^{5} & 7.385 & 881 & 629 & 167 & 26 \\ 0.293 & 6.516\times 10^{5} & 7.395 & 881 & 1.455\times 10^{3} & 168 & 1 \end{pmatrix}$$

EVALUATION OF PIPE RUNS ON LINES 1-5, 1-6, & 1-7 FOR ALL 32 REALIZATIONS

VPRB := ReadData("\PRLine1_5_6_7.prn")

PRB := C_S(VPRB, R)

$PRB_{80TH} := PR_{80th}(PRB)$

Pipe Properties for Lines 1-5 & 1-6

Pipe Run 1-5A (Element 132 & 295)

$$PRB80TH_{0,0} = \begin{pmatrix} 0.145 & 4.776\times10^{5} & 8.825 & 132 & 646 & 35 & 19 \\ 0.181 & 7.534\times10^{5} & 7.135 & 132 & 925 & 36 & 12 \\ 0.233 & 1.151\times10^{6} & 6.65 & 295 & 39 & 56 & 22 \\ 0.181 & 7.535\times10^{5} & 7.135 & 295 & 925 & 57 & 12 \end{pmatrix}$$

Pipe Run 1-6A (Element 133 & 296)

$$PRB80TH_{0,1} = \begin{pmatrix} 0.148 & 4.995\times10^{5} & 9.88 & 133 & 647 & 37 & 27 \\ 0.203 & 9.174\times10^{5} & 7.03 & 133 & 926 & 38 & 27 \\ 0.246 & 1.251\times10^{6} & 7.03 & 296 & 15 & 58 & 21 \\ 0.203 & 9.175\times10^{5} & 7.03 & 296 & 926 & 59 & 27 \end{pmatrix}$$

Pipe Run 1-5B (Element 130 & 906)

$$PRB80TH_{0,2} = \begin{pmatrix} 0.156 & 5.598\times10^{5} & 9.9 & 130 & 748 & 31 & 11 \\ 0.152 & 5.26\times10^{5} & 9.89 & 130 & 1.48\times10^{3} & 32 & 11 \\ 0.147 & 4.861\times10^{5} & 9.885 & 906 & 645 & 112 & 12 \\ 0.152 & 5.26\times10^{5} & 9.89 & 906 & 1.48\times10^{3} & 113 & 11 \end{pmatrix}$$

Pipe Run 1-6B (Element 131 & 907)

$$PRB80TH_{0,3} = \begin{pmatrix} 0.15 & 5.132\times10^{5} & 9.515 & 131 & 747 & 33 & 27 \\ 0.144 & 4.677\times10^{5} & 9.52 & 131 & 1.481\times10^{3} & 34 & 13 \\ 0.15 & 5.135\times10^{5} & 8.845 & 907 & 644 & 114 & 29 \\ 0.144 & 4.675\times10^{5} & 9.52 & 907 & 1.481\times10^{3} & 115 & 13 \end{pmatrix}$$

Pipe Properties for Lines 1-7

Pipe Run 1-7A (Elements 88, 922, 921, 315, 920, 919, & 87)

$PRB80TH_{0,4} =$

	0	1	2	3	4	5	6
0	0.134	$8.788 \cdot 10^5$	7.675	88	588	23	27
1	0.132	$8.463 \cdot 10^5$	7.675	88	590	24	25
2	0.135	$9.03 \cdot 10^5$	7.725	922	588	144	6
3	0.14	$1.024 \cdot 10^6$	7.66	922	$1.496 \cdot 10^3$	145	7
4	0.145	$1.124 \cdot 10^6$	7.095	921	$1.495 \cdot 10^3$	142	24
5	0.14	$1.025 \cdot 10^6$	7.66	921	$1.496 \cdot 10^3$	143	7
6	0.142	$1.055 \cdot 10^6$	7.095	315	942	70	24
7	0.145	$1.125 \cdot 10^6$	7.095	315	$1.495 \cdot 10^3$	71	24
8	0.142	$1.056 \cdot 10^6$	7.095	920	942	140	24
9	0.145	$1.127 \cdot 10^6$	7.085	920	$1.494 \cdot 10^3$	141	20
10	0.141	$1.033 \cdot 10^6$	8.465	919	$1.493 \cdot 10^3$	138	4
11	0.145	$1.128 \cdot 10^6$	7.085	919	$1.494 \cdot 10^3$	139	20
12	0.131	$8.263 \cdot 10^5$	9.2	87	662	21	30
13	0.141	$1.033 \cdot 10^6$	8.465	87	$1.493 \cdot 10^3$	22	4

Pipe Run 1-7B (Elements 769 & 86)

$$PRB80TH_{0,5} = \begin{pmatrix} 0.135 & 9.027 \times 10^5 & 13.66 & 769 & 661 & 102 & 10 \\ 0.137 & 9.38 \times 10^5 & 13.66 & 769 & 1.414 \times 10^3 & 103 & 7 \\ 0.133 & 8.586 \times 10^5 & 13.68 & 86 & 660 & 19 & 5 \\ 0.137 & 9.384 \times 10^5 & 13.66 & 86 & 1.414 \times 10^3 & 20 & 7 \end{pmatrix}$$

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Pipe Run 1-7C (Elements 459, 766, 918, 917, 311, 916, 915, 308, 914, 913, 305, 912, 911, 302, 910, & 85)

$PRB_{80TH_{0,6}} =$

	0	1	2	3	4	5	6
0	0.145	$1.12 \cdot 10^6$	7.485	459	659	80	17
1	0.148	$1.195 \cdot 10^6$	7.485	459	$1.118 \cdot 10^3$	81	17
2	0.148	$1.196 \cdot 10^6$	7.485	766	$1.118 \cdot 10^3$	98	17
3	0.145	$1.129 \cdot 10^6$	7.48	766	$1.411 \cdot 10^3$	99	27
4	0.145	$1.134 \cdot 10^6$	7.48	918	$1.411 \cdot 10^3$	136	27
5	0.151	$1.259 \cdot 10^6$	10.23	918	$1.492 \cdot 10^3$	137	10
6	0.169	$1.642 \cdot 10^6$	10.23	917	$1.491 \cdot 10^3$	134	10
7	0.151	$1.26 \cdot 10^6$	10.23	917	$1.492 \cdot 10^3$	135	10
8	0.19	$2.111 \cdot 10^6$	10.23	311	939	68	24
9	0.169	$1.643 \cdot 10^6$	10.23	311	$1.491 \cdot 10^3$	69	10
10	0.19	$2.117 \cdot 10^6$	10.23	916	939	132	24
11	0.18	$1.905 \cdot 10^6$	10.23	916	$1.49 \cdot 10^3$	133	25
12	0.186	$2.034 \cdot 10^6$	10.23	915	$1.489 \cdot 10^3$	130	9
13	0.18	$1.905 \cdot 10^6$	10.23	915	$1.49 \cdot 10^3$	131	25
14	0.202	$2.382 \cdot 10^6$	10.22	308	936	66	24
15	0.186	$2.034 \cdot 10^6$	10.23	308	$1.489 \cdot 10^3$	67	9
16	0.202	$2.383 \cdot 10^6$	10.22	914	936	128	24
17	0.189	$2.087 \cdot 10^6$	10.23	914	$1.488 \cdot 10^3$	129	10
18	0.178	$1.845 \cdot 10^6$	10.24	913	$1.487 \cdot 10^3$	126	30
19	0.189	$2.086 \cdot 10^6$	10.23	913	$1.488 \cdot 10^3$	127	10
20	0.169	$1.647 \cdot 10^6$	10.24	305	933	64	30
21	0.178	$1.844 \cdot 10^6$	10.24	305	$1.487 \cdot 10^3$	65	30
22	0.169	$1.65 \cdot 10^6$	10.24	912	933	124	30
23	0.157	$1.394 \cdot 10^6$	8.825	912	$1.486 \cdot 10^3$	125	3
24	0.149	$1.213 \cdot 10^6$	8.825	911	$1.485 \cdot 10^3$	122	11
25	0.157	$1.393 \cdot 10^6$	8.825	911	$1.486 \cdot 10^3$	123	3
26	0.14	$1.018 \cdot 10^6$	8.845	302	930	62	2
27	0.149	$1.212 \cdot 10^6$	8.825	302	$1.485 \cdot 10^3$	63	11
28	0.14	$1.017 \cdot 10^6$	8.845	910	930	120	2
29	0.134	$8.8 \cdot 10^5$	8.84	910	$1.484 \cdot 10^3$	121	12
30	0.129	$7.7 \cdot 10^5$	8.885	85	657	17	30
31	0.134	$8.797 \cdot 10^5$	8.84	85	$1.484 \cdot 10^3$	18	12

Pipe Run 1-7D (Elements 909, 299, 908, 756, & 84)

$PRB_{80TH_{0,7}} =$

	0	1	2	3	4	5	6
0	0.128	$7.411 \cdot 10^5$	13.42	909	658	118	13
1	0.129	$7.726 \cdot 10^5$	13.41	909	$1.483 \cdot 10^3$	119	15
2	0.142	$1.061 \cdot 10^6$	4.44	299	927	60	4
3	0.129	$7.718 \cdot 10^5$	13.41	299	$1.483 \cdot 10^3$	61	15
4	0.142	$1.061 \cdot 10^6$	4.44	908	927	116	4
5	0.154	$1.324 \cdot 10^6$	7.13	908	$1.482 \cdot 10^3$	117	21
6	0.167	$1.608 \cdot 10^6$	7.13	756	$1.399 \cdot 10^3$	92	21
7	0.154	$1.324 \cdot 10^6$	7.13	756	$1.482 \cdot 10^3$	93	21
8	0.145	$1.124 \cdot 10^6$	7.13	84	56	15	14
9	0.15	$1.243 \cdot 10^6$	7.495	84	$1.399 \cdot 10^3$	16	4

EVALUATION OF PIPE RUNS ON LINES 1-8, 1-9, 1-10, 1-11, 1-12, & 1-170 FOR ALL 32 REALIZATIONS

VPRC := ReadData("\PRLine1-8_9_10_11_12_170.prn")

PRC := C_S(VPRC, R)

$PRC_{80TH} := PR_{80th}(PRC)$

Pipe Properties for Line 1-8

Pipe Run 1-8A (Elements 97)

$$PRC80TH_{0,0} = \begin{pmatrix} 0.187 & 9.565\times10^{5} & 9.21 & 97 & 595 & 17 & 5 \\ 0.155 & 5.773\times10^{5} & 13.46 & 97 & 1.098\times10^{3} & 18 & 20 \end{pmatrix}$$

Pipe Run 1-8B (Elements 94)

$$PRC80TH_{0,1} = \begin{pmatrix} 0.173 & 7.969\times10^{5} & 13.65 & 94 & 594 & 11 & 24 \\ 0.172 & 7.775\times10^{5} & 9.22 & 94 & 1.097\times10^{3} & 12 & 10 \end{pmatrix}$$

Pipe Properties for Line 1-9, 1-10, 1-11, 1-12, & 1-170

Pipe Run 1-9A (Elements 110)

$$PRC80TH_{0,2} = \begin{pmatrix} 0.239 & 5.336\times10^{5} & 9.87 & 110 & 610 & 35 & 5 \\ 0.223 & 4.745\times10^{5} & 9.87 & 110 & 679 & 36 & 5 \end{pmatrix}$$

Pipe Run 1-9B (Element 930, 929, & 403)

$$PRC80TH_{0,3} = \begin{pmatrix} 0.205 & 4.064\times10^{5} & 13.59 & 930 & 673 & 147 & 17 \\ 0.16 & 2.332\times10^{5} & 7.69 & 930 & 1.633\times10^{3} & 148 & 27 \\ 0.152 & 2.049\times10^{5} & 8.455 & 929 & 1.632\times10^{3} & 145 & 8 \\ 0.16 & 2.331\times10^{5} & 7.69 & 929 & 1.633\times10^{3} & 146 & 27 \\ 0.21 & 4.235\times10^{5} & 9.215 & 403 & 672 & 91 & 5 \\ 0.152 & 2.049\times10^{5} & 8.455 & 403 & 1.632\times10^{3} & 92 & 8 \end{pmatrix}$$

Pipe Run 1-9C (Elements 592 & 867)

$$PRC80TH_{0,4} = \begin{pmatrix} 0.238 & 5.279\times10^{5} & 9.215 & 592 & 665 & 119 & 16 \\ 0.239 & 5.323\times10^{5} & 9.215 & 592 & 1.251\times10^{3} & 120 & 16 \\ 0.239 & 5.325\times10^{5} & 9.215 & 867 & 1.251\times10^{3} & 125 & 16 \\ 0.243 & 5.499\times10^{5} & 9.215 & 867 & 1.447\times10^{3} & 126 & 30 \end{pmatrix}$$

Pipe Run 1-10A (Elements 111)

$$PRC80TH_{0,5} = \begin{pmatrix} 0.245 & 5.544\times10^{5} & 13.6 & 111 & 607 & 37 & 11 \\ 0.241 & 5.399\times10^{5} & 13.6 & 111 & 678 & 38 & 11 \end{pmatrix}$$

Pipe Run 1-10B (Elements 928, 927, & 401)

$$PRC80TH_{0,6} = \begin{pmatrix} 0.212 & 4.301\times10^{5} & 13.61 & 928 & 674 & 143 & 13 \\ 0.172 & 2.784\times10^{5} & 7.695 & 928 & 1.631\times10^{3} & 144 & 12 \\ 0.165 & 2.548\times10^{5} & 8.45 & 927 & 1.63\times10^{3} & 141 & 29 \\ 0.172 & 2.781\times10^{5} & 7.69 & 927 & 1.631\times10^{3} & 142 & 11 \\ 0.205 & 4.061\times10^{5} & 9.86 & 401 & 671 & 89 & 28 \\ 0.165 & 2.547\times10^{5} & 8.45 & 401 & 1.63\times10^{3} & 90 & 29 \end{pmatrix}$$

Pipe Run 1-10C (Elements 868)

$$PRC80TH_{0,7} = \begin{pmatrix} 0.235 & 5.194\times10^{5} & 9.21 & 868 & 666 & 127 & 12 \\ 0.239 & 5.342\times10^{5} & 9.21 & 868 & 1.448\times10^{3} & 128 & 20 \end{pmatrix}$$

Pipe Run 1-11A (Elements 112)

$$PRC80TH_{0,8} = \begin{pmatrix} 0.243 & 5.483\times10^{5} & 9.865 & 112 & 613 & 39 & 16 \\ 0.234 & 5.145\times10^{5} & 9.865 & 112 & 680 & 40 & 13 \end{pmatrix}$$

Pipe Run 1-11B (Elements 924, 923, & 397)

$$PRC80TH_{0,9} = \begin{pmatrix} 0.221 & 4.662 \times 10^{5} & 13.6 & 924 & 675 & 135 & 17 \\ 0.179 & 3.066 \times 10^{5} & 7.7 & 924 & 1.627 \times 10^{3} & 136 & 12 \\ 0.17 & 2.706 \times 10^{5} & 13.64 & 923 & 1.626 \times 10^{3} & 133 & 15 \\ 0.179 & 3.066 \times 10^{5} & 7.7 & 923 & 1.627 \times 10^{3} & 134 & 12 \\ 0.194 & 3.629 \times 10^{5} & 13.66 & 397 & 670 & 85 & 28 \\ 0.17 & 2.706 \times 10^{5} & 13.64 & 397 & 1.626 \times 10^{3} & 86 & 15 \end{pmatrix}$$

Pipe Run 1-11C (Element 869)

$$PRC80TH_{0,10} = \begin{pmatrix} 0.223 & 4.725 \times 10^{5} & 15.16 & 869 & 667 & 129 & 18 \\ 0.226 & 4.846 \times 10^{5} & 15.16 & 869 & 1.449 \times 10^{3} & 130 & 18 \end{pmatrix}$$

Pipe Run 1-12A (Elements 113)

$$PRC80TH_{0,11} = \begin{pmatrix} 0.274 & 6.636 \times 10^{5} & 13.6 & 113 & 604 & 41 & 25 \\ 0.271 & 6.55 \times 10^{5} & 13.6 & 113 & 677 & 42 & 25 \end{pmatrix}$$

Pipe Run 1-12B (Elements 926, 925, & 399)

$$PRC80TH_{0,12} = \begin{pmatrix} 0.242 & 5.45 \times 10^{5} & 13.6 & 926 & 676 & 139 & 10 \\ 0.194 & 3.644 \times 10^{5} & 7.715 & 926 & 1.629 \times 10^{3} & 140 & 25 \\ 0.17 & 2.735 \times 10^{5} & 13.64 & 925 & 1.628 \times 10^{3} & 137 & 5 \\ 0.194 & 3.644 \times 10^{5} & 7.715 & 925 & 1.629 \times 10^{3} & 138 & 25 \\ 0.201 & 3.906 \times 10^{5} & 10.22 & 399 & 669 & 87 & 5 \\ 0.17 & 2.734 \times 10^{5} & 13.64 & 399 & 1.628 \times 10^{3} & 88 & 5 \end{pmatrix}$$

Pipe Run 1-12C (Elements 870)

$$PRC80TH_{0,13} = \begin{pmatrix} 0.222 & 4.68 \times 10^{5} & 9.865 & 870 & 668 & 131 & 13 \\ 0.227 & 4.871 \times 10^{5} & 15.16 & 870 & 1.45 \times 10^{3} & 132 & 25 \end{pmatrix}$$

Pipe Run 1-170A (Elements 117)

$$PRC80TH_{0,14} = \begin{pmatrix} 0.227 & 4.865\times10^5 & 9.235 & 117 & 619 & 47 & 30 \\ 0.22 & 4.614\times10^5 & 15.15 & 117 & 620 & 48 & 25 \end{pmatrix}$$

Pipe Run 1-170B (Elements 405, 931, & 932)

$$PRC80TH_{0,15} = \begin{pmatrix} 0.169 & 2.698\times10^5 & 9.215 & 405 & 622 & 93 & 2 \\ 0.142 & 1.65\times10^5 & 7.65 & 405 & 1.634\times10^3 & 94 & 26 \\ 0.142 & 1.65\times10^5 & 7.65 & 931 & 1.634\times10^3 & 149 & 26 \\ 0.167 & 2.615\times10^5 & 13.64 & 931 & 1.635\times10^3 & 150 & 5 \\ 0.22 & 4.611\times10^5 & 15.15 & 932 & 621 & 151 & 27 \\ 0.167 & 2.615\times10^5 & 13.64 & 932 & 1.635\times10^3 & 152 & 5 \end{pmatrix}$$

Pipe Run 1-170C (Elements 115)

$$PRC80TH_{0,16} = \begin{pmatrix} 0.144 & 1.728\times10^5 & 6.7 & 115 & 683 & 45 & 5 \\ 0.154 & 2.106\times10^5 & 10.29 & 115 & 684 & 46 & 5 \end{pmatrix}$$

Pipe Run 1-170D (Elements 439, 933, & 114)

$$PRC80TH_{0,17} = \begin{pmatrix} 0.145 & 1.773\times10^5 & 6.7 & 439 & 682 & 103 & 16 \\ 0.151 & 2\times10^5 & 7.12 & 439 & 1.096\times10^3 & 104 & 28 \\ 0.151 & 1.998\times10^5 & 7.12 & 933 & 1.096\times10^3 & 153 & 28 \\ 0.171 & 2.754\times10^5 & 9.21 & 933 & 1.636\times10^3 & 154 & 5 \\ 0.203 & 3.96\times10^5 & 9.205 & 114 & 614 & 43 & 10 \\ 0.171 & 2.755\times10^5 & 9.21 & 114 & 1.636\times10^3 & 44 & 5 \end{pmatrix}$$

EVALUATION OF PIPE RUNS ON LINES 1-34 AND 1-67 FOR ALL 32 REALIZATIONS

VPRD := ReadData("\PRLine1-34_67.prn")

PRD := C_S(VPRD, R)

$PRD_{80TH} := PR_{80th}(PRD)$

Pipe Properties for Line 1-34(A-C)

Pipe Run 1-34A (Elements 316 & 154)

$$PRD80TH_{0,0} = \begin{pmatrix} 0.179 & 6.582 \times 10^4 & 15.16 & 316 & 756 & 30 & 20 \\ 0.196 & 7.309 \times 10^4 & 15.17 & 316 & 946 & 31 & 20 \\ 0.094 & 2.811 \times 10^4 & 7.705 & 154 & 762 & 5 & 25 \\ 0.13 & 4.397 \times 10^4 & 13.61 & 154 & 763 & 6 & 22 \end{pmatrix}$$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

Pipe Run 1-34B (Elements 155, 980, 236, 625, 982, 239, 981, 979, 242, 983, 984, 243, 635, 248, 974, 975, 976, 977, 640, 249, & 978)

$PRD80TH_{0,1} =$

	0	1	2	3	4	5	6
0	0.133	$4.549\cdot10^{4}$	9.185	155	761	7	12
1	0.122	$4.063\cdot10^{4}$	9.875	155	$1.683\cdot10^{3}$	8	12
2	0.114	$3.706\cdot10^{4}$	9.875	980	854	118	25
3	0.122	$4.064\cdot10^{4}$	9.875	980	$1.683\cdot10^{3}$	119	12
4	0.114	$3.706\cdot10^{4}$	9.875	236	854	18	25
5	0.117	$3.845\cdot10^{4}$	9.875	236	$1.286\cdot10^{3}$	19	25
6	0.117	$3.847\cdot10^{4}$	9.875	625	$1.286\cdot10^{3}$	70	25
7	0.103	$3.195\cdot10^{4}$	9.88	625	$1.685\cdot10^{3}$	71	3
8	0.105	$3.282\cdot10^{4}$	9.88	982	856	122	25
9	0.103	$3.195\cdot10^{4}$	9.88	982	$1.685\cdot10^{3}$	123	3
10	0.105	$3.282\cdot10^{4}$	9.88	239	856	20	25
11	0.141	$4.886\cdot10^{4}$	15.16	239	$1.684\cdot10^{3}$	21	9
12	0.192	$7.174\cdot10^{4}$	15.16	981	859	120	9
13	0.141	$4.886\cdot10^{4}$	15.16	981	$1.684\cdot10^{3}$	121	9
14	0.193	$7.191\cdot10^{4}$	15.16	979	859	116	9
15	0.137	$4.722\cdot10^{4}$	15.15	979	860	117	9
16	0.137	$4.724\cdot10^{4}$	15.15	242	860	22	9
17	0.088	$2.538\cdot10^{4}$	13.62	242	$1.686\cdot10^{3}$	23	15
18	0.088	$2.538\cdot10^{4}$	13.62	983	$1.686\cdot10^{3}$	124	15
19	0.184	$6.799\cdot10^{4}$	9.185	983	$1.687\cdot10^{3}$	125	28
20	0.295	$1.171\cdot10^{5}$	9.87	984	862	126	28
21	0.184	$6.799\cdot10^{4}$	9.185	984	$1.687\cdot10^{3}$	127	28
22	0.295	$1.171\cdot10^{5}$	9.87	243	862	24	28
23	0.111	$3.558\cdot10^{4}$	7.71	243	$1.296\cdot10^{3}$	25	11
24	0.213	$8.101\cdot10^{4}$	9.225	635	863	72	28
25	0.111	$3.558\cdot10^{4}$	7.71	635	$1.296\cdot10^{3}$	73	11
26	0.212	$8.058\cdot10^{4}$	9.225	248	863	26	28
27	0.155	$5.489\cdot10^{4}$	9.875	248	$1.678\cdot10^{3}$	27	28
28	0.155	$5.489\cdot10^{4}$	9.875	974	$1.678\cdot10^{3}$	106	28
29	0.117	$3.823\cdot10^{4}$	9.88	974	$1.679\cdot10^{3}$	107	11
30	0.117	$3.823\cdot10^{4}$	9.88	975	$1.679\cdot10^{3}$	108	11
31	0.13	$4.38\cdot10^{4}$	8.415	975	$1.68\cdot10^{3}$	109	10
32	0.13	$4.38\cdot10^{4}$	8.415	976	$1.68\cdot10^{3}$	110	10
33	0.151	$5.322\cdot10^{4}$	9.17	976	$1.681\cdot10^{3}$	111	9
34	0.166	$5.985\cdot10^{4}$	7.8	977	$1.301\cdot10^{3}$	112	6
35	0.151	$5.322\cdot10^{4}$	9.17	977	$1.681\cdot10^{3}$	113	9
36	0.137	$4.704\cdot10^{4}$	9.25	640	868	74	5
37	0.166	$5.995\cdot10^{4}$	7.8	640	$1.301\cdot10^{3}$	75	6
38	0.137	$4.697\cdot10^{4}$	9.25	249	868	28	5
39	0.129	$4.364\cdot10^{4}$	15.15	249	$1.682\cdot10^{3}$	29	28
40	0.144	$5.008\cdot10^{4}$	9.555	978	765	114	29
41	0.129	$4.363\cdot10^{4}$	15.15	978	$1.682\cdot10^{3}$	115	28

Project:	ATR Life-Time Extension Project	ECAR No.:	ECAR-194	Rev.:	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation				
Performer:	A. L. Crawford	Date:	09/30/2008	Checker:	M. D. Landon	Date: 09/30/2008

Pipe Run 1-34C (Elements 471, 985, & 986)

$$PRD80TH_{0,2} = \begin{pmatrix} 0.133 & 4.546 \times 10^4 & 9.575 & 471 & 764 & 32 & 9 \\ 0.092 & 2.729 \times 10^4 & 13.65 & 471 & 1.688 \times 10^3 & 33 & 28 \\ 0.092 & 2.729 \times 10^4 & 13.65 & 985 & 1.688 \times 10^3 & 128 & 28 \\ 0.066 & 1.577 \times 10^4 & 7.465 & 985 & 1.689 \times 10^3 & 129 & 25 \\ 0.087 & 2.485 \times 10^4 & 9.25 & 986 & 1.127 \times 10^3 & 130 & 5 \\ 0.066 & 1.577 \times 10^4 & 7.465 & 986 & 1.689 \times 10^3 & 131 & 25 \end{pmatrix}$$

Pipe Properties for Lines 1-34(D-I)

Pipe Run 1-34D (Element 472 & 645)

$$PRD80TH_{0,3} = \begin{pmatrix} 0.2 & 2.949 \times 10^4 & 9.25 & 472 & 1.128 \times 10^3 & 34 & 5 \\ 0.203 & 2.991 \times 10^4 & 9.205 & 472 & 1.306 \times 10^3 & 35 & 22 \\ 0.176 & 2.54 \times 10^4 & 9.89 & 645 & 1.129 \times 10^3 & 76 & 29 \\ 0.186 & 2.713 \times 10^4 & 9.25 & 645 & 1.306 \times 10^3 & 77 & 5 \end{pmatrix}$$

Pipe Run 1-34E (Element 473 & 646)

$$PRD80TH_{0,4} = \begin{pmatrix} 0.121 & 1.62 \times 10^4 & 9.945 & 473 & 1.13 \times 10^3 & 36 & 27 \\ 0.122 & 1.63 \times 10^4 & 9.95 & 473 & 1.307 \times 10^3 & 37 & 12 \\ 0.096 & 1.193 \times 10^4 & 8.13 & 646 & 1.003 \times 10^3 & 78 & 25 \\ 0.105 & 1.342 \times 10^4 & 8.13 & 646 & 1.307 \times 10^3 & 79 & 27 \end{pmatrix}$$

Pipe Run 1-34F (Element 474 & 581)

$$PRD80TH_{0,5} = \begin{pmatrix} 0.09 & 1.089 \times 10^4 & 9.58 & 474 & 1.002 \times 10^3 & 38 & 21 \\ 0.089 & 1.074 \times 10^4 & 9.585 & 474 & 1.24 \times 10^3 & 39 & 26 \\ 0.092 & 1.124 \times 10^4 & 8.415 & 581 & 1.007 \times 10^3 & 68 & 12 \\ 0.089 & 1.074 \times 10^4 & 9.585 & 581 & 1.24 \times 10^3 & 69 & 26 \end{pmatrix}$$

Pipe Run 1-34G (Element 475)

$$PRD80TH_{0,6} = \begin{pmatrix} 0.075 & 8.398 \times 10^3 & 9.52 & 475 & 1.006 \times 10^3 & 40 & 31 \\ 0.088 & 1.065 \times 10^4 & 10.15 & 475 & 1.01 \times 10^3 & 41 & 22 \end{pmatrix}$$

Pipe Run 1-34H (Element 476)

$$PRD80TH_{0,7} = \begin{pmatrix} 0.095 & 1.18 \times 10^{4} & 10.14 & 476 & 1.011 \times 10^{3} & 42 & 28 \\ 0.115 & 1.511 \times 10^{4} & 10.15 & 476 & 1.015 \times 10^{3} & 43 & 10 \end{pmatrix}$$

Pipe Run 1-34I (Element 477)

$$PRD80TH_{0,8} = \begin{pmatrix} 0.174 & 2.503 \times 10^{4} & 8.415 & 477 & 974 & 44 & 27 \\ 0.126 & 1.702 \times 10^{4} & 10.15 & 477 & 1.014 \times 10^{3} & 45 & 22 \end{pmatrix}$$

EVALUATION OF PIPE RUNS ON LINE 1-39 AND 1-40 FOR ALL 32 REALIZATIONS

VPRE := ReadData("\PRLine1-39_40.prn")

PRE := C_S(VPRE, R)

$PRE_{80TH} := PR_{80th}(PRE)$

Pipe Properties for Line 1-39

Pipe Run 1-39A (Element 521)

$$PRE80TH_{0,0} = \begin{pmatrix} 0.247 & 1.001 \times 10^{5} & 8.5 & 521 & 987 & 58 & 14 \\ 0.285 & 1.186 \times 10^{5} & 5.345 & 521 & 1.035 \times 10^{3} & 59 & 19 \end{pmatrix}$$

Pipe Run 1-39B (Element 516)

$$PRE80TH_{0,1} = \begin{pmatrix} 0.22 & 8.713 \times 10^{4} & 4.97 & 516 & 1.034 \times 10^{3} & 49 & 7 \\ 0.303 & 1.271 \times 10^{5} & 4.26 & 516 & 1.176 \times 10^{3} & 50 & 8 \end{pmatrix}$$

Pipe Properties for Line 1-40

Pipe Run 1-40A (Element 162)

$$PRE80TH_{0,2} = \begin{pmatrix} 0.119 & 4.369 \times 10^{4} & 8.415 & 162 & 803 & 9 & 25 \\ 0.143 & 5.514 \times 10^{4} & 10.18 & 162 & 953 & 10 & 4 \end{pmatrix}$$

Pipe Run 1-40B (Elements 320, 649, 626, 935, 324, 934, 937, 936, 651, 327, 938, 636, 876, 939, 877, 940, 941, & 641)

$PRE80TH_{0,3} =$

	0	1	2	3	4	5	6
0	0.113	$4.07\cdot10^{4}$	8.41	320	802	35	22
1	0.107	$3.783\cdot10^{4}$	7.675	320	$1.31\cdot10^{3}$	36	30
2	0.095	$3.189\cdot10^{4}$	7.69	649	$1.287\cdot10^{3}$	74	19
3	0.107	$3.785\cdot10^{4}$	7.675	649	$1.31\cdot10^{3}$	75	30
4	0.095	$3.186\cdot10^{4}$	7.69	626	$1.287\cdot10^{3}$	68	19
5	0.092	$3.055\cdot10^{4}$	7.74	626	$1.638\cdot10^{3}$	69	4
6	0.096	$3.256\cdot10^{4}$	7.755	935	954	109	13
7	0.092	$3.055\cdot10^{4}$	7.74	935	$1.638\cdot10^{3}$	110	4
8	0.096	$3.256\cdot10^{4}$	7.755	324	954	37	13
9	0.106	$3.728\cdot10^{4}$	7.765	324	$1.637\cdot10^{3}$	38	13
10	0.125	$4.661\cdot10^{4}$	7.78	934	959	107	32
11	0.106	$3.728\cdot10^{4}$	7.765	934	$1.637\cdot10^{3}$	108	13
12	0.125	$4.659\cdot10^{4}$	7.78	937	959	113	32
13	0.139	$5.318\cdot10^{4}$	10.18	937	$1.64\cdot10^{3}$	114	26
14	0.164	$6.514\cdot10^{4}$	10.18	936	$1.639\cdot10^{3}$	111	19
15	0.139	$5.317\cdot10^{4}$	10.18	936	$1.64\cdot10^{3}$	112	26
16	0.188	$7.698\cdot10^{4}$	10.18	651	960	76	30
17	0.164	$6.514\cdot10^{4}$	10.18	651	$1.639\cdot10^{3}$	77	19
18	0.188	$7.698\cdot10^{4}$	10.18	327	960	39	19
19	0.201	$8.336\cdot10^{4}$	10.18	327	$1.641\cdot10^{3}$	40	22
20	0.216	$9.022\cdot10^{4}$	10.18	938	$1.298\cdot10^{3}$	115	28
21	0.201	$8.336\cdot10^{4}$	10.18	938	$1.641\cdot10^{3}$	116	22
22	0.222	$9.322\cdot10^{4}$	10.19	636	961	70	19
23	0.216	$9.022\cdot10^{4}$	10.18	636	$1.298\cdot10^{3}$	71	28
24	0.222	$9.346\cdot10^{4}$	10.19	876	961	103	19
25	0.166	$6.637\cdot10^{4}$	10.19	876	$1.642\cdot10^{3}$	104	13
26	0.119	$4.375\cdot10^{4}$	4.97	939	963	117	16
27	0.166	$6.636\cdot10^{4}$	10.19	939	$1.642\cdot10^{3}$	118	13
28	0.119	$4.375\cdot10^{4}$	4.97	877	963	105	16
29	0.132	$4.998\cdot10^{4}$	5.71	877	$1.643\cdot10^{3}$	106	6
30	0.132	$4.998\cdot10^{4}$	5.71	940	$1.643\cdot10^{3}$	119	6
31	0.172	$6.92\cdot10^{4}$	5.715	940	$1.644\cdot10^{3}$	120	25
32	0.221	$9.29\cdot10^{4}$	5.71	941	$1.303\cdot10^{3}$	121	27
33	0.172	$6.919\cdot10^{4}$	5.715	941	$1.644\cdot10^{3}$	122	25
34	0.169	$6.792\cdot10^{4}$	5.705	641	776	72	9
35	0.222	$9.312\cdot10^{4}$	5.71	641	$1.303\cdot10^{3}$	73	27

Pipe Run 1-40C (Element 233 & 160)

$$PRE_{80TH_{0,4}} = \begin{pmatrix} 0.14 & 5.373 \times 10^4 & 9.9 & 233 & 777 & 23 & 27 \\ 0.129 & 4.84 \times 10^4 & 10.18 & 233 & 852 & 24 & 25 \\ 0.15 & 5.882 \times 10^4 & 10.18 & 160 & 778 & 7 & 22 \\ 0.129 & 4.84 \times 10^4 & 10.18 & 160 & 852 & 8 & 25 \end{pmatrix}$$

Pipe Run 1-40D (Element 159)

$$PRE_{80TH_{0,5}} = \begin{pmatrix} 0.152 & 5.963 \times 10^4 & 9.435 & 159 & 779 & 5 & 31 \\ 0.151 & 5.931 \times 10^4 & 4.245 & 159 & 780 & 6 & 23 \end{pmatrix}$$

Pipe Run 1-40E (Element 234 & 158)

$$PRE_{80TH_{0,6}} = \begin{pmatrix} 0.146 & 5.653 \times 10^4 & 6.135 & 234 & 781 & 25 & 10 \\ 0.117 & 4.259 \times 10^4 & 6.15 & 234 & 853 & 26 & 26 \\ 0.12 & 4.405 \times 10^4 & 10.68 & 158 & 782 & 3 & 26 \\ 0.117 & 4.259 \times 10^4 & 6.15 & 158 & 853 & 4 & 26 \end{pmatrix}$$

Pipe Run 1-40F (Element 157)

$$PRE_{80TH_{0,7}} = \begin{pmatrix} 0.169 & 6.775 \times 10^4 & 4.205 & 157 & 758 & 1 & 13 \\ 0.127 & 4.753 \times 10^4 & 8.835 & 157 & 783 & 2 & 25 \end{pmatrix}$$

EVALUATION OF PIPE RUNS ON LINES 1-41 AND 1-77 FOR ALL 32 REALIZATIONS

VPRF := ReadData("\PRLine1-41_77.prn")

PRF := C_S(VPRF, R)

$PRF_{80TH} := PR_{80th}(PRF)$

Pipe Properties for Line 1-41

Pipe Run 1-41A (Element 606)

$$PRF_{80TH_{0,0}} = \begin{pmatrix} 0.168 & 6.209 \times 10^4 & 5.625 & 606 & 760 & 132 & 26 \\ 0.2 & 7.761 \times 10^4 & 5.625 & 606 & 1.018 \times 10^3 & 133 & 19 \end{pmatrix}$$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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Pipe Run 1-41B (Element 479 & 987)

$$PRF80TH_{0,1} = \begin{pmatrix} 0.211 & 8.274\times10^4 & 5.625 & 479 & 1.019\times10^3 & 1 & 11 \\ 0.17 & 6.277\times10^4 & 4.96 & 479 & 1.69\times10^3 & 2 & 25 \\ 0.317 & 1.337\times10^5 & 4.94 & 987 & 1.023\times10^3 & 182 & 22 \\ 0.17 & 6.277\times10^4 & 4.96 & 987 & 1.69\times10^3 & 183 & 25 \end{pmatrix}$$

Pipe Run 1-41C (Element 840)

$$PRF80TH_{0,2} = \begin{pmatrix} 0.278 & 1.149\times10^5 & 4.25 & 840 & 983 & 160 & 25 \\ 0.361 & 1.551\times10^5 & 5.66 & 840 & 1.435\times10^3 & 161 & 28 \end{pmatrix}$$

Pipe Run 1-41D (Element 988, 545, & 494)

$$PRF80TH_{0,3} = \begin{pmatrix} 0.369 & 1.589\times10^5 & 4.99 & 988 & 1.436\times10^3 & 184 & 17 \\ 0.206 & 8.041\times10^4 & 5.305 & 988 & 1.691\times10^3 & 185 & 3 \\ 0.122 & 3.966\times10^4 & 5.31 & 545 & 1.203\times10^3 & 84 & 3 \\ 0.206 & 8.043\times10^4 & 5.305 & 545 & 1.691\times10^3 & 85 & 3 \\ 0.119 & 3.854\times10^4 & 5.345 & 494 & 1.152\times10^3 & 31 & 26 \\ 0.133 & 4.505\times10^4 & 5.31 & 494 & 1.203\times10^3 & 32 & 3 \end{pmatrix}$$

Pipe Run 1-41E (Element 989 & 491)

$$PRF80TH_{0,4} = \begin{pmatrix} 0.148 & 5.261\times10^4 & 5.345 & 989 & 1.151\times10^3 & 186 & 26 \\ 0.209 & 8.16\times10^4 & 5.34 & 989 & 1.692\times10^3 & 187 & 9 \\ 0.333 & 1.416\times10^5 & 1.14 & 491 & 1.137\times10^3 & 23 & 15 \\ 0.209 & 8.16\times10^4 & 5.34 & 491 & 1.692\times10^3 & 24 & 9 \end{pmatrix}$$

Pipe Run 1-41F (Element 991, 875, 990, & 874)

$$PRF80TH_{0,5} = \begin{pmatrix} 0.344 & 1.468\times10^5 & 1.14 & 991 & 1.136\times10^3 & 190 & 1 \\ 0.289 & 1.204\times10^5 & 1.135 & 991 & 1.694\times10^3 & 191 & 1 \\ 0.228 & 9.097\times10^4 & 1.135 & 875 & 1.199\times10^3 & 180 & 21 \\ 0.289 & 1.204\times10^5 & 1.135 & 875 & 1.694\times10^3 & 181 & 1 \\ 0.228 & 9.097\times10^4 & 1.135 & 990 & 1.199\times10^3 & 188 & 21 \\ 0.156 & 5.633\times10^4 & 5.02 & 990 & 1.693\times10^3 & 189 & 16 \\ 0.107 & 3.238\times10^4 & 4.915 & 874 & 1.026\times10^3 & 178 & 17 \\ 0.156 & 5.632\times10^4 & 5.02 & 874 & 1.693\times10^3 & 179 & 16 \end{pmatrix}$$

Pipe Run 1-41G (Element 481, 612, 993, 539, & 992)

$PRF80TH_{0,6} =$

	0	1	2	3	4	5	6
0	0.15	$5.311 \cdot 10^4$	1.14	481	$1.027 \cdot 10^3$	6	7
1	0.207	$8.064 \cdot 10^4$	1.16	481	$1.269 \cdot 10^3$	7	16
2	0.164	$6.031 \cdot 10^4$	1	612	$1.269 \cdot 10^3$	134	27
3	0.164	$6.017 \cdot 10^4$	1.155	612	$1.696 \cdot 10^3$	135	29
4	0.159	$5.759 \cdot 10^4$	1.16	993	$1.194 \cdot 10^3$	194	5
5	0.164	$6.018 \cdot 10^4$	1.155	993	$1.696 \cdot 10^3$	195	29
6	0.159	$5.758 \cdot 10^4$	1.16	539	$1.194 \cdot 10^3$	82	5
7	0.154	$5.503 \cdot 10^4$	1.18	539	$1.695 \cdot 10^3$	83	6
8	0.159	$5.754 \cdot 10^4$	1.5	992	$1.03 \cdot 10^3$	192	9
9	0.154	$5.503 \cdot 10^4$	1.18	992	$1.695 \cdot 10^3$	193	6

Pipe Run 1-41H (Element 485)

$$PRF80TH_{0,7} = \begin{pmatrix} 0.101 & 2.958 \times 10^4 & 5.315 & 485 & 1.031 \times 10^3 & 14 & 22 \\ 0.157 & 5.657 \times 10^4 & 5.03 & 485 & 1.139 \times 10^3 & 15 & 12 \end{pmatrix}$$

Pipe Run 1-41I (Element 486)

$$PRF80TH_{0,8} = \begin{pmatrix} 0.192 & 7.369 \times 10^4 & 5.03 & 486 & 1.141 \times 10^3 & 16 & 22 \\ 0.188 & 7.182 \times 10^4 & 5.025 & 486 & 1.142 \times 10^3 & 17 & 4 \end{pmatrix}$$

Pipe Run 1-41J (Element 489 & 994)

$$PRF80TH_{0,9} = \begin{pmatrix} 0.184 & 6.971 \times 10^4 & 5.03 & 489 & 1.143 \times 10^3 & 18 & 27 \\ 0.207 & 8.101 \times 10^4 & 1.505 & 489 & 1.697 \times 10^3 & 19 & 26 \\ 0.262 & 1.074 \times 10^5 & 1.5 & 994 & 1.147 \times 10^3 & 196 & 13 \\ 0.207 & 8.101 \times 10^4 & 1.505 & 994 & 1.697 \times 10^3 & 197 & 26 \end{pmatrix}$$

Pipe Properties for Line 1-77A, 1-77F, 1-37(A-C), & 1-38(A-C)

Pipe Run 1-77A (Element 520 & 617)

$$PRF80TH_{0,10} = \begin{pmatrix} 0.277 & 4.481 \times 10^4 & 10.69 & 520 & 992 & 62 & 29 \\ 0.281 & 4.539 \times 10^4 & 10.69 & 520 & 1.274 \times 10^3 & 63 & 11 \\ 0.282 & 4.559 \times 10^4 & 10.7 & 617 & 1.172 \times 10^3 & 136 & 10 \\ 0.279 & 4.504 \times 10^4 & 10.69 & 617 & 1.274 \times 10^3 & 137 & 29 \end{pmatrix}$$

Pipe Run 1-77F (Element 499, 998, & 498)

$$PRF80TH_{0,11} = \begin{pmatrix} 0.181 & 2.731\times10^4 & 10.38 & 499 & 1.161\times10^3 & 42 & 16 \\ 0.15 & 2.167\times10^4 & 4.945 & 499 & 1.701\times10^3 & 43 & 10 \\ 0.237 & 3.751\times10^4 & 4.945 & 998 & 1.158\times10^3 & 204 & 4 \\ 0.15 & 2.167\times10^4 & 4.945 & 998 & 1.701\times10^3 & 205 & 10 \\ 0.207 & 3.196\times10^4 & 3.96 & 498 & 1.001\times10^3 & 40 & 25 \\ 0.239 & 3.776\times10^4 & 4.945 & 498 & 1.157\times10^3 & 41 & 13 \end{pmatrix}$$

Pipe Run 1-37A (Element 557 and 871)

$$PRF80TH_{0,12} = \begin{pmatrix} 0.309 & 5.063\times10^4 & 4.925 & 557 & 1.212\times10^3 & 100 & 26 \\ 0.327 & 5.383\times10^4 & 4.93 & 557 & 1.224\times10^3 & 101 & 26 \\ 0.312 & 5.108\times10^4 & 4.935 & 871 & 1.211\times10^3 & 176 & 22 \\ 0.361 & 6\times10^4 & 3.955 & 871 & 1.451\times10^3 & 177 & 17 \end{pmatrix}$$

Pipe Run 1-37B (Element 558)

$$PRF80TH_{0,13} = \begin{pmatrix} 0.244 & 3.881\times10^4 & 4.93 & 558 & 1.216\times10^3 & 102 & 26 \\ 0.301 & 4.91\times10^4 & 4.935 & 558 & 1.225\times10^3 & 103 & 26 \end{pmatrix}$$

Pipe Run 1-37C (Element 560)

$$PRF80TH_{0,14} = \begin{pmatrix} 0.123 & 1.676\times10^4 & 4.92 & 560 & 1.219\times10^3 & 106 & 27 \\ 0.162 & 2.375\times10^4 & 4.905 & 560 & 1.234\times10^3 & 107 & 25 \end{pmatrix}$$

Pipe Run 1-38A (Element 555)

$$PRF80TH_{0,15} = \begin{pmatrix} 0.211 & 3.267\times10^4 & 3.96 & 555 & 1.213\times10^3 & 96 & 25 \\ 0.225 & 3.532\times10^4 & 3.965 & 555 & 1.227\times10^3 & 97 & 25 \end{pmatrix}$$

Pipe Run 1-38B (Element 559)

$$PRF80TH_{0,16} = \begin{pmatrix} 0.18 & 2.707\times10^4 & 3.97 & 559 & 1.217\times10^3 & 104 & 22 \\ 0.212 & 3.297\times10^4 & 3.975 & 559 & 1.226\times10^3 & 105 & 24 \end{pmatrix}$$

Pipe Run 1-38C (Element 562)

$$PRF80TH_{0,17} = \begin{pmatrix} 0.139 & 1.953\times10^4 & 4.935 & 562 & 1.218\times10^3 & 108 & 27 \\ 0.181 & 2.72\times10^4 & 4.935 & 562 & 1.233\times10^3 & 109 & 17 \end{pmatrix}$$

Pipe Properties for Line 1-77(B-E)

Pipe Run 1-77B (Element 511)

$$PRF80TH_{0,18} = \begin{pmatrix} 0.133 & 4.535\times10^{4} & 10.66 & 511 & 1.038\times10^{3} & 60 & 31 \\ 0.135 & 4.634\times10^{4} & 10.68 & 511 & 1.171\times10^{3} & 61 & 28 \end{pmatrix}$$

Pipe Run 1-77C (Element 995, 509, 508, 619, 550, 996, 548, & 507)

$PRF80TH_{0,19} =$

	0	1	2	3	4	5	6
0	0.128	$4.273\cdot10^{4}$	10.66	995	$1.039\cdot10^{3}$	198	31
1	0.113	$3.568\cdot10^{4}$	10.69	995	$1.698\cdot10^{3}$	199	17
2	0.101	$2.964\cdot10^{4}$	10.7	509	$1.17\cdot10^{3}$	58	28
3	0.113	$3.569\cdot10^{4}$	10.69	509	$1.698\cdot10^{3}$	59	17
4	0.101	$2.955\cdot10^{4}$	10.7	508	996	56	28
5	0.101	$2.965\cdot10^{4}$	10.7	508	$1.17\cdot10^{3}$	57	28
6	0.101	$2.955\cdot10^{4}$	10.7	619	996	138	28
7	0.097	$2.804\cdot10^{4}$	14.74	619	$1.276\cdot10^{3}$	139	32
8	0.095	$2.701\cdot10^{4}$	10.36	550	$1.208\cdot10^{3}$	88	6
9	0.097	$2.805\cdot10^{4}$	14.74	550	$1.276\cdot10^{3}$	89	32
10	0.095	$2.702\cdot10^{4}$	10.36	996	$1.208\cdot10^{3}$	200	6
11	0.103	$3.062\cdot10^{4}$	10.37	996	$1.699\cdot10^{3}$	201	13
12	0.113	$3.54\cdot10^{4}$	10.37	548	$1.205\cdot10^{3}$	86	13
13	0.103	$3.063\cdot10^{4}$	10.37	548	$1.699\cdot10^{3}$	87	13
14	0.122	$3.969\cdot10^{4}$	4.945	507	$1.165\cdot10^{3}$	54	26
15	0.113	$3.539\cdot10^{4}$	10.37	507	$1.205\cdot10^{3}$	55	13

Pipe Run 1-77D (Element 506 & 997)

$$PRF80TH_{0,20} = \begin{pmatrix} 0.119 & 3.817\times10^{4} & 4.945 & 506 & 1.164\times10^{3} & 52 & 13 \\ 0.106 & 3.196\times10^{4} & 4.945 & 506 & 1.7\times10^{3} & 53 & 11 \\ 0.143 & 4.995\times10^{4} & 10.4 & 997 & 1.163\times10^{3} & 202 & 27 \\ 0.106 & 3.196\times10^{4} & 4.945 & 997 & 1.7\times10^{3} & 203 & 11 \end{pmatrix}$$

Pipe Run 1-77E (Element 506)

Elements associated with run P(1-77E) is also part of T(1-77) and will be calculated as T(1-77)

Pipe Properties for Line 1-37D & 1-38D

Pipe Run 1-37D (Element 569)

$$PRF80TH_{0,21} = \begin{pmatrix} 1.253 & 3.901\times10^{4} & 4.945 & 569 & 1.222\times10^{3} & 120 & 11 \\ 0.975 & 3.018\times10^{4} & 4.94 & 569 & 1.235\times10^{3} & 121 & 12 \end{pmatrix}$$

Pipe Run 1-38D (Element 567)

$$PRF80TH_{0,22} = \begin{pmatrix} 1.151 & 3.579\times10^{4} & 4.94 & 567 & 1.223\times10^{3} & 116 & 4 \\ 0.995 & 3.081\times10^{4} & 4.935 & 567 & 1.236\times10^{3} & 117 & 17 \end{pmatrix}$$

See main body of report for further information regarding the plastic hinge implemenation.

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

EVALUATION OF PIPE RUNS ON LINE 1-42 FOR ALL 32 REALIZATIONS

$VPRG := ReadData("\backslash PRLine1\text{-}42.prn")$

$PRG := C\_S(VPRG, R)$

$PRG_{80TH} := PR_{80th}(PRG)$

Pipe Properties for Line 1-42

Pipe Run 1-42A (Elements 197 & 171)

$$PRG_{80TH_{0,0}} = \begin{pmatrix} 0.1 & 2.91\times10^{4} & 8.235 & 197 & 816 & 43 & 12 \\ 0.12 & 3.871\times10^{4} & 8.235 & 197 & 1.442\times10^{3} & 44 & 12 \\ 0.064 & 1.185\times10^{4} & 8.38 & 171 & 805 & 11 & 15 \\ 0.1 & 2.91\times10^{4} & 8.235 & 171 & 816 & 12 & 12 \end{pmatrix}$$

Pipe Run 1-42B (Element 943, 942, 192, 948, 947, 946, 945, 944, 194, 193, & 170)

$PRG_{80TH_{0,1}} =$

	0	1	2	3	4	5	6
0	0.069	$1.447\cdot10^{4}$	8.935	943	804	103	29
1	0.059	$9.329\cdot10^{3}$	5.485	943	$1.646\cdot10^{3}$	104	5
2	0.064	$1.189\cdot10^{4}$	13.18	942	$1.645\cdot10^{3}$	101	17
3	0.059	$9.329\cdot10^{3}$	5.485	942	$1.646\cdot10^{3}$	102	5
4	0.079	$1.919\cdot10^{4}$	13.1	192	811	37	22
5	0.064	$1.189\cdot10^{4}$	13.18	192	$1.645\cdot10^{3}$	38	17
6	0.079	$1.919\cdot10^{4}$	13.1	948	811	113	22
7	0.08	$1.987\cdot10^{4}$	13.1	948	$1.651\cdot10^{3}$	114	27
8	0.081	$1.992\cdot10^{4}$	13.09	947	$1.65\cdot10^{3}$	111	28
9	0.08	$1.987\cdot10^{4}$	13.1	947	$1.651\cdot10^{3}$	112	27
10	0.075	$1.711\cdot10^{4}$	13.18	946	$1.649\cdot10^{3}$	109	3
11	0.081	$1.992\cdot10^{4}$	13.09	946	$1.65\cdot10^{3}$	110	28
12	0.082	$2.069\cdot10^{4}$	5.455	945	$1.648\cdot10^{3}$	107	25
13	0.075	$1.711\cdot10^{4}$	13.18	945	$1.649\cdot10^{3}$	108	3
14	0.1	$2.943\cdot10^{4}$	10.11	944	$1.647\cdot10^{3}$	105	22
15	0.082	$2.069\cdot10^{4}$	5.455	944	$1.648\cdot10^{3}$	106	25

Pipe Run 1-42C (Element 949, 216, 950, 589, 952, 951, 213, 958, 957, 956, 955, 954, 953, 595, 961, 960, 959, 200, 963, 962, 597, 964, & 169)

$PRG80TH_{0,2} =$

	0	1	2	3	4	5	6
0	0.089	$2.417\cdot10^4$	10.09	949	766	115	27
1	0.088	$2.327\cdot10^4$	8.39	949	$1.652\cdot10^3$	116	6
2	0.133	$4.516\cdot10^4$	8.395	216	833	49	9
3	0.088	$2.327\cdot10^4$	8.39	216	$1.652\cdot10^3$	50	6
4	0.133	$4.516\cdot10^4$	8.395	950	833	117	9
5	0.104	$3.136\cdot10^4$	8.395	950	$1.653\cdot10^3$	118	9
6	0.085	$2.22\cdot10^4$	5.945	589	$1.248\cdot10^3$	59	27
7	0.104	$3.136\cdot10^4$	8.395	589	$1.653\cdot10^3$	60	9
8	0.085	$2.223\cdot10^4$	8.39	952	$1.248\cdot10^3$	121	15
9	0.069	$1.433\cdot10^4$	5.955	952	$1.655\cdot10^3$	122	12
10	0.06	$1.015\cdot10^4$	10.09	951	$1.654\cdot10^3$	119	25
11	0.069	$1.432\cdot10^4$	5.955	951	$1.655\cdot10^3$	120	12
12	0.073	$1.625\cdot10^4$	8.61	213	823	47	30
13	0.06	$1.015\cdot10^4$	10.09	213	$1.654\cdot10^3$	48	25
14	0.073	$1.626\cdot10^4$	8.61	958	823	133	30
15	0.062	$1.094\cdot10^4$	9.255	958	$1.661\cdot10^3$	134	6
16	0.076	$1.775\cdot10^4$	6.175	957	$1.66\cdot10^3$	131	31
17	0.062	$1.094\cdot10^4$	9.255	957	$1.661\cdot10^3$	132	6
18	0.085	$2.221\cdot10^4$	8.38	956	$1.659\cdot10^3$	129	15
19	0.076	$1.775\cdot10^4$	6.175	956	$1.66\cdot10^3$	130	31
20	0.087	$2.311\cdot10^4$	10.63	955	$1.658\cdot10^3$	127	24
21	0.085	$2.221\cdot10^4$	8.38	955	$1.659\cdot10^3$	128	15
22	0.079	$1.9\cdot10^4$	10.63	954	$1.657\cdot10^3$	125	24
23	0.087	$2.311\cdot10^4$	10.63	954	$1.658\cdot10^3$	126	24
24	0.071	$1.533\cdot10^4$	6.71	953	$1.656\cdot10^3$	123	30
25	0.079	$1.9\cdot10^4$	10.63	953	$1.657\cdot10^3$	124	24
26	0.088	$2.363\cdot10^4$	8.08	595	$1.254\cdot10^3$	61	19
27	0.071	$1.533\cdot10^4$	6.71	595	$1.656\cdot10^3$	62	30
28	0.088	$2.358\cdot10^4$	8.08	961	$1.254\cdot10^3$	139	19
29	0.068	$1.381\cdot10^4$	8.705	961	$1.665\cdot10^3$	140	15
30	0.066	$1.269\cdot10^4$	5.88	960	$1.664\cdot10^3$	137	22
31	0.068	$1.381\cdot10^4$	8.705	960	$1.665\cdot10^3$	138	15
32	0.079	$1.939\cdot10^4$	5.87	959	$1.663\cdot10^3$	135	13
33	0.066	$1.269\cdot10^4$	5.88	959	$1.664\cdot10^3$	136	22
34	0.095	$2.671\cdot10^4$	5.86	200	819	45	29
35	0.079	$1.939\cdot10^4$	5.87	200	$1.663\cdot10^3$	46	13
36	0.095	$2.664\cdot10^4$	5.875	963	819	143	25
37	0.07	$1.49\cdot10^4$	5.965	963	$1.667\cdot10^3$	144	17
38	0.075	$1.722\cdot10^4$	4.14	962	$1.666\cdot10^3$	141	4
39	0.07	$1.49\cdot10^4$	5.965	962	$1.667\cdot10^3$	142	17
40	0.101	$2.968\cdot10^4$	10.47	597	$1.256\cdot10^3$	63	17
41	0.075	$1.722\cdot10^4$	4.14	597	$1.666\cdot10^3$	64	4
42	0.101	$2.968\cdot10^4$	10.47	964	$1.256\cdot10^3$	145	17
43	0.095	$2.681\cdot10^4$	9.01	964	$1.668\cdot10^3$	146	25
44	0.098	$2.829\cdot10^4$	9.425	169	796	7	30
45	0.095	$2.681\cdot10^4$	9.01	169	$1.668\cdot10^3$	8	25

Pipe Run 1-42D (Element 168)

$$PRG80TH_{0,3} = \begin{pmatrix} 0.098 & 2.808 \times 10^4 & 8.375 & 168 & 798 & 5 & 28 \\ 0.115 & 3.645 \times 10^4 & 6.92 & 168 & 799 & 6 & 19 \end{pmatrix}$$

Pipe Run 1-42E (Element 965, 967, 969, 968, & 334)

$PRG80TH_{0,4} =$

	0	1	2	3	4	5	6
0	0.12	$3.899 \cdot 10^4$	6.92	965	797	147	11
1	0.128	$4.272 \cdot 10^4$	6.92	965	$1.669 \cdot 10^3$	148	22
2	0.137	$4.724 \cdot 10^4$	6.925	967	967	149	28
3	0.128	$4.272 \cdot 10^4$	6.92	967	$1.669 \cdot 10^3$	150	22
4	0.137	$4.731 \cdot 10^4$	10.1	969	967	153	10
5	0.086	$2.242 \cdot 10^4$	9.48	969	$1.673 \cdot 10^3$	154	4
6	0.086	$2.258 \cdot 10^4$	9.93	968	$1.672 \cdot 10^3$	151	10
7	0.086	$2.242 \cdot 10^4$	9.48	968	$1.673 \cdot 10^3$	152	4
8	0.138	$4.778 \cdot 10^4$	6.915	334	768	55	22
9	0.086	$2.258 \cdot 10^4$	9.93	334	$1.672 \cdot 10^3$	56	10

Pipe Run 1-42F (Element 163, 970, 220, & 971)

$$PRG80TH_{0,5} = \begin{pmatrix} 0.175 & 6.547 \times 10^4 & 6.92 & 163 & 769 & 1 & 19 \\ 0.143 & 5.013 \times 10^4 & 6.73 & 163 & 1.674 \times 10^3 & 2 & 27 \\ 0.12 & 3.895 \times 10^4 & 6.725 & 970 & 838 & 155 & 28 \\ 0.143 & 5.013 \times 10^4 & 6.73 & 970 & 1.674 \times 10^3 & 156 & 27 \\ 0.12 & 3.895 \times 10^4 & 6.725 & 220 & 838 & 51 & 28 \\ 0.133 & 4.529 \times 10^4 & 4.165 & 220 & 1.675 \times 10^3 & 52 & 13 \\ 0.16 & 5.811 \times 10^4 & 9.755 & 971 & 770 & 157 & 28 \\ 0.133 & 4.528 \times 10^4 & 4.165 & 971 & 1.675 \times 10^3 & 158 & 13 \end{pmatrix}$$

Pipe Run 1-42G (Element 164 & 972)

$$PRG80TH_{0,6} = \begin{pmatrix} 0.105 & 3.149 \times 10^4 & 9.76 & 164 & 771 & 3 & 6 \\ 0.117 & 3.748 \times 10^4 & 9.76 & 164 & 1.676 \times 10^3 & 4 & 22 \\ 0.137 & 4.719 \times 10^4 & 9.75 & 972 & 772 & 159 & 26 \\ 0.117 & 3.748 \times 10^4 & 9.76 & 972 & 1.676 \times 10^3 & 160 & 22 \end{pmatrix}$$

Pipe Run 1-42H (Element 221 & 973)

$$PRG80TH_{0,7} = \begin{pmatrix} 0.136 & 4.649\times10^{4} & 9.935 & 221 & 773 & 53 & 25 \\ 0.114 & 3.578\times10^{4} & 9.915 & 221 & 1.677\times10^{3} & 54 & 22 \\ 0.151 & 5.364\times10^{4} & 9.935 & 973 & 775 & 161 & 19 \\ 0.114 & 3.578\times10^{4} & 9.915 & 973 & 1.677\times10^{3} & 162 & 22 \end{pmatrix}$$

Pipe Run 1-42I (Element 605)

$$PRG80TH_{0,8} = \begin{pmatrix} 0.142 & 4.976\times10^{4} & 9.745 & 605 & 759 & 65 & 27 \\ 0.175 & 6.565\times10^{4} & 6.12 & 605 & 774 & 66 & 25 \end{pmatrix}$$

REDUCERS

Termination output is ordered as (max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, indicie of element(s), moments about the x, y, and z axes, and realization number)

EVALUATION OF REDUCERS ON LINES 1-1L, 1-2L, 1-3L, & 1-4L FOR ALL 32 REALIZATIONS

$VRA := ReadData("\backslash RedLine1\text{-}1\_2\_3\_4.prn")$

$RA := C\_S(VRA, R)$

$RA_{80TH} := RED\_EL_{80th}(RA)$

Reducer Properties for RED(1-1LA) & RED(1-4LA)

Reducer 1-1LA (Nodes 745 & 1042)

$$RA_{80TH_0} = \begin{pmatrix} 0.149 & 3.672\times10^{5} & 9.91 & 745 & 101 & -1.245\times10^{5} & 2.235\times10^{5} & -2.634\times10^{5} & 11 \\ 0.155 & 3.244\times10^{5} & 9.91 & 1.042\times10^{3} & 94 & -1.185\times10^{5} & 1.824\times10^{5} & -2.407\times10^{5} & 11 \end{pmatrix}$$

Reducer 1-4LA (Nodes 746 & 1043)

$$RA_{80TH_1} = \begin{pmatrix} 0.15 & 3.728\times10^{5} & 9.525 & 746 & 103 & 1.357\times10^{5} & -2.634\times10^{5} & -2.261\times10^{5} & 23 \\ 0.158 & 3.396\times10^{5} & 7.85 & 1.043\times10^{3} & 96 & 1.387\times10^{5} & 2.398\times10^{5} & -1.964\times10^{5} & 28 \end{pmatrix}$$

Reducer Properties for RED(1-1LB), RED(1-4LB), RED(1-2L), & RED(1-3L)

Reducer 1-1LB (Nodes 625 & 549)

$$RA_{80TH_2} = \begin{pmatrix} 0.393 & 1.023\times10^{6} & 7.405 & 625 & 65 & -1.021\times10^{6} & -5.931\times10^{4} & -3.958\times10^{4} & 7 \\ 0.541 & 1.219\times10^{6} & 7.405 & 549 & 69 & 1.217\times10^{6} & 6.655\times10^{4} & 4.054\times10^{4} & 7 \end{pmatrix}$$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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Reducer 1-2L (Nodes 624 & 548)

$$RA_{80TH_3} = \begin{pmatrix} 0.308 & 7.385\times10^{5} & 7.39 & 624 & 67 & -7.02\times10^{5} & -1.956\times10^{5} & -1.198\times10^{5} & 1 \\ 0.412 & 8.791\times10^{5} & 7.39 & 548 & 71 & 8.392\times10^{5} & 2.303\times10^{5} & 1.244\times10^{5} & 1 \end{pmatrix}$$

Reducer 1-3L (Nodes 626 & 547)

$$RA_{80TH_4} = \begin{pmatrix} 0.278 & 6.374\times10^{5} & 6.665 & 626 & 63 & 5.662\times10^{5} & 2.724\times10^{5} & -1.073\times10^{5} & 26 \\ 0.368 & 7.635\times10^{5} & 6.665 & 547 & 75 & -6.834\times10^{5} & -3.21\times10^{5} & 1.138\times10^{5} & 26 \end{pmatrix}$$

Reducer 1-4LB (Nodes 627 & 546)

$$RA_{80TH_5} = \begin{pmatrix} 0.437 & 1.172\times10^{6} & 7.405 & 627 & 61 & 1.167\times10^{6} & 9.032\times10^{4} & -6.109\times10^{4} & 9 \\ 0.608 & 1.395\times10^{6} & 7.405 & 546 & 73 & -1.389\times10^{6} & -1.03\times10^{5} & 6.277\times10^{4} & 9 \end{pmatrix}$$

EVALUATION OF REDUCERS ON LINE 1-5, 1-6, & 1-7 FOR ALL 32 REALIZATIONS

$VRB := \text{ReadData}(\text{"\textbackslash RedLine1-5\_6\_7.prn"})$

$RB := C\_S(VRB, R)$

$RB_{80TH} := RED\_EL_{80th}(RB)$

Reducer Properties for RED(1-5) & RED(1-6)

Reducer 1-5 (Nodes 53 & 39)

$$RB_{80TH_0} = \begin{pmatrix} 0.15 & 1.436\times10^{6} & 6.665 & 53 & 10 & -2.896\times10^{5} & -1.371\times10^{6} & -3.137\times10^{5} & 12 \\ 0.166 & 1.151\times10^{6} & 6.65 & 39 & 1 & -1.733\times10^{5} & -1.123\times10^{6} & -1.883\times10^{5} & 22 \end{pmatrix}$$

Reducer 1-6 (Nodes 52 & 15)

$$RB_{80TH_1} = \begin{pmatrix} 0.153 & 1.515\times10^{6} & 7.255 & 52 & 12 & 3.817\times10^{5} & -1.466\times10^{6} & 5.079\times10^{4} & 24 \\ 0.175 & 1.251\times10^{6} & 7.03 & 15 & 3 & 4.756\times10^{5} & -1.146\times10^{6} & -1.545\times10^{5} & 21 \end{pmatrix}$$

EVALUATION OF REDUCERS ON LINE 1-8, 1-9, 1-10, 1-11, 1-12, & 1-170 FOR ALL 32 REALIZATIONS

$VRC := \text{ReadData}(\text{"\textbackslash RedLine1-8\_9\_10\_11\_12\_170.prn"})$

$RC := C\_S(VRC, R)$

$RC_{80TH} := RED\_EL_{80th}(RC)$

Reducer Properties for RED(1-8A) & RED(1-8B)

Reducer 1-8A (Nodes 592 & 595)

$$RC_{80TH_0} = \begin{pmatrix} 0.16 & 1.081\times10^{6} & 9.215 & 592 & 7 & -1.033\times10^{6} & 2.073\times10^{5} & 2.42\times10^{5} & 24 \\ 0.156 & 9.565\times10^{5} & 9.21 & 595 & 17 & -9.14\times10^{5} & 5.152\times10^{4} & 2.772\times10^{5} & 5 \end{pmatrix}$$

Reducer 1-8B (Nodes 593 & 594)

$$RC_{80TH_1} = \begin{pmatrix} 0.151 & 8.885\times10^{5} & 13.65 & 593 & 4 & -6.737\times10^{5} & 4.117\times10^{5} & -4.076\times10^{5} & 24 \\ 0.145 & 7.973\times10^{5} & 13.65 & 594 & 23 & -5.426\times10^{5} & 4.189\times10^{5} & -4.072\times10^{5} & 24 \end{pmatrix}$$

Reducer Properties for RED(1-170)

Reducer 1-170 (Nodes 597 & 614)

$$RC_{80TH_2} = \begin{pmatrix} 0.223 & 4.511\times10^{5} & 9.205 & 597 & 21 & 4.436\times10^{5} & -8.209\times10^{4} & 55.03 & 10 \\ 0.229 & 3.96\times10^{5} & 9.205 & 614 & 95 & 3.854\times10^{5} & -9.12\times10^{4} & 82.63 & 10 \end{pmatrix}$$

THERE ARE NOT ANY REDUCERS PRESENT ON LINES 1-34 AND 1-67

EVALUATION OF REDUCERS ON LINES 1-39 AND 1-40 FOR ALL 32 REALIZATIONS

VRD := ReadData("\RedLine1-39_40.prn")

RD := C_S(VRD, R)

$RD_{80TH} := RED\_EL_{80th}(RD)$

Reducer Properties for Line 1-39

Reducer 1-39 (Nodes 1175 & 1178)

$$RD_{80TH_0} = \begin{pmatrix} 0.176 & 6.614\times10^{4} & 5.335 & 1.175\times10^{3} & 46 & 2.336\times10^{3} & -2.483\times10^{3} & 6.605\times10^{4} & 31 \\ 0.361 & 6.005\times10^{4} & 5.335 & 1.178\times10^{3} & 54 & 2.359\times10^{3} & -3.353\times10^{3} & 5.991\times10^{4} & 31 \end{pmatrix}$$

EVALUATION OF REDUCERS ON LINES 1-41 AND 1-77 FOR ALL 32 REALIZATIONS

VRE := ReadData("\RedLine1-41_77.prn")

RE := C_S(VRE, R)

$RE_{80TH} := RED\_EL_{80th}(RE)$

Reducer Properties for Line 1-77

Reducer 1-77 (Nodes 1160 & 1161)

$$RE_{80TH_0} = \begin{pmatrix} 0.104 & 3.134\times10^{4} & 10.38 & 1.16\times10^{3} & 49 & 7.614\times10^{3} & 1.257\times10^{4} & 2.768\times10^{4} & 16 \\ 0.181 & 2.731\times10^{4} & 10.38 & 1.161\times10^{3} & 44 & 7.604\times10^{3} & 1.38\times10^{4} & 2.231\times10^{4} & 16 \end{pmatrix}$$

Reducer Properties for Lines 1-37 & 1-38

Reducer 1-37 (Nodes 1234 & 1235)

$$RE_{80TH_1} = \begin{pmatrix} 0.162 & 2.375\times10^{4} & 4.905 & 1.234\times10^{3} & 112 & 7.65\times10^{3} & 1.419\times10^{4} & -1.744\times10^{4} & 2 \\ 0.975 & 3.018\times10^{4} & 4.94 & 1.235\times10^{3} & 118 & -1.426\times10^{4} & -1.321\times10^{4} & 2.309\times10^{4} & 1 \end{pmatrix}$$

Reducer 1-38 (Nodes 1233 & 1236)

$$RE80TH_2 = \begin{pmatrix} 0.181 & 2.72 \times 10^4 & 4.935 & 1.233 \times 10^3 & 110 & 8.255 \times 10^3 & 1.652 \times 10^4 & -1.996 \times 10^4 & 17 \\ 0.995 & 3.081 \times 10^4 & 4.935 & 1.236 \times 10^3 & 114 & -7.714 \times 10^3 & -1.65 \times 10^4 & 2.485 \times 10^4 & 17 \end{pmatrix}$$

THERE ARE NOT ANY REDUCERS ON LINE 1-42

ELBOWS

Elbow output is ordered as (max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, indicie of element(s), moments about the x, y, and z axes, and realization number)

EVALUATION OF ELBOWS ON LINES 1-1L, 1-2L, 1-3L, & 1-4L FOR ALL 32 REALIZATIONS

VELA := ReadData("\ElbowLine1-1_2_3_4.prn")

ELA := C_S(VELA, R)

$ELA_{80TH} := RED\_EL_{80th}(ELA)$

Elbow Properties for Elbows 1-1LA, 1-1LC, 1-2LA, 1-2LB, 1-2LC, 1-3LA, 1-3LB, 1-3LC, 1-4LA, & 1-4LC

Elbow 1-1LA (Nodes 649 & 648)

$$ELA80TH_0 = \begin{pmatrix} 0.328 & 1.919 \times 10^5 & 7.385 & 649 & 18 & 1.449 \times 10^5 & -1.216 \times 10^4 & 1.252 \times 10^5 & 26 \\ 0.241 & 1.41 \times 10^5 & 7.385 & 648 & 48 & 1.135 \times 10^5 & -2.592 \times 10^4 & 7.94 \times 10^4 & 12 \end{pmatrix}$$

Elbow 1-1LC (Nodes 632 & 631)

$$ELA80TH_1 = \begin{pmatrix} 0.312 & 1.82 \times 10^5 & 9.91 & 632 & 79 & -1.704 \times 10^5 & 3.142 \times 10^4 & -5.557 \times 10^4 & 7 \\ 0.293 & 1.714 \times 10^5 & 6.67 & 631 & 161 & -1.08 \times 10^5 & -3.347 \times 10^4 & -1.289 \times 10^5 & 27 \end{pmatrix}$$

Elbow 1-2LA (Nodes 655 & 652)

$$ELA80TH_2 = \begin{pmatrix} 0.202 & 1.18 \times 10^5 & 7.615 & 655 & 110 & -4.197 \times 10^4 & -6.174 \times 10^4 & -9.14 \times 10^4 & 27 \\ 0.257 & 1.501 \times 10^5 & 7.62 & 652 & 109 & 5.016 \times 10^4 & 8.146 \times 10^4 & 1.156 \times 10^5 & 17 \end{pmatrix}$$

Elbow 1-2LB (Nodes 642 & 641)

$$ELA80TH_3 = \begin{pmatrix} 0.227 & 1.325 \times 10^5 & 7.485 & 642 & 9 & -3.544 \times 10^4 & 2.731 \times 10^4 & -1.248 \times 10^5 & 25 \\ 0.163 & 9.543 \times 10^4 & 9.9 & 641 & 39 & 7.306 \times 10^4 & 4.669 \times 10^4 & -3.985 \times 10^4 & 27 \end{pmatrix}$$

Elbow 1-2LC (Nodes 633 & 630)

$$ELA80TH_4 = \begin{pmatrix} 0.232 & 1.357 \times 10^5 & 6.68 & 633 & 31 & 7.513 \times 10^4 & 5.543 \times 10^4 & -9.844 \times 10^4 & 27 \\ 0.289 & 1.691 \times 10^5 & 6.675 & 630 & 163 & -4.252 \times 10^4 & -4.593 \times 10^3 & -1.636 \times 10^5 & 4 \end{pmatrix}$$

Elbow 1-3LA (Nodes 656 & 653)

$$ELA80TH_5 = \begin{pmatrix} 0.21 & 1.229\times10^5 & 7.39 & 656 & 113 & 4.657\times10^4 & 5.318\times10^4 & -1.006\times10^5 & 26 \\ 0.27 & 1.575\times10^5 & 7.375 & 653 & 112 & -5.13\times10^4 & -8.795\times10^4 & 1.202\times10^5 & 28 \end{pmatrix}$$

Elbow 1-3LB (Nodes 643 & 640)

$$ELA80TH_6 = \begin{pmatrix} 0.193 & 1.13\times10^5 & 7.495 & 643 & 13 & 3.248\times10^4 & -2.472\times10^4 & -1.054\times10^5 & 25 \\ 0.138 & 8.057\times10^4 & 9.51 & 640 & 135 & 7.128\times10^4 & 1.319\times10^4 & 3.516\times10^4 & 17 \end{pmatrix}$$

Elbow 1-3LC (Nodes 634 & 628)

$$ELA80TH_7 = \begin{pmatrix} 0.207 & 1.209\times10^5 & 7.39 & 634 & 83 & 8.463\times10^4 & 4.696\times10^4 & 7.248\times10^4 & 26 \\ 0.254 & 1.482\times10^5 & 7.385 & 628 & 165 & 5.777\times10^4 & 2.862\times10^4 & -1.334\times10^5 & 12 \end{pmatrix}$$

Elbow 1-4LA (Nodes 651 & 650)

$$ELA80TH_8 = \begin{pmatrix} 0.358 & 2.089\times10^5 & 7.39 & 651 & 46 & 1.641\times10^5 & -3.264\times10^4 & -1.251\times10^5 & 9 \\ 0.269 & 1.572\times10^5 & 7.385 & 650 & 45 & -1.391\times10^5 & 3.016\times10^4 & 6.678\times10^4 & 9 \end{pmatrix}$$

Elbow 1-4LC (Nodes 635 & 629)

$$ELA80TH_9 = \begin{pmatrix} 0.348 & 2.033\times10^5 & 7.405 & 635 & 85 & 2.01\times10^5 & 2.248\times10^3 & 2.994\times10^4 & 12 \\ 0.298 & 1.743\times10^5 & 7.385 & 629 & 167 & 1.395\times10^5 & 3.934\times10^4 & -9.684\times10^4 & 26 \end{pmatrix}$$

Elbow Properties for EL(1-1LB) & EL(1-4LB)

Elbow 1-1LB (Nodes 637 & 636)

$$ELA80TH_{10} = \begin{pmatrix} 0.26 & 1.159\times10^5 & 7.13 & 637 & 15 & 1.129\times10^5 & -1.176\times10^4 & 2.345\times10^4 & 17 \\ 0.214 & 9.537\times10^4 & 9.91 & 636 & 54 & 2.079\times10^4 & 3.622\times10^4 & -8.574\times10^4 & 6 \end{pmatrix}$$

Elbow 1-4LB (Nodes 639 & 638)

$$ELA80TH_{11} = \begin{pmatrix} 0.252 & 1.124\times10^5 & 7.365 & 639 & 19 & -1.036\times10^5 & 2.533\times10^4 & 3.568\times10^4 & 1 \\ 0.217 & 9.668\times10^4 & 9.52 & 638 & 130 & 3.614\times10^4 & 2.351\times10^4 & 8.653\times10^4 & 12 \end{pmatrix}$$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

EVALUATION OF ELBOWS ON LINES 1-5, 1-6, & 1-7 FOR ALL 32 REALIZATIONS

VELB := ReadData("\ElbowLine1-5_6_7.prn")

ELB := C_S(VELB, R)

$ELB_{80TH} := RED\_EL_{80th}(ELB)$

Elbow Properties for Lines 1-5 & 1-6

Elbow 1-5 (Nodes 645 & 646)

$$ELB_{80TH_0} = \begin{pmatrix} 0.614 & 4.861\times 10^5 & 9.885 & 645 & 112 & -9.45\times 10^4 & 4.274\times 10^5 & -2.112\times 10^5 & 12 \\ 0.604 & 4.776\times 10^5 & 8.825 & 646 & 35 & -1.785\times 10^5 & 3.703\times 10^5 & -2.433\times 10^5 & 19 \end{pmatrix}$$

Elbow 1-6 (Nodes 644 & 647)

$$ELB_{80TH_1} = \begin{pmatrix} 0.649 & 5.135\times 10^5 & 8.845 & 644 & 42 & -6.361\times 10^4 & 4.636\times 10^5 & 2.114\times 10^5 & 29 \\ 0.631 & 4.995\times 10^5 & 9.88 & 647 & 43 & -2.14\times 10^5 & 3.53\times 10^5 & 2.813\times 10^5 & 27 \end{pmatrix}$$

Elbow Properties for Lines 1-7

Elbow 1-7A (Nodes 586 & 590)

$$ELB_{80TH_2} = \begin{pmatrix} 0.283 & 8.222\times 10^5 & 7.69 & 586 & 25 & 1.567\times 10^4 & -7.851\times 10^5 & 2.437\times 10^5 & 32 \\ 0.291 & 8.467\times 10^5 & 7.675 & 590 & 24 & -3.654\times 10^5 & 7.227\times 10^5 & -2.474\times 10^5 & 7 \end{pmatrix}$$

Elbow 1-7B (Nodes 662 & 661)

$$ELB_{80TH_3} = \begin{pmatrix} 0.284 & 8.263\times 10^5 & 9.2 & 662 & 21 & 7.807\times 10^5 & -8.614\times 10^4 & 2.567\times 10^5 & 30 \\ 0.31 & 9.027\times 10^5 & 13.66 & 661 & 51 & -2.685\times 10^5 & 6.594\times 10^5 & 5.549\times 10^5 & 10 \end{pmatrix}$$

Elbow 1-7C (Nodes 660 & 659)

$$ELB_{80TH_4} = \begin{pmatrix} 0.295 & 8.582\times 10^5 & 13.68 & 660 & 49 & -3.111\times 10^4 & -6.739\times 10^5 & -5.304\times 10^5 & 17 \\ 0.385 & 1.12\times 10^6 & 7.485 & 659 & 80 & -1.72\times 10^5 & 1.763\times 10^5 & 1.093\times 10^6 & 17 \end{pmatrix}$$

Elbow 1-7D (Nodes 657 & 658)

$$ELB_{80TH_5} = \begin{pmatrix} 0.265 & 7.7\times 10^5 & 8.885 & 657 & 17 & 4.888\times 10^5 & -5.949\times 10^5 & -1.168\times 10^4 & 30 \\ 0.255 & 7.415\times 10^5 & 13.42 & 658 & 46 & -2.4\times 10^5 & 7.005\times 10^5 & -3.979\times 10^4 & 13 \end{pmatrix}$$

Project:	ATR Life-Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation				
Performer:	A. L. Crawford	**Date:**	09/30/2008	**Checker:**	M. D. Landon
Date:	09/30/2008				

EVALUATION OF ELBOWS ON LINES 1-8, 1-9, 1-10, 1-11, 1-12, & 1-170 FOR ALL 32 REALIZATIONS

VELC := ReadData("\ElbowLine1-8_9_10_11_12_170.prn")

ELC := C_S(VELC, R)

$ELC_{80TH} := RED\_EL_{80th}(ELC)$

Elbow Properties for Elbows on Lines 1-9, 1-10, 1-11, 1-12, & 1-170

Elbow 1-9A (Nodes 679 & 673)

$$ELC_{80TH_0} = \begin{pmatrix} 0.6 & 4.745\times10^5 & 9.87 & 679 & 36 & -2.322\times10^5 & -1.61\times10^5 & -3.812\times10^5 & 5 \\ 0.514 & 4.064\times10^5 & 13.59 & 673 & 61 & 2.872\times10^5 & 7.365\times10^4 & -2.78\times10^5 & 17 \end{pmatrix}$$

Elbow 1-9B (Nodes 672 & 665)

$$ELC_{80TH_1} = \begin{pmatrix} 0.535 & 4.235\times10^5 & 9.215 & 672 & 56 & -3.823\times10^5 & 8.333\times10^4 & 1.62\times10^5 & 5 \\ 0.667 & 5.279\times10^5 & 9.215 & 665 & 55 & 5.255\times10^5 & 5.069\times10^4 & 3.298\times10^3 & 16 \end{pmatrix}$$

Elbow 1-10A (Nodes 679 & 673)

$$ELC_{80TH_2} = \begin{pmatrix} 0.682 & 5.399\times10^5 & 13.6 & 678 & 38 & 3.425\times10^5 & 8.542\times10^4 & -4.085\times10^5 & 11 \\ 0.544 & 4.301\times10^5 & 13.61 & 674 & 64 & 3.442\times10^5 & -3.804\times10^4 & -2.551\times10^5 & 13 \end{pmatrix}$$

Elbow 1-10B (Nodes 672 & 665)

$$ELC_{80TH_3} = \begin{pmatrix} 0.513 & 4.06\times10^5 & 9.21 & 671 & 59 & -3.848\times10^5 & 8.374\times10^4 & 9.856\times10^4 & 20 \\ 0.656 & 5.194\times10^5 & 9.21 & 666 & 58 & 5.173\times10^5 & 4.145\times10^4 & 2.172\times10^4 & 12 \end{pmatrix}$$

Elbow 1-11A (Nodes 680 & 675)

$$ELC_{80TH_4} = \begin{pmatrix} 0.65 & 5.145\times10^5 & 9.865 & 680 & 40 & -2.883\times10^5 & -1.495\times10^5 & -3.991\times10^5 & 13 \\ 0.589 & 4.662\times10^5 & 13.6 & 675 & 67 & 2.737\times10^5 & 8.736\times10^4 & -3.672\times10^5 & 17 \end{pmatrix}$$

Elbow 1-11B (Nodes 670 & 667)

$$ELC_{80TH_5} = \begin{pmatrix} 0.459 & 3.629\times10^5 & 13.66 & 670 & 85 & -2.899\times10^5 & 7.556\times10^4 & -2.048\times10^5 & 28 \\ 0.597 & 4.725\times10^5 & 15.16 & 667 & 129 & 4.694\times10^5 & 5.381\times10^4 & 618 & 18 \end{pmatrix}$$

Elbow 1-12A (Nodes 677 & 676)

$$ELC_{80TH_6} = \begin{pmatrix} 0.828 & 6.55\times10^5 & 13.6 & 677 & 42 & 4.217\times10^5 & 4.946\times10^4 & -4.988\times10^5 & 25 \\ 0.689 & 5.45\times10^5 & 13.6 & 676 & 70 & 3.813\times10^5 & -7.164\times10^4 & -3.827\times10^5 & 10 \end{pmatrix}$$

Elbow 1-12B (Nodes 669 & 668)

$$ELC_{80TH_7} = \begin{pmatrix} 0.494 & 3.906\times10^5 & 10.22 & 669 & 74 & 3.11\times10^5 & -1.723\times10^5 & 1.617\times10^5 & 5 \\ 0.591 & 4.679\times10^5 & 15.18 & 668 & 131 & 4.623\times10^5 & 6.779\times10^4 & 2.555\times10^4 & 18 \end{pmatrix}$$

Elbow 1-170A (Nodes 620 & 621)

$$ELC80TH_8 = \begin{pmatrix} 0.583 & 4.614\times10^5 & 15.15 & 620 & 48 & 4.614\times10^5 & 6.363\times10^3 & 42.75 & 25 \\ 0.583 & 4.611\times10^5 & 15.15 & 621 & 83 & 4.298\times10^5 & -7.895\times10^4 & -1.471\times10^5 & 27 \end{pmatrix}$$

Elbow 1-170B (Nodes 622 & 623)

$$ELC80TH_9 = \begin{pmatrix} 0.341 & 2.699\times10^5 & 9.215 & 622 & 79 & -2.333\times10^5 & -5.015\times10^4 & 1.26\times10^5 & 2 \\ 0.314 & 2.485\times10^5 & 15.18 & 623 & 52 & 2.205\times10^5 & 3.954\times10^4 & -1.077\times10^5 & 24 \end{pmatrix}$$

Elbow 1-170C (Nodes 623 & 684)

$$ELC80TH_{10} = \begin{pmatrix} 0.314 & 2.485\times10^5 & 15.18 & 623 & 52 & 2.205\times10^5 & 3.954\times10^4 & -1.077\times10^5 & 24 \\ 0.266 & 2.107\times10^5 & 10.29 & 684 & 53 & -9.578\times10^4 & -1.322\times10^4 & 1.872\times10^5 & 5 \end{pmatrix}$$

Elbow 1-170D (Nodes 683 & 682)

$$ELC80TH_{11} = \begin{pmatrix} 0.218 & 1.728\times10^5 & 6.7 & 683 & 45 & -6.105\times10^4 & -5.421\times10^4 & -1.523\times10^5 & 5 \\ 0.224 & 1.774\times10^5 & 6.7 & 682 & 49 & -2.086\times10^4 & -4.66\times10^4 & -1.699\times10^5 & 16 \end{pmatrix}$$

EVALUATION OF ELBOWS ON LINES 1-43 AND 1-47 FOR ALL 32 REALIZATIONS

VELD := ReadData("\ElbowLine1-34_67.prn")

ELD := C_S(VELD, R)

$ELD_{80TH} := RED\_EL_{80th}(ELD)$

Elbow Properties for EL(1-34(A-C))

Elbow 1-34A (Nodes 756 & 763)

$$ELD80TH_0 = \begin{pmatrix} 0.447 & 6.582\times10^4 & 15.16 & 756 & 30 & -1.773\times10^4 & 6.299\times10^4 & 7.084\times10^3 & 20 \\ 0.299 & 4.397\times10^4 & 13.61 & 763 & 16 & 3.693\times10^3 & 4.34\times10^4 & 5.999\times10^3 & 22 \end{pmatrix}$$

Elbow 1-34B (Nodes 762 & 761)

$$ELD80TH_1 = \begin{pmatrix} 0.191 & 2.811\times10^4 & 7.705 & 762 & 13 & 6.455\times10^3 & -2.704\times10^4 & -4.156\times10^3 & 25 \\ 0.309 & 4.549\times10^4 & 9.185 & 761 & 12 & -1.374\times10^4 & 4.337\times10^4 & -364 & 12 \end{pmatrix}$$

Elbow 1-34C (Nodes 765 & 764)

$$ELD80TH_2 = \begin{pmatrix} 0.34 & 5.009\times10^4 & 9.555 & 765 & 10 & -5.252\times10^3 & -4.98\times10^4 & -678.6 & 29 \\ 0.309 & 4.546\times10^4 & 9.575 & 764 & 9 & 1.667\times10^3 & 4.543\times10^4 & -829.8 & 9 \end{pmatrix}$$

Elbow Properties for REL(1-34D)

Reducing Elbow Large Section 1-34D (Nodes 1127 & 1133)

$$ELD80TH_3 = \begin{pmatrix} 0.183 & 2.485 \times 10^4 & 9.25 & 1.127 \times 10^3 & 58 & -110.5 & -2.451 \times 10^4 & 4.097 \times 10^3 & 5 \\ 0.211 & 2.867 \times 10^4 & 9.25 & 1.133 \times 10^3 & 62 & 436.4 & -2.851 \times 10^4 & 2.971 \times 10^3 & 5 \end{pmatrix}$$

Reducing Elbow Small Section 1-34D (Nodes 1133 & 1128)

$$ELD80TH_4 = \begin{pmatrix} 0.372 & 2.867 \times 10^4 & 9.25 & 1.133 \times 10^3 & 62 & 436.4 & -2.851 \times 10^4 & 2.971 \times 10^3 & 5 \\ 0.382 & 2.949 \times 10^4 & 9.25 & 1.128 \times 10^3 & 34 & 2.835 \times 10^3 & -2.929 \times 10^4 & 2.05 \times 10^3 & 5 \end{pmatrix}$$

Elbow Properties for EL(1-34(E, G, H))

Elbow 1-34E (Nodes 1003 & 1002)

$$ELD80TH_5 = \begin{pmatrix} 0.202 & 1.193 \times 10^4 & 8.13 & 1.003 \times 10^3 & 47 & 4.917 \times 10^3 & 4.074 \times 10^3 & -1.008 \times 10^4 & 25 \\ 0.184 & 1.089 \times 10^4 & 9.58 & 1.002 \times 10^3 & 46 & 676.1 & -1.015 \times 10^4 & 3.88 \times 10^3 & 21 \end{pmatrix}$$

Elbow 1-34G (Nodes 1010 & 1011)

$$ELD80TH_6 = \begin{pmatrix} 0.18 & 1.065 \times 10^4 & 10.15 & 1.01 \times 10^3 & 49 & -1.758 \times 10^3 & 9.089 \times 10^3 & 5.268 \times 10^3 & 22 \\ 0.199 & 1.18 \times 10^4 & 10.14 & 1.011 \times 10^3 & 42 & -1.049 \times 10^3 & 1.069 \times 10^4 & 4.882 \times 10^3 & 28 \end{pmatrix}$$

Elbow 1-34H (Nodes 1015 & 1014)

$$ELD80TH_7 = \begin{pmatrix} 0.255 & 1.511 \times 10^4 & 10.15 & 1.015 \times 10^3 & 53 & 1.241 \times 10^3 & 1.466 \times 10^4 & 3.44 \times 10^3 & 10 \\ 0.287 & 1.702 \times 10^4 & 10.15 & 1.014 \times 10^3 & 45 & 2.627 \times 10^3 & 1.655 \times 10^4 & 3 \times 10^3 & 22 \end{pmatrix}$$

Elbow Properties for EL(1-34F)

Elbow 1-34F (Nodes 1007 & 1006)

$$ELD80TH_8 = \begin{pmatrix} 0.1 & 1.124 \times 10^4 & 8.415 & 1.007 \times 10^3 & 68 & -3.096 \times 10^3 & 9.22 \times 10^3 & -5.626 \times 10^3 & 1 \\ 0.079 & 8.398 \times 10^3 & 9.52 & 1.006 \times 10^3 & 40 & -3.119 \times 10^3 & 4.203 \times 10^3 & 6.567 \times 10^3 & 3 \end{pmatrix}$$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

EVALUATION OF ELBOWS ON LINE 1-39 & 1-40 FOR ALL 32 REALIZATIONS

VELE := ReadData("\ElbowLine1-39_40.prn")

ELE := C_S(VELE,R)

$ELE_{80TH} := RED\_EL_{80th}(ELE)$

Elbow Properties for EL(1-39)

Elbow 1-39 (Nodes 1034 & 1035)

$$ELE80TH_0 = \begin{pmatrix} 0.592 & 8.713\times10^4 & 4.97 & 1.034\times10^3 & 49 & -1.832\times10^4 & 1.89\times10^4 & 8.306\times10^4 & 7 \\ 0.806 & 1.186\times10^5 & 5.345 & 1.035\times10^3 & 52 & 2.859\times10^4 & -3.132\times10^3 & 1.15\times10^5 & 19 \end{pmatrix}$$

Elbow Properties for EL(1-40(A, C, D, & E))

Elbow 1-40A (Nodes 803 & 802)

$$ELE80TH_1 = \begin{pmatrix} 0.322 & 4.369\times10^4 & 8.415 & 803 & 9 & -2.316\times10^4 & 3.612\times10^4 & 8.232\times10^3 & 25 \\ 0.3 & 4.07\times10^4 & 8.41 & 802 & 80 & -2.311\times10^4 & 3.204\times10^4 & 9.824\times10^3 & 22 \end{pmatrix}$$

Elbow 1-40C (Nodes 778 & 779)

$$ELE80TH_2 = \begin{pmatrix} 0.434 & 5.882\times10^4 & 10.18 & 778 & 7 & 9.212\times10^3 & -4.699\times10^4 & -3.416\times10^4 & 22 \\ 0.44 & 5.963\times10^4 & 9.435 & 779 & 5 & 2.612\times10^4 & -1.869\times10^4 & -5.025\times10^4 & 31 \end{pmatrix}$$

Elbow 1-40D (Nodes 780 & 781)

$$ELE80TH_3 = \begin{pmatrix} 0.437 & 5.931\times10^4 & 4.245 & 780 & 14 & 1.805\times10^4 & 2.571\times10^3 & 5.644\times10^4 & 23 \\ 0.417 & 5.65\times10^4 & 7.755 & 781 & 15 & -3.576\times10^4 & 1.691\times10^4 & -4.033\times10^4 & 4 \end{pmatrix}$$

Elbow 1-40E (Nodes 782 & 783)

$$ELE80TH_4 = \begin{pmatrix} 0.325 & 4.405\times10^4 & 10.68 & 782 & 11 & 3.851\times10^4 & 1.161\times10^4 & 1.796\times10^4 & 26 \\ 0.35 & 4.753\times10^4 & 8.835 & 783 & 2 & 7.039\times10^3 & -2.193\times10^4 & 4.158\times10^4 & 25 \end{pmatrix}$$

Elbow Properties for EL(1-40B)

Elbow 1-40B (Nodes 776 & 777)

$$ELE80TH_5 = \begin{pmatrix} 0.239 & 6.792\times10^4 & 5.705 & 776 & 72 & 6.636\times10^4 & -1.017\times10^4 & 1.024\times10^4 & 9 \\ 0.192 & 5.373\times10^4 & 9.9 & 777 & 21 & -4.321\times10^4 & 3.178\times10^4 & -3.03\times10^3 & 27 \end{pmatrix}$$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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EVALUATION OF ELBOWS ON LINE 1-42 FOR ALL 32 REALIZATIONS

VELF := ReadData("\ElbowLine1-42.prn")

ELF := C_S(VELF, R)

$ELF_{80TH} := RED\_EL_{80th}(ELF)$

Elbow Properties for EL(1-42(A-D, H))

Elbow 1-42A (Nodes 805 & 804)

$$ELF_{80TH_0} = \begin{pmatrix} 0.081 & 1.185\times10^4 & 8.38 & 805 & 14 & 3.601\times10^3 & -1.95\times10^3 & 1.112\times10^4 & 15 \\ 0.098 & 1.447\times10^4 & 8.935 & 804 & 103 & 1.512\times10^3 & 8.423\times10^3 & -1.166\times10^4 & 29 \end{pmatrix}$$

Elbow 1-42B (Nodes 767 & 766)

$$ELF_{80TH_1} = \begin{pmatrix} 0.092 & 1.351\times10^4 & 5.965 & 767 & 17 & -851.1 & -1.346\times10^4 & -709.7 & 10 \\ 0.164 & 2.417\times10^4 & 10.09 & 766 & 115 & -1.243\times10^3 & 2.412\times10^4 & 788.5 & 27 \end{pmatrix}$$

Elbow 1-42C (Nodes 796 & 798)

$$ELF_{80TH_2} = \begin{pmatrix} 0.192 & 2.829\times10^4 & 9.425 & 796 & 7 & -3.27\times10^3 & -2.803\times10^4 & 1.927\times10^3 & 30 \\ 0.191 & 2.808\times10^4 & 8.375 & 798 & 20 & 2.483\times10^3 & -2.795\times10^4 & 992.7 & 28 \end{pmatrix}$$

Elbow 1-42D (Nodes 799 & 797)

$$ELF_{80TH_3} = \begin{pmatrix} 0.248 & 3.645\times10^4 & 6.92 & 799 & 6 & -237.5 & -3.643\times10^4 & 1.155\times10^3 & 19 \\ 0.265 & 3.902\times10^4 & 6.92 & 797 & 22 & 688.8 & -3.899\times10^4 & 1.459\times10^3 & 22 \end{pmatrix}$$

Elbow 1-42G (Nodes 772 & 773)

$$ELF_{80TH_4} = \begin{pmatrix} 0.321 & 4.719\times10^4 & 9.75 & 772 & 34 & 4.04\times10^4 & 1.954\times10^4 & 1.458\times10^4 & 26 \\ 0.316 & 4.649\times10^4 & 9.935 & 773 & 35 & 2.548\times10^4 & 3.436\times10^4 & 1.822\times10^4 & 25 \end{pmatrix}$$

Elbow 1-42H (Nodes 775 & 774)

$$ELF_{80TH_5} = \begin{pmatrix} 0.364 & 5.364\times10^4 & 9.935 & 775 & 161 & -2.131\times10^4 & 3.388\times10^4 & -3.571\times10^4 & 19 \\ 0.446 & 6.565\times10^4 & 6.12 & 774 & 66 & -1.333\times10^4 & 1.014\times10^4 & -6.347\times10^4 & 25 \end{pmatrix}$$

Elbow Properties for EL(1-42(E-F))

Elbow 1-42E (Nodes 768 & 769)

$$ELF_{80TH_6} = \begin{pmatrix} 0.164 & 4.778\times10^4 & 6.915 & 768 & 28 & 7.501\times10^3 & -4.719\times10^4 & -1.186 & 22 \\ 0.218 & 6.547\times10^4 & 6.92 & 769 & 1 & -1.367\times10^3 & -6.268\times10^4 & 1.889\times10^4 & 19 \end{pmatrix}$$

Elbow 1-42F (Nodes 770 & 771)

$$ELF_{80TH_7} = \begin{pmatrix} 0.195 & 5.817\times10^4 & 9.755 & 770 & 31 & 1.869\times10^3 & -2.197\times10^4 & 5.383\times10^4 & 28 \\ 0.114 & 3.149\times10^4 & 9.76 & 771 & 32 & -2.752\times10^4 & 6.706\times10^3 & -1.374\times10^4 & 6 \end{pmatrix}$$

TEES

Tees output is ordered as (max D/C ratio, applied pipe run moment when D/C ratio is highest, applied branch moment when D/C ratio is highest, time when max values occur, pipe run node retrieved for calculations, indicies of pipe run nodes, indicy of branch node, and realization number)

THERE ARE NOT ANY TEES ON LINES 1-1, 1-2, 1-3, & 1-4

EVALUATION OF TEES ON LINE 1-5, 1-6, & 1-7 FOR ALL 32 REALIZATIONS

VTeeB := ReadData("\TeeLine1-5_6_7.prn")

TeeB := C_S(VTeeB, R)

FORGED TEES (LINE 1-7)

Tee 1-7A (Node 591)

$$\left(TeeB_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.124 & 1.846\times10^{6} & 5.084\times10^{5} & 7.13 & 51 & 9 & 11 & 13 & 21 \end{pmatrix}$$

Tee 1-7B (Node 51)

$$\left(TeeB_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.124 & 1.846\times10^{6} & 5.084\times10^{5} & 7.13 & 51 & 9 & 11 & 13 & 21 \end{pmatrix}$$

EVALUATION OF TEES ON LINES 1-8, 1-9, 1-10, 1-11, 1-12, & 1-170 FOR ALL 32 REALIZATIONS

VTeeC := ReadData("\TeeLine1-8_9_10_11_12_170.prn")

TeeC := C_S(VTeeC, R)

Tees on Connecting Lines 1-9, 1-10, 1-11, & 1-12 to 1-8

Tee 1-9 (Node 600)

$$\left(TeeC_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.728 & 4.808\times10^{5} & 5.839\times10^{5} & 9.21 & 600 & 22 & 101 & 27 & 13 \end{pmatrix}$$

Tee 1-10 (Node 601)

$$\left(TeeC_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.707 & 4.861\times10^{5} & 5.57\times10^{5} & 9.215 & 601 & 19 & 107 & 29 & 20 \end{pmatrix}$$

Tee 1-11 (Node 599)

$$\left(TeeC_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.759 & 8.089\times10^{5} & 4.914\times10^{5} & 9.215 & 599 & 13 & 105 & 31 & 20 \end{pmatrix}$$

Tee 1-12 (Node 598)

$$\left(TeeC_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.695 & 5.28\times10^{5} & 5.253\times10^{5} & 15.17 & 598 & 16 & 99 & 33 & 12 \end{pmatrix}$$

EVALUATION OF TEES ON LINES 1-34 AND 1-67 FOR ALL 32 REALIZATIONS

VTeeD := ReadData("\TeeLine1-34_67.prn")

TeeD := C_S(VTeeD,R)

FABRICATED BRANCH T(1-34)

Fabricated Tee 1-34 (Node 588)

$$\left(\left(TeeD_{0,0}\right)^{T}\right)^{\langle 6\rangle T} = \left(0.42\quad 3.982\times 10^{5}\quad 7.593\times 10^{4}\quad 15.16\quad 588\quad 1\quad 104\quad 4\quad 9\right)$$

EVALUATION OF TEES ON LINES 1-39 & 1-40 FOR ALL 32 REALIZATIONS

VTeeE := ReadData("\TeeLine1-39_40.prn")

TeeE := C_S(VTeeE,R)

FORGED TEES (LINE 1-39)

Tee 1-39 (Node 989)

$$\left(\left(TeeE_{0,0}\right)^{T}\right)^{\langle 6\rangle T} = \left(1.044\quad 1.164\times 10^{5}\quad 1.045\times 10^{5}\quad 7.815\quad 989\quad 43\quad 45\quad 41\quad 27\right)$$

Refer to main body of report for discussion of this component

EVALUATION OF TEES ON LINES 1-44, 1-46, AND 8-14 FOR ALL 32 REALIZATIONS

VTeeF := ReadData("\TeeLine1-41_77.prn")

TeeF := C_S(VTeeF,R)

FORGED TEES (LINE 1-41)

Tee 1-41 (Node 977)

$$\left(\left(TeeF_{0,0}\right)^{T}\right)^{\langle 6\rangle T} = \left(1.432\quad 1.493\times 10^{5}\quad 1.6\times 10^{5}\quad 4.255\quad 977\quad 36\quad 162\quad 38\quad 14\right)$$

Refer to main body of report for discussion of this component

FABRICATED T(1-77)

Fabricated Tee 1-77 (Node 999)

$$\left(\left(TeeF_{0,1}\right)^{T}\right)^{\langle 6\rangle T} = \left(1.102\quad 5.678\times 10^{4}\quad 6.226\times 10^{4}\quad 10.4\quad 999\quad 48\quad 50\quad 98\quad 27\right)$$

Refer to main body of report for discussion of this component

THERE ARE NOT ANY TEES ON LINE 1-42

FLANGES

Flange output is ordered as (max D/C ratio, max total applied moment, time when max values occur, element(s) retrieved for calculations, indicie of element(s), moments about the x, y, and z axes, and realization number)

EVALUATION OF FLANGES ON LINES 1-1, 1-2, 1-3, & 1-4

VFLA := ReadData("\FlangeLine1-1_2_3_4.prn")

FLA := C_S(VFLA, R)

Pipe Properties of FL(1-1L(A-D)), FL(1-2L(A-D)), FL(1-3L(A-D)), & FL(1-4L(A-D))

Flange 1-1LA (Node 571)

$$\left(FLA_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.178 & 3.01\times10^{5} & 9.91 & 571 & 156 & -1.185\times10^{5} & 1.582\times10^{5} & -2.27\times10^{5} & 11 \end{pmatrix}$$

Flange 1-1LB (Node 568)

$$\left(FLA_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.178 & 2.999\times10^{5} & 9.91 & 568 & 17 & -1.187\times10^{5} & 1.571\times10^{5} & -2.262\times10^{5} & 11 \end{pmatrix}$$

Flange 1-1LC (Node 558)

$$\left(FLA_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.193 & 3.529\times10^{5} & 7.04 & 558 & 120 & -3.442\times10^{5} & -3.42\times10^{4} & -7.014\times10^{4} & 10 \end{pmatrix}$$

Flange 1-1LD (Node 554)

$$\left(FLA_{0,3}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.194 & 3.555\times10^{5} & 7.04 & 554 & 141 & -3.467\times10^{5} & -3.419\times10^{4} & -7.079\times10^{4} & 10 \end{pmatrix}$$

Flange 1-2LA (Node 579)

$$\left(FLA_{0,4}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.131 & 1.429\times10^{5} & 7.395 & 579 & 23 & 6.448\times10^{4} & -5.438\times10^{3} & 1.274\times10^{5} & 10 \end{pmatrix}$$

Flange 1-2LB (Node 576)

$$\left(FLA_{0,5}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.131 & 1.426\times10^{5} & 7.395 & 576 & 153 & 6.446\times10^{4} & -5.603\times10^{3} & 1.271\times10^{5} & 10 \end{pmatrix}$$

Flange 1-2LC (Node 559)

$$\left(FLA_{0,6}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.165 & 2.577\times10^{5} & 9.175 & 559 & 122 & -2.537\times10^{5} & -4.477\times10^{4} & -7.125\times10^{3} & 24 \end{pmatrix}$$

Flange 1-2LD (Node 555)

$$\left(FLA_{0,7}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.165 & 2.571\times10^{5} & 9.175 & 555 & 199 & -2.531\times10^{5} & -4.477\times10^{4} & -7.274\times10^{3} & 24 \end{pmatrix}$$

Flange 1-3LA (Node 578)

$$\left(\mathrm{FLA}_{0,8}{}^{T}\right)^{\langle 6\rangle T} = \left(0.132 \quad 1.482\times10^{5} \quad 7.385 \quad 578 \quad 25 \quad -5.632\times10^{4} \quad -3.082\times10^{4} \quad 1.336\times10^{5} \quad 26\right)$$

Flange 1-3LB (Node 577)

$$\left(\mathrm{FLA}_{0,9}{}^{T}\right)^{\langle 6\rangle T} = \left(0.132 \quad 1.478\times10^{5} \quad 7.385 \quad 577 \quad 157 \quad -5.63\times10^{4} \quad -3.042\times10^{4} \quad 1.332\times10^{5} \quad 26\right)$$

Flange 1-3LC (Node 560)

$$\left(\mathrm{FLA}_{0,10}{}^{T}\right)^{\langle 6\rangle T} = \left(0.159 \quad 2.372\times10^{5} \quad 7.245 \quad 560 \quad 126 \quad 2.207\times10^{5} \quad 2.66\times10^{4} \quad -8.29\times10^{4} \quad 10\right)$$

Flange 1-3LD (Node 556)

$$\left(\mathrm{FLA}_{0,11}{}^{T}\right)^{\langle 6\rangle T} = \left(0.159 \quad 2.372\times10^{5} \quad 7.245 \quad 556 \quad 207 \quad 2.205\times10^{5} \quad 2.663\times10^{4} \quad -8.331\times10^{4} \quad 10\right)$$

Flange 1-4LA (Node 570)

$$\left(\mathrm{FLA}_{0,12}{}^{T}\right)^{\langle 6\rangle T} = \left(0.184 \quad 3.228\times10^{5} \quad 9.52 \quad 570 \quad 160 \quad 1.398\times10^{5} \quad -1.565\times10^{5} \quad -2.453\times10^{5} \quad 2\right)$$

Flange 1-4LB (Node 569)

$$\left(\mathrm{FLA}_{0,13}{}^{T}\right)^{\langle 6\rangle T} = \left(0.184 \quad 3.217\times10^{5} \quad 9.52 \quad 569 \quad 21 \quad 1.399\times10^{5} \quad -1.556\times10^{5} \quad -2.445\times10^{5} \quad 2\right)$$

Flange 1-4LC (Node 561)

$$\left(\mathrm{FLA}_{0,14}{}^{T}\right)^{\langle 6\rangle T} = \left(0.187 \quad 3.319\times10^{5} \quad 7.255 \quad 561 \quad 124 \quad 3.285\times10^{5} \quad 2.451\times10^{4} \quad -3.992\times10^{4} \quad 28\right)$$

Flange 1-4LD (Node 557)

$$\left(\mathrm{FLA}_{0,15}{}^{T}\right)^{\langle 6\rangle T} = \left(0.188 \quad 3.341\times10^{5} \quad 7.255 \quad 557 \quad 131 \quad 3.308\times10^{5} \quad 2.45\times10^{4} \quad -4.033\times10^{4} \quad 28\right)$$

THERE ARE NOT ANY FLANGES ON LINES 1-5, 1-6, & 1-7

EVALUATION OF FLANGES ON LINES 1-30 TO 1-31 AND 1-48 FOR ALL 32 REALIZATIONS

VFLC := ReadData("\FlangeLine1-8_9_10_11_12_170.prn")

FLC := C_S(VFLC,R)

Pipe Properties of Line 1-9, 1-10, 1-11, 1-12, & 1-170

Flange (Heat Exchanger) 1-9 (Node 610)

$$\left(\mathrm{FLC}_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \left(0.193 \quad 5.336\times10^{5} \quad 9.87 \quad 610 \quad 35 \quad 1.363\times10^{5} \quad 1.961\times10^{5} \quad 4.772\times10^{5} \quad 5\right)$$

Flange (Heat Exchanger) 1-10 (Node 607)

$$\left(FLC_{0,1}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.197 \quad 5.544\times 10^{5} \quad 13.6 \quad 607 \quad 37 \quad -3.022\times 10^{5} \quad -1.21\times 10^{5} \quad 4.488\times 10^{5} \quad 11\right)$$

Flange (Heat Exchanger) 1-11 (Node 613)

$$\left(FLC_{0,2}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.196 \quad 5.483\times 10^{5} \quad 9.865 \quad 613 \quad 39 \quad 2.197\times 10^{5} \quad 1.896\times 10^{5} \quad 4.652\times 10^{5} \quad 16\right)$$

Flange (Heat Exchanger) 1-12 (Node 604)

$$\left(FLC_{0,3}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.219 \quad 6.636\times 10^{5} \quad 13.6 \quad 604 \quad 41 \quad -3.931\times 10^{5} \quad -8.767\times 10^{4} \quad 5.274\times 10^{5} \quad 25\right)$$

Flange (Heat Exchanger) 1-170 (Node 619)

$$\left(FLC_{0,4}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.183 \quad 4.865\times 10^{5} \quad 9.235 \quad 619 \quad 47 \quad 4.456\times 10^{5} \quad 8.379\times 10^{4} \quad 1.764\times 10^{5} \quad 30\right)$$

EVALUATION OF FLANGES ON LINES 1-34 AND 1-67 FOR ALL 32 REALIZATIONS

VFLD := ReadData("\FlangeLine1-34_67.prn")

FLD := C_S(VFLD, R)

Pipe Properties of Line 1-67

Flange 1-67A (Node 1129)

$$\left(FLD_{0,0}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.176 \quad 2.54\times 10^{4} \quad 9.89 \quad 1.129\times 10^{3} \quad 64 \quad -743.4 \quad -2.537\times 10^{4} \quad -1.04\times 10^{3} \quad 29\right)$$

Flange 1-67B (Node 1130)

$$\left(FLD_{0,1}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.121 \quad 1.62\times 10^{4} \quad 9.945 \quad 1.13\times 10^{3} \quad 36 \quad 7.208\times 10^{3} \quad -1.231\times 10^{4} \quad -7.68\times 10^{3} \quad 27\right.$$

EVALUATION OF FLANGES ON LINES 1-39 & 1-40 FOR ALL 32 REALIZATIONS

VFLE := ReadData("\FlangeLine1-39_40.prn")

FLE := C_S(VFLE, R)

Pipe Properties of FL(1-39(A-D))

Flange 1-39A (Node 983)

$$\left(FLE_{0,0}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.278 \quad 1.149\times 10^{5} \quad 4.25 \quad 983 \quad 87 \quad 2.381\times 10^{3} \quad -1.576\times 10^{4} \quad 1.138\times 10^{5} \quad 25\right)$$

Flange 1-39B (Node 987)

$$\left(FLE_{0,1}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.247 \quad 1.001\times 10^{5} \quad 8.5 \quad 987 \quad 66 \quad -2.392\times 10^{4} \quad 2.377\times 10^{4} \quad -9.423\times 10^{4} \quad 14\right)$$

Flange 1-39C (Node 758)

$$\left(FLE_{0,2}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.18 \quad 6.775\times10^{4} \quad 4.205 \quad 758 \quad 85 \quad 1.218\times10^{4} \quad 2.515\times10^{4} \quad 6.172\times10^{4} \quad 13\right)$$

Flange 1-39D (Node 1180)

$$\left(FLE_{0,3}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.232 \quad 9.269\times10^{4} \quad 10.18 \quad 1.18\times10^{3} \quad 61 \quad 1.852\times10^{4} \quad 1.89\times10^{4} \quad 8.884\times10^{4} \quad 16\right)$$

Pipe Properties of FL(1-39E)

Flange 1-39E (Node 990)

$$\left(FLE_{0,4}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.326 \quad 5.368\times10^{4} \quad 5.34 \quad 990 \quad 62 \quad -1.476\times10^{3} \quad 4.051\times10^{3} \quad -5.351\times10^{4} \quad 31\right)$$

EVALUATION OF FLANGES ON LINES 1-41 & 1-77 FOR ALL 32 REALIZATIONS

VFLF := ReadData("\FlangeLine1-41_77.prn")

FLF := C_S(VFLF,R)

Pipe Properties of Line 1-77, 1-37, & 1-38

Flange 1-77 (Node 992)

$$\left(FLF_{0,0}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.277 \quad 4.481\times10^{4} \quad 10.69 \quad 992 \quad 158 \quad 1.23\times10^{4} \quad -4.304\times10^{4} \quad -2.159\times10^{3} \quad 29\right)$$

Flange 1-37A (Node 1211)

$$\left(FLF_{0,1}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.312 \quad 5.108\times10^{4} \quad 4.935 \quad 1.211\times10^{3} \quad 176 \quad 6.577\times10^{3} \quad 1.873\times10^{4} \quad -4.706\times10^{4}\right.$$

Flange 1-37B (Node 1212)

$$\left(FLF_{0,2}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.309 \quad 5.063\times10^{4} \quad 4.925 \quad 1.212\times10^{3} \quad 156 \quad 1.847\times10^{4} \quad 3.286\times10^{3} \quad -4.703\times10^{4}\right.$$

Flange 1-37C (Node 1216)

$$\left(FLF_{0,3}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.244 \quad 3.881\times10^{4} \quad 4.93 \quad 1.216\times10^{3} \quad 102 \quad 2.192\times10^{4} \quad -1.31\times10^{4} \quad -2.922\times10^{4}\right.$$

Flange 1-37D (Node 1219)

$$\left(FLF_{0,4}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.123 \quad 1.676\times10^{4} \quad 4.92 \quad 1.219\times10^{3} \quad 106 \quad -6.693\times10^{3} \quad 1.374\times10^{4} \quad 6.882\times10^{3}\right.$$

Flange 1-38A (Node 1001)

$$\left(FLF_{0,5}{}^{T}\right)^{\langle 6 \rangle T} = \left(0.207 \quad 3.196\times10^{4} \quad 3.96 \quad 1.001\times10^{3} \quad 40 \quad -3.853\times10^{3} \quad 1.024\times10^{4} \quad -3.003\times10^{4}\right.$$

Flange 1-38B (Node 1213)

$$\left(FLF_{0,6}^{T}\right)^{\langle 6\rangle T} = \left(0.211 \quad 3.267\times 10^{4} \quad 3.96 \quad 1.213\times 10^{3} \quad 154 \quad -1.257\times 10^{4} \quad -2.474\times 10^{3} \quad -3.005\times 10\right.$$

Flange 1-38C (Node 1217)

$$\left(FLF_{0,7}^{T}\right)^{\langle 6\rangle T} = \left(0.18 \quad 2.707\times 10^{4} \quad 3.97 \quad 1.217\times 10^{3} \quad 122 \quad 1.489\times 10^{4} \quad 1.562\times 10^{4} \quad 1.633\times 10^{4} \quad 22\right.$$

Flange 1-38D (Node 1218)

$$\left(FLF_{0,7}^{T}\right)^{\langle 6\rangle T} = \left(0.18 \quad 2.707\times 10^{4} \quad 3.97 \quad 1.217\times 10^{3} \quad 122 \quad 1.489\times 10^{4} \quad 1.562\times 10^{4} \quad 1.633\times 10^{4} \quad 22\right.$$

EVALUATION OF FLANGES ON LINE 1-42 FOR ALL 32 REALIZATIONS

VFLG := ReadData("\FlangeLine1-42.prn")

FLG := C_S(VFLG, R)

Pipe Properties of Line 1-42

Flange 1-42A (Node 759)

$$\left(FLG_{0,0}^{T}\right)^{\langle 6\rangle T} = \left(0.155 \quad 4.976\times 10^{4} \quad 9.745 \quad 759 \quad 65 \quad 2.466\times 10^{4} \quad -5.72\times 10^{3} \quad 4.284\times 10^{4} \quad 27\right)$$

Flange 1-42B (Node 760)

$$\left(FLG_{0,1}^{T}\right)^{\langle 6\rangle T} = \left(0.182 \quad 6.206\times 10^{4} \quad 10.18 \quad 760 \quad 85 \quad -791.9 \quad -8.806\times 10^{3} \quad 6.142\times 10^{4} \quad 25\right)$$

FABRICATED BRANCH

Support output is ordered as (max D/C ratio, applied pipe run moment when D/C ratio is highest, applied branch moment when D/C ratio is highest, time when max values occur, pipe run node retrieved for calculations, indicies of pipe run node, and indicies of branch node)

EVALUATION OF TEES ON LINES 22 TO 26 FOR ALL 32 REALIZATIONS

VFB := ReadData("\FabBrLine_UNLIST_COMP.prn")

FB := C_S(VFB, R)

FABRICATED WYES

Refer to main body for treatment/conclusions regarding this component.

Fabricated Branch 1-2L (Node 572)

$$\left(FB_{0,0}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 1.443 & 5.451\times 10^{5} & 7.179\times 10^{4} & 9.89 & 572 & 59 & 65 & 45 & 12 \end{pmatrix}$$

Fabricated Branch 1-3L (Node 573)

$$\left(FB_{0,1}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 1.427 & 5.211\times 10^{5} & 5.693\times 10^{4} & 10.23 & 573 & 63 & 67 & 49 & 6 \end{pmatrix}$$

FABRICATED ELBOW BRANCH

Fabricated Branch 1-40 (Node 589)

$$\left(FB_{0,2}{}^{T}\right)^{\langle 6\rangle T} = \begin{pmatrix} 0.342 & 5.942\times 10^{5} & 5.345\times 10^{4} & 8.43 & 589 & 24 & 26 & 30 & 7 \end{pmatrix}$$

Appendix D.5

Spring Profiles for Supports Exibiting Nonlinear Behavior

SPRING STIFFNESS CALCULATIONS FOR SUPPORTS THAT EXHIBIT NONLINEAR BEHAVIOR (UPLIFT, GAPS, AND DIRECTIONALLY VARYING STIFFNESSES)

$E := 29000\text{ksi}$ — Modulus of Elasticity for supports (A7 steel)

Note: Photos referenced in calculations are included at the ends of the support section.

PS-10 *(Doesn't resist any uplift)*

PS-10 (Anchorage capacity of support couldn't be qualified so support doesn't resist any uplift)

PS-10 Stiffness

$A_{PS10} := 0.75\text{in}^2$ — Cross sectional area of PS-10 support [26] [8, Table 1-14 pg 1-99]

$L_{PS10} := 8\text{in}$ — Length of PS-10 support [26]

$$K_{PS10} := \frac{A_{PS10} \cdot E}{L_{PS10}}$$

Stiffness of PS-10

$$K_{PS10} = 2.719 \times 10^6 \frac{\text{lbf}}{\text{in}}$$

PS-10 Stiffness Profile

$$F_{PS10} := \begin{pmatrix} -10^6 & 0 & 0 \end{pmatrix}^T \text{lbf}$$

Force profile applied

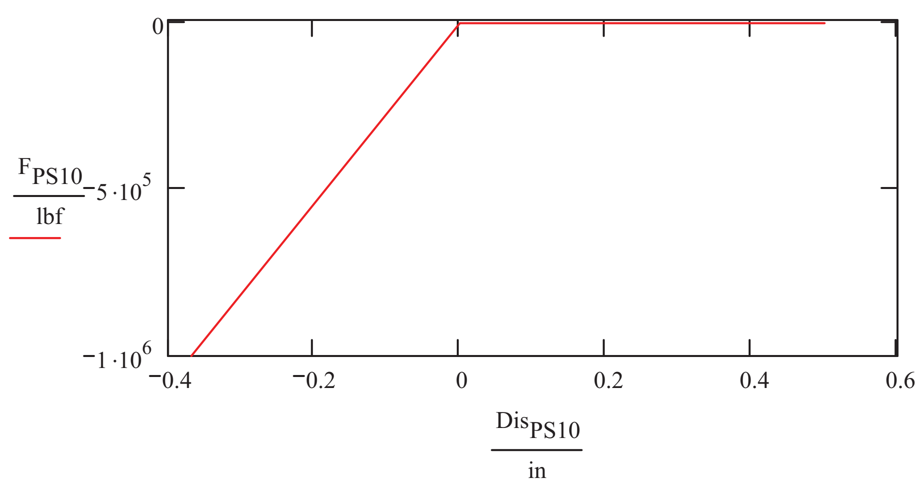
(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$$Dis_{PS10} := \begin{pmatrix} \frac{F_{PS10_0}}{K_{PS10}} & 0\text{in} & 0.5\text{in} \end{pmatrix}^T$$

$$Dis_{PS10}^T = (-0.36782 \quad 0 \quad 0.5)\,\text{in}$$

Corresponding Displacement profile to applied Force profile where 0.5 in. is used to represent the uplift displacement response trend for upward force

Resulting Force Displacement profile for PS-10



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PS-11 *(Doesn't resist any uplift)*

PS-11 (Anchorage capacity of support couldn't be qualified so support doesn't resist any uplift)

PS-11 Stiffness

$A_{PS11} := 0.75in^2$ — Cross sectional area of PS-11 support [26] [8, Table 1-14 pg 1-99]

$L_{PS11} := 26in$ — Length of PS-11 support [26]

$$K_{PS11} := \frac{A_{PS11} \cdot E}{L_{PS11}}$$ Stiffness of PS-11

$$K_{PS11} = 8.365 \times 10^5 \frac{lbf}{in}$$

PS-11 Stiffness Profile

$F_{PS11} := \begin{pmatrix} -10^6 & 0 & 0 \end{pmatrix} lbf^T$ — Force profile applied

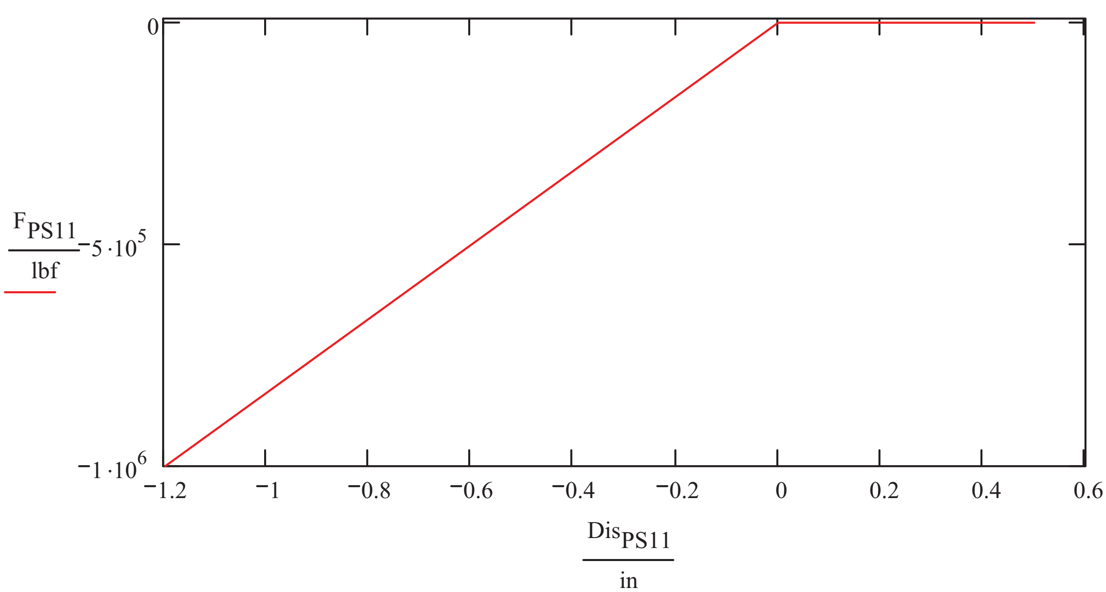
(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$$Dis_{PS11} := \begin{pmatrix} \frac{F_{PS11_0}}{K_{PS11}} & 0in & 0.5in \end{pmatrix}^T$$

Corresponding Displacement profile to applied Force profile where 0.5 in. is used to represent the uplift displacement response trend for upward force

$$Dis_{PS11}^T = \begin{pmatrix} -1.1954 & 0 & 0.5 \end{pmatrix} in$$

Resulting Force Displacement profile for PS-11



PS-23 *(Doesn't resist any uplift)*

PS-23 (Anchorage capacity of support couldn't be qualified so support doesn't resist any uplift)

PS-23 Stiffness

$A_{PS23} := 1.0in^2$ — Cross sectional area of PS-23 support [26] [8, Table 1-14 pg 1-99]

$L_{PS23} := 86in$ — Length of PS-23 support [26]

$K_{PS23} := \frac{A_{PS23} \cdot E}{L_{PS23}}$ — Stiffness of PS-23

$K_{PS23} = 3.372 \times 10^5 \frac{lbf}{in}$

PS-23 Stiffness Profile

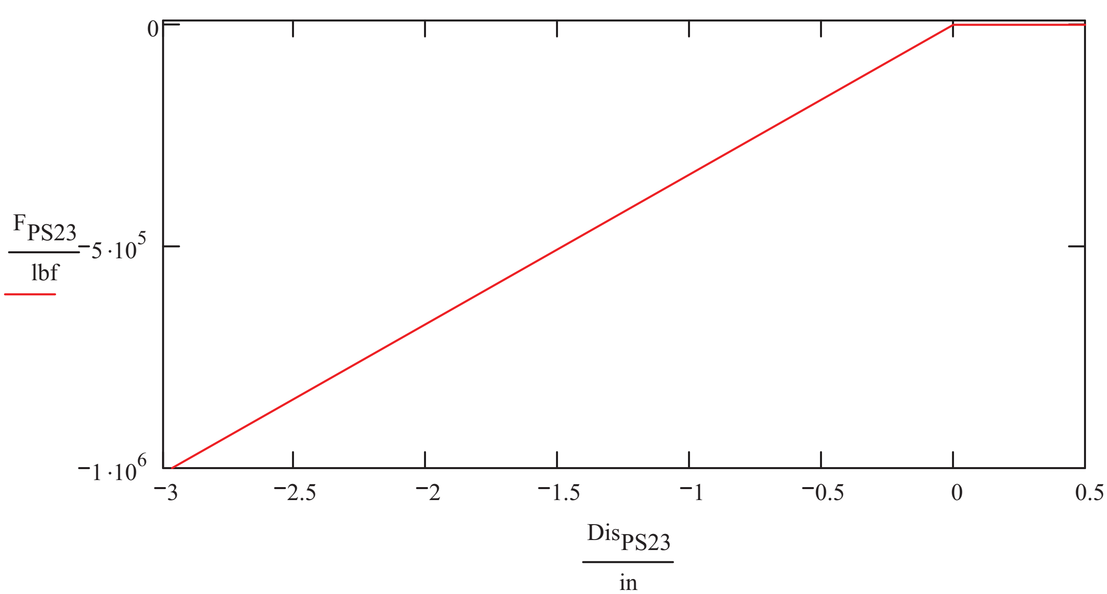
$F_{PS23} := \left(-10^6 \quad 0 \quad 0\right) lbf^T$ — Force profile applied

(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$Dis_{PS23} := \left(\frac{F_{PS23_0}}{K_{PS23}} \quad 0in \quad 0.5in\right)^T$ — Corresponding Displacement profile to applied Force profile where 0.5 in. is used to represent the uplift displacement response trend for upward force

$Dis_{PS23}^T = (-2.96552 \quad 0 \quad 0.5)\, in$

Resulting Force Displacement profile for PS-23



PR-7 (Large Gap at Base)

PR-7 Stiffness

$D_{PR7} := 1.125\text{in}$ — Diameter of rods comprising PR-7 [26]

$$A_{PR7} := \frac{\pi \cdot D_{PR7}^{\ 2}}{4}$$

Cross Sectional area of rods comprising PR-7

$$A_{PR7} = 0.994\ \text{in}^2$$

$L_{PR7} := 40\text{in}$ — Length between PR-7 connections [27, (H6)] [39, (Det 52)]

$$K_{PR7} := \frac{A_{PR7} \cdot E}{L_{PR7}}$$

Stiffness of PR-7

$$K_{PR7} = 7.207 \times 10^5 \ \frac{\text{lbf}}{\text{in}}$$

PR-7 Stiffness Profile

$G_{PR7} := 4\text{in}$ — PR-7 gap conservatively assumed to be 4" as indicated by [20] [M3-1-27-N150-FSUA-DSCN2877 (see below)]

$$F_{PR7} := \begin{pmatrix} -10^6 & 0 & 0 & 10^6 \end{pmatrix}\text{lbf}^{T}$$

Force profile applied

(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$$Dis_{PR7} := \left[\left(\frac{F_{PR7_0}}{K_{PR7}} - G_{PR7} \right) \quad -G_{PR7} \quad 0\text{in} \quad \frac{F_{PR7_3}}{K_{PR7}} \right]^T$$

Corresponding Displacement profile to applied Force profile

$$Dis_{PR7}^{\ T} = \begin{pmatrix} -5.38761 & -4 & 0 & 1.38761 \end{pmatrix}\text{in}$$

Resulting Force Displacement profile for PR-7

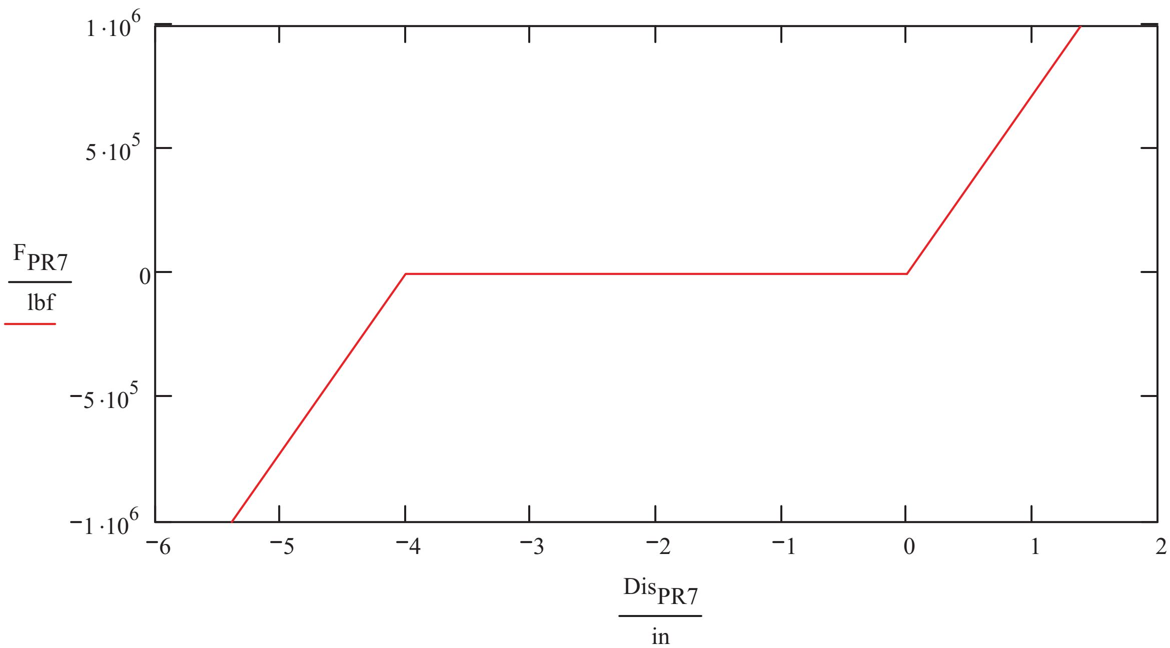


Photo [M3-1-27-N150-FSUA-DSCN2877]

Tunnel Restraint *(Varying stiffness dependant upon direction of loading (East or West))*

Tunnel Restraint Stiffness

$A_{TR} := 3.08in^2$ — Cross Sectional Tunnel Restraint sections [8, Table 1-5 pg 1-34]

$L_{TR\_E} := 24in$ — Length of east side of Tunnel Restraint support [25, (Det 28)]

$L_{TR\_W} := 60in$ — Length of west side Tunnel Restraint support [25, (Det 28)]

$$K_{TR\_E} := \frac{A_{TR} \cdot E}{L_{TR\_E}}$$

$$K_{TR\_E} = 3.722 \times 10^6 \frac{lbf}{in}$$

Stiffness of east side of Tunnel Restraint support (Assumed to be the same as that of model 3, the introduced eccentricity is accounted for in stated support capacity)

$$K_{TR\_W} := \frac{A_{TR} \cdot E}{L_{TR\_W}}$$

Stiffness of west side of Tunnel Restraint support

$$K_{TR\_W} = 1.489 \times 10^6 \frac{lbf}{in}$$

Tunnel Restraint Stiffness Profile

$G_{TR} := 0in$ — The Tunnel Restraint was observed to possess little if any gap at its interface with the pipe [M1-1-7-N62-WBUG-DSCN3048 & M3-1-27-N300-WBUI-DSCN2922 (see below)]

$F_{TR} := \left(-10^6 \quad 0 \quad 0 \quad 10^6\right) lbf^T$ — Force profile applied

(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$$Dis_{TR} := \left[\frac{F_{TR_0}}{K_{TR\_E}} \quad 0in \quad G_{TR} \quad \left(\frac{F_{TR_3}}{K_{TR\_W}} + G_{TR} \right) \right]^T$$

Corresponding Displacement profile to applied Force profile

$$Dis_{TR}^T = (-0.2687 \quad 0 \quad 0 \quad 0.67174)\, in$$

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Resulting Force Displacement profile for the Tunnel Restraint where one nonlinear spring is utilized to represent the entire profile below.

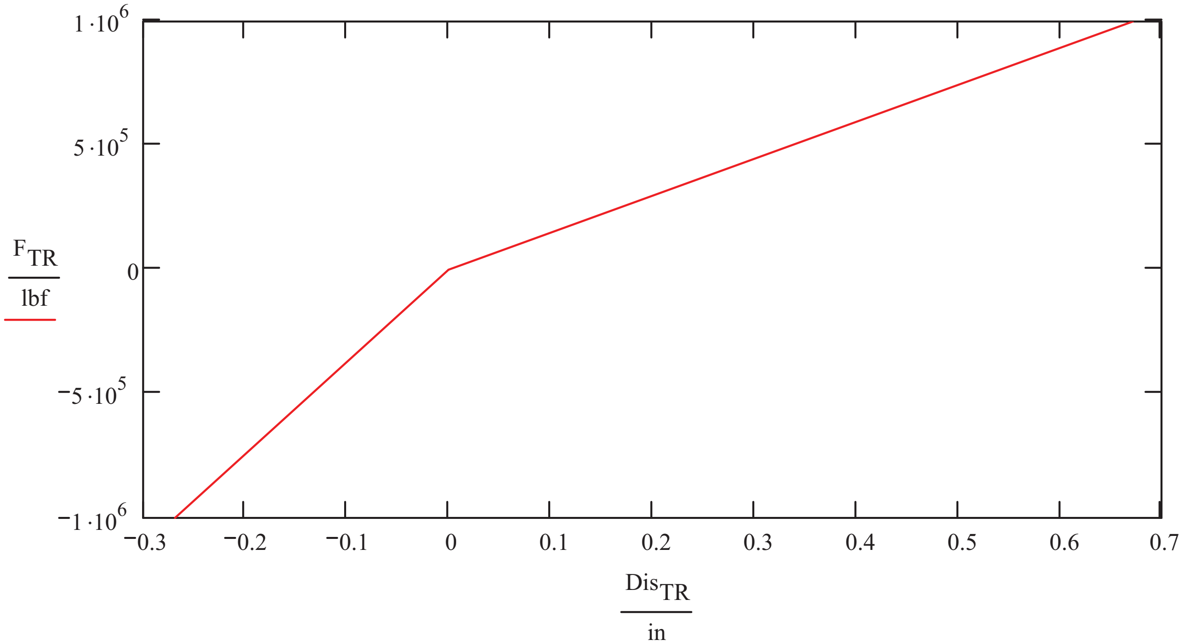


Photo [M1-1-7-N62-WBUG-DSCN3048]

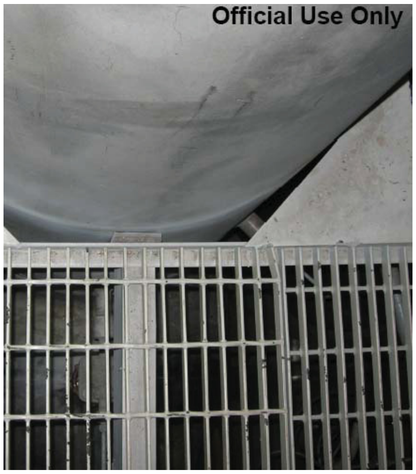


Photo [M3-1-27-N300-WBUI-DSCN2922]

PS-20A (Vertical)

PS-20A Vertical Stiffness

$F_{up} := 1\,lbf$ — Upward force applied to beam support model [32, D17A]

$d_{up} := 2.620592 \times 10^{-6} in$ — Displacement due to upward force [32, D17A]

$F_{down} := -1\,lbf$ — Upward force applied to beam support model [32, D17A]

$d_{down} := -2.263753 \times 10^{-6} in$ — Displacement due to upward force [32, D17A]

$K_{up} := \frac{F_{up}}{d_{up}}$

$K_{up} = 3.816 \times 10^{5} \frac{lbf}{in}$ — Stiffness of east side of Tunnel Restraint support

$K_{down} := \frac{F_{down}}{d_{down}}$

$K_{down} = 4.417 \times 10^{5} \frac{lbf}{in}$ — Stiffness of west side of Tunnel Restraint support

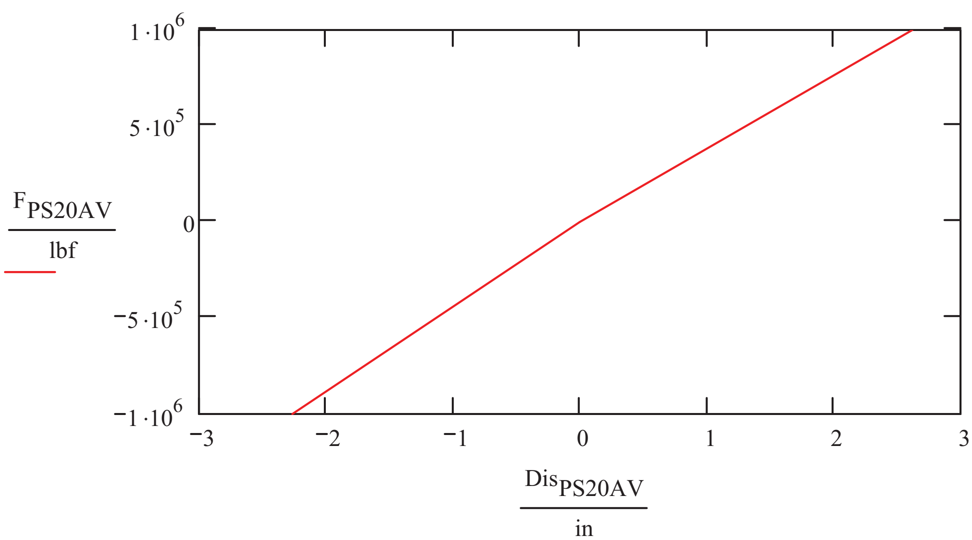
PS-20A Vertical Stiffness Profile

$F_{PS20AV} := \left(-10^{6} \quad 0 \quad 10^{6}\right)^{T} lbf$ — Force profile applied

(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$Dis_{PS20AV} := \left(\frac{F_{PS20AV_0}}{K_{down}} \quad 0in \quad \frac{F_{PS20AV_2}}{K_{up}}\right)^{T}$ — Corresponding Displacement profile to applied Force profile

$Dis_{PS20AV}^{T} = (-2.26375 \quad 0 \quad 2.62059\,)\ in$



PS-20A (Horizontal)

PS-20A Horizontal Stiffness

$F_H := 1\,\text{lbf}$ — Upward force applied to beam support model [32, D17A]

$d_H := 0.00000632835\,\text{in}$ — Displacement due to upward force [32, D17A]

$$K_H := \frac{F_H}{d_H}$$

Stiffness of east side of Tunnel Restraint support

$$K_H = 1.58 \times 10^{5}\ \frac{\text{lbf}}{\text{in}}$$

M4-1-34-N116-FSUG-DSCN2650

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Wall Penetration (Gap Between Sleeve and Pipe)

Wall Penetration Stiffness Profile

$G_{WPG} := 0.75\text{in}$

PR-7 gap conservatively assumed to be 4" as indicated by [20] [M3-1-27-N150-FSUA-DSCN2877 (see below)]

$F_{WPG} := \begin{pmatrix} -10^6 & 0 & 0 & 10^6 \end{pmatrix}\text{lbf}^T$

Force profile applied

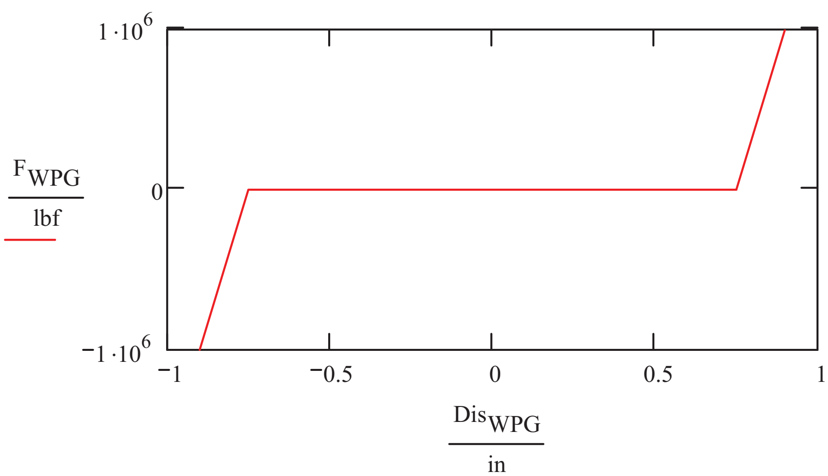
(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$Dis_{WPG} := \left[\left(-0.15\text{in} - G_{WPG}\right) \;\; -G_{WPG} \;\; G_{WPG} \;\; \left(0.15\text{in} + G_{WPG}\right)\right]^T$

$Dis_{WPG}^T = \left(-0.9 \;\; -0.75 \;\; 0.75 \;\; 0.9\right)\text{in}$

Corresponding Displacement profile to applied Force profile

Resulting Force Displacement profile for Wall Pentration Gap



M4-1-77-N5240-WPG-DSCN2682

RH-33A (Gap in Adjustable Clevis)

RH-33A Stiffness

$$D_{RH33A} := \frac{1}{2} in$$

Diameter of rod comprising RH-33A [26]

$$A_{RH33A} := \frac{\pi \cdot D_{RH33A}^{2}}{4}$$

Cross Sectional area of rods comprising RH-33A

$$A_{RH33A} = 0.196\ in^{2}$$

$$L_{RH33A} := 70in$$

Length between RH-33A connections [22] [27]

$$K_{RH33A} := \frac{A_{RH33A} \cdot E}{L_{RH33A}}$$

Stiffness of RH-33A

$$K_{RH33A} = 8.134 \times 10^{4} \frac{lbf}{in}$$

RH-33A Stiffness Profile

$$G_{RH33A} := \frac{13}{16} in$$

RH-33A gap scaled to be 13/16" as indicated by [M4-1-42-N13-CSUPC-DSCN2618 (see below)]

$$F_{RH33A} := \left(-10^{6} \quad 0 \quad 0 \quad 10^{6}\right) lbf^{T}$$

Force profile applied

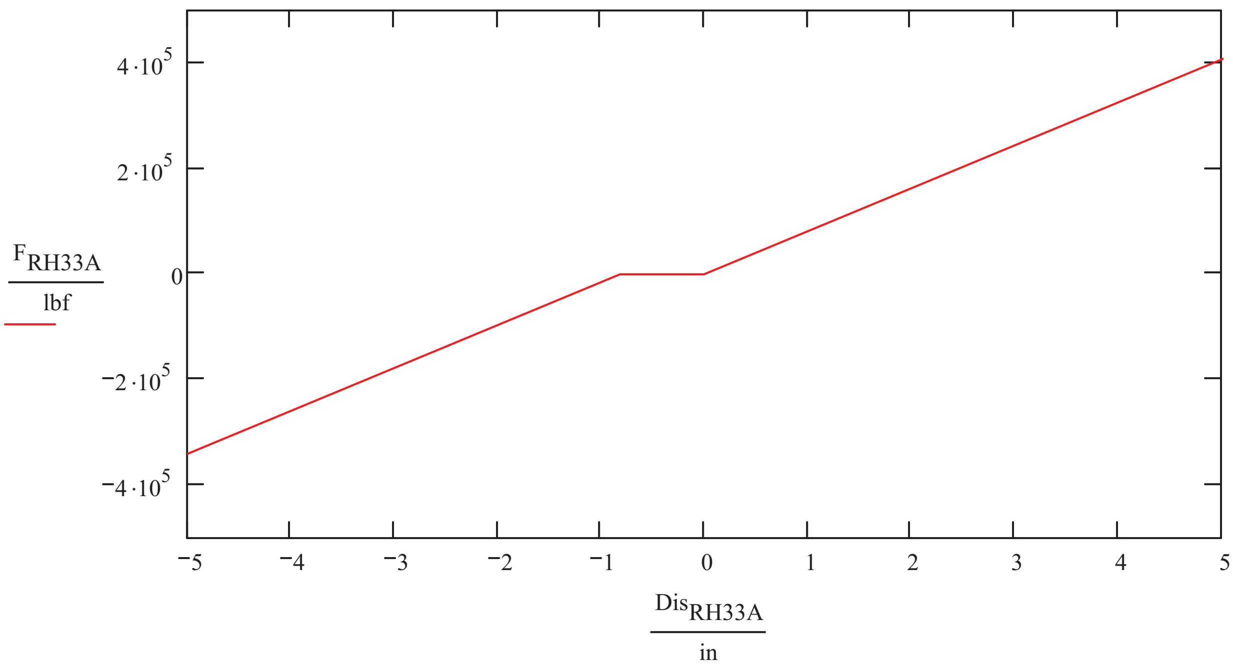
(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$$Dis_{RH33A} := \left[\left(\frac{F_{RH33A_0}}{K_{RH33A}} - G_{RH33A}\right) \quad -G_{RH33A} \quad 0in \quad \frac{F_{RH33A_3}}{K_{RH33A}}\right]^{T}$$

Corresponding Displacement profile to applied Force profile

$$Dis_{RH33A}^{T} = (-13.10585 \quad -0.8125 \quad 0 \quad 12.29335)\ in$$

Resulting Force Displacement profile for RH-33A



M4-1-42-N13-CSUPC-DSCN2618

RH-33B (Gap in Adjustable Clevis)

RH-33B Stiffness

$D_{RH33B} := 0.5in$ — Diameter of rod comprising RH-33B [26]

$A_{RH33B} := \frac{\pi \cdot D_{RH33B}^{2}}{4}$ — Cross Sectional area of rods comprising RH-33B

$A_{RH33B} = 0.196\ in^{2}$

$L_{RH33B} := 88in$ — Length between RH-33B connections [22] [27]

$K_{RH33B} := \frac{A_{RH33B} \cdot E}{L_{RH33B}}$ — Stiffness of RH-33B

$K_{RH33B} = 6.471 \times 10^{4}\ \frac{lbf}{in}$

RH-33B Stiffness Profile

$G_{RH33B} := \frac{13}{16} in$ — RH-33B gap scaled to be 13/16" as indicated by [M4-1-42-N13-CSUPC-DSCN2618 (see above)]

$F_{RH33B} := \left(-10^{6} \;\; 0 \;\; 0 \;\; 10^{6}\right) lbf^{T}$ — Force profile applied

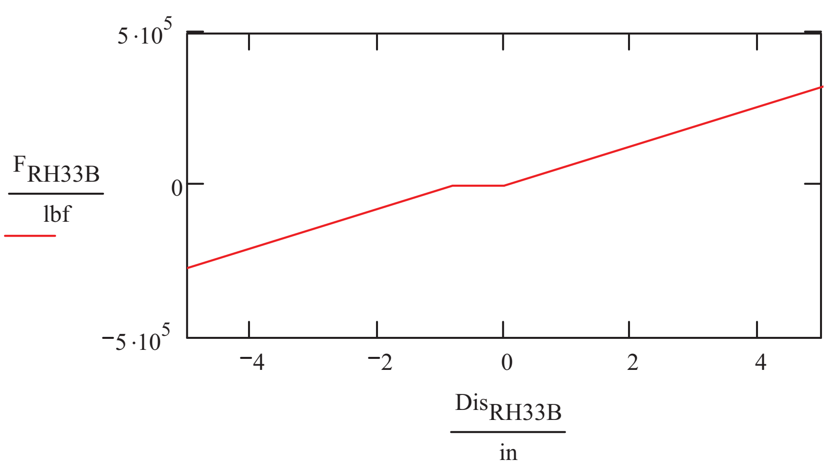
(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$$Dis_{RH33B} := \left[\left(\frac{F_{RH33B_0}}{K_{RH33B}} - G_{RH33B}\right) \;\; -G_{RH33B} \;\; 0in \;\; \frac{F_{RH33B_3}}{K_{RH33B}}\right]^{T}$$

Corresponding Displacement profile to applied Force profile

$Dis_{RH33B}^{T} = (-16.26699 \;\; -0.8125 \;\; 0 \;\; 15.45449)\ in$

Resulting Force Displacement profile for RH-33B



RH-34 (Gap in Adjustable Clevis)

RH-34 Stiffness

$$D_{RH34} := \frac{1}{2}in$$

Diameter of rod comprising RH-34 [26]

$$A_{RH34} := \frac{\pi \cdot D_{RH34}^{2}}{4}$$

Cross Sectional area of rods comprising RH-34

$$A_{RH34} = 0.196\ in^{2}$$

$$L_{RH34} := 47.3in$$

Length between RH-34 connections [31]

$$K_{RH34} := \frac{A_{RH34} \cdot E}{L_{RH34}}$$

Stiffness of RH-34

$$K_{RH34} = 1.204 \times 10^{5}\ \frac{lbf}{in}$$

RH-34 Stiffness Profile

$$G_{RH34} := \frac{13}{16}in$$

RH-34 gap scaled to be 13/16" as indicated by [M4-1-42-N13-CSUPC-DSCN2618 (see above)]

$$F_{RH34} := \begin{pmatrix} -10^{6} & 0 & 0 & 10^{6} \end{pmatrix} lbf^{T}$$

Force profile applied

(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$$Dis_{RH34} := \left[\left(\frac{F_{RH34_0}}{K_{RH34}} - G_{RH34} \right) \quad -G_{RH34} \quad 0in \quad \frac{F_{RH34_3}}{K_{RH34}} \right]^{T}$$

Corresponding Displacement profile to applied Force profile

$$Dis_{RH34}^{T} = \begin{pmatrix} -9.11929 & -0.8125 & 0 & 8.30679 \end{pmatrix} in$$

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Resulting Force Displacement profile for RH-34

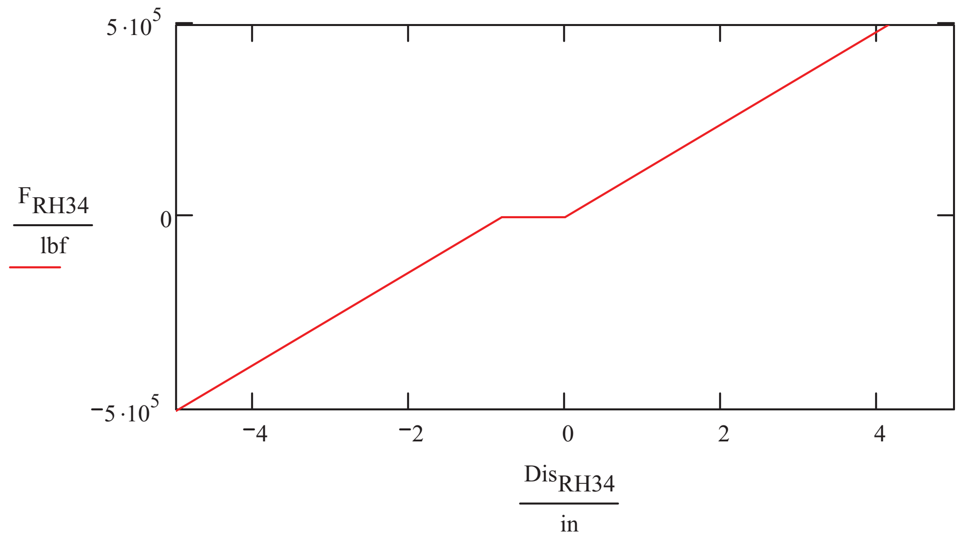


Photo of RH-34 M4-1-42-N18-PSUG-DSCN2632

RH-35 (Gap in Adjustable Clevis's)

RH-35 Stiffness

$D_{RH35} := \frac{3}{8} in$ Diameter of rod comprising RH-35 [26]

$A_{RH35} := \frac{\pi \cdot D_{RH35}^2}{4}$ Cross Sectional area of rods comprising RH-35

$A_{RH35} = 0.11\ in^2$

$L_{RH35} := 95in$ Length between RH-35 connections [31]

$K_{RH35} := \frac{A_{RH35} \cdot E}{L_{RH35}}$ Stiffness of RH-35

$K_{RH35} = 3.372 \times 10^4 \frac{lbf}{in}$

RH-35 Stiffness Profile

RH-35 gap scaled to be 13/16" [M4-1-42-N13-CSUPC-DSCN2618 (see above)] for each of the two adjustable clevis's [M4-1-40-N50-CSUPC-DSCN2639 (see below)]

$G_{RH35} := 2 \cdot \frac{13}{16} in$

$F_{RH35} := \left(-10^6 \quad 0 \quad 0 \quad 10^6\right) lbf^T$ Force profile applied

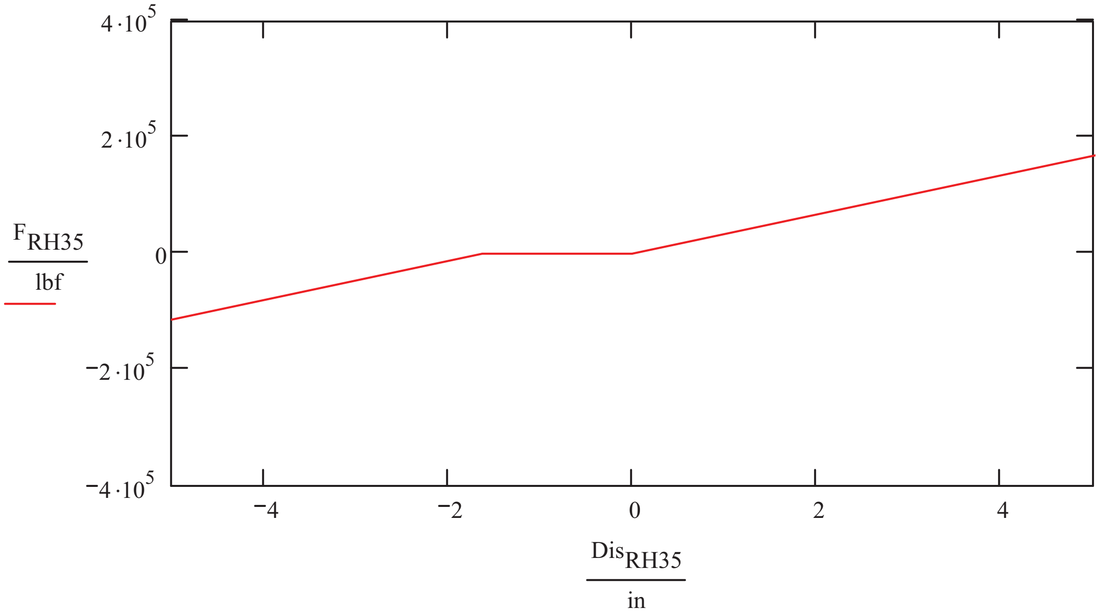
(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$$Dis_{RH35} := \left[\left(\frac{F_{RH35_0}}{K_{RH35}} - G_{RH35}\right) \quad -G_{RH35} \quad 0in \quad \frac{F_{RH35_3}}{K_{RH35}}\right]^T$$

Corresponding Displacement profile to applied Force profile

$Dis_{RH35}^T = (-31.28514 \quad -1.625 \quad 0 \quad 29.66014)\ in$

Resulting Force Displacement profile for RH-35



M4-1-40-N50-CSUPC-DSCN2639

RH-14A (Gap in Adjustable Clevis's)

RH-14A Stiffness

$$D_{RH14A} := \frac{5}{8} in$$

Diameter of rod comprising RH-14A [26]

$$A_{RH14A} := \frac{\pi \cdot D_{RH14A}^{2}}{4}$$

Cross Sectional area of rods comprising RH-14A

$$A_{RH14A} = 0.307\ in^{2}$$

$$L_{RH14A} := 49.5in$$

Length between RH-14A connections [10] [15]

$$K_{RH14A} := \frac{A_{RH14A} \cdot E}{L_{RH14A}}$$

Stiffness of RH-14A

$$K_{RH14A} = 1.797 \times 10^{5} \frac{lbf}{in}$$

RH-14A Stiffness Profile

$$G_{RH14A} := 2\frac{13}{16} in$$

RH-14A gap scaled to be 13/16" as indicated by [M4-1-42-N13-CSUPC-DSCN2618 (see below)]

$$F_{RH14A} := \begin{pmatrix} -10^{6} & 0 & 0 & 10^{6} \end{pmatrix}^{T} lbf$$

Force profile applied

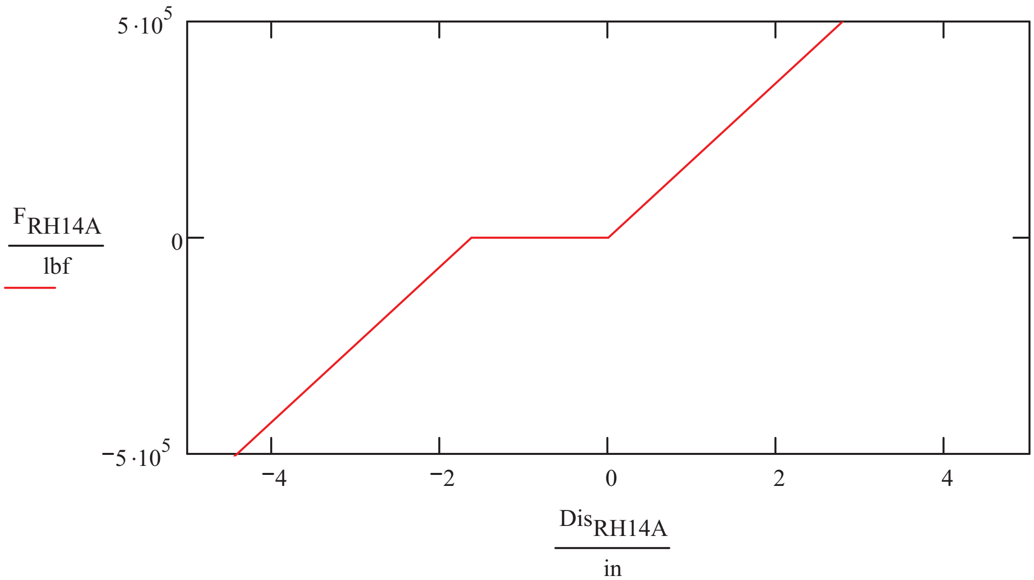
(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$$Dis_{RH14A} := \left[\left(\frac{F_{RH14A_0}}{K_{RH14A}} - G_{RH14A}\right) \quad -G_{RH14A} \quad 0in \quad \frac{F_{RH14A_3}}{K_{RH14A}}\right]^{T}$$

$$Dis_{RH14A}^{T} = (-7.18862 \quad -1.625 \quad 0 \quad 5.56362)\ in$$

Corresponding Displacement profile to applied Force profile

Resulting Force Displacement profile for RH-14A



M4-1-34-108-CSUG-DSCN2651

RH-20G between Lines 1-40 and 1-41 (Gap in Adjustable Clevis)

RH-20G Stiffness

$D_{RH20G} := \frac{5}{8} in$ — Diameter of rod comprising RH-20G [26]

$A_{RH20G} := \frac{\pi \cdot D_{RH20G}^2}{4}$ — Cross Sectional area of rods comprising RH-20G

$A_{RH20G} = 0.307\ in^2$

$L_{RH20G} := 2.83 in$ — Length in RH-20G connection representing clevis which is assumed to have same stiffness as rod [M4-1-40-N5045-PSUG-DSCN2684]

$K_{RH20G} := \frac{A_{RH20G} \cdot E}{L_{RH20G}}$ — Stiffness of RH-20G

$K_{RH20G} = 3.144 \times 10^6 \frac{lbf}{in}$

RH-20G Stiffness Profile

$G_{RH20G} := \frac{13}{16} in$ — RH-20G gap scaled to be 13/16" as indicated by [M4-1-42-N13-CSUPC-DSCN2618 (see below)]

$F_{RH20G} := \begin{pmatrix} -10^6 & 0 & 0 & 10^6 \end{pmatrix} lbf^T$ — Force profile applied

(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$Dis_{RH20G} := \left[\left(\frac{F_{RH20G_0}}{K_{RH20G}} - G_{RH20G}\right) \quad -G_{RH20G} \quad 0in \quad \frac{F_{RH20G_3}}{K_{RH20G}}\right]^T$ — Corresponding Displacement profile to applied Force profile

$Dis_{RH20G}^T = \begin{pmatrix} -1.13058 & -0.8125 & 0 & 0.31808 \end{pmatrix} in$

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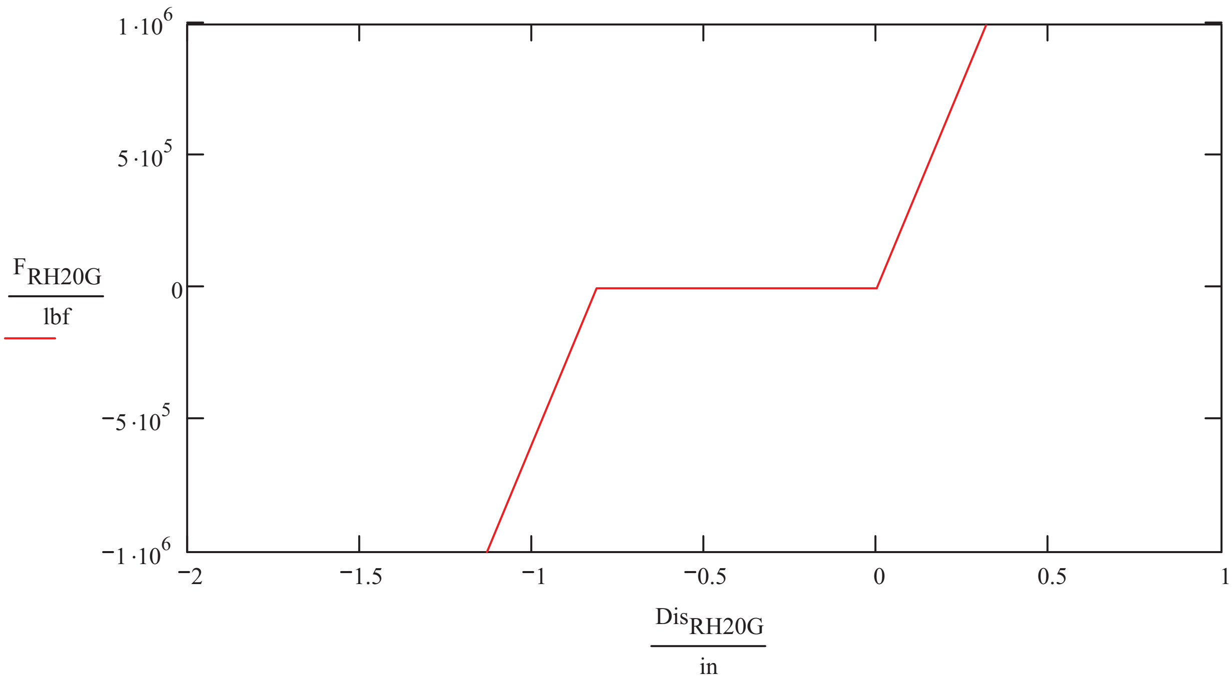
Resulting Force Displacement profile for RH-20G



M4-1-40-N5045-PSUG-DSCN2684

RH-27A u-bolt (Gap between u-bolt and plate connection)

RH-27A Stiffness

$$D_{RH27AU} := 0.625in$$

Diameter of each ubolt side comprising RH-27A [26]

$$A_{RH27AU} := 2\frac{\pi \cdot D_{RH27AU}^{2}}{4}$$

$$A_{RH27AU} = 0.614\ in^{2}$$

Cross Sectional area of ubolt comprising RH-27A

$$L_{RH27AU} := 10in + \frac{6.625in}{2}$$

Length in RH-27A connection representing clevis which is assumed to have same stiffness as rod [27]

$$K_{RH27AU} := \frac{A_{RH27AU} \cdot E}{L_{RH27AU}}$$

$$K_{RH27AU} = 1.337 \times 10^{6}\ \frac{lbf}{in}$$

Stiffness of RH-27A

$$D_{RH27AR} := 0.625in$$

Diameter of rod for RH-27A [26]

$$A_{RH27AR} := \frac{\pi \cdot D_{RH27AR}^{2}}{4}$$

$$A_{RH27AR} = 0.307\ in^{2}$$

Cross Sectional area of rod comprising RH-27A

$$L_{RH27AR} := 64in$$

Length in RH-27A rod [27]

$$K_{RH27AR} := \frac{A_{RH27AR} \cdot E}{L_{RH27AR}}$$

$$K_{RH27AR} = 1.39 \times 10^{5}\ \frac{lbf}{in}$$

Stiffness of RH-27A

$$K_{RH27A} := \frac{1}{\frac{1}{K_{RH27AU}} + \frac{1}{K_{RH27AR}}}$$

$$K_{RH27A} = 1.259 \times 10^{5}\ \frac{lbf}{in}$$

RH-27A Stiffness Profile

$$G_{RH27A} := 2\frac{13}{16}\,in$$

RH-27A gap scaled to be 13/16" as indicated by [M4-1-42-N13-CSUPC-DSCN2618 (see below)]

$$F_{RH27A} := \begin{pmatrix} -10^6 & 0 & 0 & 10^6 \end{pmatrix} lbf^T$$

Force profile applied

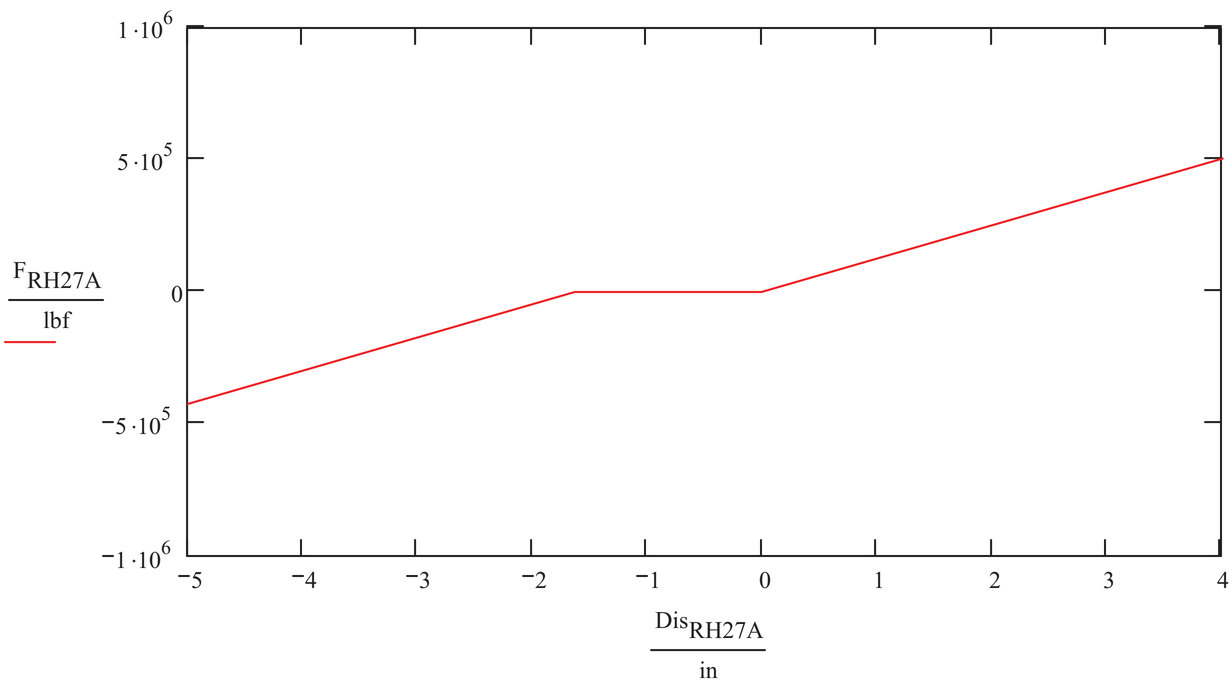
(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$$Dis_{RH27A} := \left[\left(\frac{F_{RH27A_0}}{K_{RH27A}} - G_{RH27A} \right) \quad -G_{RH27A} \quad 0in \quad \frac{F_{RH27A_3}}{K_{RH27A}} \right]^T$$

Corresponding Displacement profile to applied Force profile

$$Dis_{RH27A}^T = \begin{pmatrix} -9.5665 & -1.625 & 0 & 7.9415 \end{pmatrix} in$$

Resulting Force Displacement profile for RH-27A



RH-27B u-bolt (Gap between u-bolt and plate connection)

RH-27B Stiffness

$D_{RH27BU} := 0.5in$

Diameter of each ubolt side comprising RH-27B [26]

$$A_{RH27BU} := 2\frac{\pi \cdot D_{RH27BU}^{2}}{4}$$

Cross Sectional area of rods comprising RH-27B

$$A_{RH27BU} = 0.393\ in^{2}$$

$$L_{RH27BU} := 10in + \frac{4.5in}{2}$$

Length in RH-27B connection representing clevis which is assumed to have same stiffness as rod [27]

$$K_{RH27BU} := \frac{A_{RH27BU} \cdot E}{L_{RH27BU}}$$

Stiffness of RH-27B

$$K_{RH27BU} = 9.297 \times 10^{5}\ \frac{lbf}{in}$$

$D_{RH27BR} := 0.625in$

Diameter of rod for RH-27A [26]

$$A_{RH27BR} := \frac{\pi \cdot D_{RH27BR}^{2}}{4}$$

Cross Sectional area of rod comprising RH-27A

$$A_{RH27BR} = 0.307\ in^{2}$$

$L_{RH27BR} := 64in$

Length in RH-27A rod [27]

$$K_{RH27BR} := \frac{A_{RH27BR} \cdot E}{L_{RH27BR}}$$

Stiffness of RH-27A

$$K_{RH27BR} = 1.39 \times 10^{5}\ \frac{lbf}{in}$$

$$K_{RH27B} := \frac{1}{\frac{1}{K_{RH27BU}} + \frac{1}{K_{RH27BR}}}$$

$$K_{RH27B} = 1.209 \times 10^{5}\ \frac{lbf}{in}$$

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RH-27B Stiffness Profile

$$G_{RH27B} := 2\,\frac{13}{16}\,in$$

RH-27B gap scaled to be 13/16" as indicated by [M4-1-42-N13-CSUPC-DSCN2618 (see below)]

$$F_{RH27B} := \left(-10^6 \;\; 0 \;\; 0 \;\; 10^6\right) lbf^T$$

Force profile applied

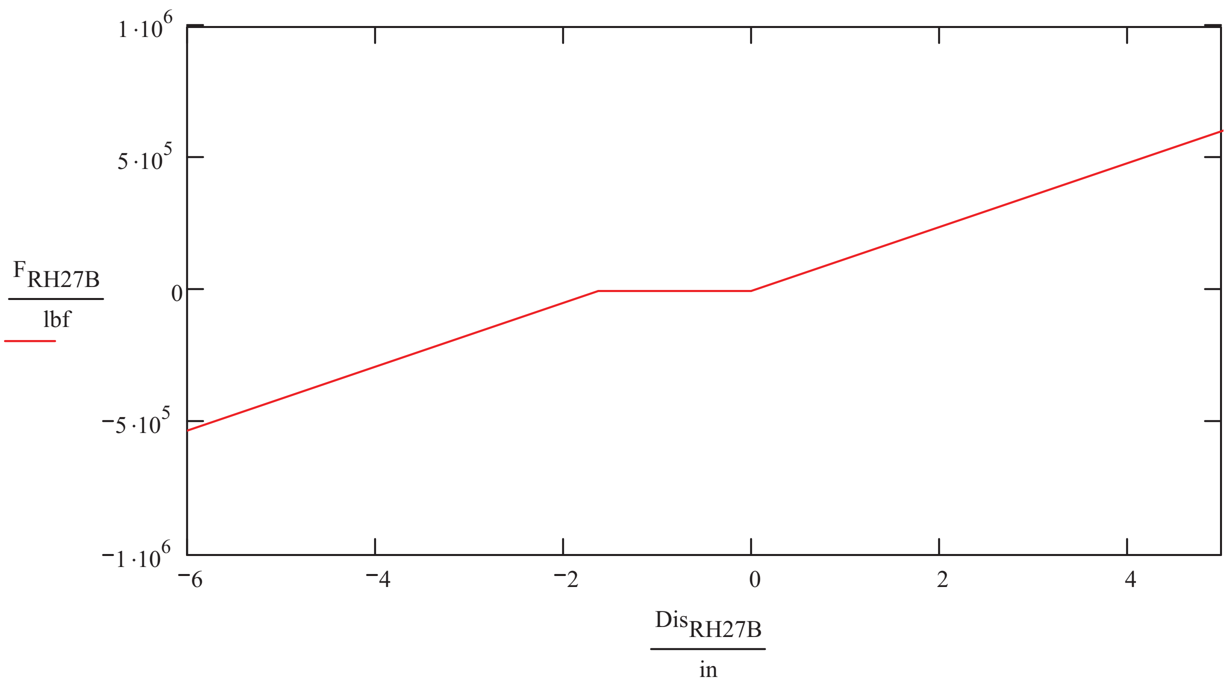
(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$$Dis_{RH27B} := \left[\left(\frac{F_{RH27B_0}}{K_{RH27B}} - G_{RH27B}\right) \;\; -G_{RH27B} \;\; 0in \;\; \frac{F_{RH27B_3}}{K_{RH27B}}\right]^T$$

Corresponding Displacement profile to applied Force profile

$$Dis_{RH27B}^{\;T} = (-9.89403 \;\; -1.625 \;\; 0 \;\; 8.26903\,)\,in$$

Resulting Force Displacement profile for RH-27B



RH-12 (Gap in Adjustable Clevis's)

RH-12 Stiffness

$D_{RH12} := \frac{5}{8} in$ — Diameter of rod comprising RH-12 [26]

$A_{RH12} := \frac{\pi \cdot D_{RH12}^{2}}{4}$ — Cross Sectional area of rods comprising RH-12

$A_{RH12} = 0.307\ in^{2}$

$L_{RH12} := 49.5 in$ — Length between RH-12 connections [27], [26, PS-10] [22]

$K_{RH12} := \frac{A_{RH12} \cdot E}{L_{RH12}}$ — Stiffness of RH-12

$K_{RH12} = 1.797 \times 10^{5} \frac{lbf}{in}$

RH-12 Stiffness Profile

$G_{RH12} := 2\frac{13}{16} in$ — RH-12 gap scaled to be 13/16" as indicated by [M4-1-42-N13-CSUPC-DSCN2618 (see below)]

$F_{RH12} := \left(-10^{6} \quad 0 \quad 0 \quad 10^{6}\right) lbf^{T}$ — Force profile applied

(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$Dis_{RH12} := \left[\left(\frac{F_{RH12_0}}{K_{RH12}} - G_{RH12}\right) \quad -G_{RH12} \quad 0in \quad \frac{F_{RH12_3}}{K_{RH12}}\right]^{T}$ — Corresponding Displacement profile to applied Force profile

$Dis_{RH12}^{T} = (-7.18862 \quad -1.625 \quad 0 \quad 5.56362)\ in$

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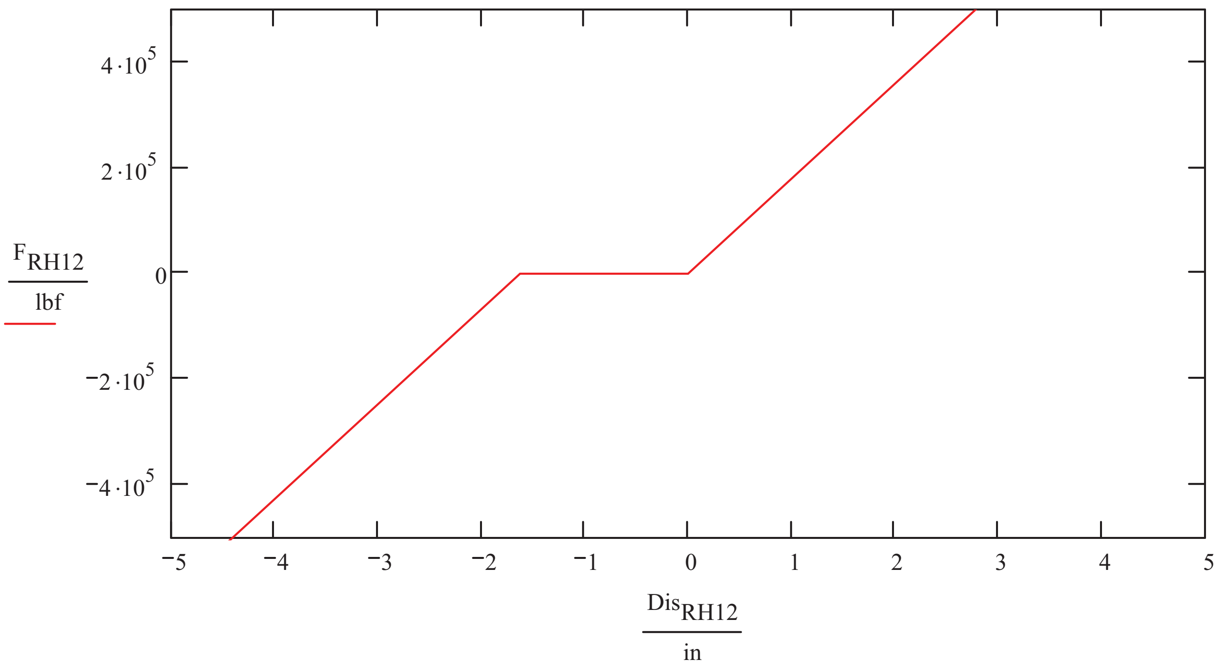
Resulting Force Displacement profile for RH-12



M4-1-42-N27-CSUG-DSCN2668

Wall Triangle Support(Gap in Adjustable Clevis's)

WTS Stiffness

$D_{WTS} := 0.75in$ — Diameter of rod comprising WTS [18]

$A_{WTS} := 0.25\pi \cdot D_{WTS}^{2}$ — Cross Sectional area of rods comprising WTS

$A_{WTS} = 0.442\ in^{2}$

$L_{WTS} := 46in$ — Length between WTS connections [M4-1-77-N5240-WSUG-DSCN323]

$K_{WTS} := \frac{A_{WTS} \cdot E}{L_{WTS}}$ — Stiffness of WTS

$K_{WTS} = 2.785 \times 10^{5}\ \frac{lbf}{in}$

WTS Stiffness Profile

$G_{WTS} := \frac{13}{16} in$ — WTS gap scaled to be 13/16" as indicated by [M4-1-42-N13-CSUPC-DSCN2618 (see below)]

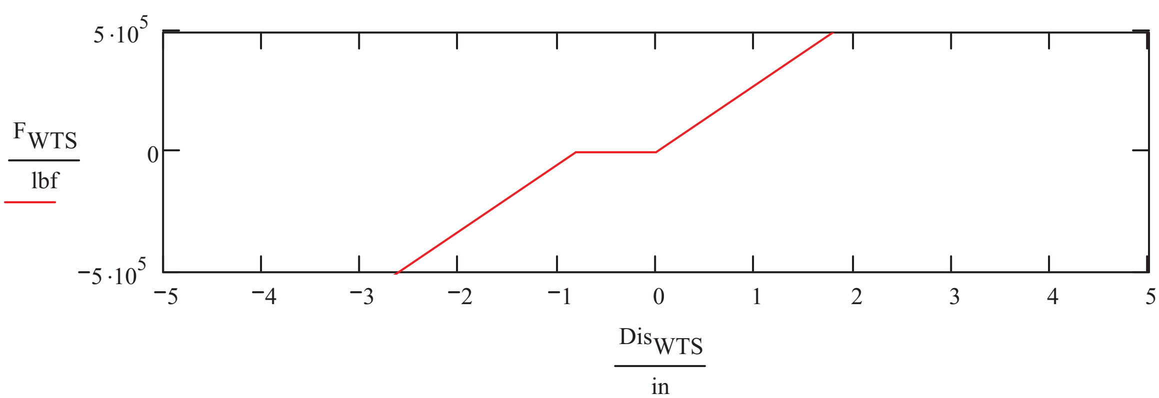
$F_{WTS} := \left(-10^{6} \quad 0 \quad 0 \quad 10^{6}\right)^{T} lbf$ — Force profile applied

(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$Dis_{WTS} := \left[\left(\frac{F_{WTS_0}}{K_{WTS}} - G_{WTS}\right) \quad -G_{WTS} \quad 0in \quad \frac{F_{WTS_3}}{K_{WTS}}\right]^{T}$ — Corresponding Displacement profile to applied Force profile

$Dis_{WTS}^{T} = (-4.40294 \quad -0.8125 \quad 0 \quad 3.59044)\ in$

Resulting Force Displacement profile for WTS



RH-14 (Gap between oversized rod 5/8" and undersized welded beam attachment)

RH-14 Stiffness

$$D_{RH14} := \frac{5}{8} in$$

Diameter of rod comprising RH-14 [26]

$$A_{RH14} := \frac{\pi \cdot D_{RH14}^{2}}{4}$$

Cross Sectional area of rods comprising RH-14

$$A_{RH14} = 0.307\ in^2$$

$$L_{RH14} := 127.5 in$$

Length between RH-14 connections [27]

$$K_{RH14} := \frac{A_{RH14} \cdot E}{L_{RH14}}$$

Stiffness of RH-14

$$K_{RH14} = 6.978 \times 10^{4}\ \frac{lbf}{in}$$

RH-14 Stiffness Profile

$$G_{RH14} := \frac{1}{4} in$$

RH-14 gap taken as difference between eye rod hole diameter minus bolt as indicated by [26] [Grinnell]

$$F_{RH14} := \begin{pmatrix} -10^6 & 0 & 0 & 10^6 \end{pmatrix}^{T} lbf$$

Force profile applied

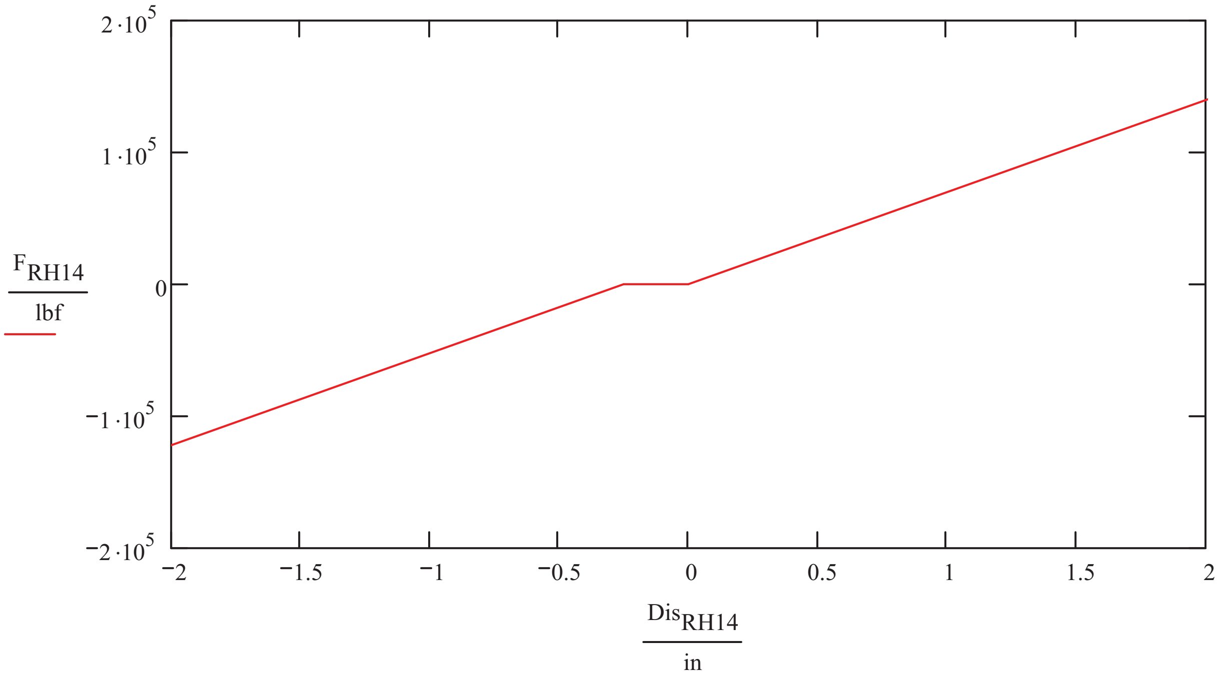
(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$$Dis_{RH14} := \left[\left(\frac{F_{RH14_0}}{K_{RH14}} - G_{RH14} \right) \quad -G_{RH14} \quad 0in \quad \frac{F_{RH14_3}}{K_{RH14}} \right]^{T}$$

Corresponding Displacement profile to applied Force profile

$$Dis_{RH14}^{T} = \begin{pmatrix} -14.58053 & -0.25 & 0 & 14.33053 \end{pmatrix} in$$

Resulting Force Displacement profile for RH-14



M4-1-34-N107-CSUA-DSCN3011

RH-22x (Support doesn't resist upward movment)

RH-22x Stiffness

$$D_{RH22xU} := 1.75in$$

Diameter of each ubolt side comprising RH-22x [26]

$$A_{RH22xU} := 2\frac{\pi \cdot D_{RH22xU}^{2}}{4}$$

Cross Sectional area of rods comprising RH-22x

$$A_{RH22xU} = 4.811\ in^{2}$$

Length in RH-22x connection representing clevis which is assumed to have same stiffness as rod [27]

$$L_{RH22xU} := 28.75in$$

$$K_{RH22xU} := \frac{A_{RH22xU} \cdot E}{L_{RH22xU}}$$

Stiffness of RH-22x

$$K_{RH22xU} = 4.852 \times 10^{6}\ \frac{lbf}{in}$$

$$D_{RH22xL} := 0.625in$$

Diameter of rod for RH-22x [26]

$$A_{RH22xL} := \frac{\pi \cdot D_{RH22xL}^{2}}{4}$$

Cross Sectional area of rod comprising RH-22x

$$A_{RH22xL} = 0.307\ in^{2}$$

$$L_{RH22xL} := 64in$$

Length in RH-22x rod [27]

$$K_{RH22xL} := \frac{A_{RH22xL} \cdot E}{L_{RH22xL}}$$

Stiffness of RH-22x

$$K_{RH22xL} = 1.39 \times 10^{5}\ \frac{lbf}{in}$$

$$K_{RH22x} := \frac{1}{\frac{1}{K_{RH22xU}} + \frac{1}{K_{RH22xL}}}$$

$$K_{RH22x} = 1.351 \times 10^{5}\ \frac{lbf}{in}$$

$$F_{RH22x} := \begin{pmatrix} 0 & 0 & 10^6 \end{pmatrix} lbf^T$$

Force profile applied

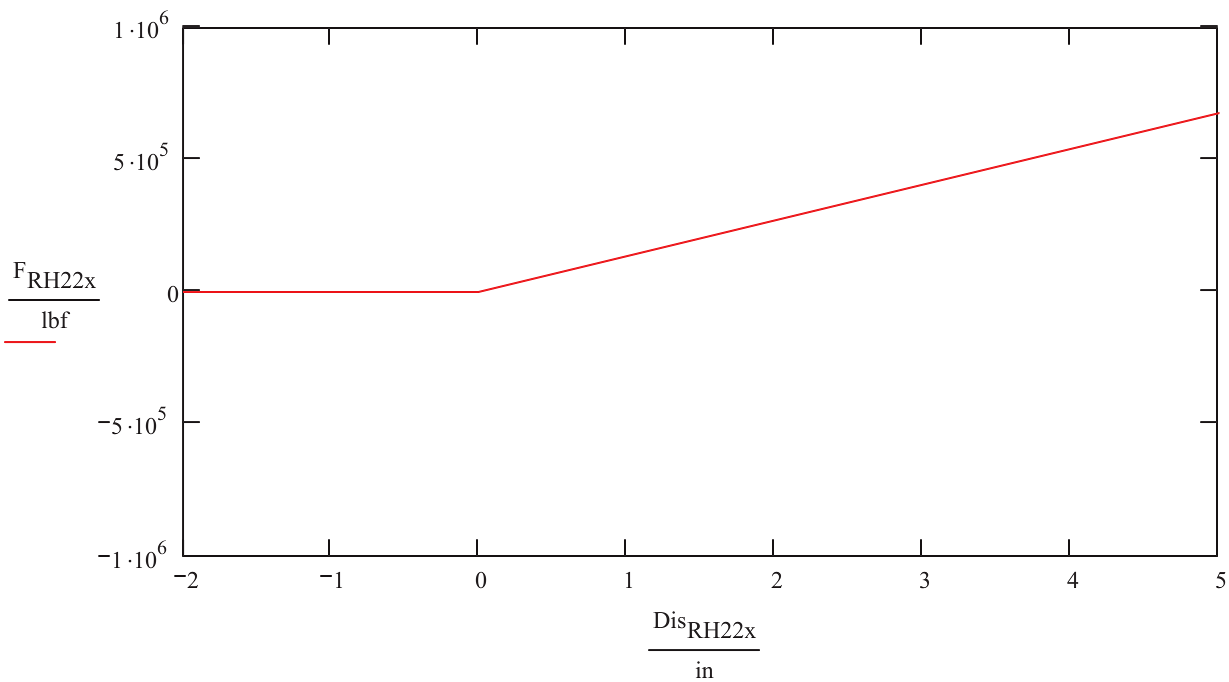
(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$$Dis_{RH22x} := \begin{pmatrix} -2in & 0in & \frac{F_{RH22x_2}}{K_{RH22x}} \end{pmatrix}^T$$

Corresponding Displacement profile to applied Force profile where 5in. is used to represent the uplift displacement response trend for upward force

$$Dis_{RH22x}^T = (-2 \quad 0 \quad 7.399\ )\ in$$

Resulting Force Displacement profile for RH-22x



RH-20 (Gap in bolt connections)

RH-20 Stiffness

$D_{RH20} := 0.625\,in$ — Diameter of rod comprising RH-20 [26]

$A_{RH20} := 0.25\pi \cdot D_{RH20}^{2}$ — Cross Sectional area of rods comprising RH-20

$A_{RH20} = 0.307\ in^2$

$L_{RH20} := 86.125\,in$ — Length between RH-20 connections [27], [26, PS-10] [22]

$K_{RH20} := \dfrac{A_{RH20} \cdot E}{L_{RH20}}$ — Stiffness of RH-20

$K_{RH20} = 1.033 \times 10^{5}\ \dfrac{lbf}{in}$

RH-20 Stiffness Profile

$G_{RH20} := 3 \cdot \left(\dfrac{1}{16}in\right)$ — RH-20 gap assumed to be developed from 1/16" slop to both eye to bolt connections and bolt to welde beam attachment

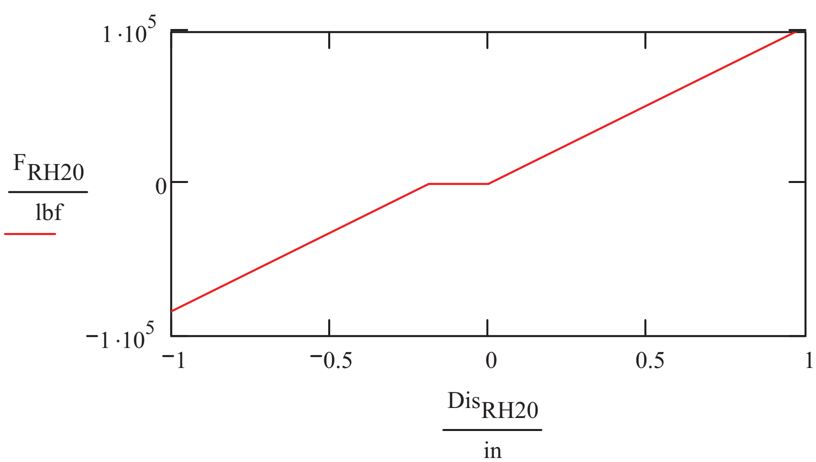
$F_{RH20} := \begin{pmatrix} -10^{6} & 0 & 0 & 10^{6} \end{pmatrix} lbf^{T}$ — Force profile applied

(Note: Negative sign indicates compression loading on nonlinear spring and positive sign indicates tension loading.)

$Dis_{RH20} := \left[\left(\dfrac{F_{RH20_0}}{K_{RH20}} - G_{RH20}\right) \quad -G_{RH20} \quad 0in \quad \dfrac{F_{RH20_3}}{K_{RH20}}\right]^{T}$ — Corresponding Displacement profile to applied Force profile

$Dis_{RH20}^{T} = (-9.86763 \quad -0.1875 \quad 0 \quad 9.68013)\ in$

Resulting Force Displacement profile for RH-20



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Appendix D.6

Dimensions Associated with Supports, Spring Hangers, Terminations, Reducers, Elbows, Tees, Fabricated Branch & Reducer, Flanges, and Valves of Model 1-4

(NOTE: Photos referenced in tables are included either below reference or in Appendix D.9.2)

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Table 1. Dimensions Associated with Supports on Line 1-1L of Model 1-4

Supports (1-1L)	*Dimensions*		*Reference*
PR-2A (North/East)	Length pipe run to attachment	5.25"	M1-1-28L-N4-WSUG-DSCN3054
	Length of pipe connection rod	10"	M1-1-28L-N4-WSUG-DSCN3054
	Length of bolt connection rods	13.25"	M1-1-28L-N4-WSUG-DSCN3054
	Size of bolt connection rods	1.25" diameter	[24]
	Length of intermediate pipe	28"	[24]
	Size of intermediate pipe	2.5" x 5 (2.88"D x 0.205"T)	[24]
	Distance from (Reference)	4.5" above FL(1-1LD)	M1-1-N24-WSUPC-DSC00059

Table 2. Dimensions Associated with Supports on Line 1-2L of Model 1-4

Supports (1-2L)	*Dimensions*		*Reference*
PR-2B (South/East)	Length pipe run to attachment	5.25"	M1-1-28L-N4-WSUG-DSCN3054
	Length of pipe connection rod	10"	M1-1-28L-N4-WSUG-DSCN3054
	Length of bolt connection rods	13.25"	M1-1-28L-N4-WSUG-DSCN3054
	Size of bolt connection rods	1.25" diameter	[24]
	Length of intermediate pipe	28"	[24]
	Size of intermediate pipe	2.5" x 5 (2.88"D x 0.205"T)	[24]
	Distance from (Reference)	9" below FL(1-2LC)	M1-1-28L-N4-WSUG-DSCN3054

Table 3. Dimensions Associated with Supports on Line 1-3L of Model 1-4

Supports (1-3L)	*Dimensions*		*Reference*
PR-2C (North/West)	Length pipe run to attachment	5.25"	M1-1-28L-N4-WSUG-DSCN3054
	Length of pipe connection rod	10"	M1-1-28L-N4-WSUG-DSCN3054
	Length of bolt connection rods	13.25"	M1-1-28L-N4-WSUG-DSCN3054
	Size of bolt connection rods	1.25" diameter	[24]
	Length of intermediate pipe	28"	[24]
	Size of intermediate pipe	2.5" x 5 (2.88"D x 0.205"T)	[24]
	Distance from (Reference)	9" below FL(1-3LC)	M1-1-28L-N4-WSUG-DSCN3054

Table 4. Dimensions Associated with Supports on Line 1-4L of Model 1-4

Supports (1-4L)	*Dimensions*		*Reference*
PR-2D (South/West)	Length pipe run to attachment	5.25"	M1-1-28L-N4-WSUG-DSCN3054
	Length of pipe connection rod	10"	M1-1-28L-N4-WSUG-DSCN3054
	Length of bolt connection rods	13.25"	M1-1-28L-N4-WSUG-DSCN3054
	Size of bolt connection rods	1.25" diameter	[24]
	Length of intermediate pipe	28"	[24]
	Size of intermediate pipe	2.5" x 5 (2.88"D x 0.205"T)	[24]
	Distance from (Reference)	4.5" above FL(1-4LD)	M1-1-N24-WSUPC-DSC00059

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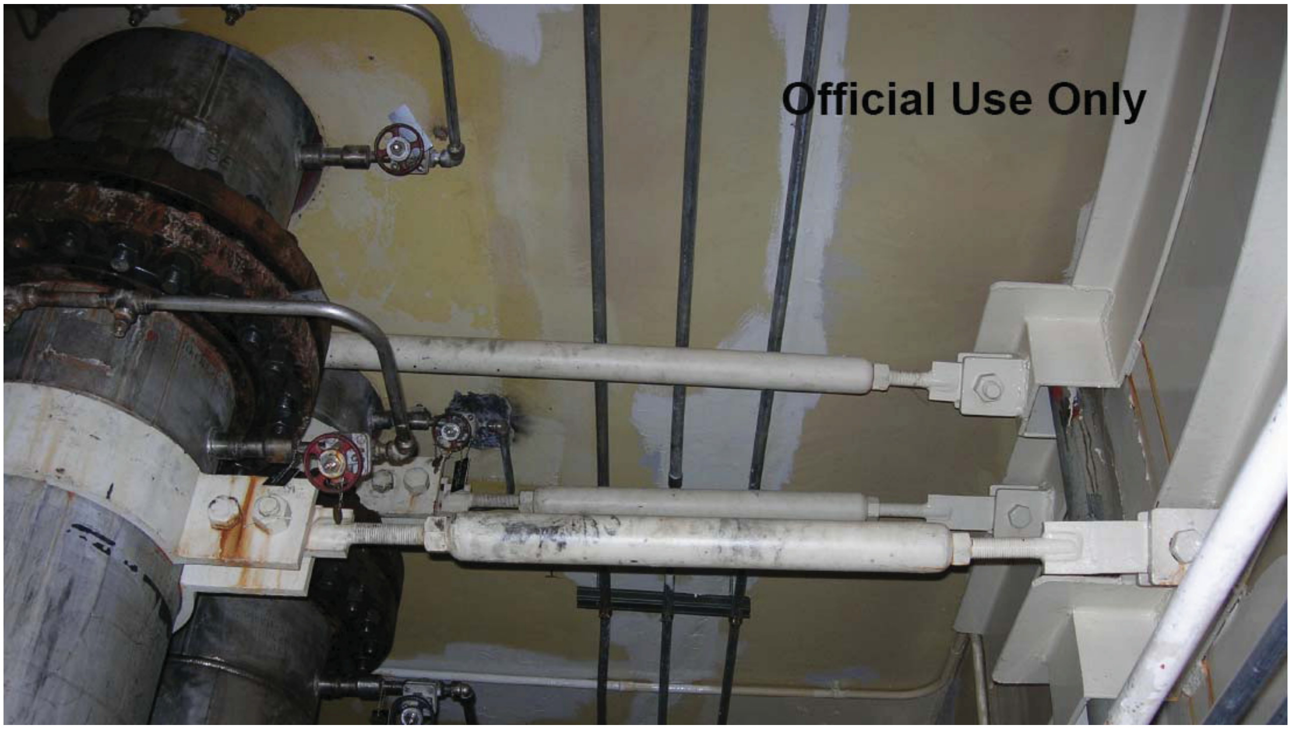

M1-1-28L-N4-WSUG-DSCN3054 (Used to determine field lengths of PR-2 Components)

M1-1-N24-WSUPC-DSC00059 (Used to determine location of PR-2A & PR-2D)

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Table 5. Dimensions Associated with Supports on Line 1-7 of Model 1-4

Supports (1-7)	*Dimensions*		*Reference*
PR-7	Length	40"	M1-1-5-N15-FSPG-DSC00090, [25, Det 13]
	Nonlinear spring profile	See Appendix D.5	
MS-1	Length of clamp cantilever	7"	M1-1-7-N61-WSNG-DSC00105
	Diameter of Snubber	6" (Used to approximate extremely stiff member)	
	Distance from (Reference)	5" from T(1-7)	M1-1-7-N61-WSNG-DSC00105
	Elevation difference from pipe clamp to anchorage	-46.286" from pipe clamp	M1-1-7-N61-WSNG-DSC00105
Tunnel Restraint	Length	84" *	
	Distance from (Reference)	105" to FORGED(1-27) center	[27], M3-1-27-N300-WBUG-DSCN3050 (Appendix B.6)
	Nonlinear spring profile	See Appendix D.5	
RH-19x	Length from ear to ceiling	42"	[25, Det 22] [27]
	Distance from (Reference)	On EL(1-7D) collinear with line 1-7D)	[27]
	Nonlinear spring profile	See Appendix D.5	
RH-20x	Length from clamp to ceiling	33.5"	[27]
	Distance from (Reference)	4' +5' +8' +8' - EL(1-7D) = 264" from EL(1-7D)	[27]
	Support rod details	1.75" diameter rod	[26]
RH-21xA	Length from clamp to ceiling	39.5"	[27]
	Distance from (Reference)	8' + 8' = 192" north of RH-20	[27]
	Support rod details	1.75" diameter rod	[26]
RH-21xB	Length from clamp to ceiling	39.5"	[27]
	Distance from (Reference)	8' + 8' = 192" north of RH-21A	[28]
	Support rod details	1.75" diameter rod	[26]
RH-22x	Length from clamp to ceiling	57.5"	[27]
	Distance from (Reference)	2' + 2' -EL(1-7C) = 12" south of EL(1-7C)	[28, E14]
	Upper support rods length	28.75"	M1-1-7-N69-CSUA-DSC00195
	Upper support rods details	2 1.75" diameter rods	M1-1-7-N69-CSUA-DSC00195
	Lower support rod details	28.75"	M1-1-7-N69-CSUA-DSC00195
	Lower support rod details	1.75" diameter rod	M1-1-7-N69-CSUA-DSC00195
MS-6	Length of clamp cantilever	7.75"	[29]
	Size of cantilever	2 sections of (1.5" x 10")*	[29], M3-1-27-N390-CSNG-DSCN2950 (Appendix B.6)
	Length of Snubber	4'-1/16"	[29]
	Diameter of Snubber	6" (Used to approximate extremely stiff member)	
	Distance from (Reference)	10" south of RH-22	M1-1-7-N69-WSNPC-DSC00201
MS-3	Length of clamp cantilever	6.625"	[30]
	Size of cantilever	2 sections of (1.5" x 10")*	[29], M3-1-27-N390-CSNG-DSCN2950 (Appendix B.6)
	Length of Snubber	5' - 1.875"	[30]
	Diameter of Snubber	5" (Used to approximate extremely stiff member)	
	Distance from (Reference)	28" above EL(1-7C)	M1-1-7-N69-CSUG-DSC00186
MS-4	Length of clamp cantilever	8"	[29]
	Angle of snubber to ceiling	20 degrees	[29], M1-1-8-N81-CSNG-DSC00030
	Length of Snubber	1' - 11"	[30]
	Diameter of Snubber	6" (Used to approximate extremely stiff member)	
	Distance from (Reference)	22.5" east of center of T(1-7)	M1-1-8-N81-CSNG-DSC00030

*Assumed to be same as MS-2 of Model 3

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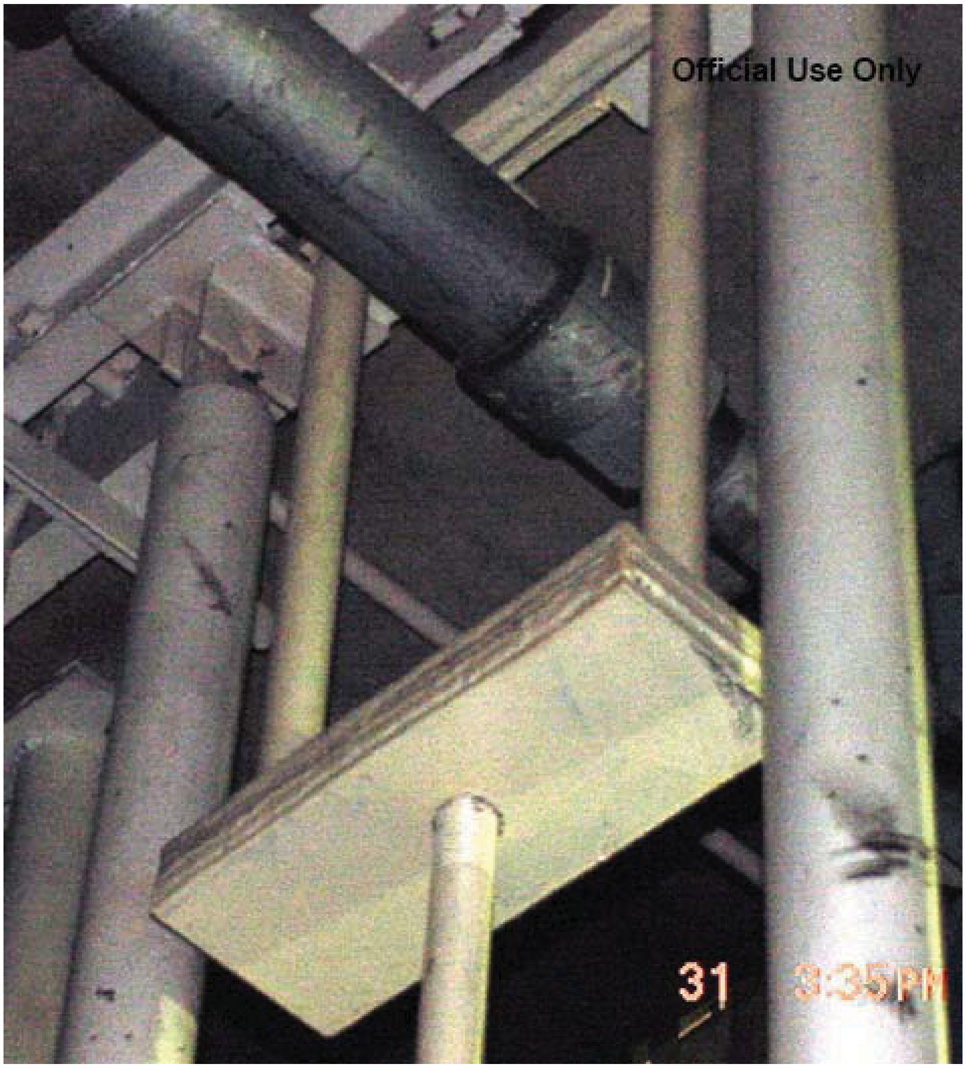

M1-1-7-N69-CSUA-DSC00195 (Used to determine rod sizes of RH-22x)

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M1-1-5-N15-FSPG-DSC00090 (Used to scale height of pipe from ground and therefore length of PR-7)

M1-1-7-N61-WSNG-DSC00105 (Used to determine length of clamp cantilever, connection, and anchorage location)

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M1-1-7-N69-WSNPC-DSC00201 (Distance from reference of MS-6)

M1-1-7-N69-CSUG-DSC00186 (Distance from reference of MS-3)

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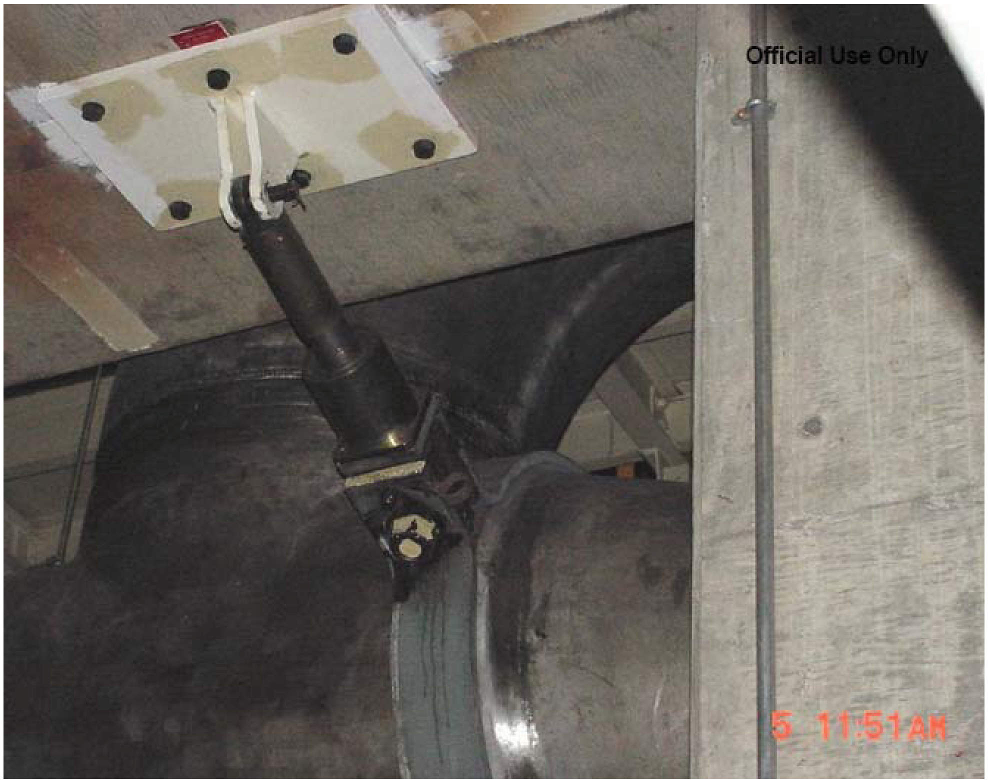

M1-1-8-n81-CSNG-DSC00030 (Distance from reference and angle from ceiling of MS-4)

Table 6. Dimensions Associated with Supports on Line 1-9 of Model 1-4

Supports (1-9)	*Dimensions*		*Reference*
PS-8E	Length from elbow top to floor	30" + 3.5" + (7'-1.5") = 119"	[22, Det 31]
	Length from connection to floor	(7'-1.5") = 85.5"	[22, Det 31]
	Nonlinear spring profile	See Appendix D.5	

Table 7. Dimensions Associated with Supports on Line 1-10 of Model 1-4

Supports (1-10)	*Dimensions*		*Reference*
PS-8F	Length from elbow top to floor	30" + 3.5" + (7'-1.5") = 119"	[22, Det 31]
	Length from connection to floor	(7'-1.5") = 85.5"	[22, Det 31]
	Nonlinear spring profile	See Appendix D.5	

Table 8. Dimensions Associated with Supports on Line 1-11 of Model 1-4

Supports (1-11)	*Dimensions*		*Reference*
PS-8G	Length from elbow top to floor	30" + 3.5" + (7'-1.5") = 119"	[22, Det 31]
	Length from connection to floor	(7'-1.5") = 85.5"	[22, Det 31]
	Nonlinear spring profile	See Appendix D.5	

Table 9. Dimensions Associated with Supports on Line 1-12 of Model 1-4

Supports (1-12)	*Dimensions*		*Reference*
PS-8H	Length from elbow top to floor	30" + 3.5" + (7'-1.5") = 119"	[22, Det 31]
	Length from connection to floor	(7'-1.5") = 85.5"	[22, Det 31]
	Nonlinear spring profile	See Appendix D.5	

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Table 10. Dimensions Associated with Supports on Line 1-170 of Model 1-4

Supports (1-170)	Dimensions		Reference
PS-20	Length from elbow top to floor	20" + 3" + 3" + (6'-4") = 102"	[22, Det 55]
	Length from connection to floor	3" + (6'-4") = 79"	[22, Det 55]
	Nonlinear spring profile	See Appendix D.5	

Table 11. Dimensions Associated with Supports on Line 1-34 of Model 1-4

Supports (1-34)	Dimensions		Reference
RH-14a	Length from clamp to ceiling	98' - 6' - 60' - (2'-6") -(5'-6") -(10'-2.5") - (2'-9") - 5" = 127.5"	[27]
	Distance from (Reference)	200" west of EL(1-34B)	[31]
	Support rod details	0.625" diameter rod	[26]
RH-14b	Length from clamp to ceiling	98' - 6' - 60' - (2'-6") -(5'-6") -(10'-2.5") - (2'-9") - 5" = 127.5"	[27]
	Distance from (Reference)	32.28" west of RH-14a	[31]
	Support rod details	0.625" diameter rod	[26]
RH-14c	Length from clamp to ceiling	98' - 6' - 60' - (2'-6") -(5'-6") -(10'-2.5") - (2'-9") - 5" = 127.5"	[27]
	Distance from (Reference)	181.26" west of RH-14b	[31]
	Support rod details	0.625" diameter rod	[26]
PS-20A	Distance from (Reference)	111.3361" west of RH-14a	[31]
	Nonlinear spring profile	See Appendix D.5	[26]
PS-14A	Length from pipe interface to floor	20.75"	[26]
	Distance from (Reference)	3" east of EL(1-34D)	M4-1-34-N114-FSUG-DSCN2695
	Nonlinear spring profile	See Appendix D.5	

M4-1-34-N1114-FSUG-DSCN2695 (Distance from reference of PS-14A)

Table 12. Dimensions Associated with Supports on Line 1-39 of Model 1-4

Supports (1-39)	*Dimensions*		*Reference*
TB2	Length from pipe interface to anchorage	15"	M4-1-39-N1015-WSUG-DSCN3290
	Width of frame at pipe interface	8.75"	M4-1-39-N1015-WSUG-DSCN3290
	Width of frame at anchorage	13.125"	M4-1-39-N1015-WSUG-DSCN3290
	Tieback Dimensions	2" x 2" x 0.25" Angle Iron	M4-1-39-N1015-WSUG-DSCN3290
	Distance from (Reference)	North of EL(1-39A)	M4-1-39-N1015-WSUG-DSCN3290

PS-11A	Length from pipe interface to floor	27.1875" (2'-2")*	[26]
	Distance from (Reference)	North side of EL(1-42H)	P9-M4-M6-DSCN0002
	Nonlinear spring profile	See Appendix D.5	

*The value 27.1875" was used instead of (2'-2") because the anchor height locations were inconsistent with that of the floor observed by PS-10A and PS-10B

M4-1-39-N1015-WSUG-DSCN3290 (Dimensional data extracted from picture for Tie Back supports)

P9-M4-M6-DSCN0002 (Location from reference)

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Table 13. Dimensions Associated with Supports on Lines 1-40 of Model 1-4

Supports (1-40)	*Dimensions*		*Reference*
PS-22	Length from pipe interface to anchor	47.5"	Assumed same as NN2 & NN3
	Distance from (Reference)	Directly below RH-14b	M4-1-34-108-CSUG-DSCN2651
	Angle Iron Form	1.5" x 1.5" x 0.25" Angle Iron	[26]

Table 14. Dimensions Associated with Supports on Lines 1-34 & 1-40 of Model 1-4

Supports (1-34 & 1-40)	*Dimensions*		*Reference*
RH-14Aa	Length of rod	9.5" + 2' + 9" - 5" - 5" = 49.5"	[10] [15]
	Distance from (1-34 Reference)	85.53057" west of EL(1-34B)	[31]
	Distance from (1-40 Reference)	Directly below line 1-34 connection	[31]
	Support rod details	0.625" diameter rod	[26]
RH-14Ab	Length of rod	59.5' - 5" - 5" = 49.5"	[10] [15]
	Distance from (1-34 Reference)	124.428" west of RH-14Aa	[31]
	Distance from (1-40 Reference)	124.428" west of RH-14Aa	[31]
	Support rod details	0.625" diameter rod	[26]
RH-14Ac	Length of rod	59.5' - 5" - 5" = 49.5"	[10] [15]
	Distance from (1-34 Reference)	124.44" west of RH-14Ab	[31]
	Distance from (1-40 Reference)	124.44" west of RH-14Ab	[31]
	Support rod details	0.625" diameter rod	[26]
RH-14Ad	Length of rod	59.5' - 5" - 5" = 49.5"	[10] [15]
	Distance from (1-34 Reference)	172.5" west of RH-14Ac	[31]
	Distance from (1-40 Reference)	172.5" west of RH-14Ac	[31]
	Support rod details	0.625" diameter rod	[26]

Table 15. Dimensions Associated with Supports on Lines 40 & 41 of Model 1-4

Supports (1-40 & 1-41)	*Dimensions*		*Reference*
RH-20	Length of rod	9" - 3.3125" -3.3125" = 2.383"	M4-1-40-N5045-PSUG-DSCN2684
	Distance from (1-40 Reference)	1.935" south EL(1-41C)*	[31]
	Distance from (1-41 Reference)	At north end of EL(1-40E)	[31]
	Support rod details	0.625" diameter rod	[26]

* Distance of 1.935" south of EL(1-41C) implemented to ensure that piping lines mated up with each other

M4-1-40-N5045-PSUG-DSCN2684 (Length of rod)

Table 16. Dimensions Associated with Supports on Lines 1-9 & 1-42 of Model 1-4

Supports (1-9 & 1-42)	***Dimensions***		***Reference***
RH-34	Length of rod	47.30435"	[31]
	Distance from (1-9 Reference)	6.062471" south of EL(1-9B)	[31]
	Distance from (1-42 Reference)	103.8095" west of NN-2	[31]
	Support rod details	0.5" diameter rod	[26]

Table 17. Dimensions Associated with Supports on Lines 1-40 & 1-42 of Model 1-4

Supports (1-40 & 1-42)	***Dimensions***		***Reference***
RH-35a	Length of rod	105" -5" - 5" = 95"	
	Distance from (1-40 Reference)	10.1566" east of RH-14Aa	[31]
	Distance from (1-42 Reference)	Directly below line 1-40 connection	[31]
	Support rod details	0.375" diameter rod	[26]

RH-35b	Length of rod	105" -5" - 5" = 95"	
	Distance from (1-40 Reference)	212.448" west of RH-35a	[31]
	Distance from (1-41 Reference)	212.448" west of RH-35a	[31]
	Support rod details	0.375" diameter rod	[26]

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Table 18. Dimensions Associated with Supports on Line 1-42 of Model 1-4

Supports (1-42)	***Dimensions***		***Reference***
RH-33A	Length from clamp to ceiling	75" - 5" = 70"	[22] [27]
	Distance from (Reference)	96" north of EL(1-42A)	[31]
	Support rod details	0.5" diameter rod	[26]
RH-33B	Length from clamp to ceiling	92" - 5" = 88"	[22] [27]
	Distance from (Reference)	191.376" north of RH-33A	[31]
	Support rod details	0.5" diameter rod	[26]
Horizontal Support	Horizontal length from pipe face to anchor	39.375"	[32,E4]
	Vertical length from pipe face to anchor	11.5625"	[32,E4]
	Distance from (Reference)	36" - EL(1-42B) = 27" south of EL(1-42B)	[32,E4]
	Support HSS Form	3"x4"x0.25" rectangular HSS	[32,E4]
PS-23	Length from pipe interface to floor	7' - 2"	[26]
	Distance from (Reference)	77" - EL(1-42B) = 68" west of EL(1-42B)	[31]
	Nonlinear spring profile	See Appendix D.5	
NN-2	Length from pipe interface to anchor	47.5"	M4-1-42-N7-WSUG-DSCN3262
	Distance from (Reference)	62.112" west of PS-23	[31]
	Angle Iron Form	3" x 3" x 0.25" Angle Iron	M4-1-42-N7-WSUG-DSCN3262
NN-3	Length from pipe interface to anchor	47.5"	M4-1-42-N7-WSUG-DSCN3262
	Distance from (Reference)	455.3039" west of NN-2	[31]
	Angle Iron Form	3" x 3" x 0.25" Angle Iron	M4-1-42-N7-WSUG-DSCN3262
PS-19	Length from pipe interface to anchor	21.5"	[120944, Detail 38]
	Distance from (Reference)	38.08193" west of EL(1-42D)	[31]
	Channel Iron Form	4" x 1.5" x 0.291" Channell iron section welded together at flanges	[120944, Detail 38]
RH-12	Length from clamp to ceiling	(14' -3") +4" - 8"- (6'-3.875") -5" = 86.125"	[27], [26, PS-10] [22]
	Distance from (Reference)	At south side of EL(1-42E)	[31]
	Support rod details	0.625" diameter rod	[26]
RH-20	Length from clamp to ceiling	(14' -3") +4" - 8"- (6'-3.875") -5" = 86.125"	[27], [26, PS-10] [22]
	Distance from (Reference)	At north side of EL(1-42F)	[31]
	Support rod details	0.625" diameter rod	[26]
PS-10A	Length from pipe interface to floor	8"	[26]
	Distance from (Reference)	North side of EL(1-42H)	P9-M4-M6-DSCN0002 (see above)
	Nonlinear spring profile	See Appendix D.5	

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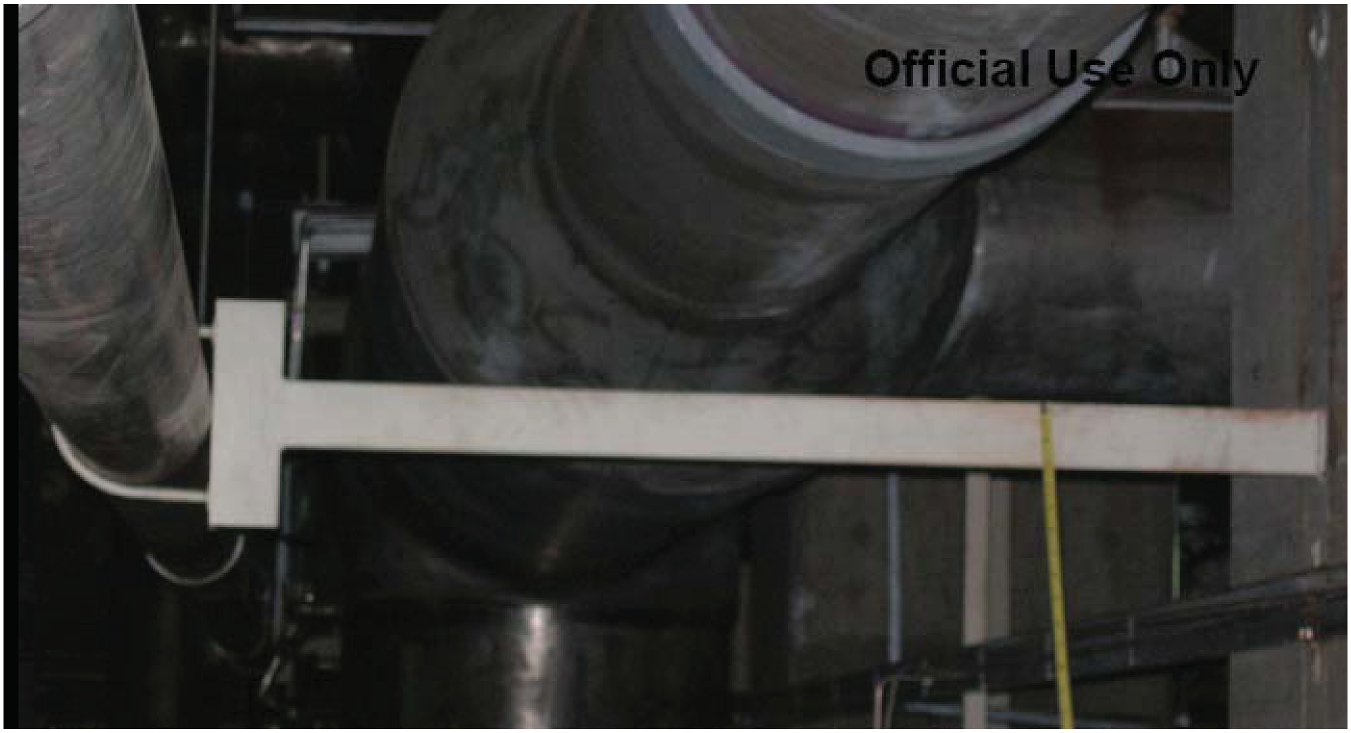

M4-1-42-N7-WSUG-DSCN3262 (Dimensions of NN2 and NN3)

Table 19. Dimensions Associated with Supports on Line 1-41 of Model 1-4

Supports (1-41)	*Dimensions*		*Reference*
PS-10B	Length from pipe interface to floor	8"	[26]
	Distance from (Reference)	South side of EL(1-41A)	P9-M4-M6-DSCN0002
	Nonlinear spring profile	See Appendix D.5	
TB1*	Length from pipe interface to anchorage	15"	M4-1-39-N1015-WSUG-DSCN3290
	Width of frame at pipe interface	8.75"	M4-1-39-N1015-WSUG-DSCN3290
	Width of frame at anchorage	13.125"	M4-1-39-N1015-WSUG-DSCN3290
	Tieback Dimensions	2" x 2" x 0.25" Angle Iron	M4-1-39-N1015-WSUG-DSCN3290
	Distance from (Reference)	Top of EL(1-41A)	M4-1-39-N1015-WSUG-DSCN3290
PS-7	Length connection to anchorage	30.375"	[25, Det 20]
	Support Shape	Fabricated Plate	[25, Det 20]
	Distance from (Reference)	24" west of EL(1-41E)	M6-1-44-N68-WSUG-DSCN2814
RH-16C	Length between connections	98' - 79' - 6' - 7' - 5" - 1.75" = 65.25"	[27, J2-3], [24, ph-18, 33]
	Distance from (Reference)	At east side of EL(1-41F)	[24, ph-18], [M6-1-44-N71-CSUG- DSCN2691]
	Support rod details	0.625" diameter rod	

*Associated photo located 4 pages prior

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M6-1-44-N68-WSUG-DSCN2814 (Length to PS-7)

M6-1-44-N71-CSUG-DSCN2691 (Length to PS-7)

Table 20. Dimensions Associated with Supports on Line 1-67 of Model 1-4

Supports (1-67)	*Dimensions*		*Reference*
PS-14B	Length from pipe interface to floor	20.75"	[26]
	Distance from (Reference)	3" west of EL(1-34E)	M4-1-34-N114-FSUG-DSCN2698
	Nonlinear spring profile	See Appendix D.5	

M4-1-34-N114-FSUG-DSCN2698 Distance from Reference)

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Table 21. Dimensions Associated with Supports on Line 1-77 of Model 1-4

Supports (1-77)	*Dimensions*		*Reference*
PS-11B	Length from pipe interface to floor	24.93753" (2'-2")*	[26]
	Distance from (Reference)	North side of EL(1-42H)	P9-M4-M6-DSCN0002 (see above)
	Nonlinear spring profile	See Appendix D.5	

*The value 24.93753" was used instead of (2'-2") because the anchor height locations were inconsistent with that of the floor observed by PS-10A and PS-10B

Wall Triangle Support	Lengthof support rod	46"	M4-1-77-N5240-WSUG-DSCN3232
	Support Rod Details	0.625" diameter	M4-1-77-N5240-WSUG-DSCN3232
	Distance from (Reference)	25" from wall penetration	P10-M4-M6-DSCN0006-1
	Length of Cantilever Angle	4"	M4-1-77-N5240-WSUG-DSCN3232
	Size of Cantilever Angle	2.5" x 2.5" x 0.25"	M4-1-77-N5240-WSUA-DSCN2702
	Length of Lower Angle	14"	M4-1-77-N5240-WSUA-DSCN2702
	Length of Hypotenuse Angle	16.125"	M4-1-77-N5240-WSUA-DSCN2702
	Distance between Lower and Hypotenuse Angles	8"	M4-1-77-N5240-WSUA-DSCN2702
	Size of Lower and Hypotenuse Angle	1.5" x 1.5" x 0.25"	M4-1-77-N5240-WSUA-DSCN2702

RH-27A & U Bolt	Length of RH-27A	73' - 60' - (6'-2") - 18" = 64"	[27]
	Length of Associated U-Bolt	10"	[27]
	Distance from (Reference)	At North side of EL(1-77D)	[27]
	RH-27B support rod details	0.625" diameter rod	[26]
	U-bolt support rod details	2 x 0.5"d = 0.707" diameter	[27]

RH-27B & U Bolt	Length of RH-27B	73' - 60' - (6'-2") - 18" = 64"	[27]
	Length of Associated U-Bolt	10"	[27]
	Distance from (Reference)	At North side of EL(1-77D)	[27]
	RH-27B support rod details	0.625" diameter rod	[26]
	U-bolt support rod details	2 x 0.625"d = 0.884" diameter	[27]

M4-1-77-N5240-WSUG-DSCN3232 (Dimensions associated with Wall Triangle Support)

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P10-M4-M6-DSCN0006-1 (Distance from reference of Wall Triangle Support)

M4-1-77-N5240-WSUA-DSCN2702 (Dimensions of Wall Triangle Support)

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Table 22. Dimensions Associated with Spring Hangers & Spring Supports on Line 1-1L of Model 1-4

Spring Hangers (1-1L)	*Dimensions*		*Reference*
SH-7A	Location	Elevation 79' - 18" - 60" = 870" Elevation	M1-1-1L-N4-CSPG-DSCN2896, [27]
	Dist from Ref	15" away from reactor vessel	M1-1-1L-N4-CSPG-DSCN2896
	Load	3700 lbf	[26]
SH-7A$_1$	Location	Elevation 79' - 18" - 60" = 870" Elevation	M1-1-1L-N4-CSPG-DSCN2896, [27]
	Dist from Ref	15" toward reactor vessel	M1-1-1L-N4-CSPG-DSCN2896
	Load	3550 lbf	[26]
SPS-4A$_1$	Location	Beneath south end of Fab Branch (1-2L)	M1-1-4-N50-FSPG-DSC00114
	Dist from Ref	6" north of connection between Fab_Br(1-2L) and PR(1-1LA)	M1-1-4-N50-FSPG-DSC00114
	Load	6000 lbf.	[26]

M1-1-1L-N4-CSPG-DSCN2896 (Locations associated with SH-7A)

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M1-1-4-N50-FSPG-DSC00114 (Dimensions SPS-4A)

Table 23. Dimensions Associated with Spring Hangers & Spring Supports on Line 1-2L of Model 1-4

Spring Hangers (1-2L)	*Dimensions*		*Reference*
SH-6A	Location	Elevation 79' - 18" - 60" = 870" Elevation	[27] ,M1-1-1L-N4-CSPG-DSCN2896 (see above)
	Dist from Ref	15" away from reactor vessel	M1-1-1L-N4-CSPG-DSCN2896 (see above)
	Load	3600 lbf	[26]

SH-6A1	Location	Elevation 79' - 18" - 60" = 870" Elevation	[27] ,M1-1-1L-N4-CSPG-DSCN2896 (see above)
	Dist from Ref	15" toward reactor vessel	M1-1-1L-N4-CSPG-DSCN2896 (see above)
	Load	3450 lbf.	[26]
SH-8A	Location	North of EL(1-2LB) on PR(1-2LB)	M1-1-1-N5-PEW-DSC00072
	Dist from Ref	27" from EL(1-2LB)	M1-1-1-N5-PEW-DSC00072
	Load	3500 lbf.	[26]

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Table 24. Dimensions Associated with Spring Hangers & Spring Supports on Line 1-3L of Model 1-4

Spring Hangers (1-3L)	*Dimensions*		*Reference*
SH-6B	Location	Elevation 79' - 18" - 60" = 870" Elevation	[27] ,M1-1-1L-N4-CSPG-DSCN2896 (see above)
	Dist from Ref	15" away from reactor vessel	M1-1-1L-N4-CSPG-DSCN2896 (see above)
	Load	3600 lbf.	[26]
SH-6B1	Location	Elevation 79' - 18" - 60" = 870" Elevation	[27] ,M1-1-1L-N4-CSPG-DSCN2896 (see above)
	Dist from Ref	15" toward reactor vessel	M1-1-1L-N4-CSPG-DSCN2896 (see above)
	Load	3600 lbf.	[26]
SH-8B	Location	North of EL(1-2LB) on PR(1-2LB)	M1-1-1-N5-PEW-DSC00072
	Dist from Ref	27" from EL(1-2LB)	M1-1-1-N5-PEW-DSC00072
	Load	2900 lbf.	

Table 25. Dimensions Associated with Spring Hangers & Spring Supports on Line 1-4L of Model 1-4

Spring Hangers (1-4L)	*Dimensions*		*Reference*
SH-7B	Location	Elevation 79' - 18" - 60" = 870" Elevation	[27] ,M1-1-1L-N4-CSPG-DSCN2896 (see above)
	Dist from Ref	15" toward reactor vessel	M1-1-1L-N4-CSPG-DSCN2896 (see above)
	Load	3450 lbf	[26]
SH-7B1	Location	Elevation 79' - 18" - 60" = 870" Elevation	[27] ,M1-1-1L-N4-CSPG-DSCN2896 (see above)
	Dist from Ref	15" away from reactor vessel	M1-1-1L-N4-CSPG-DSCN2896 (see above)
	Load	3500 lbf.	[26]
SPS-4B1	Location	Beneath south end of Fab Branch (1-3L)	M1-1-4-N50-FSPG-DSC00114
	Dist from Ref	6" north of connection between Fab_Br(1-3L) and PR(1-4LA)	M1-1-4-N50-FSPG-DSC00114
	Load	5700 lbf.	[26]

Table 26. Dimensions Associated with Spring Hangers & Spring Supports on Line 1-5 of Model 1-4

Spring Hangers (1-5)	*Dimensions*		*Reference*
SPS-4A2	Location	On PR(1-5A)	[14]
	Dist from Ref	7'-3" from center of T	[1]
	Load	9600 lbf	[26]

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Table 27. Dimensions Associated with Spring Hangers & Spring Supports on Line 1-6 of Model 1-4

Spring Hangers (1-6)	*Dimensions*		*Reference*
SPS-4B2	Location	On PR(1-6A)	[14]
	Dist from Ref	7'-3" from center of T	[1]
	Load	9600 lbf	[26]

Table 28. Dimensions Associated with Spring Hangers & Spring Supports on Line 1-7 of Model 1-4

Spring Hangers (1-7)	*Dimensions*		*Reference*
SH-20	Location	On south end of PR(1-7C)	[27]
	Dist from Ref	5' + 4' - EL(1-7D) = 72"	[27]
	Load	9200 lbf.	[26]
SH-10	Location	On backside of EL(1-7B) and vertically above PR(1-7B)	[34 Det 22]
	Dist from Ref	15" above where PR(1-7B) and PR(1-7A) Intersect	[34, Det 22]
	Load	10100 lbf.	[26]
SH-11	Location	Center of PR(1-7A)	[14]
	Dist from Ref	169.5" East of EL(1-7A) and 169.5" West of EL(1-7B)	[14]
	Load	6500 lbf.	[26]
SH-13	Location	On backside of EL(1-7A) and vertically above the branch associated with T(1-7)	[34, Det 22]
	Dist from Ref	15" above where the branch associated with T(1-7) and PR(1-7A) Intersect	[34, Det 22]
	Load	8400 lbf	[26]

Table 29. Dimensions Associated with Spring Hangers & Spring Supports on Line 1-8 of Model 1-4

Spring Hangers (1-8)	*Dimensions*		*Reference*
SH-14	Location	Between the intersection points of T(1-11) and T(1-12)	[11], [14]
	Dist from Ref	24.0625" west of T(1-11) and 24.0625" east of T(1-12)	[11], [14]
	Load	4500 lbf.	[26]
SH-12	Location	Between the intersection points of T(1-9) and T(1-10)	[11], [28]
	Dist from Ref	24.0625" west of T(1-9) and 24.0625" east of T(1-10)	[11], [28]
	Load	5600 lbf.	[26]
SH-28	Location	On east end of PR(1-170D)	M1-1-170-N131-CSUPC-DSC00028
	Dist from Ref	30" west of EL(1-170C)	M1-1-170-N131-CSUPC-DSC00028
	Load	3100 lbf.	[26]

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M1-1-170-N131-CSUPC-DSC00028 (Dimensions SH-8)

Table 30. Dimensions Associated with Spring Hangers & Spring Supports on Line 1-34 of Model 1-4

Spring Hangers (1-34)	*Dimensions*		*Reference*
SH-17	Location	On east end of PR(1-34B)	[14]
	Dist from Ref	(6'-6") - EL(1-34B) = 68"	[1]
	Load	850 lbf.	[26]

Table 31. Location Associated with Termination on Line 1-1L of Model 1-4

Termination (1-1L)	*Dimensions*		*Reference*
RV(1-1L)	Location	Where line 1-1L connects to reactor vessel	[5]

Table 32. Location Associated with Termination on Line 1-2L of Model 1-4

Termination (1-2L)	*Dimensions*		*Reference*
RV(1-2L)	Location	Where line 1-2L connects to reactor vessel	[5]

Table 33. Location Associated with Termination on Line 1-3L of Model 1-4

Termination (1-3L)	*Dimensions*		*Reference*
RV(1-3L)	Location	Where line 1-3L connects to reactor vessel	[5]

Table 34. Location Associated with Termination on Line 1-4L of Model 1-4

Termination (1-4L)	*Dimensions*		*Reference*
RV(1-4L)	Location	Where line 1-4L connects to reactor vessel	[5]

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Table 35. Location Associated with Termination on Line 1-10 of Model 1-4

Termination (1-10)	*Dimensions*		*Reference*
HX(1-10)	Location	Where line 1-10 connects to heat exchanger 670-M-3	[13]

Table 36. Location Associated with Termination on Line 1-11 of Model 1-4

Termination (1-11)	*Dimensions*		*Reference*
HX(1-11)	Location	Where line 1-11 connects to heat exchanger 670-M-4	[12]

Table 37. Location Associated with Termination on Line 1-12 of Model 1-4

Termination (1-12)	*Dimensions*		*Reference*
HX(1-12)	Location	Where line 1-12 connects to heat exchanger 670-M-5	[13]

Table 38. Location Associated with Termination on Line 1-170 of Model 1-4

Termination (1-170)	*Dimensions*		*Reference*
HX(1-170)	Location	Where line 1-170 connects to heat exchanger 670-M-85	[14]

Table 39. Location Associated with Termination on Line 1-41 of Model 1-4

Termination (1-41)	*Dimensions*		*Reference*
WFP(1-41)	Location	Where line 1-41 pentrates the floor just below west wall	[18]

Table 40. Location Associated with Termination on Line 1-67 of Model 1-4

Termination (1-67)	*Dimensions*		*Reference*
PDT(1-67)	Location	Where line 1-67 pentrates into Primary Degassing Tank	[18]

Table 41. Location Associated with Termination on Line 1-37 of Model 1-4

Termination (1-37)	*Dimensions*		*Reference*
NFP(1-37)	Location	Where line 1-37 pentrates into lower west floor	[38]

Table 42. Location Associated with Termination on Line 1-38 of Model 1-4

Termination (1-38)	*Dimensions*		*Reference*
NFP(1-38)	Location	Where line 1-38 pentrates into lower west floor	[38]

Table 43. Dimensions Associated with Pipe Runs on Line 1-1L of Model 1-4

Pipe Run (1-1L)	*Dimensions*		*Reference*
P (1-1LA)	Pipe Diameter	18"	[6]
	Pipe Thickness	0.312"	[6]
	Pipe Material	SS304L	[6]
	Length between	(5'-7") + 0.5"+ 9" + 2.5" -EL(1-1LA) = 67.5"	[6]
P (1-1LB)	Pipe Diameter	18"	[6]
	Pipe Thickness	0.312"	[6]
	Pipe Material	SS304L	[6]
	Length between	(3'-6.4375") - EL(1-1LB) - EL(1-1LA) = 13.1875"	[6]
P (1-1LC)	Pipe Diameter	18"	[5][6]
	Pipe Thickness	0.312"	[5][6]
	Pipe Material	SS304L	[5][6]
	Length between	(7'-5.5") + (34'-8") + 0.5" - EL(1-1LB) - EL(1-1LC) = 461"	[5][6]
P (1-1LD)	Pipe Diameter	18"	[5]
	Pipe Thickness	0.312"	[5]
	Pipe Material	SS304L	[5]
	Length between	(9'-7") - RED(1-1L) - EL(1-1L) = 73"	[5]

Table 44. Dimensions Associated with Pipe Runs on Line 1-2L of Model 1-4

Pipe Run (1-2L)	*Dimensions*		*Reference*
P (1-2LA)	Pipe Diameter	18"	[6]
	Pipe Thickness	0.312"	[6]
	Pipe Material	SS304L	[6]
	Length between	(4'-9.0625") - EL(1-2LA) - FAB_BR(1-2L)branch = 28.87"	[6]
P (1-2LB)	Pipe Diameter	18"	[6]
	Pipe Thickness	0.312"	[6]
	Pipe Material	SS304L	[6]
	Length between	(8'-7") + 0.5" +(4'-11.125") - EL(1-2LB)- EL(1-2LA) = 124.375"	[6]
P (1-2LC)	Pipe Diameter	18"	[5][6]
	Pipe Thickness	0.312"	[5][6]
	Pipe Material	SS304L	[5][6]
	Length between	(9'-5.5") + (34'-8") + 0.5" - EL(1-2LB) - EL(1-2LC) = 476"	[5][6]
P (1-2LD)	Pipe Diameter	18"	[5]
	Pipe Thickness	0.312"	[5]
	Pipe Material	SS304L	[5]
	Length between	(9'-7") - RED(1-2L) - EL(1-2LC) = 73"	[5]

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Table 45. . Dimensions Associated with Pipe Runs on Line 1-3L of Model 1-4

Pipe Run (1-3L)	*Dimensions*		*Reference*
P (1-3LA)	Pipe Diameter	18"	[7]
	Pipe Thickness	0.312"	[7]
	Pipe Material	SS304L	[7]
	Length between	(4'-9.0625") - EL(1-3LA) - FAB_BR(1-3L)branch = 28.87"	[7]
P (1-3LB)	Pipe Diameter	18"	[7]
	Pipe Thickness	0.312"	[7]
	Pipe Material	SS304L	[7]
	Length between	(8'-7") + 0.5" +(4'-11.125") - EL(1-3LB) - EL(1-3LA) = 124.375"	[7]
P (1-3LC)	Pipe Diameter	18"	[5][7]
	Pipe Thickness	0.312"	[5][7]
	Pipe Material	SS304L	[5][7]
	Length between	(9'-5.5") + (34'-8") + 0.5" - EL(1-3LB) - EL(1-3LC) = 476"	[5][7]
P (1-3LD)	Pipe Diameter	18"	[5]
	Pipe Thickness	0.312"	[5]
	Pipe Material	SS304L	[5]
	Length between	(9'-7") - RED(1-3L) - EL(1-3LC) = 73"	[5]

Table 46. Dimensions Associated with Pipe Runs on Line 1-4L of Model 1-4

Pipe Run (1-4L)	*Dimensions*		*Reference*
P (1-4LA)	Pipe Diameter	18"	[7]
	Pipe Thickness	0.312"	[7]
	Pipe Material	SS304L	[7]
	Length between	(5'-7") + 0.5"+ 9" + 2.5" -EL(1-1LA) = 67.5"	[7]
P (1-4LB)	Pipe Diameter	18"	[7]
	Pipe Thickness	0.312"	[7]
	Pipe Material	SS304L	[7]
	Length between	(3'-6.4375") - EL(1-4LB) - EL(1-4LA) = 13.1875"	[7]
P (1-4LC)	Pipe Diameter	18"	[5][7]
	Pipe Thickness	0.312"	[5][7]
	Pipe Material	SS304L	[5][7]
	Length between	(7'-5.5") + (34'-8") + 0.5" - EL(1-4LB) - EL(1-4LC) = 461"	[5][7]
P (1-4LD)	Pipe Diameter	18"	[5]
	Pipe Thickness	0.312"	[5]
	Pipe Material	SS304L	[5]
	Length between	(9'-7") - RED(1-4L) - EL(1-4LC) = 73"	[5]

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Table 47. Dimensions Associated with Pipe Runs on Line 1-5 & 1-5L of Model 1-4

Pipe Run (1-5 & 5L)	*Dimensions*		*Reference*
P (1-5A)	Pipe Diameter	24"	[6]
	Pipe Thickness	0.375"	[6]
	Pipe Material	SS304	[6]
	Length between	(9'-3.5") - EL(1-5A) = 75.5"	[6]
P (1-5LB)	Pipe Diameter	24"	[6]
	Pipe Thickness	0.375"	[6]
	Pipe Material	SS304L	[6]
	Length between	(10'-10") - EL(1-5A) - FAB_BR(1-2L) = 76"	[6]

Table 48. Dimensions Associated with Pipe Runs on Line 1-6 & 1-6L of Model 1-4

Pipe Run (1-6 & 6L)	*Dimensions*		*Reference*
P (1-6A)	Pipe Diameter	24"	[7]
	Pipe Thickness	0.375"	[7]
	Pipe Material	SS304	[7]
	Length between	(9'-3.5") - EL(1-5A) = 75.5"	[7]
P (1-6LB)	Pipe Diameter	24"	[7]
	Pipe Thickness	0.375"	[7]
	Pipe Material	SS304L	[7]
	Length between	(10'-10") - EL(1-6A) - FAB_BR(1-3L) = 76"	[7]

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Table 49. Dimensions Associated with Pipe Runs on Line 1-7 of Model 1-4

Pipe Run (1-7)	*Dimensions*		*Reference*
P (1-7A)	Pipe Diameter	36"	[10]
	Pipe Thickness	0.5"	[10]
	Pipe Material	SS304	[10]
	Length between	(34'-3") - EL(1-7A) - EL(1-7B) = 339"	[10]
P (1-7B)	Pipe Diameter	36"	[10]
	Pipe Thickness	0.5"	[10]
	Pipe Material	SS304	[10]
	Length between	(10'-2.5") - EL(1-7B) - EL(1-7C) = 50.5"	[10]
P (1-7C)	Pipe Diameter	36"	[10]
	Pipe Thickness	0.5"	[10]
	Pipe Material	SS304	[10]
	Length between	(78'-1.5") - EL(1-7C) - EL(1-7D) = 865.5"	[10]
P (1-7D)	Pipe Diameter	36"	[10]
	Pipe Thickness	0.5"	[10]
	Pipe Material	SS304	[10]
	Length between	(24') - 6" - EL(1-7D) - T(1-7)branch = 220.5"	[10]

Table 50. Dimensions Associated with Pipe Runs on Line 1-8 of Model 1-4

Pipe Run (1-8)	*Dimensions*		*Reference*
P (1-8A)	Pipe Diameter	30"	[11]
	Pipe Thickness	0.4375"	[11]
	Pipe Material	SS304	[11]
	Length between	(13'-4.5625") - (1'-1") - (4'-0.125") - T(1-10)L2 = 41.71875"	[11]
P (1-8B)	Pipe Diameter	30"	[11]
	Pipe Thickness	0.4375"	[11]
	Pipe Material	SS304	[11]
	Length between	(13'-4.5625") - (1'-1") - (4'-0.125") - T(1-11)L1 = 41.71875"	[11]

Table 51. Dimensions Associated with Pipe Runs on Line 1-9 of Model 1-4

Pipe Run (1-9)	*Dimensions*		*Reference*
P (1-9A)	Pipe Diameter	20"	[12]
	Pipe Thickness	0.312"	[12]
	Pipe Material	SS304	[12]
	Length between	(3'-3.25") - EL(1-9A) = 9.25"	[12]
P (1-9B)	Pipe Diameter	20"	[12]
	Pipe Thickness	0.312"	[12]
	Pipe Material	SS304	[12]
	Length between	(17'-3") - EL(1-9A) - EL(1-9B) = 147"	[12]
P (1-9C)	Pipe Diameter	20"	[12]
	Pipe Thickness	0.312"	[12]
	Pipe Material	SS304	[12]
	Length between	(5'-3.0625") - EL(1-9B) - T(1-9)branch = 6.0625"	[12]

Table 52. Dimensions Associated with Pipe Runs on Line 1-10 of Model 1-4

Pipe Run (1-10)	*Dimensions*		*Reference*
P (1-10A)	Pipe Diameter	20"	[13]
	Pipe Thickness	0.312"	[13]
	Pipe Material	SS304	[13]
	Length between	(3'-3.25") - EL(1-11A) = 9.25"	[13]
P (1-10B)	Pipe Diameter	20"	[13]
	Pipe Thickness	0.312"	[13]
	Pipe Material	SS304	[13]
	Length between	(17'-3") - EL(1-11A) - EL(1-11B) = 147"	[13]

Table 53. Dimensions Associated with Pipe Runs on Line 1-11 of Model 1-4

Pipe Run (1-11)	*Dimensions*		*Reference*
P (1-11A)	Pipe Diameter	20"	[12]
	Pipe Thickness	0.312"	[12]
	Pipe Material	SS304	[12]
	Length between	(3'-3.25") - EL(1-11A) = 9.25"	[12]
P (1-11B)	Pipe Diameter	20"	[12]
	Pipe Thickness	0.312"	[12]
	Pipe Material	SS304	[12]
	Length between	(17'-3") - EL(1-11A) - EL(1-11B) = 147"	[12]

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Table 54. Dimensions Associated with Pipe Runs on Line 1-12 of Model 1-4

Pipe Run (1-12)	*Dimensions*		*Reference*
P (1-12A)	Pipe Diameter	20"	[13]
	Pipe Thickness	0.312"	[13]
	Pipe Material	SS304	[13]
	Length between	(3'-3.25") - EL(1-11A) = 9.25"	[13]
P (1-12B)	Pipe Diameter	20"	[13]
	Pipe Thickness	0.312"	[13]
	Pipe Material	SS304	[13]
	Length between	(17'-3") - EL(1-11A) - EL(1-11B) = 147"	[13]

Table 55. Dimensions Associated with Pipe Runs on Line 1-170 of Model 1-4

Pipe Run (1-170)	*Dimensions*		*Reference*
P (1-170A)	Pipe Diameter	20"	[14]
	Pipe Thickness	0.312"	[14]
	Pipe Material	SS304	[14]
	Length between	(2'-8") - EL(1-170A) = 12"	[14]
P (1-170B)	Pipe Diameter	20"	[14]
	Pipe Thickness	0.312"	[14]
	Pipe Material	SS304	[14]
	Length between	(17'-3") - EL(1-170A) - EL(1-170B) = 157"	[14]
P (1-170C)	Pipe Diameter	20"	[14]
	Pipe Thickness	0.312"	[14]
	Pipe Material	SS304	[14]
	Length between	((3'-8.25")^2+(3'-8.25")^2)^0.5 - EL(1-170C) - EL(1-170D) = 37.579"	[14]
P (1-170D)	Pipe Diameter	20"	[14]
	Pipe Thickness	0.312"	[14]
	Pipe Material	SS304	[14]
	Length between	(9'-9.6875") - EL(1-170D) = 105.1875"	[14]

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Table 56. . Dimensions Associated with Pipe Runs on Line 1-34 of Model 1-4

Pipe Run (1-34)	*Dimensions*		*Reference*
P (1-34A)	Pipe Diameter	6.625"	[15]
	Pipe Thickness	0.28"	[15]
	Pipe Material	SS304	[15]
	Length between EL(1-34A) and EL(1-34B)	(2' -3") - EL(1-34A) - EL(1-34B) = 9"	[15]
P (1-34B)	Pipe Diameter	6.625"	[15]
	Pipe Thickness	0.28"	[15]
	Pipe Material	SS304	[15]
	Length between	(50' - 5") - EL(1-34B) - EL(1-34C) = 587"	[15]
P (1-34C)	Pipe Diameter	6.625"	[15]
	Pipe Thickness	0.28"	[15]
	Pipe Material	SS304	[15]
	Length between	(7' - 8") - EL(1-34C) - REL(1-34D) = 74"	[15]
P (1-34D)	Pipe Diameter	4.5"	[15]
	Pipe Thickness	0.237	[15]
	Pipe Material	SS304	[15]
	Length between	(1'-3") - REL(1-34D) = 6"	[15]
P (1-34E)	Pipe Diameter	4.5"	[15]
	Pipe Thickness	0.237	[15]
	Pipe Material	SS304	[15]
	Length between	(1') - EL(1-34E) = 6"	[15]
P (1-34F)	Pipe Diameter	4.5"	[15]
	Pipe Thickness	0.237	[15]
	Pipe Material	SS304	[15]
	Length between	(7'-3.8125") - EL(1-34E) - EL(1-34F) = 61.8125"	[15]
P (1-34G)	Pipe Diameter	4.5"	[15]
	Pipe Thickness	0.237	[15]
	Pipe Material	SS304	[15]
	Length between	(3'-3.25") - EL(1-34F) - EL (1-34G) = 16.75	[15]
P (1-34H)	Pipe Diameter	4.5"	[15]
	Pipe Thickness	0.237	[15]
	Pipe Material	SS304	[15]
	Length between	(6"^2 + 16"^2)^0.5 - EL(1-34G) - EL(1-34H) = 12.088" (Note: 6" and 16" triangle sides to generate hypotoneus this doesn't match 8.5" indicated in drawing)	[15]
P (1-34I)	Pipe Diameter	4.5"	[15]
	Pipe Thickness	0.237	[15]
	Pipe Material	SS304	[15]
	Length between	(1'-4.75") - EL(1-34H) = 14.25	[15]

Table 57. Dimensions Associated with Pipe Runs on Line 1-39 of Model 1-4

Pipe Run (1-39)	***Dimensions***		***Reference***
P (1-39A)	Pipe Diameter	6.625"	[16]
	Pipe Thickness	0.28"	[16]
	Pipe Material	SS304	[16]
	Length between	(2' -3.9375") - EL(1-39A) = 18.9375"	[16]
P (1-39B)	Pipe Diameter	6.625"	[16]
	Pipe Thickness	0.28"	[16]
	Pipe Material	SS304	[16]
	Length between	(3'-10.1875") - EL(1-39A) - T(1-39)L2 = 31.5625"	[16]

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Table 58. Dimensions Associated with Pipe Runs on Line 1-40 of Model 1-4

Pipe Run (1-40)	*Dimensions*		*Reference*
P (1-40A)	Pipe Diameter	6.625"	[17]
	Pipe Thickness	0.28"	[17]
	Pipe Material	SS304	[17]
	Length between	(3.75" + (2'-10.4375")) - EL(1-40A) = 34.4375"	[17]
P (1-40B)	Pipe Diameter	6.625"	[17]
	Pipe Thickness	0.28"	[17]
	Pipe Material	SS304	[17]
	Length between	(40'-0") - EL(1-40A) - EL(1-40B) = 446.25"	[17]
P (1-40C)	Pipe Diameter	6.625"	[17]
	Pipe Thickness	0.28"	[17]
	Pipe Material	SS304	[17]
	Length between	(8'-6") - EL(1-40B) - EL(1-40C) = 63"	[17]
P (1-40D)	Pipe Diameter	6.625"	[17]
	Pipe Thickness	0.28"	[17]
	Pipe Material	SS304	[17]
	Length between	(2'-8.625") - EL(1-40C) - EL(1-40D) = 14.625" (15.901" was actually used so that line 1-40 lined up with its connection to line 1-39)	[17]
P (1-40E)	Pipe Diameter	6.625"	[17]
	Pipe Thickness	0.28"	[17]
	Pipe Material	SS304	[17]
	Length between	(6'-8.6875") - EL(1-40D) - EL(1-40E) = 62.6875" (62.6875" was actually used so that line 1-40 lined up with its connection to line 1-39)	[17]
P (1-40F)	Pipe Diameter	6.625"	[17]
	Pipe Thickness	0.28"	[17]
	Pipe Material	SS304	[17]
	Length between	(2' - 9.9375") - EL(1-40E) = 24.9375"	[17]

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Table 59. Dimensions Associated with Pipe Runs on Line 1-41of Model 1-4

Pipe Run (1-41)	*Dimensions*		*Reference*
P (1-41A)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Pipe Material	SS304	[22]
	Length between	(1'-5") - EL(1-41A) = 8	[22]
P (1-41B)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Pipe Material	SS304	[22]
	Length between	(7'-3 7/8") - EL(1-41A) - EL(1-41B) = 69.875	[22]
P (1-41C)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Pipe Material	SS304	[22]
	Length between	(2'-3.9375") - T(1-41branch) = 22.3125"	[22]
P (1-41D)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Pipe Material	SS304	[22]
	Length between	(5'-3.625") - T(1-41)L1 - EL(1-41C) = 51.5"	[22]
P (1-41E)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Pipe Material	SS304	[22]
	Length between	(5'-3.625") - EL(1-41C) - EL(1-41D) = 56.625"	[22]
P (1-41F)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Pipe Material	SS304	[22]
	Length between	(13'-9") - EL(1-41D) - EL(1-41E) = 131.25"	[22]
P (1-41G)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Pipe Material	SS304	[22]
	Length between	(17'-7 3/8") - EL(1-41E) - EL(1-41F) = 151.375"	[22]
P (1-41H)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Pipe Material	SS304	[22]
	Length between	(4'-8") - EL(1-41F) - EL(1-41G) = 17"	[22]
P (1-41I)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Pipe Material	SS304	[22]
	Length between	(2') - EL(1-41G) - EL(1-41H) = 12.574"	[22]
P (1-41J)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Pipe Material	SS304	[22]
	Length between	(5'-3.1875") - EL(1-41H) - EL(1-41I) = 57.0115"	[22]

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Table 60. Dimensions Associated with Pipe Runs on Line 1-42 of Model 1-4

Pipe Run (1-42)	*Dimensions*		*Reference*
P (1-42A)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Pipe Material	SS304	[22]
	Length between	((2'-6")^2 + (5')^2)^0.5 - EL(1-42A) = 58.082	[22]
P (1-42B)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Pipe Material	SS304	[22]
	Length between	(30'-8.375") - EL(1-42A) - EL(1-42B) = 350.375"	[22]
P (1-42C)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Pipe Material	SS304	[22]
	Length between	(61'-0") - EL(1-42B) - EL(1-42C) = 719.25"	[22]
P (1-42D)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Pipe Material	SS304	[22]
	Length between	((2'-3")^2 + (2'-3")^2)^0.5 - EL(1-42C) - EL(1-42D) = 30.6837"	[22]
P (1-42E)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Pipe Material	SS304	[22]
	Length between	(12'-1") - EL(1-42D) - EL(1-42E) = 111.25	[22]
P (1-42F)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Pipe Material	SS304	[22]
	Length between	(13'-8.5") - EL(1-42E) - EL(1-42F) = 104.5"	[22]
P (1-42G)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Pipe Material	SS304	[22]
	Length between GT(1-18) and EL(1-18A)	(6'-4.625") - EL(1-42F) - EL(1-42G) = 37.625"	[22]
P (1-42H)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Pipe Material	SS304	[22]
	Length between EL(1-18A) and RED(1-18A)	(6'-3.875") - EL(1-42G) - EL(1-42H) = 57.875"	[22]
P (1-42I)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Pipe Material	SS304	[22]
	Length between RED(1-18A) and PP(1-18)	(1'-5") - EL(1-42H) = 8"	[22]

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Table 61. Dimensions Associated with Pipe Runs on Line 1-77 of Model 1-4

Pipe Run (1-77)	*Dimensions*		*Reference*
P (1-77A)	Pipe Diameter	4.5"	[20]
	Pipe Thickness	0.237	[20]
	Pipe Material	SS304	[20]
	Length between	(1'-3") - REL(1-77A) = 6"	[20]
P (1-77B)	Pipe Diameter	6.625"	[20]
	Pipe Thickness	0.28"	[20]
	Pipe Material	SS304	[20]
	Length between	(3'-6") - REL(1-77A) - EL(1-77B) = 24"	[20]
P (1-77C)	Pipe Diameter	6.625"	[20]
	Pipe Thickness	0.28"	[20]
	Pipe Material	SS304	[20]
	Length between	(4'-0.25") - EL(1-77C) - EL(1-77D) = 38.7448"	[20]
P (1-77D)	Pipe Diameter	6.625"	[20]
	Pipe Thickness	0.28"	[20]
	Pipe Material	SS304	[20]
	Length between	((2'-3")^2 + (2'-3")^2)^0.5 - EL(1-42C) - EL(1-42D) = 30.6837"	[20]
P (1-77E)	Pipe Diameter	ACTUALLY REPRESENTED AS L2 OF T(1-77)	
	Pipe Thickness		
	Pipe Material		
	Length between		
P (1-77F)	Pipe Diameter	4.5"	[20]
	Pipe Thickness	0.237	[20]
	Pipe Material	SS304	[20]
	Length between	5' - 5.625" - RED(1-77C) - EL(1-77E) = 42.875"	[20]
P (1-37A)	Pipe Diameter	4.5"	[21]
	Pipe Thickness	0.237	[21]
	Pipe Material	SS304	[21]
	Length between	(1') - EL(1-37) = 6"	[21]
P (1-37B)	Pipe Diameter	4.5"	[21]
	Pipe Thickness	0.237	[21]
	Pipe Material	SS304	[21]
	Length between	(1') - EL(1-37) = 6"	[21]

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P (1-37C)	Pipe Diameter	4.5"	[21]
	Pipe Thickness	0.237	[21]
	Pipe Material	SS304	[21]
	Length between	10.25" + ((1'-2")-RED(1-37))/2 = 15.25"	[21] [35]

P (1-37D)	Pipe Diameter	2.375"	[21]
	Pipe Thickness	0.154"	[21]
	Pipe Material	SS304	[21]
	Length between	((1'-2")-RED(1-37))/2 = 5"	[21] [35]

P (1-38A)	Pipe Diameter	4.5"	[21]
	Pipe Thickness	0.237	[21]
	Pipe Material	SS304	[21]
	Length between	(1') - EL(1-38) = 6"	[21]

P (1-38B)	Pipe Diameter	4.5"	[21]
	Pipe Thickness	0.237	[21]
	Pipe Material	SS304	[21]
	Length between	(1') - EL(1-38) = 6"	[21]

P (1-38C)	Pipe Diameter	4.5"	[21]
	Pipe Thickness	0.237	[21]
	Pipe Material	SS304	[21]
	Length between	10.25" + ((1'-2")-RED(1-37))/2 = 15.25"	[21] [35]

P (1-38D)	Pipe Diameter	2.375"	[21]
	Pipe Thickness	0.154"	[21]
	Pipe Material	SS304	[21]
	Length between	((1'-2")-RED(1-37))/2 = 5"	[21] [35]

Table 62. Dimensions Associated with Reducers on Line 1-1L of Model 1-4

Reducers (1-1L)	***Dimensions***		***Reference***
RED(1-1LA)	Small Diameter	16"	[5]
	Large Diameter	18"	[5]
	Length	15"	[5]
	Thickness	0.312"	[5]
	Eccentric Offset	2"	[5]
RED(1-1LB)	Small Diameter	18"	[6]
	Large Diameter	24"	[6]
	Length	20"	[6]
	Thickness	0.375"	[6]
	Eccentric Offset	3"	[6]

Table 63. Dimensions Associated with Reducers on Line 1-2L of Model 1-4

Reducers (1-2L)	***Dimensions***		***Reference***
RED(1-2L)	Small Diameter	16"	[5]
	Large Diameter	18"	[5]
	Length	15"	[5]
	Thickness	0.312"	[5]
	Eccentric Offset	2"	[5]

Table 64. Dimensions Associated with Reducers on Line 1-3L of Model 1-4

Reducers (1-3L)	***Dimensions***		***Reference***
RED(1-3L)	Small Diameter	16"	[5]
	Large Diameter	18"	[5]
	Length	15"	[5]
	Thickness	0.312"	[5]
	Eccentric Offset	2"	[5]

Table 65. Dimensions Associated with Reducers on Line 1-4L of Model 1-4

Reducers (1-4L)	***Dimensions***		***Reference***
RED(1-4LA)	Small Diameter	16"	[5]
	Large Diameter	18"	[5]
	Length	15"	[5]
	Thickness	0.312"	[5]
	Eccentric Offset	2"	[5]
RED(1-4LB)	Small Diameter	18"	[7]
	Large Diameter	24"	[7]
	Length	20"	[7]
	Thickness	0.375"	[7]
	Eccentric Offset	3"	[7]

Table 66. Dimensions Associated with Reducers on Line 1-5 of Model 1-4

Reducers (1-5)	***Dimensions***		***Reference***
RED(1-5)	Small Diameter	24"	[10]
	Large Diameter	36"	[10]
	Length	24"	[36]
	Thickness	0.5"	[10]
	Eccentric Offset	6"	[10]

Table 67. Dimensions Associated with Reducers on Line 1-6 of Model 1-4

Reducers (1-6)	*Dimensions*		*Reference*
RED(1-6)	Small Diameter	24"	[10]
	Large Diameter	36"	[10]
	Length	24"	[36]
	Thickness	0.5"	[10]
	Eccentric Offset	6"	[10]

Table 68. Dimensions Associated with Reducers on Line 1-8 of Model 1-4

Reducers (1-8)	*Dimensions*		*Reference*
RED(1-8A)	Small Diameter	30"	[11]
	Large Diameter	36"	[11]
	Length	24"	[11]
	Thickness	0.5"	[11]
	Eccentric Offset	6"	[11]
RED(1-8B)	Small Diameter	30"	[11]
	Large Diameter	36"	[11]
	Length	24"	[11]
	Thickness	0.5"	[11]
	Eccentric Offset	6"	[11]

Table 69. Dimensions Associated with Reducers on Line 1-37 of Model 1-4

Reducers (1-37)	*Dimensions*		*Reference*
RED(1-37)	Small Diameter	2.375"	[21]
	Large Diameter	4.5"	[21]
	Length	4"	[35]
	Thickness	0.237" to 0.154"	[21]
	Eccentric Offset	0"	[21]

Table 70. Dimensions Associated with Reducers on Line 1-38 of Model 1-4

Reducers (1-38)	*Dimensions*		*Reference*
RED(1-38)	Small Diameter	2.375"	[21]
	Large Diameter	4.5"	[21]
	Length	4"	[35]
	Thickness	0.237" to 0.154"	[21]
	Eccentric Offset	0"	[21]

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Table 71. Dimensions Associated with Reducers on Line 1-38 of Model 1-4

Reducers (1-39)	*Dimensions*		*Reference*
RED(1-39)	Small Diameter	4.5"	[20]
	Large Diameter	6.625"	[20]
	Length	5.5"	[35]
	Thickness	0.28" to 0.237"	[20]
	Eccentric Offset	0"	[16]

Table 72. Dimensions Associated with Reducers on Line 1-38 of Model 1-4

Reducers (1-77)	*Dimensions*		*Reference*
RED(1-77)	Small Diameter	4.5"	[20]
	Large Diameter	6.625"	[20]
	Length	5.5"	[35]
	Thickness	0.28" to 0.237"	[20]
	Eccentric Offset	0"	[20]

Table 73. Dimensions Associated with Reducers on Line 1-38 of Model 1-4

Reducers (1-170)	*Dimensions*		*Reference*
RED(1-170)	Small Diameter	20"	[14]
	Large Diameter	30"	[14]
	Length	20"	[14]
	Thickness	0.5"	[14]
	Eccentric Offset	0"	[14]

Table 74. Dimensions Associated with Elbows on Line 1-1L of Model 1-4

Elbows (1-1L)	*Dimensions*		*Reference*
EL (1-1LA)	Pipe Diameter	18"	[6]
	Pipe Thickness	0.312"	[6]
	Elbow Type	45º Long Radius	[6]
	Elbow Leg Lengths	11.25"	[35, pg 23]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-1LB)	Pipe Diameter	18"	[6]
	Pipe Thickness	0.312"	[6]
	Elbow Type	90º Short Radius	[6]
	Elbow Leg Lengths	18"	[35, pg 19]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-1LC)	Pipe Diameter	18"	[5]
	Pipe Thickness	0.312"	[5]
	Elbow Type	90º Long Radius	[5]
	Elbow Leg Lengths	27"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]

Table 75. Dimensions Associated with Elbows on Line 1-2L of Model 1-4

Elbows (1-2L)	Dimensions		Reference
EL (1-2LA)	Pipe Diameter	18"	[6]
	Pipe Thickness	0.312"	[6]
	Elbow Type	45º Long Radius	[6]
	Elbow Leg Lengths	11.25"	[35, pg 23]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-2LB)	Pipe Diameter	18"	[6]
	Pipe Thickness	0.312"	[6]
	Elbow Type	90º Long Radius	[6]
	Elbow Leg Lengths	27"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-2LC)	Pipe Diameter	18"	[5]
	Pipe Thickness	0.312"	[5]
	Elbow Type	90º Long Radius	[5]
	Elbow Leg Lengths	27"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]

Table 76. . Dimensions Associated with Elbows on Line 1-3L of Model 1-4

Elbows (1-3L)	Dimensions		Reference
EL (1-3LA)	Pipe Diameter	18"	[7]
	Pipe Thickness	0.312"	[7]
	Elbow Type	45º Long Radius	[7]
	Elbow Leg Lengths	11.25"	[35, pg 23]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-3LB)	Pipe Diameter	18"	[7]
	Pipe Thickness	0.312"	[7]
	Elbow Type	90º Long Radius	[7]
	Elbow Leg Lengths	27"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-3LC)	Pipe Diameter	18"	[5]
	Pipe Thickness	0.312"	[5]
	Elbow Type	90º Long Radius	[5]
	Elbow Leg Lengths	27"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]

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Table 77. Dimensions Associated with Elbows on Line 1-4L of Model 1-4

Elbows (1-4L)	*Dimensions*		*Reference*
EL (1-4LA)	Pipe Diameter	18"	[7]
	Pipe Thickness	0.312"	[7]
	Elbow Type	45º Long Radius	[7]
	Elbow Leg Lengths	11.25"	[35, pg 23]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-4LB)	Pipe Diameter	18"	[7]
	Pipe Thickness	0.312"	[7]
	Elbow Type	90º Short Radius	[7]
	Elbow Leg Lengths	18"	[35, pg 19]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-4LC)	Pipe Diameter	18"	[5]
	Pipe Thickness	0.312"	[5]
	Elbow Type	90º Long Radius	[5]
	Elbow Leg Lengths	27"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]

Table 78. Dimensions Associated with Elbows on Line 1-5 of Model 1-4

Elbows (1-5)	*Dimensions*		*Reference*
EL (1-5)	Pipe Diameter	24"	[6]
	Pipe Thickness	0.375"	[6]
	Elbow Type	90º Long Radius	[6]
	Elbow Leg Lengths	36"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]

Table 79. Dimensions Associated with Elbows on Line 1-6 of Model 1-4

Elbows (1-6)	*Dimensions*		*Reference*
EL (1-6)	Pipe Diameter	24"	[7]
	Pipe Thickness	0.375"	[7]
	Elbow Type	90º Long Radius	[7]
	Elbow Leg Lengths	36"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]

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Table 80. Dimensions Associated with Elbows on Line 1-7 of Model 1-4

Elbows (1-7)	*Dimensions*		*Reference*
EL (1-7A)*	Pipe Diameter	36"	[7]
	Pipe Thickness	0.5"	[7]
	Elbow Type	90º Short Radius	[7]
	Elbow Leg Lengths	36"	[35, pg 19]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-7B)	Pipe Diameter	36"	[7]
	Pipe Thickness	0.5"	[7]
	Elbow Type	90º Short Radius	[7]
	Elbow Leg Lengths	36"	[35, pg 19]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-7C)	Pipe Diameter	36"	[7]
	Pipe Thickness	0.5"	[7]
	Elbow Type	90º Short Radius	[7]
	Elbow Leg Lengths	36"	[35, pg 19]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-7D)	Pipe Diameter	36"	[7]
	Pipe Thickness	0.5"	[7]
	Elbow Type	90º Short Radius	[7]
	Elbow Leg Lengths	36"	[35, pg 19]
	Pressure/Temp	272 psi / 167ºF	[3]

* EL (1-7A) also has a branch out of it and is also documented as FAB_BR(1-40)

Table 81. Dimensions Associated with Elbows on Line 1-9 of Model 1-4

Elbows (1-9)	*Dimensions*		*Reference*
EL (1-9A)	Pipe Diameter	20"	[12]
	Pipe Thickness	0.312"	[12]
	Elbow Type	90º Long Radius	[12]
	Elbow Leg Lengths	30"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-9B)	Pipe Diameter	20"	[12]
	Pipe Thickness	0.312"	[12]
	Elbow Type	90º Long Radius	[12]
	Elbow Leg Lengths	30"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]

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Table 82. Dimensions Associated with Elbows on Line 1-10 of Model 1-4

Elbows (1-10)	*Dimensions*		*Reference*
EL (1-10A)	Pipe Diameter	20"	[13]
	Pipe Thickness	0.312"	[13]
	Elbow Type	90º Long Radius	[13]
	Elbow Leg Lengths	30"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-10B)	Pipe Diameter	20"	[13]
	Pipe Thickness	0.312"	[13]
	Elbow Type	90º Long Radius	[13]
	Elbow Leg Lengths	30"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]

Table 83. Dimensions Associated with Elbows on Line 1-11 of Model 1-4

Elbows (1-11)	*Dimensions*		*Reference*
EL (1-11A)	Pipe Diameter	20"	[12]
	Pipe Thickness	0.312"	[12]
	Elbow Type	90º Long Radius	[12]
	Elbow Leg Lengths	30"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-11B)	Pipe Diameter	20"	[12]
	Pipe Thickness	0.312"	[12]
	Elbow Type	90º Long Radius	[12]
	Elbow Leg Lengths	30"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]

Table 84. Dimensions Associated with Elbows on Line 1-12 of Model 1-4

Elbows (1-12)	*Dimensions*		*Reference*
EL (1-12A)	Pipe Diameter	20"	[13]
	Pipe Thickness	0.312"	[13]
	Elbow Type	90º Long Radius	[13]
	Elbow Leg Lengths	30"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-12B)	Pipe Diameter	20"	[13]
	Pipe Thickness	0.312"	[13]
	Elbow Type	90º Long Radius	[13]
	Elbow Leg Lengths	30"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]

Table 85. Dimensions Associated with Elbows on Line 1-170 of Model 1-4

Elbows (1-170)	*Dimensions*		*Reference*
EL (1-170A)	Pipe Diameter	20"	[14]
	Pipe Thickness	0.312"	[14]
	Elbow Type	90º Short Radius	[14]
	Elbow Leg Lengths	20"	[35, pg 19]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-170B)	Pipe Diameter	20"	[14]
	Pipe Thickness	0.312"	[14]
	Elbow Type	90º Long Radius	[14]
	Elbow Leg Lengths	30"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-170C)	Pipe Diameter	20"	[14]
	Pipe Thickness	0.312"	[14]
	Elbow Type	45º Long Radius	[14]
	Elbow Leg Lengths	12.5"	[35, pg 23]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-170D)	Pipe Diameter	20"	[14]
	Pipe Thickness	0.312"	[14]
	Elbow Type	45º Long Radius	[14]
	Elbow Leg Lengths	12.5"	[35, pg 23]
	Pressure/Temp	272 psi / 167ºF	[3]

Table 86. Dimensions Associated with Elbows on Line 1-34 of Model 1-4

Elbows (1-34)	*Dimensions*		*Reference*
EL (1-34A)	Pipe Diameter	6.625"	[15]
	Pipe Thickness	0.28"	[15]
	Elbow Type	90º Long Radius	[15]
	Elbow Leg Lengths	9"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-34B)	Pipe Diameter	6.625"	[15]
	Pipe Thickness	0.28"	[15]
	Elbow Type	90º Long Radius	[15]
	Elbow Leg Lengths	9"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-34C)	Pipe Diameter	6.625"	[15]
	Pipe Thickness	0.28"	[15]
	Elbow Type	90º Long Radius	[15]
	Elbow Leg Lengths	9"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]
REL (1-34D)	Elbow Type	6" x 4" reducer	[15]
	Lg Pipe Diameter	6.625"	[15]
	Lg Pipe Thickness	0.28"	[15]
	Sm Pipe Diameter	4.5"	[15]
	Sm Pipe Thickness	0.237"	[15]
	Elbow Leg Lengths	9"	[35, pg 15]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-34E)	Pipe Diameter	4.5"	[15]
	Pipe Thickness	0.237"	[15]
	Elbow Type	90º Long Radius	[15]
	Elbow Leg Lengths	6"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-34F)	Pipe Diameter	4.5"	[15]
	Pipe Thickness	0.237"	[15]
	Elbow Type	90º 20" Radius	[15]
	Elbow Leg Lengths	20"	[15]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-34G)	Pipe Diameter	4.5"	[15]
	Pipe Thickness	0.237"	[15]
	Elbow Type	45º Long Radius	[15]
	Elbow Leg Lengths	2.5"	[35, pg 23]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-34H)	Pipe Diameter	4.5"	[15]
	Pipe Thickness	0.237"	[15]
	Elbow Type	45º Long Radius	[15]
	Elbow Leg Lengths	2.5"	[35, pg 23]
	Pressure/Temp	272 psi / 167ºF	[3]

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Table 87. Dimensions Associated with Elbows on Line 1-39 of Model 1-4

Elbows (1-39)	*Dimensions*		*Reference*
EL (1-39)	Pipe Diameter	6.625"	[16]
	Pipe Thickness	0.28"	[16]
	Elbow Type	90º Long Radius	[16]
	Elbow Leg Lengths	9"	[35, pg 9]
	Pressure/Temp	376 psi / 125ºF	[3]

Table 88. Dimensions Associated with Elbows on Line 1-40 of Model 1-4

Elbows (1-40)	*Dimensions*		*Reference*
EL (1-40A)	Pipe Diameter	6.625"	[17]
	Pipe Thickness	0.28"	[17]
	Elbow Type	45º Long Radius	[17]
	Elbow Leg Lengths	3.75"	[35, pg 23]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-40B)	Pipe Diameter	6.625"	[17]
	Pipe Thickness	0.28"	[17]
	Elbow Type	90º 30" Radius	[17]
	Elbow Leg Lengths	30"	[17]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-40C)	Pipe Diameter	6.625"	[17]
	Pipe Thickness	0.28"	[17]
	Elbow Type	90º Long Radius	[17]
	Elbow Leg Lengths	9"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-40D)	Pipe Diameter	6.625"	[17]
	Pipe Thickness	0.28"	[17]
	Elbow Type	90º Long Radius	[17]
	Elbow Leg Lengths	9"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]
EL (1-40E)	Pipe Diameter	6.625"	[17]
	Pipe Thickness	0.28"	[17]
	Elbow Type	90º Long Radius	[17]
	Elbow Leg Lengths	9"	[35, pg 9]
	Pressure/Temp	272 psi / 167ºF	[3]

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Table 89. Dimensions Associated with Elbows on Line 1-42 of Model 1-4

Elbows (1-42)	Dimensions		Reference
EL (1-42A)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Elbow Type	90º Long Radius	[22]
	Elbow Leg Lengths	9"	[35, pg 9]
	Pressure/Temp	376 psi / 125ºF	[3]
EL (1-42B)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Elbow Type	90º Long Radius	[22]
	Elbow Leg Lengths	9"	[35, pg 9]
	Pressure/Temp	376 psi / 125ºF	[3]
EL (1-42C)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Elbow Type	45º Long Radius	[22]
	Elbow Leg Lengths	3.75"	[35, pg 23]
	Pressure/Temp	376 psi / 125ºF	[3]
EL (1-42D)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Elbow Type	45º Long Radius	[22]
	Elbow Leg Lengths	3.75"	[35, pg 23]
	Pressure/Temp	376 psi / 125ºF	[3]
EL (1-42E)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Elbow Type	90º 30" Radius	[22]
	Elbow Leg Lengths	30"	[22]
	Pressure/Temp	376 psi / 125ºF	[3]
EL (1-42F)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Elbow Type	90º 30" Radius	[22]
	Elbow Leg Lengths	30"	[22]
	Pressure/Temp	376 psi / 125ºF	[3]
EL (1-42G)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Elbow Type	90º Long Radius	[22]
	Elbow Leg Lengths	9"	[35, pg 9]
	Pressure/Temp	376 psi / 125ºF	[3]
EL (1-42H)	Pipe Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Elbow Type	90º Long Radius	[22]
	Elbow Leg Lengths	9"	[35, pg 9]
	Pressure/Temp	376 psi / 125ºF	[3]

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Table 90. Dimensions Associated with Elbows on Line 1-41 of Model 1-4

Elbows (1-41)	Dimensions		Reference
EL (1-41A)	Pipe Diameter	6.625"	[18]
	Pipe Thickness	0.28"	[18]
	Elbow Type	90º Long Radius	[18]
	Elbow Leg Lengths	9"	[35, pg 9]
	Pressure/Temp	376 psi / 125ºF	[3]
EL (1-41B)	Pipe Diameter	6.625"	[18]
	Pipe Thickness	0.28"	[18]
	Elbow Type	90º Long Radius	[18]
	Elbow Leg Lengths	9"	[35, pg 9]
	Pressure/Temp	376 psi / 125ºF	[3]
EL (1-41C)	Pipe Diameter	6.625"	[18]
	Pipe Thickness	0.28"	[18]
	Elbow Type	45º Long Radius	[18]
	Elbow Leg Lengths	3.75"	[35, pg 23]
	Pressure/Temp	376 psi / 125ºF	[3]
EL (1-41D)	Pipe Diameter	6.625"	[18]
	Pipe Thickness	0.28"	[18]
	Elbow Type	45º Long Radius	[18]
	Elbow Leg Lengths	3.75"	[35, pg 23]
	Pressure/Temp	376 psi / 125ºF	[3]
EL (1-41E)	Pipe Diameter	6.625"	[18]
	Pipe Thickness	0.28"	[18]
	Elbow Type	90º 30" Long Radius	[18]
	Elbow Leg Lengths	30"	[18]
	Pressure/Temp	376 psi / 125ºF	[3]
EL (1-41F)	Pipe Diameter	6.625"	[18]
	Pipe Thickness	0.28"	[18]
	Elbow Type	90º 30" Long Radius	[18]
	Elbow Leg Lengths	30"	[18]
	Pressure/Temp	376 psi / 125ºF	[3]
EL (1-41G)	Pipe Diameter	6.625"	[18]
	Pipe Thickness	0.28"	[18]
	Elbow Type	90º Long Radius	[18]
	Elbow Leg Lengths	9"	[35, pg 9]
	Pressure/Temp	376 psi / 125ºF	[3]
EL (1-41H)	Pipe Diameter	6.625"	[18]
	Pipe Thickness	0.28"	[18]
	Elbow Type	45º Long Radius Trimed	[18]
	Elbow Leg Lengths	3.75"	[35, pg 23]
	Pressure/Temp	376 psi / 125ºF	[3]

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Table 91. Dimensions Associated with Elbows on Line 1-37 of Model 1-4

Elbows (1-37)	Dimensions		Reference
EL (1-37)	Pipe Diameter	4.5"	[21]
	Pipe Thickness	0.237"	[21]
	Elbow Type	90º Long Radius	[21]
	Elbow Leg Lengths	6"	[35, pg 9]
	Pressure/Temp	376 psi / 125ºF	[3]

Table 92. Dimensions Associated with Elbows on Line 1-38 of Model 1-4

Elbows (1-38)	Dimensions		Reference
EL (1-38)	Pipe Diameter	4.5"	[21]
	Pipe Thickness	0.237"	[21]
	Elbow Type	90º Long Radius	[21]
	Elbow Leg Lengths	6"	[35, pg 9]
	Pressure/Temp	376 psi / 125ºF	[3]

Table 93. Dimensions Associated with Elbows on Line 1-77 of Model 1-4

Elbows (1-77)	Dimensions		Reference
REL (1-77A)	Elbow Type	6" x 4" reducer	[20]
	Lg Pipe Diameter	6.625"	[20]
	Lg Pipe Thickness	0.28"	[20]
	Sm Pipe Diameter	4.5"	[20]
	Sm Pipe Thickness	0.237"	[20]
	Elbow Leg Lengths	9"	[35, pg 15]
	Pressure/Temp	376 psi / 125ºF	[3]
EL (1-77B)	Pipe Diameter	6.625"	[20]
	Pipe Thickness	0.28"	[20]
	Elbow Type	90º Long Radius	[20]
	Elbow Leg Lengths	9"	[35, pg 9]
	Pressure/Temp	376 psi / 125ºF	[3]
EL (1-77C)	Pipe Diameter	6.625"	[20]
	Pipe Thickness	0.28"	[20]
	Elbow Type	45º Long Radius	[20]
	Elbow Leg Lengths	3.75"	[35, pg 23]
	Pressure/Temp	376 psi / 125ºF	[3]
EL (1-77D)	Pipe Diameter	6.625"	[20]
	Pipe Thickness	0.28"	[20]
	Elbow Type	45º Long Radius	[20]
	Elbow Leg Lengths	3.75"	[35, pg 23]
	Pressure/Temp	376 psi / 125ºF	[3]
EL (1-77E)	Pipe Diameter	4.5"	[20]
	Pipe Thickness	0.237"	[20]
	Elbow Type	90º Long Radius	[20]
	Elbow Leg Lengths	6"	[20]
	Pressure/Temp	376 psi / 125ºF	[3]

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Table 94. Dimensions Associated with Tees on Line 1-7 of Model 1-4

Tees (1-7)	Dimensions		Reference
T(1-7A)	Run Diameter	36"	[36]
	Run Length	52"	[36]
	Run Thickness	1.375"	[36]
	Branch Diameter	36"	[36]
	Branch Length	25.5"	[36]
	Branch Thickness	1.375"	[36]
T(1-7B)	Run Diameter	36"	[36]
	Run Length	52"	[36]
	Run Thickness	1.375"	[36]
	Branch Diameter	36"	[36]
	Branch Length	25.5"	[36]
	Branch Thickness	1.375"	[36]

Table 95. Dimensions Associated with Tees on Line 1-9 of Model 1-4

Tees (1-9)	Dimensions		Reference
T(1-9)	Run Diameter	30"	[11]
	Run Thickness	0.4375"	[11]
	Run Leg1 Length	13"	[11]
	Run Leg2 Length	24.0625"	Result of FE Modeling
	Branch Diameter	20"	[11]
	Branch Length	27"	Result of FE Modeling
	Branch Thickness	0.312"	[11]

Table 96. Dimensions Associated with Tees on Line 1-10 of Model 1-4

Tees (1-10)	Dimensions		Reference
T(1-10)	Run Diameter	30"	[11]
	Run Thickness	0.4375"	[11]
	Run Leg1 Length	24.0625"	Result of FE Modeling
	Run Leg2 Length	49.71875"	Result of FE Modeling
	Branch Diameter	20"	[11]
	Branch Length	33.0625"	Result of FE Modeling
	Branch Thickness	0.312"	[11]

Table 97. Dimensions Associated with Tees on Line 1-11 of Model 1-4

Tees (1-11)	Dimensions		Reference
T(1-11)	Run Diameter	30"	[11]
	Run Thickness	0.4375"	[11]
	Run Leg1 Length	49.71875"	Result of FE Modeling
	Run Leg2 Length	24.0625"	Result of FE Modeling
	Branch Diameter	20"	[11]
	Branch Length	33.0625"	Result of FE Modeling
	Branch Thickness	0.312"	[11]

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Table 98. Dimensions Associated with Tees on Line 1-12 of Model 1-4

Tees (1-12)	*Dimensions*		*Reference*
T(1-12)	Run Diameter	30"	[11]
	Run Thickness	0.4375"	[11]
	Run Leg1 Length	24.0625"	[11]
	Run Leg2 Length	13"	Result of FE Modeling
	Branch Diameter	20"	[11]
	Branch Length	33.0625"	Result of FE Modeling
	Branch Thickness	0.312"	[11]

Table 99. Dimensions Associated with Tees on Line 1-34 of Model 1-4

Tees (1-34)	*Dimensions*		*Reference*
T(1-34)	Run Diameter	36"	[10]
	Run Thickness	0.5"	[10]
	Run Leg1 Length	65.4"	Result of FE Modeling
	Run Leg2 Length	12"	[10]
	Branch Diameter	6.625"	[15]
	Branch Length	18"	Result of FE Modeling
	Branch Thickness	0.28"	[15]

Table 100. Dimensions Associated with Tees on Line 1-39 of Model 1-4

Tees (1-39)	*Dimensions*		*Reference*
T(1-39)	Run Diameter	6.625"	[16]
	Run Thickness	0.28"	[16]
	Run Leg1 Length	5.625"	[35]
	Run Leg2 Length	5.625"	[35]
	Branch Diameter	6.625"	[16]
	Branch Length	5.625"	[35]
	Branch Thickness	0.28"	[16]

Table 101. Dimensions Associated with Tees on Line 1-41 of Model 1-4

Tees (1-41)	*Dimensions*		*Reference*
T(1-41)	Run Diameter	6.625"	[18]
	Run Thickness	0.28"	[18]
	Run Leg1 Length	5.625"	[35]
	Run Leg2 Length	5.625"	[35]
	Branch Diameter	6.625"	[18]
	Branch Length	5.625"	[35]
	Branch Thickness	0.28"	[18]

Table 102. Dimensions Associated with Tees on Line 1-42 of Model 1-4

Tees (1-42)	*Dimensions*		*Reference*
T(1-42)	Run Diameter	36"*	[37]
	Run Thickness	0.5"*	[37]
	Run Leg1 Length	18"*	[37]
	Run Leg2 Length	8.125"*	Result of FE Modeling
	Branch Diameter	6.625"	[22]
	Branch Length	18"	Result of FE Modeling
	Branch Thickness	0.28"	[22]

* Values are represented by Model 3

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Table 103. Dimensions Associated with Tees on Line 1-77 of Model 1-4

Tees (1-77)	*Dimensions*		*Reference*
T(1-77)	Run Diameter	6.625"	[20]
	Run Thickness	0.28"	[20]
	Run Leg1 Length	5.625"	[20]
	Run Leg2 Length	4.73"	Result of FE Modeling
	Branch Diameter	4.5"	[20]
	Branch Length	17.6875"	[20]
	Branch Thickness	0.237"	[20]

Table 104. Dimensions Associated with Fabricated Branches Associated with Model 1-4

Fabricated Branch	*Dimensions*		*Reference*
FAB_BR (1-3L)	Pipe Diameter	25.5"	[23]
	Pipe Thickness	1"	[23]
	Run Leg1 Length	18"	M1-1-5-N11-PBRF-DSCN3052
	Run Leg2 Length	41"	M1-1-5-N11-PBRF-DSCN3052
	Branch Diameter	18"	[23]
	Branch Length from Run Centerline	16.976"*	[23]
	Branch Thickness	0.312"	[23]
FAB_BR (1-2L)	Pipe Diameter	25.5"	[23]
	Pipe Thickness	1"	[23]
	Elbow Type	18"	M1-1-5-N11-PBRF-DSCN3052
	Elbow Leg Lengths	41"	M1-1-5-N11-PBRF-DSCN3052
	Branch Diameter	18"	[23]
	Branch Length from Centerline of Upper Elbow Leg	16.976"*	[23]
	Branch Thickness	0.312"	[23]
FAB_BR (1-40)	Pipe Diameter	36"	[10]
	Pipe Thickness	0.5"	[10]
	Elbow Type	Short Radius	[10]
	Elbow Leg Lengths	36"	[35]
	Branch Diameter	6.625"	[17]
	Branch Length from Centerline of Elbow in Horizontal Plane of Attachment	18"	[17]
	Branch Thickness	0.28"	[17]

Table 105. Dimensions Associated with Flanges on Line 1-1L of Model 1-4

Flanges (1-1L)	***Dimensions***		***Reference***
FL (1-1LA)	Location	Northern flange on Line P(1-1LA)	
	Mass	258 lb = 0.668 lbf*s^2/in	[35, pg 99]
FL (1-1LB)	Location	Southern flange on Line P(1-1LA)	
	Mass	258 lb = 0.668 lbf*s^2/in	[35, pg 99]
FL (1-1LC)	Location	Lower flange on Line P(1-1LC)	
	Mass	258 lb = 0.668 lbf*s^2/in	[35, pg 99]
FL (1-1LD)	Location	Upper flange on Line P(1-1LC)	
	Mass	258 lb = 0.668 lbf*s^2/in	[35, pg 99]
FL (1-1LE)	Location	At reactor vessel nozzel	
	Mass	Neglected due to fixation of nozzels	[35, pg 99]

Table 106. Dimensions Associated with Flanges on Line 1-2L of Model 1-4

Flanges (1-2L)	***Dimensions***		***Reference***
FL (1-2LA)	Location	Northern flange on Line P(1-2LB)	
	Mass	258 lb = 0.668 lbf*s^2/in	[35, pg 99]
FL (1-2LB)	Location	Southern flange on Line P(1-2LB)	
	Mass	258 lb = 0.668 lbf*s^2/in	[35, pg 99]
FL (1-2LC)	Location	Lower flange on Line P(1-2LC)	
	Mass	258 lb = 0.668 lbf*s^2/in	[35, pg 99]
FL (1-2LD)	Location	Upper flange on Line P(1-2LC)	
	Mass	258 lb = 0.668 lbf*s^2/in	[35, pg 99]
FL (1-2LE)	Location	At reactor vessel nozzel	
	Mass	Neglected due to fixation of nozzels	

Table 107. Dimensions Associated with Flanges on Line 1-3L of Model 1-4

Flanges (1-3L)	*Dimensions*		*Reference*
FL (1-3LA)	Location	Northern flange on Line P(1-3LB)	
	Mass	258 lb = 0.668 lbf*s^2/in	[35, pg 99]
FL (1-3LB)	Location	Southern flange on Line P(1-3LB)	
	Mass	258 lb = 0.668 lbf*s^2/in	[35, pg 99]
FL (1-3LC)	Location	Lower flange on Line P(1-3LC)	
	Mass	258 lb = 0.668 lbf*s^2/in	[35, pg 99]
FL (1-3LD)	Location	Upper flange on Line P(1-3LC)	
	Mass	258 lb = 0.668 lbf*s^2/in	[35, pg 99]
FL (1-3LE)	Location	At reactor vessel nozzel	
	Mass	Neglected due to fixation of nozzels	

Table 108. Dimensions Associated with Flanges on Line 1-4L of Model 1-4

Flanges (1-4L)	*Dimensions*		*Reference*
FL (1-4LA)	Location	Northern flange on Line P(1-4LA)	
	Mass	258 lb = 0.668 lbf*s^2/in	[35, pg 99]
FL (1-4LB)	Location	Southern flange on Line P(1-4LA)	
	Mass	258 lb = 0.668 lbf*s^2/in	[35, pg 99]
FL (1-4LC)	Location	Lower flange on Line P(1-4LC)	
	Mass	258 lb = 0.668 lbf*s^2/in	[35, pg 99]
FL (1-4LD)	Location	Upper flange on Line P(1-4LC)	
	Mass	258 lb = 0.668 lbf*s^2/in	[35, pg 99]
FL (1-4LE)	Location	At reactor vessel nozzel	
	Mass	Neglected due to fixation of nozzels	[35, pg 99]

Table 109. Dimensions Associated with Flanges on Line 1-9 of Model 1-4

Flanges (1-9)	*Dimensions*		*Reference*
FL (1-9)	Location	At reactor heat exchanger	
	Mass	Neglected due to fixation of heat exchanger	

Table 110. Dimensions Associated with Flanges on Line 1-10 of Model 1-4

Flanges (1-10)	*Dimensions*		*Reference*
FL (1-10)	Location	At reactor heat exchanger	
	Mass	Neglected due to fixation of heat exchanger	

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Table 111. Dimensions Associated with Flanges on Line 1-11 of Model 1-4

Flanges (1-11)	*Dimensions*		*Reference*
FL (1-11)	Location	At reactor heat exchanger	
	Mass	Neglected due to fixation of heat exchanger	

Table 112. Dimensions Associated with Flanges on Line 1-12 of Model 1-4

Flanges (1-12)	*Dimensions*		*Reference*
FL (1-12)	Location	At reactor heat exchanger	
	Mass	Neglected due to fixation of heat exchanger	

Table 113. Dimensions Associated with Flanges on Line 1-170 of Model 1-4

Flanges (1-170)	*Dimensions*		*Reference*
FL (1-170)	Location	At reactor heat exchanger	
	Mass	Neglected due to fixation of heat exchanger	

Table 114. Dimensions Associated with Flanges on Line 1-37 of Model 1-4

Flanges (1-37)	*Dimensions*		*Reference*
FL (1-37A)	Location	East flange of GT(1-37)	
	Mass	22 lb = 0.05697 lbf*s^2/in	[35, pg 99]
FL (1-37B)	Location	West flange of GT(1-37)	
	Mass	22 lb = 0.05697 lbf*s^2/in	[35, pg 99]
FL (1-37C)	Location	Upper flange on CK(1-37)	
	Mass	22 lb = 0.05697 lbf*s^2/in	[35, pg 99]
FL (1-37D)	Location	Lower flange on CK(1-37)	
	Mass	22 lb = 0.05697 lbf*s^2/in	[35, pg 99]

Table 115. Dimensions Associated with Flanges on Line 1-38 of Model 1-4

Flanges (1-38)	*Dimensions*		*Reference*
FL (1-38A)	Location	East flange of GT(1-38)	
	Mass	22 lb = 0.05697 lbf*s^2/in	[35, pg 99]
FL (1-38B)	Location	West flange of GT(1-38)	
	Mass	22 lb = 0.05697 lbf*s^2/in	[35, pg 99]
FL (1-38C)	Location	Upper flange on CK(1-38)	
	Mass	22 lb = 0.05697 lbf*s^2/in	[35, pg 99]
FL (1-38D)	Location	Lower flange on CK(1-38)	
	Mass	22 lb = 0.05697 lbf*s^2/in	[35, pg 99]

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Table 116. Dimensions Associated with Flanges on Line 1-39 of Model 1-4

Flanges (1-39)	***Dimensions***		***Reference***
FL (1-39A)	Location	Upper flange of GT(1-39A)	
	Mass	39 lb = 0.101 lbf*s^2/in	[35, pg 99]
FL (1-39B)	Location	Lower flange of GT(1-39A)	
	Mass	39 lb = 0.101 lbf*s^2/in	[35, pg 99]
FL (1-39C)	Location	Upper flange of GT(1-39B)	
	Mass	39 lb = 0.101 lbf*s^2/in	[35, pg 99]
FL (1-39D)	Location	Lower flange of GT(1-39B)	
	Mass	39 lb = 0.101 lbf*s^2/in	[35, pg 99]
FL (1-39E)	Location	South flange on CK(1-39)	
	Mass	22 lb = 0.05697 lbf*s^2/in	[35, pg 99]

Table 117. Dimensions Associated with Flanges on Line 1-42 of Model 1-4

Flanges (1-42)	***Dimensions***		***Reference***
FL (1-42A)	Location	North flange of GT(1-42)	
	Mass	39 lb = 0.101 lbf*s^2/in	[35, pg 99]
FL (1-42B)	Location	South flange of GT(1-42)	
	Mass	39 lb = 0.101 lbf*s^2/in	[35, pg 99]

Table 118. Dimensions Associated with Flanges on Line 1-67 of Model 1-4

Flanges (1-67)	***Dimensions***		***Reference***
FL (1-67A)	Location	West flange of GT(1-67)	
	Mass	22 lb = 0.05697 lbf*s^2/in	[35, pg 99]
FL (1-67B)	Location	East flange of PCV(1-67)	
	Mass	22 lb = 0.05697 lbf*s^2/in	[35, pg 99]

Table 119. Dimensions Associated with Flanges on Line 1-77 of Model 1-4

Flanges (1-77)	***Dimensions***		***Reference***
FL (1-77)	Location	West flange of GT(1-67)	
	Mass	22 lb = 0.05697 lbf*s^2/in	[35, pg 99]

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Table 120. Dimensions Associated with Valves on Line 1-37 of Model 1-4

Valves (1-37)	*Dimensions*		*Reference*
GT (1-37)	Pipe/Valve Diameter	4.5"	[21]
	Pipe Thickness	0.237"	[21]
	Equiv Valve OD	5.5"	App D.7
	Equiv Valve Thickness	1.235"	App D.7
	Valve Lengths	1'-0.25"	[21]
	Valve Name	GT-D-1-27	[21]
	Valve Mass	273 lb = 0.708 lbf*s^2/in	[3, pg B-2]

CK (1-37)	Pipe/Valve Diameter	4.5"	[21]
	Pipe Thickness	0.237"	[21]
	Equiv Valve OD	5.5"	App D.7
	Equiv Valve Thickness	1.235"	App D.7
	Valve Lengths	1'-2.25"	[21]
	Valve Name	CK-B-1-26	[21]
	Valve Mass	203.5 lb = 0.527 lbf*s^2/in	[3, pg B-2]

Table 121. Dimensions Associated with Valves on Line 1-38 of Model 1-4

Valves (1-38)	*Dimensions*		*Reference*
GT (1-38)	Pipe/Valve Diameter	4.5"	[21]
	Pipe Thickness	0.237"	[21]
	Equiv Valve OD	5.5"	App D.7
	Equiv Valve Thickness	1.235"	App D.7
	Valve Lengths	1'-0.25"	[21]
	Valve Name	GT-D-1-30	[21]
	Valve Mass	273 lb = 0.708 lbf*s^2/in	[3, pg B-2]

CK (1-38)	Pipe/Valve Diameter	4.5"	[21]
	Pipe Thickness	0.237"	[21]
	Equiv Valve OD	5.5"	App D.7
	Equiv Valve Thickness	1.235"	App D.7
	Valve Lengths	1'-2.25"	[21]
	Valve Name	CK-B-1-29	[21]
	Valve Mass	203.5 lb = 0.527 lbf*s^2/in	[3, pg B-2]

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Table 122. Dimensions Associated with Valves on Line 1-39 of Model 1-4

Valves (1-39)	*Dimensions*		*Reference*
GT (1-39A)	Pipe/Valve Diameter	6.625"	[16]
	Pipe Thickness	0.28"	[16]
	Equiv Valve Thickness	1.417"	App D.7
	Valve Lengths	1'-4.125"	[16]
	Valve Name	GT-D-1-32	[16]
	Valve Mass	491 lb = 1.272 lbf*s^2/in	[3]
GT (1-39B)	Pipe/Valve Diameter	6.625"	[16]
	Pipe Thickness	0.28"	[16]
	Equiv Valve Thickness	1.417"	App D.7
	Valve Lengths	1'-4.125"	[16]
	Valve Name	GT-D-1-31	[16]
	Valve Mass	491 lb = 1.272 lbf*s^2/in	[3]
CK (1-39)	Pipe/Valve Diameter	4.5"	[16]
	Pipe Thickness	0.237"	[16]
	Equiv Valve OD	5.5"	App D.7
	Equiv Valve Thickness	1.235"	App D.7
	Valve Lengths	1'-2.25"	[16]
	Valve Name	CK-B-1-89	[16]
	Valve Mass	203.5 lb = 0.527 lbf*s^2/in	[3, pg B-2]

Table 123. Dimensions Associated with Valves on Line 1-42 of Model 1-4

Valves (1-42)	*Dimensions*		*Reference*
GT (1-42)	Pipe/Valve Diameter	6.625"	[22]
	Pipe Thickness	0.28"	[22]
	Equiv Valve Thickness	1.417"	App D.7
	Valve Lengths	1'-4.125"	[22]
	Valve Name	GT-D-1-34	[22]
	Valve Mass	491 lb = 1.272 lbf*s^2/in	[3, pg B-2]

Table 124. Dimensions Associated with Valves on Line 1-67 of Model 1-4

Valves (1-67)	*Dimensions*		*Reference*
GT (1-67)	Pipe/Valve Diameter	4.5"	[15]
	Pipe Thickness	0.237"	[15]
	Equiv Valve OD	5.5"	App D.7
	Equiv Valve Thickness	1.235"	App D.7
	Valve Lengths	1'-0.375"	[15]
	Valve Name	GT-E-1-85	[15]
	Valve Mass	273 lb = 0.708 lbf*s^2/in	[3, pg B-2]
PCV (1-67)	Pipe/Valve Diameter	4.5"	[15]
	Pipe Thickness	0.237"	[15]
	Equiv Valve OD	5.5"	App D.7
	Equiv Valve Thickness	1.235"	App D.7
	Valve Lengths	1'-2.375"	[15]
	Valve Name	PCV 1-1	[15]
	Valve Mass	*203.5 lb = 0.527 lbf*s^2/in	[3, pg B-3]

* Assumed to have the same mass as 4" check valves

Table 125. Dimensions Associated with Valves on Line 1-77 of Model 1-4

Valves (1-77)	*Dimensions*		*Reference*
FGV (1-77)	Pipe/Valve Diameter	4.5"	[20]
	Pipe Thickness	0.237"	[20]
	Equiv Valve OD	5.5"	App D.7
	Equiv Valve Thickness	1.235"	App D.7
	Valve Lengths	1' - 0.625"	[20]
	Valve Name	FCV 1-8	[20]
	Valve Mass	*203.5 lb = 0.527 lbf*s^2/in	[3, pg B-3]

* Assumed to have the same mass as 4" check valves

Appendix D.7

Calculations of Pipe Thickness to Mimic Valve Behavior in Model

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Valve Thickness Calculations

According to Nu-Pipe the moment of inertia of the pipe valves is to be three times that of the pipe for which it is attached to. [40, 2-21]

6" GATE VALVES ASSOCIATED WITH LINES 1-40, 1-41, & 1-42

$GT_{1\text{-}40}$, $GT_{1\text{-}41}$, $GT_{1\text{-}42}$

The above three gate valves are located where line 1-40 connects to 1-39, 1-41 connects to 1-39, and 1-42 connects to 1-41.

$$t_{GT6in} := 0.28in$$

Thickness of PCS on either side of valve [17] [22]

$$od_{GT6in} := 6.625in$$

Outer diameter of PCS pipe on either side of valve [17] [22]

$$id_{GT6in} := od_{GT6in} - 2 \cdot t_{GT6in}$$

$$id_{GT6in} = 6.065 \text{ in}$$

Inner diameter of PCS pipe below primary coolant pumps

$$I_{GT6in} := \frac{\pi \cdot \left(od_{GT6in}{}^4 - id_{GT6in}{}^4\right)}{4}$$

$$I_{GT6in} = 450.275 \text{ in}^4$$

Moment of inertia of PCS pipe below primary coolant pumps [8, Table 17-27, pg 17-39]

$$T_{GT6in} := \left[\frac{\left[-\frac{4 \cdot (3 \cdot I_{GT6in})}{\pi} + od_{GT6in}{}^4\right]^{0.25} - od_{GT6in}}{-2}\right]$$

$$\boxed{T_{GT6in} = 1.417 \text{ in}}$$

Thickness of pipe representing valve if outer diameter is to remain consistent with attached pipe where equation is modification of moment of inertia equation for a pipe thickness as the output and the moment of inertia for the valve represented by 3 times the value of the moment of inertia of the pipe [8, Table 17-27, pg 17-39]

4" GATE AND CHECK VALVES ASSOCIATED WITH LINES 1-34, 1-38, 1-39, & 1-77

$GT_{1\text{-}34}$, $GT_{1\text{-}38}$, $GT_{1\text{-}39}$, $CK_{1\text{-}38}$, $CK_{1\text{-}39}$, $CK_{1\text{-}77}$, $PCV_{1\text{-}67}$, & $FGV_{1\text{-}77}$

The above three gate valves are located where line 1-34 connects to 1-67, 1-38 connects to 1-77, and 1-39 connects to 1-77. The above three check valves are located on the center of lines 1-38 and 1-38 and where 1-77 connects to 1-39. The above FGV and PCV valves are located on the north and east sides of $CK_{1\text{-}77}$ and $GT_{1\text{-}34}$.

$t_{GT4in} := 0.237\,in$

Thickness of PCS pipe on either side of gate valves [15] [16] [20] [21]

$od_{GT4in\_actual} := 4.5in$

Actual outer diameter of PCS pipe below primary coolant pumps [15] [16] [20] [21]

$od_{GT4in} := od_{GT4in\_actual} + 1in$

$od_{GT4in} = 5.5\,in$

An extra inch was added to outside diameter since adjustments to thickness alone while keeping outer diameter fixed generated a complex solution

$id_{GT4in} := od_{GT4in} - 2 \cdot t_{GT4in}$

$id_{GT4in} = 5.026\,in$

Inner diameter of PCS pipe below primary coolant pumps

$$I_{GT4in} := \frac{\pi \cdot \left(od_{GT4in}^{\;4} - id_{GT4in}^{\;4}\right)}{4}$$

$I_{GT4in} = 217.524\,in^4$

Moment of inertia of PCS pipe below primary coolant pumps [8, Table 17-27, pg 17-39]

$$T_{GT4in} := \left[\frac{\left[-\frac{4 \cdot (3 \cdot I_{GT4in})}{\pi} + od_{GT4in}^{\;4}\right]^{0.25} - od_{GT4in}}{-2}\right]$$

$\boxed{T_{GT4in} = 1.235\,in}$

Thickness of pipe representing valve if outer diameter is to remain consistent with attached pipe where equation is modification of moment of inertia equation for a pipe thickness as the output and the moment of inertia for the valve represented by 3 times the value of the moment of inertia of the pipe [8, Table 17-27, pg 17-39]

Appendix D.8

Elbow Stiffness and Water Filled Pipe Density Calculations

MATERIAL PROPERTIES USED IN ELBOW STIFFNESS CALCULATIONS

Stainless Steel Material Properties

The material properties below represent reasonable values that could be used in an analysis.

$E_{s125} := 2.8 \cdot 10^{7} \cdot psi$

$E_{s167} := 2.77 \cdot 10^{7} \cdot psi$

Modulus of elasticity @ 125 & 167 Fahrenheit [2, Table TM]

$\nu_s := 0.30$

Poisson's ratio [4, NB-3683.1(b)]

$$G_{s125} := \frac{E_{s125}}{2 \cdot (1 + \nu_s)} \qquad G_{s167} := \frac{E_{s167}}{2 \cdot (1 + \nu_s)}$$

Shear modulus [41, Eq 2-19]

$G_{s125} = 1.077 \times 10^{7}$ psi $\qquad G_{s167} = 1.065 \times 10^{7}$ psi

$\rho_s := 0.28 \frac{lb}{in^3}$

Mass density [41]

Steel Material Properties

The material properties below represent reasonable values that could be used in an analysis.

$E_c := 3.0 \cdot 10^{7} \cdot psi$

Modulus of elasticity [41, Table A-5]

$\nu_c := 0.29$

Poisson's ratio [41]

$\rho_c := 0.282 \frac{lb}{in^3}$

Mass density [41]

Water Material Properties

The material properties below represent reasonable values that could be used in an analysis.

$\rho_w := 62.4 \cdot \frac{lb}{ft^3}$

Mass density [42, Table A]

$\rho_w = 0.0361 \frac{lb}{in^3}$

FLEXIBILITY FACTOR FUNCTION AND CALCULATIONS APPROACH

Flexibility Factor

(a) R/r is not less than 1.7 [9, NB-3686.2]

(b) center line length $R\alpha$ is greater than 2r [9, NB-3686.2]

(c) there are no flanges or other similar stiffeners within a distance r from either end of the curved section of pipe or from the ends of welding elbows. [9, NB-3686.2]

$$k(d_o, t, P, R, E) := \left| \begin{array}{l} d_i \leftarrow d_o - 2 \cdot t \\ r \leftarrow \frac{1}{4} \cdot (d_o + d_i) \\ h \leftarrow t \cdot R \cdot r^{-2} \\ X_k \leftarrow 6 \cdot \left(\frac{r}{t}\right)^{\frac{4}{3}} \cdot \left(\frac{R}{r}\right)^{\frac{1}{3}} \\ k_o \leftarrow 0 \\ k_o \leftarrow \frac{1.65}{h} \cdot \frac{1}{1 + \left(\frac{P \cdot r}{t \cdot E}\right) \cdot X_k} \quad \text{if } \frac{R}{r} \geq 1.7 \\ k_o \end{array} \right.$$

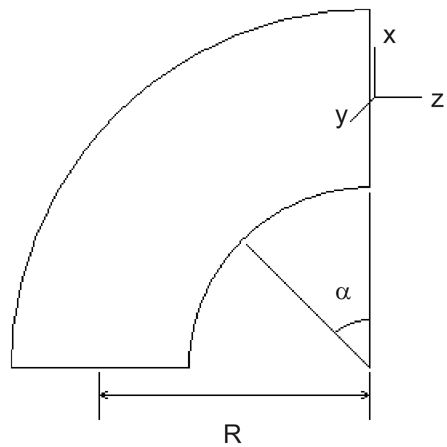
[4, NB-3686.2]

$$\theta_{nom1} = \frac{R}{E \cdot I} \cdot \int_0^{\theta} M_1 \, d\alpha \qquad \theta_{ab1} = k \cdot \theta_{nom1} = \frac{k \cdot R}{E \cdot I} \cdot \int_0^{\theta} M_1 \, d\alpha$$

$$\theta_{nom2} = \frac{R}{E \cdot I} \cdot \int_0^{\theta} M_2 \, d\alpha \qquad \theta_{ab2} = k \cdot \theta_{nom2} = \frac{k \cdot R}{E \cdot I} \cdot \int_0^{\theta} M_2 \, d\alpha$$

$$\theta_{nom3} = \frac{R}{G \cdot J} \cdot \int_0^{\theta} M_3 \, d\alpha \qquad \theta_{ab3} = \theta_{nom3} = \frac{R}{G \cdot J} \cdot \int_0^{\theta} M_3 \, d\alpha$$

To address the flexibility factor in the finite element model, an effective area moment of inertia will be established:



$$I_e = \frac{I}{k}$$

Therefore:

$$\theta_{ab1} = \frac{R}{E \cdot I_e} \cdot \int_0^{\theta} M_1 \, d\alpha$$

$$\theta_{ab2} = \frac{R}{E \cdot I_e} \cdot \int_0^{\theta} M_2 \, d\alpha$$

$$\theta_{ab3} = \frac{R}{G \cdot J} \cdot \int_0^{\theta} M_3 \, d\alpha$$

FLEXIBILITY FACTOR AND MOMENT OF INERTIA CALCULATIONS FOR MODEL 1 & 4

Pipe 36 Inch Diameter and 1/2 (Pressure 272 psi, Temperature 167 Degrees F)

$d_{36} := 36 \cdot in$ — Pipe outside diameter.

$t_{36} := 0.5 \cdot in$ — Pipe thickness.

$p_{272} := 272 \cdot psi$ — Internal pressure [3]

$r_{s36} := d_{36}$ — Radius for short radius elbow.

$r_{s36} = 36\ in$

$r_{l36} := 1.5 \cdot r_{s36}$ — Radius for long radius elbow.

$r_{l36} = 54\ in$

$$A_{36} := \frac{\pi}{4} \cdot \left[d_{36}^{\ 2} - \left(d_{36} - 2 \cdot t_{36} \right)^2 \right]$$

Pipe cross section area.

$A_{36} = 55.7633\ in^2$

$$A_{i36} := \frac{\pi}{4} \cdot \left(d_{36} - 2 \cdot t_{36} \right)^2$$

Pipe internal area.

$A_{i36} = 962.1\ in^2$

$$\rho_{sw36} := \frac{A_{36} \cdot \rho_s + A_{i36} \cdot \rho_w}{A_{36}}$$

Mass density for the pipe with water.

$$\rho_{sw36} = 2.339 \times 10^{-3} \frac{lbf \cdot sec^2}{in^4}$$

$$I_{36} := \frac{\pi}{64} \cdot \left[d_{36}^{\ 4} - \left(d_{36} - 2 \cdot t_{36} \right)^4 \right]$$

Pipe area moment of inertia.

$I_{36} = 8786.20\ in^4$

$$J_{36} := \frac{\pi}{32} \cdot \left[d_{36}^{\ 4} - \left(d_{36} - 2 \cdot t_{36} \right)^4 \right]$$

Pipe polar moment of inertia.

$J_{36} = 17572.4\ in^4$

$k_{s36} := k(d_{36}, t_{36}, p_{272}, r_{s36}, E_{s167})$

Flexibility factor for short radius.

$k_{s36} = 22.065$

$I_{es36} := \frac{I_{36}}{k_{s36}}$

Effective moment of inertia for short radius.

$\boxed{I_{es36} = 398.196\,in^4}$

$k_{l36} := k(d_{36}, t_{36}, p_{272}, r_{l36}, E_{s167})$

Flexibility factor for long radius.

$k_{l36} = 14.224$

$I_{el36} := \frac{I_{36}}{k_{l36}}$

Effective moment of inertia for long radius.

$\boxed{I_{el36} = 617.693\,in^4}$

Pipe 24 Inch Diameter and 0.375 Thickness (Pressure 272 psi, Temperature 167 Degrees F)

$d_{24} := 24 \cdot in$

Pipe outside diameter.

$t_{24} := 0.375 \cdot in$

Pipe thickness.

$p_{272} = 272\,psi$

Internal pressure.

$r_{s24} := d_{24}$

Radius for short radius elbow.

$r_{s24} = 24\,in$

$r_{l24} := 1.5 \cdot r_{s24}$

Radius for long radius elbow.

$r_{l24} = 36\,in$

$A_{24} := \frac{\pi}{4} \cdot \left[d_{24}^2 - (d_{24} - 2 \cdot t_{24})^2\right]$

Pipe cross section area.

$A_{24} = 27.8325\,in^2$

$A_{i24} := \frac{\pi}{4} \cdot (d_{24} - 2 \cdot t_{24})^2$

Pipe internal area.

$A_{i24} = 424.6\,in^2$

$$\rho_{sw24} := \frac{A_{24} \cdot \rho_s + A_{i24} \cdot \rho_w}{A_{24}}$$

Mass density for the pipe with water.

$\rho_{sw24} = 2.152 \times 10^{-3} \dfrac{lbf \cdot sec^2}{in^4}$

$$I_{24} := \frac{\pi}{64} \cdot \left[d_{24}{}^4 - \left(d_{24} - 2 \cdot t_{24} \right)^4 \right]$$

Pipe area moment of inertia.

$I_{24} = 1942.30\,in^4$

$$J_{24} := \frac{\pi}{32} \cdot \left[d_{24}{}^4 - \left(d_{24} - 2 \cdot t_{24} \right)^4 \right]$$

Pipe polar moment of inertia.

$J_{24} = 3884.6\,in^4$

$$k_{s24} := k\left(d_{24}, t_{24}, p_{272}, r_{s24}, E_{s167}\right)$$

Flexibility factor for short radius.

$k_{s24} = 20.733$

$$I_{es24} := \frac{I_{24}}{k_{s24}}$$

Effective moment of inertia for short radius.

$\boxed{I_{es24} = 93.681\,in^4}$

$$k_{l24} := k\left(d_{24}, t_{24}, p_{272}, r_{l24}, E_{s167}\right)$$

Flexibility factor for long radius.

$k_{l24} = 13.453$

$$I_{el24} := \frac{I_{24}}{k_{l24}}$$

Effective moment of inertia for long radius.

$\boxed{I_{el24} = 144.375\,in^4}$

Pipe 20 Inch Diameter and 0.3125 Thickness (Pressure 272 psi, Temperature 167 Degrees F)

$d_{20} := 20 \cdot in$ — Pipe outside diameter.

$t_{20} := 0.3125 \cdot in$ — Pipe thickness.

$p_{272} = 272\,psi$ — Internal pressure.

$r_{s20} := d_{20}$ — Radius for short radius elbow.

$r_{s20} = 20\,in$

$r_{l20} := 1.5 \cdot r_{s20}$ — Radius for long radius elbow.

$r_{l20} = 30\,in$

$$A_{20} := \frac{\pi}{4} \cdot \left[d_{20}^{\;2} - \left(d_{20} - 2 \cdot t_{20} \right)^2 \right]$$

Pipe cross section area.

$A_{20} = 19.3282\,in^2$

$$A_{i20} := \frac{\pi}{4} \cdot \left(d_{20} - 2 \cdot t_{20} \right)^2$$

Pipe internal area.

$A_{i20} = 294.8\,in^2$

$$\rho_{sw20} := \frac{A_{20} \cdot \rho_s + A_{i20} \cdot \rho_w}{A_{20}}$$

Mass density for the pipe with water.

$$\rho_{sw20} = 2.152 \times 10^{-3}\,\frac{lbf \cdot sec^2}{in^4}$$

$$I_{20} := \frac{\pi}{64} \cdot \left[d_{20}^{\;4} - \left(d_{20} - 2 \cdot t_{20} \right)^4 \right]$$

Pipe area moment of inertia.

$I_{20} = 936.68\,in^4$

$$J_{20} := \frac{\pi}{32} \cdot \left[d_{20}^{\;4} - \left(d_{20} - 2 \cdot t_{20} \right)^4 \right]$$

Pipe polar moment of inertia.

$J_{20} = 1873.4\,in^4$

$k_{s20} := k\left(d_{20}, t_{20}, p_{272}, r_{s20}, E_{s167}\right)$ — Flexibility factor for short radius.

$k_{s20} = 20.733$

$I_{es20} := \frac{I_{20}}{k_{s20}}$ — Effective moment of inertia for short radius.

$I_{es20} = 45.178\,in^4$

$k_{l20} := k\left(d_{20}, t_{20}, p_{272}, r_{l20}, E_{s167}\right)$ — Flexibility factor for long radius.

$k_{l20} = 13.453$

$I_{el20} := \frac{I_{20}}{k_{l20}}$ — Effective moment of inertia for long radius.

$I_{el20} = 69.625\,in^4$

Pipe 18 Inch Diameter and 0.312 Inch Thickness (Pressure 272 psi, Temperature 167 Degrees F)

$d_{18} := 18 \cdot in$ — Pipe outside diameter.

$t_{18} := 0.312 \cdot in$ — Pipe thickness.

$p_{272} = 272\,psi$ — Internal pressure [3]

$r_{s18} := d_{18}$ — Radius for short radius elbow.

$r_{s18} = 18\,in$

$r_{l18} := 1.5 \cdot r_{s18}$ — Radius for long radius elbow.

$r_{l18} = 27\,in$

$A_{18} := \frac{\pi}{4} \cdot \left[d_{18}^{\;2} - \left(d_{18} - 2 \cdot t_{18}\right)^2\right]$ — Pipe cross section area.

$A_{18} = 17.3\,in^2$

$$A_{i18} := \frac{\pi}{4}\cdot\left(d_{18} - 2\cdot t_{18}\right)^2$$

Pipe internal area.

$$A_{i18} = 237.1\,in^2$$

$$\rho_{sw18} := \frac{A_{18}\cdot\rho_s + A_{i18}\cdot\rho_w}{A_{18}}$$

Mass density for the pipe with water.

$$\rho_{sw18} = 2.004\times 10^{-3}\,\frac{lbf\cdot sec^2}{in^4}$$

$$I_{18} := \frac{\pi}{64}\cdot\left[d_{18}{}^4 - \left(d_{18} - 2\cdot t_{18}\right)^4\right]$$

Pipe area moment of inertia.

$$I_{18} = 678.2\,in^4$$

$$J_{18} := \frac{\pi}{32}\cdot\left[d_{18}{}^4 - \left(d_{18} - 2\cdot t_{18}\right)^4\right]$$

Pipe polar moment of inertia.

$$J_{18} = 1356.5\,in^4$$

$$k_{s18} := k\left(d_{18}, t_{18}, p_{272}, r_{s18}, E_{s167}\right)$$

Flexibility factor for short radius.

$$k_{s18} = 19.427$$

$$I_{es18} := \frac{I_{18}}{k_{s18}}$$

Effective moment of inertia for short radius.

$$\boxed{I_{es18} = 34.913\,in^4}$$

$$k_{l18} := k\left(d_{18}, t_{18}, p_{272}, r_{l18}, E_{s167}\right)$$

Flexibility factor for long radius.

$$k_{l18} = 12.668$$

$$I_{el18} := \frac{I_{18}}{k_{l18}}$$

Effective moment of inertia for long radius.

$$\boxed{I_{el18} = 53.542\,in^4}$$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: Spears/Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

Pipe 6 Inch Diameter (Actually 6.625 Inch OD) and 0.28 Thick (Pressure 272 psi, Temperature 167 Degrees F)

$d_{6p272} := 6.625 \cdot in$ — Pipe outside diameter.

$t_{6p272} := 0.28 \cdot in$ — Pipe thickness.

$p_{272} = 272\,psi$ — Internal pressure [3]

$r_{s6p272} := 6in$ — Radius for short radius elbow.

$r_{s6p272} = 6\,in$

$r_{l6p272} := 1.5 \cdot r_{s6p272}$ — Radius for long radius elbow.

$r_{l6p272} = 9\,in$

$r_{xl6p272} := 30in$ — Radius for 30" extra long radius elbow

$r_{xl6p272} = 30\,in$

$$A_{6p272} := \frac{\pi}{4} \cdot \left[{d_{6p272}}^2 - \left(d_{6p272} - 2 \cdot t_{6p272} \right)^2 \right]$$

Pipe cross section area.

$A_{6p272} = 5.5814\,in^2$

$$A_{i6p272} := \frac{\pi}{4} \cdot \left(d_{6p272} - 2 \cdot t_{6p272} \right)^2$$

Pipe internal area.

$A_{i6p272} = 28.9\,in^2$

$$\rho_{sw6p272} := \frac{A_{6p272} \cdot \rho_s + A_{i6p272} \cdot \rho_w}{A_{6p272}}$$

Mass density for the pipe with water.

$$\rho_{sw6p272} = 1.209 \times 10^{-3} \frac{lbf \cdot sec^2}{in^4}$$

$$I_{6p272} := \frac{\pi}{64} \cdot \left[{d_{6p272}}^4 - \left(d_{6p272} - 2 \cdot t_{6p272} \right)^4 \right]$$

Pipe area moment of inertia.

$I_{6p272} = 28.14\,in^4$

$J_{6p272} := \frac{\pi}{32} \cdot \left[d_{6p272}{}^4 - \left(d_{6p272} - 2 \cdot t_{6p272} \right)^4 \right]$ Pipe polar moment of inertia.

$J_{6p272} = 56.3\,in^4$

$k_{s6p272} := k\left(d_{6p272}, t_{6p272}, p_{272}, r_{s6p272}, E_{s167} \right)$ Flexibility factor for short radius.

$k_{s6p272} = 9.682$

$I_{es6p272} := \frac{I_{6p272}}{k_{s6p272}}$ Effective moment of inertia for short radius.

$I_{es6p272} = 2.907\,in^4$

$k_{l6p272} := k\left(d_{6p272}, t_{6p272}, p_{272}, r_{l6p272}, E_{s167} \right)$ Flexibility factor for long radius.

$k_{l6p272} = 6.435$

$I_{el6p272} := \frac{I_{6p272}}{k_{l6p272}}$ Effective moment of inertia for long radius.

$I_{el6p272} = 4.373\,in^4$

$k_{xl6p272} := k\left(d_{6p272}, t_{6p272}, p_{272}, r_{xl6p272}, E_{s167} \right)$ Flexibility factor for 30" long radius

$k_{xl6p272} = 1.908$

$I_{exl6p272} := \frac{I_{6p272}}{k_{xl6p272}}$ Effective moment of inertia for 30" extra long radius.

$I_{exl6p272} = 14.746\,in^4$

Pipe 6 Inch Diameter (Actually 6.625 Inch OD) and 0.28 Thick (Pressure 376 psi, Temperature 125 Degrees F)

$d_{6p376} := 6.625 \cdot in$ Pipe outside diameter.

$t_{6p376} := 0.28 \cdot in$ Pipe thickness.

$p_{376} := 376psi$ Internal pressure [3]

$r_{s6p376} := 6in$

Radius for short radius elbow.

$r_{s6p376} = 6\,in$

$r_{l6p376} := 1.5 \cdot r_{s6p376}$

Radius for long radius elbow.

$r_{l6p376} = 9\,in$

$r_{xl6p376} := 30in$

Radius for 30" extra long radius elbow

$r_{xl6p376} = 30\,in$

$$A_{6p376} := \frac{\pi}{4} \cdot \left[d_{6p376}{}^2 - \left(d_{6p376} - 2 \cdot t_{6p376}\right)^2\right]$$

Pipe cross section area.

$A_{6p376} = 5.5814\,in^2$

$$A_{i6p376} := \frac{\pi}{4} \cdot \left(d_{6p376} - 2 \cdot t_{6p376}\right)^2$$

Pipe internal area.

$A_{i6p376} = 28.9\,in^2$

$$\rho_{sw6p376} := \frac{A_{6p376} \cdot \rho_s + A_{i6p376} \cdot \rho_w}{A_{6p376}}$$

Mass density for the pipe with water.

$$\rho_{sw6p376} = 1.209 \times 10^{-3} \frac{lbf \cdot sec^2}{in^4}$$

$$I_{6p376} := \frac{\pi}{64} \cdot \left[d_{6p376}{}^4 - \left(d_{6p376} - 2 \cdot t_{6p376}\right)^4\right]$$

Pipe area moment of inertia.

$I_{6p376} = 28.14\,in^4$

$$J_{6p376} := \frac{\pi}{32} \cdot \left[d_{6p376}{}^4 - \left(d_{6p376} - 2 \cdot t_{6p376}\right)^4\right]$$

Pipe polar moment of inertia.

$J_{6p376} = 56.3\,in^4$

$k_{s6p376} := k\left(d_{6p376}, t_{6p376}, p_{376}, r_{s6p376}, E_{s125}\right)$

Flexibility factor for short radius.

$k_{s6p376} = 9.609$

$I_{es6p376} := \frac{I_{6p376}}{k_{s6p376}}$

Effective moment of inertia for short radius.

$I_{es6p376} = 2.929\,in^4$

$k_{l6p376} := k\left(d_{6p376}, t_{6p376}, p_{376}, r_{l6p376}, E_{s125}\right)$

Flexibility factor for long radius.

$k_{l6p376} = 6.38$

$I_{el6p376} := \frac{I_{6p376}}{k_{l6p376}}$

Effective moment of inertia for long radius.

$I_{el6p376} = 4.411\,in^4$

$k_{xl6p376} := k\left(d_{6p376}, t_{6p376}, p_{376}, r_{xl6p376}, E_{s125}\right)$

Flexibility factor for 30" long radius

$k_{xl6p376} = 1.884$

$I_{exl6p376} := \frac{I_{6p376}}{k_{xl6p376}}$

Effective moment of inertia for 30" extra long radius.

$I_{exl6p376} = 14.934\,in^4$

Pipe 4 Inch Diameter (Actually 4.5 Inch OD) and 0.237 Thick (Pressure 272 psi, Temperature 167 Degrees F)

$d_{4p272} := 4.5 \cdot in$ — Pipe outside diameter.

$t_{4p272} := 0.237 \cdot in$ — Pipe thickness.

$p_{272} = 272\,psi$ — Internal pressure [3]

$r_{s4p272} := 4in$

Radius for short radius elbow.

$r_{s4p272} = 4\,in$

$r_{l4p272} := 1.5 \cdot r_{s4p272}$

Radius for long radius elbow.

$r_{l4p272} = 6\,in$

$r_{redl4p272} := 2.25 \cdot r_{s4p272}$

Radius for reducing elbow.

$r_{redl4p272} = 9\,in$

$r_{xl4p272} := 5 \cdot r_{s4p272}$ Radius for extra long radius elbow

$r_{xl4p272} = 20\,in$

$A_{4p272} := \frac{\pi}{4} \cdot \left[d_{4p272}{}^2 - \left(d_{4p272} - 2 \cdot t_{4p272} \right)^2 \right]$ Pipe cross section area.

$A_{4p272} = 3.174\,in^2$

$A_{i4p272} := \frac{\pi}{4} \cdot \left(d_{4p272} - 2 \cdot t_{4p272} \right)^2$ Pipe internal area.

$A_{i4p272} = 12.7\,in^2$

$\rho_{sw4p272} := \frac{A_{4p272} \cdot \rho_s + A_{i4p272} \cdot \rho_w}{A_{4p272}}$ Mass density for the pipe with water.

$\rho_{sw4p272} = 1.1 \times 10^{-3} \frac{lbf \cdot sec^2}{in^4}$

$I_{4p272} := \frac{\pi}{64} \cdot \left[d_{4p272}{}^4 - \left(d_{4p272} - 2 \cdot t_{4p272} \right)^4 \right]$ Pipe area moment of inertia.

$I_{4p272} = 7.23\,in^4$

$J_{4p272} := \frac{\pi}{32} \cdot \left[d_{4p272}{}^4 - \left(d_{4p272} - 2 \cdot t_{4p272} \right)^4 \right]$ Pipe polar moment of inertia.

$J_{4p272} = 14.5\,in^4$

$k_{s4p272} := k\left(d_{4p272}, t_{4p272}, p_{272}, r_{s4p272}, E_{s167} \right)$ Flexibility factor for short radius.

$k_{s4p272} = 7.812$

$I_{es4p272} := \frac{I_{4p272}}{k_{s4p272}}$ Effective moment of inertia for short radius.

$\boxed{I_{es4p272} = 0.926\,in^4}$

$k_{l4p272} := k\left(d_{4p272}, t_{4p272}, p_{272}, r_{l4p272}, E_{s167}\right)$ — Flexibility factor for long radius.

$k_{l4p272} = 5.199$

$I_{el4p272} := \dfrac{I_{4p272}}{k_{l4p272}}$ — Effective moment of inertia for long radius.

$\boxed{I_{el4p272} = 1.391\ in^4}$

$k_{redl4p272} := k\left(d_{4p272}, t_{4p272}, p_{272}, r_{redl4p272}, E_{s167}\right)$ — Flexibility factor for long radius.

$k_{redl4p272} = 3.459$

$I_{eredl4p272} := \dfrac{I_{4p272}}{k_{redl4p272}}$ — Effective moment of inertia for long radius.

$\boxed{I_{eredl4p272} = 2.091\ in^4}$

$k_{xl4p272} := k\left(d_{4p272}, t_{4p272}, p_{272}, r_{xl4p272}, E_{s167}\right)$ — Flexibility factor for long radius.

$k_{xl4p272} = 1.549$

$I_{exl4p272} := \dfrac{I_{4p272}}{k_{xl4p272}}$ — Effective moment of inertia for long radius.

$\boxed{I_{exl4p272} = 4.669\ in^4}$

Pipe 4 Inch Diameter (Actually 4.5 Inch OD) and 0.237 Thick (Pressure 376 psi, Temperature 125 Degrees F)

$d_{4p376} := 4.5 \cdot in$ — Pipe outside diameter.

$t_{4p376} := 0.237 \cdot in$ — Pipe thickness.

$p_{376} = 376\ psi$ — Internal pressure [3]

$r_{s4p376} := 4in$ — Radius for short radius elbow.

$r_{s4p376} = 4\ in$

$r_{l4p376} := 1.5 \cdot r_{s4p376}$ — Radius for long radius elbow.

$r_{l4p376} = 6\,in$

$r_{redl4p376} := 2.25 \cdot r_{s4p376}$

Radius for reducing elbow.

$r_{redl4p376} = 9\,in$

$A_{4p376} := \frac{\pi}{4} \cdot \left[d_{4p376}^{\ 2} - \left(d_{4p376} - 2 \cdot t_{4p376} \right)^2 \right]$

Pipe cross section area.

$A_{4p376} = 3.174\,in^2$

$A_{i4p376} := \frac{\pi}{4} \cdot \left(d_{4p376} - 2 \cdot t_{4p376} \right)^2$

Pipe internal area.

$A_{i4p376} = 12.7\,in^2$

$\rho_{sw4p376} := \frac{A_{4p376} \cdot \rho_s + A_{i4p376} \cdot \rho_w}{A_{4p376}}$

Mass density for the pipe with water.

$\rho_{sw4p376} = 1.1 \times 10^{-3} \frac{lbf \cdot sec^2}{in^4}$

$I_{4p376} := \frac{\pi}{64} \cdot \left[d_{4p376}^{\ 4} - \left(d_{4p376} - 2 \cdot t_{4p376} \right)^4 \right]$

Pipe area moment of inertia.

$I_{4p376} = 7.23\,in^4$

$J_{4p376} := \frac{\pi}{32} \cdot \left[d_{4p376}^{\ 4} - \left(d_{4p376} - 2 \cdot t_{4p376} \right)^4 \right]$

Pipe polar moment of inertia.

$J_{4p376} = 14.5\,in^4$

$k_{s4p376} := k\left(d_{4p376}, t_{4p376}, p_{376}, r_{s4p376}, E_{s125} \right)$

Flexibility factor for short radius.

$k_{s4p376} = 7.778$

$I_{es4p376} := \frac{I_{4p376}}{k_{s4p376}}$

Effective moment of inertia for short radius.

$\boxed{I_{es4p376} = 0.93\,in^4}$

$k_{l4p376} := k\left(d_{4p376}, t_{4p376}, p_{376}, r_{l4p376}, E_{s125}\right)$

Flexibility factor for long radius.

$k_{l4p376} = 5.173$

$I_{el4p376} := \frac{I_{4p376}}{k_{l4p376}}$

Effective moment of inertia for long radius.

$\boxed{I_{el4p376} = 1.398\,in^4}$

$k_{redl4p376} := k\left(d_{4p376}, t_{4p376}, p_{376}, r_{redl4p376}, E_{s125}\right)$

Flexibility factor for long radius.

$k_{redl4p376} = 3.439$

$I_{eredl4p376} := \frac{I_{4p376}}{k_{redl4p376}}$

Effective moment of inertia for long radius.

$\boxed{I_{eredl4p376} = 2.103\,in^4}$

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: Spears/Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

SUMMARY OF RESULTS

Pipe 36 Inch Diameter and 1/2 (Pressure 272 psi, Temperature 167 Degrees F)

$k_{s36} = 22.065$ — Flexibility factor for short radius.

$I_{es36} = 398.196\,in^4$ — Effective moment of inertia for short radius.

$k_{l36} = 14.224$ — Flexibility factor for long radius.

$I_{el36} = 617.693\,in^4$ — Effective moment of inertia for long radius.

Pipe 24 Inch Diameter and 0.375 Thickness (Pressure 272 psi, Temperature 167 Degrees F)

$k_{s24} = 20.733$ — Flexibility factor for short radius.

$I_{es24} = 93.681\,in^4$ — Effective moment of inertia for short radius.

$k_{l24} = 13.453$ — Flexibility factor for long radius.

$I_{el24} = 144.375\,in^4$ — Effective moment of inertia for long radius.

Pipe 20 Inch Diameter and 0.3125 Thickness (Pressure 272 psi, Temperature 167 Degrees F)

$k_{s20} = 20.733$ — Flexibility factor for short radius.

$I_{es20} = 45.178\,in^4$ — Effective moment of inertia for short radius.

$k_{l20} = 13.453$ — Flexibility factor for long radius.

$I_{el20} = 69.625\,in^4$ — Effective moment of inertia for long radius.

Pipe 18 Inch Diameter and 0.312 Inch Thickness (Pressure 272 psi, Temperature 167 Degrees F)

$k_{s18} = 19.427$ — Flexibility factor for short radius.

$I_{es18} = 34.913\,in^4$ — Effective moment of inertia for short radius.

$k_{l18} = 12.668$ — Flexibility factor for long radius.

$I_{el18} = 53.542\,in^4$ — Effective moment of inertia for long radius.

Pipe 6 Inch Diameter (Actually 6.625 Inch OD) and 0.28 Thick (Pressure 272 psi, Temperature 167 Degrees F)

$k_{s6p272} = 9.682$ — Flexibility factor for short radius.

$I_{es6p272} = 2.907\,in^4$ — Effective moment of inertia for short radius.

$k_{l6p272} = 6.435$ — Flexibility factor for long radius.

$I_{el6p272} = 4.373\,in^4$ — Effective moment of inertia for long radius.

$k_{xl6p272} = 1.908$ — Flexibility factor for 30" long radius

$I_{exl6p272} = 14.746\,in^4$ — Effective moment of inertia for 30" extra long radius.

Pipe 6 Inch Diameter (Actually 6.625 Inch OD) and 0.28 Thick (Pressure 376 psi, Temperature 125 Degrees F)

$k_{s6p376} = 9.609$ — Flexibility factor for short radius.

$I_{es6p376} = 2.929\,in^4$ — Effective moment of inertia for short radius.

$k_{l6p376} = 6.38$ — Flexibility factor for long radius.

$I_{el6p376} = 4.411\,in^4$ — Effective moment of inertia for long radius.

$k_{xl6p376} = 1.884$ — Flexibility factor for 30" long radius

$I_{exl6p376} = 14.934\,in^4$ — Effective moment of inertia for 30" extra long radius.

Pipe 4 Inch Diameter (Actually 4.5 Inch OD) and 0.237 Thick (Pressure 272 psi, Temperature 167 Degrees F)

$k_{s4p272} = 7.812$ — Flexibility factor for short radius.

$I_{es4p272} = 0.926\,in^4$ — Effective moment of inertia for short radius.

$k_{l4p272} = 5.199$ — Flexibility factor for long radius.

$I_{el4p272} = 1.391\,in^4$ — Effective moment of inertia for long radius.

$k_{redl4p272} = 3.459$ — Flexibility factor for long radius.

$I_{eredl4p272} = 2.091\,in^4$ — Effective moment of inertia for long radius.

$k_{xl4p272} = 1.549$ — Flexibility factor for long radius.

$\boxed{I_{exl4p272} = 4.669\,in^4}$ — Effective moment of inertia for long radius.

Pipe 4 Inch Diameter (Actually 4.5 Inch OD) and 0.237 Thick (Pressure 376 psi, Temperature 125 Degrees F)

$k_{s4p376} = 7.778$ — Flexibility factor for short radius.

$\boxed{I_{es4p376} = 0.93\,in^4}$ — Effective moment of inertia for short radius.

$k_{l4p376} = 5.173$ — Flexibility factor for long radius.

$\boxed{I_{el4p376} = 1.398\,in^4}$ — Effective moment of inertia for long radius.

$k_{redl4p376} = 3.439$ — Flexibility factor for long radius.

$\boxed{I_{eredl4p376} = 2.103\,in^4}$ — Effective moment of inertia for long radius.

WATER FILLED PIPE DENSITY CALCULATIONS

$$\rho_s = 0.28\,\frac{lb}{in^3}$$ Mass density of Stainless Steel [41]

$$\rho_w = 0.0361\,\frac{lb}{in^3}$$ Mass density of Water [42, Table A]

Pipe Sections

The density of the pipe sections will be calculated by taking the density associated with the steel and the water and multiplying the value by the cross sectional area that each will have as well as a common length variable (L). The resulting weight will be divided by the cross sectional area of the pipe section and the L multiplier. The L multiplier will cancel from the top and bottom of the equation and the result will be the density that the pipe would need to be to represent the weight of the steel and water simultaneously in the beam model.

$i := 1 .. 10$

$j := 0 .. 9$

Ranges used to iterate through data

$$Pipe_{Dt} := \begin{pmatrix} \text{"Diameter"} & \text{"Thickness"} \\ 36 & 0.5 \\ 30 & 0.4375 \\ 24 & 0.375 \\ 20 & 0.312 \\ 18 & 0.375 \\ 18 & 0.312 \\ 16 & 0.312 \\ 6.625 & 0.28 \\ 4.5 & 0.237 \\ 2.375 & 0.154 \end{pmatrix}$$

$$Di\_p_{i-1} := \left(Pipe_{Dt_{i,0}} - 2\cdot Pipe_{Dt_{i,1}}\right) in$$

$Di\_p^T =$ (in)

	0	1	2	3	4	5	6	7	8	9
0	35	29.125	23.25	19.376	17.25	17.376	15.376	6.065	4.026	2.067

$$A_{w\_p_j} := \frac{\pi\cdot\left(Di\_p_j\right)^2}{4}$$

$A_{w\_p}{}^{T} =$

	0	1	2	3	4	5	6	7	8	9
0	962.113	666.226	424.557	294.862	233.705	237.132	185.685	28.89	12.73	3.356

in^2

$$A_{s\_p_{i-1}} := \left[\frac{\pi\cdot\left(Pipe_{Dt_{i,0}}\cdot in\right)^2}{4} - A_{w\_p_{i-1}}\right]$$

$A_{s\_p}{}^{T} =$

	0	1	2	3	4	5	6	7	8	9
0	55.763	40.632	27.833	19.298	20.764	17.337	15.377	5.581	3.174	1.075

in^2

$$Eq\_\rho\_p_{j,1} := \frac{\rho_s\cdot A_{s\_p_j} + \rho_w\cdot A_{w\_p_j}}{A_{s\_p_j}}$$

$$Eq\_\rho\_p^{\langle 0\rangle} := \begin{pmatrix} \text{"36 x 0.5"} \\ \text{"30 x 0.4375"} \\ \text{"24 x 0.375"} \\ \text{"20 x 0.312"} \\ \text{"18 x 0.375"} \\ \text{"18 x 0.312"} \\ \text{"16 x 0.312"} \\ \text{"6.625 x 0.28"} \\ \text{"4.5 x 0.237"} \\ \text{"2.375 x 0.154"} \end{pmatrix}$$

$Eq\_\rho\_p =$

	0	1
0	"36 x 0.5"	2.339·10-3
1	"30 x 0.4375"	2.259·10-3
2	"24 x 0.375"	2.152·10-3
3	"20 x 0.312"	2.154·10-3
4	"18 x 0.375"	1.778·10-3
5	"18 x 0.312"	2.004·10-3
6	"16 x 0.312"	1.855·10-3
7	"6.625 x 0.28"	1.209·10-3
8	"4.5 x 0.237"	1.1·10-3
9	"2.375 x 0.154"	1.017·10-3

$\frac{lbf\cdot s^2}{in^4}$

Reducers

The density of the reducers will be calculated by first considering the reducer to be two beams connected in the middle of the reducer where one beam has dimensions associated with the large open end and the other beam has dimensions associated with the small open end. The method used to determine the density of each section will be the same as that for the pipe sections described above.

$i := 1 .. 14$

$j := 0 .. 13$

Ranges used to iterate through data

$$Red_{Dt} := \begin{pmatrix} \text{"Diameter"} & \text{"Thickness"} \\ 18 & 0.312 \\ 16 & 0.312 \\ 24 & 0.375 \\ 18 & 0.375 \\ 36 & 0.5 \\ 24 & 0.5 \\ 36 & 0.5 \\ 30 & 0.5 \\ 30 & 0.5 \\ 20 & 0.5 \\ 4.5 & 0.237 \\ 2.375 & 0.154 \\ 6.625 & 0.28 \\ 4.5 & 0.237 \end{pmatrix}$$

$$Di\_r_{i-1} := \left(Red_{Dt_{i,0}} - 2 \cdot Red_{Dt_{i,1}}\right) in$$

$Di\_r^T =$ (in)

	0	1	2	3	4	5	6	7	8	9
0	17.376	15.376	23.25	17.25	35	23	35	29	29	19

$$A_{w\_r_j} := \frac{\pi \cdot \left(Di\_r_j\right)^2}{4}$$

$A_{w\_r}^T =$ (in^2)

	0	1	2	3	4	5	6	7	8	9
0	237.132	185.685	424.557	233.705	962.113	415.476	962.113	660.52	660.52	283.529

$$A_{s\_r_{i-1}} := \left[\frac{\pi \cdot \left(Red_{Dt_{i,0}} \cdot in\right)^2}{4} - A_{w\_r_{i-1}}\right]$$

$A_{s\_r}^{T} =$

	0	1	2	3	4	5	6	7	8	9
0	17.337	15.377	27.833	20.764	55.763	36.914	55.763	46.338	46.338	30.631

in^2

$$Eq\_\rho\_r_{j,1} := \frac{\rho_s \cdot A_{s\_r_j} + \rho_w \cdot A_{w\_r_j}}{A_{s\_r_j}}$$

$$Eq\_\rho\_r^{\langle 0 \rangle} := \begin{pmatrix} \text{"18x16 lg"} \\ \text{"18x16 sm"} \\ \text{"24x18 lg"} \\ \text{"24x18 sm"} \\ \text{"36x24 lg"} \\ \text{"36x24 sm"} \\ \text{"36x30 lg"} \\ \text{"36x30 sm"} \\ \text{"30x20 lg"} \\ \text{"30x20 sm"} \\ \text{"4x2 lg"} \\ \text{"4x2 sm"} \\ \text{"6x4 lg"} \\ \text{"6x4 sm"} \end{pmatrix}$$

$Eq\_\rho\_r =$

	0	1
0	"18x16 lg"	$2.004 \cdot 10^{-3}$
1	"18x16 sm"	$1.855 \cdot 10^{-3}$
2	"24x18 lg"	$2.152 \cdot 10^{-3}$
3	"24x18 sm"	$1.778 \cdot 10^{-3}$
4	"36x24 lg"	$2.339 \cdot 10^{-3}$
5	"36x24 sm"	$1.778 \cdot 10^{-3}$
6	"36x30 lg"	$2.339 \cdot 10^{-3}$
7	"36x30 sm"	$2.058 \cdot 10^{-3}$
8	"30x20 lg"	$2.058 \cdot 10^{-3}$
9	"30x20 sm"	$1.591 \cdot 10^{-3}$
10	"4x2 lg"	$1.1 \cdot 10^{-3}$
11	"4x2 sm"	$1.017 \cdot 10^{-3}$
12	"6x4 lg"	$1.209 \cdot 10^{-3}$
13	"6x4 sm"	$1.1 \cdot 10^{-3}$

$\frac{lbf \cdot s^2}{in^4}$

Elbows

The density of the Elbows will be considered to be the same as that of the pipe with the same dimensions as an relatively close approximation.

Tees and Branches

The density of the Tees will be calculated by observing that the run and branch are both comprised of the same pipe type and one density will be associated with that pipe type. The Branches will be calculated by considering the run and branch as two separate components and a density for each will be calculated. The method used to determine the density of each section will be the same as that for the pipe sections described above.

$i := 1 .. 8$

$j := 0 .. 7$

Ranges used to iterate through data

$$T\_Br_{Dt} := \begin{pmatrix} \text{"Diameter"} & \text{"Thickness"} \\ 37.75 & 1.375 \\ 6.625 & 0.28 \\ 30 & 0.4375 \\ 20 & 0.312 \\ 36 & 0.5 \\ 6.625 & 0.28 \\ 6.625 & 0.28 \\ 4.5 & 0.237 \end{pmatrix}$$

$$Di\_TB_{i-1} := \left(T\_Br_{Dt_{i,0}} - 2 \cdot T\_Br_{Dt_{i,1}}\right) in$$

$$Di\_TB^T = (35 \quad 6.065 \quad 29.125 \quad 19.376 \quad 35 \quad 6.065 \quad 6.065 \quad 4.026)\ in$$

$$A_{w\_TB_j} := \frac{\pi \cdot \left(Di\_TB_j\right)^2}{4}$$

$$A_{w\_TB}^T = (962.113 \quad 28.89 \quad 666.226 \quad 294.862 \quad 962.113 \quad 28.89 \quad 28.89 \quad 12.73)\ in^2$$

$$A_{s\_TB_{i-1}} := \left[\frac{\pi \cdot \left(T\_Br_{Dt_{i,0}} \cdot in\right)^2}{4} - A_{w\_TB_{i-1}}\right]$$

$$A_{s\_TB}^T = (157.129 \quad 5.581 \quad 40.632 \quad 19.298 \quad 55.763 \quad 5.581 \quad 5.581 \quad 3.174)\ in^2$$

$$Eq\_\rho\_TB_{j,1} := \frac{\rho_s \cdot A_{s\_TB_j} + \rho_w \cdot A_{w\_TB_j}}{A_{s\_TB_j}}$$

$$Eq\_\rho\_TB^{\langle 0 \rangle} := \begin{pmatrix} \text{"T 37.75"} \\ \text{"T 6"} \\ \text{"Br 30x20\_r"} \\ \text{"Br 30x20 br"} \\ \text{"Br 36x6 r"} \\ \text{"Br 36x6 br"} \\ \text{"Br 6x4 r"} \\ \text{"Br 6x4 br"} \end{pmatrix} \qquad Eq\_\rho\_TB = \begin{pmatrix} \text{"T 37.75"} & 1.298 \times 10^{-3} \\ \text{"T 6"} & 1.209 \times 10^{-3} \\ \text{"Br 30x20\_r"} & 2.259 \times 10^{-3} \\ \text{"Br 30x20 br"} & 2.154 \times 10^{-3} \\ \text{"Br 36x6 r"} & 2.339 \times 10^{-3} \\ \text{"Br 36x6 br"} & 1.209 \times 10^{-3} \\ \text{"Br 6x4 r"} & 1.209 \times 10^{-3} \\ \text{"Br 6x4 br"} & 1.1 \times 10^{-3} \end{pmatrix} \frac{lbf \cdot s^2}{in^4}$$

Valves

The density of the Valves will be calculated by observing that the approach adopted by this project was to approximate the valves influence by increasing the thickness of the pipe until the moment of inertia was increased to 3 times that of the connecting pipe. However, since a lump mass representing the mass of the valve was included in the model the density of the valves will be adjusted such that it is only 10% of the mass of the pipe run that the valve intermediates.

$i := 1..2$

$j := 0..1$

Ranges used to iterate through data

$$PR_{Dt} := \begin{pmatrix} \text{"Pipe Diameter"} & \text{"Pipe Thickness"} \\ 6.625in & 0.28in \\ 4.5in & 0.237in \end{pmatrix} \qquad Valve_{Dt} := \begin{pmatrix} \text{"Valve Diameter"} & \text{"Valve Thickness"} \\ 6.625in & 1.417in \\ 5.5in & 1.235in \end{pmatrix}$$

$$A_{s\_PR_{i-1}} := \left[\frac{\pi\cdot\left(PR_{Dt_{i,0}}\right)^2}{4} - \frac{\pi\cdot\left(PR_{Dt_{i,0}} - 2\cdot PR_{Dt_{i,1}}\right)^2}{4}\right]$$

$$A_{s\_PR}{}^{T} = (5.581 \quad 3.174)\,in^2$$

$$A_{s\_V_{i-1}} := \left[\frac{\pi\cdot\left(Valve_{Dt_{i,0}}\right)^2}{4} - \frac{\pi\cdot\left(Valve_{Dt_{i,0}} - 2\cdot Valve_{Dt_{i,1}}\right)^2}{4}\right]$$

$$A_{s\_V}{}^{T} = (23.184 \quad 16.548)\,in^2$$

$$Eq\_\rho\_V_{j,1} := \frac{0.1\cdot\rho_s\cdot A_{s\_PR_j}}{A_{s\_V_j}} \qquad Eq\_\rho\_V^{\langle 0\rangle} := \begin{pmatrix} \text{"6.625in Pipe Run"} \\ \text{"4.5in Pipe Run"} \end{pmatrix}$$

$$Eq\_\rho\_V = \begin{pmatrix} \text{"6.625in Pipe Run"} & 1.746\times 10^{-5} \\ \text{"4.5in Pipe Run"} & 1.391\times 10^{-5} \end{pmatrix} \frac{lbf\cdot s^2}{in^4}$$

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Appendix D.9

Support / Anchorage Capacities

Note: Limiting capacities for each appendix are highlighted yellow in their respective summary sections

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Appendix D.9.1

Capacity Table for Supports / Anchorage Associated with Model 1-4

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PCS Support/Anchorage Capacities for Models 2, 6, & 5

Support	Line #	Direction	Capacity Type	Calculated Anchorage Capacity (kips)	Anchorage Reference	Calculated Support Capacity (kips)	Support Reference
PR-2A+	1-1L	E(+Z)	TEN	3.188	[32, App E7]	41.417	App D.9.7
	1-1L	W(-Z)	COM	NA		17.939	App D.9.7
PR-2B+	1-2L	E(+Z)	TEN	7.132	[32, App E7]	41.417	App D.9.7
	1-2L	W(-Z)	COM	NA		17.939	App D.9.7
PR-2C+	1-3L	E(+Z)	COM	NA	[32, App E7]	17.939	App D.9.7
	1-3L	W(-Z)	TEN	7.132		41.417	App D.9.7
PR-2D+	1-4L	E(+Z)	COM	NA	[32, App E7]	17.939	App D.9.7
	1-4L	W(-Z)	TEN	3.188		41.417	App D.9.7
PR-7	1-7	V(+Y)	COM	NA		11.102	App D.9.8
	1-7	V(-Y)	TEN	0	App B.10.11	33.548	App B.10.5
MS-1	1-7	Up-South	TEN	45.171	[32, App E7]	30.55	App D.9.3
	1-7	Down-North	COM	45.171	[32, App E7]	30.55	App D.9.3
Tunnel Restraint	1-27	W (-Y)	NA			85.842	[32, App D22B-9]
	1-27	E (+Y)	NA			6.258	[32, App D22B-9]
RH-19x	1-7	V(+Y)	TEN	56.28	[32, App E5]	59.4	[32, App D14-13]
	1-7	V(-Y)	COM	NA		45.79	App D.9.2
RH-20x	1-7	V(+Y)	TEN	56.28	[32, App E5]	81.178	[32, App D13-11]
	1-7	V(-Y)	COM	NA		53.832	App D.9.2
RH-21xA	1-7	V(+Y)	TEN	56.28	[32, App E5]	81.178	[32, App D13-11]
	1-7	V(-Y)	COM	NA		48.204	App D.9.2
RH-21xB	1-7	V(+Y)	TEN	Combined (28.14)	[32, App E5]	81.178	[32, App D13-11]
	1-7	V(-Y)	COM	NA		48.204	App D.9
RH-22x	1-7	V(+Y)	TEN	Combined (28.14)	[32, App E5]	81.178	[32, App D13-11]
MS-6*	1-7	E(+Z)	TEN	18.514	[32, App E7]	15	App D.9.4
	1-7	W(-Z)	COM	NA		15	App D.9.4
MS-3	1-7	N(+X)	TEN	App D.9.5	[32, App E7]	50	App D.9.5
	1-7	S(-X)	COM	NA		50	App D.9.5
MS-4*	1-8	Up-South	COM	28.178	[32, App E7]	15	[32, App D8-5]
	1-8	Down-North	TEN	28.178	[32, App E7]	15	[32, App D8-5]
PS-8E	1-9	V(-Y)	COM	NA		75.565	[32, App D3-4]
	1-9	V(+Y)	TEN	14.07	[32, App E6]		
PS-8F	1-10	V(-Y)	COM	NA		75.565	[32, App D3-4]
	1-10	V(+Y)	TEN	14.07	[32, App E6]		
PS-8G	1-11	V(-Y)	COM	NA		75.565	[32, App D3-4]
	1-11	V(+Y)	TEN	14.07	[32, App E6]		
PS-8H	1-12	V(-Y)	COM	NA		75.565	[32, App D3-4]
	1-12	V(+Y)	TEN	14.07	[32, App E6]		
PS-20b	1-170	V(-Y)	COM	NA		155.021	[32, App D3]
	1-170	V(+Y)	TEN	14.07	[32, App E6]		
RH-14a	1-34	V(+Y)	TEN	11.25	[32, App E5]	10.354	[32, App D3]
	1-34	V(-Y)	COM	NA		0.104	App D.9.2
RH-14b	1-34	V(+Y)	TEN	11.25	[32, App E5]	10.354	[32, App D3]
	1-34	V(-Y)	COM	NA		0.104	App D.9.2
RH-14c	1-34	V(+Y)	TEN	11.25	[32, App E5]	10.354	[32, App D3]
	1-34	V(-Y)	COM	NA		0.104	App D.9.2
PS-14A	1-34	V(-Y)	COM	NA		22.106	[32, App D3-4]
PS-14B	1-67	V(+Y)	COM	NA		22.106	[32, App D3-4]

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Support	Line #	Direction	Capacity Type	Calculated Anchorage Capacity (kips)	Anchorage Reference	Calculated Support Capacity (kips)	Support Reference
PS-20A	1-34	V(-Y)	TEN	11.839	[32, App E5]	5.763	[32, App D17B-12]
	1-34	V(+Y)	COM	NA		8.518	[32, App D17B-12]
	1-34	NS(X)	FLEXURE	2.789	[32, App E5]	4.65	[32, App D17B-12]
TB2	1-39	E(+Z)	COM	NA		5.577	[32, App D19B-18]
	1-39	W(-Z)	TEN	3.435	[32, App E6]	1.528	[32, App D19B-18]
	1-39	V(Y)	FLEXURE	1.356	[32, App E6]	0.908 `	[32, App D19B-18]
PS-11A	1-39	V(-Y)	COM	NA		20.496	[32, App D3-4
RH-14Aa	1-34 & 1-40	V(+Y)	TEN	NA		7.069	App D.9
	1-34 & 1-41	V(-Y)	COM	NA		0.691	App D.9
RH-14Ab	1-34 & 1-42	V(+Y)	TEN	NA		7.069	App D.9
	1-34 & 1-43	V(-Y)	COM	NA		0.691	App D.9
RH-14Ac	1-34 & 1-44	V(+Y)	TEN	NA		7.069	App D.9
	1-34 & 1-45	V(-Y)	COM	NA		0.691	App D.9
RH-14Ad	1-34 & 1-46	V(+Y)	TEN	NA		7.069	App D.9
	1-34 & 1-47	V(-Y)	COM	NA		0.691	App D.9
RH-20G	1-40 & 1-41	V(+Y)	TEN	NA		7.069	App D.9
	1-40 & 1-41	V(-Y)	COM	NA	Does Not Experience Uplift		
RH-35a	1-40 & 1-42	V(+Y)	TEN	NA		3.728	App D.9
	1-40 & 1-42	V(-Y)	COM	NA		0.228	App D.9
RH-35b	1-40 & 1-42	V(+Y)	TEN	NA		3.728	App D.9
	1-40 & 1-42	V(-Y)	COM	NA		0.228	App D.9
RH-33A	1-42	V(+Y)	TEN	4.117	[32, App E5]	4.117	[32, App D3]
	1-42	V(-Y)	COM	NA		0.024	App D.9
RH-33B	1-42	V(+Y)	TEN	3.47	[32, App E5]	6.627	[32, App D3]
	1-42	V(-Y)	COM	NA		0.024	App D.9
Horizontal Support	1-42	E(+Z)	TEN	12.32	[32, App E7]	8.467	[32, App D21-18]
	1-42	W(-Z)	COM	NA		8.342	[32, App D21-18]
PS-23	1-42	V(-Y)	COM	NA		16.789	[32, App D3-4
NN-2	1-42	N(+X)	COM	NA		35.487	[32, App D20-13]
	1-42	S(-X)	TEN	11.25	[32, App E5]	20.709	[32, App D20-13]
NN-3	1-42	N(+X)	COM	NA		35.487	[32, App D20-13]
	1-42	S(-X)	TEN	11.25	[32, App E5]	20.709	[32, App D20-13]
PS-19	1-42	N(+X)	COM	NA		96.792	App D.9
	1-42	S(-X)	TEN	11.25	[32, App E5]	13.254	App D.9
	1-42	V(Y)	FLEXURE	0.584	[32, App E5]	3.37 `	App D.9
RH-12	1-42	V(+Y)	TEN	11.25	[32, App E5]	3.976	App D.9
	1-42	V(-Y)	COM	NA		0.228	App D.9
RH-20	1-42	V(+Y)	TEN	11.25	[32, App E5]	10.354	[32, D7]
	1-42	V(-Y)	COM	NA		0.228	App D.9
PS-10A	1-42	V(+Y)	COM	NA		22.1	[32, App D3-4]
PS-10B	1-41	V(+Y)	COM	NA		22.1	[32, App D3-4]

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Support	Line #	Direction	Capacity Type	Calculated Anchorage Capacity (kips)	Anchorage Reference	Calculated Support Capacity (kips)	Support Reference
TB1	1-41	NS(X)	FLEXURE	1.356	[32, App E6]	0.908 `	[32, App D19B-18]
	1-41	E(+Z)	COM	NA		5.577	[32, App D19B-18]
	1-41	W(-Z)	TEN	3.435	[32, App E6]	1.528	[32, App D19B-18]
PS-7	1-41	V(+Y)	FLEXURE	2.2	[32, App E6]	See Breakout Evaluation (App E9) for Recommendations	
	1-41	V(-Y)	FLEXURE	2.2	[32, App E6]		
	1-41	N(+X)	TEN	6.686	[32, App E6]	3.37 `	App E.6
	1-41	S(-X)	COM	NA	[32, App E6]	3.37 `	App E.6
RH-16C*	1-42	V(+Y)	TEN	1.047	[32, App E5]	10.354	[32, App D4]
	1-42	V(-Y)	COM	NA		0.397	App D.9
PS-11B	1-77	V(+Y)	COM	NA		20.496	[32, App D3-4]
WTS	1-77	V(+Y)	TEN	> Support	App D.9	0.59	App D.9
	1-77	V(-Y)	COM	Does Not Experience Uplift			
RH-27A	1-77	V(+Y)	TEN	11.25	[32, App E5]	7.069	App D.9
	1-77	V(-Y)	COM	Does Not Experience Uplift			
RH-27B	1-77	V(+Y)	TEN	11.25	[32, App E5]	7.069	App D.9
	1-77	V(-Y)	COM	Does Not Experience Uplift			
PS-22	1-40	N(+X)	TEN	11.25	[32, D2]	29.821	[32, D2]
	1-40	S(-X)	COM	NA		5.658	[32, D2]
RH-34	1-42 & 1-9	V(+Y)	TEN	NA	[32, App E5]	7.069	App D.9
	1-42 & 1-9	V(-Y)	COM	Does Not Experience Uplift			

* MS-4 and MS-6 were released in the model due to overloading observations from a preliminary iteration (See main body of report for treatment/recommendations regarding each of these individual components)

+ PR-2's are further evaluated in combination with PR-1's in appendix E

` U-Bolt analysis in App. E was implemented resulting in a higher u-bolt capacity and thus initiating an alternate controlling capacity component

Combined (28.14) - Indicates that the support shares a common anchorage with another support and the stated value is a place holder and the extended evaluation is shown in App E.8

Appendix D.9.2

Compression Capacity of RH-19x, 20x, 21x, 14, 14A, 20, 35, 33, 12

RH-19x, 20x, 21x, 14, 14A, 20, 35, 33, 12 & 34 COMPRESSION CAPACITY

RH-19x, 20x, 21x, 14, 14A, 20, 35, 33, 12, and 34 primarily support the PCS piping system from downward loading and PR-7 is primarily designed to be a tie down. However, the effects of the 32 seismic events applied to the support provides some upward (downward for PR-7) loading therefore capacity in the associated compression direction is calculated below.

Component Capacity Overview:

- Upward Loading:

- Compression capacity in eye rod sections

(**Procedures from AISC 13th Edition (applying LRFD) [8]**)

$i := 0, 1 .. 10$

Assigned indices corresponding to number of support types associated with these calculations

Geometric and Material Properties of Support Components

ROD SECTION

Material Properties as Defined in the Material Section of this Report:

$F_y := 33\text{ksi}$ Yield Strength for A7 Carbon Steel

$F_u := 60\text{ksi}$ Ultimate Strength for A7 Carbon Steel

$E := 29000\text{ksi}$ Modulus of Elasticity for A7 Carbon Steel

$$\begin{pmatrix} RH_{19x} \\ RH_{20x} \\ RH_{21xa} \\ RH_{21xb} \\ RH_{14} \\ RH_{14A} \\ RH_{20} \\ RH_{35} \\ RH_{33} \\ RH_{12} \\ RH_{34} \end{pmatrix} \quad L := \begin{pmatrix} 42 \\ 33.5 \\ 39.5 \\ 39.5 \\ 127.5 \\ 49.5 \\ 86.125 \\ 95 \\ 70 \\ 86.125 \\ 47.3 \end{pmatrix} in \quad D := \begin{pmatrix} 1.75 \\ 1.75 \\ 1.75 \\ 1.75 \\ 0.625 \\ 0.625 \\ 0.625 \\ 0.375 \\ 0.5 \\ 0.625 \\ 0.5 \end{pmatrix} in \quad r_{gyration} := \frac{D}{4} \quad A := \pi \cdot \left(\frac{D}{2}\right)^2$$

$A =$

	0
0	2.405
1	2.405
2	2.405
3	2.405
4	0.307
5	0.307
6	0.307
7	0.11
8	0.196
9	0.307
10	0.196

$\cdot in^2$

Capacities for Upward Loading

Compression, capacity in rod hangers [AISC, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

$\phi_c := 0.9$

Resistance factor for compression

E2. Slenderness Limitations and Effective Length

$K := 1.0$

Effective length in accordance with C2.b1, [AISC, comm.C2 (Table C-C2.2) (case d) pg 16.1-240] Case d was chosen because the support was allowed to rotate on the top as well as on the bottom.

The Slenderness ratio KL/r should preferably not exceed 200

$$KLr_i := \left(\frac{K \cdot L_i}{r_{gyration_i}}\right)$$

The below KLr values verify that all supports do not exceed the 200 recommended limitation

$KLr^T =$

	0	1	2	3	4	5	6
0	96	76.571	90.286	90.286	816	316.8	...

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified through classification)

$$F_{e_i} := \frac{\pi^2 E}{\left(KLr_i\right)^2}$$

F_e is the elastic critical buckling stress (E3-4)

$F_e^T =$

	0	1	2	3	4	5	6	7	8
0	31.057	48.816	35.112	35.112	0.43	2.852	0.942	0.279	...

$\cdot ksi$

Calculating the variables Limit, Op1, and Op2 to be utilized in logic to determine flexural buckling stress.

$$Limit := 4.71 \cdot \sqrt{\frac{E}{F_y}} \qquad Op1_i := \left(0.658^{\frac{F_y}{F_{e_i}}}\right) F_y \qquad Op2_i := 0.877 \cdot F_{e_i}$$

$Limit = 139.625$

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Calculating the flexural buckling stress

$$F_{cr_i} := \begin{cases} Op1_i & \text{if } KLr_i \le Limit \\ Op2_i & \text{if } KLr_i > Limit \end{cases}$$ (E3-2) (E3-3)

$F_{cr}^T =$ ·ksi

	0	1	2	3	4	5	6	7	8
0	21.153	24.868	22.268	22.268	0.377	2.501	0.826	0.244	...

$\phi P_{n_i} := \phi_c \cdot F_{cr_i} \cdot A_i$ Design compressive strength

$\phi P_n^T =$ ·kip

	0	1	2	3	4	5	6	7	8	9	10
0	45.79	53.832	48.204	48.204	0.104	0.691	0.228	0.024	0.141	0.228	0.31

$\phi P_n =$ ·kip

ϕP_n (kip)	Support
45.79	RH_{19x}
53.832	RH_{20x}
48.204	RH_{21xa}
48.204	RH_{21xb}
0.104	RH_{14}
0.691	RH_{14A}
0.228	RH_{20}
0.024	RH_{35}
0.141	RH_{33}
0.228	RH_{12}
0.31	RH_{34}

Appendix D.9.3

MS-1 Capacities

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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MS-1 CAPACITY

MS-1 restricts PCS piping seismic motion in the north/south and vertical directions. MS-1 is comprised of the PSA-35 mechanical snubber, base plate bolted to the wall, a schedule 80 pipe extension, and clamp attaching the support to the 36" PSC pipe. The snubber is connected to the clamp and base plate by a pin and the clamp is secured to the pipe by two large threaded rods on either side. Note that the snubber is at a 30 degree angle from the horizontal and the limiting capacity of the support needs to be resolved into vertical and horizontal components. The anchorage assembly capacities and the associated capacities of the wall embedment are found in the anchorage and embedment portions of this report while the capacities for the remainder of the components are calculated below.

Component Capacity Overview:

- Eastward/Westward Loading:
- Shear capacity of mechanical snubber's anchorage and clamp pin
- Tension/Compression capacity of mechanical snubber
- Tension/Compression capacity of clamp
- Tension capacity of pipe extension
- Compression capacity of pipe extension

(**Procedures from SEI/ASCE 8-02 (Applying LRFD) [8])**

References

1. Drawing 453164, "ATR Primary Coolant System Mechanical Snubber Pin Detail," Lockheed Idaho Technologies Company,
July, 24, 1996
2. SEI/ASCE 8-02, "Specification for the Design of Cold-Formed Stainless Steel Structural Members," American Society of Civil
Engineers, Sept. 24, 2007
3. ASTM SA-564/SA-564M, "Specification for Hot-Rolled and Cold-Finished Age-Hardening Stainless Steel Bars and Shapes,"
American Society for Testing and Materials, 2004
4. Drawing 159775, "ATR Seismic Modification, Primary System Snubber Details," Rev. 2, EG&G Idaho, Inc., August 5, 1980
5. Basic-PSA, Inc. Catalog 193, "Pipe Hangers, Supports, and Controls," Basic-PSA, Inc.
6. DAG, "Allowable Loads for Angle Loaded Pipe Clamps (Mech Snubber Model:PSA-35)," Basic Engineers October 12, 1984
7. ANSI/AISC 360-05, "Steel Construction Manual, 13th ed.," American Institute of Steel Construction, Inc., March 9, 2005.

Note:

SEI/ASCE 8-02 was applied for these supports instead of AISC 13th Edition because the vendor data capacities for the mechanical snubbers and their associated clamps were available, however, the stainless steel pins implemented were associated with a drawing given specific material properties and dimensions of the stainless steel.

$i := 0$ — Assigned indices corresponding to number of support types associated with these calculations

Support =	0
	(MS-1)

Relationship between support and corresponding indices

Geometric and Material Properties of Support Components

MECHANICAL SNUBBER PINS (Mechanical Snubber Pin Detail [453164])

Material Properties of Mechanical Snubber Pins as Defined in the [453164] and [ASTM SA-564]:

$F_{y\_pin} := 115ksi$ — Yield Strength for SA-564, Tp 630, Cond 1100

$F_{u\_pin} := 140ksi$ — Ultimate Strength for SA-564, Tp 630, Cond 1100

Geometric Properties of Mechanical Snubber Pins:

$d_{pin} := (1.4970in)^T$ — Diameter of mechanical snubber pins [159776], [453164]

$L_{pin} := (7in)^T$ — Length of mechanical snubber pins [159776], [453164]

MECHANICAL SNUBBER (PSA Mechanical Snubber [159775])

Rated Capacity of Mechanical Snubbers:

$Capacity_{MS} := (50kip)^T$ — Rated capacity of mechanical snubbers [Basic-PSA, pg 171]

INTERMEDIATE SNUBBER PIPE (4" Schedule 80 [159775])

Material Properties of Intermediate Snubber Pipe as Defined in the Material Section of this Report:

$F_{y\_sp} := 33ksi$ — Yield Strength for A7 Carbon Steel

$F_{u\_sp} := 60ksi$ — Ultimate Strength for A7 Carbon Steel

$E_{sp} := 29000ksi$ — Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Intermediate Snubber Pipe:

$OD_{sp} := (4.5in)^T$ — Outside diameter of intermediate snubber pipe [159775], [AISC, Table 1-14, pg 1-99]

$ID_{sp} := (3.83in)^T$ — Inside diameter of intermediate snubber pipe [159775], [AISC, Table 1-14, pg 1-99]

$t_{sp} := (0.337in)^T$ — Nominal thickness of intermediate snubber pipe [159775], [AISC, Table 1-14, pg 1-99]

$A_{sp} := \left(4.14in^2\right)^T$ — Area of intermediate snubber pipe [159775], [AISC, Table 1-14, pg 1-99]

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$r_{gyration\_sp} := (1.48in)^T$

Radius of gyration of intermediate snubber pipe [159775], [AISC, Table 1-14, pg 1-99]

$L_{sp\_pins} := \left(78\frac{3}{8}in\right)^T$

Length between pin connections of snubber plus intermediate snubber pipe spanning between [159775], [AISC, Table 1-14, pg 1-99]

CLAMP (Pipe Clamp at 30 degree angle [159776])

Rated Capacity of Mechanical Snubbers' Pipe Clamp at 30 Degrees:

$Capacity_{cl} := (30.550kip)^T$

Rated capacity of pipe clamp connecting mechanical snubber [Basic Engineers]

Applicability of applying SEI/ASCE 8-02

MECHANICAL SNUBBER PINS

1.3.3 Ductility

This code does not list SA-564 as an applicable stainless steel unless it meets the following criteria

Ratio of tensile strength to yield strength must not be less than 1.08

$\frac{F_{u\_pin}}{F_{y\_pin}} = 1.217$

Since this value is greater than the 1.08 specification SA-564 meets this requirement

Total elongation shall not be less than 10% for a two-in. gage length standard specimen

Elongation = 14% [ASTM SA-564, pg1092]

Since this value is greater than the 10% requirement SA-564 meets this requirement as well

Capacities For Eastward/Westward Loading

MECHANICAL SNUBBER PINS

Shear, capacity of mechanical snubber anchorage and clamp pins [ASCE, Ch. 5 pg 24 thru 25]

5. Connections and Joints

5.3.4. Shear and Tension in Stainless Steel Bolts

$\phi := 0.65$

[SEI/ASCE 8-02, Table 6 pg 25]

$A_{pin_i} := \pi \cdot \left(\frac{d_{pin_i}}{2}\right)^2$

Gross cross sectional area of pin

$A_{pin\_ds_i} := 2 \cdot A_{pin_i}$

Applicable area for this case since the bolt is in double shear

$F_{nv\_cl\_bolt} := 0.5 \cdot F_{y\_pin}$

Since F_{nv} is not provided for SA-564 type 630 stainless steel in SEI/ASCE 8-02 it is observed from [SEI/ASCE 8-02, Table A1] that the shear yield strength of the represented materials is no less than 0.51 of the yield strength, thus to be conservative it has been estimated to be 0.5 of the yield strength

$R_{nv\_cl\_bolt_i} := F_{nv\_cl\_bolt} \cdot A_{pin\_ds_i}$ Nominal strength (R_n) (5.3.4-1)

$\phi R_{nv\_cl\_bolt_i} := \phi \cdot R_{nv\_cl\_bolt_i}$

$\phi R_{nv\_cl\_bolt}^T = (131.566) \cdot kip$ Design shear strength

It appears that even with the conservative assumptions that these values are much greater than that of the snubber and clamp capacities, thus this treatment is adequate in determining if these components will govern this support

MECHANICAL SNUBBER

Compression/Tension, capacity of mechanical snubber

$P_{MS} := Capacity_{MS}$

$P_{MS}^T = (50) \cdot kip$ Vendor supplied mechanical snubber strength

INTERMEDIATE SNUBBER PIPE

Determine if supports are ***compact (1)***, ***non-compact (2)***, or ***slender (3)*** as defined in first paragraph of B4

B4. Classification of sections for local buckling (Table B4.1 Case 15)

$D2t_{sp_i} := \frac{OD_{sp_i}}{t_{sp_i}}$ $D2t_{sp}^T = (13.353)$

Definition of λ_p and λ_r from Table B4.1 Case 15 (Circular hollow sections in uniform compression) to be applied in classification logic. λ_p is the separation point between a compact and non compact member. λ_r is separation point between a non compact and slender member. However, Table B4.1 Case 15 defines λ_p = NA because the only thing of concern is if the support is slender or non-slender, thus only if the classification is 3 do we apply slenderness considerations, otherwise we treat the member as not having slender elements.

$\lambda_p := 0$ $\lambda_r := 0.11 \frac{E_{sp}}{F_{y\_sp}}$

$$Classification_i := \begin{cases} 1 & \text{if } D2t_{sp_i} \le \lambda_p \\ 2 & \text{if } \lambda_p < D2t_{sp_i} \le \lambda_r \\ 3 & \text{if } \lambda_r < D2t_{sp_i} \end{cases}$$

$Classification^T = (2)$

Compression, capacity in intermediate snubber pipe [AISC, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

$\phi_c := 0.9$ — Resistance factor for compression

E2. Slenderness Limitations and Effective Length

$K := 1.0$ — Effective length in accordance with C2.b1, [AISC, comm.C2 (Table C-C2.2) (case d) pg 16.1-240] Case d was chosen because the support was allowed on both ends.

The Slenderness ratio KL/r should preferably not exceed 200

$$KLr_i := \left(\frac{K \cdot L_{sp\_pins_i}}{r_{gyration\_sp_i}}\right)$$

L_{sp_pins} was chosen as it was the effective length between the pin locations.

The below KLr values verify that all supports do not exceed the 200 recommended limitation

$$KLr^T = (52.956)$$

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified through classificatic

$$F_{e_i} := \frac{\pi^2 E_{sp}}{\left(KLr_i\right)^2}$$

F_e is the elastic critical buckling stress (E3-4)

$$F_e^T = (102.062) \cdot ksi$$

Calculating the variables Limit, Op1, and Op2 to be utilized in logic to determine flexural buckling stress.

$$Limit := 4.71 \cdot \sqrt{\frac{E_{sp}}{F_{y\_sp}}} \qquad Op1_i := \left(0.658^{\frac{F_{y\_sp}}{F_{e_i}}}\right) F_{y\_sp} \qquad Op2_i := 0.877 \cdot F_{e_i}$$

$$Limit = 139.625$$

Calculating the flexural buckling stress

$$F_{cr_i} := \begin{cases} Op1_i & \text{if } KLr_i \le Limit \quad \text{(E3-2)} \\ Op2_i & \text{if } KLr_i > Limit \quad \text{(E3-3)} \end{cases}$$

$$F_{cr}^T = (28.823) \cdot ksi$$

$$\phi P_{n_i} := \phi_c \cdot F_{cr_i} \cdot A_{sp_i}$$

$$\boxed{\phi P_n^T = (107.395) \cdot kip}$$

Design compressive strength

Tension, capacity in intermediate snubber pipe [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_sp_i} := A_{sp_i}$ — Gross area

2. Net Area

$A_{net\_sp_i} := A_{sp_i}$ — Net area

3. Effective Net Area

$U_{sp} := 1.0$ — Shear Lag Factor [AISC, Table D3.1]

$A_{e\_sp_i} := A_{net\_sp_i} \cdot U_{sp}$ — Effective net area

(a) For tensile yielding in the gross section:

$P_{n\_sp\_ty_i} := F_{y\_sp} \cdot A_{g\_sp_i}$ — Nominal axial strength (P_n)

$\phi_{ty} := 0.9$ — Resistance factor for tension yielding (ϕ_{ty})

$\phi P_{n\_sp\_ty_i} := \phi_{ty} \cdot P_{n\_sp\_ty_i}$ — Design tensile yielding strength

$\boxed{\phi P_{n\_sp\_ty} = (122.958) \cdot kip}$

(b) For tensile rupture in net section:

$P_{n\_sp\_tr_i} := F_{u\_sp} \cdot A_{e\_sp_i}$ — Nominal axial strength (P_n)

$\phi_{tr} := 0.75$ — Resistance factor for tension rupture (ϕ_{tr})

$\phi P_{n\_sp\_tr_i} := \phi_{tr} \cdot P_{n\_sp\_tr_i}$ — Design tensile rupture strength

$\boxed{\phi P_{n\_sp\_tr} = (186.3) \cdot kip}$

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CLAMP

Compression/Tension, capacity of clamp

$P_{cl} := Capacity_{cl}$

$P_{cl}^{T} = (30.55) \cdot kip$ Supplied clamp strength

SUMMARY OF RESULTS

Capacities For Eastward/Westward Loading

MECHANICAL SNUBBER PINS

Shear, capacity of mechanical snubber anchorage and clamp pins [ASCE, Ch. 5 pg 24 thru 25]

5. Connections and Joints

5.3.4. Shear and Tension in Stainless Steel Bolts

$\phi R_{nv\_cl\_bolt}^{T} = (131.566) \cdot kip$ Design shear strength

MECHANICAL SNUBBER

Compression/Tension, capacity of mechanical snubber

$P_{MS}^{T} = (50) \cdot kip$ Supplied mechanical snubber strength

INTERMEDIATE SNUBBER PIPE

Compression, capacity in intermediate snubber pipe [AISC, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

E2. Slenderness Limitations and Effective Length

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified through classificatic

$\phi P_{n}^{T} = (107.395) \cdot kip$ Design compressive strength

Tension, capacity in intermediate snubber pipe [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_sp\_ty} = (122.958) \cdot kip$ Design tensile yielding strength

(b) For tensile rupture in net section:

$\phi P_{n\_sp\_tr} = (186.3) \cdot kip$ Design tensile rupture strength

CLAMP

Compression/Tension, capacity of clamp

$P_{cl}^{T} = (30.55) \cdot kip$ Supplied clamp strength

Appendix D.9.4

MS-6 Capacities

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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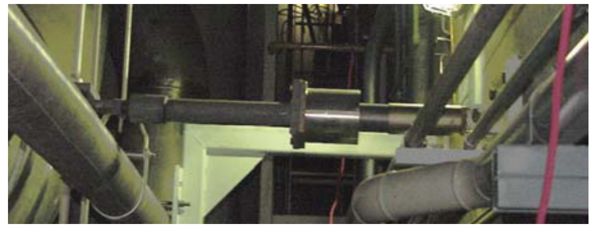
Performer: A L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

MS-6 CAPACITY

MS-6 restricts seismic motion in the east/west direction of the horizontally oriented PCS piping traveling in the north/south direction. MS-6 is comprised of the PSA-10 mechanical snubber, base plate bolted to the wall, a 2 foot 2" schedule 80 pipe extension, and clamp attaching the support to the 36" PSC pipe. The snubber is connected to the clamp and base plate by a pin and the clamp is secured to the pipe by two large threaded rods on either side. The anchorage assembly capacities and the associated capacities of the wall embedment are found in the anchorage and embedment portions of this report while the capacities for the remainder of the previously mentioned components are calculated below.



Component Capacity Overview:

- Eastward/Westward Loading:

- Shear capacity of mechanical snubber's anchorage and clamp pin
- Tension/Compression capacity of mechanical snubber
- Tension/Compression capacity of clamp
- Tension capacity of pipe extension
- Compression capacity of pipe extension

(**Procedures from SEI/ASCE 8-02 (Applying LRFD)**)

References

1. Drawing 453164, "ATR Primary Coolant System Mechanical Snubber Pin Detail," Lockheed Idaho Technologies Company, July, 24, 1996
2. SEI/ASCE 8-02, "Specification for the Design of Cold-Formed Stainless Steel Structural Members," American Society of Civil Engineers, Sept. 24, 2007
3. ASTM SA-564/SA-564M, "Specification for Hot-Rolled and Cold-Finished Age-Hardening Stainless Steel Bars and Shapes," American Society for Testing and Materials, 2004
4. Drawing 159776, "ATR Seismic Modification, Primary System Snubber Details," Rev. 4, EG&G Idaho, Inc., August 7, 1980
5. Basic-PSA, Inc. Catalog 193, "Pipe Hangers, Supports, and Controls," Basic-PSA, Inc.
6. DAG, "Allowable Loads for Angle Loaded Pipe Clamps (Mech Snubber Model:PSA-10)," Basic Engineers October 12, 1984
7. ANSI/AISC 360-05, "Steel Construction Manual, 13th ed.," American Institute of Steel Construction, Inc., March 9, 2005.

Note:

SEI/ASCE 8-02 was applied for these supports instead of AISC 13th Edition because the vendor data capacities for the mechanical snubbers and their associated clamps were available, however, the stainless steel pins implemented were associated with a drawing given specific material properties and dimensions of the stainless steel.

$i := 0$ — Assigned indices corresponding to number of support types associated with these calculations

Support = 0 (MS-6)

Relationship between support and corresponding indices

Geometric and Material Properties of Support Components

MECHANICAL SNUBBER PINS (Mechanical Snubber Pin Detail [453164]

Material Properties of Mechanical Snubber Pins as Defined in the [453164] and [ASTM SA-564]:

$F_{y\_pin} := 115ksi$ — Yield Strength for SA-564, Tp 630, Cond 1100

$F_{u\_pin} := 140ksi$ — Ultimate Strength for SA-564, Tp 630, Cond 1100

Geometric Properties of Mechanical Snubber Pins:

$d_{pin} := (0.9992in)^T$ — Diameter of mechanical snubber pins [159776], [453164]

$L_{pin} := (5in)^T$ — Length of mechanical snubber pins [159776], [453164]

MECHANICAL SNUBBER (PSA Mechanical Snubber [159776]

Rated Capacity of Mechanical Snubbers:

$Capacity_{MS} := (15kip)^T$ — Rated capacity of mechanical snubbers [Basic-PSA, pg 171]

INTERMEDIATE SNUBBER PIPE (2" Schedule 80 [159776]

Material Properties of Intermediate Snubber Pipe as Defined in the Material Section of this Report:

$F_{y\_sp} := 33ksi$ — Yield Strength for A7 Carbon Steel

$F_{u\_sp} := 60ksi$ — Ultimate Strength for A7 Carbon Steel

$E_{sp} := 29000ksi$ — Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Intermediate Snubber Pipe:

$OD_{sp} := (2.38in)^T$ — Outside diameter of intermediate snubber pipe [159776], [AISC, Table 1-14, pg 1-99]

$ID_{sp} := (1.94in)^T$ — Inside diameter of intermediate snubber pipe [159776], [AISC, Table 1-14, pg 1-99]

$t_{sp} := (0.218in)^T$ — Nominal thickness of intermediate snubber pipe [159776], [AISC, Table 1-14, pg 1-99]

$A_{sp} := \left(1.39in^2\right)^T$ — Area of intermediate snubber pipe [159776], [AISC, Table 1-14, pg 1-99]

$r_{gyration\_sp} := (0.771\,in)^T$ — Radius of gyration of intermediate snubber pipe [159776], [AISC, Table 1-14, pg 1-99]

$L_{sp} := (24in)^T$ — Length of intermediate snubber pipe [159776], [AISC, Table 1-14, pg 1-99]

$L_{sp\_pins} := (48in)^T$ — Length between pin connections of snubber plus intermediate snubber pipe spanning between [159776], [AISC, Table 1-14, pg 1-99]

CLAMP (Pipe Clamp [159776])

Rated Capacity of Mechanical Snubbers' Pipe Clamp:

$Capacity_{cl} := (16kip)^T$ — Rated capacity of pipe clamp connecting mechanical snubber [Basic Engineers]

Applicability of applying SEI/ASCE 8-02

MECHANICAL SNUBBER PINS

1.3.3 Ductility

This code does not list SA-564 as an applicable stainless steel unless it meets the following criteria

Ratio of tensile strength to yield strength must not be less than 1.08

$$\frac{F_{u\_pin}}{F_{y\_pin}} = 1.217$$

Since this value is greater than the 1.08 specification SA-564 meets this requirement

Total elongation shall not be less than 10% for a two-in. gage length standard specimen

Elongation = 14% [ASTM SA-564, pg1092]

Since this value is greater than the 10% requirement SA-564 meets this requirement as well

Capacities For Eastward/Westward Loading

MECHANICAL SNUBBER PINS

Shear, capacity of mechanical snubber anchorage and clamp pins [ASCE, Ch. 5 pg 24 thru 25]

5. Connections and Joints

5.3.4. Shear and Tension in Stainless Steel Bolts

$\phi := 0.65$ — [SEI/ASCE 8-02, Table 6 pg 25]

$$A_{pin_i} := \pi \cdot \left(\frac{d_{pin_i}}{2}\right)^2$$

Gross cross sectional area of pin

$$A_{pin\_ds_i} := 2 \cdot A_{pin_i}$$

Applicable area for this case since the bolt is in double shear

Since F_{nv} is not provided for SA-564 type 630

$F_{nv\_cl\_bolt} := 0.5 \cdot F_{y\_pin}$

stainless steel in SEI/ASCE 8-02 it is observed from [SEI/ASCE 8-02, Table A1] that the shear yield strength of the represented materials is no less than 0.51 of the yield strength, thus to be conservative it has been estimated to be 0.5 of the yield strength

$R_{nv\_cl\_bolt_i} := F_{nv\_cl\_bolt} \cdot A_{pin\_ds_i}$ Nominal strength (R_n) (5.3.4-1)

$\phi R_{nv\_cl\_bolt_i} := \phi \cdot R_{nv\_cl\_bolt_i}$

$\boxed{\phi R_{nv\_cl\_bolt}^{T} = (58.615) \cdot kip}$ Design shear strength

It appears that even with the conservative assumptions that these values are much greater than that of the snubber and clamp capacities, thus this treatment is adequate in determining if these components will govern this support

MECHANICAL SNUBBER

Compression/Tension, capacity of mechanical snubber

$P_{MS} := Capacity_{MS}$

$\boxed{P_{MS}^{T} = (15) \cdot kip}$ Supplied mechanical snubber strength

INTERMEDIATE SNUBBER PIPE

Determine if supports are ***compact (1)***, ***non-compact (2)***, or ***slender (3)*** as defined in first paragraph of B4

B4. Classification of sections for local buckling (Table B4.1 Case 15)

$D2t_{sp_i} := \frac{OD_{sp_i}}{t_{sp_i}}$ $D2t_{sp}^{T} = (10.917)$

Definition of λ_p and λ_r from Table B4.1 Case 15 (Circular hollow sections in uniform compression) to be applied in classification logic. λ_p is the separation point between a compact and non compact member. λ_r is separation point between a non compact and slender member. However, Table B4.1 Case 15 defines λ_p = NA because the only thing of concern is if the support is slender or non-slender, thus only if the classification is 3 do we apply slenderness considerations, otherwise we treat the member as not having slender elements.

$\lambda_p := 0$ $\lambda_r := 0.11 \frac{E_{sp}}{F_{y\_sp}}$

$$\text{Classification}_i := \begin{cases} 1 & \text{if } D2t_{sp_i} \le \lambda_p \\ 2 & \text{if } \lambda_p < D2t_{sp_i} \le \lambda_r \\ 3 & \text{if } \lambda_r < D2t_{sp_i} \end{cases}$$

$$\text{Classification}^T = (2)$$

Compression, capacity in intermediate snubber pipe [AISC, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

$\phi_c := 0.9$ — Resistance factor for compression

E2. Slenderness Limitations and Effective Length

$K := 1.0$ — Effective length in accordance with C2.b1, [AISC, comm.C2 (Table C-C2.2) (case d) pg 16.1-240] Case d was chosen because the support was allowed on both ends.

The Slenderness ratio KL/r should preferably not exceed 200

$$KLr_i := \left(\frac{K \cdot L_{sp\_pins_i}}{r_{gyration\_sp_i}}\right)$$

L_{sp_pins} was chosen as it was the effective length between the pin locations.

The below KLr values verify that all supports do not exceed the 200 recommended limitation

$$KLr^T = (62.257)$$

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified through classificatic

$$F_{e_i} := \frac{\pi^2 E_{sp}}{\left(KLr_i\right)^2}$$

F_e is the elastic critical buckling stress (E3-4)

$$F_e^T = (73.845) \cdot ksi$$

Calculating the variables Limit, Op1, and Op2 to be utilized in logic to determine flexural buckling stress.

$$\text{Limit} := 4.71 \cdot \sqrt{\frac{E_{sp}}{F_{y\_sp}}} \qquad Op1_i := \left(0.658^{\frac{F_{y\_sp}}{F_{e_i}}}\right) F_{y\_sp} \qquad Op2_i := 0.877 \cdot F_{e_i}$$

$$\text{Limit} = 139.625$$

Calculating the flexural buckling stress

$$F_{cr_i} := \begin{cases} Op1_i & \text{if } KLr_i \le Limit \\ Op2_i & \text{if } KLr_i > Limit \end{cases}$$ (E3-2) (E3-3)

$$F_{cr}^T = (27.371) \cdot ksi$$

$$\phi P_{n_i} := \phi_c \cdot F_{cr_i} \cdot A_{sp_i}$$

$$\boxed{\phi P_n^T = (34.241) \cdot kip}$$ Design compressive strength

Tension, capacity in intermediate snubber pipe [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$$A_{g\_sp_i} := A_{sp_i}$$ Gross area

2. Net Area

$$A_{net\_sp_i} := A_{sp_i}$$ Net area

3. Effective Net Area

$$U_{sp} := 1.0$$ Shear Lag Factor [AISC, Table D3.1]

$$A_{e\_sp_i} := A_{net\_sp_i} \cdot U_{sp}$$ Effective net area

(a) For tensile yielding in the gross section:

$$P_{n\_sp\_ty_i} := F_{y\_sp} \cdot A_{g\_sp_i}$$ Nominal axial strength (P_n)

$$\phi_{ty} := 0.9$$ Resistance factor for tension yielding (ϕ_{ty})

$$\phi P_{n\_sp\_ty_i} := \phi_{ty} \cdot P_{n\_sp\_ty_i}$$

Design tensile yielding strength

$$\boxed{\phi P_{n\_sp\_ty} = (41.283) \cdot kip}$$

(b) For tensile rupture in net section:

$$P_{n\_sp\_tr_i} := F_{u\_sp} \cdot A_{e\_sp_i}$$ Nominal axial strength (P_n)

$\phi_{tr} := 0.75$ — Resistance factor for tension rupture (ϕ_{tr})

$\phi P_{n\_sp\_tr_i} := \phi_{tr} \cdot P_{n\_sp\_tr_i}$

$\boxed{\phi P_{n\_sp\_tr} = (62.55) \cdot kip}$ — Design tensile rupture strength

CLAMP

Compression/Tension, capacity of clamp

$P_{cl} := Capacity_{cl}$

$\boxed{P_{cl}^{T} = (16) \cdot kip}$ — Supplied clamp strength

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Performer: A L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

SUMMARY OF RESULTS

Capacities For Eastward/Westward Loading

MECHANICAL SNUBBER PINS

Shear, capacity of mechanical snubber anchorage and clamp pins [ASCE, Ch. 5 pg 24 thru 25]

5. Connections and Joints

5.3.4. Shear and Tension in Stainless Steel Bolts

$$\phi R_{nv\_cl\_bolt}^{T} = (58.615) \cdot kip$$ Design shear strength

MECHANICAL SNUBBER

Compression/Tension, capacity of mechanical snubber

$$P_{MS}^{T} = (15) \cdot kip$$ Supplied mechanical snubber strength

INTERMEDIATE SNUBBER PIPE

Compression, capacity in intermediate snubber pipe [AISC, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

E2. Slenderness Limitations and Effective Length

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified through classificatic

$$\phi P_{n}^{T} = (34.241) \cdot kip$$ Design compressive strength

Tension, capacity in intermediate snubber pipe [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_sp\_ty} = (41.283) \cdot kip$$ Design tensile yielding strength

(b) For tensile rupture in net section:

$$\phi P_{n\_sp\_tr} = (62.55) \cdot kip$$ Design tensile rupture strength

CLAMP

Compression/Tension, capacity of clamp

$$P_{cl}^{T} = (16) \cdot kip$$ Supplied clamp strength

Appendix D.9.5

MS-3 Capacities

MS-3 CAPACITY

MS-3 restricts seismic motion in the north south direction of the vertically oriented PCS piping. MS-3 is comprised of the PSA-35 mechanical snubber, base plate bolted to the ceiling, and clamp attaching the support to the 36" PSC pipe. The snubber is connected to the clamp and base plate by a pin and the clamp is secured to the pipe by two large threaded rods on either side. The anchorage assembly capacities and the associated capacities of the wall embedment are found in the anchorage and embedment portions of this report while the capacities for the remainder of the previously mentioned components are calculated below.

Component Capacity Overview:

- Northward/Southward Loading:
- Shear capacity of mechanical snubber's anchorage and clamp pin
- Tension/Compression capacity of mechanical snubber
- Tension/Compression capacity of clamp

(**Procedures from SEI/ASCE 8-02 (Applying LRFD))**

References
1. Drawing 453164, "ATR Primary Coolant System Mechanical Snubber Pin Detail," Lockheed Idaho Technologies Company, July, 24, 1996
2. SEI/ASCE 8-02, "Specification for the Design of Cold-Formed Stainless Steel Structural Members," American Society of Civil Engineers, Sept. 24, 2007
3. ASTM SA-564/SA-564M, "Specification for Hot-Rolled and Cold-Finished Age-Hardening Stainless Steel Bars and Shapes,"American Society for Testing and Materials, 2004
4. Drawing 159775, "ATR Seismic Modification, Primary System Snubber Details," Rev. 2, EG&G Idaho, Inc., August 5, 1980
5. Basic-PSA, Inc. Catalog 193, "Pipe Hangers, Supports, and Controls," Basic-PSA, Inc.
6. DAG, "Allowable Loads for Angle Loaded Pipe Clamps (Mech Snubber Model:PSA-35)," Basic Engineers October 12, 1984

Note:

SEI/ASCE 8-02 was applied for these supports instead of AISC 13th Edition because the vendor data capacities for the mechanical snubbers and their associated clamps were available, however, the stainless steel pins implemented were associated with a drawing given specific material properties and dimensions of the stainless steel.

$i := 0$ — Assigned indices corresponding to number of support types associated with these calculations

Support = 0 (MS-3) — Relationship between support and corresponding indices

Geometric and Material Properties of Support Components

MECHANICAL SNUBBER PINS (Mechanical Snubber Pin Detail [453164])

Material Properties of Mechanical Snubber Pins as Defined in the [453164] and [ASTM SA-564]:

$F_{y\_pin} := 115\text{ksi}$ — Yield Strength for SA-564, Tp 630, Cond 1100

$F_{u\_pin} := 140\text{ksi}$ — Ultimate Strength for SA-564, Tp 630, Cond 1100

Geometric Properties of Mechanical Snubber Pins:

$d_{pin} := (1.4970\text{in})^T$ — Diameter of mechanical snubber pins [159775], [453164]

$L_{pin} := (7\text{in})^T$ — Length of mechanical snubber pins [159775], [453164]

MECHANICAL SNUBBER (PSA Mechanical Snubber [159775])

Rated Capacity of Mechanical Snubbers:

$\text{Capacity}_{MS} := (50\text{kip})^T$ — Rated capacity of mechanical snubbers [Basic-PSA, pg 171]

CLAMP (Pipe Clamp [159776])

Rated Capacity of Mechanical Snubbers' Pipe Clamp:

$\text{Capacity}_{cl} := (55\text{kip})^T$ — Rated capacity of pipe clamp connecting mechanical snubber [Basic Engineers]

Applicability of applying SEI/ASCE 8-02

MECHANICAL SNUBBER PINS

1.3.3 Ductility

This code does not list SA-564 as an applicable stainless steel unless it meets the following criteria

Ratio of tensile strength to yield strength must not be less than 1.08

$$\frac{F_{u\_pin}}{F_{y\_pin}} = 1.217$$

Since this value is greater than the 1.08 specification SA-564 meets this requirement

Total elongation shall not be less than 10% for a two-in. gage length standard specimen

Elongation = 14% [ASTM SA-564, pg1092]

Since this value is greater than the 10% requirement SA-564 meets this requirement as well

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Performer: A L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

Capacities For Northward/Southward Loading

MECHANICAL SNUBBER PINS

Shear, capacity of mechanical snubber anchorage and clamp pins [ASCE, Ch. 5 pg 24 thru 25]

5. Connections and Joints

5.3.4. Shear and Tension in Stainless Steel Bolts

$\phi := 0.65$ — [SEI/ASCE 8-02, Table 6 pg 25]

$A_{pin_i} := \pi \cdot \left(\frac{d_{pin_i}}{2}\right)^2$ — Gross cross sectional area of pin

$A_{pin\_ds_i} := 2 \cdot A_{pin_i}$ — Applicable area for this case since the bolt is in double shear

$F_{nv\_cl\_bolt} := 0.5 \cdot F_{y\_pin}$ — Since F_{nv} is not provided for SA-564 type 630 stainless steel in SEI/ASCE 8-02 it is observed from [SEI/ASCE 8-02, Table A1] that the shear yield strength of the represented materials is no less than 0.51 of the yield strength, thus to be conservative it has been estimated to be 0.5 of the yield strength

$R_{nv\_cl\_bolt_i} := F_{nv\_cl\_bolt} \cdot A_{pin\_ds_i}$ — Nominal strength (R_n) (5.3.4-1)

$\phi R_{nv\_cl\_bolt_i} := \phi \cdot R_{nv\_cl\_bolt_i}$

$\phi R_{nv\_cl\_bolt}^T = (131.566) \cdot kip$ — Design shear strength

It appears that even with the conservative assumptions that these values are much greater than that of the snubber and clamp capacities, thus this treatment is adequate in determining if these components will govern this support

Compression/Tension, capacity of mechanical snubber

MECHANICAL SNUBBER

$P_{MS} := Capacity_{MS}$

$P_{MS}^T = (50) \cdot kip$ — Supplied mechanical snubber strength

Compression/Tension, capacity of clamp

CLAMP

$P_{cl} := Capacity_{cl}$

$P_{cl}^T = (55) \cdot kip$ — Supplied clamp strength

SUMMARY OF RESULTS

Capacities For Northward/Southward Loading

MECHANICAL SNUBBER PINS

Shear, capacity of mechanical snubber anchorage and clamp pins [ASCE, Ch 5 pg 24 thru 25]

5. Connections and Joints

5.3.4. Shear and Tension in Stainless Steel Bolts

$\phi R_{nv\_cl\_bolt}^{T} = (131.566) \cdot kip$ Design shear strength

It appears that even with the conservative assumptions that these values are much greater than that of the snubber and clamp capacities, thus this treatment is adequate in determining if these components will govern this support

Compression/Tension, capacity of mechanical snubber

MECHANICAL SNUBBER

$P_{MS}^{T} = (50) \cdot kip$ Supplied mechanical snubber strength

Compression/Tension, capacity of clamp

CLAMP

$P_{cl}^{T} = (55) \cdot kip$ Supplied clamp strength

Appendix D.9.6

RH-33 Capacities

RH-33 CAPACITY

The RH-33 supports hang from the ceiling to support a horizontal PCS pipe traveling in the north/south direction. The RH-33 supports are composed of a 6" adjustable clevis, a 1/2" rod attached to the top of the adjustable clevis, and an angle section hanging from a channel section welded to the ceiling embedment. The capacities for these components are calculated below, however, the capacity for the welds attaching the welded beam attachment and the associated capacities of the ceiling embedment are found in the anchorage and embedment portions of this report.

Component Capacity Overview:

- Downward Loading:

- Tension capacity of clamp (D)
- Shear capacity of clamp's upper bolt (J)
- Tension capacity of clamp's lower bolt (J)
- Tension + Flexure capacity of eye rod (H).
- Tension capacity of eye rod (J)
- Tension capacity of adjustable clevis's intermediate cross section
- Shear capacity of adjustable clevis's bolt
- Shear capacity of anchorage weld given downward loading ?

(**Procedures from AISC 13th Edition (LRFD)**)

References

1. ANSI/AISC 360-05, "Steel Construction Manual, 13th ed.," American Institute of Steel Construction, Inc., March 9, 2005
2. ITT Grinnell Catalog PH81, "Pipe Hangers," ITT Grinnell Corporation, 1981
3. Drawing 120925, "Primary Coolant System Pipe Hangers and Details," Revision 11, Lockheed Martin, April 21, 1997

Note: There are two RH-33 supports, they are identical except for their anchorage. One is embedded in the ceiling's concrete whereas the other is fastened by means of a hole drilled in the protruding angle section with one of its outer faces welded to the back face of a vertical channel section. Therefore the RH-33 support corresponding to Node 14 of Model 4 is also associated with the angle section calculation performed below.

$i := 0$

Assigned indices corresponding to number of support types associated with these calculations

Support =	0
	(RH-33)

Relationship between support and correspondinc indices

Geometric and Material Properties of Support Components

ADJUSTABLE CLEVIS (Clevis FIG 260 6")

Material Properties of Adjustable Clevis as Defined in the Material Section of this Report:

$F_{y\_acv} := 33\text{ksi}$ — Yield Strength for A7 Carbon Steel

$F_{u\_acv} := 60\text{ksi}$ — Ultimate Strength for A7 Carbon Steel

$E_{acv} := 29000\text{ksi}$ — Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Adjustable Clevis:

$$t_{acv\_up} := \left[2 \cdot \left(\frac{1}{4}\text{in}\right)\right]^T$$

Combined thickness of upper portions of adjustable clevis [Grinnell, Fig 260]

$$w_{acv\_up} := \left(1\frac{1}{2}\text{in}\right)^T$$

Width of upper portions of adjustable clevis [Grinnell, Fig 260]

$$A_{acv\_up_i} := t_{acv\_up_i} \cdot w_{acv\_up_i}$$

Cross sectional area of upper portion of adjustable clevis [Grinnell, Fig 260]

$$A_{acv\_up}{}^T = (0.75)\,\text{in}^2$$

$$t_{acv\_low} := \left[2 \cdot \left(\frac{3}{16}\text{in}\right)\right]^T$$

Combined thickness of lower portions of adjustable clevis [Grinnell, Fig 260]

$$w_{acv\_low} := \left(1\frac{1}{2}\text{in}\right)^T$$

Width of lower portions of adjustable clevis [Grinnell, Fig 260]

$$A_{acv\_low_i} := t_{acv\_low_i} \cdot w_{acv\_low_i}$$

Cross sectional area of lower portion of adjustable clevis [Grinnell, Fig 260]

$$A_{acv\_low}{}^T = (0.562)\,\text{in}^2$$

$$d_{acv\_bolt} := \left(\frac{1}{2}\text{in}\right)^T$$

Diameter of adjustable clevis bolt [Grinnell, Fig 260]

$$d_{acv\_hole} := \left(\frac{9}{16}\text{in}\right)^T$$

Nominal bolt hole Diameter, in. (mm) [AISC, Table J3.3]

$$a_{parrallel\_acv\_up} := d_{acv\_bolt}$$

Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force, in. (mm) relation estimated from photo DSCN2683

$$a_{normal\_acv\_up_i} := \frac{w_{acv\_up_i} - d_{acv\_hole_i}}{2}$$

Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force, in. (mm)

$$a_{parrallel\_acv\_low} := d_{acv\_bolt}$$

Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force, in. (mm) relation estimated from photo DSCN2683

$$a_{normal\_acv\_low_i} := \frac{w_{acv\_low_i} - d_{acv\_hole_i}}{2}$$

Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force, in. (mm)

ROD (Rod FIG 140 1/2")

Material Properties of Rod as Defined in the Material Section of this Report:

$F_{y\_rod} := 33ksi$ Yield Strength for A7 Carbon Steel

$F_{u\_rod} := 60ksi$ Ultimate Strength for A7 Carbon Steel

$E_{rod} := 29000ksi$ Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Rod:

$$d_R := \left(\frac{1}{2}in\right)^T$$

Unthreaded diameter of eye rod, in. (mm) [120925]

$$Z_{R_i} := \frac{\left(d_{R_i}\right)^3}{6}$$

Plastic section modulus about the axis of bending, in.^{3} [AISC, Table 17-27 pg17-39]

ANGLE SECTION

Material Properties of Rod as Defined in the Material Section of this Report:

$F_{yAngle} := 33ksi$ Yield Strength for A7 Carbon Steel

$F_{uAngle} := 60ksi$ Ultimate Strength for A7 Carbon Steel

$E_{Angle} := 29000ksi$ Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Rod:

$$L1_{Angle} := \left(2\frac{1}{2}in\right)^T$$

Length of top leg of angle section scaled from photo dscn3041

$$L2_{Angle} := \left(2\frac{1}{2}in\right)^T$$

Length of bottom leg of angle section scaled from photo dscn3041

$$t_{Angle} := \left(\frac{3}{8}in\right)^T$$

Conservative estimation of angle section thickness scaled from photo dscn3041

$L_{Angle} := \left(3\frac{1}{2}in\right)^T$ — Length of angle section scaled from photo dscn3041

$t_{Plate_i} := t_{Angle_i}$ — Thickness of assumed plate section

$w_{Plate_i} := L_{Angle_i}$ — Width of assumed plate section

$L_{Plate_i} := L1_{Angle_i}$

$I_{XPlate_i} := \frac{w_{Plate_i} \cdot \left(t_{Plate_i}\right)^3}{12}$ — Moment of inertia about the horizontal X-axis of the bottom angle leg approximated as a plate [AISC, Table 17-27]

$Z_{Plate_i} := \frac{w_{Plate_i} \cdot \left(t_{Plate_i}\right)^2}{4}$ — Plastic section modulus [AISC, Table 17-27]

Capacities Resulting From Downward Loading

ADJUSTABLE CLEVIS

Tension, capacity of upper adjustable clevis's pin connection [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$b_{acv\_up_i} := 2\,t_{acv\_up_i} + 0.63in$

$b_{acv\_up}^T = (1.63)\,in$

$b_{eff\_acv\_up_i} := \min\left(b_{acv\_up_i}, a_{normal\_acv\_up_i}\right)$

$b_{eff\_acv\_up}^T = (0.469)\,in$

b_{eff} is an effective length calculated as (2t + 0.63in) for which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$P_{n\_acv\_up\_trp_i} := 2 \cdot t_{acv\_up_i} \cdot b_{eff\_acv\_up_i} \cdot F_{u\_acv}$ — Nominal axial strength (P_n) (D5-1)

$\phi_{n\_trp} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_acv\_up\_trp_i} := \phi_{n\_trp} \cdot P_{n\_acv\_up\_trp_i}$

$\phi P_{n\_acv\_up\_trp}^T = (21.094) \cdot kip$ Design tensile strength

(b) For shear rupture on the effective area:

$A_{sf\_acv\_up\_bolt_i} := 2 \cdot t_{acv\_up_i} \cdot \left(a_{parrallel\_acv\_up_i} + \frac{d_{acv\_bolt_i}}{2} \right)$

$A_{sf\_acv\_up\_bolt}^T = (0.75)\, in^2$ Effective Area

$P_{n\_acv\_up\_bolt\_srp_i} := 0.6 \cdot F_{u\_acv} \cdot A_{sf\_acv\_up\_bolt_i}$ Nominal axial strength (P_n) (D5-2)

$\phi_{n\_srp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_acv\_up\_bolt\_srp_i} := \phi_{n\_srp} \cdot P_{n\_acv\_up\_bolt\_srp_i}$

$\phi P_{n\_acv\_up\_bolt\_srp}^T = (20.25) \cdot kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_acv\_up_i} := d_{acv\_bolt_i} \cdot t_{acv\_up_i}$ Projected bearing area in.^{2} (mm^2)

$R_{n\_acv\_up\_bs_i} := 1.8 \cdot F_{y\_acv} \cdot A_{pd\_acv\_up_i}$ Nominal bearing strength

$\phi := 0.75$ Resistance factor

$\phi R_{n\_acv\_up\_bs_i} := \phi \cdot R_{n\_acv\_up\_bs_i}$

$\phi R_{n\_acv\_up\_bs}^T = (11.138) \cdot kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_acv\_up_i} := A_{acv\_up_i}$ Gross Area

(a) For tensile yielding in the gross section:

$P_{n\_acv\_up\_ty_i} := F_{y\_acv} \cdot A_{g\_acv\_up_i}$ Nominal axial strength (P_n)

(D2-1)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_acv\_up\_ty_i} := \phi_{t\_ty} \cdot P_{n\_acv\_up\_ty_i}$

$\phi P_{n\_acv\_up\_ty}^T = (22.275) \cdot kip$ Design tensile strength

Tension, capacity of lower adjustable clevis's pin connection [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$b_{acv\_low_i} := 2\, t_{acv\_low_i} + 0.63in$

$b_{acv\_low}^T = (1.38)\, in$

$b_{eff\_acv\_low_i} := \min\left(b_{acv\_low_i}, a_{normal\_acv\_low_i}\right)$

$b_{eff\_acv\_low}^T = (0.469)\, in$

b_{eff} is an effective length calculated as (2t + 0.63in) for which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$P_{n\_acv\_low\_trp_i} := 2 \cdot t_{acv\_low_i} \cdot b_{eff\_acv\_low_i} \cdot F_{u\_acv}$ Nominal axial strength (P_n)

(D5-1)

$\phi_{n\_trp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_acv\_low\_trp_i} := \phi_{n\_trp} \cdot P_{n\_acv\_low\_trp_i}$

$\phi P_{n\_acv\_low\_trp}^T = (15.82) \cdot kip$ Design tensile strength

(b) For shear rupture on the effective area:

$A_{sf\_acv\_low\_bolt_i} := 2 \cdot t_{acv\_low_i} \cdot \left(a_{parrallel\_acv\_low_i} + \frac{d_{acv\_bolt_i}}{2}\right)$

$A_{sf\_acv\_low\_bolt}^T = (0.562)\, in^2$ Effective Area

$P_{n\_acv\_low\_bolt\_srp_i} := 0.6 \cdot F_{u\_acv} \cdot A_{sf\_acv\_low\_bolt_i}$ Nominal axial strength (P_n)

(D5-2)

$\phi_{n\_srp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_acv\_low\_bolt\_srp_i} := \phi_{n\_srp} \cdot P_{n\_acv\_low\_bolt\_srp_i}$

$\phi P_{n\_acv\_low\_bolt\_srp}^{T} = (15.187) \cdot kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_acv\_low_i} := d_{acv\_bolt_i} \cdot t_{acv\_low_i}$ Projected bearing area in.^{2} (mm^2)

$R_{n\_acv\_low\_bs_i} := 1.8 \cdot F_{y\_acv} \cdot A_{pd\_acv\_low_i}$ Nominal bearing strength

$\phi := 0.75$ Resistance factor

$\phi R_{n\_acv\_low\_bs_i} := \phi \cdot R_{n\_acv\_low\_bs_i}$

$\phi R_{n\_acv\_low\_bs}^{T} = (8.353) \cdot kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_acv\_low_i} := A_{acv\_low_i}$ Gross Area

(a) For tensile yielding in the gross section:

$P_{n\_acv\_low\_ty_i} := F_{y\_acv} \cdot A_{g\_acv\_low_i}$ Nominal axial strength (P_n)
(D2-1

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_acv\_low\_ty_i} := \phi_{t\_ty} \cdot P_{n\_acv\_low\_ty_i}$

$\phi P_{n\_acv\_low\_ty}^{T} = (16.706) \cdot kip$ Design tensile strength

Shear, capacity of adjustable clevis's pin [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$A_{acv\_bolt_i} := \pi \cdot \left(\frac{d_{acv\_bolt_i}}{2}\right)^2$$ Nominal unthreaded body area

$$A_{acv\_bolt\_ds_i} := 2 \cdot A_{acv\_bolt_i}$$ Applicable area for this case since the bolt is in double shear

$$F_{nv\_bolt} := 24ksi$$ Nominal Shear Stress in Bearing Type Connections (A307) [AISC, Table J3.2]

$$R_{nv\_acv\_bolt_i} := F_{nv\_bolt} \cdot A_{acv\_bolt\_ds_i}$$ Nominal strength (R_n) (J3-1)

$$\phi_{b\_sr} := 0.75$$ Resistance factor

$$\phi R_{nv\_acv\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_acv\_bolt_i}$$

$$\boxed{\phi R_{nv\_acv\_bolt}^{\ T} = (7.069) \cdot kip}$$ Design shear strength

ROD

Tension, capacity of rod [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$A_{b\_R_i} := \pi \cdot \left(\frac{d_{R_i}}{2}\right)^2$$ Nominal unthreaded body area

$$F_{nt\_R} := 45ksi$$ Nominal tensile stress (A307) [AISC, Table J3.2]

$$R_{nt\_R_i} := F_{nt\_R} \cdot A_{b\_R_i}$$ Nominal strength (R_n) (J3-1)

$$\phi_{b\_tr} := 0.75$$ Resistance factor

$$\phi R_{nt\_R_i} := \phi_{b\_tr} \cdot R_{nt\_R_i}$$

$$\boxed{\phi R_{nt\_R}^{\ T} = (6.627) \cdot kip}$$ Design tension strength

ANGLE

Flexure, capacity of angle's protruding section [AISC, Ch. F pg 16.1-44 thru 63]

This section is to be treated as a cantilever plate in bending since the top section of the angle member is welded to the side of the much larger channel member.

Flexure, capacity of angle section conservatively approximated as a flat plate due to cut out notch [AISC, Ch. F pg 16.1-44 thru 63]

F1. General Provisions

$\phi_b := 0.9$ — Resistance factor for flexure

F11. Rectangular Bars and Rounds

1. Yielding

Calculate the yielding moment

$$M_{yPlate_i} := \frac{F_{yAngle} \cdot I_{XPlate_i}}{\frac{t_{Plate_i}}{2}}$$

Equation to calculate yielding moment from moment of inertia and Extreme values [Mechanics of Materials, Equation 6-74]

$$M_{yPlate}^{T} = (2.707) \cdot kip \cdot in$$

Yielding moment

$$M_{pPlate_i} := F_{yAngle} \cdot Z_{Plate_i}$$

$$M_{pPlate}^{T} = (4.061) \cdot kip \cdot in$$

Plastic bending moment

$$M_{nPlate_i} := \begin{cases} M_{pPlate_i} & \text{if } M_{pPlate_i} \le 1.6 \cdot M_{yPlate_i} \\ 1.6 \cdot M_{yPlate_i} & \text{otherwise} \end{cases}$$

Nominal flexural strength

$$\phi M_{nPlate_i} := \phi_b \cdot M_{nPlate_i}$$

$$\boxed{\phi M_{nPlate}^{T} = (3.654) \cdot kip \cdot in}$$

Design flexural strength

Relate design flexural strength to a force capacity

$$\phi F_{MnPlate_i} := \frac{\phi M_{nPlate_i}}{\frac{L1_{Angle_i}}{2} - t_{Plate_i}}$$

It is scaled from photo dscn2951 that the load is applied at the midpoint of the angle face

$$\boxed{\phi F_{MnPlate}^{T} = (4.177) \cdot kip}$$

Summary of Results

ADJUSTABLE CLEVIS

Tension, capacity of upper adjustable clevis's pin connection [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_acv\_up\_trp}{}^{T} = (21.094) \cdot kip$$ Design tensile strength

(b) For shear rupture on the effective area:

$$\phi P_{n\_acv\_up\_bolt\_srp}{}^{T} = (20.25) \cdot kip$$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\phi R_{n\_acv\_up\_bs}{}^{T} = (11.138) \cdot kip$$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_acv\_up\_ty}{}^{T} = (22.275) \cdot kip$$ Design tensile strength

Tension, capacity of lower adjustable clevis's pin connection [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_acv\_low\_trp}{}^{T} = (15.82) \cdot kip$$ Design tensile strength

(b) For shear rupture on the effective area:

$$\phi P_{n\_acv\_low\_bolt\_srp}{}^{T} = (15.187) \cdot kip$$ Design tensile strength

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(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_acv\_low\_bs}{}^{T} = (8.353) \cdot kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_acv\_low\_ty}{}^{T} = (16.706) \cdot kip$ Design tensile strength

Shear, capacity of adjustable clevis's pin [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$\phi R_{nv\_acv\_bolt}{}^{T} = (7.069) \cdot kip$ Design shear strength

ROD

Tension, capacity of rod [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$\phi R_{nt\_R}{}^{T} = (6.627) \cdot kip$ Design tension strength

ANGLE

Flexure, capacity of angle section conservatively approximated as a flat plate due to cut out notch [AISC, Ch. F pg 16.1-44 thru 63]

F1. General Provisions

F11. Rectangular Bars and Rounds

1. Yielding

$\phi F_{MnPlate}{}^{T} = (4.177) \cdot kip$

Appendix D.9.7

PR-2 Capacities

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

PR-2 CAPACITY

PR-2 restricts seismic motion in the east/west direction of the vertically oriented PCS piping which it is attached. PR-2 is comprised of a 18" pipe clamp, a bolt connecting the pipe clamp to a plate welded to a threaded rod, a pipe tapped to accommodate the threaded rod, another threaded rod welded to a plate, another bolt attaching the second threaded rod and plate to the welded beam attachment. The anchorage assembly capacities and the associated capacities of the wall embedment are found in the anchorage and embedment portions of this report while the capacities for the remainder of the previously mentioned components are calculated below.

Component Capacity Overview:

- Eastward Loading:
- Compression capacity of pipe clamp
- Shear capacity of pipe clamp's bolt
- Compression capacity of threaded rods
- Compression capacity of support pipe
- Shear capacity of welded beam attachment bolt

- **Westward Loading:**
- Tension capacity of clamp
- Shear capacity of pipe clamp's bolt
- Tension capacity of plates welded to threaded rods
- Tension capacity of weld between plates and threaded rods
- Tension capacity of threaded rods
- Tension capacity of support pipe
- Shear capacity of welded beam attachment bolt
- Tension capacity of welded beam attachment

(**Procedures from SEI/ASCE 8-02 (Applying LRFD)**)

References

1. ANSI/AISC 360-05, "Steel Construction Manual, 13th ed.," American Institute of Steel Construction, Inc., March 9, 2005.
2. ITT Grinnell Catalog PH81, "Pipe Hangers," ITT Grinnell Corporation, 1981.
3. Drawing 120923, "Primary Coolant System Pipe Hangers and Details SH 7," Revision 3, Ebasco Services Inc., Feb 21, 1966.
4. Specification S-10, "ATR Specification for Structural Steel," Revision 4, Ebaso Services Inc., September 24, 1962.
5. ATR-P-7, "Section II ATR Specification for Welding – Carbon Steel Pipe," September 7, 1965.

$i := 0$

Assigned indices corresponding to number of support types associated with these calculations

Support =	0
	(PR-1)

Relationship between support and corresponding indices

Geometric and Material Properties of Support Components

PIPE CLAMP

Material Properties of Clamp as Defined in the Material Section of this Report:

$F_{y\_cl} := 33ksi$ — Yield Strength for A7 Carbon Steel

$F_{u\_cl} := 60ksi$ — Ultimate Strength for A7 Carbon Steel

$E_{cl} := 29000ksi$ — Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Clamp:

$t_{cl} := \left(\frac{3}{4}in\right)^T$ — Thickness of plates forming the cantilever portion of the clamp, in. (mm) [DSC00053]

$w_{cl} := \left(5\frac{1}{2}in\right)^T$ — Conservative estimation of plate widths forming the clamp, in. (mm) [DSC00059], [120923]

$A_{cl_i} := \left(2\,t_{cl_i}\right)\cdot w_{cl_i}$ — Total cross sectional area of both sides of clamp, in.^{2} (mm^2)

$A_{cl}^T = (8.25)\,in^2$

$d_{cl\_bolt} := \left(1\frac{3}{8}in\right)^T$ — Bolt diameter, in. of all three bolts based on allowable provided by rod [120925, Sheet 2], [Grinnell, Fig 66 ph-33]

$d_{cl\_hole} := \left(1\frac{1}{2}in\right)^T$ — Nominal bolt hole diameter as estimated from welded beam attachment dimensions estimated from [Grinnell, Fig 66 ph-33]

$a_{parrallel\_cl} := (1in)^T$ — Shortest distance from edge of the pin hole to the edge of the member measured parallel to the direction of the force from top of bolt hole to top of clamp bracket, in. (mm) conservatively estimated from [DSC00059]

$a_{normal\_cl} := (2in)^T$ — Shortest distance from edge of pin hole to the edge of the member measured normal to the direction of the force, in. scaled from photo [DSC00059]

$L_{cl\_cantilever} := (9in)^T$ — Length of cantilever section from pipe to connection bolt conservatively scaled from photo [DSC00059]

$r_{gyrationH} := \frac{w_{cl}}{\sqrt{12}}$ — Radius of gyration about horizontal axis [AISC, Table 17-27]

$r_{gyrationH} = (1.588)\,in$

$r_{gyrationV} := \frac{t_{cl}}{\sqrt{12}}$ — Radius of gyration about vertical axis [AISC, Table 17-27]

$r_{gyrationV} = (0.217)\,in$

PLATES WELDED TO THREADED RODS

Material Properties of Plate as Defined in the Material Section of this Report:

$F_{y\_pl\_tr} := 33ksi$ — Yield Strength for A7 Carbon Steel

$F_{u\_pl\_tr} := 60ksi$ — Ultimate Strength for A7 Carbon Steel

$E_{pl\_tr} := 29000ksi$ — Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Plate:

$t_{pl\_tr} := \left(\frac{3}{4}in\right)^T$ — Thickness of plates forming the cantilever portion of the clamp, in. (mm) [120923]

$w_{pl\_tr} := (3in)^T$ — Width of plates forming the clamp, in. (mm) [120923]

$A_{pl\_tr_i} := t_{pl\_tr_i} \cdot w_{pl\_tr_i}$ — Total cross sectional area of both sides of clamp, in.^{2} (mm^2)

$A_{pl\_tr}^T = (2.25)\,in^2$

$d_{pl\_tr\_hole} := \left(1\frac{1}{2}in\right)^T$ — Nominal bolt hole diameter as estimated from welded beam attachment dimensions estimated from [Grinnell, Fig 66 ph-33]

$a_{parrallel\_pl\_tr} := (1in)^T$ — Shortest distance from edge of the pin hole to the edge of the member measured parallel to the direction of the force from top of bolt hole to top of clamp bracket, in. (mm) conservatively estimated from [DSCN2864]

$a_{normal\_pl\_tr} := \left(\frac{3}{4}in\right)^T$ — Shortest distance from edge of pin hole to the edge of the member measured normal to the direction of the force, in. scaled from photo [DSCN2864]

$d_{tr} := \left(1\frac{1}{4}in\right)^T$ — Threaded rod diameter [120923]

$A_{tr\_minor} := \left[\pi \cdot \left(\frac{1.0644in}{2}\right)^2\right]^T$ — Minor area of treaded rods with welded plate

[Machine Design, Table 14-1 pg 881]

$$A_{tr\_minor} = (0.89)\,in^2$$

$$L_{pl\_tr} := (14in)^T$$

Conservative estimate of rod length from pin hole to support pipe connection [120923]

$$r_{gyration\_pl\_tr_i} := \frac{d_{tr_i}}{4}$$

Radius of gyration for threaded portion [AISC, Table 17-27, pg 17-39]

$$r_{gyration\_pl\_tr} = (0.313)\,in$$

$$F_{EXX} := 60ksi$$

E6013 ultimate strength [Specification S-10, pg I-9], [ATR-P-7]

$$\theta_{transverse} := \frac{\pi}{2}$$

Angle between loading and traverse welds

$$F_{w\_transverse} := 0.60 \cdot F_{EXX} \cdot \left(1.0 + 0.5 \cdot \sin\left(\theta_{transverse}\right)^{1.5}\right) \qquad \text{(J2-5)}$$

Nominal Shear Strength of transverse welds

$$F_{w\_transverse} = 54 \cdot ksi$$

$$\theta_{longitudinal} := 0$$

Angle between loading and traverse welds

$$F_{w\_longitudinal} := 0.60 \cdot F_{EXX} \cdot \left(1.0 + 0.5 \cdot \sin\left(\theta_{longitudinal}\right)^{1.5}\right) \qquad \text{(J2-5)}$$

Nominal Shear Strength of longitudinal welds

$$F_{w\_longitudinal} = 36 \cdot ksi$$

$$\omega := \left(\frac{1}{4}in\right)^T$$

Minimum size of fillet given that thinner joined part (plate) = 3/4" [AISC, Table J2.4, pg 16.1-96] [120923]

$$L_{w\_traverse} := \left(3\frac{1}{2}in\right)^T$$

Traverse length of weld [120923]

$$L_{w\_longitudinal} := (8in)^T$$

Longitudinal length of weld [120923]

$$A_{w\_traverse_i} := L_{w\_traverse_i} \cdot \omega_i$$

Effective area of weld throat of traverse welds

$$A_{w\_traverse} = (0.875)\,in^2$$

$$A_{w\_longitudinal_i} := L_{w\_longitudinal_i} \cdot \omega_i$$

Effective area of weld throat of traverse welds

$$A_{w\_longitudinal} = (2)\,in^2$$

SUPPORT PIPE (Pipe 2-1/2" x S [120923])

Material Properties of Support Pipe as Defined in the Material Section of this Report:

$F_{y\_sp} := 33ksi$ Yield Strength for A7 Carbon Steel

$F_{u\_sp} := 60ksi$ Ultimate Strength for A7 Carbon Steel

$E_{sp} := 29000ksi$ Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Support Pipe:

$d_{sp\_od} := (2.88in)^T$ Outside diameter of support pipe [AISC, Table 1-14]

$d_{sp\_id} := (2.47in)^T$ Inside diameter of support pipe [AISC, Table 1-14]

$t_{sp} := (0.276in)^T$ Thickness of support pipe [AISC, Table 1-14]

$A_{sp} := \left(1.59in^2\right)^T$ Cross sectional are of support pipe [AISC, Table 1-14]

$L_{sp} := (58in)^T$ Conservatively estimated length between pins connecting support pipe to PCS pipe and anchorage [120923]

$r_{gyration\_sp} := (0.952in)^T$ Radius of gyration for support pipe [AISC, Table 1-14]

WELDED BEAM ATTACHMENT (Welded Beam Attachment FIG 66 1-1/4" Rod [120925, Sheet 2])

Material Properties of Welded Beam Attachment as Defined in the Material Section of this Report:

$F_{y\_wba} := 33ksi$ Yield Strength for A7 Carbon Steel

$F_{u\_wba} := 60ksi$ Ultimate Strength for A7 Carbon Steel

$E_{wba} := 29000ksi$ Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Welded Beam Attachment:

$t_{wba} := \left[2 \cdot \left(\frac{5}{8}in\right)\right]^T$ Combined thickness of welded beam attachment [Grinnell, Fig 66 ph-33]

$w_{wba} := (4in)^T$ Width of welded beam attachment [Grinnell, Fig 66 ph-33]

$A_{wba_i} := t_{wba_i} \cdot w_{wba_i}$

$A_{wba} = (5)\ in^2$

Cross sectional area of welded beam attachment

$d_{wba\_bolt} := \left(1\frac{3}{8}in\right)^T$

Diameter of welded beam attachment bolt [Grinnell, Fig 66 ph-33]

$d_{wba\_hole} := \left(1\frac{1}{2}in\right)^T$

Diameter of welded beam attachment bolt hole [Grinnell, Fig 66 ph-33], [AISC, Table J3.3 pg 16.1-105]

$a_{parrallel\_wba} := \left(1\frac{1}{4}in\right)^T$

Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force from bottom of bolt hole to the bottom of the welded beam attachment, in. (mm) hand calculated from d_{wba_hole} and [Grinnell, Fig 66 ph-33] data

$a_{normal\_wba_i} := \frac{w_{wba_i} - d_{wba\_hole_i}}{2}$

$a_{normal\_wba}{}^T = (1.25)\ in$

Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force, in. (mm) [Grinnell, Fig 66 ph-33]

Capacities For Inward Loading

PIPE CLAMP

Compression, capacity of clamp's cantilever section [AISC, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

$\phi_c := 0.9$

Resistance factor for compression

E2. Slenderness Limitations and Effective Length

$K := 2.1$

Effective length in accordance with C2.1b, [AISC, comm.C2 (Table C-C2.2 case e) pg 16.1-240], conservatively chosen as the behavior will actually be something between case c and case e.

The slenderness ratio (KL/r) should preferably not exceed 200

$r_{gyration\_gov_i} := \min\left(r_{gyrationH_i}, r_{gyrationV_i}\right)$

Governing radius of gyration

$$KLr_i := \left(\frac{K \cdot L_{cl\_cantilever_i}}{r_{gyration\_gov_i}}\right)$$

The below KLr values verify that all supports do not exceed the 200 recommended limitation

$KLr^T = (87.295)$

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified through classification)

$$F_{e_i} := \frac{\pi^2 E_{cl}}{\left(KLr_i\right)^2}$$

F_e is the elastic critical buckling stress (E3-4)

$$F_e^T = (37.559) \cdot ksi$$

Calculating the variables Limit, Op1, and Op2 to be utilized in logic to determine flexural buckling stress.

$$Limit := 4.71 \cdot \sqrt{\frac{E_{cl}}{F_{y\_cl}}}$$

$$Limit = 139.625$$

$$Op1_i := \left(0.658^{\frac{F_{y\_cl}}{F_{e_i}}}\right) F_{y\_cl}$$

$$Op2_i := 0.877 \cdot F_{e_i}$$

Calculating the flexural buckling stress

$$F_{cr_i} := \begin{cases} Op1_i & \text{if } KLr_i \le Limit \quad \text{(E3-2)} \\ Op2_i & \text{if } KLr_i > Limit \quad \text{(E3-3)} \end{cases}$$

$$F_{cr}^T = (22.846) \cdot ksi$$

Results:

$$\phi P_{n\_SL_i} := 2 \cdot \phi_c \cdot F_{cr_i} \cdot A_{cl_i}$$

2 is included to account for both sides of clamp

$$\boxed{\phi P_{n\_SL}^T = (339.259) \cdot kip}$$

Design compressive strength

Shear, capacity of clamp's bolt [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$A_{cl\_bolt_i} := \pi \cdot \left(\frac{d_{cl\_bolt_i}}{2}\right)^2$$

Nominal unthreaded body area

$$A_{cl\_bolt\_ds_i} := 2 \cdot A_{cl\_bolt_i}$$

Applicable area for this case since the bolt is in double shear

Nominal shear stress in bearing type

$F_{nv\_cl\_bolt} := 24ksi$

connections (A307) [AISC, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment and includes an allowance for threads in the shear plane

$R_{nv\_cl\_bolt_i} := F_{nv\_cl\_bolt} \cdot A_{cl\_bolt\_ds_i}$

Nominal strength (R_n) (J3-1)

$\phi_{b\_sr} := 0.75$

Resistance factor

$\phi R_{nv\_cl\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_cl\_bolt_i}$

$\boxed{\phi R_{nv\_cl\_bolt}^{T} = (53.456) \cdot kip}$

Design shear strength

PLATES WELDED TO THREADED RODS

Compression, capacity of threaded rods [AISC, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

$\phi_c := 0.9$

Resistance factor for compression

E2. Slenderness Limitations and Effective Length

$K_{pl\_tr} := 2.0$

Effective length in accordance with C2.b1, [AISC, comm.C2 (Table C-C2.2) (case e) pg 16.1-240] Case e was chosen because the support was conservatively allowed to rotate at its base and translate at its top without rotation.

The Slenderness ratio KL/r should preferably not exceed 200

$$KLr_{pl\_tr_i} := \left(\frac{K_{pl\_tr} \cdot L_{pl\_tr_i}}{r_{gyration\_pl\_tr_i}} \right)$$

The below KLr values verify that all supports do not exceed the 200 recommended limitation

$KLr_{pl\_tr}^{T} = (89.6)$

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified through classification)

$$F_{e\_pl\_tr_i} := \frac{\pi^2 E_{pl\_tr}}{\left(KLr_{pl\_tr_i}\right)^2}$$

F_e is the elastic critical buckling stress (E3-4)

$F_{e\_pl\_tr}^{T} = (35.652) \cdot ksi$

Calculating the variables Limit, Op1, and Op2 to be utilized in logic to determine flexural buckling stress.

$$Limit := 4.71 \cdot \sqrt{\frac{E_{pl\_tr}}{F_{y\_pl\_tr}}} \qquad Op1_i := \left(0.658^{\frac{F_{y\_pl\_tr}}{F_{e\_pl\_tr_i}}}\right) F_{y\_pl\_tr} \qquad Op2_i := 0.877 \cdot F_{e\_pl\_tr_i}$$

$$Limit = 139.625 \qquad Op1 = (22.401) \cdot ksi \qquad Op2 = (31.267) \cdot ksi$$

Calculating the flexural buckling stress

$$F_{cr\_pl\_tr_i} := \begin{cases} Op1_i & \text{if } KLr_{pl\_tr_i} \le Limit \quad \text{(E3-2)} \\ Op2_i & \text{if } KLr_{pl\_tr_i} > Limit \quad \text{(E3-3)} \end{cases}$$

$$F_{cr\_pl\_tr}^{\ T} = (22.401) \cdot ksi$$

$$\phi P_{n\_pl\_tr_i} := \phi_c \cdot F_{cr\_pl\_tr_i} \cdot A_{tr\_minor_i}$$ Design compressive strength

$$\boxed{\phi P_{n\_pl\_tr}^{\ T} = (17.939) \cdot kip}$$

SUPPORT PIPE

Determine if support pipe is ***compact (1)***, ***non-compact (2)***, or ***slender (3)*** as defined in first paragraph of B4

B4. Classification of sections for local buckling (Table B4.1 Case 15)

$$D2t_{sp_i} := \frac{d_{sp\_od_i}}{t_{sp_i}} \qquad D2t_{sp}^{\ T} = (10.435)$$

Definition of λ_p and λ_r from Table B4.1 Case 15 (Circular hollow sections in uniform compression) to be applied in classification logic. λ_p is the separation point between a compact and non compact member. λ_r is separation point between a non compact and slender member. However, Table B4.1 Case 15 defines λ_p = NA because the only thing of concern is if the support is slender or non-slender, thus only if the classification is 3 do we apply slenderness considerations, otherwise we treat the member as not having slender elements.

$$\lambda_p := 0 \qquad \lambda_r := 0.11 \frac{E_{sp}}{F_{y\_sp}}$$

$$\text{Classification}_{sp_i} := \begin{cases} 1 & \text{if } D2t_{sp_i} \le \lambda_p \\ 2 & \text{if } \lambda_p < D2t_{sp_i} \le \lambda_r \\ 3 & \text{if } \lambda_r < D2t_{sp_i} \end{cases}$$

$$\text{Classification}_{sp}^{T} = (2)$$

Compression, capacity in pipe [AISC, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

$\phi_c := 0.9$ Resistance factor for compression

E2. Slenderness Limitations and Effective Length

$K_{sp} := 1.0$

Effective length in accordance with C2.b1, [AISC, comm.C2 (Table C-C2.2) (case d) pg 16.1-240] Case d was chosen because the support was allowed to rotate on both ends.

The Slenderness ratio KL/r should preferably not exceed 200

$$KLr_{sp_i} := \left(\frac{K_{sp} \cdot L_{sp_i}}{r_{gyration\_sp_i}}\right)$$

The below KLr values verify that all supports do not exceed the 200 recommended limitation

$$KLr_{sp}^{T} = (60.924)$$

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified through classification)

$$F_{e\_sp_i} := \frac{\pi^2 E_{sp}}{\left(KLr_{sp_i}\right)^2}$$

F_e is the elastic critical buckling stress (E3-4)

$$F_{e\_sp}^{T} = (77.111) \cdot \text{ksi}$$

Calculating the variables Limit, Op1, and Op2 to be utilized in logic to determine flexural buckling stress.

$$Limit := 4.71 \cdot \sqrt{\frac{E_{sp}}{F_{y\_sp}}} \qquad Op1_i := \left(0.658^{\frac{F_{y\_sp}}{F_{e\_sp_i}}}\right) F_{y\_sp} \qquad Op2_i := 0.877 \cdot F_{e\_sp_i}$$

$$Limit = 139.625$$

Calculating the flexural buckling stress

$$F_{cr\_sp_i} := \begin{cases} Op1_i & \text{if } KLr_{sp_i} \le Limit \\ Op2_i & \text{if } KLr_{sp_i} > Limit \end{cases}$$

(E3-2)

(E3-3)

$$F_{cr\_sp}^{T} = (27.588) \cdot ksi$$

$$\phi P_{n\_sp_i} := \phi_c \cdot F_{cr\_sp_i} \cdot A_{sp_i}$$ Design compressive strength

$$\boxed{\phi P_{n\_sp}^{T} = (39.479) \cdot kip}$$

WELDED BEAM ATTACHMENT

Shear, capacity of welded beam attachment bolt [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$A_{wba\_bolt_i} := \pi \cdot \left(\frac{d_{wba\_bolt_i}}{2}\right)^2$$ Nominal unthreaded body area

$$A_{wba\_bolt\_ds_i} := 2 \cdot A_{wba\_bolt_i}$$ Applicable area for this case since the bolt is in double shear

$$F_{nv\_wba\_bolt} := 24ksi$$ Nominal shear stress in bearing type connections (A307) [AISC, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment and includes an allowance for threads in the shear plane

$R_{nv\_wba\_bolt_i} := F_{nv\_wba\_bolt} \cdot A_{wba\_bolt\_ds_i}$ Nominal strength (R_n) (J3-1)

$\phi_{b\_sr} = 0.75$ Resistance factor

$\phi R_{nv\_wba\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_wba\_bolt_i}$

$\boxed{\phi R_{nv\_wba\_bolt}^{T} = (53.456) \cdot kip}$ Design shear strength

Capacities For Outward Loading

PIPE CLAMP

Tension, capacity of clamp [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$b_{cl_i} := 2\,t_{cl_i} + 0.63in$

$b_{cl}^{T} = (2.13)\ in$

$b_{eff\_cl_i} := \min\left(b_{cl_i}, a_{normal\_cl_i}\right)$

$b_{eff\_cl}^{T} = (2)\ in$

b_{eff} is an effective length calculated as (2t + 0.63in) which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$P_{n\_cl\_trp_i} := 2 \cdot \left(2\,t_{cl_i}\right) \cdot b_{eff\_cl_i} \cdot F_{u\_cl}$ Nominal axial strength (P_n) (D5-1)

$\phi_{n\_trp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_cl\_trp_i} := \phi_{n\_trp} \cdot P_{n\_cl\_trp_i}$

$\boxed{\phi P_{n\_cl\_trp}^{T} = (270) \cdot kip}$ Design tensile strength

(b) For shear rupture on the effective area:

$$A_{sf\_cl_i} := 2 \cdot \left(2\, t_{cl_i}\right) \cdot \left(a_{parrallel\_cl_i} + \frac{d_{cl\_bolt_i}}{2}\right)$$

$A_{sf\_cl}^{T} = (5.062)\ in^2$ Effective area

$P_{n\_cl\_srp_i} := 0.6 \cdot F_{u\_cl} \cdot A_{sf\_cl_i}$ Nominal axial strength (P_n) (D5-2)

$\phi_{n\_srp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_cl\_srp_i} := \phi_{n\_srp} \cdot P_{n\_cl\_srp_i}$

$\phi P_{n\_cl\_srp}^{T} = (136.687) \cdot kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_cl_i} := d_{cl\_bolt_i} \cdot \left(2\, t_{cl_i}\right)$ Projected bearing area in.^{2} (mm^2)

$R_{n\_cl\_bs_i} := 1.8 \cdot F_{y\_cl} \cdot A_{pd\_cl_i}$ Nominal bearing strength (J7-1)

$\phi := 0.75$ Resistance factor

$\phi R_{n\_cl\_bs_i} := \phi \cdot R_{n\_cl\_bs_i}$

$\phi R_{n\_cl\_bs}^{T} = (91.884) \cdot kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_cl_i} := A_{cl_i}$ Gross area

(a) For tensile yielding in the gross section:

$P_{n\_cl\_ty_i} := F_{y\_cl} \cdot A_{g\_cl_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$$\phi P_{n\_cl\_ty_i} := \phi_{t\_ty} \cdot P_{n\_cl\_ty_i}$$

$$\phi P_{n\_cl\_ty}^{T} = (245.025) \cdot kip$$ Design tensile strength

Shear, capacity of pipe clamp's bolt [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$A_{cl\_bolt_i} := \pi \cdot \left(\frac{d_{cl\_bolt_i}}{2}\right)^2$$ Nominal unthreaded body area

$$A_{cl\_bolt\_ds_i} := 2 \cdot A_{cl\_bolt_i}$$ Applicable area for this case since the bolt is in double shear

$$F_{nv\_cl\_bolt} := 24ksi$$ Nominal shear stress in bearing type connections (A307) [AISC, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment and includes an allowance for threads in the shear plane

$$R_{nv\_cl\_bolt_i} := F_{nv\_cl\_bolt} \cdot A_{cl\_bolt\_ds_i}$$ Nominal strength (R_n) (J3-1)

$$\phi_{b\_sr} := 0.75$$ Resistance factor

$$\phi R_{nv\_cl\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_cl\_bolt_i}$$

$$\phi R_{nv\_cl\_bolt}^{T} = (53.456) \cdot kip$$ Design shear strength

PLATES WELDED TO THREADED RODS

Tension, capacity of plates welded to threaded rods [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$b_{pl\_tr_i} := 2\,t_{pl\_tr_i} + 0.63in$

$b_{pl\_tr}{}^T = (2.13)\,in$

$b_{eff\_pl\_tr_i} := \min\left(b_{pl\_tr_i}, a_{normal\_pl\_tr_i}\right)$

$b_{eff\_pl\_tr}{}^T = (0.75)\,in$

b_{eff} is an effective length calculated as (2t + 0.63in) which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$P_{n\_pl\_tr\_trp_i} := 2 \cdot t_{pl\_tr_i} \cdot b_{eff\_pl\_tr_i} \cdot F_{u\_pl\_tr}$ — Nominal axial strength (P_n) (D5-1)

$\phi_{n\_trp} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_pl\_tr\_trp_i} := \phi_{n\_trp} \cdot P_{n\_pl\_tr\_trp_i}$

$\boxed{\phi P_{n\_pl\_tr\_trp}{}^T = (50.625) \cdot kip}$ — Design tensile strength

(b) For shear rupture on the effective area:

$A_{sf\_pl\_tr_i} := 2 \cdot t_{pl\_tr_i} \cdot \left(a_{parrallel\_pl\_tr_i} + \frac{d_{tr_i}}{2}\right)$

$A_{sf\_pl\_tr}{}^T = (2.438)\,in^2$ — Effective area

$P_{n\_pl\_tr\_srp_i} := 0.6 \cdot F_{u\_pl\_tr} \cdot A_{sf\_pl\_tr_i}$ — Nominal axial strength (P_n) (D5-2)

$\phi_{n\_srp} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_pl\_tr\_srp_i} := \phi_{n\_srp} \cdot P_{n\_pl\_tr\_srp_i}$

$\boxed{\phi P_{n\_pl\_tr\_srp}{}^T = (65.813) \cdot kip}$ — Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_pl\_tr_i} := d_{tr_i} \cdot t_{pl\_tr_i}$ — Projected bearing area in.^{2} (mm^2)

$R_{n\_pl\_tr\_bs_i} := 1.8 \cdot F_{y\_pl\_tr} \cdot A_{pd\_pl\_tr_i}$ — Nominal bearing strength (J7-1)

$\phi := 0.75$ — Resistance factor

$\phi R_{n\_pl\_tr\_bs_i} := \phi \cdot R_{n\_pl\_tr\_bs_i}$

$\boxed{\phi R_{n\_pl\_tr\_bs}{}^T = (41.766) \cdot kip}$ — Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_pl\_tr_i} := A_{pl\_tr_i}$ Gross area

(a) For tensile yielding in the gross section:

$P_{n\_pl\_tr\_ty_i} := F_{y\_pl\_tr} \cdot A_{g\_pl\_tr_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_pl\_tr\_ty_i} := \phi_{t\_ty} \cdot P_{n\_pl\_tr\_ty_i}$

$\boxed{\phi P_{n\_pl\_tr\_ty}^{T} = (66.825) \cdot kip}$ Design tensile strength

Tension, capacity of weld between plates and threaded rods [AISC, Ch. J pg 16.1-90 thru 121]

J2. Welds

4. Strength

$\phi_{weld} := 0.75$ Resistance factor of weld

$$R_{n\_weld_i} := \phi_{weld} \cdot \left(F_{w\_transverse} \cdot A_{w\_traverse_i} + F_{w\_longitudinal} \cdot A_{w\_longitudinal_i}\right) \quad \text{(J2-4)}$$

$\boxed{R_{n\_weld} = (89.438) \cdot kip}$ Nominal shear strength of weld

Tension, capacity of threaded rods [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$A_{b\_tr_i} := \pi \cdot \left(\frac{d_{tr_i}}{2}\right)^2$ Nominal unthreaded body area

$F_{nt\_tr} := 45ksi$ Nominal tensile stress (A307) [AISC, Table J3.2] [AISC, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment

$R_{nt\_tr_i} := F_{nt\_tr} \cdot A_{b\_tr_i}$ Nominal strength (R_n) (J3-1)

$\phi_{b\_tr} := 0.75$ Resistance factor

$\phi R_{nt\_tr_i} := \phi_{b\_tr} \cdot R_{nt\_tr_i}$

$\boxed{\phi R_{nt\_tr}^{T} = (41.417) \cdot kip}$ Design tension strength

SUPPORT PIPE

Tension, capacity of support pipe [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_sp_i} := A_{sp_i}$ Gross area

2. Net Area

$A_{net\_sp_i} := A_{sp_i}$ Net area

3. Effective Net Area

$U_{sp} := 1.0$ Shear Lag Factor [AISC, Table D3.1]

$A_{e\_sp_i} := A_{net\_sp_i} \cdot U_{sp}$ Effective net area

(a) For tensile yielding in the gross section:

$P_{n\_sp\_ty_i} := F_{y\_sp} \cdot A_{g\_sp_i}$ Nominal axial strength (P_n)

$\phi_{ty} := 0.9$ Resistance factor for tension yielding (ϕ_{ty})

$\phi P_{n\_sp\_ty_i} := \phi_{ty} \cdot P_{n\_sp\_ty_i}$ Design tensile yielding strength

$\boxed{\phi P_{n\_sp\_ty} = (47.223) \cdot kip}$

(b) For tensile rupture in net section:

$P_{n\_sp\_tr_i} := F_{u\_sp} \cdot A_{e\_sp_i}$ Nominal axial strength (P_n)

$\phi_{tr} := 0.75$ Resistance factor for tension rupture (ϕ_{tr})

$\phi P_{n\_sp\_tr_i} := \phi_{tr} \cdot P_{n\_sp\_tr_i}$ Design tensile rupture strength

$\boxed{\phi P_{n\_sp\_tr} = (71.55) \cdot kip}$

WELDED BEAM ATTACHMENT

Tension, capacity of welded beam attachment [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$b_i := 2\,t_{wba_i} + 0.63in$

$b^T = (3.13)\,in$

$b_{eff_i} := \min\left(b_i, a_{normal\_wba_i}\right)$

$b_{eff}^T = (1.25)\,in$

b_{eff} is an effective length calculated as (2t + 0.63in) which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$P_{n\_wba\_trp_i} := 2 \cdot t_{wba_i} \cdot b_{eff_i} \cdot F_{u\_wba}$ Nominal axial strength (P_n) (D5-1)

$\phi_{n\_trp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_wba\_trp_i} := \phi_{n\_trp} \cdot P_{n\_wba\_trp_i}$

$\boxed{\phi P_{n\_wba\_trp}^T = (140.625) \cdot kip}$ Design tensile strength

(b) For shear rupture on the effective area:

$$A_{sf\_wba_i} := 2 \cdot t_{wba_i} \cdot \left(a_{parrallel\_wba_i} + \frac{d_{wba\_bolt_i}}{2} \right)$$

$A_{sf\_wba}{}^T = (4.844)\,in^2$ Effective area

$P_{n\_wba\_srp_i} := 0.6 \cdot F_{u\_wba} \cdot A_{sf\_wba_i}$ Nominal axial strength (P_n) (D5-2)

$\phi_{n\_srp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_wba\_srp_i} := \phi_{n\_srp} \cdot P_{n\_wba\_srp_i}$

$\phi P_{n\_wba\_srp}{}^T = (130.781) \cdot kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_wba_i} := d_{wba\_bolt_i} \cdot t_{wba_i}$ Projected bearing area in.^{2} (mm^2)

$R_{n\_wba\_bs_i} := 1.8 \cdot F_{y\_wba} \cdot A_{pd\_wba_i}$ Nominal bearing strength (J7-1)

$\phi := 0.75$ Resistance factor

$\phi R_{n\_wba\_bs_i} := \phi \cdot R_{n\_wba\_bs_i}$

$\phi R_{n\_wba\_bs}{}^T = (76.57) \cdot kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_wba_i} := A_{wba_i}$ Gross area

(a) For tensile yielding in the gross section:

$P_{n\_wba\_ty_i} := F_{y\_wba} \cdot A_{g\_wba_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_wba\_ty_i} := \phi_{t\_ty} \cdot P_{n\_wba\_ty_i}$

$\boxed{\phi P_{n\_wba\_ty}^T = (148.5) \cdot kip}$ Design tensile strength

Shear, capacity of welded beam attachment bolt [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$A_{wba\_bolt_i} := \pi \cdot \left(\frac{d_{wba\_bolt_i}}{2}\right)^2$ Nominal unthreaded body area

$A_{wba\_bolt\_ds_i} := 2 \cdot A_{wba\_bolt_i}$ Applicable area for this case since the bolt is in double shear

$F_{nv\_wba\_bolt} := 24ksi$ Nominal shear stress in bearing type connections (A307) [AISC, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment and includes an allowance for threads in the shear plane

$R_{nv\_wba\_bolt_i} := F_{nv\_wba\_bolt} \cdot A_{wba\_bolt\_ds_i}$ Nominal strength (R_n) (J3-1)

$\phi_{b\_sr} = 0.75$ Resistance factor

$\phi R_{nv\_wba\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_wba\_bolt_i}$

$\boxed{\phi R_{nv\_wba\_bolt}^T = (53.456) \cdot kip}$ Design shear strength

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Performer: A L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

SUMMARY OF RESULTS

Capacities For Inward Loading

PIPE CLAMP

Compression, capacity of clamp's cantilever section [AISC, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

E2. Slenderness Limitations and Effective Length

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified through classification)

$$\phi P_{n\_SL}{}^{T} = (339.259) \cdot kip$$

Design compressive strength

Shear, capacity of clamp's bolt [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$\phi R_{nv\_cl\_bolt}{}^{T} = (53.456) \cdot kip$$

Design shear strength

PLATES WELDED TO THREADED RODS

Compression, capacity of threaded rods [AISC, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

E2. Slenderness Limitations and Effective Length

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified through classification)

$$\phi P_{n\_pl\_tr}{}^{T} = (17.939) \cdot kip$$

SUPPORT PIPE

Compression, capacity in pipe [AISC, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

E2. Slenderness Limitations and Effective Length

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified through classification)

$$\phi P_{n\_sp}{}^{T} = (39.479) \cdot kip$$

WELDED BEAM ATTACHMENT

Shear, capacity of welded beam attachment bolt [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$\phi R_{nv\_wba\_bolt}{}^{T} = (53.456) \cdot kip$ Design shear strength

Capacities For Outward Loading

PIPE CLAMP

Tension, capacity of clamp [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_cl\_trp}{}^{T} = (270) \cdot kip$ Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_cl\_srp}{}^{T} = (136.687) \cdot kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_cl\_bs}{}^{T} = (91.884) \cdot kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_cl\_ty}{}^{T} = (245.025) \cdot kip$ Design tensile strength

Shear, capacity of pipe clamp's bolt [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$\phi R_{nv\_cl\_bolt}{}^{T} = (53.456) \cdot kip$ Design shear strength

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Performer: A L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

PLATES WELDED TO THREADED RODS

Tension, capacity of plates welded to threaded rods [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_pl\_tr\_trp}{}^{T} = (50.625)\cdot kip$$ Design tensile strength

(b) For shear rupture on the effective area:

$$\phi P_{n\_pl\_tr\_srp}{}^{T} = (65.813)\cdot kip$$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\phi R_{n\_pl\_tr\_bs}{}^{T} = (41.766)\cdot kip$$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_pl\_tr\_ty}{}^{T} = (66.825)\cdot kip$$ Design tensile strength

Tension, capacity of weld between plates and threaded rods [AISC, Ch. J pg 16.1-90 thru 121]

J3. Welds

4. Strength

$$R_{n\_weld} = (89.438)\cdot kip$$ Nominal shear strength of weld

Tension, capacity of threaded rods [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nt\_tr}{}^{T} = (41.417)\cdot kip$$ Design tension strength

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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SUPPORT PIPE

Tension, capacity of support pipe [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_sp\_ty} = (47.223) \cdot kip$$

Design tensile yielding strength

(b) For tensile rupture in net section:

$$\phi P_{n\_sp\_tr} = (71.55) \cdot kip$$

Design tensile rupture strength

WELDED BEAM ATTACHMENT

Tension, capacity of welded beam attachment [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_wba\_trp}^{T} = (140.625) \cdot kip$$

Design tensile strength

(b) For shear rupture on the effective area:

$$\phi P_{n\_wba\_srp}^{T} = (130.781) \cdot kip$$

Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\phi R_{n\_wba\_bs}^{T} = (76.57) \cdot kip$$

Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_wba\_ty}^{T} = (148.5) \cdot kip$$

Design tensile strength

Shear, capacity of welded beam attachment bolt [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$\phi R_{nv\_wba\_bolt}^{T} = (53.456) \cdot kip$$

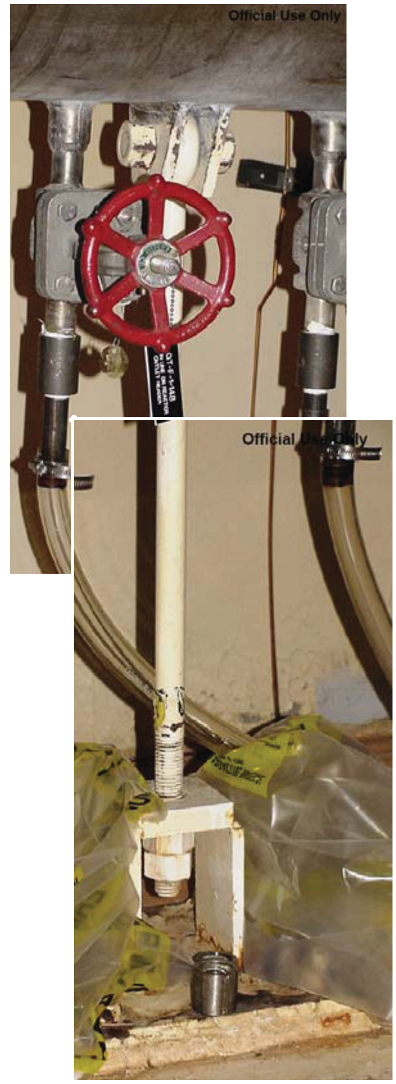
Design shear strength

Appendix D.9.8

PR-7 Capacities

PR-7 CAPACITY

The PR-7 support is composed of tee ears welded to the bottom of the forged tee joining lines 1-5 and 1-6 to 1-7. A bolt attaches the tee ears to an eye rod which is attached to a welded box structure that is fixed to the ground by four bolts and grout pad. The capacities for these components are calculated below, however, the capacity for the bolt fixating the box structure to the floor is found in the anchorage and embedment portions of this report.



Component Capacity Overview:

- Downward Loading:
  - Shear capacity of tee ears welds
  - Tension capacity of tee ears
  - Shear capacity of tee ears' upper bolt
  - Tension capacity of upper eye rod
  - Flexure capacity of welded box structure's upper section
  - Shear capacity of welded box structure's upper section
  - Shear capacity of welded box structure's upper welds
  - Tension capacity of welded box structure's side sections

(**Procedures from AISC 13th Edition (Applying LRFD)**)

References

1. ANSI/AISC 360-05, "Steel Construction Manual, 13th ed.," American Institute of Steel Construction, Inc., March 9, 2005
2. ITT Grinnell Catalog PH81, "Pipe Hangers," ITT Grinnell Corporation, 1981
3. Drawing 120925, "Primary Coolant System Pipe Hangers and Details," Rev 11, Lockheed Martin, April 1997
4. Drawing 120963, "Primary Coolant System Pipe Hangers," Rev 2, Ebasco Services Incorporated, April 1967

$i := 0$

Assigned indices corresponding to number of support types associated with these calculations

Support =	0
	(PR-8)

Relationship between support and corresponding indices

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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Geometric and Material Properties of Support Components

TEE EARS ([120963])

Material Properties of Tee Ears as Defined in the Material Section of this Report:

$F_{y\_te} := 33ksi$ — Yield Strength for A7 Carbon Steel

$F_{u\_te} := 60ksi$ — Ultimate Strength for A7 Carbon Steel

$E_{te} := 29000ksi$ — Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Tee Ears:

$$t_{te} := \left[2 \cdot \left(\frac{1}{2}in\right)\right]^T$$

Combined thickness of both plates forming the upper portion of the clamp, in. (mm) [120925, Sheet 2], [120963, Detail 52]

$$w_{te} := (3in)^T$$

Width of plates forming the ears conservatively chosen from supplied dimensions of trapezoidal form [120963, Detail 52]

$$A_{te_i} := t_{te_i} \cdot w_{te_i}$$

$$A_{te}^T = (3)\ in^2$$

Total cross sectional area of both sides of clamp

$$d_{te\_bolt} := \left(1\frac{1}{4}in\right)^T$$

Bolt diameter [120925, Sheet 2], [120963, Detail 52]

$$d_{te\_hole} := \left(1\frac{1}{4}in\right)^T$$

Nominal bolt hole Diameter [120963, Detail 52]

$$a_{parrallel\_te} := \left(1\frac{3}{8}in\right)^T$$

Shortest distance from edge of the pin hole to the edge of the member measured parallel to the direction of the force from top of bolt hole to top of clamp bracket, in. (mm) hand calculated from d_{cl_hole} and [120963, Detail 52] data

$$a_{normal\_te_i} := \frac{w_{te_i} - d_{te\_hole_i}}{2}$$

$$a_{normal\_te} = (0.875)\ in$$

Shortest distance from edge of pin hole to the edge of the member measured normal to the direction of the force

EYE ROD (Welded Eye Rod FIG 278 1-1/8" [120925, Sheet 2])

Material Properties of Eye Rod as Defined in the Material Section of this Report:

$F_{y\_I} := 33\text{ksi}$ — Yield Strength for A7 Carbon Steel

$F_{u\_I} := 60\text{ksi}$ — Ultimate Strength for A7 Carbon Steel

$E_I := 29000\text{ksi}$ — Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Eye Rod:

$$d_I := \left(1\frac{1}{8}\text{in}\right)^T$$

Unthreaded diameter of eye rod, [Grinnell, Fig 278 ph-52]

$$Z_{I_i} := \frac{\left(d_{I_i}\right)^3}{6}$$

Plastic section modulus about the axis of bending [AISC, Table 17-27 pg17-39]

$$r_{gyrationI_i} := \frac{d_{I_i}}{4}$$

Radius of gyration of combined rod

$$A_{I_i} := \pi \cdot \left(\frac{d_{I_i}}{2}\right)^2$$

Area of combined rod

$$L_{I_i} := 40\text{in}$$

Length of combined rod M1-1-5-N15-FSPG-DSC00090, [120931, Det 13]

WELDED BOX STRUCTURE ([120963])

Material Properties of Welded Box Structure as Defined in the Material Section of this Report:

$F_{y\_wbs} := 33\text{ksi}$ — Yield Strength for A7 Carbon Steel

$F_{u\_wbs} := 60\text{ksi}$ — Ultimate Strength for A7 Carbon Steel

$E\_wbs := 29000\text{ksi}$ — Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Welded Box Structure:

$$t_{wbs\_top} := (1\text{in})^T$$

Combined thickness of welded box structure's top portion [120963]

$$w_{wbs\_top} := (4\text{in})^T$$

Width and length of welded box structure's top portion [120963]

$$t_{wbs\_sides} := \left[2 \cdot \left(\frac{1}{2}\text{in}\right)\right]^T$$

Combined thickness of welded box structure sides [120963]

$w_{wbs\_sides} := (4in)^T$

Width of welded beam attachment [Grinnell, Fig 66 ph-33]

$A_{wbs\_sides_i} := t_{wbs\_sides_i} \cdot w_{wbs\_sides_i}$

$A_{wbs\_sides} = (4)\, in^2$

Cross sectional area of welded beam attachment

$F_{EXX} := 60ksi$

E6013 weld material ultimate strength [Specification S-10, pg I-9], [ATR-P-7]

$\theta_{transverse} := \frac{\pi}{2}$

Angle between loading and traverse welds

$F_{w\_transverse} := 0.60 \cdot F_{EXX} \cdot \left(1.0 + 0.5 \cdot \sin\left(\theta_{transverse}\right)^{1.5}\right)$ (J2-5)

$F_{w\_transverse} = 54 \cdot ksi$

Nominal Shear Strength of transverse welds

$\omega := \left(\frac{3}{16} in\right)^T$

Minimum size of fillet given that thinner joined part (plate) = 1/2" [AISC, Table J2.4, pg 16.1-96] [120923]

$L_{w\_traverse} := 2 \cdot w_{wbs\_top}$

Traverse length of welds [120923]

$A_{w\_traverse_i} := L_{w\_traverse_i} \cdot 0.707\, \omega_i$

$A_{w\_traverse} = (1.06)\, in^2$

Effective area of weld throat of traverse welds

Capacities For Upward Loading

TEE EARS

Tension, capacity of tee ears [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$b_{te_i} := 2\, t_{te_i} + 0.63in$

$b_{te}^T = (2.63)\, in$

$b_{eff\_te_i} := \min\left(b_{te_i}, a_{normal\_te_i}\right)$

$b_{eff\_te}^T = (0.875)\, in$

b_{eff} is an effective length calculated as (2t + 0.63in) which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$P_{n\_te\_trp_i} := 2 \cdot t_{te_i} \cdot b_{eff\_te_i} \cdot F_{u\_te}$ Nominal axial strength (P_n)

(D5-1)

$\phi_{n\_trp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_te\_trp_i} := \phi_{n\_trp} \cdot P_{n\_te\_trp_i}$

$\boxed{\phi P_{n\_te\_trp}^T = (78.75) \cdot kip}$ Design tensile strength

(b) For shear rupture on the effective area:

$A_{sf\_te_i} := 2 \cdot t_{te_i} \cdot \left(a_{parrallel\_te_i} + \frac{d_{te\_hole_i}}{2} \right)$

$A_{sf\_te}^T = (4)\, in^2$ Effective area

$P_{n\_te\_srp_i} := 0.6 \cdot F_{u\_te} \cdot A_{sf\_te_i}$ Nominal axial strength (P_n)

$\phi_{n\_srp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_te\_srp_i} := \phi_{n\_srp} \cdot P_{n\_te\_srp_i}$ (D5-2)

$\boxed{\phi P_{n\_te\_srp}^T = (108) \cdot kip}$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_te_i} := d_{te\_bolt_i} \cdot t_{te_i}$ Projected bearing area in.^{2} (mm^2)

$R_{n\_te\_bs_i} := 1.8 \cdot F_{y\_te} \cdot A_{pd\_te_i}$ Nominal bearing strength

$\phi := 0.75$ Resistance factor

$\phi R_{n\_te\_bs_i} := \phi \cdot R_{n\_te\_bs_i}$

$\boxed{\phi R_{n\_te\_bs}^T = (55.688) \cdot kip}$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_te_i} := A_{te_i}$ Gross area

(a) For tensile yielding in the gross section: (D3-1)

$P_{n\_te\_ty_i} := F_{y\_te} \cdot A_{g\_te_i}$ Nominal axial strength (P_n)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t) (D2-1)

$\phi P_{n\_te\_ty_i} := \phi_{t\_ty} \cdot P_{n\_te\_ty_i}$

$\boxed{\phi P_{n\_te\_ty}^T = (89.1) \cdot kip}$ Design tensile strength

Shear, capacity of tee ear's upper bolt [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$A_{te\_bolt_i} := \pi \cdot \left(\frac{d_{te\_bolt_i}}{2}\right)^2$ Nominal unthreaded body area

$A_{te\_bolt\_ds_i} := 2 \cdot A_{te\_bolt_i}$ Applicable area for this case since the bolt is in double shear

$F_{nv\_te\_bolt} := 24ksi$ Nominal shear stress in bearing type connections (A307) [AISC, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment and includes an allowance for threads in shear plane

$R_{nv\_te\_bolt_i} := F_{nv\_te\_bolt} \cdot A_{te\_bolt\_ds_i}$ Nominal strength (R_n) (J3-1)

$\phi_{b\_sr} := 0.75$ Resistance factor

$\phi R_{nv\_te\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_te\_bolt_i}$

$\boxed{\phi R_{nv\_te\_bolt}^T = (44.179) \cdot kip}$ Design shear strength

EYE ROD

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NOTE:It was observed during inspection that all of the applicable eye rods have welded eyes even though they indicate otherwise on Drawing 120925, thus all eye rods in these calculations will be treated as welded eye rods

Tension, capacity of lower eye rod [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$A_{b\_I_i} := \pi \cdot \left(\frac{d_{I_i}}{2}\right)^2$$ Nominal unthreaded body area

$$F_{nt\_I} := 45ksi$$ Nominal tensile stress (A307) [AISC, Table J3.2] [AISC, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment

$$R_{nt\_I_i} := F_{nt\_I} \cdot A_{b\_I_i}$$ Nominal strength (R_n) (J3-1)

$$\phi_{b\_tr} := 0.75$$ Resistance factor

$$\phi R_{nt\_I_i} := \phi_{b\_tr} \cdot R_{nt\_I_i}$$

$$\phi R_{nt\_I}^{T} = (33.548) \cdot kip$$ Design tension strength

WELDED BOX STRUCTURE

Shear, capacity of welded box structure's upper section [AISC, Ch. G pg 16.1-64 thru 69]

G7. Weak Axis Shear in Singly and Doubly Symmetric Shapes

For singly and doubly symmetric shapes loaded in the weak axis without torsion, the nominal shear strength, V_n, for each shear resisting element shall be determined using Equation G2-1 and Section G2.1(b) with $A_w = b_f t_f$ and kV = 1.2.

$$C_v := 1.0$$ Web shear coefficient [AISC, pg16.1-291]

$$A_{w\_wbs} := 2 \cdot t_{wbs\_top} \cdot w_{wbs\_top}$$ Cross sectional area of top portion of welded box structure, 2 is included to account for double shear

$$V_{n\_wbs} := 0.6 \cdot F_{y\_wbs} \cdot A_{w\_wbs} \cdot C_v$$ Nominal shear (G2-1)

$$\phi_v := 1.00$$ Resistance factor

$$\phi V_{n\_wbs} := \phi_v \cdot V_{n\_wbs}$$

$$\phi V_{n\_wbs} = 158.4 \cdot kip$$ Design shear strength

Shear, capacity of welded box structure's upper welds [AISC, Ch. J pg 16.1-90 thru 121]

J2. Welds

4. Strength

$\phi_{weld} := 0.75$ Resistance factor of weld

$R_{n\_weld_i} := \phi_{weld} \cdot \left(F_{w\_transverse} \cdot A_{w\_traverse_i}\right)$ (J2-4)

$R_{n\_weld} = (42.95) \cdot kip$ Nominal shear strength of weld

Tension, capacity of welded box structure's side sections [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D2. Tensile Strength

Must solve for applicable areas presented in D3 prior to proceeding through D2

D3. Area Determination

1. Gross Area

The gross area, A_g, of a member is the total cross-sectional area

$A_{g\_wbs} := 2 \cdot w_{wbs\_sides} \cdot t_{wbs\_sides}$ Gross area

2. Net Area

$A_{n\_wbs} := A_{g\_wbs}$ Net area

3. Effective Net Area

$U := 1$ The shear lag factor

$A_{e\_wbs} := U \cdot A_{n\_wbs}$ The effective area

(a) For tensile yielding in the gross section:

$P_{n\_ty\_wbs_i} := F_{y\_wbs} \cdot A_{g\_wbs}$

$\phi_{n\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_ty\_wbs_i} := \phi_{n\_ty} \cdot P_{n\_ty\_wbs_i}$

$\phi P_{n\_ty\_wbs}^{T} = (237.6) \cdot kip$ Design tensile strength (D2-1)

(b) For tensile rupture in the net section:

$P_{n\_tr\_wbs_i} := F_{u\_wbs} \cdot A_{e\_wbs}$

$\phi_{n\_tr} := 0.75$ Resistance factor for tension (ϕ_t)

$$\phi P_{n\_tr\_wbs_i} := \phi_{n\_tr} \cdot P_{n\_tr\_wbs_i}$$

$$\phi P_{n\_tr\_wbs}^{T} = (360) \cdot kip$$

Design tensile strength (D5-1)

Capacities for Downward Loading

Compression, capacity in rod hangers [AISC, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

$$\phi_c := 0.9$$

Resistance factor for compression

E2. Slenderness Limitations and Effective Length

$$K := 1.0$$

Effective length in accordance with C2.b1, [AISC, comm.C2 (Table C-C2.2) (case d) pg 16.1-240] Case d was chosen because the support was allowed to rotate on the top as well as on the bottom.

The Slenderness ratio KL/r should preferably not exceed 200

$$KLr_i := \left(\frac{K \cdot L_{I_i}}{r_{gyrationI_i}}\right)$$

The below KLr values verify that all supports do not exceed the 200 recommended limitation

$$KLr^{T} = (142.222)$$

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified through classification)

$$F_{e_i} := \frac{\pi^2 E_I}{\left(KLr_i\right)^2}$$

F_e is the elastic critical buckling stress (E3-4)

$$F_e^{T} = (14.15) \cdot ksi$$

Calculating the variables Limit, Op1, and Op2 to be utilized in logic to determine flexural buckling stress.

$$Limit := 4.71 \cdot \sqrt{\frac{E_I}{F_{y\_I}}} \qquad Op1_i := \left(0.658^{\frac{F_{y\_I}}{F_{e_i}}}\right) F_{y\_I} \qquad Op2_i := 0.877 \cdot F_{e_i}$$

$$Limit = 139.625$$

Calculating the flexural buckling stress

$$F_{cr_i} := \begin{cases} Op1_i & \text{if } KLr_i \le Limit \\ Op2_i & \text{if } KLr_i > Limit \end{cases}$$ (E3-2) (E3-3)

$$F_{cr}^{T} = (12.41) \cdot ksi$$

$$\phi P_{n_i} := \phi_c \cdot F_{cr_i} \cdot A_{I_i}$$ Design compressive strength

$$\boxed{\phi P_n^{T} = (11.102) \cdot kip}$$

SUMMARY OF RESULTS

Capacities For Upward Loading

TEE EARS

Tension, capacity of tee ears [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\boxed{\phi P_{n\_te\_trp}^{T} = (78.75) \cdot kip}$$ Design tensile strength

(b) For shear rupture on the effective area:

$$\boxed{\phi P_{n\_te\_srp}^{T} = (108) \cdot kip}$$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\boxed{\phi R_{n\_te\_bs}^{T} = (55.688) \cdot kip}$$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\boxed{\phi P_{n\_te\_ty}^{T} = (89.1) \cdot kip}$$ Design tensile strength

Shear, capacity of tee ear's upper bolt [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nv\_te\_bolt}{}^{T} = (44.179)\cdot kip$$ Design shear strength

EYE ROD

Tension, capacity of lower eye rod [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nt\_l}{}^{T} = (33.548)\cdot kip$$ Design tension strength

WELDED BOX STRUCTURE

Shear, capacity of welded box structure's upper section [AISC, Ch. G pg 16.1-64 thru 69]

G7. Weak Axis Shear in Singly and Doubly Symmetric Shapes

$$\phi V_{n\_wbs} = 158.4\cdot kip$$ Design shear strength

Shear, capacity of welded box structure's upper welds [AISC, Ch. J pg 16.1-90 thru 121]

J2. Welds

4. Strength

$$R_{n\_weld} = (42.95)\cdot kip$$ Nominal shear strength of weld

Tension, capacity of welded box structure's side sections [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_ty\_wbs}{}^{T} = (237.6)\cdot kip$$ Design tensile strength

(b) For tensile rupture in the net section:

$$\phi P_{n\_tr\_wbs}{}^{T} = (360)\cdot kip$$ Design tensile strength

Capacities for Downward Loading

Compression, capacity in rod hangers [AISC, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

E2. Slenderness Limitations and Effective Length

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified through classification)

$\phi P_n{}^T = (11.102) \cdot kip$ Design compressive strength

Appendix D.9.9

PS-19 Capacities

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Performer: A L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

PS-19 CAPACITY

The PS-19 supports a horizontal PCS pipe traveling in the east/west direction. The PS-19 support is comprised of a u-bolt, plate, and two channel iron sections welded together. The capacities for these components are calculated below, however, the capacity for the welds attaching the angle iron and the associated capacities of the wall embedment are found in the anchorage and embedment portions of this report.

Component Capacity Overview:

- Southward Loading:
- Compression capacity of channel iron sections

- Northward Loading:
- Tension capacity of channel iron sections
- Tension capacity of u-bolt

- Lateral (Downward/Upward) Loading:
- Flexure capacity of channel iron section
- Shear capacity of channel iron section
- Lateral capacity of u-bolt

(**Procedures from AISC 13th Edition (Applying LRFD)**)

References

1. ANSI/AISC 360-05, "Steel Construction Manual, 13th ed.," American Institute of Steel Construction, Inc., March 9, 2005
2. R. F. Davidson, "ATR Primary Coolant System Piping Design Analysis", EG&G Idaho, Inc., Jan. 22, 1979
3. Brian Hawkes, "Allowable Loads for U-bolts," Revision 0, Oct. 13, 1997
4. Drawing 127029, Spool Drawing (Line 1-42), The Fluor Corporation, LTD., June 19, 1962
5. ITT Grinnell Catalog PH81, "Pipe Hangers," ITT Grinnell Corporation, 1981
6. James M. Gere, *Mechanics of Materials, 5th ed.,* Thomson Learning (Brooks/Cole Division), 2001

NOTE: For compressive and flexural loading the welded channel iron section are approximated as a rectangular HSS section with conservative dimensions.

$i := 0$

Assigned indices corresponding to number of support types associated with these calculations

Support =	0
	(PS-19)

Relationship between support and corresponding indices

Geometric and Material Properties of Support Components

CHANNEL IRON SECTIONS

Material Properties of Channel Iron Section as Defined in the Material Section of this Report:

$F_{y\_Ch} := 33ksi$ Yield Strength for A7 Carbon Steel

$F_{u\_Ch} := 60ksi$ Ultimate Strength for A7 Carbon Steel

$E_{Ch} := 29000ksi$ Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Channel Iron Sections:

Since the channel iron sections are welded together they will be treated as one rectangular HSS section with wall thickness closest but not exceeding the minimum thickness of either the flange or web. In this case the closest conservative rectangular HSS section is a 4x3x5/16 HSS.

$t_{HSS} := (0.291in)^T$ Thickness of HSS [AISC, Table 1-11, pg 1-86], [120944, Detail 38]

$h_{HSS} := (4in)^T$ Height of HSS [AISC, Table 1-11, pg 1-86], [120944, Detail 38]

$w_{HSS} := (3in)^T$ Width of HSS [AISC, Table 1-11, pg 1-86], [120944, Detail 38] *(this is a conservative length compared to that provided by [120944, Detail 38])*

$A_{HSS} := \left(3.52in^2\right)^T$ Area of HSS [AISC, Table 1-11, pg 1-86], [120944, Detail 38]

$r_{gyrationX\_HSS} := (1.42in)^T$ Radius of gyration about x axis [AISC, Table 1-11, pg 1-86], [120944, Detail 38]

$r_{gyrationY\_HSS} := (1.13in)^T$ Radius of gyration about y axis [AISC, Table 1-11, pg 1-86], [120944, Detail 38]

$I_{X\_HSS} := \left(7.14in^4\right)^T$ Moment of inertia about x axis [AISC, Table 1-11, pg 1-86], [120944, Detail 38]

$L_{Ch} := \left(21\frac{1}{2}in\right)^T$ Length of channel iron sections [120944, Detail 38]

$Z_{X\_Ch} := \left(2.84in^3\right)^T$ Plastic modulus about the x axis

$t_{Ch\_web} := (0.321in)^T$ Thickness of channel iron section web [AISC, Table 1-5, pg 1-34], [120963, Detail 29]

$t_{Ch\_flange} := (0.296in)^T$ Thickness of channel iron section flange [AISC, Table 1-5, pg 1-34], [120963, Detail 29]

$w_{Ch\_flange} := (1.72in)^T$ — Width of upper portion of angle iron [AISC, Table 1-5, pg 1-34], [120963, Detail 29]

$depth_{Ch} := (4in)^T$ — Depth of channel iron sections [AISC, Table 1-5, pg 1-34], [120963, Detail 29]

$h_{Ch\_web} := (2.5in)^T$ — Height of channel iron web [AISC, Table 1-5, pg 1-34], [120963, Detail 29]

$b2t_{Ch_i} := \frac{h_{Ch\_web_i}}{t_{Ch\_web_i}}$ — Web height to thickness ratio

$b2t_{Ch} = (7.788)$

$A_{Ch} := \left(2.13in^2\right)^T$ — Area of channel iron sections [AISC, Table 1-5, pg 1-34], [120963, Detail 29]

$r_{gyrationX\_Ch} := (1.47in)^T$ — Radius of gyration of channel iron sections about their horizontal axis [AISC, Table 1-5, pg 1-34], [120963, Detail 29]

$r_{gyrationY\_Ch} := (0.447in)^T$ — Radius of gyration of channel iron sections about their vertical axis [AISC, Table 1-5, pg 1-34], [120963, Detail 29]

$Z_{x\_Ch} := \left(2.84in^3\right)^T$ — Plastic section modulus about the x-axis [AISC, Table 1-5, pg 1-34], [120963, Detail 29]

$S_{x\_Ch} := \left(2.29in^3\right)^T$ — Elastic section modulus about the x-axis [AISC, Table 1-5, pg 1-34], [120963, Detail 29]

$I_{y\_Ch} := \left(0.425in^4\right)^T$ — Moment of inertia about y axis [AISC, Table 1-5, pg 1-34], [120963, Detail 29

U-BOLT (U-Bolt 6")

Note: In this analysis the tensile capacity of the u-bolt will be calculated based on the cross sectional area of both u-bolt legs straddling the pipe. Due to the complexity of u-bolt behavior given lateral loading, the associated capacity was determined based on the [Hawkes] document, where the lateral capacity was shown to be 0.0412 that of the u-bolt's tensile capacity. Given that the resistance factor is equivalent for both tension and shear (ϕ = 0.75) is was determined that the AISC resistance factors would be appropriately applied by multiplying the resulting tensile capacity by the 0.0412 factor stated above.

Material Properties of U-bolt as Defined in the Material Section of this Report:

$F_{y\_ub} := 33ksi$ — Yield Strength for A7 Carbon Steel

$F_{u\_ub} := 60ksi$ — Ultimate Strength for A7 Carbon Steel

$E_{ub} := 29000ksi$ — Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of U-bolt:

$D_{ub} := \left(6\frac{5}{8}in\right)^T$ — Diameter of pipe which the u-bolt supports [127029], [Grinnell, Fig 137 ph-55]

$d_{ub} := \left(\frac{1}{2}in\right)^T$ — Diameter of u-bolt rod [127029], [Grinnell, Fig 137 ph-55]

Capacities For Southward Loading

CHANNEL IRON SECTION

Compression, capacity of channel iron sections [AISC, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

$\phi_c := 0.9$ — Resistance factor for compression

E2. Slenderness Limitations and Effective Length

$K := 2.1$ — Design K value [Table C-C2.2, pg 16.1-240]

$r_{gyration\_gov_i} := \min\left(r_{gyrationX\_HSS_i}, r_{gyrationY\_HSS_i}\right)$ — Governing radius of gyration

$$KLr_i := \frac{K \cdot L_{Ch_i}}{r_{gyration\_gov_i}}$$

$KLr = (39.956)$

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements

Determine if each channel iron section are ***compact (1), non-compact (2),*** *or* ***slender (3)*** *to determine if it is appropriate to apply E3 or E7*

B4. Classification of sections for local buckling (See Case 14 of Table B4.1)

$$b2t_i := \frac{h_{Ch\_web_i}}{t_{Ch\_web_i}}$$

Width to thickness ratio

$$b2t^T = (7.788)$$

Definition of λ_p and λ_r from Table B4.1 Case 6 (Flexure in legs of single angles) to be applied in classification logic. λ_p is the separation point between a compact and noncompact member. λ_r is separation point between a noncompact and slender member.

$$\lambda_p := 0 \cdot \sqrt{\frac{E_{Ch}}{F_{y\_Ch}}} \qquad \lambda_r := 1.49 \cdot \sqrt{\frac{E_{Ch}}{F_{y\_Ch}}}$$

$$Classification_i := \begin{cases} 1 & \text{if } b2t_i \le \lambda_p \\ 2 & \text{if } \lambda_p < b2t_i \le \lambda_r \\ 3 & \text{if } \lambda_r < b2t_i \end{cases}$$

$$Classification^T = (2)$$

Since the channel iron sections are determined to be compact E3 is applicable (however it is to be noted that this will be applied with the channel iron section approximated as a rectangular HSS since the two sections are welded together.

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified through classificatic

$$F_{e_i} := \frac{\pi^2 E_{Ch}}{\left(KLr_i\right)^2}$$

F_e is the elastic critical buckling stress (E3-4)

$$F_e^T = (179.283) \cdot ksi$$

Calculating the variables Limit, Op1, and Op2 to be utilized in logic to determine flexural buckling stress.

$$Limit := 4.71 \cdot \sqrt{\frac{E_{Ch}}{F_{y\_Ch}}} \qquad Op1_i := \left(0.658^{\frac{F_{y\_Ch}}{F_{e_i}}}\right) F_{y\_Ch} \qquad Op2_i := 0.877 \cdot F_{e_i}$$

$$Limit = 139.625$$

$$F_{cr_i} := \begin{cases} Op1_i & \text{if } KLr_i \le Limit \\ Op2_i & \text{if } KLr_i > Limit \end{cases}$$ (E3-2) (E3-3)

F_{cr} is the flexural buckling stress

$$F_{cr}^{T} = (30.553)\cdot ksi$$

$$\phi P_{n\_SL_i} := \phi_c \cdot F_{cr_i} \cdot A_{HSS_i}$$

$$\boxed{\phi P_{n\_SL}^{T} = (96.792)\cdot kip}$$ Design compressive strength

Capacities For Northward Loading

ANGLE IRON SECTION

Tension, capacity of channel iron section [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D2. Tensile Strength

Must apply section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$$A_{g\_Ch_i} := 2\cdot A_{Ch_i}$$ Gross area

2. Net Area

$$A_{n\_Ch_i} := A_{g\_Ch_i}$$ Net area

3. Effective Net Area

$$U_{Ch} := 1.0$$ Shear lag factor [AISC, Table D3.1 pg 16.1-29]

$$A_{e\_Ch_i} := A_{n\_Ch_i} \cdot U_{Ch}$$ Effective net area (D3-1)

(a) For tensile yielding in the gross section:

$$P_{n\_Ch\_ty} := F_{y\_Ch} \cdot A_{g\_Ch}$$ Nominal axial strength (P_n) (D2-1)

$$\phi_{t\_ty} := 0.9$$ Resistance factor for tension (ϕ_t)

$$\phi P_{n\_Ch\_ty\_NL} := \phi_{t\_ty} \cdot P_{n\_Ch\_ty}$$

$$\boxed{\phi P_{n\_Ch\_ty\_NL}^{T} = (126.522)\cdot kip}$$ Design tensile strength

(b) For tensile rupture in the net section:

$P_{n\_Ch\_tr} := F_{u\_Ch} \cdot A_{e\_Ch}$ — Nominal axial strength (P_n) (D2-2)

$\phi_{t\_tr} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_Ch\_tr\_NL} := \phi_{t\_tr} \cdot P_{n\_Ch\_tr}$

$\boxed{\phi P_{n\_Ch\_tr\_NL}^{\,T} = (191.7) \cdot kip}$ — Design tensile strength

U-BOLT

Tension, capacity of u-bolt [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$A_{ub_i} := 2 \cdot \left[\pi \cdot \left(\frac{d_{ub_i}}{2}\right)^2\right]$$

Nominal unthreaded body area for BOTH bolts in combination

$F_{nv\_ub} := 45ksi$ — Nominal tensile stress (A307) [AISC, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment

$R_{nv\_ub_i} := F_{nv\_ub} \cdot A_{ub_i}$ — Nominal strength (R_n) (J3-1)

$\phi_{b\_sr} := 0.75$ — Resistance factor

$\phi R_{nv\_ub\_NL_i} := \phi_{b\_sr} \cdot R_{nv\_ub_i}$

$\boxed{\phi R_{nv\_ub\_NL}^{\,T} = (13.254) \cdot kip}$ — Design tensile strength

Capacities For Lateral (Upward/Downward) Loading

RECTANGULAR HSS

Flexure, capacity of horizontal rectangular HSS [AISC, Ch. F pg 16.1-44 thru 63]

F1. General Provisions

Given resistance factor for shear

$\phi_b := 0.9$

Calculate the lateral-torsional buckling modification factor for a nonuniform moment loading on the beam cau by eastward loading of the pipe

$M_{max}(F, Length) := F \cdot Length$ — Absolute value of maximum moment in the unbraced segment

$M_A(F, Length) := \frac{3}{4} \cdot F \cdot Length$ Absolute value of moment at quarter point of the unbraced segment

$M_B(F, Length) := \frac{1}{2} \cdot F \cdot Length$ Absolute value of moment at centerline of the unbraced segment

$M_C(F, Length) := \frac{1}{4} \cdot F \cdot Length$ Absolute value of moment at three-quarter point of the unbraced segment

$R_m := 1.0$ Cross-section monosymmetry parameter (value of 1.0 is assigned because it correlates to singly symmetric members subjected to single curvature bending)

$$C_b(F, Length) := \left(\frac{12.5 \cdot M_{max}(F, Length)}{2.5 \cdot M_{max}(F, Length) + 3 \cdot M_A(F, Length) + 4 \cdot M_B(F, Length) + 3 \cdot M_C(F, Length)} \cdot R_m \right)$$

$$C_b\left(F, L_{Angle_i}\right) \rightarrow 1.6666666666666666667$$

F7. Square and Rectangular HSS and Box-Shaped Members

1. Yielding

$M_{py\_Ch\_EL_i} := F_{y\_Ch} \cdot Z_{x\_Ch_i}$

$M_{ny\_Ch\_EL_i} := M_{py\_Ch\_EL_i}$ Nominal flexural strength

$\phi M_{ny\_Ch\_EL_i} := \phi_b \cdot M_{ny\_Ch\_EL_i}$

$\boxed{\phi M_{ny\_Ch\_EL}^T = (84.348) \cdot kip \cdot in}$ Design flexural strength

$$\phi F_{ny\_Ch\_EL\_Tot_i} := \frac{\phi M_{ny\_Ch\_EL_i}}{L_{Ch_i}}$$

Converting flexural strength to strength at applied load by dividing the design flexural strength by the moment arm comprised of the angle iron length, the leg length of the horizontal angle iron section, and the radius of the pipe which the clamp is connected to

$\boxed{\phi F_{ny\_Ch\_EL\_Tot}^T = (3.923) \cdot kip}$ Total design strength of angle iron section given flexural loading

Determine if supports are ***compact (1)***, ***non-compact (2)***, or ***slender (3)*** as defined in first paragraph of B4

B4. Classification of sections for local buckling (Table B4.1 Case 13)

Definition of λ_p and λ_r from Table B4.1 Case 13 to be applied in classification logic. λ_p is the separation point between a compact and non compact member. λ_r is separation point between a non compact and slender member.

$$\lambda_p := 2.42 \cdot \sqrt{\frac{E_{Ch}}{F_{y\_Ch}}} \qquad \lambda_r := 5.70 \sqrt{\frac{E_{Ch}}{F_{y\_Ch}}}$$

$$Classification_i := \begin{cases} 1 & \text{if } b2t_{Ch_i} \le \lambda_p \\ 2 & \text{if } \lambda_p < b2t_{Ch_i} \le \lambda_r \\ 3 & \text{if } \lambda_r < b2t_{Ch_i} \end{cases} \qquad \text{(F10-1)}$$

$$Classification^T = (1)$$

The rectangular HSS has been determined to be compact in flexure

2. Flange Local Buckling

(a) For compact sections, the limit state of flange local buckling does not apply

3. Web Local Buckling

(a) For compact sections, the limit state of web local buckling does not apply

Shear, capacity of horizontal rectangular HSS [AISC, Ch. G pg 16.1-64 thru 69]

G1. General Provisions

$\phi_v := 0.9$ Resistance factor for shear

G5. Rectangular HSS and Box Members

The nominal shear strength, V_n, of rectangular HSS and box members shall be determined using the provisions of Section G2.1 with A_w = 2ht where h for the width resisting the shear force shall be taken as the clear distance between the flanges less the inside corner radius on each side and t_w = t and k_v = 5. If the corner radius is not known, h shall be taken as the corresponding outside dimension minus three times the thickness.

$$h2t_{Ch_i} := b2t_{Ch_i}$$

$A_{w\_Ch_i} := 2 \cdot \left(h_{Ch\_web_i} \cdot t_{Ch\_web_i}\right)$ Web area

$k_{v\_Ch} := (5)^T$ Web plate buckling coefficient since h2t is less than 267

Note: C_v shall be determined through Section G2.1 prior to applying Equation G2-1

G2. Members with Unstiffened or Stiffened Webs

1. Nominal Shear Strength

This section applies to webs of singly or doubly symmetric members and channels subject to shear in the plane of the web.

Must determine C_v prior to applying this section

(b) For webs of all other doubly symmetric shapes... the web shear coefficient, C_v, is determined as follows:

(i thru iii) Calculating web shear coefficient (C_v)

(F10-2)

(F10-3)

$$C_{v\_Ch_i} := \begin{cases} 1.0 & \text{if } h2t_{Ch_i} \le 1.10\cdot\sqrt{k_{v\_Ch_i}\cdot\frac{E_{Ch}}{F_{y\_Ch}}} \\ \frac{1.10\cdot\sqrt{k_{v\_Ch_i}\cdot\frac{E_{Ch}}{F_{y\_Ch}}}}{h2t_{Ch_i}} & \text{if } 1.10\cdot\sqrt{k_{v\_Ch_i}\cdot\frac{E_{Ch}}{F_{y\_Ch}}} < h2t_{Ch_i} \le 1.37\cdot\sqrt{k_{v\_Ch_i}\cdot\frac{E_{Ch}}{F_{y\_Ch}}} \\ \frac{1.51\cdot E_{Ch}\cdot k_{v\_Ch_i}}{\left(h2t_{Ch_i}\right)^2\cdot F_{y\_Ch}} & \text{if } h2t_{Ch_i} > 1.37\cdot\sqrt{k_{v\_Ch_i}\cdot\frac{E_{Ch}}{F_{y\_Ch}}} \end{cases}$$

$$C_{v\_Ch_i} = 1$$

$$V_{n\_Ch_i} := 0.6\cdot F_{y\_Ch}\cdot A_{w\_Ch_i}\cdot C_{v\_Ch_i}$$ Nominal shear strength

$$V_{n\_Ch}^{T} = (31.779)\cdot kip$$

$$\phi V_{n\_Ch\_EL} := \phi_v\cdot V_{n\_Ch}$$

(G2-1)

$$\boxed{\phi V_{n\_Ch\_EL}^{T} = (28.601)\cdot kip}$$ Design shear strength

Flexure + Compression, capacity of horizontal rectangular HSS [AISC, Ch. H pg 16.1-70 thru 76]

H1. Doubly and Singly Symmetric Members Subject to Flexure and Axial Force

$$App_{moment\_arm_i} := L_{Ch_i} + \frac{6.625in}{2}$$

Applicable moment arm from center of pipe to center of horizontal rectangular HSS [SK-01, Sheet 2

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$$\phi F_{FC\_EL} := \frac{1}{\frac{1}{2\cdot\phi P_{n\_SL_0}} + \left(\frac{App_{moment\_arm_0}}{\phi M_{ny\_Ch\_EL_0}}\right)}$$

Applied Force capacity for flexure + compression (H1-1b)

$$\boxed{\phi F_{FC\_EL} = 3.341\cdot kip}$$

Flexure + Tension, capacity of horizontal rectangular HSS [AISC, Ch. H pg 16.1-70 thru 76]

H1. Doubly and Singly Symmetric Members Subject to Flexure and Axial Force

$$App_{moment\_arm_i} := L_{Ch_i} + \frac{6.625in}{2}$$

Applicable moment arm from center of pipe to center of horizontal rectangular HSS [SK-01, Sheet 2

$$\phi F_{FT\_EL} := \frac{1}{\frac{1}{2\cdot\phi P_{n\_Ch\_tr\_NL}} + \left(\frac{App_{moment\_arm_0}}{\phi M_{ny\_Ch\_EL_0}}\right)}$$

Applied Force capacity for flexure + compression

$$\boxed{\phi F_{FT\_EL} = (3.37)\cdot kip}$$

U-BOLT

Lateral, capacity of u-bolt [Hawkes, 6" U-bolt]

$$\phi V_{nv\_ub\_WL} := 0.0412\cdot\phi R_{nv\_ub\_NL}$$

Relationship between vertical and horizontal capacity of 6" u-bolt [Hawkes, 6" U-bolt]

$$\boxed{\phi V_{nv\_ub\_WL} = (0.546)\cdot kip}$$

Design lateral strength

SUMMARY OF RESULTS

Capacities For Southward Loading

CHANNEL IRON SECTION

Compression, capacity of channel iron sections [AISC, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

E2. Slenderness Limitations and Effective Length

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements

B4. Classification of sections for local buckling (See Case 14 of Table B4.1)

E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified through classificatic

$$\boxed{\phi P_{n\_SL}^{T} = (96.792)\cdot kip}$$

Design compressive strength

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Capacities For Northward Loading

ANGLE IRON SECTION

Tension, capacity of channel iron section [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D2. Tensile Strength

D3. Area Determination

(a) For tensile yielding in the gross section:

$$\phi P_{n\_Ch\_ty\_NL}^{T} = (126.522)\cdot kip$$ Design tensile strength

(b) For tensile rupture in the net section:

$$\phi P_{n\_Ch\_tr\_NL}^{T} = (191.7)\cdot kip$$ Design tensile strength

U-BOLT

Tension, capacity of u-bolt [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nv\_ub\_NL}^{T} = (13.254)\cdot kip$$ Design tensile strength

Capacities For Lateral (Upward/Downward) Loading

RECTANGULAR HSS

Flexure, capacity of horizontal rectangular HSS [AISC, Ch. F pg 16.1-44 thru 63]

F1. General Provisions

F7. Square and Rectangular HSS and Box-Shaped Members

1. Yielding

$$\phi M_{ny\_Ch\_EL}^{T} = (84.348)\cdot kip\cdot in$$ Design flexural strength

$$\phi F_{ny\_Ch\_EL\_Tot}^{T} = (3.923)\cdot kip$$ Total design strength of angle iron section given flexural loading

B4. Classification of sections for local buckling (Table B4.1 Case 13)

2. Flange Local Buckling

3. Web Local Buckling

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Shear, capacity of horizontal rectangular HSS [AISC, Ch. G pg 16.1-64 thru 69]

G1. General Provisions

G5. Rectangular HSS and Box Members

G2. Members with Unstiffened or Stiffened Webs

1. Nominal Shear Strength

(b) For webs of all other doubly symmetric shapes... the web shear coefficient, C_v, is determined as follows:

$$\phi V_{n\_Ch\_EL}^{T} = (28.601)\cdot kip$$

Design shear strength (G2-1)

Flexure + Compression, capacity of horizontal rectangular HSS [AISC, Ch. H pg 16.1-70 thru 76]

H1. Doubly and Singly Symmetric Members Subject to Flexure and Axial Force

$$\phi F_{FC\_EL} = 3.341\cdot kip$$

Flexure + Tension, capacity of horizontal rectangular HSS [AISC, Ch. H pg 16.1-70 thru 76]

H1. Doubly and Singly Symmetric Members Subject to Flexure and Axial Force

$$\phi F_{FT\_EL} = (3.37)\cdot kip$$

U-BOLT

Lateral, capacity of u-bolt [Hawkes, 6" U-bolt]

$$\phi V_{nv\_ub\_WL} = (0.546)\cdot kip$$

Design lateral strength

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Appendix D.9.10

RH-12 Capacities

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RH-12 CAPACITY

RH-12 is a gang hanger type support composed of a 3" adjustable clevis, a 5/8" rod hanging from the 3" adjustable clevis, and a 6" adjustable clevis hanging from the rod. RH-12 hangs from and supports horizontal PCS pipes traveling in the north/south direction. The capacities of these components are calculated below.

Component Capacity Overview:

- Downward Loading:
- Tension capacity of bottom portion of lower adjustable clevis's pin connection
- Tension capacity of top portion of lower adjustable clevis's pin connection
- Shear capacity of lower adjustable clevis's pin
- Tension capacity of rod
- Tension capacity of bottom portion of upper adjustable clevis's pin connection
- Tension capacity of top portion of upper adjustable clevis's pin connection
- Shear capacity of upper adjustable clevis's pin

(**Procedures from AISC 13th Edition (LRFD)**)

References

1. Drawing 120925, "Primary Coolant System Pipe Hangers and Details," Revision 11, Lockheed Martin, April 21, 1997
2. ITT Grinnell Catalog PH81, "Pipe Hangers," ITT Grinnell Corporation, 1981
3. ANSI/AISC 360-05, "Steel Construction Manual, 13th ed.," American Institute of Steel Construction, Inc., March 9, 2005

Note: RH-12 is a gang hanger support with the above support comprised of the same 3" adjustable clevis and 5/8" rod as that in the following calculations thus causing the capacity of the entire support to be limited by the interaction of the two piping systems.

$i := 0$ — Assigned indices corresponding to number of support types associated with these calculations

Support = 0 (RH-12)	Relationship between support and corresponding indices

Geometric and Material Properties of Support Components

LOWER ADJUSTABLE CLEVIS (Clevis FIG 260 6")

Material Properties of Lower Adjustable Clevis as Defined in the Material Section of this Report:

$F_{y\_LAC} := 33ksi$ — Yield Strength for A7 Carbon Steel

$F_{u\_LAC} := 60ksi$ — Ultimate Strength for A7 Carbon Steel

$E_{LAC} := 29000ksi$ — Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Lower Adjustable Clevis:

$t_{LAC\_up} := \left[2\cdot\left(\frac{1}{4}in\right)\right]^{T}$ — Combined thickness of upper portions of adjustable clevis [Grinnell, Fig 260]

$w_{LAC\_up} := \left(1\frac{1}{2}in\right)^{T}$ — Width of upper portions of adjustable clevis [Grinnell, Fig 260]

$A_{LAC\_up_i} := t_{LAC\_up_i}\cdot w_{LAC\_up_i}$ — Cross sectional area of upper portion of adjustable clevis [Grinnell, Fig 260]

$A_{LAC\_up}{}^{T} = (0.75)\ in^2$

$t_{LAC\_low} := \left[2\cdot\left(\frac{3}{16}in\right)\right]^{T}$ — Combined thickness of lower portions of adjustable clevis [Grinnell, Fig 260]

$w_{LAC\_low} := \left(1\frac{1}{2}in\right)^{T}$ — Width of lower portions of adjustable clevis [Grinnell, Fig 260]

$A_{LAC\_low_i} := t_{LAC\_low_i}\cdot w_{LAC\_low_i}$ — Cross sectional area of lower portion of adjustable clevis [Grinnell, Fig 260]

$A_{LAC\_low}{}^{T} = (0.562)\ in^2$

$d_{LAC\_bolt} := \left(\frac{1}{2}in\right)^{T}$ — Diameter of adjustable clevis bolt [Grinnell, Fig 260]

$d_{LAC\_hole} := \left(\frac{9}{16}in\right)^{T}$ — Nominal bolt hole Diameter, in. (mm) [AISC, Table J3.3]

$a_{parrallel\_LAC\_up} := d_{LAC\_bolt}$ — Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force, in. (mm) relation estimated from photo DSCN2683

$a_{normal\_LAC\_up_i} := \frac{w_{LAC\_up_i} - d_{LAC\_hole_i}}{2}$ — Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force, in. (mm)

$a_{parrallel\_LAC\_low} := d_{LAC\_bolt}$ — Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force, in. (mm) relation estimated from photo DSCN2683

$a_{normal\_LAC\_low_i} := \frac{w_{LAC\_low_i} - d_{LAC\_hole_i}}{2}$ — Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force, in. (mm)

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UPPER ADJUSTABLE CLEVIS (Clevis FIG 260 3")

Material Properties of Upper Adjustable Clevis as Defined in the Material Section of this Report:

$F_{y\_UAC} := 33ksi$ — Yield Strength for A7 Carbon Steel

$F_{u\_UAC} := 60ksi$ — Ultimate Strength for A7 Carbon Steel

$E_{UAC} := 29000ksi$ — Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Upper Adjustable Clevis:

$t_{UAC\_up} := \left[2 \cdot \left(\frac{3}{16} in\right)\right]^T$ — Combined thickness of upper portions of adjustable clevis [Grinnell, Fig 260]

$w_{UAC\_up} := \left(1\frac{1}{4} in\right)^T$ — Width of upper portions of adjustable clevis [Grinnell, Fig 260]

$A_{UAC\_up_i} := t_{UAC\_up_i} \cdot w_{UAC\_up_i}$ — Cross sectional area of upper portion of adjustable clevis [Grinnell, Fig 260]

$$A_{UAC\_up}^T = (0.469)\ in^2$$

$t_{UAC\_low} := \left[2 \cdot \left(\frac{3}{16} in\right)\right]^T$ — Combined thickness of lower portions of adjustable clevis [Grinnell, Fig 260]

$w_{UAC\_low} := \left(1\frac{1}{4} in\right)^T$ — Width of lower portions of adjustable clevis [Grinnell, Fig 260]

$A_{UAC\_low_i} := t_{UAC\_low_i} \cdot w_{UAC\_low_i}$ — Cross sectional area of lower portion of adjustable clevis [Grinnell, Fig 260]

$$A_{UAC\_low}^T = (0.469)\ in^2$$

$d_{UAC\_bolt} := \left(\frac{3}{8} in\right)^T$ — Diameter of adjustable clevis bolt [Grinnell, Fig 260]

$d_{UAC\_hole} := \left(\frac{7}{16} in\right)^T$ — Nominal bolt hole Diameter, in. (mm) [AISC, Table J3.3]

$a_{parrallel\_UAC\_up} := d_{UAC\_bolt}$ — Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force, in. (mm) relation estimated from photo DSCN2683

$a_{normal\_UAC\_up_i} := \dfrac{w_{UAC\_up_i} - d_{UAC\_hole_i}}{2}$ — Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force, in. (mm)

$a_{parrallel\_UAC\_low} := d_{UAC\_bolt}$

Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force, in. (mm) relation estimated from photo DSCN2683

$a_{normal\_UAC\_low_i} := \frac{w_{UAC\_low_i} - d_{UAC\_hole_i}}{2}$

Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force, in. (mm)

ROD (Rod FIG 140 5/8")

Material Properties of Rod as Defined in the Material Section of this Report:

$F_{y\_LAC} := 33ksi$ — Yield Strength for A7 Carbon Steel

$F_{u\_LAC} := 60ksi$ — Ultimate Strength for A7 Carbon Steel

$E_{LAC} := 29000ksi$ — Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Rod:

$d_R := \left(\frac{5}{8}in\right)^T$ — Unthreaded diameter of eye rod, in. (mm) [120925]

$Z_{R_i} := \frac{\left(d_{R_i}\right)^3}{6}$ — Plastic section modulus about the axis of bending, in.^{3} [AISC, Table 17-27 pg17-39]

PIPE SECTION (2.5")

Material Properties of U-bolt as Defined in the Material Section of this Report:

$F_{y\_PS} := 33ksi$ — Yield Strength for A7 Carbon Steel

$F_{u\_PS} := 60ksi$ — Ultimate Strength for A7 Carbon Steel

$E_{PS} := 29000ksi$ — Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Pipe Section:

$A_g := \left(2.08in^2\right)^T$ — Area of pipe [????]

$D_o := (3.5in)^T$ — Diameter pipe [????]

$t := (0.216in)^T$ — Thickness of pipe section [???]

$L_v := (0.203in)^T$ — Distance from maximum to zero shear????

Capacities Resulting From Downward Loading

UPPER ADJUSTABLE CLEVIS

Tension, capacity of top portion of upper adjustable clevis's pin connection [AISC, Ch. D pg 16.1-26 thru 31

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$b_{UAC\_up_i} := 2\,t_{UAC\_up_i} + 0.63in$$

$$b_{UAC\_up}^{T} = (1.38)\,in$$

$$b_{eff\_UAC\_up_i} := \min\left(b_{UAC\_up_i}, a_{normal\_UAC\_up_i}\right)$$

$$b_{eff\_UAC\_up}^{T} = (0.406)\,in$$

b_{eff} is an effective length calculated as (2t + 0.63in) for which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$$P_{n\_UAC\_up\_trp_i} := 2 \cdot t_{UAC\_up_i} \cdot b_{eff\_UAC\_up_i} \cdot F_{u\_UAC}$$

Nominal axial strength (P_n) (D5-1)

$$\phi_{n\_trp} := 0.75$$

Resistance factor for tension (ϕ_t)

$$\phi P_{n\_UAC\_up\_trp_i} := \phi_{n\_trp} \cdot P_{n\_UAC\_up\_trp_i}$$

$$\boxed{\phi P_{n\_UAC\_up\_trp}^{T} = (13.711)\,kip}$$

Design tensile strength

(b) For shear rupture on the effective area:

$$A_{sf\_UAC\_up\_bolt_i} := 2 \cdot t_{UAC\_up_i} \cdot \left(a_{parrallel\_UAC\_up_i} + \frac{d_{UAC\_bolt_i}}{2}\right)$$

$$A_{sf\_UAC\_up\_bolt}^{T} = (0.422)\,in^2$$

Effective Area

$$P_{n\_UAC\_up\_bolt\_srp_i} := 0.6 \cdot F_{u\_UAC} \cdot A_{sf\_UAC\_up\_bolt_i}$$

Nominal axial strength (P_n) (D5-2)

$$\phi_{n\_srp} := 0.75$$

Resistance factor for tension (ϕ_t)

$$\phi P_{n\_UAC\_up\_bolt\_srp_i} := \phi_{n\_srp} \cdot P_{n\_UAC\_up\_bolt\_srp_i}$$

$$\boxed{\phi P_{n\_UAC\_up\_bolt\_srp}^{T} = (11.391)\,kip}$$

Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_UAC\_up_i} := d_{UAC\_bolt_i} \cdot t_{UAC\_up_i}$ — Projected bearing area in.^{2} (mm^2

$R_{n\_UAC\_up\_bs_i} := 1.8 \cdot F_{y\_UAC} \cdot A_{pd\_UAC\_up_i}$ — Nominal bearing strength

$\phi := 0.75$ — Resistance factor

$\phi R_{n\_UAC\_up\_bs_i} := \phi \cdot R_{n\_UAC\_up\_bs_i}$

$\phi R_{n\_UAC\_up\_bs}^{T} = (6.265)\ \text{kip}$ — Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_UAC\_up_i} := A_{UAC\_up_i}$ — Gross Area

(a) For tensile yielding in the gross section:

$P_{n\_UAC\_up\_ty_i} := F_{y\_UAC} \cdot A_{g\_UAC\_up_i}$ — Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_UAC\_up\_ty_i} := \phi_{t\_ty} \cdot P_{n\_UAC\_up\_ty_i}$

$\phi P_{n\_UAC\_up\_ty}^{T} = (13.922)\ \text{kip}$ — Design tensile strength

Tension, capacity of bottom portion of upper adjustable clevis's pin connection [AISC, Ch. D pg 16.1-26 thr

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$b_{UAC\_low_i} := 2\,t_{UAC\_low_i} + 0.63\text{in}$

$b_{UAC\_low}^{T} = (1.38)\ \text{in}$

b_{eff} is an effective length calculated as (2t + 0.63in) for which can not be larger than the

$b_{eff\_UAC\_low_i} := \min\left(b_{UAC\_low_i}, a_{normal\_UAC\_low_i}\right)$ — actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$b_{eff\_UAC\_low}^T = (0.406)\ in$

$P_{n\_UAC\_low\_trp_i} := 2 \cdot t_{UAC\_low_i} \cdot b_{eff\_UAC\_low_i} \cdot F_{u\_UAC}$ — Nominal axial strength (P_n) (D5-1)

$\phi_{n\_trp} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_UAC\_low\_trp_i} := \phi_{n\_trp} \cdot P_{n\_UAC\_low\_trp_i}$

$\boxed{\phi P_{n\_UAC\_low\_trp}^T = (13.711)\ kip}$ — Design tensile strength

(b) For shear rupture on the effective area:

$A_{sf\_UAC\_low\_bolt_i} := 2 \cdot t_{UAC\_low_i} \cdot \left(a_{parrallel\_UAC\_low_i} + \frac{d_{UAC\_bolt_i}}{2}\right)$

$A_{sf\_UAC\_low\_bolt}^T = (0.422)\ in^2$ — Effective Area

$P_{n\_UAC\_low\_bolt\_srp_i} := 0.6 \cdot F_{u\_UAC} \cdot A_{sf\_UAC\_low\_bolt_i}$ — Nominal axial strength (P_n) (D5-2)

$\phi_{n\_srp} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_UAC\_low\_bolt\_srp_i} := \phi_{n\_srp} \cdot P_{n\_UAC\_low\_bolt\_srp_i}$

$\boxed{\phi P_{n\_UAC\_low\_bolt\_srp}^T = (11.391)\ kip}$ — Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_UAC\_low_i} := d_{UAC\_bolt_i} \cdot t_{UAC\_low_i}$ — Projected bearing area in.^{2} (mm^2

$R_{n\_UAC\_low\_bs_i} := 1.8 \cdot F_{y\_UAC} \cdot A_{pd\_UAC\_low_i}$ — Nominal bearing strength

$\phi := 0.75$ — Resistance factor

$\phi R_{n\_UAC\_low\_bs_i} := \phi \cdot R_{n\_UAC\_low\_bs_i}$

$\boxed{\phi R_{n\_UAC\_low\_bs}^T = (6.265)\ kip}$ — Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the *only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"*

D3. Area Determination

1. Gross Area

$A_{g\_UAC\_low_i} := A_{UAC\_low_i}$ Gross Area

(a) For tensile yielding in the gross section:

$P_{n\_UAC\_low\_ty_i} := F_{y\_UAC} \cdot A_{g\_UAC\_low_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_UAC\_low\_ty_i} := \phi_{t\_ty} \cdot P_{n\_UAC\_low\_ty_i}$

$\boxed{\phi P_{n\_UAC\_low\_ty}^{T} = (13.922)\,kip}$ Design tensile strength

Shear, capacity of upper adjustable clevis's pin [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$A_{UAC\_bolt_i} := \pi \cdot \left(\frac{d_{UAC\_bolt_i}}{2}\right)^2$ Nominal unthreaded body area

$A_{UAC\_bolt\_ds_i} := 2 \cdot A_{UAC\_bolt_i}$ Applicable area for this case since the bolt is in double shear

$F_{nv\_bolt} := 24ksi$ Nominal Shear Stress in Bearing Type Connections (A307) [AISC, Table J3.2]

$R_{nv\_UAC\_bolt_i} := F_{nv\_bolt} \cdot A_{UAC\_bolt\_ds_i}$ Nominal strength (R_n) (J3-1)

$\phi_{b\_sr} := 0.75$ Resistance factor

$\phi R_{nv\_UAC\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_UAC\_bolt_i}$

$\boxed{\phi R_{nv\_UAC\_bolt}^{T} = (3.976)\,kip}$ Design shear strength

ROD

Tension, capacity of rod [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$A_{b\_R_i} := \pi \cdot \left(\frac{d_{R_i}}{2}\right)^2$$ Nominal unthreaded body area

$$F_{nt\_R} := 45ksi$$ Nominal tensile stress (A307) [AISC, Table J3.2]

$$R_{nt\_R_i} := F_{nt\_R} \cdot A_{b\_R_i}$$ Nominal strength (R_n) (J3-1)

$$\phi_{b\_tr} := 0.75$$ Resistance factor

$$\phi R_{nt\_R_i} := \phi_{b\_tr} \cdot R_{nt\_R_i}$$

$$\boxed{\phi R_{nt\_R}^{\ T} = (10.354)\,kip}$$ Design tension strength

LOWER ADJUSTABLE CLEVIS

Tension, capacity of top portion of lower adjustable clevis's pin connection [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$b_{LAC\_up_i} := 2\,t_{LAC\_up_i} + 0.63in$$

$$b_{LAC\_up}^{\ T} = (1.63)\,in$$

$$b_{eff\_LAC\_up_i} := \min\left(b_{LAC\_up_i}, a_{normal\_LAC\_up_i}\right)$$

$$b_{eff\_LAC\_up}^{\ T} = (0.469)\,in$$

b_{eff} is an effective length calculated as (2t + 0.63in) for which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$$P_{n\_LAC\_up\_trp_i} := 2 \cdot t_{LAC\_up_i} \cdot b_{eff\_LAC\_up_i} \cdot F_{u\_LAC}$$ Nominal axial strength (P_n) (D5-1)

$$\phi_{n\_trp} := 0.75$$ Resistance factor for tension (ϕ_t)

$$\phi P_{n\_LAC\_up\_trp_i} := \phi_{n\_trp} \cdot P_{n\_LAC\_up\_trp_i}$$

$$\boxed{\phi P_{n\_LAC\_up\_trp}^{\ T} = (21.094)\,kip}$$ Design tensile strength

(b) For shear rupture on the effective area:

$$A_{sf\_LAC\_up\_bolt_i} := 2 \cdot t_{LAC\_up_i} \cdot \left(a_{parrallel\_LAC\_up_i} + \frac{d_{LAC\_bolt_i}}{2}\right)$$

$A_{sf\_LAC\_up\_bolt}^{T} = (0.75)\ in^2$ Effective Area

$P_{n\_LAC\_up\_bolt\_srp_i} := 0.6 \cdot F_{u\_LAC} \cdot A_{sf\_LAC\_up\_bolt_i}$ Nominal axial strength (P_n) (D5-2)

$\phi_{n\_srp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_LAC\_up\_bolt\_srp_i} := \phi_{n\_srp} \cdot P_{n\_LAC\_up\_bolt\_srp_i}$

$\boxed{\phi P_{n\_LAC\_up\_bolt\_srp}^{T} = (20.25)\ kip}$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_LAC\_up_i} := d_{LAC\_bolt_i} \cdot t_{LAC\_up_i}$ Projected bearing area in.^{2} (mm^2

$R_{n\_LAC\_up\_bs_i} := 1.8 \cdot F_{y\_LAC} \cdot A_{pd\_LAC\_up_i}$ Nominal bearing strength

$\phi := 0.75$ Resistance factor

$\phi R_{n\_LAC\_up\_bs_i} := \phi \cdot R_{n\_LAC\_up\_bs_i}$

$\boxed{\phi R_{n\_LAC\_up\_bs}^{T} = (11.138)\ kip}$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_LAC\_up_i} := A_{LAC\_up_i}$ Gross Area

(a) For tensile yielding in the gross section:

$P_{n\_LAC\_up\_ty_i} := F_{y\_LAC} \cdot A_{g\_LAC\_up_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_LAC\_up\_ty_i} := \phi_{t\_ty} \cdot P_{n\_LAC\_up\_ty_i}$

$\boxed{\phi P_{n\_LAC\_up\_ty}^{T} = (22.275)\ kip}$ Design tensile strength

Tension, capacity of bottom adjustable clevis's pin connection [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$b_{LAC\_low_i} := 2\,t_{LAC\_low_i} + 0.63in$$

$$b_{LAC\_low}^{T} = (1.38)\ in$$

$$b_{eff\_LAC\_low_i} := \min\left(b_{LAC\_low_i}, a_{normal\_LAC\_low_i}\right)$$

$$b_{eff\_LAC\_low}^{T} = (0.469)\ in$$

b_{eff} is an effective length calculated as (2t + 0.63in) for which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$$P_{n\_LAC\_low\_trp_i} := 2 \cdot t_{LAC\_low_i} \cdot b_{eff\_LAC\_low_i} \cdot F_{u\_LAC}$$

Nominal axial strength (P_n) (D5-1)

$$\phi_{n\_trp} := 0.75$$

Resistance factor for tension (ϕ_t)

$$\phi P_{n\_LAC\_low\_trp_i} := \phi_{n\_trp} \cdot P_{n\_LAC\_low\_trp_i}$$

$$\boxed{\phi P_{n\_LAC\_low\_trp}^{T} = (15.82)\ kip}$$

Design tensile strength

(b) For shear rupture on the effective area:

$$A_{sf\_LAC\_low\_bolt_i} := 2 \cdot t_{LAC\_low_i} \cdot \left(a_{parrallel\_LAC\_low_i} + \frac{d_{LAC\_bolt_i}}{2}\right)$$

$$A_{sf\_LAC\_low\_bolt}^{T} = (0.562)\ in^2$$

Effective Area

$$P_{n\_LAC\_low\_bolt\_srp_i} := 0.6 \cdot F_{u\_LAC} \cdot A_{sf\_LAC\_low\_bolt_i}$$

Nominal axial strength (P_n) (D5-2)

$$\phi_{n\_srp} := 0.75$$

Resistance factor for tension (ϕ_t)

$$\phi P_{n\_LAC\_low\_bolt\_srp_i} := \phi_{n\_srp} \cdot P_{n\_LAC\_low\_bolt\_srp_i}$$

$$\boxed{\phi P_{n\_LAC\_low\_bolt\_srp}^{T} = (15.187)\ kip}$$

Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$A_{pd\_LAC\_low_i} := d_{LAC\_bolt_i} \cdot t_{LAC\_low_i}$$

Projected bearing area in.^{2} (mm^2

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$R_{n\_LAC\_low\_bs_i} := 1.8 \cdot F_{y\_LAC} \cdot A_{pd\_LAC\_low_i}$ Nominal bearing strength

$\phi := 0.75$ Resistance factor

$\phi R_{n\_LAC\_low\_bs_i} := \phi \cdot R_{n\_LAC\_low\_bs_i}$

$\phi R_{n\_LAC\_low\_bs}{}^T = (8.353)\,kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_LAC\_low_i} := A_{LAC\_low_i}$ Gross Area

(a) For tensile yielding in the gross section:

$P_{n\_LAC\_low\_ty_i} := F_{y\_LAC} \cdot A_{g\_LAC\_low_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_LAC\_low\_ty_i} := \phi_{t\_ty} \cdot P_{n\_LAC\_low\_ty_i}$

$\phi P_{n\_LAC\_low\_ty}{}^T = (16.706)\,kip$ Design tensile strength

Shear, capacity of lower adjustable clevis's pin [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$A_{LAC\_bolt_i} := \pi \cdot \left(\frac{d_{LAC\_bolt_i}}{2}\right)^2$$ Nominal unthreaded body area

$A_{LAC\_bolt\_ds_i} := 2 \cdot A_{LAC\_bolt_i}$ Applicable area for this case since the bolt is in double shear

$F_{nv\_bolt} := 24ksi$ Nominal Shear Stress in Bearing Type Connections (A307) [AISC, Table J3.2]

$R_{nv\_LAC\_bolt_i} := F_{nv\_bolt} \cdot A_{LAC\_bolt\_ds_i}$ Nominal strength (R_n) (J3-1)

$\phi_{b\_sr} := 0.75$ Resistance factor

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$$\phi R_{nv\_LAC\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_LAC\_bolt_i}$$

$$\phi R_{nv\_LAC\_bolt}^{T} = (7.069)\ kip$$ Design shear strength

PIPE INTERMEDIATE OF GANG SUPPORT

Shear, capacity of intermediate pipe [AISC, Ch. G pg 16.1-68]

$$F_{cr} := \begin{cases} \max\left[\dfrac{1.60 \cdot E_{PS}}{\sqrt{\dfrac{L_v}{D_o} \cdot \left(\dfrac{D_o}{t}\right)^{\frac{5}{4}}}}, \dfrac{0.78 \cdot E_{PS}}{\left(\dfrac{D_o}{t}\right)^{\frac{3}{2}}}\right] & \text{if } \max\left[\dfrac{1.60 \cdot E_{PS}}{\sqrt{\dfrac{L_v}{D_o} \cdot \left(\dfrac{D_o}{t}\right)^{\frac{5}{4}}}}, \dfrac{0.78 \cdot E_{PS}}{\left(\dfrac{D_o}{t}\right)^{\frac{3}{2}}}\right] < 0.6 \cdot F_{y\_PS} \\ 0.6 \cdot F_{y\_PS} & \text{otherwise} \end{cases}$$

$$F_{cr} = 1.98 \times 10^{4}\ psi$$

NEED TO SEE WHAT Lv REALLY IS!!!!

$$\phi_{shear} := 0.9$$

$$V_n := \phi_{shear} \cdot F_{cr} \cdot \frac{A_g}{2}$$

$$V_n = (18.533)\ kip$$

SUMMARY OF RESULTS

Capacities Resulting From Downward Loading

LOWER ADJUSTABLE CLEVIS

Tension, capacity of top portion of upper adjustable clevis's pin connection [AISC, Ch. D pg 16.1-26 thru 31

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_UAC\_up\_trp}^{T} = (13.711)\ kip$$ Design tensile strength

(b) For shear rupture on the effective area:

$$\phi P_{n\_UAC\_up\_bolt\_srp}^{T} = (11.391)\ kip$$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_UAC\_up\_bs}{}^{T} = (6.265)\ kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_UAC\_up\_ty}{}^{T} = (13.922)\ kip$ Design tensile strength

Tension, capacity of bottom portion of upper adjustable clevis's pin connection [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_UAC\_low\_trp}{}^{T} = (13.711)\ kip$ Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_UAC\_low\_bolt\_srp}{}^{T} = (11.391)\ kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_UAC\_low\_bs}{}^{T} = (6.265)\ kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_UAC\_low\_ty}{}^{T} = (13.922)\ kip$ Design tensile strength

Shear, capacity of upper adjustable clevis's pin [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$\phi R_{nv\_UAC\_bolt}{}^{T} = (3.976)\ kip$ Design shear strength

ROD

Tension, capacity of rod [AISC, Ch. J pg 16.1-90 thru 121]

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J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$\phi R_{nt\_R}{}^{T} = (10.354)\ kip$ Design tension strength

LOWER ADJUSTABLE CLEVIS

Tension, capacity of top portion of lower adjustable clevis's pin connection [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_LAC\_up\_trp}{}^{T} = (21.094)\ kip$ Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_LAC\_up\_bolt\_srp}{}^{T} = (20.25)\ kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_LAC\_up\_bs}{}^{T} = (11.138)\ kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_LAC\_up\_ty}{}^{T} = (22.275)\ kip$ Design tensile strength

Tension, capacity of bottom portion of lower adjustable clevis's pin connection [AISC, Ch. D pg 16.1-26 thru

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_LAC\_low\_trp}{}^{T} = (15.82)\ kip$ Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_LAC\_low\_bolt\_srp}{}^{T} = (15.187)\ kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_LAC\_low\_bs}{}^{T} = (8.353)\,\text{kip}$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_LAC\_low\_ty}{}^{T} = (16.706)\,\text{kip}$ Design tensile strength

Shear, capacity of lower adjustable clevis's pin [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$\phi R_{nv\_LAC\_bolt}{}^{T} = (7.069)\,\text{kip}$ Design shear strength

PIPE INTERMEDIATE OF GANG SUPPORT

Shear, capacity of intermediate pipe [AISC, Ch. G pg 16.1-68]

$V_n = (18.533)\,\text{kip}$

Appendix D.9.11

RH-14A Capacities

RH-14A CAPACITY

RH-14A spans between lines 1-34 and 1-40 and is comprised of two 6" adjustable clevis's and a 5/8" rod. It is observed that RH-33 also is comprised of a 6" adjustable clevis and RH-14 is comprised of a 5/8" rod. Therefore this capacity calculation will represent the formerly mentioned supports in determining its own tension capacity (Note: Compression capacity for this support is evaluated in App D.9.2])

Component Capacity Overview:

- Tension Loading:
- Tension capacity of RH-33's adjustable clevis [App D.9.6]
- Tension capacity of RH-14's 5/8" rod [??, App D15]

(**Procedures from SEI/ASCE 8-02 (Applying LRFD)**)

Capacities For Downward Loading

ADJUSTABLE CLEVIS'S

Tension, capacity of upper adjustable clevis's pin connection [See [App D.9.6] for calculations associated with results]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_acv\_up\_trp} := (21.094 kip)$$ Design tensile strength

(b) For shear rupture on the effective area:

$$\phi P_{n\_acv\_up\_bolt\_srp} := (20.25 kip)$$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\phi R_{n\_acv\_up\_bs} := (11.138 kip)$$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_acv\_up\_ty} := 22.275 kip$$ Design tensile strength

Tension, capacity of lower adjustable clevis's pin connection [See [App D.9.6] for calculations associated with results]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_acv\_low\_trp} := 15.82kip$ Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_acv\_low\_bolt\_srp} := 15.187kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_acv\_low\_bs} := 8.353kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_acv\_low\_ty} := 16.706kip$ Design tensile strength

Shear, capacity of adjustable clevis's pin [See [App D.9.6] for calculations associated with results]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$\phi R_{nv\_acv\_bolt} := 7.069kip$ Design shear strength

ROD

Tension, capacity of rod [See [??, App D15] for calculations associated with these results]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$i := 0$ — Assigned indices corresponding to number of support types associated with these calculations

$d_{UI} := \left(\frac{5}{8} in\right)^T$ — Unthreaded diameter of eye rod, in. (mm) [Grinnell, Fig 278 ph-52]

$A_{b\_UI_i} := \pi \cdot \left(\frac{d_{UI_i}}{2}\right)^2$ — Nominal unthreaded body area

$F_{nt\_UI} := 45ksi$ — Nominal tensile stress (A307) [AISC, Table J3.2] [AISC, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment

$R_{nt\_UI_i} := F_{nt\_UI} \cdot A_{b\_UI_i}$ — Nominal strength (R_n) (J3-1)

$\phi_{b\_tr} := 0.75$ — Resistance factor

$\phi R_{nt\_UI_i} := \phi_{b\_tr} \cdot R_{nt\_UI_i}$

$\boxed{\phi R_{nt\_UI}^T = (10.354) \cdot kip}$ — Design tension strength

Appendix D.9.12

RH-20G Capacities

RH-20G CAPACITY

RH-20G spans between lines 1-41 and 1-40 and is comprised of one 6" adjustable clevis a 5/8" eye rod and a 6" pipe clamp. It is observed that RH-33 is also comprised of a 6" adjustable clevis and RH-14 is comprised of a 5/8" rod and 6" pipe clamp. Therefore this capacity calculation will represent the formerly mentioned supports in determining its own tension capacity (Note: Compression capacity for this support is evaluated in App D.9.2)

Component Capacity Overview:

- Tension Loading:

- Tension capacity of RH-33's adjustable clevis [App D.9.6]
- Tension capacity of RH-14's 5/8" rod [??, App D15]
- Tension capacity of RH-14's pipe clamp [??, App D15]

(**Procedures from SEI/ASCE 8-02 (Applying LRFD)**)

Capacities For Downward Loading

ADJUSTABLE CLEVIS'S

Tension, capacity of upper adjustable clevis's pin connection [See [App D.9.6] for calculations associated with results

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_acv\_up\_trp} := (21.094\text{kip})$$ Design tensile strength

(b) For shear rupture on the effective area:

$$\phi P_{n\_acv\_up\_bolt\_srp} := (20.25\text{kip})$$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\phi R_{n\_acv\_up\_bs} := (11.138\text{kip})$$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_acv\_up\_ty} := 22.275\text{kip}$$ Design tensile strength

Tension, capacity of lower adjustable clevis's pin connection [See [App D.9.6] for calculations associated with results]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_acv\_low\_trp} := 15.82kip$ Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_acv\_low\_bolt\_srp} := 15.187kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_acv\_low\_bs} := 8.353kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_acv\_low\_ty} := 16.706kip$ Design tensile strength

Shear, capacity of adjustable clevis's pin [See [App D.9.6] for calculations associated with results]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$\phi R_{nv\_acv\_bolt} := 7.069kip$ Design shear strength

ROD

Tension, capacity of rod [See [??, App D15] for calculations associated with results]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$\phi R_{nt\_UI} := 10.354kip$ Design tension strength

PIPE CLAMP

Tension, capacity of clamp [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_cl\_trp} := 23.203kip$ Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_cl\_srp} := 34.172kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_cl\_bs} := 25.059kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_cl\_ty} := 33.412kip$ Design tensile strength

Shear, capacity of clamp's upper bolt [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$\phi R_{nv\_cl\_bolt} := 15.904kip$ Design shear strength

Appendix D.9.13

RH-35 Capacities

RH-35 CAPACITY

RH-35 spans between lines 1-40 and 1-42 and is comprised of two 6" adjustable clevis's and a 3/8" rod. It is observed that RH-33 is also comprised of a 6" adjustable clevis and an evaluation will be performed to determine the capacity of the rod. Therefore this capacity calculation will represent clevis capacity calculation results from RH-33 in determining its own tension capacity (Note: Compression capacity for this support is evaluated in App D.9.2)

Component Capacity Overview:

- Tension Loading:
- Tension capacity of RH-33's adjustable clevis [App D.9.6]
- Tension capacity of RH-35's 3/8" rod

(**Procedures from SEI/ASCE 8-02 (Applying LRFD)**)

Capacities For Downward Loading

ADJUSTABLE CLEVIS'S

Tension, capacity of upper adjustable clevis's pin connection [See [App D.9.6] for calculations associated with results]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_acv\_up\_trp} := (21.094 kip)$$ Design tensile strength

(b) For shear rupture on the effective area:

$$\phi P_{n\_acv\_up\_bolt\_srp} := (20.25 kip)$$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\phi R_{n\_acv\_up\_bs} := (11.138 kip)$$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_acv\_up\_ty} := 22.275 kip$$ Design tensile strength

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Tension, capacity of lower adjustable clevis's pin connection [See [App D.9.6] for calculations associated with results]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_acv\_low\_trp} := 15.82kip$ Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_acv\_low\_bolt\_srp} := 15.187kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_acv\_low\_bs} := 8.353kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_acv\_low\_ty} := 16.706kip$ Design tensile strength

Shear, capacity of adjustable clevis's pin [See [App D.9.6] for calculations associated with results

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$\phi R_{nv\_acv\_bolt} := 7.069kip$ Design shear strength

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ROD

Tension, capacity of rod [??, App D15] for calculations associated with these results]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$i := 0$ — Assigned indices corresponding to number of support types associated with these calculations

$d_{UI} := \left(\frac{3}{8}\text{in}\right)^T$ — Unthreaded diameter of eye rod, in. (mm) [Grinnell, Fig 278 ph-52]

$A_{b\_UI_i} := \pi \cdot \left(\frac{d_{UI_i}}{2}\right)^2$ — Nominal unthreaded body area

$F_{nt\_UI} := 45\text{ksi}$ — Nominal tensile stress (A307) [AISC, Table J3.2] [AISC, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment

$R_{nt\_UI_i} := F_{nt\_UI} \cdot A_{b\_UI_i}$ — Nominal strength (R_n) (J3-1)

$\phi_{b\_tr} := 0.75$ — Resistance factor

$\phi R_{nt\_UI_i} := \phi_{b\_tr} \cdot R_{nt\_UI_i}$

$\phi R_{nt\_UI}^T = (3.728) \cdot \text{kip}$ — Design tension strength

Appendix D.9.14

RH-20 Capacities

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RH-20 CAPACITY

RH-20 is attached to line1-42 and is comprised of a 6" pipe clamp, 5/8" rod, clevis, and a plate welded to the ceiling. It is observed that RH-22 also has an identical set of components except for the ceiling connection. Therefore this capacity calculation will represent the capacity calculation results from the RH-22 calculation to the extent of the ceiling connection plate where the ceiling plate calculation associated with RH-25 will be implemented as they are the same with this respect. (Note: Compression capacity for this support is evaluated in App D.9.2])

Component Capacity Overview:

- Tension Loading:
- Tension capacity of RH-20's pipe clamp [32, D11]
- Tension capacity of RH-20's 5/8" rod [32, D11]
- Tension capacity of RH-20's clevis [32, D11]
- Tension capacity of RH-20's ceiling plate [32, D11]

(**Procedures from SEI/ASCE 8-02 (Applying LRFD))**

Capacities For Downward Loading

CLAMP

Tension, capacity of clamp [See [32, App D11] for calculations associated with these results]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_cl\_trp} := 23.203kip$$ Design tensile strength

(b) For shear rupture on the effective area:

$$\phi P_{n\_cl\_srp} := 34.172kip$$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_cl\_bs} := 25.059kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_cl\_ty} := 33.412kip$ Design tensile strength

Shear, capacity of clamp's upper bolt [See [32, App D11] for calculations associated with these results]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$\phi R_{nv\_cl\_bolt} := 15.904kip$ Design shear strength

EYE ROD

Tension, capacity of eye rod [See [32, App D11] for calculations associated with these results]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$\phi R_{nt\_I} := 10.354kip$ Design tension strength

CLEVIS

Tension, capacity of clevis's intermediate section [See [32, App D11] for calculations associated with these results]

D1. Slenderness Limitations

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_cv\_int\_ty} := 19.723kip$ Design tensile strength

(b) For tensile rupture in the net section:

$P_{n\_cv\_int\_tr} := 39.844kip$ Design tensile strength

Tension, capacity of clevis's pin connection [See [32, App D11] for calculations associated with these results]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_cv\_con\_trp} := 17.578kip$ Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_cv\_bolt\_srp} := 23.203kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_cv\_bs} := 20.883kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_cv\_con\_ty} := 26.684kip$ Design tensile strength

Shear, capacity of clevis's pin [See [32, App D11] for calculations associated with these results]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$\phi R_{nv\_bolt} := 15.904kip$ Design shear strength

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TAB

Tension, capacity of tab [See [32, App D7] for calculations associated with these results]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_Tab\_trp} := 71.719kip$ — Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_Tab\_bolt\_srp} := 38.812kip$ — Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_Tab\_bs} := 16.706kip$ — Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_Tab\_ty} := 59.4kip$ — Design tensile strength

Appendix D.9.15

RH-34 Capacities

RH-34 CAPACITY

RH-34 is composed of a 6" adjustable clevis, 5/8" eye rod, and a 20" pipe clamp.

Component Failure Overview:

- Downward Loading:
- Tension capacity of adjustable clevis
- Tension capacity of eye rod
- Tension capacity of clamp
- Shear capacity of clamp's upper bolt

$i := 0$

Geometric and Material Properties of Support Components

ADJUSTABLE CLEVIS (Clevis FIG 260 6")

Material Properties of Clevis:

$F_{y\_acv} := 33ksi$ Yield Strength — ASTM (A7)

$F_{u\_acv} := 60ksi$ Ultimate Strength — ASTM (A7)

$E\_acv := 29000ksi$ Modulus of Elasticity — AISC Symbols definition

Geometric Properties of Clevis:

$$t_{acv\_up} := \left[2\cdot\left(\frac{1}{4}in\right)\right]^T$$

Combined thickness of upper portions of adjustable clevis [Grinnell, Fig 260]

$$w_{acv\_up} := \left(1\frac{1}{2}in\right)^T$$

Width of upper portions of adjustable clevis [Grinnell, Fig 260]

$$A_{acv\_up_i} := t_{acv\_up_i}\cdot w_{acv\_up_i}$$

Cross sectional area of upper portion of adjustable clevis [Grinnell, Fig 260]

$$A_{acv\_up}{}^T = (0.75)\ in^2$$

$$t_{acv\_low} := \left[2\cdot\left(\frac{3}{16}in\right)\right]^T$$

Combined thickness of lower portions of adjustable clevis [Grinnell, Fig 260]

$$w_{acv\_low} := \left(1\frac{1}{2}in\right)^T$$

Width of lower portions of adjustable clevis [Grinnell, Fig 260]

$A_{acv\_low_i} := t_{acv\_low_i} \cdot w_{acv\_low_i}$

$A_{acv\_low}^T = (0.562)\,in^2$ — Cross sectional area of lower portion of adjustable clevis [Grinnell, Fig 260]

$d_{acv\_bolt} := \left(\frac{1}{2}in\right)^T$ — Diameter of adjustable clevis bolt [Grinnell, Fig 260]

$d_{acv\_hole} := \left(\frac{9}{16}in\right)^T$ — Nominal bolt hole Diameter, in. (mm) [AISC, Table J3.3]

$a_{parrallel\_acv\_up} := d_{acv\_bolt}$ — Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force, in. (mm) relation estimated from photo DSCN2683

$a_{normal\_acv\_up_i} := \frac{w_{acv\_up_i} - d_{acv\_hole_i}}{2}$ — Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force, in. (mm)

$a_{parrallel\_acv\_low} := d_{acv\_bolt}$ — Shortest distance from edge of the bolt hole to the edge of the member measured parallel to the direction of the force, in. (mm) relation estimated from photo DSCN2683

$a_{normal\_acv\_low_i} := \frac{w_{acv\_low_i} - d_{acv\_hole_i}}{2}$ — Shortest distance from edge of bolt hole to the edge of the member measured normal to the direction of the force, in. (mm)

EYE ROD (Welded Eye Rod FIG 248 5/8")

Material Properties of Eye Rod:

$F_{y\_I} := 33ksi$	Yield Strength, ksi	ASTM (A7)
$F_{u\_I} := 60ksi$	Ultimate Strength, ksi	ASTM (A7)
$E_I := 29000ksi$	Modulus of Elasticity, ksi	AISC Symbols definition

Geometric Properties of Eye Rod:

$d_I := \left(\frac{5}{8}in\right)^T$ — Unthreaded diameter of eye rod, in. (mm) [Grinnell, Fig 278]

$Z_{I_i} := \frac{\left(d_{I_i}\right)^3}{6}$ — Plastic section modulus about the axis of bending, $in.^3$ (mm^3) [Grinnell, Table 17-27]

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CLAMP (Pipe Clamp FIG 212 20")

Material Properties of Clamp:

$F_{y\_cl} := 33ksi$	Yield Strength	ASTM (A7)
$F_{u\_cl} := 60ksi$	Ultimate Strength	ASTM (A7)
$E_{cl} := 29000ksi$	Modulus of Elasticity	AISC Symbols definition

Geometric Properties of Clamp:

$$t_{cl} := \left[2 \cdot \left(\frac{5}{8} in\right)\right]^T$$

Combined thickness of both plates forming the upper portion of the clamp, in. (mm) [120925], [Grinnell, Fig 212]

$$w_{cl} := \left(2\frac{1}{2} in\right)^T$$

Width of plates forming the clamp, in. (mm) [120925], [Grinnell, Fig 212]

$$A_{cl_i} := t_{cl_i} \cdot w_{cl_i}$$

$$A_{cl}^T = (3.125)\, in^2$$

Total cross sectional area of both sides of clamp, in.^{2} (mm^2)

$$d_{cl\_bolt} := \left(1\frac{1}{8} in\right)^T$$

Bolt diameter, in. (mm) [120925], [Grinnell, Fig 212]

$$d_{cl\_hole} := \left(1\frac{3}{16} in\right)^T$$

Nominal bolt hole Diameter, in. (mm) [AISC, Table J3.3]

$$a_{parrallel\_cl} := \left(\frac{25}{32} in\right)^T$$

Shortest distance from edge of the pin hole to the edge of the member measured parallel to the direction of the force, in. (mm) hand calculated from d_{cl_hole} and [Grinnell, Fig 212] data

$$a_{normal\_cl_i} := \frac{w_{cl_i} - d_{cl\_hole_i}}{2}$$

$$a_{normal\_cl}^T = (0.656)\, in$$

Shortest distance from edge of pin hole to the edge of the member measured normal to the direction of the force, in. (mm)

Capacities Resulting From Downward Loading

ADJUSTABLE CLEVIS

Tension, failure of upper adjustable clevis's pin connection [Design of Members for Tension (D)]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$b_{acv\_up_i} := 2\,t_{acv\_up_i} + 0.63in$$

$$b_{acv\_up}^{T} = (1.63)\,in$$

$$b_{eff\_acv\_up_i} := \min\left(b_{acv\_up_i}, a_{normal\_acv\_up_i}\right)$$

$$b_{eff\_acv\_up}^{T} = (0.469)\,in$$

b_{eff} is an effective length calculated as (2t + 0.63in) for which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$$P_{n\_acv\_up\_trp_i} := 2\cdot t_{acv\_up_i}\cdot b_{eff\_acv\_up_i}\cdot F_{u\_acv}$$

Nominal axial strength (P_n) (D5-1)

$$\phi_{n\_trp} := 0.75$$

Resistance factor for tension (ϕ_t)

$$\phi P_{n\_acv\_up\_trp_i} := \phi_{n\_trp}\cdot P_{n\_acv\_up\_trp_i}$$

$$\boxed{\phi P_{n\_acv\_up\_trp}^{T} = (21.094)\cdot kip}$$

Design tensile strength

(b) For shear rupture on the effective area:

$$A_{sf\_acv\_up\_bolt_i} := 2\cdot t_{acv\_up_i}\cdot\left(a_{parrallel\_acv\_up_i} + \frac{d_{acv\_bolt_i}}{2}\right)$$

$$A_{sf\_acv\_up\_bolt}^{T} = (0.75)\,in^2$$

Effective Area

$$P_{n\_acv\_up\_bolt\_srp_i} := 0.6\cdot F_{u\_acv}\cdot A_{sf\_acv\_up\_bolt_i}$$

Nominal axial strength (P_n) (D5-2)

$$\phi_{n\_srp} := 0.75$$

Resistance factor for tension (ϕ_t)

$$\phi P_{n\_acv\_up\_bolt\_srp_i} := \phi_{n\_srp}\cdot P_{n\_acv\_up\_bolt\_srp_i}$$

$$\boxed{\phi P_{n\_acv\_up\_bolt\_srp}^{T} = (20.25)\cdot kip}$$

Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_acv\_up_i} := d_{acv\_bolt_i} \cdot t_{acv\_up_i}$ Projected bearing area in.^{2} (mm^2)

$R_{n\_acv\_up\_bs_i} := 1.8 \cdot F_{y\_acv} \cdot A_{pd\_acv\_up_i}$ Nominal bearing strength

$\phi := 0.75$ Resistance factor

$\phi R_{n\_acv\_up\_bs_i} := \phi \cdot R_{n\_acv\_up\_bs_i}$

$\phi R_{n\_acv\_up\_bs}{}^T = (11.138) \cdot kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_acv\_up_i} := A_{acv\_up_i}$ Gross Area

(a) For tensile yielding in the gross section:

$P_{n\_acv\_up\_ty_i} := F_{y\_acv} \cdot A_{g\_acv\_up_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_acv\_up\_ty_i} := \phi_{t\_ty} \cdot P_{n\_acv\_up\_ty_i}$

$\phi P_{n\_acv\_up\_ty}{}^T = (22.275) \cdot kip$ Design tensile strength

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Tension, failure of lower adjustable clevis's pin connection [Design of Members for Tension (D)]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$b_{acv\_low_i} := 2\,t_{acv\_low_i} + 0.63in$$

$$b_{acv\_low}^T = (1.38)\ in$$

$$b_{eff\_acv\_low_i} := \min\left(b_{acv\_low_i}, a_{normal\_acv\_low_i}\right)$$

$$b_{eff\_acv\_low}^T = (0.469)\ in$$

b_{eff} is an effective length calculated as (2t + 0.63in) for which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$$P_{n\_acv\_low\_trp_i} := 2\cdot t_{acv\_low_i}\cdot b_{eff\_acv\_low_i}\cdot F_{u\_acv}$$ Nominal axial strength (P_n) (D5-1)

$$\phi_{n\_trp} = 0.75$$ Resistance factor for tension (ϕ_t)

$$\phi P_{n\_acv\_low\_trp_i} := \phi_{n\_trp}\cdot P_{n\_acv\_low\_trp_i}$$

$$\boxed{\phi P_{n\_acv\_low\_trp}^T = (15.82)\cdot kip}$$ Design tensile strength

(b) For shear rupture on the effective area:

$$A_{sf\_acv\_low\_bolt_i} := 2\cdot t_{acv\_low_i}\cdot\left(a_{parrallel\_acv\_low_i} + \frac{d_{acv\_bolt_i}}{2}\right)$$

$$A_{sf\_acv\_low\_bolt}^T = (0.562)\ in^2$$ Effective Area

$$P_{n\_acv\_low\_bolt\_srp_i} := 0.6\cdot F_{u\_acv}\cdot A_{sf\_acv\_low\_bolt_i}$$ Nominal axial strength (P_n) (D5-2)

$$\phi_{n\_srp} = 0.75$$ Resistance factor for tension (ϕ_t)

$$\phi P_{n\_acv\_low\_bolt\_srp_i} := \phi_{n\_srp}\cdot P_{n\_acv\_low\_bolt\_srp_i}$$

$$\boxed{\phi P_{n\_acv\_low\_bolt\_srp}^T = (15.187)\cdot kip}$$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_acv\_low_i} := d_{acv\_bolt_i} \cdot t_{acv\_low_i}$ Projected bearing area in.^{2} (mm^2)

$R_{n\_acv\_low\_bs_i} := 1.8 \cdot F_{y\_acv} \cdot A_{pd\_acv\_low_i}$ Nominal bearing strength

$\phi := 0.75$ Resistance factor

$\phi R_{n\_acv\_low\_bs_i} := \phi \cdot R_{n\_acv\_low\_bs_i}$

$\phi R_{n\_acv\_low\_bs}^T = (8.353) \cdot kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_acv\_low_i} := A_{acv\_low_i}$ Gross Area

(a) For tensile yielding in the gross section:

$P_{n\_acv\_low\_ty_i} := F_{y\_acv} \cdot A_{g\_acv\_low_i}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} = 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_acv\_low\_ty_i} := \phi_{t\_ty} \cdot P_{n\_acv\_low\_ty_i}$

$\phi P_{n\_acv\_low\_ty}^T = (16.706) \cdot kip$ Design tensile strength

Shear, failure of adjustable clevis's pin [Design of Connections (J)]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$A_{acv\_bolt_i} := \pi \cdot \left(\frac{d_{acv\_bolt_i}}{2} \right)^2$$ Nominal unthreaded body area

$$A_{acv\_bolt\_ds_i} := 2 \cdot A_{acv\_bolt_i}$$ Applicable area for this case since the bolt is in double shear

$$F_{nv\_bolt} := 24ksi$$ Nominal Shear Stress in Bearing Type Connections (A307) [AISC, Table J3.2]

$$R_{nv\_acv\_bolt_i} := F_{nv\_bolt} \cdot A_{acv\_bolt\_ds_i}$$ Nominal strength (R_n) (J3-1)

$$\phi_{b\_sr} := 0.75$$ Resistance factor

$$\phi R_{nv\_acv\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_acv\_bolt_i}$$

$$\phi R_{nv\_acv\_bolt}^{T} = (7.069) \cdot kip$$ Design shear strength

EYE ROD

NOTE:It was observed during inspection by Mark Russell that all of the applicable eye rods have welded eyes even though they indicate otherwise on Drawing 120925, thus all eye rods in these calculations will be treated as welded eye rods

Tension, failure of eye rod [Design of Connections (J)]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$A_{b\_I_i} := \pi \cdot \left(\frac{d_{I_i}}{2}\right)^2$$ Nominal unthreaded body area

$$F_{nt\_I} := 45\text{ksi}$$ Nominal tensile stress (A307) [AISC, Table J3.2]

$$R_{nt\_I_i} := F_{nt\_I} \cdot A_{b\_I_i}$$ Nominal strength (R_n) (J3-1)

$$\phi_{b\_tr} := 0.75$$ Resistance factor

$$\phi R_{nt\_I_i} := \phi_{b\_tr} \cdot R_{nt\_I_i}$$

$$\phi R_{nt\_I}^{T} = (10.354) \cdot \text{kip}$$ Design tension strength

CLAMP

Tension, failure of clamp [Design of Members for Tension (D)]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$b_{cl_i} := 2\,t_{cl_i} + 0.63\text{in}$$

$$b_{cl}^{T} = (3.13)\ \text{in}$$

$$b_{eff\_cl_i} := \min\left(b_{cl_i}, a_{normal\_cl_i}\right)$$

$$b_{eff\_cl}^{T} = (0.656)\ \text{in}$$

b_{eff} is an effective length calculated as (2t + 0.63in) for which can not be larger than the actual distance fro the edge of the hole to the edge of the part measured in the direction normal to the applied force

$P_{n\_cl\_trp_i} := 2 \cdot t_{cl_i} \cdot b_{eff\_cl_i} \cdot F_{u\_cl}$ — Nominal axial strength (P_n) (D5-1)

$\phi_{n\_trp} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_cl\_trp_i} := \phi_{n\_trp} \cdot P_{n\_cl\_trp_i}$

$\boxed{\phi P_{n\_cl\_trp}{}^T = (73.828) \cdot kip}$ — Design tensile strength

(b) For shear rupture on the effective area:

$$A_{sf\_cl_i} := 2 \cdot t_{cl_i} \cdot \left(a_{parrallel\_cl_i} + \frac{d_{cl\_hole_i}}{2} \right)$$

$A_{sf\_cl}{}^T = (3.437)\, in^2$ — Effective area

$P_{n\_cl\_srp_i} := 0.6 \cdot F_{u\_cl} \cdot A_{sf\_cl_i}$ — Nominal axial strength (P_n) (D5-2)

$\phi_{n\_srp} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_cl\_srp_i} := \phi_{n\_srp} \cdot P_{n\_cl\_srp_i}$

$\boxed{\phi P_{n\_cl\_srp}{}^T = (92.812) \cdot kip}$ — Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_cl_i} := d_{cl\_bolt_i} \cdot t_{cl_i}$ — Projected bearing area in.^{2} (mm^2)

$R_{n\_cl\_bs_i} := 1.8 \cdot F_{y\_cl} \cdot A_{pd\_cl_i}$ — Nominal bearing strength

$\phi := 0.75$ — Resistance factor

$\phi R_{n\_cl\_bs_i} := \phi \cdot R_{n\_cl\_bs_i}$

$\boxed{\phi R_{n\_cl\_bs}{}^T = (62.648) \cdot kip}$ — Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_cl_i} := A_{cl_i}$ Gross area (D3-1)

(a) For tensile yielding in the gross section:

$P_{n\_cl\_ty} := F_{y\_cl} \cdot A_{g\_cl}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_cl\_ty} := \phi_{t\_ty} \cdot P_{n\_cl\_ty}$

$\boxed{\phi P_{n\_cl\_ty}{}^T = (92.813) \cdot kip}$ Design tensile strength

Shear, failure of clamp's upper bolt [Design of Connections (J)]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$A_{cl\_bolt_i} := \pi \cdot \left(\frac{d_{cl\_bolt_i}}{2}\right)^2$ Nominal unthreaded body area

$A_{cl\_bolt\_ds_i} := 2 \cdot A_{cl\_bolt_i}$ Applicable area for this case since the bolt is in double shear

$F_{nv\_cl\_bolt} := 24ksi$ Nominal shear stress in bearing type connections (A307) [AISC, Table J3.2]

$R_{nv\_cl\_bolt_i} := F_{nv\_cl\_bolt} \cdot A_{cl\_bolt\_ds_i}$ Nominal strength (R_n) (J3-1)

$\phi_{b\_sr} := 0.75$ Resistance factor

$\phi R_{nv\_cl\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_cl\_bolt_i}$

$\boxed{\phi R_{nv\_cl\_bolt}{}^T = (35.785) \cdot kip}$ Design shear strength

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Summary of Results

Capacities Resulting From Downward Loading

ADJUSTABLE CLEVIS

Tension, failure of upper adjustable clevis's pin connection [Design of Members for Tension (D)]

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_acv\_up\_trp}{}^{T} = (21.094)\cdot kip$$

(b) For shear rupture on the effective area:

$$\phi P_{n\_acv\_up\_bolt\_srp}{}^{T} = (20.25)\cdot kip$$

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\phi R_{n\_acv\_up\_bs}{}^{T} = (11.138)\cdot kip$$

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_acv\_up\_ty}{}^{T} = (22.275)\cdot kip$$

Tension, failure of lower adjustable clevis's pin connection [Design of Members for Tension (D)]

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_acv\_low\_trp}{}^{T} = (15.82)\cdot kip$$

(b) For shear rupture on the effective area:

$$\phi P_{n\_acv\_low\_bolt\_srp}{}^{T} = (15.187)\cdot kip$$

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\phi R_{n\_acv\_low\_bs}{}^{T} = (8.353)\cdot kip$$

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(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_acv\_low\_ty}{}^{T} = (16.706)\cdot kip$$

Shear, failure of adjustable clevis's pin [Design of Connections (J)]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$$\phi R_{nv\_acv\_bolt}{}^{T} = (7.069)\cdot kip$$

EYE ROD

Tension, failure of eye rod [Design of Connections (J)]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nt\_I}{}^{T} = (10.354)\cdot kip$$

CLAMP

Tension, failure of clamp [Design of Members for Tension (D)]

(b) For shear rupture on the effective area:

$$\phi P_{n\_cl\_srp}{}^{T} = (92.812)\cdot kip$$

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\phi R_{n\_cl\_bs}{}^{T} = (62.648)\cdot kip$$

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_cl\_ty}{}^{T} = (92.813)\cdot kip$$

Shear, failure of clamp's upper bolt [Design of Connections (J)]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$\phi R_{nv\_cl\_bolt}{}^{T} = (35.785)\cdot kip$$

Appendix D.9.16

RH-27A & 27B Capacities

RH-27A & 27B CAPACITY

The upper portion of RH-27A & 27B is attached to line1-42 and is comprised of a 2.5" pipe clamp, 5/8" rod, clevis, and a plate welded to the ceiling. It is observed that RH-25 also has an identical set of components except for the pipe. Therefore this capacity calculation will represent the upper portion capacity calculation results from the RH-25 calculation to the extent of the pipe clamp. The remaining lower portion of the support gang hangs from pipe for which the upper portion is attached with a 5/8" diameter u-bolt associated with RH-27A and 1/2" diameter u-bolt associated with RH-27B (tension capacity is calculated for this portion of the support). The shear in the pipe between these two support portions is also calculated.
(Note: Compression capacity for this support is evaluated in App D.9.2])

Component Capacity Overview:

- Tension Loading:
- Tension capacity of RH-27's pipe clamp [32, D11]
- Tension capacity of RH-27's 5/8" rod [32, D11]
- Tension capacity of RH-27's clevis [32, D11]
- Tension capacity of RH-27's ceiling plate [32, D11]

(**Procedures from SEI/ASCE 8-02 (Applying LRFD)**)

$i := 0$

CLAMP (Pipe Clamp FIG 212 2.5" [120925, Sheet 2])

Material Properties of Clamp as Defined in the Material Section of this Report:

$F_{y\_cl} := 33ksi$ Yield Strength for A7 Carbon Steel

$F_{u\_cl} := 60ksi$ Ultimate Strength for A7 Carbon Steel

$E_{cl} := 29000ksi$ Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Clamp:

$t_{cl} := \left[2 \cdot \left(\frac{1}{4}\right) in\right]^T$ Combined thickness of both plates forming the upper portion of the clamp, in. (mm) [120925, Sheet 2], [Grinnell, Fig 212 ph-18]

$w_{cl} := (1in)^T$ Width of plates forming the clamp, in. (mm) [120925, Sheet 2], [Grinnell, Fig 212 ph-18]

$A_{cl_i} := t_{cl_i} \cdot w_{cl_i}$ Total cross sectional area of both sides of clamp, in.^{2} (mm^2)

$A_{cl}^T = (0.5)\,in^2$

$d_{cl\_bolt} := (0.5in)^T$ — Bolt diameter, in. (mm) [120925, Sheet 2], [Grinnell, Fig 212 ph-18]

$d_{cl\_hole} := \left(\frac{9}{16}in\right)^T$ — Nominal bolt hole Diameter, in. (mm) [AISC, Table J3.3 pg 16.1-105]

$a_{parrallel\_cl} := \left(\frac{11}{32}in\right)^T$ — Shortest distance from edge of the pin hole to the edge of the member measured parallel to the direction of the force, in. (mm) hand calculated from d_{cl_hole} and [Grinnell, Fig 212 ph-18] data

$a_{normal\_cl_i} := \frac{w_{cl_i} - d_{cl\_hole_i}}{2}$ — Shortest distance from edge of pin hole to the edge of the member measured normal to the direction of the force, in. (mm)

$a_{normal\_cl}^T = (0.219)\,in$

U-BOLT (U-Bolt 2.5")

Note: In this analysis the tensile capacity of the u-bolt will be calculated based on the cross sectional area of both u-bolt legs straddling the pipe. Due to the complexity of u-bolt behavior given lateral loading, the associated capacity was determined based on the [Hawkes] document, where the lateral capacity was shown to be 0.0412 that of the u-bolt's tensile capacity. Given that the resistance factor is equivalent for both tension and shear (ϕ = 0.75) is was determined that the AISC resistance factors would be appropriately applied by multiplying the resulting tensile capacity by the 0.0412 factor stated above.

$j := 0 .. 1$

Material Properties of U-bolt as Defined in the Material Section of this Report:

$F_{y\_ub} := 33ksi$ — Yield Strength for A7 Carbon Steel

$F_{u\_ub} := 60ksi$ — Ultimate Strength for A7 Carbon Steel

$E_{ub} := 29000ksi$ — Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of U-bolt:

$D_{ub} := (6.625in \;\; 4.5in)^T$ — Diameter of pipe which the u-bolt supports [127029], [Grinnell, Fig 137 ph-55]

$d_{ub} := \left(\frac{5}{8}in \;\; \frac{1}{2}in\right)^T$ — Diameter of u-bolt rod [127029], [Grinnell, Fig 137 ph-55]

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PIPE SECTION (2.5")

Material Properties of U-bolt as Defined in the Material Section of this Report:

$F_{y\_PS} := 33ksi$ Yield Strength for A7 Carbon Steel

$F_{u\_PS} := 60ksi$ Ultimate Strength for A7 Carbon Steel

$E_{PS} := 29000ksi$ Modulus of Elasticity for A7 Carbon Steel

Geometric Properties of Pipe Section:

$A_g := \left(1.59in^2\right)^T$ Area of pipe [32]

$D_o := (2.5in)^T$ Diameter pipe [32]

$t := (0.203in)^T$ Thickness of pipe section [32]

$L_v := (0.203in)^T$ Distance from maximum to zero shear

Capacities For Downward Loading

CLAMP

Tension, capacity of clamp [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$b_{cl_i} := 2\,t_{cl_i} + 0.63in$

$b_{cl}^T = (1.63)\,in$

$b_{eff\_cl_i} := \min\left(b_{cl_i}, a_{normal\_cl_i}\right)$

$b_{eff\_cl}^T = (0.219)\,in$

b_{eff} is an effective length calculated as (2t + 0.63in) which can not be larger than the actual distance from the edge of the hole to the edge of the part measured in the direction normal to the applied force

$P_{n\_cl\_trp_i} := 2 \cdot t_{cl_i} \cdot b_{eff\_cl_i} \cdot F_{u\_cl}$ Nominal axial strength (P_n)

(D5-1)

$\phi_{n\_trp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_cl\_trp_i} := \phi_{n\_trp} \cdot P_{n\_cl\_trp_i}$

$\phi P_{n\_cl\_trp}{}^{T} = (9.844) \cdot kip$ Design tensile strength

(b) For shear rupture on the effective area:

$A_{sf\_cl_i} := 2 \cdot t_{cl_i} \cdot \left(a_{parrallel\_cl_i} + \frac{d_{cl\_bolt_i}}{2} \right)$

$A_{sf\_cl}{}^{T} = (0.594)\ in^2$ Effective area

$P_{n\_cl\_srp_i} := 0.6 \cdot F_{u\_cl} \cdot A_{sf\_cl_i}$ Nominal axial strength (P_n) (D5-2)

$\phi_{n\_srp} := 0.75$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_cl\_srp_i} := \phi_{n\_srp} \cdot P_{n\_cl\_srp_i}$

$\phi P_{n\_cl\_srp}{}^{T} = (16.031) \cdot kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$A_{pd\_cl_i} := d_{cl\_bolt_i} \cdot t_{cl_i}$ Projected bearing area in.^{2} (mm^2)

$R_{n\_cl\_bs_i} := 1.8 \cdot F_{y\_cl} \cdot A_{pd\_cl_i}$ Nominal bearing strength

$\phi := 0.75$ Resistance factor

$\phi R_{n\_cl\_bs_i} := \phi \cdot R_{n\_cl\_bs_i}$

$\phi R_{n\_cl\_bs}{}^{T} = (11.138) \cdot kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

Since tensile yielding is the only value desired from D5.1.d, the gross area is the only value required from section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$A_{g\_cl_i} := A_{cl_i}$ Gross area (D3-1)

(a) For tensile yielding in the gross section:

$P_{n\_cl\_ty} := F_{y\_cl} \cdot A_{g\_cl}$ Nominal axial strength (P_n) (D2-1)

$\phi_{t\_ty} := 0.9$ Resistance factor for tension (ϕ_t)

$\phi P_{n\_cl\_ty} := \phi_{t\_ty} \cdot P_{n\_cl\_ty}$

$\phi P_{n\_cl\_ty}^{T} = (14.85) \cdot kip$ Design tensile strength

Shear, capacity of clamp's upper bolt [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$A_{cl\_bolt_i} := \pi \cdot \left(\frac{d_{cl\_bolt_i}}{2}\right)^2$ Nominal unthreaded body area

$A_{cl\_bolt\_ds_i} := 2 \cdot A_{cl\_bolt_i}$ Applicable area for this case since the bolt is in double shear

$F_{nv\_cl\_bolt} := 24ksi$ Nominal shear stress in bearing type connections (A307) [AISC, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment and includes an allowance for threads in the shear plane

$R_{nv\_cl\_bolt_i} := F_{nv\_cl\_bolt} \cdot A_{cl\_bolt\_ds_i}$ Nominal strength (R_n) (J3-1)

$\phi_{b\_sr} := 0.75$ Resistance factor

$\phi R_{nv\_cl\_bolt_i} := \phi_{b\_sr} \cdot R_{nv\_cl\_bolt_i}$

$\phi R_{nv\_cl\_bolt}^{T} = (7.069) \cdot kip$ Design shear strength

EYE ROD

Tension, capacity of eye rod [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$\phi R_{nt\_I} := 10.354kip$ Design tension strength

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CLEVIS

Tension, capacity of clevis's intermediate section [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_cv\_int\_ty} := 19.723kip$ Design tensile strength

(b) For tensile rupture in the net section:

$P_{n\_cv\_int\_tr} := 39.844kip$ Design tensile strength

Tension, capacity of clevis's pin connection [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_cv\_con\_trp} := 17.578kip$ Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_cv\_bolt\_srp} := 23.203kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_cv\_bs} := 20.883kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_cv\_con\_ty} := 26.684kip$ Design tensile strength

Shear, capacity of clevis's pin [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$\phi R_{nv\_bolt} := 15.904kip$ Design shear strength

TAB

Tension, capacity of tab [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$$\phi P_{n\_Tab\_trp} := 71.719\text{kip}$$ Design tensile strength

(b) For shear rupture on the effective area:

$$\phi P_{n\_Tab\_bolt\_srp} := 38.812\text{kip}$$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$$\phi R_{n\_Tab\_bs} := 16.706\text{kip}$$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$$\phi P_{n\_Tab\_ty} := 59.4\text{kip}$$ Design tensile strength

U-BOLT

Tension, capacity of u-bolt [AISC, Ch. J pg 16.1-90 thru 121]

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$$A_{ub_j} := 2 \cdot \left[\pi \cdot \left(\frac{d_{ub_j}}{2}\right)^2\right]$$ Nominal unthreaded body area for BOTH bolts in combination

$$F_{nv\_ub} := 45\text{ksi}$$ Nominal tensile stress (A307) [AISC, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment

$$R_{nv\_ub_j} := F_{nv\_ub} \cdot A_{ub_j}$$ Nominal strength (R_n) (J3-1)

$$\phi_{b\_sr} := 0.75$$ Resistance factor

$$\phi R_{nv\_ub\_NL_j} := \phi_{b\_sr} \cdot R_{nv\_ub_j}$$

$$\boxed{\phi R_{nv\_ub\_NL}{}^T = (20.709 \quad 13.254) \cdot kip}$$ Design tensile strength

PIPE INTERMEDIATE OF GANG SUPPORT

Shear, capacity of intermediate pipe [AISC, Ch. G pg 16.1-68]

$$F_{cr} := \begin{cases} \max\left[\dfrac{1.60 \cdot E_{PS}}{\sqrt{\dfrac{L_v}{D_o} \cdot \left(\dfrac{D_o}{t}\right)^{\frac{5}{4}}}}, \dfrac{0.78 \cdot E_{PS}}{\left(\dfrac{D_o}{t}\right)^{\frac{3}{2}}}\right] & \text{if } \max\left[\dfrac{1.60 \cdot E_{PS}}{\sqrt{\dfrac{L_v}{D_o} \cdot \left(\dfrac{D_o}{t}\right)^{\frac{5}{4}}}}, \dfrac{0.78 \cdot E_{PS}}{\left(\dfrac{D_o}{t}\right)^{\frac{3}{2}}}\right] < 0.6 \cdot F_{y\_PS} \\ 0.6 \cdot F_{y\_PS} & \text{otherwise} \end{cases}$$

$$F_{cr} = 1.98 \times 10^4 \, psi$$

$$\phi_{shear} := 0.9$$

$$V_n := \phi_{shear} \cdot F_{cr} \cdot \frac{A_g}{2}$$

$$V_n = (14.167) \cdot kip$$

Appendix D.9.17

Wall Triangle Support Capacities

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. D. Landon **Date:** 09/30/2008

WALL TRIANGLE SUPPORT CAPACITY

WTB support is anchored from the wall by an angle wall support frame and the remainder of the support is comprised of a 6" adjustable clevis's and a 5/8" rod. It is observed that RH-33 also is comprised of a 6" adjustable clevis and RH-14 is comprised of a 5/8" rod. Therefore this capacity calculation will represent the formerly mentioned supports in determining its own tension capacity and will evaluate the capacity of the angle support from a linear finite element model. (Note: Compression capacity for this support is evaluated in App D.9.2])

Component Capacity Overview:

- Tension Loading:
- Tension capacity of RH-33's adjustable clevis [App D.9.6]
- Tension capacity of RH-14's 5/8" rod [37, App D15]
- Angle support frame

(**Procedures from SEI/ASCE 8-02 (Applying LRFD)**)

Capacities For Downward Loading

ADJUSTABLE CLEVIS'S

Tension, capacity of upper adjustable clevis's pin connection [See [App D.9.6] for calculations associated with results]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_acv\_up\_trp} := (21.094\text{kip})$ Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_acv\_up\_bolt\_srp} := (20.25\text{kip})$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_acv\_up\_bs} := (11.138\text{kip})$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_acv\_up\_ty} := 22.275kip$ Design tensile strength

Tension, capacity of lower adjustable clevis's pin connection [See [App D.9.6] for calculations associated with results]

D1. Slenderness Limitations

D5. Pin-Connected Members

1. Tensile Strength

(a) For tensile rupture on the net effective area:

$\phi P_{n\_acv\_low\_trp} := 15.82kip$ Design tensile strength

(b) For shear rupture on the effective area:

$\phi P_{n\_acv\_low\_bolt\_srp} := 15.187kip$ Design tensile strength

(c) For bearing on the projected area of the pin, see Section J7

J7. Bearing Strength

$\phi R_{n\_acv\_low\_bs} := 8.353kip$ Design bearing strength

(d) For yielding on the gross section ,use Equation D2-1

D2. Tensile Strength

(a) For tensile yielding in the gross section:

$\phi P_{n\_acv\_low\_ty} := 16.706kip$ Design tensile strength

Shear, capacity of adjustable clevis's pin [See [App D.9.6] for calculations associated with results

J3. Bolts and Threaded Parts

6. Tension and shear Strength of Bolts and Threaded Parts

$\phi R_{nv\_acv\_bolt} := 7.069kip$ Design shear strength

ROD

Tension, capacity of rod [See [??, App D15] for calculations associated with these results

J3. Bolts and Threaded Parts

6. Tension and Shear Strength of Bolts and Threaded Parts

$i := 0$ — Assigned indices corresponding to number of support types associated with these calculations

$d_{UI} := \left(\frac{5}{8} in\right)^T$ — Unthreaded diameter of eye rod, in. (mm) [Grinnell, Fig 278 ph-52]

$A_{b\_UI_i} := \pi \cdot \left(\frac{d_{UI_i}}{2}\right)^2$ — Nominal unthreaded body area

$F_{nt\_UI} := 45ksi$ — Nominal tensile stress (A307) [AISC, Table J3.2 pg 16.1-104], A307 was selected as a conservative bolt treatment

$R_{nt\_UI_i} := F_{nt\_UI} \cdot A_{b\_UI_i}$ — Nominal strength (R_n) (J3-1)

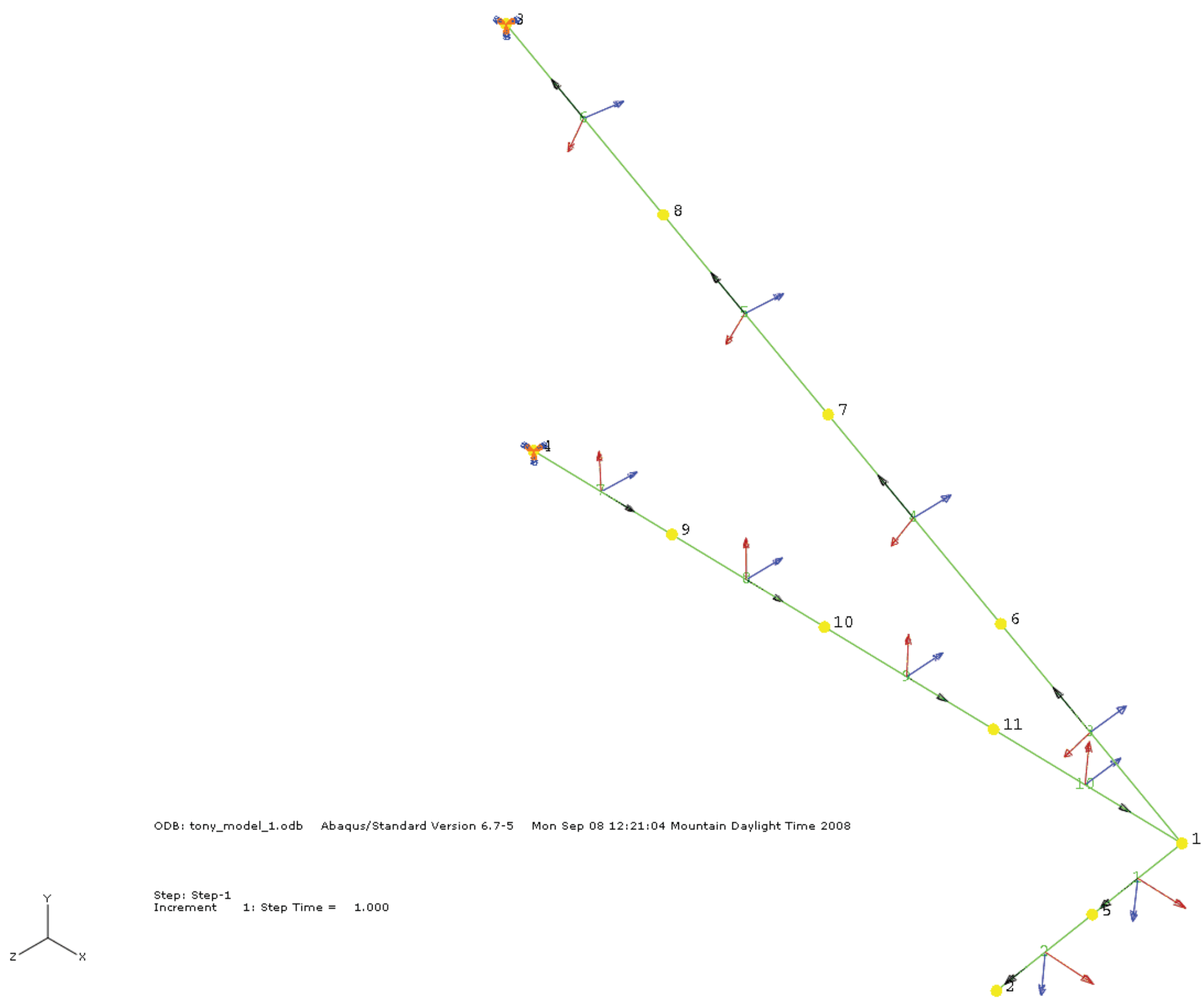
$\phi_{b\_tr} := 0.75$ — Resistance factor

$\phi R_{nt\_UI_i} := \phi_{b\_tr} \cdot R_{nt\_UI_i}$

$\phi R_{nt\_UI}{}^T = (10.354) \cdot kip$ — Design tensile strength

ANGLE FRAME

Finite Element Model



Finite Element Model Results

```
********************************************************************************
Field Output Report, written Mon Sep 08 12:21:52 2008

Source 1
---------

   ODB: C:/Abaqus/AbaqusData/tony_model_1.odb
   Step: Step-1
   Frame: Increment      1: Step Time =    1.000

Loc 1 : Element nodal values from source 1 ( Average criteria = 75%, Not averaged across region boundaries )

Output sorted by column "Element Label".

Field Output reported at element nodes for region: PART-3-1.Region_1
   Computation algorithm: EXTRAPOLATE_COMPUTE_AVERAGE
   Averaged at nodes
   Averaging regions: ODB_REGIONS
```

Element Label	Node Label	NFORC1 @Loc 1	NFORC2 @Loc 1	NFORC3 @Loc 1	NFORC4 @Loc 1	NFORC5 @Loc 1	NFORC6 @Loc 1
1	1	19.8035E-15	-1.	28.8936E-15	4.	9.69784E-15	0.
1	5	-34.6561E-15	1.	-28.8936E-15	0.	45.8756E-15	0.
2	5	-34.6561E-15	-1.	14.5925E-15	0.	45.8756E-15	0.
2	2	49.5087E-15	1.	-14.5925E-15	-43.8538E-15	-160.86E-15	0.
Total		1.69407E-21	0.	0.	4.00000	-59.4104E-15	0.

```
Field Output reported at element nodes for region: PART-3-1.Region_2
   Computation algorithm: EXTRAPOLATE_COMPUTE_AVERAGE
   Averaged at nodes
   Averaging regions: ODB_REGIONS
```

Element Label	Node Label	NFORC1 @Loc 1	NFORC2 @Loc 1	NFORC3 @Loc 1	NFORC4 @Loc 1	NFORC5 @Loc 1	NFORC6 @Loc 1
3	1	-1.59848	993.661E-03	-716.457E-03	-3.55217	-5.4438	-534.532E-03
3	6	1.59848	-993.661E-03	716.457E-03	0.	0.	0.
4	6	-1.59848	993.661E-03	-716.457E-03	0.	0.	0.
4	7	1.59848	-993.661E-03	716.457E-03	0.	0.	0.
5	7	-1.59848	993.661E-03	-716.457E-03	0.	0.	0.
5	8	1.59848	-993.661E-03	716.457E-03	0.	0.	0.
6	8	-1.59848	993.661E-03	-716.457E-03	0.	0.	0.
6	3	1.59848	-993.661E-03	716.457E-03	-2.17948	-4.58659	-588.876E-03
Total		0.	0.	0.	-5.73165	-10.0304	-1.12341

```
Field Output reported at element nodes for region: PART-3-1.Region_3
   Computation algorithm: EXTRAPOLATE_COMPUTE_AVERAGE
   Averaged at nodes
   Averaging regions: ODB_REGIONS
```

Element Label	Node Label	NFORC1 @Loc 1	NFORC2 @Loc 1	NFORC3 @Loc 1	NFORC4 @Loc 1	NFORC5 @Loc 1	NFORC6 @Loc 1
7	4	-1.59848	-6.33939E-03	-716.457E-03	447.827E-03	4.58659	-623.283E-03
7	9	1.59848	0.	716.457E-03	0.	0.	601.096E-03
8	9	-1.59848	0.	-716.457E-03	0.	0.	-601.096E-03
8	10	1.59848	0.	716.457E-03	0.	0.	578.908E-03
9	10	-1.59848	0.	-716.457E-03	0.	0.	-578.908E-03
9	11	1.59848	0.	716.457E-03	0.	0.	556.72E-03
10	11	-1.59848	0.	-716.457E-03	0.	0.	-556.72E-03
10	1	1.59848	6.33939E-03	716.457E-03	-447.827E-03	5.4438	534.532E-03
Total		0.	0.	0.	0.	10.0304	-88.7515E-03

Geometric and Material Properties of Support Components

ANGLE SECTIONS (1-1/2" x 1-1/2" x 3/16" Angle Cross Section)

Material Properties of Angle Sections as Defined in the Material Section of this Report:

$F_{yAngle} := 33ksi$ — Yield Strength for A7 Carbon Steel

$F_{uAngle} := 60ksi$ — Ultimate Strength for A7 Carbon Steel

$E_{Angle} := 29000ksi$ — Modulus of Elasticity for A7 Carbon Steel

Section Properties:

$L1_{Angle} := \left(1\frac{1}{2}in\right)^T$ — Length of top leg of angle section [120931, Detail 15]

$L2_{Angle} := \left(1\frac{1}{2}in\right)^T$ — Length of lower side leg of angle section [120931, Detail 15]

$t_{Angle} := \left(\frac{1}{4}in\right)^T$ — Thickness of angle section [120931, Detail 15]

scaled it to be 1/4in but might actually be 3/16

$A_{Angle} := \left(0.688in^2\right)^T$ — Cross sectional area of angle section [AISC 1958, pg 33]

$r_{Angle\_gyrationXX} := (0.46in)^T$

$r_{Angle\_gyrationYY} := (0.46in)^T$

$r_{Angle\_gyrationZZ} := (0.29in)^T$

Radius of gyration about the geometric neutral axes XX and YY and principal minor Z-Z axis [AISC 1958, pg 32]

$I_{AngleXX} := \left(0.11in^4\right)^T$

$I_{AngleYY} := \left(0.11in^4\right)^T$

Moment of inertia about principle geometric axes [AISC 1958, pg 32]

$I_{AngleZZ_i} := \left(r_{Angle\_gyrationZZ_i}\right)^2 \cdot A_{Angle_i}$ — Moment of inertia about minor Z-Z axis as modified from [Mechanics of Materials, Eqn. 12-10a,b pg 823]

$I_{AngleZZ}^T = (0.058)\,in^4$

$I_{AngleMP_i} := I_{AngleXX_i} + I_{AngleYY_i} - I_{AngleZZ_i}$ — Moment of inertia about major principle axis as derived from Note 6 of [Mechanics of Materials, Table E-5, pg 888]

$I_{AngleMP}^T = (0.162)\,in^4$

$x_{Angle} := (0.44in)^T$ — Distance between geometric neutral axes and outer face of flanges [AISC 1958, pg 32]

$L_{Angle\_Top} := (16.125in)^T$ — Length of top angle member of support frame [120931, Detail 15]

$L_{Angle\_Side} := (3in)^T$ — Length of side angle member of support frame [120931, Detail 15]

$L_{Angle\_Bottom} := (14in)^T$ — Length of bottom angle member of support frame as scaled from [120931, Detail 15]

$L_{Angle} := \left(L_{Angle\_Top_i} \; L_{Angle\_Bottom_i}\right)^T$ — Vector representing three lengths

$q := 0..1$ — Indices used to account for two different sections

ANGLE SECTIONS (1-1/2" x 1-1/2" x 3/16" Angle Cross Section)

Section Properties:

$L1_{CAngle} := (2.5in)^T$ — Length of top leg of angle section [120931, Detail 15]

$L2_{CAngle} := (2.5in)^T$ — Length of lower side leg of angle section [120931, Detail 15]

$t_{CAngle} := \left(\frac{1}{4}in\right)^T$ — Thickness of angle section [120931, Detail 15]

$A_{CAngle} := \left(0.53in^2\right)^T$ — Cross sectional area of angle section [AISC 1958, pg 33]

$r_{CAngle\_gyrationXX} := (0.46in)^T$

$r_{CAngle\_gyrationYY} := (0.46in)^T$

$r_{CAngle\_gyrationZZ} := (0.29in)^T$

Radius of gyration about the geometric neutral axes XX and YY and principal minor Z-Z axis [AISC 1958, pg 32]

$I_{CAngleXX} := \left(0.11in^4\right)^T$

$I_{CAngleYY} := \left(0.11in^4\right)^T$

Moment of inertia about principle geometric axes [AISC 1958, pg 32]

$I_{CAngleZZ_i} := \left(r_{CAngle\_gyrationZZ_i}\right)^2 \cdot A_{CAngle_i}$

$I_{CAngleZZ}^T = (0.045)\,in^4$

Moment of inertia about minor Z-Z axis as modified from [Mechanics of Materials, Eqn. 12-10a,b pg 823]

$I_{CAngleMP_i} := I_{CAngleXX_i} + I_{CAngleYY_i} - I_{CAngleZZ_i}$ Moment of inertia about major principle axis as derived from Note 6 of [Mechanics of Materials, Table E-5, pg 888]

$I_{CAngleMP}^{T} = (0.175)\,in^4$

$x_{CAngle} := (0.44in)^T$ Distance between geometric neutral axes and outer face of flanges [AISC 1958, pg 32]

$L_{CAngle} := (4in)^T$ Vector representing three lengths

U-BOLT (U-Bolt 6")

Note: In this analysis the tensile capacity of the u-bolt will be calculated based on the cross sectional area of both u-bolt legs straddling the pipe. Due to the complexity of u-bolt behavior given lateral loading, the associated capacity was determined based on the [Hawkes] document, where the lateral capacity was shown to be 0.0412 that of the u-bolt's tensile capacity. Given that the resistance factor is equivalent for both tension and shear (ϕ = 0.75) is was determined that the AISC resistance factors would be appropriately applied by multiplying the resulting tensile capacity by the 0.0412 factor stated above. Since this support is only held by one nut this is a conservative estimation as the [Hawkes] document is more applicable for U-Bolts with double nuts.

Material Properties of U-bolt are Defined Immediately Prior to Applicable Calculations for this Support:

Geometric Properties of U-bolt:

$D_{ub} := \left(6\frac{5}{8}in\right)^T$ Diameter of pipe which the u-bolt supports [127033], [Grinnell, Fig 137 ph-55]

$d_{ub} := \left(\frac{5}{8}in\right)^T$ Diameter of u-bolt rod [127033], [Grinnell, Fig 137 ph-55]

Modes that will Propagate into Capacity Calculations for 1.5 x 1.5 x 0.25 Angle (Flexure, Tension, Compression, Shear)

ANGLE SECTIONS

Flexure, capacity of angle section [AISC, Ch. F pg 16.1-44 thru 63]

F1. General Provisions

Given resistance factor for shear

$\phi_b := 0.9$

Calculate the lateral-torsional buckling modification factor for a nonuniform moment loading on the beam caused by loading of the pipe

$M_{max}(F, Length) := F \cdot Length$ Absolute value of maximum moment in the unbraced segment

$M_A(F, Length) := \frac{3}{4} \cdot F \cdot Length$ Absolute value of moment at quarter point of the unbraced segment

$M_B(F, Length) := \frac{1}{2} \cdot F \cdot Length$ Absolute value of moment at centerline of the unbraced segment

$M_C(F, Length) := \frac{1}{4} \cdot F \cdot Length$

Absolute value of moment at three-quarter point of the unbraced segment

$R_m := 1.0$

Cross-section monosymmetry parameter (value of 1.0 is assigned because it correlates to singly symmetric members subjected to single curvature bending)

$$C_b(F, Length) := \left(\frac{12.5 \cdot M_{max}(F, Length)}{2.5 \cdot M_{max}(F, Length) + 3 \cdot M_A(F, Length) + 4 \cdot M_B(F, Length) + 3 \cdot M_C(F, Length)} \cdot R_m \right)$$

$$C_b\left(F, L_{Angle_i}\right) \rightarrow 1.6666666666666666667$$

F10. Single Angles

First determine value between geometric axis of rotation and extreme fiber to determine yielding moment about axis of bending (one for major, one for minor) [AISC, Table 17-27 pg 17-42]

$D_{legs\_m_i} := \left(L1_{Angle_i} - 2 \cdot x_{Angle_i}\right) \cdot \cos\left(\frac{\pi}{4}\right)$

Perpendicular distance from minor axis to end of angle legs

$D_{tip\_m_i} := x_{Angle_i} \cdot \sqrt{2}$

Perpendicular distance from minor axis to outer point where legs meet

$Extreme_{minor_i} := \max\left(D_{legs\_m}, D_{tip\_m}\right)$

Point farthest from the principle minor neutral axis

$$Extreme_{minor}^T = (0.622)\ in$$

$M_{y\_minor_i} := \frac{F_{yAngle} \cdot I_{AngleZZ_i}}{Extreme_{minor_i}}$

Equation to calculate yielding moment about minor axis of rotation from moment of inertia and Extreme values [Mechanics of Materials, Equation 6-74 pg 454]

$$M_{y\_minor}^T = (3.069) \cdot kip \cdot in$$

Yielding Moment for rotation about the principle minor axis

$D_{legs\_M_i} := \frac{L1_{Angle_i}}{\sqrt{2}}$

Perpendicular distance from major axis to each of the angle legs

$Extreme_{Major_i} := \max\left(D_{legs\_M}\right)$

Point farthest from the principle major neutral axis

$$Extreme_{Major}^T = (1.061)\ in$$

$M_{y\_Major_i} := \frac{F_{yAngle} \cdot I_{AngleMP_i}}{Extreme_{Major_i}}$

Equation to calculate yielding moment about major axis of rotation from moment of inertia and Extreme values [Mechanics of Materials, Equation 6-74 pg 454]

$M_{y\_Major} = (5.045) \cdot kip \cdot in$ — Yielding Moment for rotation about the principle major axis

1. Yielding *(Applied to both minor and major axis bending)*

$M_{ny\_minor_i} := 1.5 \cdot M_{y\_minor_i}$

$M_{ny\_minor}^T = (4.603) \cdot kip \cdot in$ — Nominal flexural strength for rotation about minor principle axis

$\phi M_{ny\_minor} := \phi_b \cdot M_{ny\_minor}$

$\boxed{\phi M_{ny\_minor}^T = (4.143) \cdot kip \cdot in}$ — Design flexural strength for rotation about minor principle axis

$M_{ny\_Major_i} := 1.5 \cdot M_{y\_Major_i}$

$M_{ny\_Major}^T = (7.567) \cdot kip \cdot in$ — Nominal flexural strength for rotation about minor principle axis

$\phi M_{ny\_Major} := \phi_b \cdot M_{ny\_Major}$

$\boxed{\phi M_{ny\_Major}^T = (6.81) \cdot kip \cdot in}$ — Design flexural strength for rotation about minor principle axis

2. Lateral-Torsional Buckling *(Applied for major axis bending)*

Calculate the lateral-torsional buckling moment

(iii) For bending about the major principal axis of equal-leg angles:

$$M_{e_q} := \frac{0.46 \cdot E_{Angle} \cdot \left(L1_{Angle_i}\right)^2 \cdot \left(t_{Angle_i}\right)^2 \cdot C_b\left(F, L_{Angle_q}\right)}{L_{Angle_q}} \qquad \text{(F10-5)}$$

$M_e^T = (193.895 \quad 223.326) \cdot kip \cdot in$

For single angles without continuous lateral-torsional restraint along the length

(a & b) calculation

$$M_{nLTB_q} := \begin{cases} \left(0.92 - \dfrac{0.17 \cdot M_{e_q}}{M_{y\_Major_i}}\right) \cdot M_{e_q} & \text{if } M_{e_q} \le M_{y\_Major_i} \\ \left(1.92 - 1.17 \cdot \sqrt{\dfrac{M_{y\_Major_i}}{M_{e_q}}}\right) \cdot M_{y\_Major_i} & \text{if } M_{e_q} > M_{y\_Major_i} \\ 1.5 \cdot M_{y\_Major_i} \text{ if } 1.5 M_{y\_Major_i} \le \left(1.92 - 1.17 \cdot \sqrt{\dfrac{M_{y\_Major_i}}{M_{e_q}}}\right) \cdot M_{y\_Major_i} & \text{if } M_{e_q} > M_{y\_Major_i} \end{cases}$$

$M_{nLTB}^{T} = (7.567 \quad 7.567) \cdot kip \cdot in$ Nominal flexural strength

$\phi M_{nLTB} := \phi_b \cdot M_{nLTB}$

$\boxed{\phi M_{nLTB}^{T} = (6.81 \quad 6.81) \cdot kip \cdot in}$ Design flexural strength for flexure about major principle axis for top, side, and bottom angle sections

3. Leg Local Buckling

Determine if supports are ***compact (1), non-compact (2),*** *or* ***slender (3)***

B4. Classification of sections for local buckling (See Case 6 of Table B4.1)

$$b2t_i := \frac{L1_{Angle_i}}{t_{Angle_i}}$$

Width to thickness ratio

$b2t^{T} = (6)$

Definition of λ_p and λ_r from Table B4.1 Case 6 (Flexure in legs of single angles) to be applied in classification logic. λ_p is the separation point between a compact and noncompact member. λ_r is separation point between a noncompact and slender member.

$$\lambda_p := 0.54 \cdot \sqrt{\frac{E_{Angle}}{F_{yAngle}}} \qquad \lambda_r := 0.91 \cdot \sqrt{\frac{E_{Angle}}{F_{yAngle}}}$$

$$Classification_i := \begin{cases} 1 & \text{if } b2t_i \le \lambda_p \\ 2 & \text{if } \lambda_p < b2t_i \le \lambda_r \\ 3 & \text{if } \lambda_r < b2t_i \end{cases}$$

$$Classification^T = (1)$$

(a) For compact sections, the limit state of leg local buckling does not apply.

Find the minimum capacity for flexure

$$\phi M_{n\_minor_i} := \min\left(\phi M_{ny\_minor_i}\right)$$ Capacity for flexure about minor axis

$$\boxed{\phi M_{n\_minor}^T = (4.143) \cdot kip \cdot in}$$

$$\phi M_{n\_Major_q} := \min\left(\phi M_{ny\_Major_i}, \phi M_{nLTB_q}\right)$$ Capacity for flexure about minor axis

$$\boxed{\phi M_{n\_Major}^T = (6.81 \quad 6.81) \cdot kip \cdot in}$$

Tension, capacity of angle section [AISC, Ch. D pg 16.1-26 thru 31]

D1. Slenderness Limitations

There is no maximum slenderness limit for design of members in tension

D2. Tensile Strength

Must apply section D3. "Area Determination" prior to applying D2. "Tensile Strength"

D3. Area Determination

1. Gross Area

$$A_{g\_Angle_i} := A_{Angle_i}$$ Gross area

2. Net Area

$$A_{n\_Angle_i} := A_{g\_Angle_i}$$ Net area

3. Effective Net Area

$$U_{Angle} := 0.6$$ Shear lag factor
[AISC, Table D3.1 (case 8) pg 16.1-29]

$$A_{e\_Angle_i} := A_{n\_Angle_i} \cdot U_{Angle}$$ Effective net area

(a) For tensile yielding in the gross section:

$P_{n\_Angle\_ty} := F_{yAngle} \cdot A_{g\_Angle}$ — Nominal axial strength (P_n)

$\phi_{t\_ty} := 0.9$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_Angle\_ty} := \phi_{t\_ty} \cdot P_{n\_Angle\_ty}$

$\phi P_{n\_Angle\_ty}{}^{T} = (20.434) \cdot kip$ — Design tensile strength

(b) For tensile rupture in the net section:

$P_{n\_Angle\_tr} := F_{uAngle} \cdot A_{e\_Angle}$ — Nominal axial strength (P_n)

$\phi_{t\_tr} := 0.75$ — Resistance factor for tension (ϕ_t)

$\phi P_{n\_Angle\_tr} := \phi_{t\_tr} \cdot P_{n\_Angle\_tr}$

$\phi P_{n\_Angle\_tr}{}^{T} = (18.576) \cdot kip$ — Design tensile strength

Find the minimum capacity for tension

$\phi P_{n\_Angle\_t_i} := \min\left(\phi P_{n\_Angle\_ty_i}, \phi P_{n\_Angle\_tr_i}\right)$

$\phi P_{n\_Angle\_t}{}^{T} = (18.576) \cdot kip$ — Absolute tensile strength

Compression, capacity of angle section [AISC, Ch. E pg 16.1-32 thru 43]

E1. General Provisions

$\phi_c := 0.9$ — Resistance factor for compression

E2. Slenderness Limitations and Effective Length

Apply E5 to determine the slenderness ratio (KL/r) for single angles

E5. Single Angle Compression Members

The nominal compressive strength of single angle members shall be determined in accordance with Section E3 (compressive Strength for Flexural Buckling of Members Without Slender Elements) or Section E7 (Members with Slender Elements), as appropriate, for axially loaded members, as well as those subject to the slenderness modification of Section E5(a) or E5(b), provided the members meet the criteria imposed.

The effects of eccentricity on single angle members are permitted to be neglected when the members are evaluated as axially loaded compression members using the effective slenderness ratios specified below, provided that : (1) members are loaded at the ends in compression through the same one leg; (2) members are attached by welding or by minimum two-bolt connections; and (3) there are not intermediate transverse loads.

*Determine if supports are **compact (1), non-compact (2),** or **slender (3)** to determine if it is appropriate to apply E3 or E7*

B4. Classification of sections for local buckling (See Case 6 of Table B4.1)

$$b2t_i := \frac{L1_{Angle_i}}{t_{Angle_i}}$$

Width to thickness ratio

$$b2t^T = (6)$$

Definition of λ_p and λ_r from Table B4.1 Case 6 (Flexure in legs of single angles) to be applied in classification logic. λ_p is the separation point between a compact and noncompact member. λ_r is separation point between a noncompact and slender member.

$$\lambda_p := 0.54 \cdot \sqrt{\frac{E_{Angle}}{F_{yAngle}}} \qquad \lambda_r := 0.91 \cdot \sqrt{\frac{E_{Angle}}{F_{yAngle}}}$$

$$Classification_i := \begin{cases} 1 & \text{if } b2t_i \le \lambda_p \\ 2 & \text{if } \lambda_p < b2t_i \le \lambda_r \\ 3 & \text{if } \lambda_r < b2t_i \end{cases}$$

$$Classification^T = (1)$$

Since the angle sections are determined to be compact E3 is applicable

(a) For equal-leg angles or unequal leg angles connected through the longer leg that are individual members or are web members of planar trusses with adjacent web members attached to the same side of the gusset plate or chord:

These calculations are with reference to the neutral geometric axes

$$L2r_q := \frac{L_{Angle_q}}{r_{Angle\_gyrationXX_i}}$$

Length to radius of gyration ratio

$$KLr_q := \begin{cases} 72 + 0.75 \cdot L2r_q & \text{if } L2r_q \le 80 \\ 32 + 1.25 \cdot L2r_q & \text{if } L2r_q > 80 \end{cases}$$

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E3. Compressive Strength for Flexural Buckling of Members Without Slender Elements (verified through classification)

$$F_{e_q} := \frac{\pi^2 E_{Angle}}{\left(KLr_q\right)^2}$$

F_e is the elastic critical buckling stress

$$F_e^T = (29.626 \quad 31.83) \cdot ksi$$

Calculating the variables Limit, Op1, and Op2 to be utilized in logic to determine flexural buckling stress.

$$Limit := 4.71 \cdot \sqrt{\frac{E_{Angle}}{F_{yAngle}}} \qquad Op1_q := \left(0.658^{\frac{F_{yAngle}}{F_{e_q}}}\right) F_{yAngle} \qquad Op2_q := 0.877 \cdot F_{e_q}$$

$$Limit = 139.625$$

$$F_{cr_q} := \begin{vmatrix} Op1_q & \text{if } KLr_q \le Limit \\ Op2_q & \text{if } KLr_q > Limit \end{vmatrix}$$

F_{cr} is the flexural buckling stress

$$F_{cr}^T = (20.703 \quad 21.383) \cdot ksi$$

$$\phi P_{n\_Angle\_c_q} := \phi_c \cdot F_{cr_q} \cdot A_{Angle_i}$$

$$\boxed{\phi P_{n\_Angle\_c}^T = (12.819 \quad 13.24) \cdot kip}$$

Design compressive strength

Shear, capacity of angle cross section [AISC, Ch. G pg 16.1-64 thru 69]

G1. General Provisions

$$\phi_v := 0.9$$

Resistance factor for shear

G4. Single Angles

The nominal shear strength, V_n, of a single angle leg shall be determined using equation G2-1 with C_v = 1.0, A_w = bt where b = width of the leg resisting the shear force, in. (mm) and k_v = 1.2.

$$C_v := (1.0)^T$$

Web shear coefficient

$$A_{w_i} := L1_{Angle_i} \cdot t_{Angle_i}$$

Web area *(Since $L1_{Angle}$ = $L2_{Angle}$ this is applicable regardless of which leg is resisting the shear.*

$$k_v := (1.2)^T$$

Web plate buckling coefficient

$V_{n_i} := 0.6 \cdot F_{yAngle} \cdot A_{w_i} \cdot C_{v_i}$

$V_n^T = (7.425) \cdot kip$ Nominal shear strength

$\phi V_n := \phi_v \cdot V_n$

$\phi V_n^T = (6.682) \cdot kip$ Design shear strength

Capacities Due to Downward Loading for 1.5 x 1.5 x 3/16" sections

ANGLE SECTIONS

Flexure + Tension, capacity of element 3 (node 1) [AISC, Ch. H pg 16.1-70 thru 76]

$f_{T\_DL\_e6n2} := 0.716$

$f_{F\_DLy\_e6n2} := 3.55in$

$f_{F\_DLz\_e6n2} := 5.4438in$

Factor relating capacity to applied loading generated by finite element model [App D18A, pg D18A-6]

$$\phi AF_{FT\_DL\_e6n2} := \frac{1}{\frac{f_{T\_DL\_e6n2}}{\phi P_{n\_Angle\_t_0}} + \frac{8}{9} \cdot \left(\frac{f_{F\_DLy\_e6n2}}{\phi M_{n\_minor_0}} + \frac{f_{F\_DLz\_e6n2}}{\phi M_{n\_Major_0}} \right)}$$

Applied Force capacity for flexure + tension (H1-1a)

$\phi AF_{FT\_DL\_e6n2} = 0.662 \cdot kip$

Shear, capacity of elements 3, 4, 5, & 6 (nodes 1, 6, 7, 8, & 3) [AISC, Ch. G pg 16.1-64 thru 69]

AISC's shear provisions for single angles [AISC, Ch. G4, pg 16.1-68] only provides treatment for loading applied in the direction of the geometric axes. The shear ratios provided from part A of this Appendix provides the shear ratios along the major and minor principle axes. Therefore a rotation matrix rotating the system by π/4 radians was applied to generate the equivalent shear ratios along the geometric axes and the maximum of these was applied to the above calculated shear capacity of one leg in order to relate the shear capacity to the applied loading. Since this coordinate transformation would generate equivalent results despite the leg which the shear load was applied or the direction which it is applied the absolute values of the shear factors were applied as the principle axes.

$f_{S\_DLy\_e9n11} := 1.59$

Factor relating capacity to applied principle minor y-axis shear loading generated by finite element model [App D18A, pg D18A-6]

$f_{S\_DLz\_e9n11} := 0.993$

Factor relating capacity to applied principle major z-axis shear loading generated by finite element model [App D18A, pg D18A-6]

Converting primary axis shear loading to geometric axis shear loading using rotation matrix rotation by $\pi / 4$ radians

$$f_{S\_DLmax\_e9n11} := \max\left(f_{S\_DLy\_e9n11}, f_{S\_DLz\_e9n11}\right)$$

$$f_{S\_DLmax\_e9n11} = 1.59$$

$$\phi AF_{S\_DL\_e9n11} := \frac{\phi V_{n_i}}{f_{S\_DLmax\_e9n11}}$$

$$\boxed{\phi AF_{S\_DL\_e9n11} = 4.203 \cdot kip}$$

Applied Force capacity for shear

Flexure + Compression, capacity of elements 7, 8, 9, & 10 (nodes 4, 9 , 10 ,11, & 1) [AISC, Ch. H pg 16.1-70 thru 76]

$$f_{C\_DL\_e11n4} := 0.716$$

$$f_{F\_DLy\_e11n4} := 0.447in$$

$$f_{F\_DLz\_e11n4} := 4.58659in$$

Factor relating capacity to applied loading generated by finite element model [App D18A, pg D18A-6]

$$\phi AF_{FC\_DL\_e11n4} := \frac{1}{\frac{f_{C\_DL\_e11n4}}{\phi P_{n\_Angle\_c_1}} + \frac{8}{9} \cdot \left(\frac{f_{F\_DLy\_e11n4}}{\phi M_{n\_minor_0}} + \frac{f_{F\_DLz\_e11n4}}{\phi M_{n\_Major_1}}\right)}$$

Applied Force capacity for flexure + compression

$$\boxed{\phi AF_{FC\_DL\_e11n4} = 1.336 \cdot kip}$$

(H1-1a)

Modes that will Propagate into Capacity Calculations for 2.5 x 2.5 x 0.25 Angle (Flexure, Tension, Compression, Shear)

ANGLE SECTIONS

Flexure, capacity of angle section [AISC, Ch. F pg 16.1-44 thru 63]

F1. General Provisions

Given resistance factor for shear

$\phi_b := 0.9$

Calculate the lateral-torsional buckling modification factor for a nonuniform moment loading on the beam caused by loading of the pipe

$M_{max}(F, Length) := F \cdot Length$ — Absolute value of maximum moment in the unbraced segment

$M_A(F, Length) := \frac{3}{4} \cdot F \cdot Length$ — Absolute value of moment at quarter point of the unbraced segment

$M_B(F, Length) := \frac{1}{2} \cdot F \cdot Length$ — Absolute value of moment at centerline of the unbraced segment

$M_C(F, Length) := \frac{1}{4} \cdot F \cdot Length$ — Absolute value of moment at three-quarter point of the unbraced segment

$R_m := 1.0$ — Cross-section monosymmetry parameter (value of 1.0 is assigned because it correlates to singly symmetric members subjected to single curvature bending)

$$C_b(F, Length) := \left(\frac{12.5 \cdot M_{max}(F, Length)}{2.5 \cdot M_{max}(F, Length) + 3 \cdot M_A(F, Length) + 4 \cdot M_B(F, Length) + 3 \cdot M_C(F, Length)} \cdot R_m\right)$$

$$C_b\left(F, L_{Angle_i}\right) \rightarrow 1.6666666666666666667$$

F10. Single Angles

First determine value between geometric axis of rotation and extreme fiber to determine yielding moment about axis of bending (one for major, one for minor) [AISC, Table 17-27 pg 17-42]

$D_{legs\_m_i} := \left(L1_{CAngle_i} - 2 \cdot x_{CAngle_i}\right) \cdot \cos\left(\frac{\pi}{4}\right)$ — Perpendicular distance from minor axis to end of angle legs

$D_{tip\_m_i} := x_{CAngle_i} \cdot \sqrt{2}$ — Perpendicular distance from minor axis to outer point where legs meet

$Extreme_{minor_i} := \max(D_{legs\_m}, D_{tip\_m})$

Point farthest from the principle minor neutral axis

$Extreme_{minor}^T = (1.146)\ in$

$M_{y\_minor_i} := \frac{F_{yAngle} \cdot I_{CAngleZZ_i}}{Extreme_{minor_i}}$

Equation to calculate yielding moment about minor axis of rotation from moment of inertia and Extreme values [Mechanics of Materials, Equation 6-74 pg 454]

$M_{y\_minor}^T = (1.284) \cdot kip \cdot in$

Yielding Moment for rotation about the principle minor axis

$D_{legs\_M_i} := \frac{L1_{CAngle_i}}{\sqrt{2}}$

Perpendicular distance from major axis to each of the angle legs

$Extreme_{Major_i} := \max(D_{legs\_M})$

Point farthest from the principle major neutral axis

$Extreme_{Major}^T = (1.768)\ in$

$M_{y\_Major_i} := \frac{F_{yAngle} \cdot I_{CAngleMP_i}}{Extreme_{Major_i}}$

Equation to calculate yielding moment about major axis of rotation from moment of inertia and Extreme values [Mechanics of Materials, Equation 6-74 pg 454]

$M_{y\_Major} = (3.275) \cdot kip \cdot in$

Yielding Moment for rotation about the principle major axis

1. Yielding *(Applied to both minor and major axis bending)*

$M_{ny\_minor_i} := 1.5 \cdot M_{y\_minor_i}$

Nominal flexural strength for rotation about minor principle axis

$M_{ny\_minor}^T = (1.926) \cdot kip \cdot in$

$\phi M_{ny\_minor} := \phi_b \cdot M_{ny\_minor}$

$\phi M_{ny\_minor}^T = (1.733) \cdot kip \cdot in$

Design flexural strength for rotation about minor principle axis

$M_{ny\_Major_i} := 1.5 \cdot M_{y\_Major_i}$

Nominal flexural strength for rotation about minor principle axis

$M_{ny\_Major}^T = (4.912) \cdot kip \cdot in$

$$\phi M_{ny\_Major} := \phi_b \cdot M_{ny\_Major}$$

$$\boxed{\phi M_{ny\_Major}{}^T = (4.421) \cdot kip \cdot in}$$

Design flexural strength for rotation about minor principle axis

2. Lateral-Torsional Buckling *(Applied for major axis bending)*

Calculate the lateral-torsional buckling moment

(iii) For bending about the major principal axis of equal-leg angles:

$$M_{e_q} := \frac{0.46 \cdot E_{Angle} \cdot \left(L1_{CAngle_i}\right)^2 \cdot \left(t_{CAngle_i}\right)^2 \cdot C_b\left(F, L_{CAngle_0}\right)}{L_{CAngle_0}} \qquad \text{(F10-5)}$$

$$M_e{}^T = \left(2.171 \times 10^3 \quad 2.171 \times 10^3\right) \cdot kip \cdot in$$

For single angles without continuous lateral-torsional restraint along the length

(a & b) calculation

$$M_{nLTB_q} := \begin{array}{|l} \left(0.92 - \frac{0.17 \cdot M_{e_q}}{M_{y\_Major_i}}\right) \cdot M_{e_q} \ \text{ if } M_{e_q} \le M_{y\_Major_i} \\ \left(1.92 - 1.17 \cdot \sqrt{\frac{M_{y\_Major_i}}{M_{e_q}}}\right) \cdot M_{y\_Major_i} \ \text{ if } M_{e_q} > M_{y\_Major_i} \\ 1.5 \cdot M_{y\_Major_i} \ \text{ if } 1.5 M_{y\_Major_i} \le \left(1.92 - 1.17 \cdot \sqrt{\frac{M_{y\_Major_i}}{M_{e_q}}}\right) \cdot M_{y\_Major_i} \ \text{ if } M_{e_q} > M_{y\_Major_i} \end{array}$$

$$M_{nLTB}{}^T = (4.912 \quad 4.912) \cdot kip \cdot in$$ Nominal flexural strength

$$\phi M_{nLTB} := \phi_b \cdot M_{nLTB}$$

$$\boxed{\phi M_{nLTB}{}^T = (4.421 \quad 4.421) \cdot kip \cdot in}$$

Design flexural strength for flexure about major principle axis for top, side, and bottom angle sections

3. Leg Local Buckling

Determine if supports are ***compact (1), non-compact (2),*** *or* ***slender (3)***

B4. Classification of sections for local buckling (See Case 6 of Table B4.1)

$$b2t_i := \frac{L1_{CAngle_i}}{t_{CAngle_i}}$$

Width to thickness ratio

$$b2t^T = (10)$$

Definition of λ_p and λ_r from Table B4.1 Case 6 (Flexure in legs of single angles) to be applied in classification logic. λ_p is the separation point between a compact and noncompact member. λ_r is separation point between a noncompact and slender member.

$$\lambda_p := 0.54 \cdot \sqrt{\frac{E_{Angle}}{F_{yAngle}}} \qquad \lambda_r := 0.91 \cdot \sqrt{\frac{E_{Angle}}{F_{yAngle}}}$$

$$Classification_i := \begin{cases} 1 & \text{if } b2t_i \le \lambda_p \\ 2 & \text{if } \lambda_p < b2t_i \le \lambda_r \\ 3 & \text{if } \lambda_r < b2t_i \end{cases}$$

$$Classification^T = (1)$$

(a) For compact sections, the limit state of leg local buckling does not apply.

Find the minimum capacity for flexure

$$\phi M_{n\_minor_i} := \min\left(\phi M_{ny\_minor_i}\right)$$

Capacity for flexure about minor axis

$$\boxed{\phi M_{n\_minor}^T = (1.733) \cdot kip \cdot in}$$

$$\phi M_{n\_Major_q} := \min\left(\phi M_{ny\_Major_i}, \phi M_{nLTB_q}\right)$$

Capacity for flexure about minor axis

$$\boxed{\phi M_{n\_Major}^T = (4.421 \quad 4.421) \cdot kip \cdot in}$$

Shear, capacity of angle cross section [AISC, Ch. G pg 16.1-64 thru 69]

G1. General Provisions

$\phi_v := 0.9$ Resistance factor for shear

G4. Single Angles

The nominal shear strength, V_n, of a single angle leg shall be determined using equation G2-1 with C_v = 1.0, A_w = bt where b = width of the leg resisting the shear force, in. (mm) and k_v = 1.2.

$C_v := (1.0)^T$ Web shear coefficient

$A_{w_i} := L1_{CAngle_i} \cdot t_{CAngle_i}$ Web area *(Since $L1_{Angle}$ = $L2_{Angle}$ this is applicable regardless of which leg is resisting the shear.*

$k_v := (1.2)^T$ Web plate buckling coefficient

$V_{n_i} := 0.6 \cdot F_{yAngle} \cdot A_{w_i} \cdot C_{v_i}$

$V_n^T = (12.375) \cdot kip$ Nominal shear strength

$\phi V_n := \phi_v \cdot V_n$

$\phi V_n^T = (11.137) \cdot kip$ Design shear strength

Capacities Due to Downward Loading for 1.5 x 1.5 x 3/16" sections

ANGLE SECTIONS

Shear, capacity of element 1 (node 1) [AISC, Ch. G pg 16.1-64 thru 69]

AISC's shear provisions for single angles [AISC, Ch. G4, pg 16.1-68] only provides treatment for loading applied in the direction of the geometric axes. The shear ratios provided from part A of this Appendix provides the shear ratios along the major and minor principle axes. Therefore a rotation matrix rotating the system by π/4 radians was applied to generate the equivalent shear ratios along the geometric axes and the maximum of these was applied to the above calculated shear capacity of one leg in order to relate the shear capacity to the applied loading. Since this coordinate transformation would generate equivalent results despite the leg which the shear load was applied or the direction which it is applied the absolute values of the shear factors were applied as the principle axes.

$f_{S\_DLy\_e9n11} := 1$ Factor relating capacity to geometric vertical axis [App D18A, pg D18A-6]

Converting primary axis shear loading to geometric axis shear loading using rotation matrix rotation by π / 4 radians

$$f_{S\_DLmax\_e9n11} := \max\left(f_{S\_DLy\_e9n11}, f_{S\_DLz\_e9n11}\right)$$

$$f_{S\_DLmax\_e9n11} = 1$$

$$\phi AF_{S\_DL\_e9n11} := \frac{\phi V_{n_i}}{f_{S\_DLmax\_e9n11}}$$

$$\boxed{\phi AF_{S\_DL\_e9n11} = 11.137 \cdot kip}$$

Applied Force capacity for shear

Appendix D.9.18

Anchorage Refinements Associated With Model 1-4

Anchorage Refinement

The purpose of this section is to perform analysis refinement of select anchorage capacities, previously determined in a previous analysis [37, Appendix E7]. Reference numbering (shown following) corresponds to references as defined in previous analysis [37].

From previous capacity analysis [37, Appendices E4 & E7]. Will depict references as {xx}, using different brackets.:

Common Weld parameters

$Fy_{cs} := 33 \cdot ksi$ $Fu_{cs} := 60 \cdot ksi$ Minimum yield and tensile strengths of ASTM A7 {1} carbon steel, used to evaluate support and anchorage structures.

$F_{exx} := 60 \cdot ksi$ E6010 & E6011 weld filler electrode ultimate strength {2}

$Fy_{a36} := 36 \cdot ksi$ Minimum material yield and tensile strengths of ASTM A36 {17} carbon steel, used to evaluate some anchorage structures.

$Fu_{a36} := 58 \cdot ksi$

$\phi_{fw} := 0.75$ Fillet weld resistance factor {3, Table J2.5}

$F_w = 0.6 \cdot F_{exx} \cdot \left(1.0 + 0.5 \cdot \sin(\theta)^{1.5}\right)$ Nominal strength of the weld metal {3, eqn J2-5}

For => $\theta := 0 \cdot deg$

$F_{wl} := \left[0.6 \cdot F_{exx} \cdot \left(1.0 + 0.5 \cdot \sin(\theta)^{1.5}\right)\right]$ $F_{wl} = 36\,ksi$ Nominal strength for longitudinal loaded fillet welds

For => $\theta := 90 \cdot deg$

$F_{wt} := \left[0.6 \cdot F_{exx} \cdot \left(1.0 + 0.5 \cdot \sin(\theta)^{1.5}\right)\right]$ $F_{wt} = 54\,ksi$ Nominal strength for transversely loaded fillet welds

$Rt_w := \frac{F_{wt}}{F_{wl}}$ $Rt_w = 1.5$ Strength capacity ratio of transverse to longitudinal welds

As indicated above, transverse welds provide 50% strength capacity increase over that of longitudinal welds.

Note - If there are combinations of longitudinal and transverse segments within the same weld pattern, Fwl (longitudinal nominal strength) will be used to determine corresponding weld capacities. Also, if the weld is loaded in differing orthogonal directions, Fwl is used to determine weld capacities.

$A_w := \frac{\sqrt{2}}{2} \cdot \frac{1}{16} \cdot in^2$ $\quad A_w = 0.044\ in^2$ Area of 1/16-in fillet per inch of weld

Let => $Rn_w := F_{wl} \cdot A_w$ $\quad Rn_w = 1.591\ kip$ Nominal strength of weld {3, eqn J2-4} to be used for longitudinal and mixed weld patterns.

$Vn_w := \phi_{fw} \cdot Rn_w$ $\quad Vn_w = 1.19\ kip$ Nominal shear strength of longitudinal & mixed fillet per 1/16-in of weld per inch {3, Table J2.5}

$Vnt_w := Rt_w \cdot Vn_w$ $\quad Vnt_w = 1.79\ kip$ Nominal shear strength of transverse fillet per 1/16-in of weld per inch {3, Table J2.5}

Steel Plate Embed parameters

$w_{emb} := 4 \cdot in$ $\quad t_{emb} := 0.5 \cdot in$ Width and thickness of steel plate embed {4, det. 25} that anchorage welds are attached to.

When the load acts in same direction as the axis of the weld, the base metal (or steel plate embed) capacity must also be considered to determine which condition is limiting.

$\phi F_{cs} := 0.9 \cdot 0.6 \cdot Fy_{cs}$ $\quad \phi F_{cs} = 17.82\ ksi$ Nominal shear strength of steel plate embed (or base material) {30, p. 345}.

$Rn_{emb} := w_{emb} \cdot t_{emb} \cdot \phi F_{cs}$ Nominal shear strength of steel plate embed along width {30, eqn 7.23}.

$Rn_{emb} = 35.64\ kip$

When the resultant load acts in differing directions (i.e., out of plane) to the weld axis, the steel plate embed anchorage governs the design strength capacity of weld. All weld resultant loads are SRSS using methods as defined by Blodgett {6, p. 7.4-7}.

$\phi t_{emb} := 11.25 \cdot kip$ Design pull-out strength of steel plate embed's anchor in tension and shear, obtained from Appendix C [37].

$\phi s_{emb} := 12.188 \cdot kip$

$Lemb_{anc} := 1 \cdot ft$ Anchor spacing along steel plate embed

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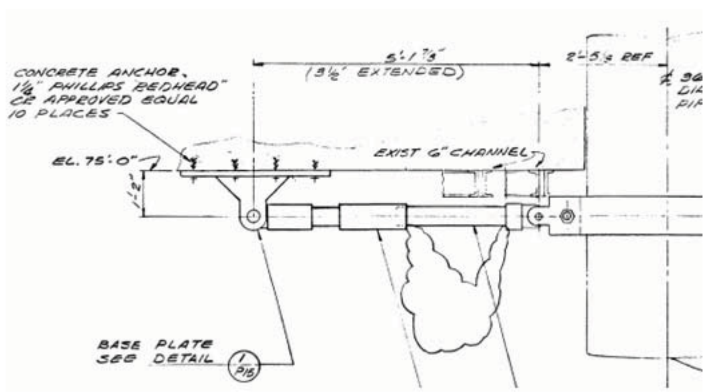
$n\phi t_{emb} := 9.38 \cdot kip$

$n\phi s_{emb} := 12.188 \cdot kip$

Design axial and shear capacity for a group of steel plate embed anchors remote from edges, obtained from Appendix C [37]. The "n" corresponds to number of anchors overlapped.

MS-3, (Type 43) Anchorage

Support MS-3 [23, det. 3] is a horizontal mechanical snubber that is anchored through a clevis structure [20, det. 1] to the ceiling. The snubbers is rated for 50-kips [19, PSA-35]. The clevis structure is anchored with ten 1-1/4 Phillips Redhead bolts. However, inspection of the anchors revealed that three anchors were loose and would not accept torque (See NCR 42043). For the analysis that follows, these three anchors are assumed to have no tensile or shear capacity. The locations of the loose bolts are shown in the figure below. The snubber is loaded in the N-S direction.



Common Anchor Structure parameters

$\phi_t := 0.75$ Resistance factor for tensile rupture [3, Sect. D2]

$\phi_{sf} := 0.75$ Resistance factor for shear rupture [3, Sect. D5]

$\phi := 0.75$ Resistance factor for bearing [3, Sect. J7]

$\phi_b := 0.9$ Resistance factor for flexure [3, Sect. F1]

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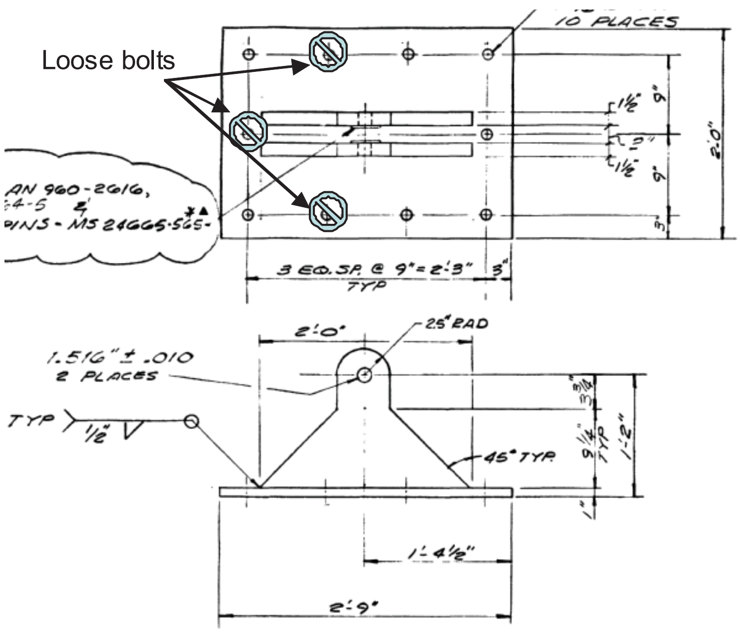
$db_{ms3} := 1.25 \cdot in$ Anchor bolt diameter

Anchor bolts - In the N-S direction, the studs are subject to shear and pull-out, as a result of the clevis plate pivoting about its short side edge and prying the bolts outward.

$Pall_{ms3} := 4.89 \cdot kip$ Allowable pull-out strength capacity of single anchor is the same as computed for MS-2.

$Pbt_{ms3} := 1 \cdot Pall_{ms3}$ $Pbt_{ms3} = 4.89\,kip$ Pull-out strength capacity of a single MS-3 anchor.



$$Pbtp_{ms3} := \frac{Pbt_{ms3} \cdot (70.5 \cdot in)}{(14 \cdot in)}$$

Taking moments about the front plate edge and assuming that the load in each bolt is proportional to the distance from the edge. Maximum lateral load that may be placed on clevis, based on anchor pull-out capacity.

$Pbtp_{ms3} = 24.625\,kip$

Maximum shear capacity of anchor bolts are determined, using DOE/EH-0545 [13, Section 6.3].

$Ls_{ms3} := 9 \cdot in$ Center-to-center anchor spacing [20, det. 1]

$\frac{Ls_{ms3}}{2 \cdot db_{ms3}} = 3.6$ => $RSs_{ms2} := 1.0$ Spacing reduction factor [13, Sect. 6.3.4.1]

$Vnom_{ms3} := \frac{44.385 \cdot kip}{3}$ Nominal shear load of 1-1/4 Redhead Trubolt, with minimum embedment and based on 4,000-psi concrete ultimate strength [24] divided by factor of 3.

$Vnom_{ms3} = 14.795\,kip$

$RF_s := 0.95$

$Vall_{ms3} := Vnom_{ms3} \cdot RF_s \cdot (1)$ $Vall_{ms3} = 14.055\,kip$ Allowable shear capacity of single anchor

$Vsb_{ms3} := 7 \cdot Vall_{ms3}$ $Vsb_{ms3} = 98.387\,kip$ Maximum shear strength capacity of MS-3 anchors.

$\frac{Pbtp_{ms3}}{Vsb_{ms3}} = 0.25$ $Pbtp_{ms3} = 24.625\,kip$ Anchor pull-out capacity governs

Determine MS-3 clevis structure limiting capacity:

$tc_{ms3} := 1.5 \cdot in$ $dch_{ms3} := 1.526 \cdot in$ Clevis plate thickness, hole diameter, & width at top and bottom.

$wct_{ms3} := 5 \cdot in$ $wcb_{ms3} := 2 \cdot ft$

The design tensile strength of pin-connected members shall be the lower value obtained according to the limit states of tensile rupture, shear rupture (also known as tear-out) bearing, and yielding [3, Sect. D5.1]. Yielding need not be checked, for the clevis plate (for this application) is subjected to bending and not tension.

Clevis plates tensile rupture on net effective area

$ac_{ms3} := \frac{wct_{ms3} - dch_{ms3}}{2}$ $ac_{ms3} = 1.737\,in$ Shortest distance from hole edge to clevis plate edge, in direction of tensile load.

$bceff_{ms3} := if\left[2 \cdot tc_{ms3} + 0.63 \cdot in \le ac_{ms3}, \left(2 \cdot tc_{ms3} + 0.63 \cdot in\right), ac_{ms3}\right]$

$bceff_{ms3} = 1.737\,in$

Nominal tensile rupture

$Pcnt_{ms3} := 2 \cdot tc_{ms3} \cdot bceff_{ms3} \cdot Fu_{cs}$ $Pcnt_{ms3} = 312.66\,kip$ strength capacity [3, eqn D5-1]

$Pcntr_{ms3} := 2\,\phi_t \cdot Pcnt_{ms3}$ $Pcntr_{ms3} = 468.99\,kip$ Design tensile rupture strength capacity for 2x clevis plates

Check shear rupture of clevis at pinned connection:

$Acsf_{ms3} := 2 \cdot tc_{ms3} \cdot \left(ac_{ms3} + \frac{dch_{ms3}}{2}\right)$ $Acsf_{ms3} = 7.5\,in^2$ Shear rupture area

$Pcnsf_{ms3} := 0.6 \cdot Fu_{cs} \cdot Acsf_{ms3}$ Nominal shear rupture strength capacity [3, eqn D5-2] of single plate

$Pcnsf_{ms3} = 270\,kip$

$Pcnsr_{ms3} := 2\phi_{sf} \cdot Pcnsf_{ms3}$ $Pcnsr_{ms3} = 405\,kip$ Design tensile rupture strength capacity of 2x clevis plates

Check bearing strength of pin-connection:

$dcp_{ms3} := 1.5 \cdot in$ Pin diameter

$Acpd_{ms3} := dcp_{ms3} \cdot tc_{ms3}$ $Acpd_{ms3} = 2.25\,in^2$ Projected bearing area of single clevis plate

$Rcnpd_{ms3} := 1.8 \cdot Fy_{cs} \cdot Acpd_{ms3}$ $Rcnpd_{ms3} = 133.65\,kip$ Nominal bearing strength capacity for single clevis plate [3, eqn J7-1]

$Pcnpd_{ms3} := 2\phi \cdot Rcnpd_{ms3}$ $Pcnpd_{ms3} = 200.475\,kip$ Design bearing strength capacity for 2x clevis plates.

Pin bearing strength capacity limiting for pin-connection members

$\frac{Pcnpd_{ms3}}{Pcntr_{ms3}} = 0.427$ < $\frac{Pcnsr_{ms3}}{Pcntr_{ms3}} = 0.864$ => $Pcnpd_{ms3} = 200.475\,kip$

Check clevis plate bending (at transition):

$Zt_{ms3} := 2 \cdot \left(\frac{tc_{ms3} \cdot wct_{ms3}^{2}}{4} \right)$ $Zt_{ms3} = 18.75\ in^{3}$ Plastic modulus for 2x clevis plate, at transition section [3, Table 17-27]

$Mnt_{ms3} := Fy_{cs} \cdot Zt_{ms3}$ $Mnt_{ms3} = 51562.5\ ft \cdot lbf$ Nominal flexure strength at transition [3, eqn F11-1]

$Pnt_{ms3} := \frac{\phi_b \cdot Mnt_{ms3}}{(9.25 \cdot in)}$ $Pnt_{ms3} = 60.2\ kip$ Design bending capacity at transition of clevis plates

Check clevis plate weld (at base):

$t_{s\_ms3} := \frac{1}{2} \cdot in$ Clevis plate attachment fillet weld size

$Lw_{ms3} := (wcb_{ms3})$ $Lw_{ms3} = 24\ in$ Weld perimeter of single clevis plate

Check fillet throat area in localized region of single clevis plate:

$t_{plt3} := 1 \cdot in$ Clevis structure base plate thickness

$As_{plt3} := t_{plt3} \cdot wcb_{ms3}$ $As_{plt3} = 24\ in^{2}$ Cross-section shear area of base plate, located directly under clevis plate.

$Awt_{cplt3} := \frac{\sqrt{2}}{2} \cdot t_{s\_ms3} \cdot Lw_{ms3}$ Fillet throat area of weld perimeter about single clevis plate.

$Awt_{cplt3} = 8.485\ in^{2}$

$\frac{Awt_{cplt3}}{As_{plt3}} = 0.354$ Fillet throat area is less than that of base plate section. No adjustment of weld perimeter is necessary.

$Vnw_{ms3} := Vn_w \cdot t_{s\_ms3} \cdot \left(\frac{16}{in} \right) \cdot \frac{2Lw_{ms3}}{in}$ Maximum design shear strength capacity of 2x clevis plates longitudinal weld loaded in shear

$Vnw_{ms3} = 458.21\ kip$

Determine maximum load that may be placed on clevis plate weld, due to combined shear and bending:

$fnw_{ms3} := \frac{Vnw_{ms3}}{2 \cdot Lw_{ms3}}$ $fnw_{ms3} = 9.546\ \frac{kip}{in}$ Unit force capacity of weld

$Aw_{ms3} := 2 \cdot Lw_{ms3}$ $Aw_{ms3} = 48\ in$ Line area of 2x clevis plate weld segments

$$Sw_{ms3} := 2 \cdot \left(tc_{ms3} \cdot wcb_{ms3} + \frac{wcb_{ms3}^{\ 2}}{3} \right)$$

Line section modulus of 2x rectangular perimeter weld segments [6, p. 7.4-7]

$Sw_{ms3} = 456\ in^2$

$$\sqrt{\left(\frac{Pnw_{ms3}}{Aw_{ms3}} \right)^2 + \left[\frac{Pnw_{ms3} \cdot (14 \cdot in)}{Sw_{ms3}} \right]^2} = fnw_{ms3}$$

Shear & bending resultant loading clevis structure weld

$$Pnw_{ms3} \cdot \sqrt{\frac{1}{Aw_{ms3}^{\ 2}} + \frac{(14 \cdot in)^2}{Sw_{ms3}^{\ 2}}} = fnw_{ms3}$$

$$Pnw_{ms3} := \frac{fnw_{ms3}}{\sqrt{\frac{1}{Aw_{ms3}^{\ 2}} + \frac{(14 \cdot in)^2}{Sw_{ms3}^{\ 2}}}}$$

$Pnw_{ms3} = 257.283\ kip$ Maximum combined shear & bending capacity for clevis plate attachment weld

Clevis plate bending at transition, is limiting strength capacity of clevis structure.

$\frac{Pnt_{ms3}}{Pnw_{ms3}} = 0.234$ < $\frac{Pcnpd_{ms3}}{Pnw_{ms3}} = 0.779$ => $Pnt_{ms3} = 60.203\ kip$

$\frac{Pbtp_{ms3}}{Pnt_{ms3}} = 0.409$ => $Pbtp_{ms3} = 24.625\,kip$

Maximum capacity of anchor bolt pull-out governs anchorage strength capacity of MS-3 support.

Wall Triangle Support Anchorage

The anchorage associated with this support was not analysed because the angle iron frame portion was shown to have a very low capacity due to the eccentricity introduced by the anchorage offset. The fact that the support did not qualify for the loadings that would be provided by the seismic event of interest and the anchorage would need to be moved in order to rid the support of unessacary eccentricity supports our decision to not calculate the associated anchorage capacity.

Appendix D.10

References

Project:	ATR Life-Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation				
Performer:	A. L. Crawford	**Date:** 09/30/08	**Checker:** M. J. Russell	**Date:**	09/30/08

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Engineering Calculations and Analysis Report

ATR Primary Coolant System Piping Seismic Evaluation

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Appendix E, Appendix F

Idaho National Laboratory

The INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance.

Project:	ATR Life-Time Extension Project	ECAR No.:	ECAR-194	Rev.:	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation				
Performer:	Ellis / Crawford	Date: 09/30/2008	Checker: M. J. Russell	Date:	09/30/2008

Appendix E

Evaluation of Pump Anchorage and Miscellaneous Calculations

Contents

Analysis of Primary Coolant Pump Anchorage

The ATR Primary Coolant System (PCS) uses four primary pumps designated pumps 670-M-6 thru 670-M-9. The primary coolant pumps are bolted through heavy, rigid, "bathtub" style brackets to a welded steel frame which in turn is bolted to six concrete embedded anchors in the reinforced concrete floor. Additional 'seismic anchorage' was added to the foundation attachment. These additional anchorages consist of two added anchors per pump, one each on the east and west sides of the pump foundation. See Drawings 121997 (Reference 1) and 159777 (Reference 2)

The capacity of the concrete embedded anchors and the additional seismic anchors are detailed in Reference 3. The report indicates that the seismic anchors do not have any shear capacity. Hence the analysis that follows does not include the seismic anchors in the shear analysis.

$n := 6$ Number of concrete embedded anchors. These anchors have tensile and shear capacity.

$m := 2$ Number of seismic anchors. These anchors have tensile capacity but not shear capacity.

$\phi N_{cea} := 9.11 \cdot kip$ Tensile capacity of the concrete embedded anchors (cea) See Reference 3 page 54.

$\phi V_{cea} := 11.34 \cdot kip$ Shear capacity of the concrete embedded anchors (cea) See Reference 3 page 54.

$P_L := 16.2 \cdot kip$ Tensile capacity of the seismic anchors. These anchors do not have any shear capacity. See Reference 3 page 54.

$$Dist := \begin{pmatrix} -38 & 0 & -24.75 \\ 0 & 0 & -24.75 \\ 38 & 0 & -24.75 \\ 38 & 0 & 24.75 \\ 0 & 0 & 24.75 \\ -38 & 0 & 24.75 \end{pmatrix} \cdot in$$

Positions of the concrete embedded anchors. Each row is a different bolt and each column is its x, y, and z position, respectively. The bolts should lie in a single plane so one column of the matrix must be zero. In this case, the bolts lie in the xz plane. See Figure E.1-1.

$i := 1 .. n$ Counter for the concrete embedded anchors

$d_i := \sqrt{\left(Dist_{i,1}\right)^2 + \left(Dist_{i,2}\right)^2 + \left(Dist_{i,3}\right)^2}$

Distance from centroid of anchor group (cg) to each anchor. Note each anchor is the same size.

$d = \blacksquare \cdot in$

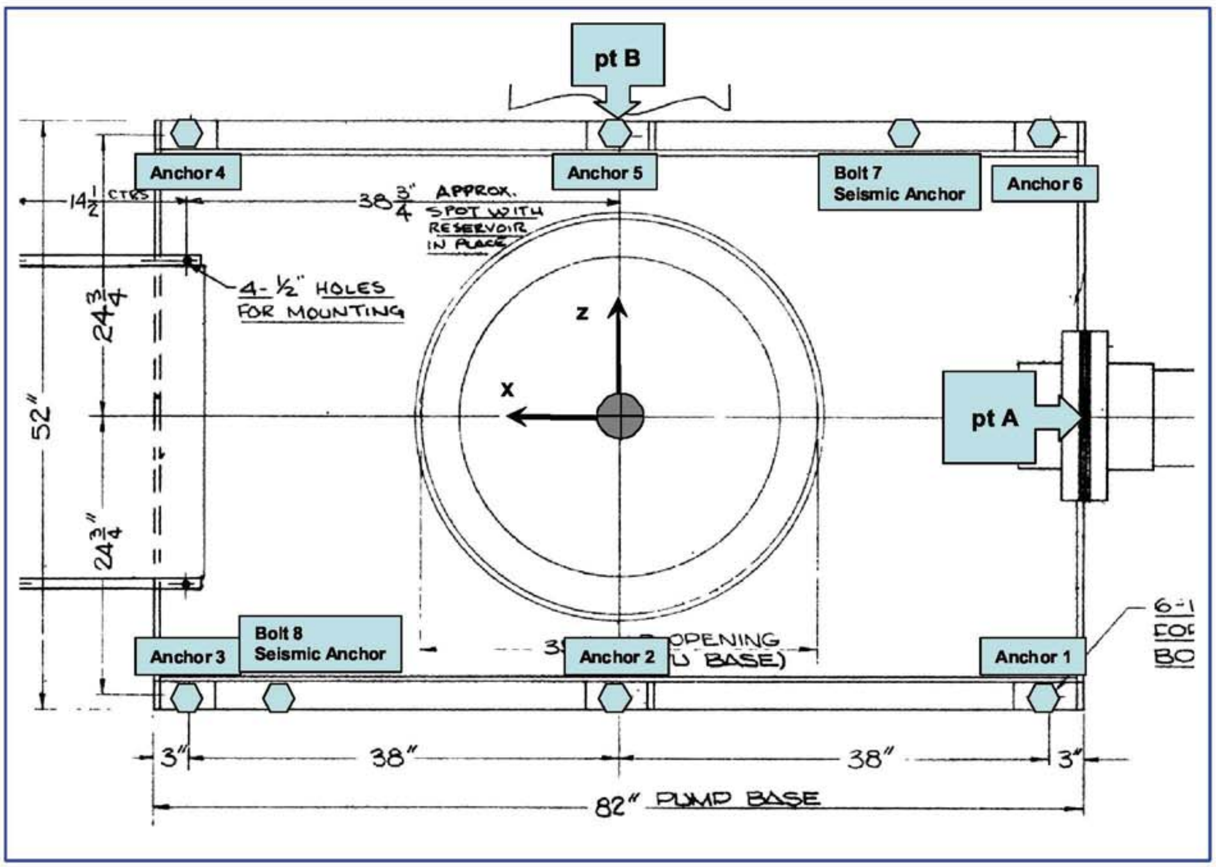

Figure E.1-1: Location of concrete embedded anchors and seismic anchors

$w := 16375$

Weight in lbf of primary coolant pump. See Reference 3 page 33.

$\alpha_x := 0 \cdot in$ $\alpha_y := 34 \cdot in$ $\alpha_z := 36 \cdot in$

Position of the discharge nozzle of the primary coolant pump. See Figure E.1-2.

$\beta_x := 0 \cdot in$ $\beta_y := 16 \cdot in$ $\beta_z := 0 \cdot in$

Position of the suction nozzle of the primary coolant pump. See Figure E.1-2.

$\theta_x := 0 \cdot in$ $\theta_y := 64 \cdot in$ $\theta_z := 0 \cdot in$

Assumed position of the pump center of mass (CM). See Figure E.1-2.

$r_x := 41 \cdot in$ $r_y := 0 \cdot in$ $r_z := 0 \cdot in$

Vector from an an axis parallel to the z axis but offset to the right of the support structure. This will be used later to calculate the tension in each anchor. See point A, Figure E.1-1.

$s_x := 0 \cdot in$ $s_y := 0 \cdot in$ $s_z := -26 \cdot in$

Vector from an axis parallel to the x axis but offset to the top of the support structure. This will be used later to calculate the tension in each anchor. See point B, Figure E.1-1.

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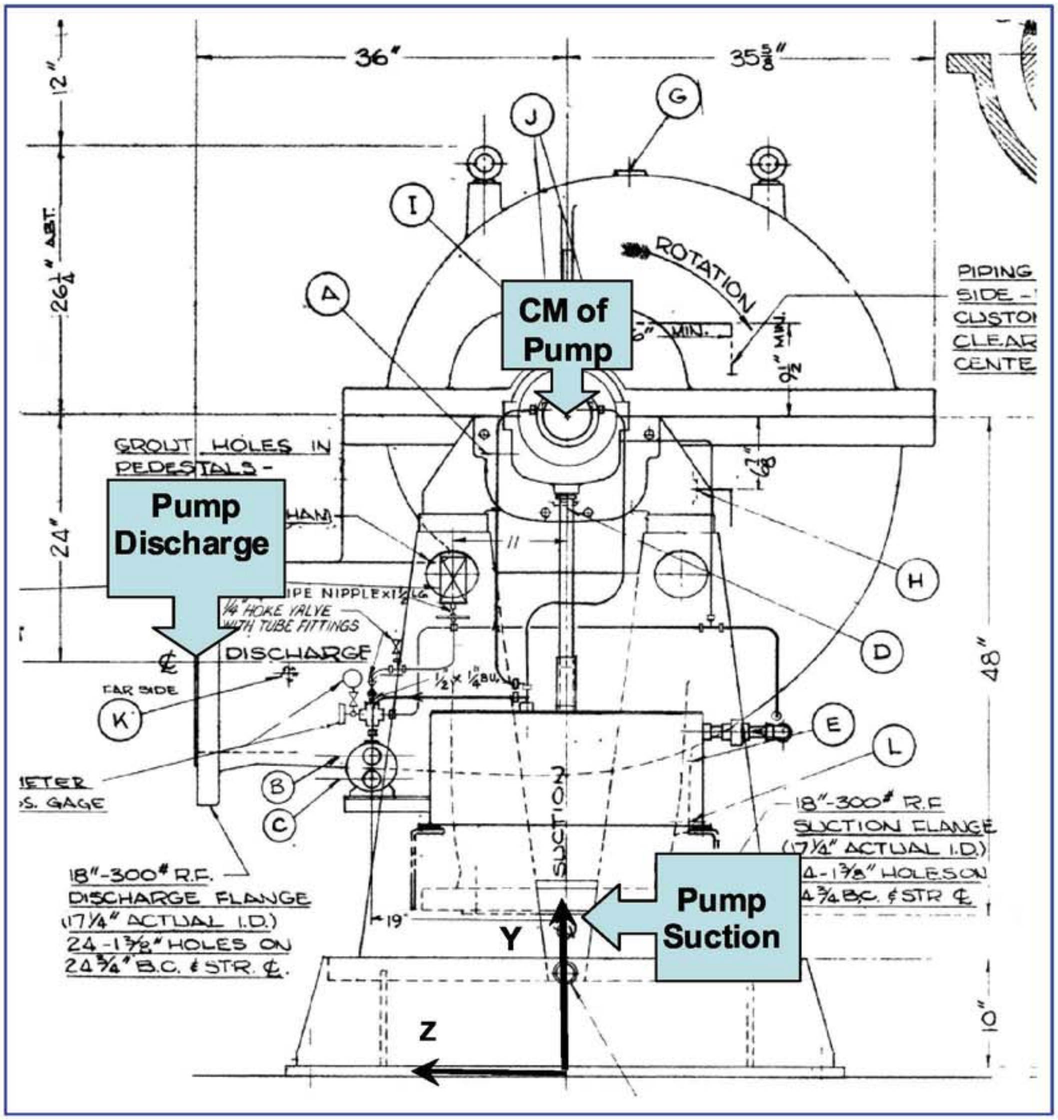

Figure E.1-2: Position of pump discharge, suction, and center of mass.

$$\text{combine}(a,b,c) := \left| \begin{array}{l} \begin{pmatrix} g^{\langle 1\rangle} \\ g^{\langle 2\rangle} \\ g^{\langle 3\rangle} \\ g^{\langle 4\rangle} \\ g^{\langle 5\rangle} \\ g^{\langle 6\rangle} \\ g^{\langle 7\rangle} \\ g^{\langle 8\rangle} \\ g^{\langle 9\rangle} \\ g^{\langle 10\rangle} \\ g^{\langle 11\rangle} \\ g^{\langle 12\rangle} \\ g^{\langle 13\rangle} \\ g^{\langle 14\rangle} \\ g^{\langle 15\rangle} \\ g^{\langle 16\rangle} \end{pmatrix} \leftarrow \begin{pmatrix} a^{\langle 1\rangle} \\ a^{\langle 2\rangle} \\ a^{\langle 3\rangle} \\ a^{\langle 4\rangle} \\ a^{\langle 5\rangle} \\ a^{\langle 6\rangle} \\ a^{\langle 7\rangle} \\ b^{\langle 2\rangle} \\ b^{\langle 3\rangle} \\ b^{\langle 4\rangle} \\ b^{\langle 5\rangle} \\ b^{\langle 6\rangle} \\ b^{\langle 7\rangle} \\ c^{\langle 2\rangle} \\ c^{\langle 3\rangle} \\ c^{\langle 4\rangle} \end{pmatrix} \\ g \end{array} \right.$$

Time History

TH :=
't552_552_542.prr

Primary Pump M-6

PP_Dis_M6 := 'P_Discharge_122_nd196.prı PP_Suc_M6 := 'P_Suction_118_nd1.prı

matM6 := combine(PP_Dis_M6, PP_Suc_M6, TH)

Primary Pump M-7

PP_Dis_M7 := 'P_Discharge_123_nd183.pn PP_Suc_M7 := 'P_Suction_119_nd31.pn

matM7 := combine(PP_Dis_M7, PP_Suc_M7, TH)

Primary Pump M-8

PP_Dis_M8 := 'P_Discharge_124_nd184.pn PP_Suc_M8 := 'P_Suction_120_nd15.pn

matM8 := combine(PP_Dis_M8, PP_Suc_M8, TH)

Primary Pump M-9

PP_Dis_M9 := 'P_Discharge_125_nd207.pn PP_Suc_M9 := 'P_Suction_121_nd22.pn

matM9 := combine(PP_Dis_M9, PP_Suc_M9, TH)

ii := rows(matM6) ii is the number of time steps in the matrix mat

The following forces and moments are read in from the matrix mat at each time step:

t = time step

$F\alpha x$ = Force in the x direction at the discharge nozzle
$F\alpha y$ = Force in the y direction at the discharge nozzle
$F\alpha z$ = Force in the z direction at the discharge nozzle
$M\alpha x$ = Moment in the x direction at the discharge nozzle
$M\alpha y$ = Moment in the y direction at the discharge nozzle
$M\alpha z$ = Moment in the z direction at the discharge nozzle

$F\beta x$ = Force in the x direction at the suction nozzle
$F\beta y$ = Force in the y direction at the suction nozzle
$F\beta z$ = Force in the z direction at the suction nozzle
$M\beta x$ = Moment in the x direction at the suction nozzle
$M\beta y$ = Moment in the y direction at the suction nozzle

Mβz = Moment in the z direction at the suction nozzle

Fθx = Force in the x direction at the pump center of mass
Fθy = Force in the y direction at the pump center of mass
Fθz = Force in the z direction at the pump center of mass

The following forces and moments calculated using the above forces and moments:

Fωx = Force in the x direction at the cg of the bolt group
Fωy = Force in the y direction at the cg of the bolt group
Fωz = Force in the z direction at the cg of the bolt group
Mωx = Moment in the x direction at the cg of the bolt group
Mωy = Moment in the y direction at the cg of the bolt group
Mωz = Moment in the z direction at the cg of the bolt group

DCShear (i) = Maximum Demand to Capacity ratio for shear for each bolt i. This value is set to zero for the first time step (jj = 1) and is always zero for the seismic anchors.

DCSher (i) = Demand to Capacity ratio for shear for each bolt i and time step jj. This value is determined at each time step, then compared with DCShear. If it is greater than DCShear, it replaces the current DCShear value.

Shear = Matrix containing the shear forces caused by various forces. Each row of the matrix is a different bolt and each column shows the shear load as follows:
Shear (i,1) = Shear caused by Fωx on bolt i.
Shear (i,2) = Shear caused by Fωz on bolt i.
Shear (i,3) = Shear in the x direction caused by Mωy on bolt i. See Reference 5, page 395.
Shear (i,4) = Shear in the y direction caused by Mωy on bolt i. See Reference 5, page 395.
Shear (i,5) = Magnitude of the total shear in bolt i.

DCTension (i) = Maximum Demand to Capacity ratio for tension for each bolt i. This value is set to zero for the first time step (jj = 1).

DCTensin (i) = Demand to Capacity ratio for tension for each bolt i and time step jj. This value is determined at each time step, then compared with DCTension. If it is greater than DCTension, it replaces the current DCTension value.

MptA = Moment about an parallel to the z axis but offset to the bottom of the support structure.

MptB = Moment about an axis parallel to the x axis but offset to the right of the support structure.

TenptA (i) = Tension force in bolt i caused by MptA. The tension force in each bolt is assumed to be proportional to the distance from ptA.

TenptB (i) = Tension force in bolt i caused by MptB. The tension force in each bolt is assumed to be proportional to the distance from ptB.

TenM (k) = Sum of tension forces TenptA and TenptB for each bolt k. Note that the bolts do not carry compression loads. Therefore, if either TenptA and/or TenptB are negative, they are excluded from TenM.

$$Cat(mat) := \text{for } jj \in 1..ii$$

$$t \leftarrow mat_{jj,1}$$

$$\left(F_{\alpha x}\ F_{\alpha y}\ F_{\alpha z}\right) \leftarrow \left(mat_{jj,2}\ mat_{jj,3}\ mat_{jj,4}\right)\cdot lbf$$

$$\left(M_{\alpha x}\ M_{\alpha y}\ M_{\alpha z}\right) \leftarrow \left(mat_{jj,5}\ mat_{jj,6}\ mat_{jj,7}\right)\cdot lbf\cdot in$$

$$\left(F_{\beta x}\ F_{\beta y}\ F_{\beta z}\right) \leftarrow \left(mat_{jj,8}\ mat_{jj,9}\ mat_{jj,10}\right)\cdot lbf$$

$$\left(M_{\beta x}\ M_{\beta y}\ M_{\beta z}\right) \leftarrow \left(mat_{jj,11}\ mat_{jj,12}\ mat_{jj,13}\right)\cdot lbf\cdot in$$

$$\left(F_{\theta x}\ F_{\theta y}\ F_{\theta z}\right) \leftarrow \left[mat_{jj,14}\cdot\frac{w}{386.4}\ \ w\cdot\left(\frac{mat_{jj,15}}{386.4}-1\right)\ \ mat_{jj,16}\cdot\frac{w}{386.4}\right]\cdot lbf$$

$$\begin{pmatrix}F_{\omega x}\\F_{\omega y}\\F_{\omega z}\end{pmatrix} \leftarrow \begin{pmatrix}F_{\alpha x}+F_{\beta x}+F_{\theta x}\\F_{\alpha y}+F_{\beta y}+F_{\theta y}\\F_{\alpha z}+F_{\beta z}+F_{\theta z}\end{pmatrix}$$

$$\begin{pmatrix}M_{\omega x}\\M_{\omega y}\\M_{\omega z}\end{pmatrix} \leftarrow \begin{bmatrix}(M_{\alpha x}+M_{\beta x})\\(M_{\alpha y}+M_{\beta y})\\(M_{\alpha z}+M_{\beta z})\end{bmatrix} + \begin{pmatrix}\alpha_x\\\alpha_y\\\alpha_z\end{pmatrix}\times\begin{pmatrix}F_{\alpha x}\\F_{\alpha y}\\F_{\alpha z}\end{pmatrix} + \begin{pmatrix}\beta_x\\\beta_y\\\beta_z\end{pmatrix}\times\begin{pmatrix}F_{\beta x}\\F_{\beta y}\\F_{\beta z}\end{pmatrix} + \begin{pmatrix}\theta_x\\\theta_y\\\theta_z\end{pmatrix}\times\begin{pmatrix}F_{\theta x}\\F_{\theta y}\\F_{\theta z}\end{pmatrix}$$

$$DCShear \leftarrow \begin{pmatrix}0\\0\\0\\0\\0\\0\\0\\0\end{pmatrix} \text{ if } jj = 1$$

$$DCTension \leftarrow \begin{pmatrix}0\\0\\0\\0\\0\\0\end{pmatrix} \text{ if } jj = 1$$

$$\begin{matrix} 0 \\ 0 \end{pmatrix}$$

$$DCCombined \leftarrow \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \text{ if } jj = 1$$

$$tmaxS \leftarrow \begin{pmatrix} t \\ t \\ t \\ t \\ t \\ t \\ t \\ t \end{pmatrix} \text{ if } jj = 1$$

$$tmaxT \leftarrow \begin{pmatrix} t \\ t \\ t \\ t \\ t \\ t \\ t \\ t \end{pmatrix} \text{ if } jj = 1$$

$$tmaxC \leftarrow \begin{pmatrix} t \\ t \\ t \\ t \\ t \\ t \\ t \\ t \end{pmatrix} \text{ if } jj = 1$$

$$MptA \leftarrow \begin{pmatrix} M_{\omega x} \\ M_{\omega y} \\ M_{\omega z} \end{pmatrix} + \begin{pmatrix} r_x \\ r_y \\ r_z \end{pmatrix} \times \begin{pmatrix} F_{\omega x} \\ F_{\omega y} \\ F_{\omega z} \end{pmatrix}$$

$$MptB \leftarrow \begin{pmatrix} M_{\omega x} \\ M_{\omega y} \\ M_{\omega z} \end{pmatrix} + \begin{pmatrix} s_x \\ s_y \\ s_z \end{pmatrix} \times \begin{pmatrix} F_{\omega x} \\ F_{\omega y} \\ F_{\omega z} \end{pmatrix}$$

$$TenptA \leftarrow \begin{pmatrix} \frac{3}{79} \\ \frac{41}{79} \\ 1 \\ 1 \\ \frac{41}{79} \\ \frac{3}{79} \\ \frac{12}{79} \\ \frac{70}{79} \end{pmatrix} \cdot \frac{MptA_3}{264.63 \cdot in}$$

$$TenptB \leftarrow \begin{pmatrix} 1 \\ 1 \\ 1 \\ \frac{1.25}{50.75} \\ \frac{1.25}{50.75} \\ \frac{1.25}{50.75} \\ \frac{1.25}{50.75} \\ 1 \end{pmatrix} \cdot \frac{MptB_1}{203.12 \cdot in}$$

for $i \in 1..\ n + m$

$$Shear_{i,1} \leftarrow \begin{cases} \frac{F_{\omega x}}{n} & \text{if } i \le n \\ 0 & \text{otherwise} \end{cases}$$

$$Shear_{i,2} \leftarrow \begin{cases} \frac{F_{\omega z}}{n} & \text{if } i \le n \\ 0 & \text{otherwise} \end{cases}$$

$$Shear_{i,3} \leftarrow \begin{cases} \frac{M_{\omega y} \cdot \left(Dist_{i,3}\right)}{\sum_{j=1}^{n} \left(d_j\right)^2} & \text{if } i \le n \\ 0 & \text{otherwise} \end{cases}$$

$$Shear_{i,4} \leftarrow \begin{cases} \frac{M_{\omega y} \cdot \left[(-Dist)_{i,1}\right]}{\sum_{j=1}^{n} \left(d_j\right)^2} & \text{if } i \le 0 \\ 0 & \text{otherwise} \end{cases}$$

$$Shear_{i,5} \leftarrow \sqrt{\left(Shear_{i,1} + Shear_{i,3}\right)^2 + \left(Shear_{i,2} + Shear_{i,4}\right)^2}$$

$$DCSher_i \leftarrow \frac{Shear_{i,5}}{\phi N_{cea}}$$

$$TenM_i \leftarrow \begin{cases} TenptA_i + TenptB_i & \text{if } TenptA_i \ge 0 \wedge TenptB_i \ge 0 \\ TenptA_i & \text{if } TenptA_i \ge 0 \wedge TenptB_i < 0 \\ TenptB_i & \text{if } TenptB_i \ge 0 \wedge TenptA_i < 0 \\ 0 & \text{if } TenptA_i < 0 \wedge TenptB_i < 0 \end{cases}$$

$$TotalTension_i \leftarrow \begin{cases} TenM_i + \frac{F_{\omega y}}{m+n} & \text{if } F_{\omega y} > 0 \\ TenM_i & \text{otherwise} \end{cases}$$

$$DCTensin_i \leftarrow \begin{cases} \frac{TotalTension_i}{\phi N_{cea}} & \text{if } i \le n \\ \frac{TotalTension_i}{P_L} & \text{if } i > n \end{cases}$$

$$DCComb_i \leftarrow \frac{DCSher_i + DCTensin_i}{1.2}$$

$$tmaxS_i \leftarrow \begin{cases} t & \text{if } DCSher_i > DCShear_i \\ tmaxS_i & \text{otherwise} \end{cases}$$

$$tmaxT_i \leftarrow \begin{cases} t & \text{if } DCTensin_i > DCTension_i \\ tmaxT_i & \text{otherwise} \end{cases}$$

$$tmaxC_i \leftarrow \begin{cases} t & \text{if } DCComb_i > DCCombined_i \\ tmaxC_i & \text{otherwise} \end{cases}$$

$$DCShear_i \leftarrow \begin{cases} DCSher_i & \text{if } DCSher_i > DCShear_i \\ DCShear_i & \text{otherwise} \end{cases}$$

$$DCTension_i \leftarrow \begin{cases} DCTensin_i & \text{if } DCTensin_i > DCTension_i \\ DCTension_i & \text{otherwise} \end{cases}$$

$$DCCombined_i \leftarrow \begin{cases} DCComb_i & \text{if } DCComb_i > DCCombined_i \\ DCCombined_i & \text{otherwise} \end{cases}$$

$$(DCShear \;\; tmaxS \;\; DCTension \;\; tmaxT \;\; DCCombined \;\; tmaxC)$$

$$(DCShear6 \;\; tmaxS6 \;\; DCTension6 \;\; tmaxT6 \;\; DCCombined6 \;\; tmaxC6) := Cat(matM6)$$

$$(DCShear7 \;\; tmaxS7 \;\; DCTension7 \;\; tmaxT7 \;\; DCCombined7 \;\; tmaxC7) := Cat(matM7)$$

$$(DCShear8 \;\; tmaxS8 \;\; DCTension8 \;\; tmaxT8 \;\; DCCombined8 \;\; tmaxC8) := Cat(matM8)$$

$$(DCShear9 \;\; tmaxS9 \;\; DCTension9 \;\; tmaxT9 \;\; DCCombined9 \;\; tmaxC9) := Cat(matM9)$$

Write the demand to capacity ratios to an external file for later use

DC6 := WRITEPRN("DC6.prn" , augment(DCShear6, DCTension6, DCCombined6))

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DC7 := WRITEPRN("DC7.prn" , augment(DCShear7, DCTension7, DCCombined7))

DC8 := WRITEPRN("DC8.prn" , augment(DCShear8, DCTension8, DCCombined8))

DC9 := WRITEPRN("DC9.prn" , augment(DCShear9, DCTension9, DCCombined9))

References:

1. INL Drawing 121997, "Z-4611A Bingham Pump", August 1, 1985
2. INL Drawing 159777, "ATR Seismic Modification Base Plate Details & Pump Base Modifications", April 23, 2008
3. ECAR EDF-8366, "ATR Primary Coolant System Piping Support and Anchorage Capacity Evaluation", Appendix F Revision 0, September 2007
4. ACI 349-01, "Code Requirements for Nuclear Safety Related Concrete Structures", American Concrete Institute, 2001
5. Jack C. McCormac and James K. Nelson, Structural Steel Design, LRFD Method, 3rd edition, Prentice Hall, 2003

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Appendix E.2 Analysis of Emergency Coolant Pump Anchorage

The ATR Primary Coolant System (PCS) uses two emergency pumps designated pumps 670-M-10 thru 670-M-11. The emergency coolant pumps are bolted to their support frames through heavy, thick , integral foot pad which in turn is bolted to the reinforced concrete pump foundation using 4 concrete hooked embedments. Additional 'seismic anchorage' was added to the foundation attachment. These additional anchorages consist of four added anchors per pump. See Drawings 121090 (Reference 1) and 159777 (Reference 2)

The capacity of the concrete embedded anchors and the additional seismic anchors are detailed in Reference 3. The report indicates that the seismic anchors do not have any shear capacity. Hence the analysis that follows does not include the seismic anchors in the shear analysis.

$n := 4$ — Number of concrete embedded anchors. These anchors have tensile and shear capacity.

$m := 4$ — Number of seismic anchors. These anchors have tensile capacity but not shear capacity.

$\phi N_{cea} := 9.11 \cdot kip$ — Tensile capacity of the concrete embedded anchors (cea) See Reference 3 page 54.

$\phi V_{cea} := 4.5 \cdot kip$ — Shear capacity of the concrete embedded anchors (cea) See Reference 3 page 54.

$P_L := 8.1 \cdot kip$ — Tensile capacity of the seismic anchors. These anchors do not have any shear capacity. See Reference 3 page 54.

$$Dist := \begin{pmatrix} -15 & 0 & -13.25 \\ 15 & 0 & -13.25 \\ 15 & 0 & 13.25 \\ -15 & 0 & 13.25 \end{pmatrix} in$$

Positions of the concrete embedded anchors. Each row is a different bolt and each column is its x, y, and z position, respectively. The bolts should lie in a single plane so one column of the matrix must be zero. In this case, the bolts lie in the xz plane. See Figure E.2-1.

$i := 1..n$ — Counter for the concrete embedded anchors

$$d_i := \sqrt{\left(Dist_{i,1}\right)^2 + \left(Dist_{i,2}\right)^2 + \left(Dist_{i,3}\right)^2}$$

Distance from centroid of anchor group (cg) to each anchor. Note each anchor is the same size.

$d = \blacksquare \cdot in$

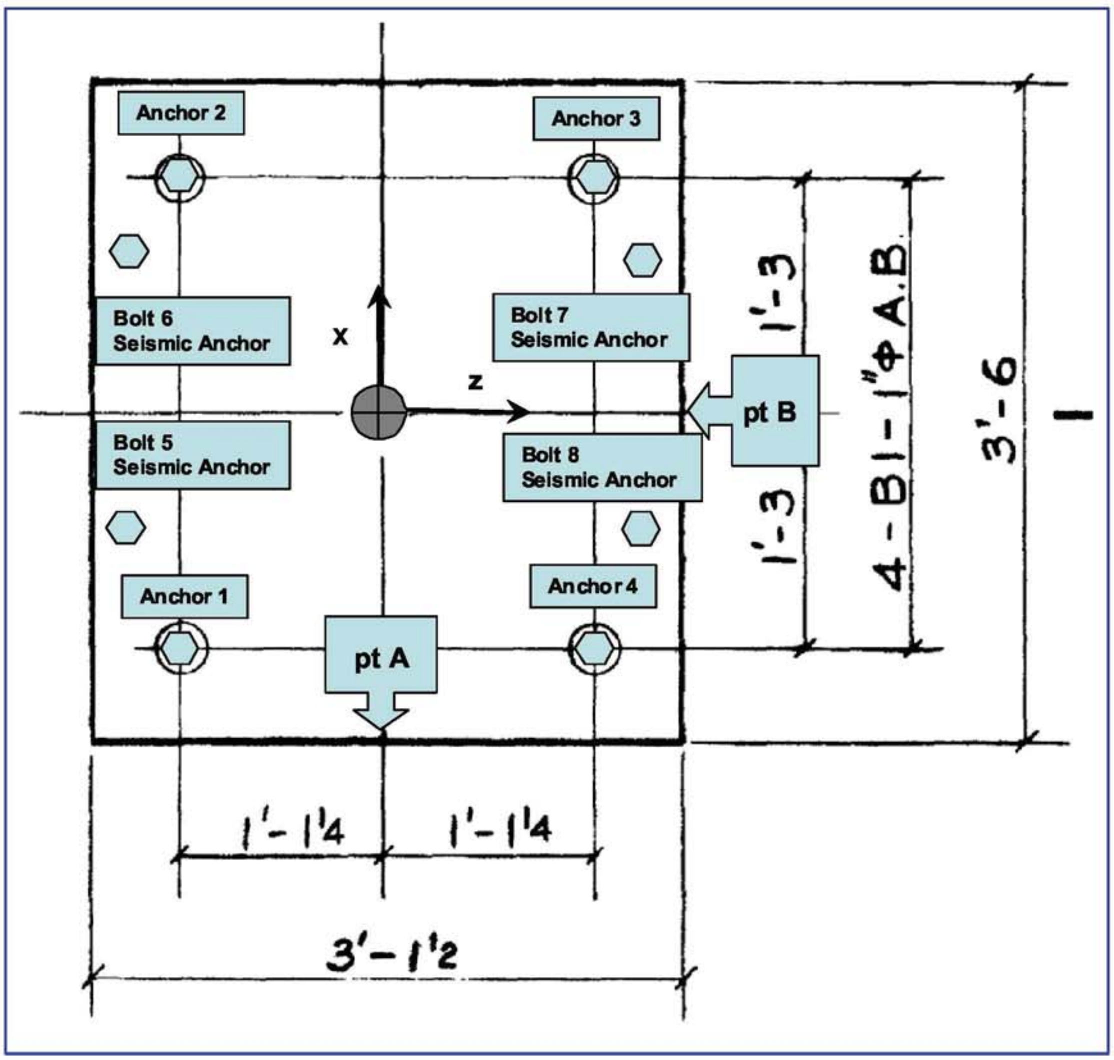

Figure E.2-1: Location of concrete embedded anchors and seismic anchors

$w := 3688$

Weight in lbf of primary coolant pump.
See Reference 4 page 2.

$\alpha_x := 0 \cdot in$ $\alpha_y := 7.25 \cdot in$ $\alpha_z := 19.75 \cdot in$

Position of the discharge nozzle of the primary coolant pump.

$\beta_x := 0 \cdot in$ $\beta_y := 8.4 \cdot in$ $\beta_z := 26 \cdot in$

Position of the suction nozzle of the primary coolant pump.

$\theta_x := 0 \cdot in$ $\theta_y := 20.75 \cdot in$ $\theta_z := 0 \cdot in$

Assumed position of the pump center of mass (CM).

$r_x := 21 \cdot in$ $r_y := 0 \cdot in$ $r_z := 0 \cdot in$

Vector from an an axis parallel to the z axis but offset to the bottom of the support structure. This will be used later to calculate the tension in each anchor. See point A, Figure E.2-1.

$s_x := 0 \cdot in$ $s_y := 0 \cdot in$ $s_z := -18.75 \cdot in$

Vector from an axis parallel to the x axis but offset to the right of the support structure. This will be used later to calculate the tension in each anchor. See point B, Figure E.2-1.

$$\text{combine}(a,b,c) := \left| \begin{array}{l} \begin{pmatrix} g^{\langle 1\rangle} \\ g^{\langle 2\rangle} \\ g^{\langle 3\rangle} \\ g^{\langle 4\rangle} \\ g^{\langle 5\rangle} \\ g^{\langle 6\rangle} \\ g^{\langle 7\rangle} \\ g^{\langle 8\rangle} \\ g^{\langle 9\rangle} \\ g^{\langle 10\rangle} \\ g^{\langle 11\rangle} \\ g^{\langle 12\rangle} \\ g^{\langle 13\rangle} \\ g^{\langle 14\rangle} \\ g^{\langle 15\rangle} \\ g^{\langle 16\rangle} \end{pmatrix} \leftarrow \begin{pmatrix} a^{\langle 1\rangle} \\ a^{\langle 2\rangle} \\ a^{\langle 3\rangle} \\ a^{\langle 4\rangle} \\ a^{\langle 5\rangle} \\ a^{\langle 6\rangle} \\ a^{\langle 7\rangle} \\ b^{\langle 2\rangle} \\ b^{\langle 3\rangle} \\ b^{\langle 4\rangle} \\ b^{\langle 5\rangle} \\ b^{\langle 6\rangle} \\ b^{\langle 7\rangle} \\ c^{\langle 2\rangle} \\ c^{\langle 3\rangle} \\ c^{\langle 4\rangle} \end{pmatrix} \\ g \end{array} \right.$$

Time History

TH :=
›t552_552_542.prr

Emergency Pump M-10

EP_Dis_M10 := :P_Discharge_132_nd149.prn EP_Suc_M10 := :P_Suction_131_nd194.prn

matM10 := combine(EP_Dis_M10, EP_Suc_M10, TH)

Emergency Pump M-11

EP_Dis_M11 := :P_Discharge_133_nd140.prn EP_Suc_M11 := :P_Suction_130_nd160.prn

matM11 := combine(EP_Dis_M11, EP_Suc_M11, TH)

ii := rows(matM11) ii is the number of time steps in the matrix mat

The following forces and moments are read in from the matrix mat10 and matM11 at each time step:

t = time step

$F\alpha x$ = Force in the x direction at the discharge nozzle
$F\alpha y$ = Force in the y direction at the discharge nozzle
$F\alpha z$ = Force in the z direction at the discharge nozzle
$M\alpha x$ = Moment in the x direction at the discharge nozzle
$M\alpha y$ = Moment in the y direction at the discharge nozzle
$M\alpha z$ = Moment in the z direction at the discharge nozzle

$F\beta x$ = Force in the x direction at the suction nozzle
$F\beta y$ = Force in the y direction at the suction nozzle
$F\beta z$ = Force in the z direction at the suction nozzle
$M\beta x$ = Moment in the x direction at the suction nozzle
$M\beta y$ = Moment in the y direction at the suction nozzle
$M\beta z$ = Moment in the z direction at the suction nozzle

$F\theta x$ = Force in the x direction at the pump center of mass
$F\theta y$ = Force in the y direction at the pump center of mass
$F\theta z$ = Force in the z direction at the pump center of mass

The following forces and moments calculated using the above forces and moments:

$F\omega x$ = Force in the x direction at the cg of the bolt group
$F\omega y$ = Force in the y direction at the cg of the bolt group
$F\omega z$ = Force in the z direction at the cg of the bolt group
$M\omega x$ = Moment in the x direction at the cg of the bolt group
$M\omega y$ = Moment in the y direction at the cg of the bolt group
$M\omega z$ = Moment in the z direction at the cg of the bolt group

DCShear (i) = Maximum Demand to Capacity ratio for shear for each bolt i. This value is set to zero for the first time step (jj = 1) and is always zero for the seismic anchors.

DCSher (i) = Demand to Capacity ratio for shear for each bolt i and time step jj. This value is determined at each time step, then compared with DCShear. If it is greater than DCShear, it replaces the current DCShear value.

Shear = Matrix containing the shear forces caused by various forces. Each row of the matrix is a different bolt and each column shows the shear load as follows:

- Shear (i,1) = Shear caused by $F_{\omega}x$ on bolt i.
- Shear (i,2) = Shear caused by $F_{\omega}z$ on bolt i.
- Shear (i,3) = Shear in the x direction caused by $M_{\omega}y$ on bolt i. See Reference 5, page 395.
- Shear (i,4) = Shear in the y direction caused by $M_{\omega}y$ on bolt i. See Reference 5, page 395.
- Shear (i,5) = Magnitude of the total shear in bolt i.

DCTension (i) = Maximum Demand to Capacity ratio for tension for each bolt i. This value is set to zero for the first time step (jj = 1).

DCTensin (i) = Demand to Capacity ratio for tension for each bolt i and time step jj. This value is determined at each time step, then compared with DCTension. If it is greater than DCTension, it replaces the current DCTension value.

MptA = Moment about an parallel to the z axis but offset to the bottom of the support structure.

MptB = Moment about an axis parallel to the x axis but offset to the right of the support structure.

TenptA (i) = Tension force in bolt i caused by MptA. The tension force in each bolt is assumed to be proportional to the distance from ptA.

TenptB (i) = Tension force in bolt i caused by MptB. The tension force in each bolt is assumed to be proportional to the distance from ptB.

TenM (k) = Sum of tension forces TenptA and TenptB for each bolt k. Note that the bolts do not carry compression loads. Therefore, if either TenptA and/or TenptB are negative, they are excluded from TenM.

Cat(mat) := for $jj \in 1..ii$

$t \leftarrow mat_{jj,1}$

$(F_{\alpha x}\ F_{\alpha y}\ F_{\alpha z}) \leftarrow (mat_{jj,2}\ mat_{jj,3}\ mat_{jj,4})\cdot lbf$

$(M_{\alpha x}\ M_{\alpha y}\ M_{\alpha z}) \leftarrow (mat_{jj,5}\ mat_{jj,6}\ mat_{jj,7})\cdot lbf\cdot in$

$(F_{\beta x}\ F_{\beta y}\ F_{\beta z}) \leftarrow (mat_{jj,8}\ mat_{jj,9}\ mat_{jj,10})\cdot lbf$

$(M_{\beta x}\ M_{\beta y}\ M_{\beta z}) \leftarrow (mat_{jj,11}\ mat_{jj,12}\ mat_{jj,13})\cdot lbf\cdot in$

$$(F_{\theta x}\ F_{\theta y}\ F_{\theta z}) \leftarrow \left[mat_{jj,14}\cdot\frac{w}{386.4}\ \ w\cdot\left(\frac{mat_{jj,15}}{386.4}-1\right)\ \ mat_{jj,16}\cdot\frac{w}{386.4}\right]\cdot lbf$$

$$\begin{pmatrix} F_{\omega x} \\ F_{\omega y} \\ F_{\omega z} \end{pmatrix} \leftarrow \begin{pmatrix} F_{\alpha x}+F_{\beta x}+F_{\theta x} \\ F_{\alpha y}+F_{\beta y}+F_{\theta y} \\ F_{\alpha z}+F_{\beta z}+F_{\theta z} \end{pmatrix}$$

$$\begin{pmatrix} M_{\omega x} \\ M_{\omega y} \\ M_{\omega z} \end{pmatrix} \leftarrow \begin{bmatrix} (M_{\alpha x}+M_{\beta x}) \\ (M_{\alpha y}+M_{\beta y}) \\ (M_{\alpha z}+M_{\beta z}) \end{bmatrix} + \begin{pmatrix} \alpha_x \\ \alpha_y \\ \alpha_z \end{pmatrix} \times \begin{pmatrix} F_{\alpha x} \\ F_{\alpha y} \\ F_{\alpha z} \end{pmatrix} + \begin{pmatrix} \beta_x \\ \beta_y \\ \beta_z \end{pmatrix} \times \begin{pmatrix} F_{\beta x} \\ F_{\beta y} \\ F_{\beta z} \end{pmatrix} + \begin{pmatrix} \theta_x \\ \theta_y \\ \theta_z \end{pmatrix} \times \begin{pmatrix} F_{\theta x} \\ F_{\theta y} \\ F_{\theta z} \end{pmatrix}$$

$$DCShear \leftarrow \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \text{ if } jj = 1$$

$$DCTension \leftarrow \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \text{ if } jj = 1$$

(0

$$DCCombined \leftarrow \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \text{ if } jj = 1$$

$$tmaxS \leftarrow \begin{pmatrix} t \\ t \\ t \\ t \\ t \\ t \\ t \\ t \end{pmatrix} \text{ if } jj = 1$$

$$tmaxT \leftarrow \begin{pmatrix} t \\ t \\ t \\ t \\ t \\ t \\ t \\ t \end{pmatrix} \text{ if } jj = 1$$

$$tmaxC \leftarrow \begin{pmatrix} t \\ t \\ t \\ t \\ t \\ t \\ t \\ t \end{pmatrix} \text{ if } jj = 1$$

$$MptA \leftarrow \begin{pmatrix} M_{\omega x} \\ M_{\omega y} \end{pmatrix} + \begin{pmatrix} r_x \\ r_y \end{pmatrix} \times \begin{pmatrix} F_{\omega x} \\ F_{\omega y} \end{pmatrix}$$

$$\begin{pmatrix} M_{\omega z} \end{pmatrix} \begin{pmatrix} r_z \end{pmatrix} \begin{pmatrix} F_{\omega z} \end{pmatrix}$$

$$MptB \leftarrow \begin{pmatrix} M_{\omega x} \\ M_{\omega y} \\ M_{\omega z} \end{pmatrix} + \begin{pmatrix} s_x \\ s_y \\ s_z \end{pmatrix} \times \begin{pmatrix} F_{\omega x} \\ F_{\omega y} \\ F_{\omega z} \end{pmatrix}$$

$$TenptA \leftarrow \begin{pmatrix} \frac{6}{36} \\ \frac{36}{36} \\ \frac{36}{36} \\ \frac{6}{36} \\ \frac{12}{36} \\ \frac{30}{36} \\ \frac{30}{36} \\ \frac{12}{36} \end{pmatrix} \cdot \frac{MptA_3}{132 \cdot in}$$

$$TenptB \leftarrow \begin{pmatrix} \frac{32}{35.5} \\ \frac{32}{35.5} \\ \frac{5.5}{35.5} \\ \frac{5.5}{35.5} \\ \frac{35.5}{35.5} \\ \frac{35.5}{35.5} \\ \frac{2}{35.5} \\ 2 \end{pmatrix} \cdot \frac{MptB_1}{130.62 \cdot in}$$

$$\left(\begin{matrix} 2 \\ 35.5 \end{matrix} \right)$$

for $i \in 1 .. n + m$

$$Shear_{i,1} \leftarrow \begin{cases} \frac{F_{\omega x}}{n} & \text{if } i \le n \\ 0 & \text{otherwise} \end{cases}$$

$$Shear_{i,2} \leftarrow \begin{cases} \frac{F_{\omega z}}{n} & \text{if } i \le n \\ 0 & \text{otherwise} \end{cases}$$

$$Shear_{i,3} \leftarrow \begin{cases} \frac{M_{\omega y} \cdot \left(Dist_{i,3}\right)}{\sum_{j=1}^{n} \left(d_j\right)^2} & \text{if } i \le n \\ 0 & \text{otherwise} \end{cases}$$

$$Shear_{i,4} \leftarrow \begin{cases} \frac{M_{\omega y} \cdot \left[(-Dist)_{i,1}\right]}{\sum_{j=1}^{n} \left(d_j\right)^2} & \text{if } i \le n \\ 0 & \text{otherwise} \end{cases}$$

$$Shear_{i,5} \leftarrow \sqrt{\left(Shear_{i,1} + Shear_{i,3}\right)^2 + \left(Shear_{i,2} + Shear_{i,4}\right)^2}$$

$$DCSher_i \leftarrow \frac{Shear_{i,5}}{\phi N_{cea}}$$

$$TenM_i \leftarrow \begin{cases} TenptA_i + TenptB_i & \text{if } TenptA_i \ge 0 \wedge TenptB_i \ge 0 \\ TenptA_i & \text{if } TenptA_i \ge 0 \wedge TenptB_i < 0 \\ TenptB_i & \text{if } TenptB_i \ge 0 \wedge TenptA_i < 0 \\ 0 & \text{if } TenptA_i < 0 \wedge TenptB_i < 0 \end{cases}$$

$$TotalTension_i \leftarrow \begin{cases} TenM_i + \frac{F_{\omega y}}{m + n} & \text{if } F_{\omega y} > 0 \\ TenM_i & \text{otherwise} \end{cases}$$

$$DCTensin_i \leftarrow \begin{cases} \frac{TotalTension_i}{\phi N_{cea}} & \text{if } i \le n \end{cases}$$

$$\frac{TotalTension_i}{P_L} \quad \text{if } i > n$$

$$DCComb_i \leftarrow \frac{DCShear_i + DCTensin_i}{1.2}$$

$$tmaxS_i \leftarrow \begin{cases} t & \text{if } DCSher_i > DCShear_i \\ tmaxS_i & \text{otherwise} \end{cases}$$

$$tmaxT_i \leftarrow \begin{cases} t & \text{if } DCTensin_i > DCTension_i \\ tmaxT_i & \text{otherwise} \end{cases}$$

$$tmaxC_i \leftarrow \begin{cases} t & \text{if } DCComb_i > DCCombined_i \\ tmaxC_i & \text{otherwise} \end{cases}$$

$$DCShear_i \leftarrow \begin{cases} DCSher_i & \text{if } DCSher_i > DCShear_i \\ DCShear_i & \text{otherwise} \end{cases}$$

$$DCTension_i \leftarrow \begin{cases} DCTensin_i & \text{if } DCTensin_i > DCTension_i \\ DCTension_i & \text{otherwise} \end{cases}$$

$$DCCombined_i \leftarrow \begin{cases} DCComb_i & \text{if } DCComb_i > DCCombined_i \\ DCCombined_i & \text{otherwise} \end{cases}$$

$$(DCShear \;\; tmaxS \;\; DCTension \;\; tmaxT \;\; DCCombined \;\; tmaxC)$$

$$(DCShear10 \;\; tmaxS10 \;\; DCTension10 \;\; tmaxT10 \;\; DCCombined10 \;\; tmaxC10) := Cat(matM10)$$

$$(DCShear11 \;\; tmaxS11 \;\; DCTension11 \;\; tmaxT11 \;\; DCCombined11 \;\; tmaxC11) := Cat(matM11)$$

Write the demand to capacity ratios to an external file for later use

DC10 := WRITEPRN("DC10.prn" , augment(DCShear10, DCTension10, DCCombined10))

DC11 := WRITEPRN("DC11.prn" , augment(DCShear11, DCTension11, DCCombined11))

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References:

1. INL Drawing 121090, "Reactor Building Equipment Foundations Conc. & Reinf. - Sheet #6" , February 04, 1983
2. INL Drawing 159777, "ATR Seismic Modification Base Plate Details & Pump Base Modifications", April 23, 2008
3. ECAR EDF-8366, "ATR Primary Coolant System Piping Support and Anchorage Capacity Evaluation", Appendix F Revision 0, September 2007
4. D. L. Rowsell, "Seismic Analysis of the New ATR M-10 Pump Mounting Pads", TRA-ATR-1383, November 3, 1998
5. ACI 349-01, "Code Requirements for Nuclear Safety Related Concrete Structures", American Concrete Institute, 2001
6. Jack C. McCormac and James K. Nelson, Structural Steel Design, LRFD Method, 3rd edition, Prentice Hall, 2003

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Appendix E.3 DC ratios for Coolant Pump Anchorage

80th Percentile Results of All 32 Realizations

LOGIC USED TO READ IN DATA FROM ALL 32 REALIZATIONS INTO THE APPROPRIATE EMBEDDED MATRIX FORM

a := "Y:\PCS2\Automated_Evaluation\Pump Evaluations\real"

ReadData(b) := for $k \in 1..32$

$$d_{k-1} \leftarrow \text{READPRN}(\text{concat}(a, \text{num2str}(k), b))$$

LOGIC USED TO SORT DATA BASED ON D/C RATIOS OF ALL 32 REALIZATIONS

R := stack(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32)

C_S(v, R) :=

```
for i ∈ 0.. cols(v) − 1
  for k ∈ 0.. rows(v_{0,i}) − 1
    for j ∈ 0.. rows(v) − 1
      a_{0,j} ← [[(v_{j,i})^T]^<k>]^T
      A ← a_{0,j}  if j = 0
      A ← stack(A, a_{0,j})  if j > 0
    b_{k,i} ← stack(A^T, R^T)^T
    Sorted_{k,i} ← reverse(csort(b_{k,i}, 0))
Sorted
```

LOGIC USED TO SEPERATE SHEAR, TENSION, AND COMBINED DATA SETS EMBEDDED IN BELOW MATRICIES

Sep(STC) :=

```
for k ∈ 0.. 31
  (S_k  T_k  C_k) ← [(STC_{k,0})^<0>  (STC_{k,0})^<1>  (STC_{k,0})^<2>]
(S  T  C)
```

LOGIC USED TO COMBINE 80TH PERCENTILE RESULTS INTO ONE MATRIX

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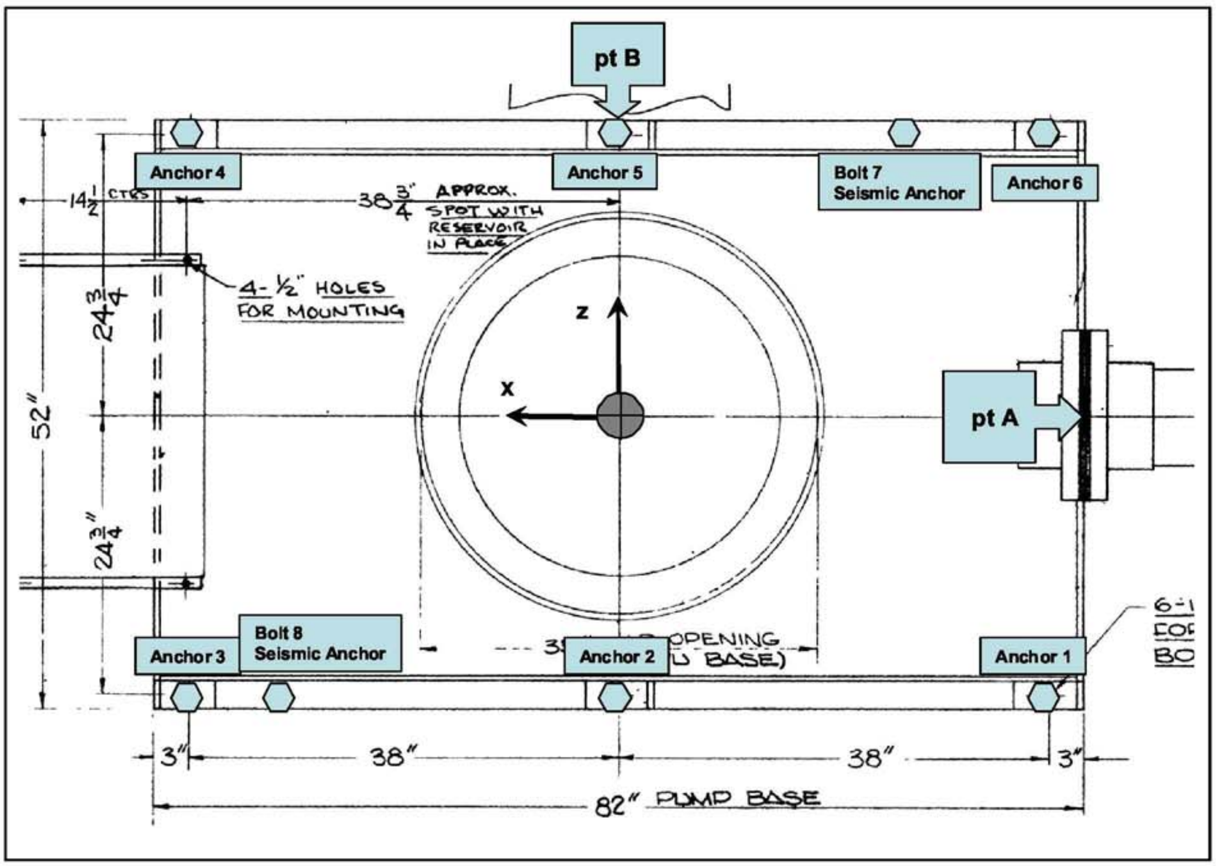
$$\mathrm{Com}(S_{sort}, T_{sort}, C_{sort}, B) := \left| \begin{array}{l} \text{for } k \in 0..7 \\ \quad \left| \begin{array}{l} \left(S80_{k,0}\ S80_{k,1}\ S80_{k,2}\right) \leftarrow \left[B_k\ \left(S_{sort_k}\right)_{6,0}\ \left(S_{sort_k}\right)_{6,1}\right] \\ \left(T80_{k,0}\ T80_{k,1}\ T80_{k,2}\right) \leftarrow \left[B_k\ \left(T_{sort_k}\right)_{6,0}\ \left(T_{sort_k}\right)_{6,1}\right] \\ \left(C80_{k,0}\ C80_{k,1}\ C80_{k,2}\right) \leftarrow \left[B_k\ \left(C_{sort_k}\right)_{6,0}\ \left(C_{sort_k}\right)_{6,1}\right] \end{array}\right. \\ \left(S_{80}\ T_{80}\ C_{80}\right) \end{array}\right.$$

PRIMARY PUMPS

LOCATION OF BOLTS ATTACHED TO PRIMARY PUMPS



PP_Bolts :=

"M6_B1"	"M7_B2"	"M8_B2"	"M9_B2"
"M6_B2"	"M7_B2"	"M8_B2"	"M9_B2"
"M6_B3"	"M7_B2"	"M8_B2"	"M9_B2"
"M6_B4"	"M7_B4"	"M8_B4"	"M9_B4"
"M6_B5"	"M7_B5"	"M8_B5"	"M9_B5"
"M6_B6"	"M7_B6"	"M8_B6"	"M9_B6"
"M6_B7"	"M7_B7"	"M8_B7"	"M9_B7"
"M6_B8"	"M7_B8"	"M8_B8"	"M9_B8"

M6 Primary Pump Results

PP_M6 := ReadData("\DC10.prn")

Separate Shear, Tension, and Combined D/C results

$\left(S_{M6}\ T_{M6}\ C_{M6}\right) := \mathrm{Sep}(PP\_M6)$

Sort Shear, Tension, and Combined D/C results

$S0_{M6} := C\_S\left(S_{M6}, R\right) \qquad T0_{M6} := C\_S\left(T_{M6}, R\right) \qquad C0_{M6} := C\_S\left(C_{M6}, R\right)$

Combine 80th Percentile D/C Results Into One Table

$\left(PP_{M6\_S}\ PP_{M6\_T}\ PP_{M6\_C}\right) := \mathrm{Com}\left(S0_{M6}, T0_{M6}, C0_{M6}, PP\_Bolts^{\langle 0 \rangle}\right)$

Shear

PP_{M6_S} =

"M6_B1"	0.323	8
"M6_B2"	0.361	3
"M6_B3"	0.446	22
"M6_B4"	0.38	22
"M6_B5"	0	27
"M6_B6"	0	27
"M6_B7"	0	27
"M6_B8"	0	27

Tension

PP_{M6_T} =

"M6_B1"	0.0459	22
"M6_B2"	0.12	25
"M6_B3"	0.12	25
"M6_B4"	0.0459	22
"M6_B5"	0.0687	22
"M6_B6"	0.118	24
"M6_B7"	0.118	24
"M6_B8"	0.0687	22

Combined

PP_{M6_C} =

"M6_B1"	0.298	30
"M6_B2"	0.371	17
"M6_B3"	0.442	22
"M6_B4"	0.335	22
"M6_B5"	0.0573	22
"M6_B6"	0.0985	25
"M6_B7"	0.0985	25
"M6_B8"	0.0573	22

M7 Primary Pump Results

PP_M7 := ReadData("\DC7.prn")

Separate Shear, Tension, and Combined D/C results

$\left(S_{M7}\ \ T_{M7}\ \ C_{M7}\right) := \mathrm{Sep}(PP\_M7)$

Sort Shear, Tension, and Combined D/C results

$S0_{M7} := C\_S\left(S_{M7}, R\right) \qquad T0_{M7} := C\_S\left(T_{M7}, R\right) \qquad C0_{M7} := C\_S\left(C_{M7}, R\right)$

Combine 80th Percentile D/C Results Into One Table

$\left(PP_{M7\_S}\ \ PP_{M7\_T}\ \ PP_{M7\_C}\right) := \mathrm{Com}\left(S0_{M7}, T0_{M7}, C0_{M7}, PP\_Bolts^{\langle 1\rangle}\right)$

Shear

$PP_{M7\_S} =$

"M7_B2"	0.23	27
"M7_B2"	0.23	27
"M7_B2"	0.23	27
"M7_B4"	0.25	25
"M7_B5"	0.25	25
"M7_B6"	0.25	25
"M7_B7"	0	27
"M7_B8"	0	27

Tension

$PP_{M7\_T} =$

"M7_B2"	0.28	14
"M7_B2"	0.28	14
"M7_B2"	0.28	14
"M7_B4"	0.13	28
"M7_B5"	0.065	28
"M7_B6"	6.9×10^{-3}	14
"M7_B7"	0.011	3
"M7_B8"	0.16	14

Combined

$PP_{M7\_C} =$

"M7_B2"	0.41	22
"M7_B2"	0.41	22
"M7_B2"	0.41	22
"M7_B4"	0.27	22
"M7_B5"	0.24	28
"M7_B6"	0.21	25
"M7_B7"	9×10^{-3}	28
"M7_B8"	0.13	27

M8 Primary Pump Results

PP_M8 := ReadData("\DC8.prn")

Separate Shear, Tension, and Combined D/C results

$(S_{M8}\ \ T_{M8}\ \ C_{M8}) := \mathrm{Sep}(PP\_M8)$

Sort Shear, Tension, and Combined D/C results

$S0_{M8} := C\_S(S_{M8}, R)$

$T0_{M8} := C\_S(T_{M8}, R)$

$C0_{M8} := C\_S(C_{M8}, R)$

Combine 80th Percentile D/C Results Into One Table

$(PP_{M8\_S}\ \ PP_{M8\_T}\ \ PP_{M8\_C}) := \mathrm{Com}\left(S0_{M8}, T0_{M8}, C0_{M8}, PP\_Bolts^{\langle 2\rangle}\right)$

Shear

$$PP_{M8\_S} = \begin{pmatrix} \text{"M8\_B2"} & 0.23 & 28 \\ \text{"M8\_B2"} & 0.23 & 28 \\ \text{"M8\_B2"} & 0.23 & 28 \\ \text{"M8\_B4"} & 0.3 & 27 \\ \text{"M8\_B5"} & 0.3 & 27 \\ \text{"M8\_B6"} & 0.3 & 27 \\ \text{"M8\_B7"} & 0 & 27 \\ \text{"M8\_B8"} & 0 & 27 \end{pmatrix}$$

Tension

$$PP_{M8\_T} = \begin{pmatrix} \text{"M8\_B2"} & 0.34 & 11 \\ \text{"M8\_B2"} & 0.34 & 11 \\ \text{"M8\_B2"} & 0.34 & 11 \\ \text{"M8\_B4"} & 0.12 & 7 \\ \text{"M8\_B5"} & 0.061 & 27 \\ \text{"M8\_B6"} & 8.4\times 10^{-3} & 25 \\ \text{"M8\_B7"} & 0.01 & 7 \\ \text{"M8\_B8"} & 0.19 & 11 \end{pmatrix}$$

Combined

$$PP_{M8\_C} = \begin{pmatrix} \text{"M8\_B2"} & 0.46 & 27 \\ \text{"M8\_B2"} & 0.46 & 27 \\ \text{"M8\_B2"} & 0.46 & 27 \\ \text{"M8\_B4"} & 0.31 & 28 \\ \text{"M8\_B5"} & 0.27 & 25 \\ \text{"M8\_B6"} & 0.25 & 27 \\ \text{"M8\_B7"} & 8.4\times 10^{-3} & 27 \\ \text{"M8\_B8"} & 0.16 & 11 \end{pmatrix}$$

M9 Primary Pump Results

PP_M9 := ReadData("\DC9.prn")

Separate Shear, Tension, and Combined D/C results

$\left(S_{M9}\ \ T_{M9}\ \ C_{M9}\right) := \text{Sep(PP\_M9)}$

Sort Shear, Tension, and Combined D/C results

$S0_{M9} := C\_S\left(S_{M9}, R\right)$

$T0_{M9} := C\_S\left(T_{M9}, R\right)$

$C0_{M9} := C\_S\left(C_{M9}, R\right)$

Combine 80th Percentile D/C Results Into One Table

$\left(PP_{M9\_S}\ \ PP_{M9\_T}\ \ PP_{M9\_C}\right) := \text{Com}\left(S0_{M9}, T0_{M9}, C0_{M9}, PP\_Bolts^{\langle 3\rangle}\right)$

Shear

$PP_{M9\_S} =$

"M9_B2"	0.22	25
"M9_B2"	0.22	25
"M9_B2"	0.22	25
"M9_B4"	0.4	27
"M9_B5"	0.4	27
"M9_B6"	0.4	27
"M9_B7"	0	27
"M9_B8"	0	27

Tension

$PP_{M9\_T} =$

"M9_B2"	0.42	27
"M9_B2"	0.42	27
"M9_B2"	0.42	27
"M9_B4"	0.24	11
"M9_B5"	0.12	32
"M9_B6"	0.01	3
"M9_B7"	0.02	32
"M9_B8"	0.24	28

Combined

$PP_{M9\_C} =$

"M9_B2"	0.47	25
"M9_B2"	0.47	25
"M9_B2"	0.47	25
"M9_B4"	0.47	28
"M9_B5"	0.39	25
"M9_B6"	0.34	25
"M9_B7"	0.017	10
"M9_B8"	0.2	28

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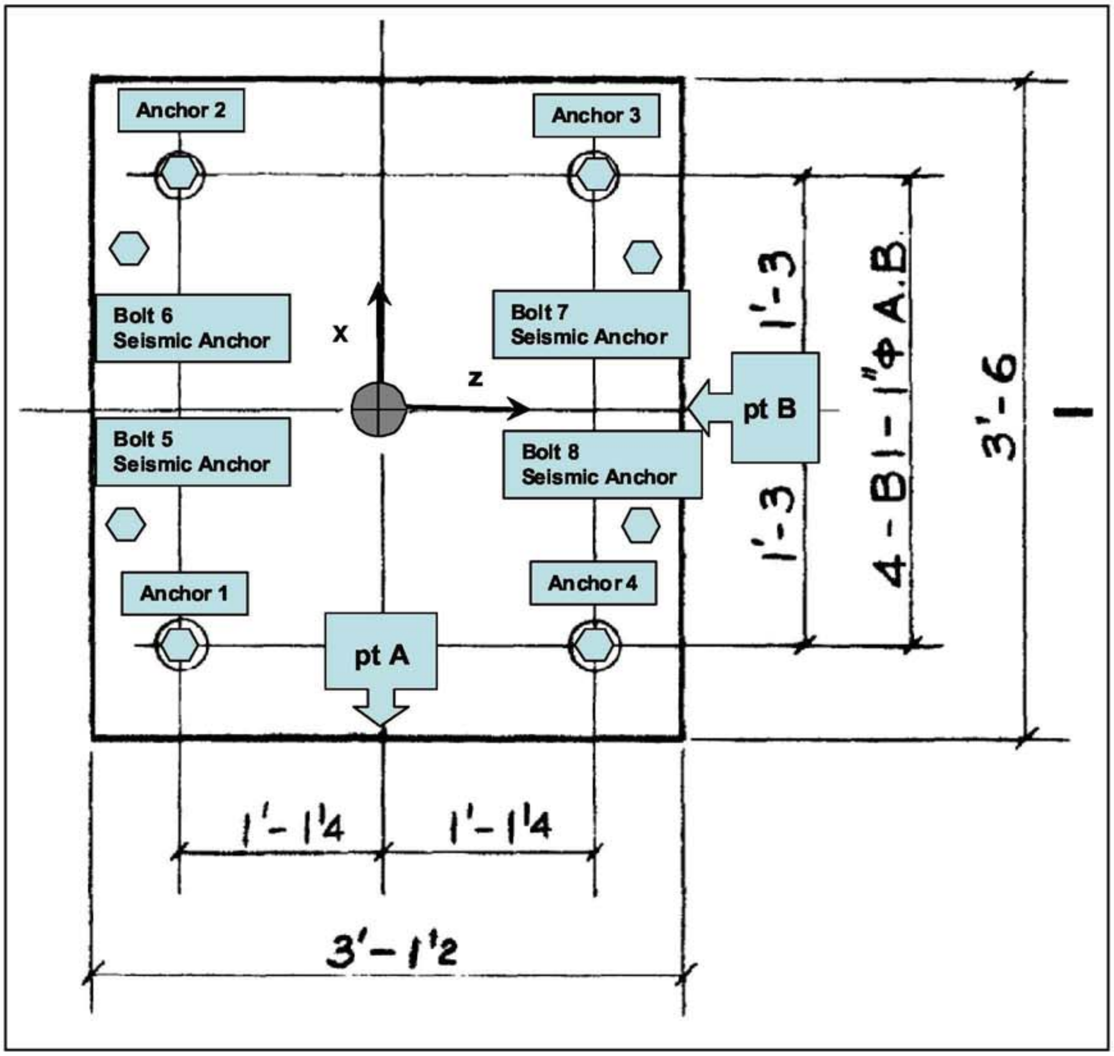
EMERGENCY PUMPS

LOCATION OF BOLTS ATTACHED TO EMERGENCY PUMPS



$$EP\_Bolts := \begin{pmatrix} \text{"M10\_B1"} & \text{"M11\_B1"} \\ \text{"M10\_B2"} & \text{"M11\_B2"} \\ \text{"M10\_B3"} & \text{"M11\_B3"} \\ \text{"M10\_B4"} & \text{"M11\_B4"} \\ \text{"M10\_B5"} & \text{"M11\_B5"} \\ \text{"M10\_B6"} & \text{"M11\_B6"} \\ \text{"M10\_B7"} & \text{"M11\_B7"} \\ \text{"M10\_B8"} & \text{"M11\_B8"} \end{pmatrix}$$

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M10 Emergency Pump Results

EP_M10 := ReadData("\DC10.prn")

Separate Shear, Tension, and Combined D/C results

$\left(S_{M10}\ \ T_{M10}\ \ C_{M10}\right) := \text{Sep(EP\_M10)}$

Sort Shear, Tension, and Combined D/C results

$S0_{M10} := \text{C\_S}\left(S_{M10}, R\right)$

$T0_{M10} := \text{C\_S}\left(T_{M10}, R\right)$

$C0_{M10} := \text{C\_S}\left(C_{M10}, R\right)$

Combine 80th Percentile D/C Results Into One Table

$\left(EP_{M10\_S}\ \ EP_{M10\_T}\ \ EP_{M10\_C}\right) := \text{Com}\left(S0_{M10}, T0_{M10}, C0_{M10}, \text{EP\_Bolts}^{\langle 0\rangle}\right)$

Shear — EP_{M10_S} =

"M10_B1"	0.323	8
"M10_B2"	0.361	3
"M10_B3"	0.446	22
"M10_B4"	0.38	22
"M10_B5"	0	27
"M10_B6"	0	27
"M10_B7"	0	27
"M10_B8"	0	27

Tension — EP_{M10_T} =

"M10_B1"	0.0459	22
"M10_B2"	0.12	25
"M10_B3"	0.12	25
"M10_B4"	0.0459	22
"M10_B5"	0.0687	22
"M10_B6"	0.118	24
"M10_B7"	0.118	24
"M10_B8"	0.0687	22

Combined — EP_{M10_C} =

"M10_B1"	0.298	30
"M10_B2"	0.371	17
"M10_B3"	0.442	22
"M10_B4"	0.335	22
"M10_B5"	0.0573	22
"M10_B6"	0.0985	25
"M10_B7"	0.0985	25
"M10_B8"	0.0573	22

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M11 Emergency Pump Results

EP_M11 := ReadData("\DC11.prn")

Separate Shear, Tension, and Combined D/C results

$\left(S_{M11}\ \ T_{M11}\ \ C_{M11}\right) := \text{Sep(EP\_M11)}$

Sort Shear, Tension, and Combined D/C results

$S0_{M11} := \text{C\_S}\left(S_{M11}, R\right)$

$T0_{M11} := \text{C\_S}\left(T_{M11}, R\right)$

$C0_{M11} := \text{C\_S}\left(C_{M11}, R\right)$

Combine 80th Percentile D/C Results Into One Table

$\left(EP_{M11\_S}\ \ EP_{M11\_T}\ \ EP_{M11\_C}\right) := \text{Com}\left(S0_{M11}, T0_{M11}, C0_{M11}, \text{EP\_Bolts}^{\langle 1\rangle}\right)$

Shear

$EP_{M11\_S} =$

"M11_B1"	0.437	24
"M11_B2"	0.515	28
"M11_B3"	0.615	22
"M11_B4"	0.554	22
"M11_B5"	0	27
"M11_B6"	0	27
"M11_B7"	0	27
"M11_B8"	0	27

Tension

$EP_{M11\_T} =$

"M11_B1"	0.0622	26
"M11_B2"	0.109	30
"M11_B3"	0.109	30
"M11_B4"	0.0181	30
"M11_B5"	0.0776	26
"M11_B6"	0.102	30
"M11_B7"	0.102	30
"M11_B8"	0.0407	30

Combined

$EP_{M11\_C} =$

"M11_B1"	0.414	22
"M11_B2"	0.502	6
"M11_B3"	0.589	22
"M11_B4"	0.475	22
"M11_B5"	0.0646	26
"M11_B6"	0.0847	30
"M11_B7"	0.0847	30
"M11_B8"	0.0339	30

Conclusion:

M6 Primary Pump: DC ratios for Shear, Tension, and Combined are below 1.0.

M7Primary Pump: DC ratios for Shear, Tension, and Combined are at or below 1.0.

M8 Primary Pump: DC ratios for Shear, Tension, and Combined are at or below 1.0.

M9 Primary Pump: DC ratios for Shear, Tension, and Combined are at or below 1.0.

M10 Emergency Pump: DC ratios for Shear, Tension, and Combined are below 1.0

M11 Emergency Pump: DC ratios for Shear, Tension, and Combined are below 1.0.

Appendix E.4 PR-1 and PR-2 Angle Bracket

Weld Analysis of angle bracket

The restraints and loads on the finite element model are shown in Figure E.4-1. The angle bracket is loaded by PR-1 and PR-2. It is held in place by 6 welds. The geometry for the bracket and the locations for the welds are shown in drawing 120923 (Reference 1).

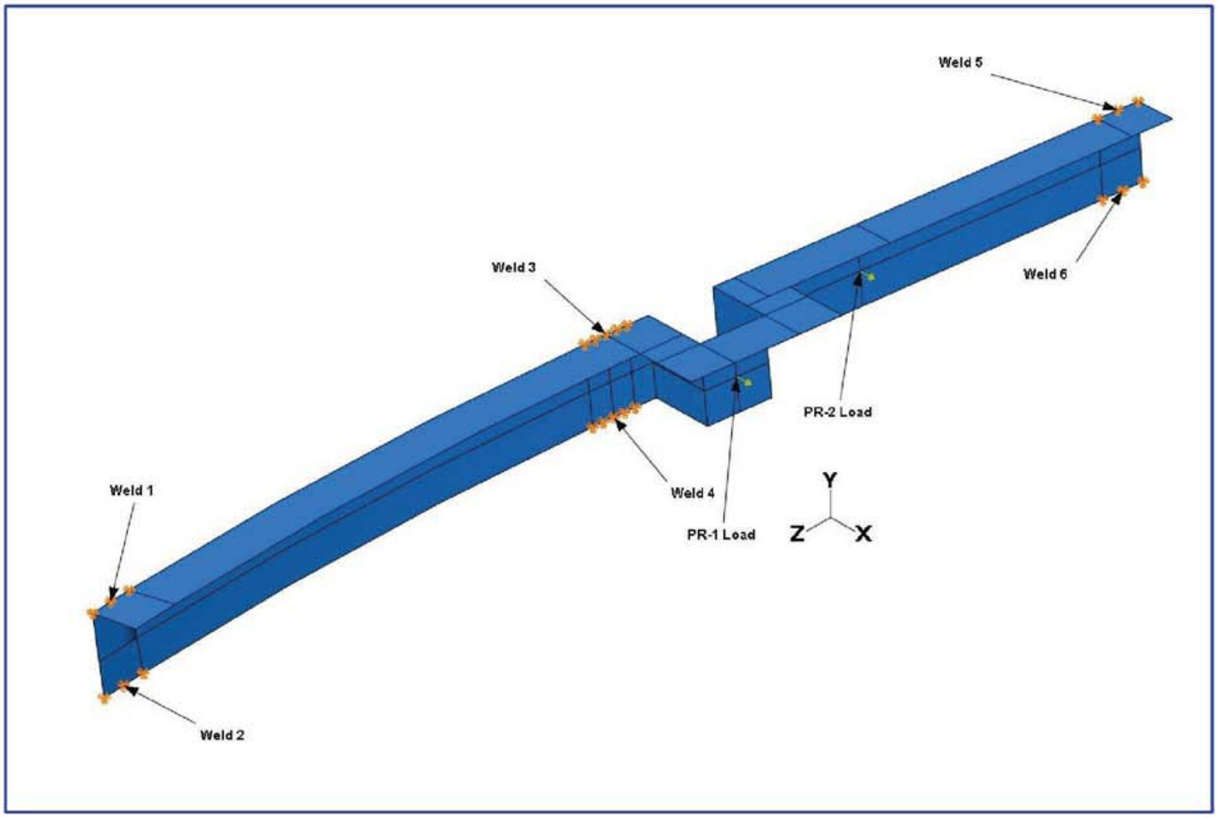

Figure E.4-1: Loads and restraints on the angle bracket

The loads on the bracket are from Pipe Restraint 1 (PR-1) and Pipe Restraint 2 (PR-2). Loads are applied in the positive x direction in the locations shown in Figure E.4-1. The magnitude of the loads are PR-1 = 6532 lbf and PR-2 = 5774 lbf. These loads are determined from the maximum loads experienced by these supports in pipe model 3 and pipe model 1 (See Appendix B and D).

The matrix shown below, Fweld, is the matrix of the restraints at the welds from the finite element model. Each column is a different weld and each row is the load in the x, y, and z directions, respectively. For example, the first column is the loads on weld 1.

$$Fweld := \begin{pmatrix} -385 & 171 & 4294 & 5754 & 1141 & 1330 \\ 80.97 & -400 & 590 & 1914 & -115 & -2069 \\ 39.94 & 852 & 3078 & -1414 & 9320 & -11876 \end{pmatrix} \cdot lbf$$

$\phi := 0.75$

Resistance factor for fillet welds.
See AISC13th pg. 16.1-100 (Reference 2)

$F_{EXX} := 60 \cdot ksi$

E6010 and E6011 weld filler electrode ultimate strength
See EDF-8366 pg. E-19 (Reference 3)

$L := 4.0 \cdot in$

Approximate length of each weld. See Dwg. 120923 (Reference 1)

$A_w := 0.707 \cdot \left(\frac{1}{2} \cdot in\right) \cdot L$

Throat area of 1/2-in fillet weld. The angle is 7x4x1/2 (See Dwg 120923, Reference 1). The weld is assumed to be the same thickness as the angle thickness.

$A_w = 1.414 \cdot in^2$

$n := \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$

Unit vector in the longitudinal direction of the weld. All the welds are aligned with the z axis. There is a slight curvature for welds 1 and 2 but this is ignored for this analysis.

$i := 1 .. cols(Fweld)$

Number of welds

$\theta_i := acos\left(\frac{Fweld^{\langle i \rangle} \cdot n}{\left|Fweld^{\langle i \rangle}\right|}\right)$

Angle in radians of the loading measured from the weld longitudinal axis. See Kraige pg. 66 (Reference 4).

$$\theta = \begin{pmatrix} 1.47 \\ 0.472 \\ 0.953 \\ 1.8 \\ 0.122 \\ 2.937 \end{pmatrix}$$

$$\theta deg := \theta \cdot \frac{360}{2 \cdot \pi}$$

Angle in degrees of the loading measured from the weld longitudinal axis.

$$\theta deg = \begin{pmatrix} 84.203 \\ 27.048 \\ 54.62 \\ 103.126 \\ 7.015 \\ 168.299 \end{pmatrix}$$

$$F_w := 0.60 \cdot F_{EXX} \cdot \left[1.0 + 0.50 \cdot (\sin(\theta))^{1.5}\right]$$

Nominal strength of the weld metal. See AISC pg. 16.1-100 (Reference 2)

$$Cap := \phi \cdot F_w \cdot A_w$$

Design strength for each weld
See AISC pg. 16.1-98 (Reference 2)

$$Cap = \begin{pmatrix} 57.121 \\ 44.032 \\ 52.231 \\ 56.524 \\ 38.993 \\ 39.921 \end{pmatrix} \cdot kip$$

$$DC_i := \frac{\left|Fweld^{\langle i \rangle}\right|}{Cap_i}$$

Demand to Capacity ratio for each weld.

$$DC = \begin{pmatrix} 6.923 \times 10^{-3} \\ 0.022 \\ 0.102 \\ 0.11 \\ 0.241 \\ 0.304 \end{pmatrix}$$

Conclusion: Welds have Demand to Capacity ratios less than 1.0

Analysis of Angle Bracket

Figure E.4-2 shows the finite element model of the angle bracket. In general, the stresses throughout the bracket are approximately 30 to 40 ksi except near weld 4.

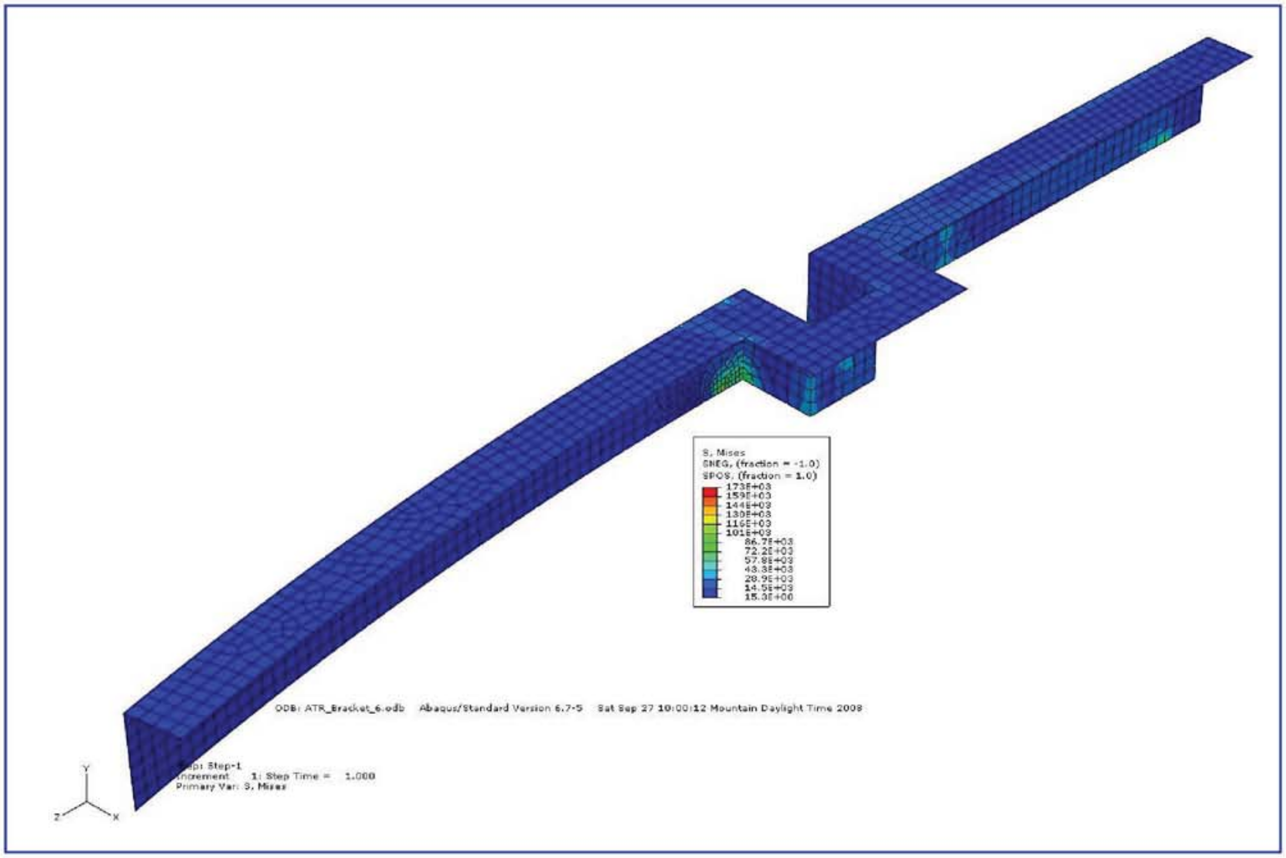

Figure E.4-2: Finite element model of angle bracket

Figure E.4-3 shows a close up view of the area near Weld 4. The stress well above the yield strength of the material in this area.

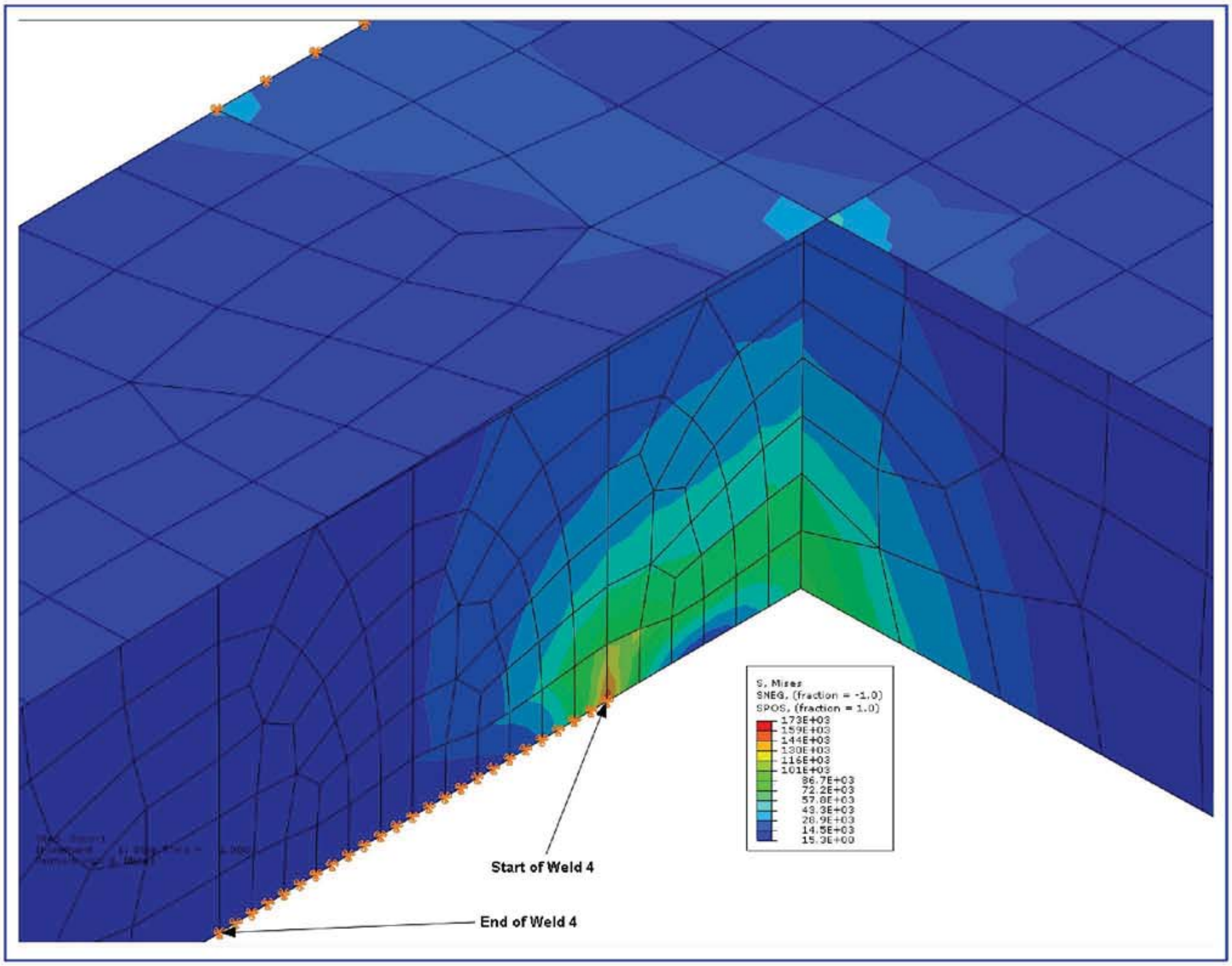

Figure E.4-3: Close up of finite element model of angle bracket

Conclusion: At the location of weld 4, the stresses in the angle bracket are well above the yield stress of the material.

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Analysis of embedment

The capacity of the embedment was determine in EDF-8366 Appendix C (See Reference 3). For tension, pullout strength of the anchor is the minimum capacity. For shear, steel strength of the anchor is the minimum capacity. Embedment design to capacity ratios are defined in ACI-349 (See Reference 5).

$Tension_{cap} := 9.38 \cdot kip$

Tension capacity of anchor. See Reference 3 page C-6.

$Shear_{cap} := 12.188 \cdot kip$

Shear capacity of anchor. See Reference 3 page C-6.

$Ftension := \left[\left(Fweld^T \right)^{\langle 1 \rangle} \right]$

Create a vector from the first row of the weld loads. These are the tension loads in the embedment at the location of the weld.

$$Ftension = \begin{pmatrix} -385 \\ 171 \\ 4.294 \times 10^3 \\ 5.754 \times 10^3 \\ 1.141 \times 10^3 \\ 1.33 \times 10^3 \end{pmatrix} \cdot lbf$$

$i := 1 .. cols(Fweld)$

$Fshear_{srss_i} := \sqrt{\left(Fweld_{2,i}\right)^2 + \left(Fweld_{3,i}\right)^2}$

Sum root of squares shear force at each embedment.

$$Fshear_{srss} = \begin{pmatrix} 90.285 \\ 941.225 \\ 3.134 \times 10^{3} \\ 2.38 \times 10^{3} \\ 9.321 \times 10^{3} \\ 1.205 \times 10^{4} \end{pmatrix} \cdot lbf$$

$$DC_{tension} := \frac{Ftension}{Tension_{cap}}$$

Demand to capacity ratio in tension. See ACI 349 (Reference 5)

$$DC_{tension} = \begin{pmatrix} -0.041 \\ 0.018 \\ 0.458 \\ 0.613 \\ 0.122 \\ 0.142 \end{pmatrix}$$

$$DC_{shear} := \frac{Fshear_{srss}}{Shear_{cap}}$$

Demand to capacity ratio in shear. See ACI 349 (Reference 5)

$$DC_{shear} = \begin{pmatrix} 7.408 \times 10^{-3} \\ 0.077 \\ 0.257 \\ 0.195 \\ 0.765 \\ 0.989 \end{pmatrix}$$

$$DC_{combined} := \frac{DC_{tension} + DC_{shear}}{1.2}$$

Combined demand to capacity ratio. See ACI 349 (Reference 5)

$$DC_{combined} = \begin{pmatrix} -0.028 \\ 0.08 \\ 0.596 \\ 0.674 \\ 0.739 \\ 0.942 \end{pmatrix}$$

Conclusion:

Tension: Demand to capacity ratios are below 1.0 for each embedment.

Shear: Demand to capacity ratios are below 1.0 for each embedment.

Combined: Demand to capacity ratios are below 1.0 for each embedment.

References:

1. INL Drawing 120923, "Primary Coolant System Pipe Hangers & Details SH7", February 21, 1966
2. AISC, Steel Construction Manual, American Institute of Steel Construction, 13th edition, 2005
3. A. L. Crawford, "ATR Primary Coolant System Piping Support and Anchorage Capacity Evaluation", EDF-8366 Rev. 0, December 17, 2007
4. J. L. Meriam and L. G. Kraige, Engineering Mechanics: Statics, 5th edition, 2002
5. ACI 349-01, American Concrete Institute, "Code Requirements for Nuclear Safety Related Concrete Structures (ACI-349-01)."

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Restraint Output from Abaqus
(used for weld and embedment analysis)

Field Output reported at nodes for part: PART-8-1 Weld 1

Node Label	RF.RF1 @Loc 1	RF.RF2 @Loc 1	RF.RF3 @Loc 1
25	1.05454E+03	110.344	-734.82
26	-290.729	-58.0396	180.993
203	151.549	9.59716	-8.66084
204	-23.7467	-6.69253	53.5364
205	-132.762	-15.2893	110.23
2183	209.684	-33.9284	-46.32
2184	75.5614	-5.10139	86.3055
2187	-155.686	-19.7732	150.496
2206	-502.829	-62.0898	168.292
Total	385.578	-80.9732	-39.9475

Field Output reported at nodes for part: PART-8-1 Weld 2

Node Label	RF.RF1 @Loc 1	RF.RF2 @Loc 1	RF.RF3 @Loc 1
45	-23.4527	23.9726	-269.417
47	-9.69423	65.5721	-29.9138
455	-8.66316	20.6972	-39.0267
456	-10.642	20.0876	-44.9123
457	-15.7638	26.8987	-77.1463
3394	-46.105	76.7742	-158.491
3409	-10.9287	80.4665	-41.1732
3410	-19.0344	40.6961	-82.239
3412	-26.7817	45.0843	-109.727
Total	-171.066	400.249	-852.047

Field Output reported at nodes for part: PART-8-1 Weld 3

Node Label	RF.RF1 @Loc 1	RF.RF2 @Loc 1	RF.RF3 @Loc 1
28	7.5896E+03	-223.121	-1.1292E+03
30	415.762	-1.13191	-672.112
32	-13.1514E+03	-435.104	4.87399E+03
302	1.51285E+03	15.0851	-1.35201E+03
307	-1.56785E+03	-111.262	-416.175
2615	1.61584E+03	23.9063	-1.7311E+03
2618	2.78963E+03	-3.79217	-1.76489E+03
2633	-2.90507E+03	192.739	212.188
2635	-594.054	-47.3953	-1.09964E+03
Total	-4.29469E+03	-590.076	-3.07894E+03

Field Output reported at nodes for part: PART-8-1 Weld 4

Node Label	RF.RF1 @Loc 1	RF.RF2 @Loc 1	RF.RF3 @Loc 1
41	-37.1316	-53.7378	-221.049
42	42.8818	-32.6267	5.41864
43	-8.77963E+03	-251.797	972.469
377	4.39935	-22.7536	-39.2541
378	11.3006	-27.5274	-22.5897
379	15.5259	-26.2579	-14.0011
380	21.5351	-26.9748	-7.57221
381	29.4133	-29.3514	-979.468E-03
588	70.1856	-36.9132	13.1014
589	120.968	-43.5664	23.9285
590	196.785	-53.8817	40.1595
591	368.495	-74.7166	72.2667
592	-807.514	-97.381	207.66
2957	25.8691	-52.8632	-32.7871
2963	21.1588	-52.1379	-49.3989
2969	74.4509	-62.0679	3.5127
2990	16.7361	-50.4548	-53.7647
3006	33.99	-54.6156	-20.6444
3008	49.1469	-58.2665	-8.74158
4442	118.708	-70.8217	18.7257
4444	300.703	-98.5492	60.7794
4460	774.415	-165.433	144.934
4468	867.567	-265.358	192.729
4470	186.606	-82.1734	36.8834

4479	519.075	-123.902	92.9725
Total	-5.75436E+03	-1.91413E+03	1.41476E+03

Field Output reported at nodes for part: PART-8-1 Weld 5

Node Label	RF.RF1 @Loc 1	RF.RF2 @Loc 1	RF.RF3 @Loc 1
14	-3.83513E+03	431.922	-7.65853E+03
49	959.063	88.8571	461.909
508	550.186	-184.103	219.948
509	194.471	-61.8579	-22.5996
510	-411.545	39.9436	-1.01996E+03
3857	736.108	-268.995	229.498
3867	1.82726E+03	-350.849	164.563
3878	-1.08644E+03	503.457	-1.32958E+03
3879	-75.1131	-83.0108	-365.793
Total	-1.14114E+03	115.364	-9.32054E+03

Field Output reported at nodes for part: PART-8-1 Weld 6

Node Label	RF.RF1 @Loc 1	RF.RF2 @Loc 1	RF.RF3 @Loc 1
36	-3.84562E+03	145.406	5.43161E+03
37	77.0346	330.166	180.212
318	-508.635	150.157	1.31367E+03
319	97.4164	71.2034	479.183
320	14.0542	-20.4047	325.394
2671	56.0028	163.051	356.021
2674	2.26363E+03	1.01608E+03	1.77482E+03
2677	93.3006	22.2837	760.927
2680	422.501	191.622	1.25489E+03
Total	-1.33031E+03	2.06956E+03	11.8767E+03

Project:	ATR Life-Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Piping Seismic Evaluation				
Performer:	A. L. Crawford	**Date:**	09/30/2008	**Checker:**	M. J. Russell	**Date:**	09/30/2008

Appendix E.5

DC Ratio Calculation for Model 3 and Model 4 Branch Connection

Contents

Project: ATR Life-Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Piping Seismic Evaluation
Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

Appendix E.5.1

Branch Calculations Applied to Each Realization

(NOTE: Values represented here are shown for one realization (Nodal Force files = Pipe_Run_nd63_EL67_77_test_R1.dat and Pipe_Branch_nd1442_EL197_844_test_R1.prn) and may or may not be consistent with the 80th percentile results contained in Appendix E.5.2)

Force Outputs from Abaqus

NF1 := READPRN("Pipe_Run_nd63_EL67_77_test_R1.prn")

NF2 := READPRN("Pipe_Branch_nd1442_EL197_844_test_R1.prn")

(N)odal (F)orces from Model 3 and Model 4 surrounding Branch

$$\text{length}\left(NF2^{\langle 0\rangle}\right) = 2.401 \times 10^{4}$$

$$\left(NF^{\langle 0\rangle}\ NF^{\langle 1\rangle}\ NF^{\langle 2\rangle}\ NF^{\langle 3\rangle}\ NF^{\langle 4\rangle}\right) := \left(NF1^{\langle 0\rangle}\ NF1^{\langle 1\rangle}\ NF1^{\langle 2\rangle}\ NF2^{\langle 1\rangle}\ NF2^{\langle 2\rangle}\right)$$

NF =

	0	1	2	3	4
0	"Time/EL"	67	77	197	844
1	"Time/nd"	63	63	1.442 103	1.442 103
2	1	602.3	-602.3	-5.451	5.451
3	1.005	634.5	-633.2	-5.449	5.541
4	1.01	716.8	-713.8	-5.651	5.842
5	1.015	731.5	-730.5	-6.119	5.949
6	1.02	592.4	-594.8	-7.15	7.144
7	1.025	342.9	-349.1	-6.918	6.478
8	1.03	82.55	-92.97	-5.255	4.914
9	1.035	-86.21	73.22	-1.978	1.321

Defined Elemental and Corresponding Nodal Order

$$EL := \begin{pmatrix} \text{"Element"} & \text{"Node"} \\ 67 & 63 \\ 77 & 63 \\ 197 & 1442 \\ 844 & 1442 \end{pmatrix}$$

Element and corresponding nodal order for the branch joining Model 3 and 4

Time Boundaries

$t_{initial} := 1$ Initial time for which dynamic loading is applied

$t_{final} := 21$ Final time for which dynamic loading stops

Seismic Scale Factor (F_a)

$F_a := 1$ Seismic scale factor [30]

Allowable Design Stress Intensity Factor (S_m): *S_m is defined below for SS304 at temperature 125ºF and SS304L at 125ºF.*

$S_{m\_125} := 20\text{ksi}$ For SS304 at 125ºF [2, pg 316-318] [3, pg 23]

Yield Strength (S_y): *S_y is defined below for SS304 at temperature 125ºF and SS304L at 125ºF.*

$S_{y\_125} := 28.35\text{ksi}$ For SS304 at 125ºF [2, pg 646-648] [3, pg 23]

Maximum Strength Applicable for Equation 9 (S): *S is defined below for SS304 at temperature 125ºF and SS304L at 125ºF.*

$S_{125} := \min\left(3 \cdot S_{m\_125}, 2 \cdot S_{y\_125}\right)$ Maximum allowable stress applied to SS304 piping [9, NB-3656]

$\boxed{S_{125} = 56.7\,\text{ksi}}$

FABRICATED BRANCH TEES

Tees Strategy: *Search based on the elements comprising the tee. The input identifies which elements are associated with the pipe run and which element is associated with the branch from the run. The indices for the defined common node for all three elements is identified and the associated SRSS moment is identified for each time step. The maximum moment for the elements comprising the pipe run is found and applied as M_r in equation (9) of ASME III, Division I - NB - 3652 which is modified to represent tees. The maximum moment for the branch element is found and applied as M_b in equation (9) of ASME III, Division I - NB - 3652 [9]. The D/C ratio will be determined by dividing the left side of the equation by the right side of the equation.*

$$\text{FabBrDC}\left(P, D_o, T_r, B_1, B_{2b}, B_{2r}, M_b, M_r, Z_b, Z_r, S\right) := \frac{B_1 \cdot \frac{P \cdot D_o}{2 \cdot T_r} + B_{2b} \cdot \left[\frac{M_b \cdot (1\text{lbf} \cdot \text{in})}{Z_b}\right] + B_{2r} \cdot \left[\frac{M_r \cdot (1\text{lbf} \cdot \text{in})}{Z_r}\right]}{S}$$

$FabBr(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S, nf, el_R, el_B, nd_R, nd_B, C_o, EL) :=$

$ind_{nfi} \leftarrow match\left(t_{initial}, nf^{\langle 0\rangle}\right)$

$ind_{nfo} \leftarrow match\left(t_{final}, nf^{\langle 0\rangle}\right)$

$ind_{elR} \leftarrow match\left(el_{R_0}, EL^{\langle 0\rangle}\right)$

for $i \in 1 .. last(el_R)$

  $ind_{elR} \leftarrow stack\left[ind_{elR}, \left(match\left(el_{R_i}, EL^{\langle 0\rangle}\right)\right.\right.$

$EL'R_{last(EL^{\langle 0\rangle})} \leftarrow 0$

for $i \in 0 .. last(ind_{elR})$

  $EL'R_{ind_{elR_i}} \leftarrow EL_{ind_{elR_i}, 1}$

$ind_{ndR} \leftarrow match\left(nd_{R_0}, EL'R^{\langle 0\rangle}\right)$

for $i \in 1 .. last(nd_R)$

  $ind_{ndR} \leftarrow stack\left[ind_{ndR}, \left(match\left(nd_{R_i}, EL'R\right.\right.\right.$

$ind_{elB} \leftarrow match\left(el_{B_0}, EL^{\langle 0\rangle}\right)$

for $i \in 1 .. last(el_B)$

  $ind_{elB} \leftarrow stack\left[ind_{elB}, \left(match\left(el_{B_i}, EL^{\langle 0\rangle}\right)\right.\right.$

$EL'B_{last(EL^{\langle 0\rangle})} \leftarrow 0$

for $i \in 0 .. last(ind_{elB})$

  $EL'B_{ind_{elB_i}} \leftarrow EL_{ind_{elB_i}, 1}$

$ind_{ndB} \leftarrow match\left(nd_{B_0}, EL'B^{\langle 0\rangle}\right)$

for $i \in 1 .. last(nd_B)$

  $ind_{ndB} \leftarrow stack\left[ind_{ndB}, \left(match\left(nd_{B_i}, EL'E\right.\right.\right.$

$\left(M_R \;\; M_B \;\; Int_0\right) \leftarrow (0 \;\; 0 \;\; 0)$

for $i \in 0 .. ind_{nfo_0} - ind_{nfi_0}$

  for $j \in 0 .. last(ind_{ndR})$

    for $k \in 0 .. last(ind_{ndB})$

      $M_{rxgR_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}}+2, ind_{ndR_j}}$

$M_{rygR_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}+2}, ind_{ndR_j}}$

$M_{rzgR_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}+2}, ind_{ndR_j}}$

$M_{rxR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}+2+i}, ind_{ndR_j}} -\right.$

$M_{ryR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}+2+i}, ind_{ndR_j}} -\right.$

$M_{rzR_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}+2+i}, ind_{ndR_j}} -\right.$

$M_{R_j} \leftarrow \sqrt{\left(M_{rxR_j}\right)^2 + \left(M_{ryR_j}\right)^2 + (}$

$M_{rxgB_j} \leftarrow nf_{ind_{nfiC_{o_{0,1}}+2}, ind_{ndB_k}}$

$M_{rygB_j} \leftarrow nf_{ind_{nfiC_{o_{1,1}}+2}, ind_{ndB_k}}$

$M_{rzgB_j} \leftarrow nf_{ind_{nfiC_{o_{2,1}}+2}, ind_{ndB_k}}$

$M_{rxB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{0,1}}+2+i}, ind_{ndB_k}} -\right.$

$M_{ryB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{1,1}}+2+i}, ind_{ndB_k}} -\right.$

$M_{rzB_j} \leftarrow \left(nf_{ind_{nfiC_{o_{2,1}}+2+i}, ind_{ndB_k}} -\right.$

$M_{B_j} \leftarrow \sqrt{\left(M_{rxB_j}\right)^2 + \left(M_{ryB_j}\right)^2 + (}$

$Int'_j \leftarrow FabBrDC\left(P, D_o, T_r, B_1, B_{2b}, B\right.$

if $Int'_j > Int_0$

$Int \leftarrow stack\left(Int'_j, M_{R_j}, M_{B_j}, nf_{ind}\right.$

$Result \leftarrow stack\left(M_{R_j}, M_{B_j}, M_{rxR_j}\right.$

$M \leftarrow M_R$

Int

Conditions applicable to forged tee

$M_{cx} := 0 \qquad M_{cy} := 0 \qquad M_{cz} := 0$

Defining place holding directional moment variables

$$FabBr\_C_o := \begin{pmatrix} M_{cx} & 1 \\ M_{cy} & 2 \\ M_{cz} & 3 \\ F_a & 0 \end{pmatrix}$$

Constants associated with elbow's capacity direction x(North), y(Up), and z(East) correspond to positive 1, 2, and 3 and seismic factor

FABRICATED BRANCH

Define pertinent tee variables

$P := 376psi$

Internal Pressure [3, pg 23]

$D_o := 36in$

Outside Diameter of pipe run [17]

$d_o := 6.625in$

Outside Diameter of branch [17]

$B_1 := 0.5$

B_1 primary stress Index for tees and branches [9, Table NB-3681(a)-1]]

$T_r := 0.5in$

Nominal wall thickness of designated run pipe [17]

$$R_m := \frac{D_o - T_r}{2}$$

Mean radius of designated run pipe [17]

$Z_r := \pi \cdot R_m^{\ 2} \cdot T_r$

$Z_r = 494.899\ in^3$

Approximate section modulus of designated run pipe [9, NB-3683.1(d)]

$T'_b := 0.28in$

Nominal wall thickness of attached branch pipe [16]

$$r'_m := \frac{d_o - T'_b}{2}$$

Mean radius of attached branch pipe [16]

$Z_b := \pi \cdot r'_m{}^{2} \cdot T'_b$

$Z_b = 8.853\ in^3$

Approximate section modulus of attached branch pipe [9, NB-3683.1(d)]

C_{2b} Secondary stress Index [9,NB-3683.8]

$$C_{2b} := \begin{cases} 1.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}}\left(\frac{r'_m}{R_m}\right)^{\frac{1}{2}}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{\frac{d_o}{2}}\right) & \text{if } 1.5\cdot\left(\frac{R_m}{T_r}\right)^{\frac{2}{3}}\left(\frac{r'_m}{R_m}\right)^{\frac{1}{2}}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{\frac{d_o}{2}}\right) \ge 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$$C_{2b} = 3.674$$

C_{2r} Secondary stress Index [9,NB-3683.8]

$t_n := T'_b$

Wall thickness of nozzle or branch connection reinforcement associated with [9, NB-3643.4(A)-1, sketch (d)]

$$C_{2r} := \begin{cases} 1.15\cdot\left(\frac{r'_m}{t_n}\right)^{\frac{1}{4}} & \text{if } 1.15\cdot\left(\frac{r'_m}{t_n}\right)^{\frac{1}{4}} \ge 1.5 \\ 1.5 & \text{otherwise} \end{cases}$$

$$C_{2r} = 2.11$$

$$B_{2b} := \begin{cases} 0.5\cdot C_{2b} & \text{if } 0.5\cdot C_{2b} \ge 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2b} primary stress Index for branches [9, NB-3683.8]

$$B_{2b} = 1.837$$

$$B_{2r} := \begin{cases} 0.75\cdot C_{2r} & \text{if } 0.75\cdot C_{2r} \ge 1 \\ 1 & \text{otherwise} \end{cases}$$

B_{2r} primary stress Index for branches [9, NB-3683.8]

$$B_{2r} = 1.582$$

Branch from Model 1 to Model 4

$elR_{M34} := (67\ \ 77)^T$ Elements associated with pipe run

$ndR_{M34} := (63)^T$ Node between pipe run elements

$elB_{M34} := (844)^T$ Element associated with branch

$ndB_{M34} := (1442)^T$ Node where branch intersects pipe run

$$AL_{M34} := \text{FabBr}(P, D_o, T_r, B_1, B_{2b}, B_{2r}, Z_b, Z_r, S_{125}, NF, elR_{M34}, elB_{M34}, ndR_{M34}, ndB_{M34}, \text{FabBr\_C}_o, EL)$$

$$AL_{M34}^T = (0.257\ \ 3.177\times10^5\ \ 3.276\times10^4\ \ 5.575\ \ 63\ \ 1\ \ 2\ \ 4)$$

THIS RESULT ONLY REPRESENTS THE TEST CASE!!!!!!!!!!!!!!!!!!!!!!

$$\text{DC\_BrM3to4} := \text{WRITEPRN}(\text{"DC\_BrM3toM4\_test.prn"}, AL_{M34}^T)$$

Appendix E.5.2

80th Percentile Total Demand to Capacity Ratio

LOGIC USED TO READ IN DATA FROM ALL 32 REALIZATIONS INTO THE APPROPRIATE EMBEDDED MATRIX FORM

a := "Y:\PCS2\Automated_Evaluation\M34_Branch_Calc\real"

ReadData(b) := for $k \in 1..32$
  $d_{k-1} \leftarrow$ READPRN(concat(a, num2str(k), b))

LOGIC USED TO SORT DATA BASED ON D/C RATIOS OF ALL 32 REALIZATIONS

R := stack(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32)

```
C_S(v,R) := | for i ∈ 0.. cols(v) − 1
            |   for k ∈ 0.. rows(v_{0,i}) − 1
            |     for j ∈ 0.. rows(v) − 1
            |       a_{0,j} ← [((v_{j,i})^T)^⟨k⟩]^T
            |       A ← a_{0,j}  if j = 0
            |       A ← stack(A, a_{0,j})  if j > 0
            |     b_{k,i} ← stack(A^T, R^T)^T
            |     Sorted_{k,i} ← reverse(csort(b_{k,i}, 0))
            | Sorted
```

Model 3 and Model 4 Branch

M34_nd63_el := ReadData("\DC_BrM3toM4.prn")

M34_Branch_80 := C_S(M34_nd63_el, R)

$$\left(\left(M34\_Branch\_80_{0,0}\right)^{T\langle 2\rangle}\right)^{T} = \begin{pmatrix} 0.359 & 3.032\times 10^{5} & 6.067\times 10^{4} & 9.08 & 63 & 1 & 2 & 4 & 17 \end{pmatrix}$$

THIS IS THE 80TH PERCENTILE RESULT FOR THE MODEL 3 AND 4 BRANCH

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Appendix E.6 Capacity of U bolts

Standard U bolts are used as in several locations as pipe supports. The U bolts geometry can be found in the Grinnell catalog page ph-47 (See Reference 1). This document calculates the capacities of several U bolt sizes. The material is assumed to be A307.

$$rodsize := \begin{pmatrix} \frac{1}{2} \\ \frac{5}{8} \\ \frac{3}{4} \end{pmatrix} \cdot in$$

Standard U bolt rod sizes used in PCS piping. See Grinnell ph-47 (Reference 1).

$$F_{nt} := 45 \cdot ksi$$

Nominal tensile stress of A307 bolt material. See AISI pg. 16.1-104 Table J3.2 (Reference 2)

$$F_{nv} := 24 \cdot ksi$$

Nominal shear stress of A307 in bearing-type connections. See AISI pg. 16.1-104 Table J3.2. (Reference 2)

$$\phi := 0.75$$

Capacity reduction factor for bolts. See AISI pg. 16.1-108 (Reference 2)

$$A_b := \frac{\pi}{4} \cdot (rodsize)^2$$

Nominal unthreaded body area of bolt

$$A_b = \begin{pmatrix} 0.196 \\ 0.307 \\ 0.442 \end{pmatrix} \cdot in^2$$

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$DTS_{ubolt} := 2 \cdot (\phi \cdot F_{nt} \cdot A_b)$

Design tension strength. A factor of 2 was used here to account for both legs of the u bolt.

$$DTS_{ubolt} = \begin{pmatrix} 13.254 \\ 20.709 \\ 29.821 \end{pmatrix} \cdot kip \qquad Size := \begin{pmatrix} \text{"1/2-in"} \\ \text{"5/8-in"} \\ \text{"3/4-in"} \end{pmatrix}$$

$DSS_{ubolt} := \phi \cdot F_{nv} \cdot A_b$

Design shear strength.

$$DSS_{ubolt} = \begin{pmatrix} 3.534 \\ 5.522 \\ 7.952 \end{pmatrix} \cdot kip \qquad Size = \begin{pmatrix} \text{"1/2-in"} \\ \text{"5/8-in"} \\ \text{"3/4-in"} \end{pmatrix}$$

References:

1. Grinnell Company, "Adjustable Pipe Hangers and Supports, catalog ph-1951", 1951
2. AISC, "Steel Construction Manual", 13th edition, 2005, American Institute of Steel Construction

Appendix E.7

Applying Ductility Factor to Challenged Components

THIS DOCUMENT CALCULATES THE NEW D/C RATIOS OF CHALLENGED SUPPORTS ELIGIBLE FOR DUCTILITY FACTOR APPLICATION

References:

1. ASCE/SEI 43-05, "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities," American Society of Civil Engineers, 2005

LOGIC USED TO DETERMINE D/C RATIOS WITH AN APPLIED DUCTILITY FACTOR

$F_u := 1.25$

Ductility Factor for Limit State C Equipment Supports

$DC_{Fu}(DC_L, Gr_L, dir) :=$

$$D_{NS} \leftarrow Gr_{L_{dir-1,1}}$$
$$D_S \leftarrow DC_{L_{0,1}} - Gr_{L_{dir-1,1}}$$
$$Capacity \leftarrow \frac{DC_{L_{0,1}}}{DC_{L_{0,0}}}$$
$$R_{0,0} \leftarrow \frac{\frac{D_S}{F_u} + D_{NS}}{Capacity}$$
$$\text{for } i \in 1 .. length\left(DC_L^T\right) - 1$$
$$\quad R_{0,i} \leftarrow DC_{L_{0,i}}$$
$$R_{0,length\left(DC_L^T\right)} \leftarrow \text{"Fu=2"}$$

LOGIC USED TO DETERMINE DUCTILITY FACTOR NEEDED TO GET D/C OF 1

$Fu\_DC1(DC_L, Gr_L, dir) :=$

$$D_{NS} \leftarrow Gr_{L_{dir-1,1}}$$
$$D_S \leftarrow DC_{L_{0,1}} - Gr_{L_{dir-1,1}}$$
$$Capacity \leftarrow \frac{DC_{L_{0,1}}}{DC_{L_{0,0}}}$$
$$F_u \leftarrow \left|\frac{D_S}{D_{NS} - Capacity}\right|$$
$$F_u$$

LOGIC USED TO DEMONSTRATE THAT THE ANCHORAGE CAPACITY IS 125% THAT OF THE SUPPORT CAPACITY

$$\text{RatioA2S}\left(DC_L, \text{A\_Capacity}\right) := \left| \begin{array}{l} \text{S\_Capacity} \leftarrow \dfrac{DC_{L_{0,1}}}{DC_{L_{0,0}}} \\ \text{RatioA2S} \leftarrow \left| \dfrac{\text{A\_Capacity}}{\text{S\_Capacity} \cdot \text{lbf}} \right| \\ \text{RatioA2S} \end{array} \right.$$

LOGIC USED TO ENSURE THAT ANCHORAGE CAPACITY IS GREATER THAN THAT OF THE LOADING IF THE ANCHORAGE CAPACITY DOES NOT EXCEED THE 125% ANCHORAGE TO SUPPORT CAPACITY RATIO

$$\text{DC\_Anchor}\left(DC_L, \text{A\_Capacity}\right) := \left| \begin{array}{l} \text{Loading} \leftarrow DC_{L_{0,1}} \\ \text{DC\_Anchor} \leftarrow \left| \dfrac{\text{Loading} \cdot \text{lbf}}{\text{A\_Capacity}} \right| \\ \text{DC\_Anchor} \end{array} \right.$$

GRAVITY LOAD APPLIED FOR EACH SUPPORT USED TO DETERMINE D/C RATIOS WITH AN APPLIED DUCTILITY FACTOR

Gr_{RH23x} := READPRN("GL_RH23x.prn")

Gr_{RH19} := READPRN("GL_RH19.prn")

Gr_{RH25B} := READPRN("GL_RH25B.prn")

Gr_{AIWS} := READPRN("GL_AIWS.prn")

Gr_{PendU} := READPRN("GL_PendU.prn")

Gr_{TB2} := READPRN("GL_TB2.prn")

Gr_{PS20A} := READPRN("GL_PS20A.prn")

RH-23x Support (1x)

RH-23x (Node 394, Line 1-27)

RH-23x vertically supports the vertical PCS pipe on line 1-27 traveling up from the reactor vessel area and into the tunnel

$DC_{RH23x} := READPRN("Y:\backslash PCS2\backslash PCS\ Documentation\backslash App\_E\backslash E7\ DUCTILITY\ CALCS\backslash RH23x.prn")$

Tension Capacity Prior to Ductility Factor Implementation

$$DC_{RH23x} = \begin{pmatrix} 0.993 & -4.113 \times 10^4 & 8.74 & 394 & 139 & 28 \end{pmatrix}$$

Tension Capacity After Ductility Factor Implementation

$$\left(Gr_{RH23x}{}^{T}\right)^{\langle 1 \rangle T} = (1 \quad -52.67 \quad 653 \quad 394)$$

Gravity loading in vertical direction

$$Fu\_DC_{RH23x} := DC_{Fu}\left(DC_{RH23x}, Gr_{RH23x}, 2\right)$$

$$Fu\_DC_{RH23x} = \begin{pmatrix} 0.795 & -4.113 \times 10^4 & 8.74 & 394 & 139 & 28 & \text{"Fu=2"} \end{pmatrix}$$

Ductility Factor Required to Achieve a Demand/Capacity Ratio of 1

$$Fu\_RH23x := Fu\_DC1\left(DC_{RH23x}, Gr_{RH23x}, 2\right)$$

$$Fu\_RH23x = 0.993$$

Anchorage to Support Capacity Ratio

$$Cap_{RH23x\_A} := 56.28\,kip$$

$$Ratio\_A2S\_RH23x := RatioA2S\left(DC_{RH23x}, Cap_{RH23x\_A}\right)$$

$$Ratio\_A2S\_RH23x = 1.359$$

As required the anchorage capacity is greater than 125% that of the support capacity.

RH-25 Support (1x)

RH-25B (Node 617)

RH-25B vertically supports line 1-43 near the center of P(1-43J) from any downward movement.

$DC_{RH25B} :=$ READPRN("Y:\PCS2\PCS Documentation\App_E\E7 DUCTILITY CALCS\RH25B.prn")

Tension Capacity Prior to Ductility Factor Implementation

$$DC_{RH25B} = \left(1.062 \quad -1.1\times10^{4} \quad 4.795 \quad 617 \quad 96 \quad 31\right)$$

Tension Capacity After Ductility Factor Implementation

$$\left(Gr_{RH25B}{}^{T}\right)^{\langle 1\rangle T} = (1 \quad 485 \quad 405 \quad 617)$$ Gravity loading in vertical direction

$$Fu\_DC_{RH25B} := DC_{Fu}\left(DC_{RH25B}, Gr_{RH25B}, 2\right)$$

$$Fu\_DC_{RH25B} = \left(0.84 \quad -1.1\times10^{4} \quad 4.795 \quad 617 \quad 96 \quad 31 \quad \text{"Fu=2"}\right)$$

Ductility Factor Required to Achieve a Demand/Capacity Ratio of 1

$$Fu\_RH25B := Fu\_DC1\left(DC_{RH25B}, Gr_{RH25B}, 2\right)$$

$$Fu\_RH25B = 1.059$$

Anchorage to Support Capacity Ratio

$$Cap_{RH25B\_A} := 11.25kip$$

$$Ratio\_A2S\_RH25B := RatioA2S\left(DC_{RH25B}, Cap_{RH25B\_A}\right)$$

$$Ratio\_A2S\_RH25B = 1.086$$

This support does not exceed the 125% anchorage to support capacity, however, the loading is not greater than the capacity of the anchorage as shown below.

$$DC\_Anchor\_RH25B := DC\_Anchor\left(DC_{RH25B}, Cap_{RH25B\_A}\right)$$

$$DC\_Anchor\_RH25B = 0.978$$

PS-20A Supports (1x)

PS-20A Vertical (Node 1388)

PS-20A vertically and laterally supports the horizontal PCS pipe on line 1-34 between RH-14a and RH-14b.

$DC_{PS20A} :=$ READPRN("Y:\PCS2\PCS Documentation\App_E\E7 DUCTILITY CALCS\PS20A.prn")

Tension Capacity Prior to Ductility Factor Implementation

$$DC_{PS20A} = \begin{pmatrix} 1.272 & 7.329 \times 10^3 & 9.22 & 1.388 \times 10^3 & 89 & 28 \end{pmatrix}$$

Tension Capacity After Ductility Factor Implementation

$$\left(Gr_{PS20A}{}^{T}\right)^{\langle 1 \rangle T} = \begin{pmatrix} 1 & -205.5 & 727 & 1.388 \times 10^3 \end{pmatrix}$$ Gravity loading in vertical direction

$$Fu\_DC_{PS20A} := DC_{Fu}\left(DC_{PS20A}, Gr_{PS20A}, 2\right)$$

$$Fu\_DC_{PS20A} = \begin{pmatrix} 1.01 & 7.329 \times 10^3 & 9.22 & 1.388 \times 10^3 & 89 & 28 & \text{"Fu=2"} \end{pmatrix}$$

Ductility Factor Required to Achieve a Demand/Capacity Ratio of 1

$$Fu\_PS20A := Fu\_DC1\left(DC_{PS20A}, Gr_{PS20A}, 2\right)$$

$$Fu\_PS20A = 1.263$$

Anchorage to Support Capacity Ratio

$$Cap_{PS20A\_A} := 11.839\text{kip}$$

$$Ratio\_A2S\_PS20A := RatioA2S\left(DC_{PS20A}, Cap_{PS20A\_A}\right)$$

$$Ratio\_A2S\_PS20A = 2.055$$

As required the anchorage capacity is greater than 125% that of the support capacity.

Appendix E.8

Combination of Loading for Multiple Supports Utilizing a Common Anchorage

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THE FOLLOWING CALCULATIONS DETERMINE THE SRSS COMBINATION OF LOADINGS BEING OBSERVED BY THE ANCHORAGE SUPPORTING RH-21x AND RH-26x

Importing Data for RH-21x and RH-26x Anchorage Loading Combination

RH21x := READPRN("RH-21x.prn")

$$RH21x = \left(1.316 \quad -3.704 \times 10^{4} \quad 7.805 \quad 1.123 \times 10^{3} \quad 89 \quad 29\right)$$

RH26x127 := READPRN("RH-26x127.prn")

$$RH26x127 = \left(0.344 \quad -1.937 \times 10^{4} \quad 4.6 \quad 538 \quad 134 \quad 27\right)$$

RH26x814 := READPRN("RH-26x814.prn")

$$RH26x814 = \left(0.04 \quad -1.132 \times 10^{3} \quad 5.26 \quad 222 \quad 65 \quad 12\right)$$

Note: All loading is downward and has a negative value associated, therefore the algebraic combination is appropriate for these multiple values.

Calculating Combination D/C Ratio for RH-21x and RH-26x

Capacity := 56.28kip

$$SRSS(a,b,c) := \left(a^{2} + b^{2} + c^{2}\right)^{0.5}$$

$$DC := \left| \frac{\left(RH21x_{0,1} + RH26x127_{0,1} + RH26x814_{0,1}\right)lbf}{Capacity} \right|$$

$\boxed{DC = 1.022}$ This is the D/C ratio of the anchorage of RH-21x and RH-26x sharing the loading from lines 8-14, 1-27, and 1-7.

Importing Data for RH-22x and RH-27x Anchorage Loading Combination

RH22x := READPRN("RH-22x.prn")

$$RH22x = \begin{pmatrix} 0.754 & -2.121 \times 10^{4} & 5.24 & 1.12 \times 10^{3} & 111 & 5 \end{pmatrix}$$

RH27x := READPRN("RH-27x.prn")

$$RH27x = \begin{pmatrix} 0.786 & -2.186 \times 10^{4} & 5.565 & 539 & 142 & 1 \end{pmatrix}$$

Note: All loading is downward and has a negative value associated, therefore the algebraic combination is appropriate for these multiple values.

Calculating Combination D/C Ratio for RH-22x and RH-27x

$Capacity := 56.28kip$

$$DC := \left| \frac{\left(RH22x_{0,1} + RH27x_{0,1}\right)lbf}{Capacity} \right|$$

$\boxed{DC = 0.765}$ This is the D/C ratio of the anchorage of RH-22x and RH-27x sharing the loading from lines 8-14, 1-27, and 1-7.

Appendix E.9

Loading Experienced by PS-7 Support

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Performer: A. L. Crawford **Date:** 09/30/2008 **Checker:** M. J. Russell **Date:** 09/30/2008

THE FOLLOWING CALCULATIONS ARE TO FURTHER EVALUATE THE PS-7 SUPPORT FROM LOADS EXTRACTED FROM MODEL 14 AND MODEL265

Importing Data for Model 4 Loading on Line 1-41

PS7_N_M4 := READPRN("PS7_N_M4.prn")

$PS7\_N\_M4_{0,1} = -1.24 \times 10^3$ ***Maximum North Load (lbf)***

PS7_S_M4 := READPRN("PS7_S_M4.prn")

$PS7\_S\_M4_{0,1} = 1.696 \times 10^3$ ***Maximum South Load (lbf)***

PS7_D_M4 := READPRN("PS7_D_M4.prn")

$PS7\_D\_M4_{0,1} = -2.454 \times 10^3$ ***Maximum Down Load (lbf)***

PS7_U_M4 := READPRN("PS7_U_M4.prn")

$PS7\_U\_M4_{0,1} = 1.764 \times 10^3$ ***Maximum Up Load (lbf)***

Importing Data for Model 6 Loading on Line 1-44

PS7_N_M6 := READPRN("PS7_N_M6.prn")

$PS7\_N\_M6_{0,1} = -1.621 \times 10^3$ ***Maximum North Load (lbf)***

PS7_S_M6 := READPRN("PS7_S_M6.prn")

$PS7\_S\_M6_{0,1} = 1.343 \times 10^3$ ***Maximum South Load (lbf)***

PS7_D_M6 := READPRN("PS7_D_M6.prn")

$PS7\_D\_M6_{0,1} = -4.072 \times 10^3$ ***Maximum Down Load (lbf)***

PS7_U_M6 := READPRN("PS7_U_M6.prn")

$PS7\_U\_M6_{0,1} = 0$ ***Maximum Up Load (lbf)***

Appendix E.10

Branch Flexibility Calculations for ASME Qualified Branch Components

(NOTE: Branches that did not meet the ASME requirements are evaluated in Appendix F)

LOGIC USED TO CALCULATE THE ASSOCIATED MOMENT OF INERTIA NEEDED BY A BEAM IN ORDER TO MATCH ASME CODE REQUIREMENTS FOR A BRANCH

$Fnc(D_o, T_r, d_o, T'_b) :=$ for $i \in 0 .. length(D_o) - 1$

$$R_{m_i} \leftarrow 0.5(D_{o_i} - T_{r_i})$$

$$Z_{r_i} \leftarrow \pi \cdot (R_{m_i})^2 \cdot T_{r_i}$$

$$r'_{m_i} \leftarrow 0.5(d_{o_i} - T'_{b_i})$$

$$t_{n_i} \leftarrow T'_{b_i}$$

$$\begin{pmatrix} Rm2rm_i & Rm2Tr_i \end{pmatrix} \leftarrow \begin{pmatrix} \dfrac{r'_{m_i}}{R_{m_i}} & \dfrac{R_{m_i}}{T_{r_i}} \end{pmatrix}$$

$RM2TR_i \leftarrow$ "TRUE" if $Rm2Tr_i < 50$

$RM2TR_i \leftarrow$ "FALSE" if $Rm2Tr_i \geq 50$

$$I_{b_i} \leftarrow \pi \cdot \frac{(d_{o_i})^4 - (d_{o_i} - 2 \cdot T'_{b_i})^4}{64}$$

$$\begin{pmatrix} k_{x3_i} & k_{z3_i} \end{pmatrix} \leftarrow \left[\left[0.1 \cdot \left(\frac{D_{o_i}}{T_{r_i}} \right)^{1.5} \cdot \left[\left(\frac{T_{r_i}}{t_{n_i}} \right) \cdot \frac{d_{o_i}}{D_{o_i}} \right]^{\frac{1}{2}} \cdot \left(\frac{T'_{b_i}}{T_{r_i}} \right) \right] \; \left[0.2 \cdot \left(\frac{D_{o_i}}{T_{r_i}} \right) \cdot \left[\left(\frac{T_{r_i}}{t_{n_i}} \right) \cdot \frac{d_{o_i}}{D_{o_i}} \right]^{\frac{1}{2}} \cdot \left(\frac{T'_{b_i}}{T_{r_i}} \right) \right] \right]$$

$$\begin{pmatrix} I_{x\_eq_i} & I_{z\_eq_i} \end{pmatrix} \leftarrow \begin{pmatrix} \dfrac{0.5 I_{b_i} \cdot D_{o_i}}{k_{x3_i} \cdot d_{o_i}} & \dfrac{0.5 \cdot I_{b_i} \cdot D_{o_i}}{k_{z3_i} \cdot d_{o_i}} \end{pmatrix}$$

$RM2rm_i \leftarrow$ "TRUE" if $Rm2rm_i < 0.5$

if $Rm2rm_i \geq 0.5$

- $RM2rm_i \leftarrow$ "FALSE"
- $\begin{pmatrix} I_{x\_eq_i} & I_{z\_eq_i} \end{pmatrix} \leftarrow \begin{pmatrix} 0.56 \cdot I_{x\_eq_i} & 0.81 \cdot I_{z\_eq_i} \end{pmatrix}$

$$\begin{pmatrix} K_x & K_z \end{pmatrix} \leftarrow \begin{pmatrix} \dfrac{I_{b_i}}{I_{x\_eq_i}} & \dfrac{I_{b_i}}{I_{z\_eq_i}} \end{pmatrix}$$

$$\begin{pmatrix} I_{x\_eq} & I_{z\_eq} \end{pmatrix}$$

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COMMON PROPERTIES FOR ALL BRANCHES

$E := 28.0 \cdot 10^{6} \cdot psi$ Modulus of Elasticity for stainless steel (See Table 2 in Main Body of Report)

$S_{y\_125} := 28.35ksi$ For SS304 at 125ºF [2, pg 646-648] [3, pg 23]

Branch Calculations

Moments of Inertia Associated with Branches

Nominal Pipe Dimensions

Outside Diameter of Pipe Run	Nominal wall thickness of designated run pipe	Outside Diameter of Branch	Nominal wall thickness of branch

$$Br := \begin{pmatrix} \text{" 36" x 20" "} \\ \text{" 36" x 6" "} \\ \text{" 30" x 16" "} \\ \text{" 20" x 6" "} \\ \text{" 16" x 4" "} \\ \text{" 14" x 4" "} \\ \text{" 6" x 4" "} \end{pmatrix} \quad D_o := \begin{pmatrix} 36 \\ 36 \\ 30 \\ 20 \\ 16 \\ 14 \\ 6.625 \end{pmatrix} in \quad T_r := \begin{pmatrix} 0.5625 \\ 0.5 \\ 0.438 \\ 0.312 \\ 0.25 \\ 0.25 \\ 0.28 \end{pmatrix} in \quad d_o := \begin{pmatrix} 20 \\ 6.625 \\ 16 \\ 6.625 \\ 4.5 \\ 4.5 \\ 4.5 \end{pmatrix} in \quad T'_b := \begin{pmatrix} 0.375 \\ 0.28 \\ 0.25 \\ 0.28 \\ 0.237 \\ 0.237 \\ 0.237 \end{pmatrix} in$$

Dimensions of Reinforcement on Pipe Run

$$Referece := \begin{pmatrix} \text{" 36" x 20" M3-1-27-N690-PRF-DSCN2968 "} \\ \text{" 36" x 6" "} \\ \text{" 30" x 16" Conservative from [1] "} \\ \text{" 20" x 6" M5-1-45-N1-PBRG-DSCN2761"} \\ \text{" 16" x 4" M3-1-32-N970-WSUG-DSC00068"} \\ \text{" 14" x 4"M2-1-30-N12-PBRRF-DSCN2746 "} \\ \text{" 6" x 4" Conservatively assumed = 0 in"} \end{pmatrix} \quad Reinforce := \begin{pmatrix} 0.375 \\ 0.25 \\ 0.25 \\ 0.25 \\ 0 \\ 0.25 \\ 0 \end{pmatrix} in$$

Thickness of Pipe Run Including Reinforcement

$$j := 0 .. length(T_r) - 1$$

$$T_{R_j} := T_{r_j} + Reinforce_j \qquad T_R = \begin{pmatrix} 0.938 \\ 0.75 \\ 0.688 \\ 0.562 \\ 0.25 \\ 0.5 \\ 0.28 \end{pmatrix} in$$

Equivelent Moments of Inertia for ASME x and z Axes
(Corresponds to the Weak and Strong Axes of the Branch)

$$\left(I_{x\_eq}^{\langle 1\rangle} \;\; I_{z\_eq}^{\langle 1\rangle}\right) := \mathrm{Fnc}\left(D_o, T_R, d_o, T'_b\right)$$

$$I_{x\_eq}^{\langle 0\rangle} := \mathrm{Br}$$

$$I_{z\_eq}^{\langle 0\rangle} := I_{x\_eq}^{\langle 0\rangle}$$

$I_{x\_eq} =$ (in^4)

" 36" x 20" "	50.029
" 36" x 6" "	8.772
" 30" x 16" "	15.89
" 20" x 6" "	4.925
" 16" x 4" "	0.486
" 14" x 4" "	1.945
" 6" x 4" "	0.342

$I_{z\_eq} =$ (in^4)

" 36" x 20" "	224.208
" 36" x 6" "	30.387
" 30" x 16" "	75.887
" 20" x 6" "	14.691
" 16" x 4" "	1.945
" 14" x 4" "	5.147
" 6" x 4" "	1.202

Torsional Constants Associated with Branches

$$\mathrm{PolarM}\left(d_o, T'_b\right) := \text{ for } i \in 0 .. \mathrm{length}\left(d_o\right) - 1$$

$$J_i \leftarrow \frac{\pi}{32}\left[{d_o}^4 - \left(d_o - 2 \cdot T'_b\right)^4\right]$$

$$J^{\langle 1\rangle} := \mathrm{PolarM}\left(d_o, T'_b\right)$$

$$J^{\langle 0\rangle} := \mathrm{Br}$$

$J =$ (in^4)

" 36" x 20" "	{7,1}
" 36" x 6" "	{7,1}
" 30" x 16" "	{7,1}
" 20" x 6" "	{7,1}
" 16" x 4" "	{7,1}
" 14" x 4" "	{7,1}
" 6" x 4" "	{7,1}

Areas Associated with Branches

$$\mathrm{Area}\left(d_o, T'_b\right) := \text{ for } i \in 0 .. \mathrm{length}\left(d_o\right) - 1$$

$$A_i \leftarrow \frac{\pi}{4}\left[{d_o}^2 - \left(d_o - 2 \cdot T'_b\right)^2\right]$$

$$A^{\langle 1\rangle} := \mathrm{Area}\left(d_o, T'_b\right)$$

$$A^{\langle 0\rangle} := \mathrm{Br}$$

$A =$ (in^2)

" 36" x 20" "	{7,1}
" 36" x 6" "	{7,1}
" 30" x 16" "	{7,1}
" 20" x 6" "	{7,1}
" 16" x 4" "	{7,1}
" 14" x 4" "	{7,1}
" 6" x 4" "	{7,1}

Appendix E.11

Plastic Hinge Calculations for Lines 1-37 & 1-38

Plastic Hinge Calculations for Lines 1-37 and 1-28

$D_o := 2.375\,in$ — Outside Diameter [18]

$t := 0.154\,in$ — Thickness [18]

$P := 376\,psi$ — Internal Pressure [3, pg 23]

$$I := \frac{\pi \cdot \left[D_o^{\ 4} - \left(D_o - 2 \cdot t\right)^4\right]}{64}$$

$$I = 0.666\,in^4$$

Moment of inertia [8, Table 17-27, pg 17-39]

$S_{125} := 56.7\,ksi$ — Allowable design stress intensity value

Define primary stress indices

$B_1 := 0.5$

$$B_2 := \begin{cases} 1.0 & \text{if } \frac{D_o}{t} \le 50 \\ \text{if } \frac{D_o}{t} > 50: & T \leftarrow 125,\; X \leftarrow \min\left(1, 1.3 - 0.006 \cdot \frac{D_o}{t}\right),\; Y \leftarrow 1,\; 1.0 \cdot \frac{1}{X \cdot Y} \end{cases}$$

$B_2 = 1$

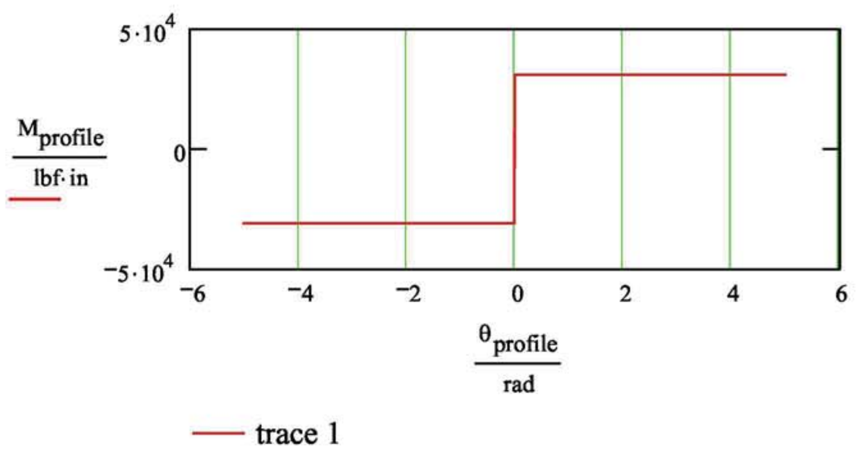
Stress Indices are derived from [4, Table NB-3681(a)-1] where B_2 is subjected to additional logic as defined in [4, NB-3683.2 (d)] to check for D/t ratios greater than 50 and use the X and Y equations (T in degrees Fahrenheit) to adjust B_2 accordingly

$$M_p := \frac{S_{125} - B_1 \cdot \frac{P \cdot D_o}{2 \cdot t}}{B_2 \cdot \frac{D_o}{2 \cdot I}}$$

$M_{profile} := \left(\left(-M_p \;\; -M_p \;\; M_p \;\; M_p\right)\right)^T$ Moment Profile

$$M_{profile}^T = \left(-3.097\times 10^4 \;\; -3.097\times 10^4 \;\; 3.097\times 10^4 \;\; 3.097\times 10^4\right) lbf\cdot in$$

$\theta_{profile} := [(-5 \;\; -.005 \;\; 0.005 \;\; 5)rad]^T$ Rotation Profile



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Engineering Calculations and Analysis Report

ATR Primary Coolant System Piping Seismic Evaluation

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Appendix E, Appendix F

Idaho National Laboratory

The INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance.

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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Appendix F

Unlisted Component Evaluations

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Introduction

The ATR Primary Coolant System (PCS) piping contains several unlisted components within its boundaries. Hence, these components are termed as "unlisted," for they are not part of the listed components as identified within the 2007 ASME Boiler & Pressure Vessel Code, Section III, Division 1, Subsection NB [1]. Subsection NB addresses Class 1 components within a nuclear facility. Evaluation of listed Class 1 components require the retrieval of code table values or the results from specific equations to obtain pertinent flexural and stress indices information, per each listed component type. Although unlisted component data is not readily available within Section NB, provisions are provided such that pertinent flexural and stress indices may be evaluated and obtained for eventual evaluation. It should be noted that past versions of ASME Section III code have referred to these unlisted components as "nonstandard" and the listed components as "standard."

In past INL piping analyses [2, 3], the ATR PCS piping have been evaluated through six (6) finite element (FE) models based on reduced sized computational methods of its day. Many of these previous PCS analyses have not addressed the unlisted (or nonstandard) component faction within the PCS, but have chosen to ignore this issue by modeling these components as being listed (or standard). This report (ECAR-194) has combined the previous six piping models into three FE models and eliminates many of the artificial restraint connections caused by model reductions based on computational limits. This report also evaluates all unlisted component types as they occur within their respective piping model. For example, Models 1 and 4 have been combined to form Model 14 and Models 2, 5, and 6 have been combined to for Model 256 (also referred to as 265). Thus, unlisted component evaluations take place within this Appendix for the Pilot model (Model 3), Models 256, and 14.

Purpose & Scope

The purpose of this Appendix is to evaluate the prominate unlisted components (within each of the three piping models) to determine compliance with the 2007 ASME Section III, Division 1, Subsection NB [1] acceptance criteria.

The scope of this Appendix is to create FE models of prominate unlisted component type and determine corresponding flexibility factors and stress indices that are then used to determine their acceptance as documented in Subsection NB-3630 for level D service limits. If an unlisted component does not meet the requirements of Subsection NB-3630, then a plastic analysis of the component is pursued to determine compliance with ASME Section III, Appendix F [4] acceptance criteria. Flexibility factors for some components (of similar population) which have demand to capacity ratios in excess of one, are determined.

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Appendix F.1
Unlisted Component Evaluations Associated with Pilot Model

The Pilot model (or Model 3) contains one prominate unlisted component within its piping boundary.

The unlisted component [5, Figure 19] is a 36-in x 0.562-in thick elbow that has a 14-in x 0.25-in thick pipe that extends out its back radius, forming a branch connection [6]. The 14-inch pipe is reinforced to the elbow with a 0.5-in thick plate [7]. Figure F.1-1 illustrates the Pilot model's unlisted branch component. The concrete square column (as viewed within Figure F.1-1) is on the unlisted component's North side. The unlisted branch component is fabricated from 304 stainless steel materials.

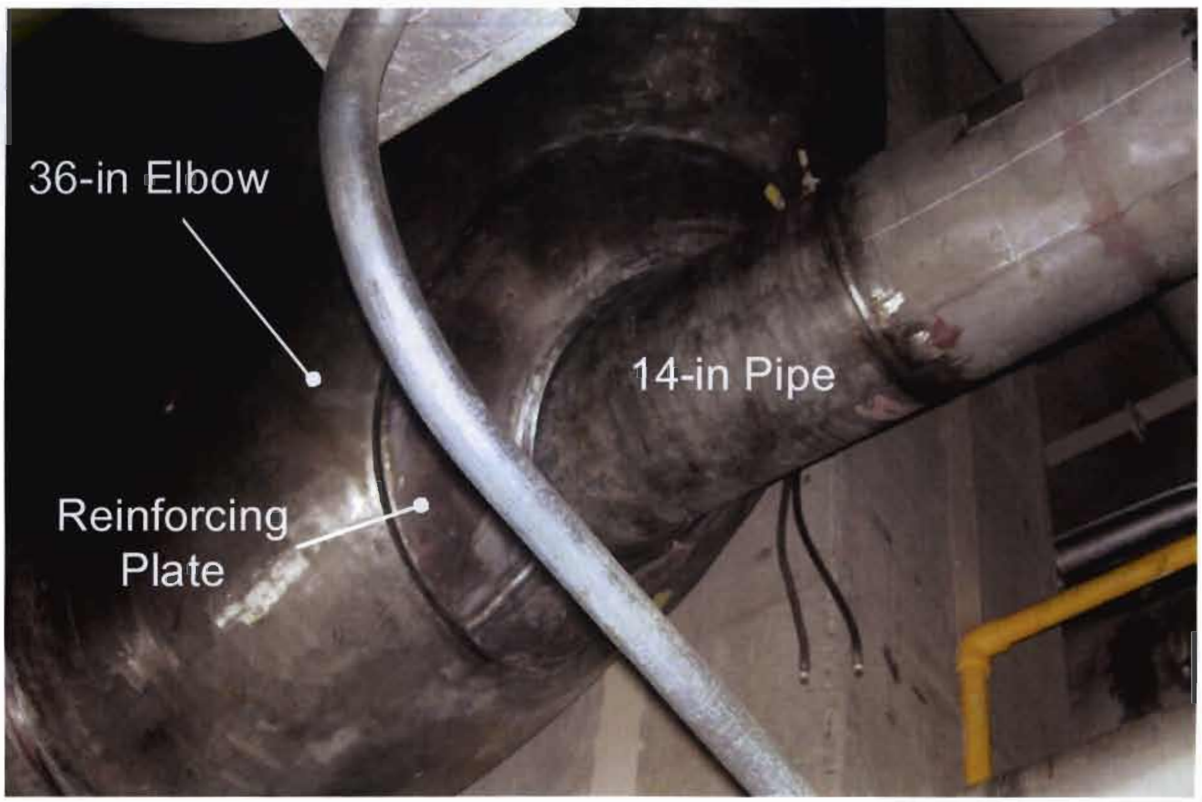

Figure F.1-1 – The Pilot model's unlisted branch component is shown, as viewed from below

The following sections (listed below) contain information used to evaluate the Pilot model's unlisted branch and unlisted tee components.

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F.1.1 – FE Model Description of Unlisted Branch Component

The Pilot model's unlisted branch component was solid-modeled and meshed within I-DEAS Master Series, Simulation, Version 12 [9]. With the meshing complete, input files were written for ABAQUS [10]. Final editing of the input files were performed in a text editor and then solution runs were performed with ABAQUS Standard, Version 6.7-5. Results of the FE models are displayed with ABAQUS Viewer, Version 6.7-5, and are shown in Appendix F.1.2.

The unlisted branch component was meshed primarily with four-node quadrilateral elements and some rigid beam elements. The quadrilateral elements support six degrees of freedom (3-translations, 3 rotations) at each node and were used to model the 36-in elbow, 14-in pipe, and 0.5-in thick reinforcement plate. The rigid beams were used as an aid in defining boundary conditions (i.e., applying loads and defining restraints) to the meshed unlisted branch component. Figures F.1.1-2 through F.1.1-4 illustrates the unlisted branch component as meshed with the quadrilateral elements. Table F.1,1 correlates element color to member name and thickness.

Figure F.1.1-2 – Quadrilateral shell mesh of the Pilot model's unlisted branch component is shown.

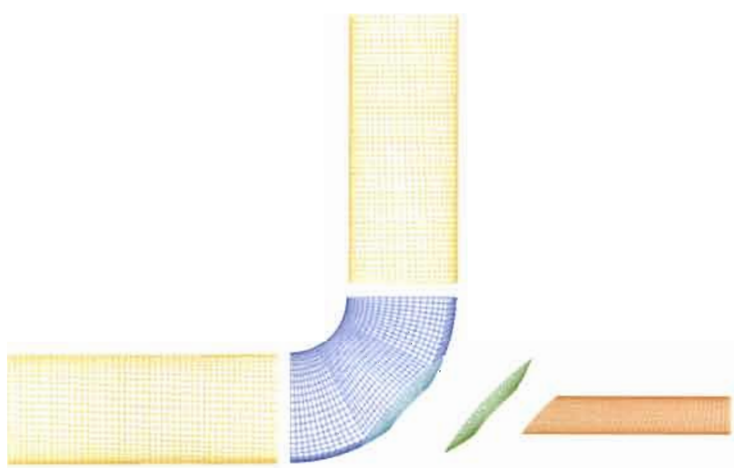

Figure F.1.1-3 – Side view of unlisted branch component showing member meshes.

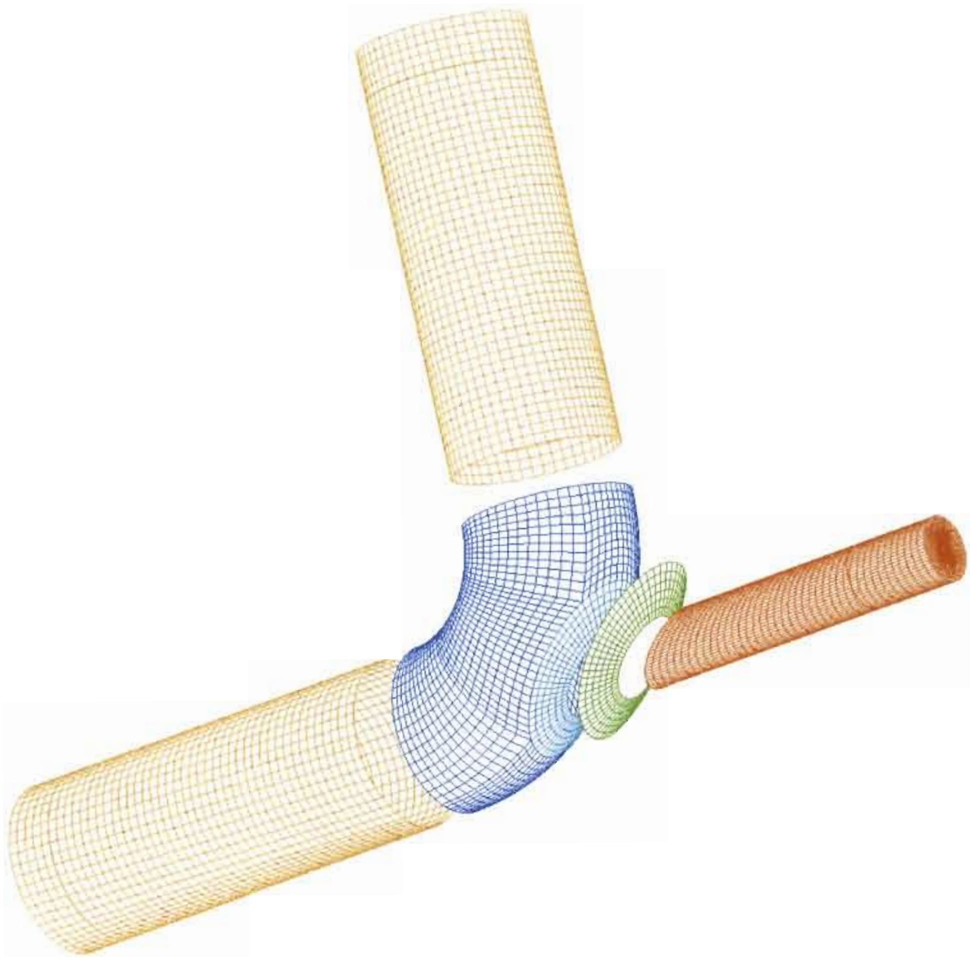

Figure F.1.1-4 – Isometric view of unlisted branch component showing member meshes.

Table F.1.1-1 – Mesh color, thickness, and component member correlation

Member Name	Mesh Color(s)	Element Thickness
36" Short Radius Elbow	Dark Blue & Cyan	9/16" (0.562-in)
Reinforcement Plate	Green	½" (0.50-in)
Branch (14" Pipe)	Redish-orange	¼" (0.25-in)
*Run (36" Pipe) extended from both ends of elbow	Gold, or light-orange	9/16" (0.562-in)

*These component members were used as an aid to apply boundary conditions to unlisted branch.

As shown in Figures F.1.1-2 through F.1.1-4 and in Table F.1.1-1, the unlisted branch component's reinforced plate is oriented right next to the elbow's back surface (part of run) and surrounds the 14-in Piping (forming the branch). The combined thickness in the reinforced plate region is 1.062-inches (0.562-in elbow thickness + 0.5-in reinforcement plate thickness). The run portion of this "branch component" is comprised of the elbow and two 36-in pipe extensions. The two 36-in pipe extensions were used as an aid to apply boundary conditions to the unlisted branch component.

The unlisted branch component is fabricated with 304 stainless steel [6] and operates at 125°F while maintaining a constant internal gauge pressure of 400-psi [11, Section 7.1]. Material properties of the unlisted branch component are shown in Table F.1.2, where most of the property values are taken from ASME Section II, Subpart D, "Materials" [12] and reprinted from the report's main body.

Table F.1.1-2 – 304 Stainless Steel Material Properties at 125°F.

Symbol	Property Value	Property Description
μ	*0.30 in/in	Poisson's Ration [1, Section NB-3683.1(b)]
E	28.0E+6	Modulus of Elasticity at 125°F Temperature [12, Table TM]
Sy	28.35 ksi	Material Yield Strength at 125°F Temperature [12, Table Y-1]
Sm	20 ksi	Maximum allowable Stress Intensity at 125°F Temperature [12, Table 2A]

*μ = 0.29 in/in was used for scoping stress indices calculation of the unlisted branch component.

FE Boundary Conditions

A total of fourteen (14) ABAQUS solution runs were used to determine the unlisted branch component's flexibility factor (FF) and stress indices (SI) values. The FF runs used two model meshes with a single boundary condition. The SI runs utilized one model, with six different boundary conditions.

FF Models & Boundary Conditions

Two FE model meshes were used to determine deflection information necessary for computing the unlisted branch component's FF. Both models utilize rigid beams at the pipe ends to transmit applied moments and restraints from pipe section center nodes to perimeter nodes. The first model mesh (shown in Figure F.1.1-5) reflects how restraints and applied moments are placed on the unlisted branch component mesh. The angular deflection results (within the Y-Z plane) of this FF elbow/branch model are compared to that of the angular deflection of a regular elbow (without branch or reinforcement plate) model mesh, as shown in Figure F.1.1-6. The elbow model mesh is merely a reduction of the previous unlisted branch model mesh. Both model meshes have the same boundary condition applied, but provide differing angular deflections - which information is used to determine the unlisted branch component's flexibility factor (in Appendix F.1.3). Table F.3 summaries the boundary condition placed on the two FF model meshes and identifies corresponding ABAQUS input files. A brief listing (without nodal and element definitions) of each input file is reprinted in Appendix F.1.6.

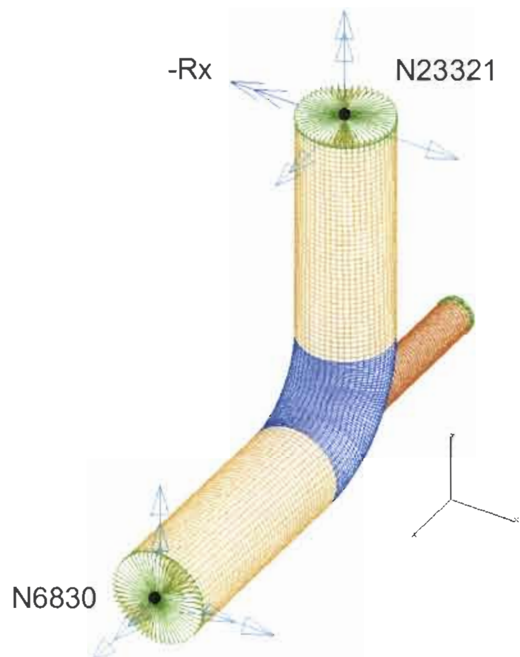

Figure F.1.1-5 – Isometric view of FF elbow/branch model mesh showing applied boundary condition.

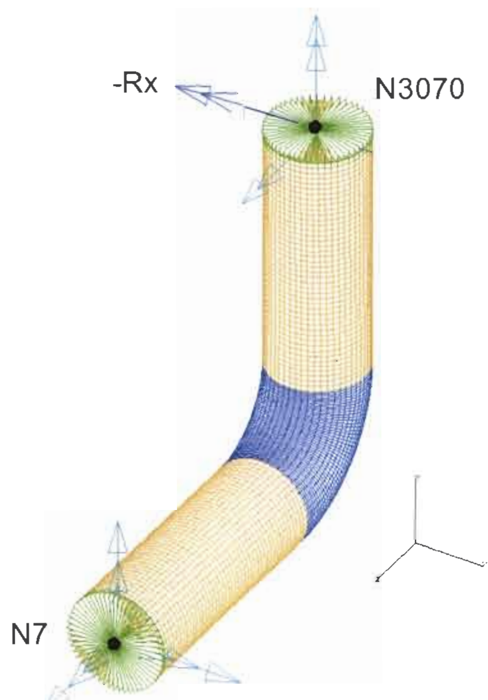

Figure F.1.1-6 – Isometric view of FF elbow model mesh showing applied boundary condition.

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Table F.1.1-3 – FF Models Boundary Conditions.

Model Meshes	Restraint Nodes & Degrees of Freedom (DOF)	Applied Loads (IP-internal pressure) (Rx – applied moment)	Input File Name (Appendix F.1.11)
Elbow/Branch (unlisted branch)	N6830: 6 dof fixed (X, Y, Z, RX, RY, RZ) N23321: 3 dof fixed: (X, RY, RZ)	IP = 400 psi N23321: RX = 1.4E+6 in*lbf	branch_np.inp
" "	" "	" " N23321: RX = -1.4E+6 in*lbf	branch_npn2_new.inp (includes plastic material properties)
Elbow (without branch & reinforcing plate)	N7 : 6 dof fixed (X, Y, Z, RX, RY, RZ) N3070: 3 dof fixed (X, RY, RZ)	" " N3070: RX = +1.4E+6 in*lbf	elbow_np.inp

Note that the applied moment of each FF model mesh has a different sign. The applied moment direction that produces the maximum angular displacement for each FF model mesh is used.

SI Model & Boundary Conditions

As previously described, the SI model mesh matches that of the elbow/branch (or unlisted branch component) mesh for which the physical properties (Table F.1.1-1) and material properties (Table F.1.1-2) apply. Twelve boundary conditions corresponding to twelve solution runs were used to apply corresponding results for determining the unlisted branch component's stress indices. The twelve boundary conditions stem from two restraint sets that apply a single nodal moment at six different locations. Six additional nodal moments are applied, with opposing signs, bringing the total boundary conditions (or ABAQUS input files) to twelve. As was shown for the FF model meshes, rigid beams were used at pipe ends for restraint and moment application.

Applied moments were extracted from a scpoing set of 32 pilot model's piping system runs (Appendix B), in which the 80 percentile run pertaining to corresponding moments incurred within the unlisted branch component scoping set are identified. Figure F.1.1-7 shows a representation of corresponding system beam nodes in which nodal moments are extracted.

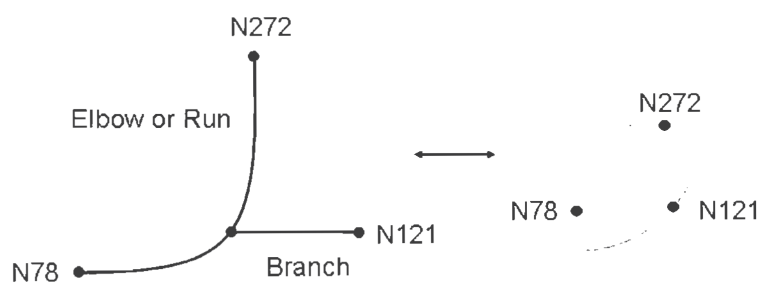

Figure F.1.1-7 – Corresponding nodes in which moments are extracted for 80 percentile solution.

As can be seen in figure F.1.1-7, moments (Mx, My, Mz) extracted at node 121 correspond to the branch segment and moments (Mx, My, Mz) extracted at nodes N78 and N272 correspond to the run segment. Table F.4 lists the nodal moment values extracted from a preliminary 80 percentile Pilot model run at these nodes that were used for scoping SI calculations.

Table F.1.1-4 – Unlisted Branch Component's SI Moment Extractions.

Node Number	MX (in*lbf)	MY (in*lbf)	MZ (in*lbf)
N121 (branch)	1.47417E+4	-5.33164E+5	1.48736E+5
N78 (run)	-1.5479E+6	-2.03468E+4	-1.35239E+5
N272 (run)	3.94024E+5	5.81897E+5	-3.18892E+4

From Table F.1.1-4, the maximum moment magnitude values and their opposite negative magnitudes were used to define the twelve boundary conditions at the extended branch and run pipe ends. Figure F.1.1-8 illustrates a single boundary condition where restraint set 1 is used along with a single moment applied at the branch (or 14-in Pipe) end. Six boundary conditions utilize restraint set 1, where varying moments are applied at the branch pipe end. Figure F.1.1-9 shows a single boundary condition where restraint set 2 is used along with a single moment applied at the top end of run (or 36-in Pipe) end. Six boundary conditions utilize restraint set 2, where varying moments are applied at the run's top pipe end. Table F.1.1-5 summaries boundary conditions placed on the twelve SI solution runs and identify corresponding ABAQUS input files. A brief listing (without nodal and element definitions) of each SI input file is reprinted in Appendix F.1.6.

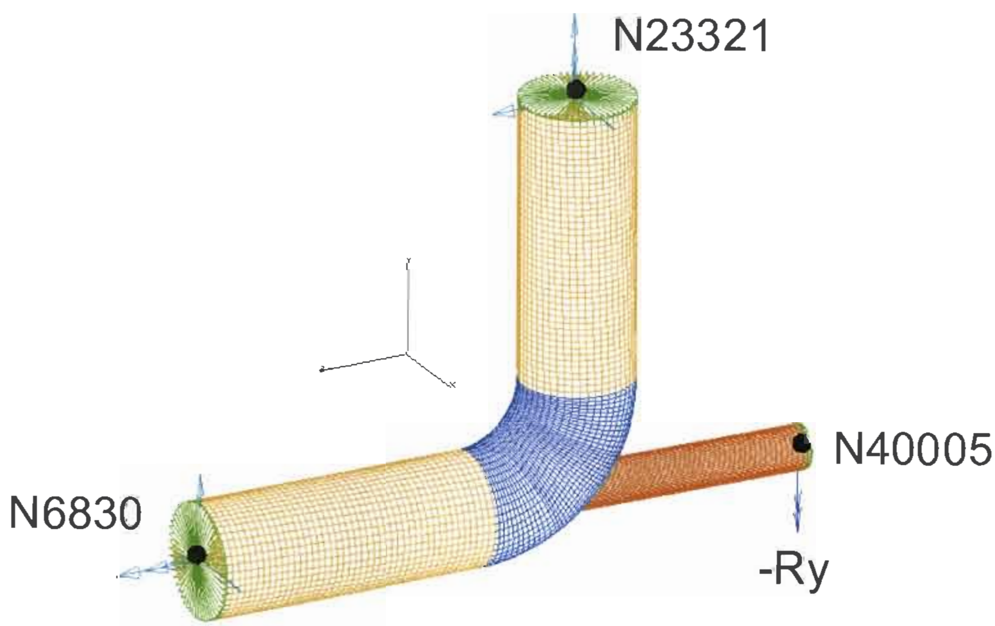

Figure F.1.1-8 – Isometric view of unlisted branch mesh showing restraint set 1 boundary condition applied.

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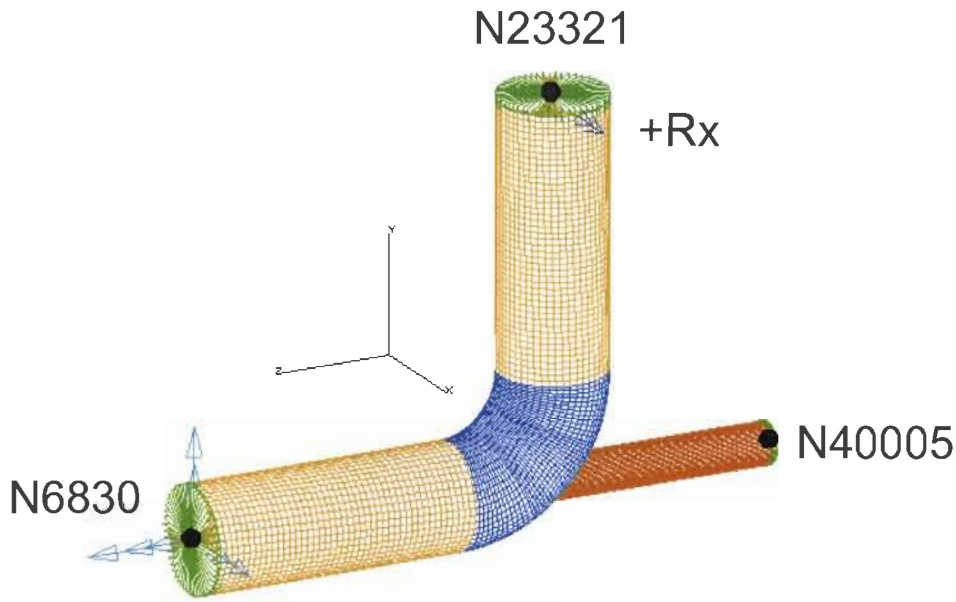

Figure F.1.1-9 – Isometric view of unlisted branch mesh showing restraint set 2 boundary condition applied.

Table F.1.1-5 – SI Boundary Conditions.

Model (Appendix F.1.11)	**Restraint Set Degrees of Freedom (DOF)**	**Applied Loads (IP – internal pressure) (Rx, Ry, Rz – applied moments)**
p_branch_si_bxA.inp	Set 1 N6830 - 6 dof fixed: (X, Y, Z, RX, RY, RZ) N23321 - 3 dof fixed: (X, RY, RZ)	IP = 400 psi N40005: Rx = +1.47417E+4 in*lbf
p_branch_si_bxO.inp	" "	" " N40005: Rx = -1.47417E+6 in*lbf
p_branch_si_byA.inp	" "	" " N40005: Ry = +5.33164E+5 in*lbf
p_branch_si_byO.inp	" "	" " N40005: Ry = +5.33164E+5 in*lbf
p_branch_si_bzA.inp	" "	" " N40005: Rz = +1.48736E+5 in*lbf
p_branch_si_bzO.inp	" "	" " N40005: Rz = -1.48736E+5 in*lbf
p_vertrun_si_rxA.inp	Set 2 N6830 - 6 dof fixed: (X, Y, Z, RX, RY, RZ)	IP = 400 psi N23321: Rx = +1.54812E+6 in*lbf

p_vertrun_si_rxO.inp	" "	" " N23321: Rx = -1.54812E+6 in*lbf
p_vertrun_si_ryA.inp	" "	" " N23321: Ry = +5.81897E+5 in*lbf
p_vertrun_si_ryO.inp	" "	" " N23321: Ry = -5.81897E+5 in*lbf
p_vertrun_si_rzA.inp	" "	" " N23321: Rz = +1.35239E+5 in*lbf
p_vertrun_si_rzO.inp	" "	" " N23321: Rz = -1.35239E+5 in*lbf

F.1.2 – FE Model Results of Unlisted Branch Component

ABAQUS post processing results for the fourteen (14) preliminary 80 percentile solution runs are shown within this section.

The first two FF solution results extract nodal coordinate values which are then used (in Appendix F.1.3) to determine angular displacements and a flexibility factor. Figure F.1.2-1 shows displacement magnitude results of the unlisted branch mesh (1st FF model mesh) and identifies nodes that are used for FF determination (within Appendix F.1.3).

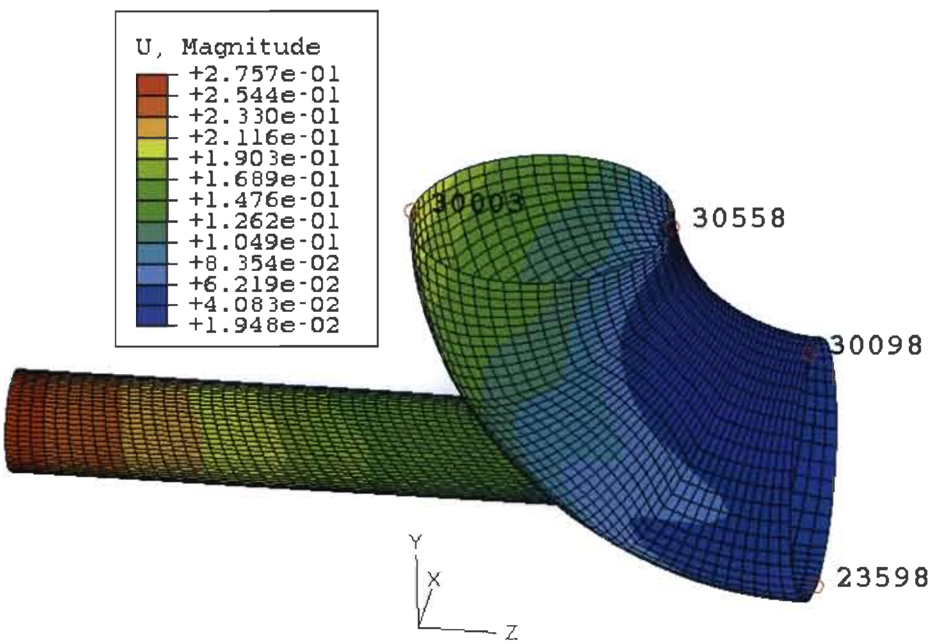

Figure F.1.2-1 – Isometric view of FF unlisted branch mesh results identifying displaced nodes.

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Nodal coordinate data (from Figure F.1.2-1) has been extracted from the unlisted branch post processing results and reprinted following.

```
********************************************************************************
Probe Values Report, written on Wed Mar 05 17:05:07 2008

Source
-------

   ODB: C:/pcs/pcs2/nonstandard_runs/branch_np.odb
   Step: Step-1
   Frame: Increment     14: Step Time =     1.000

Probe values reported at nodes

  Part Instance      Node ID                     Def. Coords
                                      X                Y                Z
---------------------------------------------------------------------------------
    PART-1-1        30003     -7.36668E-06         35.8021          -53.911
    PART-1-1        30558     -5.45163E-06         36.0012         -18.3682
    PART-1-1        23598     -11.8249E-06        -17.7899      1.66025E-03
    PART-1-1        30098     -20.3925E-06         17.7537     -11.3385E-03
```

Figure F.1.2-2 shows displacement magnitude results of the elbow mesh (2nd FF model mesh) and identifies nodes that are used for FF determination (within Appendix F.1.3).

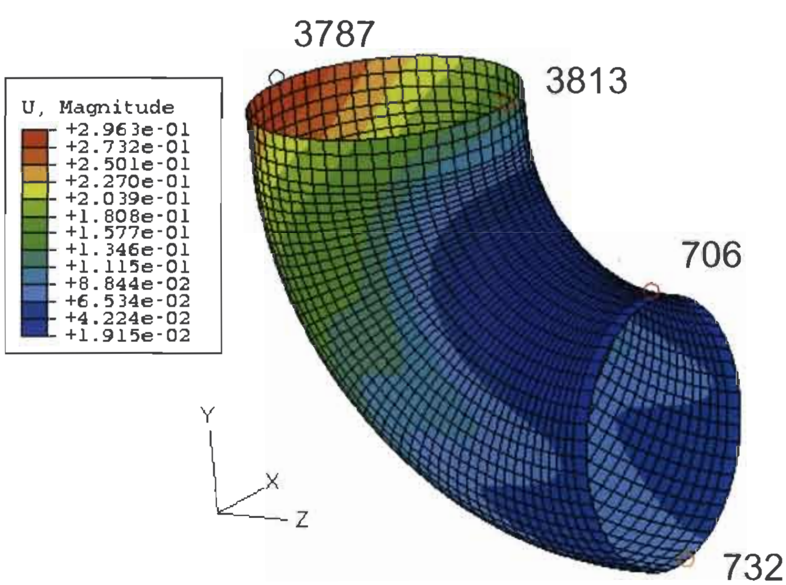

Figure F.1.2-2 – Isometric view of FF elbow mesh results identifying displaced nodes.

Nodal coordinate data (from Figure F.1.2-2) has been extracted from the unlisted branch post processing results and reprinted following.

```
********************************************************************************
Probe Values Report, written on Wed Mar 05 17:22:05 2008

Source
-------

   ODB: C:/pcs/pcs2/nonstandard_runs/elbow_np.odb
   Step: Step-1
   Frame: Increment     14: Step Time =    1.000

Probe values reported at nodes

  Part Instance     Node ID                    Def. Coords
                                      X                Y                Z
---------------------------------------------------------------------------------
    PART-1-1        3787    1.65314E-06        35.8066         -53.9118
    PART-1-1        3813   -17.4132E-06        36.0021         -18.3668
    PART-1-1         732    1.64985E-06       -17.7915      2.02214E-03
    PART-1-1         706   -17.3943E-06         17.754     -11.2106E-03
```

Nodal coordinate data (from Appendix A.1.3) has been extracted from the unlisted branch post processing results and reprinted following.

The next twelve SI solution results extract maximum membrane tresca stresses from each SI result model. The input file for each SI input file creates two resultant steps in which a third step is generated to obtain the tresca stress state needed. As shown in the following run bending moment example, at the bottom of each SI input file the first step (step 1) produces results for an internal pressure (400-psi) loading. The second step (step 2) computes results for combined internal pressure and bending loading.

```
**% ====== STEP NUMBER   1 ======
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1RX
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S
*END STEP
**% ====== STEP NUMBER   2 ======
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1RX
```

```
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + RX
*CLOAD,OP=NEW
      23321,    4, 1.5479E+06
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S
*END STEP
```

A third step (step 3) is created within ABAQUS Viewer that subtracts step 1 (P) from step 2 (P+Ri) to obtain corresponding bending tresca stress results (Ri). This is done to capture the added stiffness from internal pressure reflected into the Ri results [Ri = (P+Ri) – (P)]. Maximum tresca stress results (extracted from the twelve SI result models) for the three moments (Mx, My, & Mz) are used to determine branch and run stress indices computed in Appendix F.1.3.

Figures F.1.2-3 through F.1.2-8 show maximum membrane tresca stress plots (shown in psi) corresponding to +/- bending moment results applied to the branch pipe end. Figure F.1.2-9 shows the corresponding maximum membrane tresca stress plot due to branch pressure. The corresponding maximum tresca stress values for each load case (+Mx, -Mx, +My, -My, +Mz, -Mz, P) are contained in file "branch.rpt" reprinted in Appendix F.1.2.1.

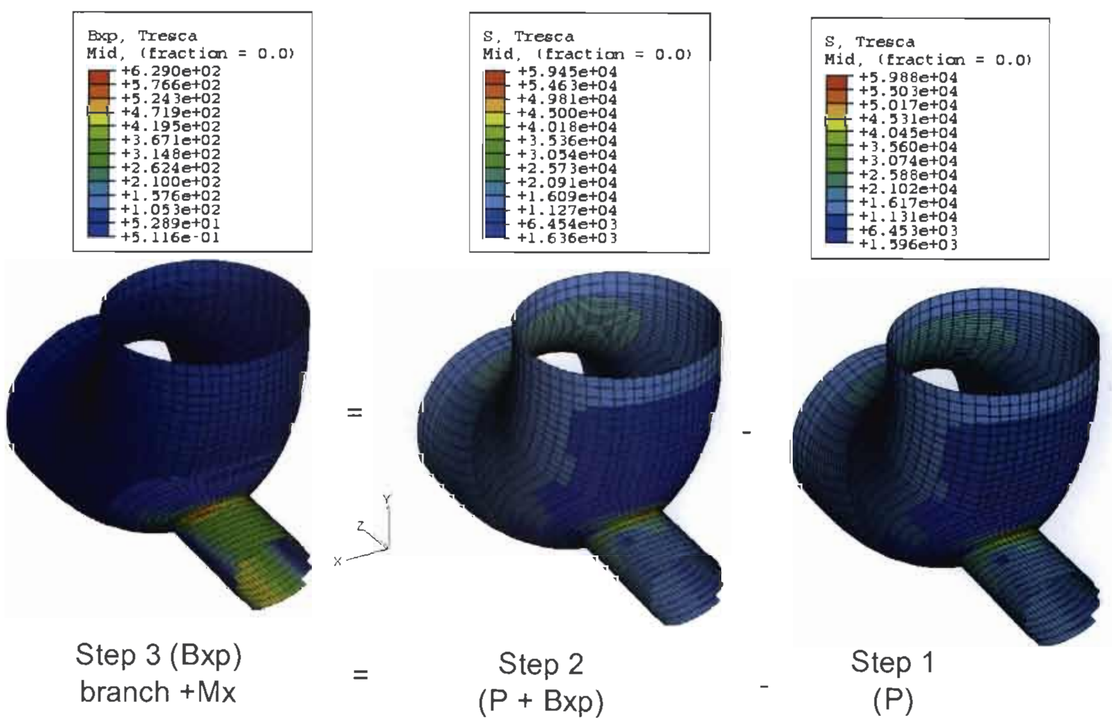

Figure F.1.2-3 – Step 3 membrane Bxp (branch +Mx bending) tresca stresses, shown as difference of steps 2 and step 1.

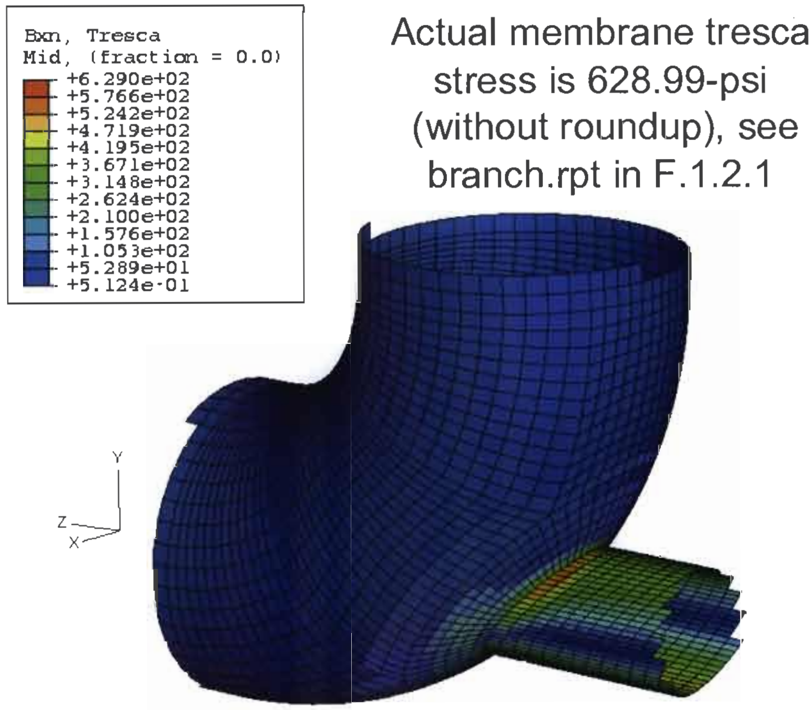

Figure F.1.2-4 – Step 3 membrane Bxn (branch –Mx bending) tresca stresses.

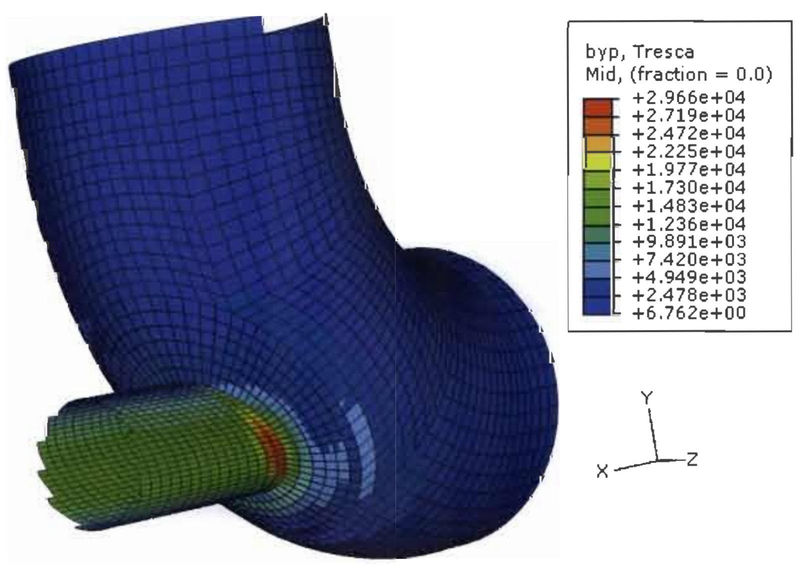

Figure F.1.2-5 – Step 3 membrane Byp (branch +My bending) tresca stresses.

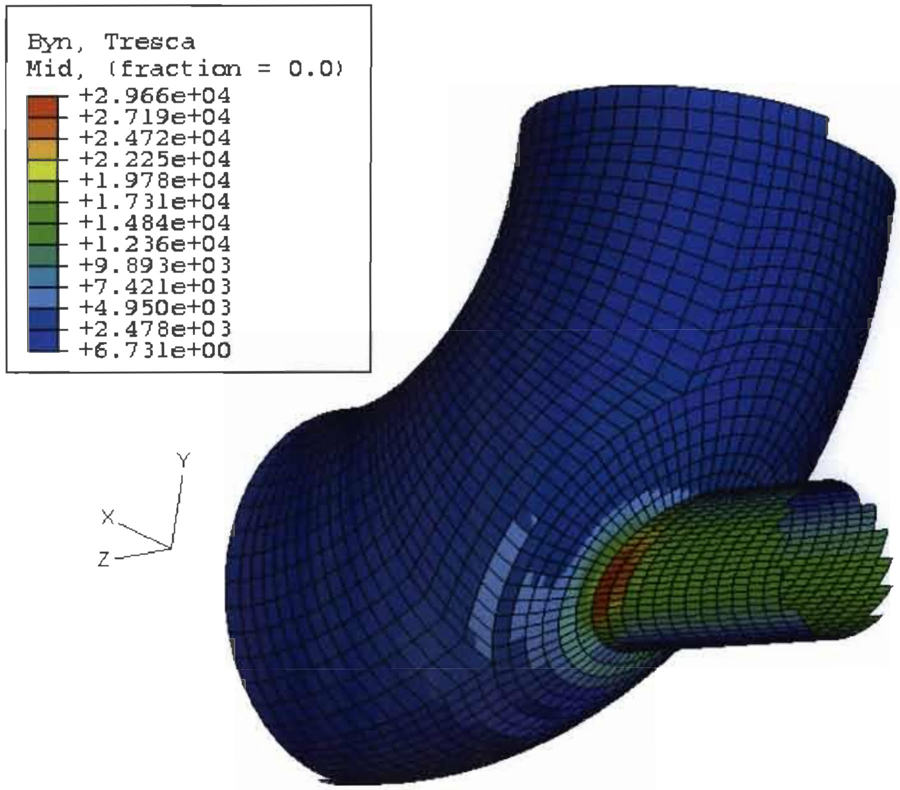

Figure F.1.2-6 – Step 3 membrane Byn (branch –My bending) tresca stresses.

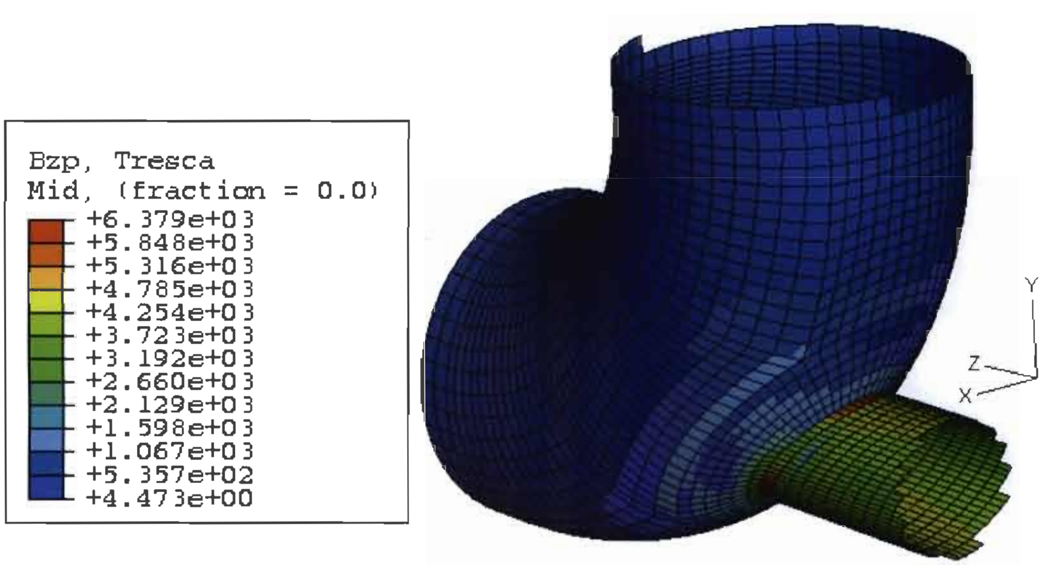

Figure F.1.2-7 – Step 3 membrane Bzp (branch +Mz torsion) tresca stresses.

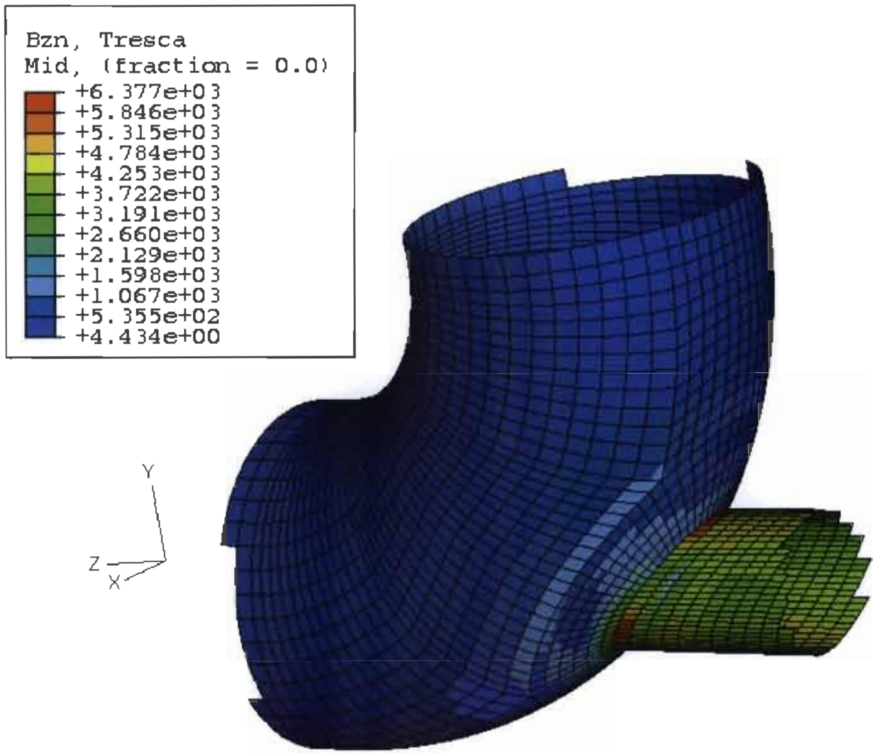

Figure F.1.2-8 – Step 3 membrane Bzn (branch –Mz torsion) tresca stresses.

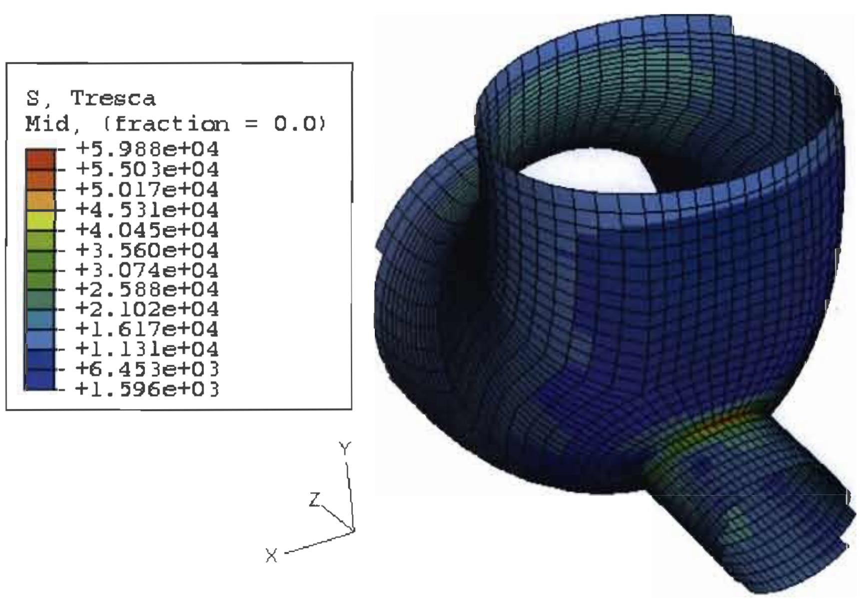

Figure F.1.2-9 – Step 1 membrane (branch pressure) tresca stresses.

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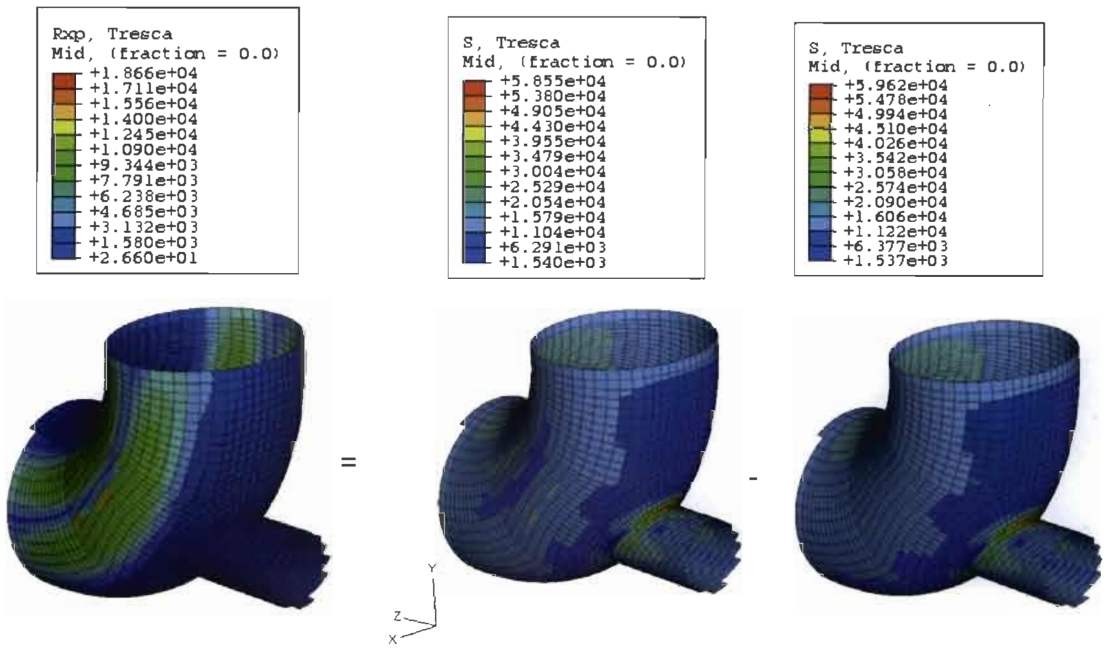
Figures F.1.2-10 through F.1.2-15 show maximum membrane tresca stress plots corresponding to +/- bending moment results applied to the top run pipe end. Figure F.1.2-16 shows the corresponding maximum membrane tresca stress plot due to run pressure. The corresponding maximum tresca stress values for each load case (+Mx, -Mx, +My, -My, +Mz, -Mz, P) are contained in file "run.rpt" reprinted in Appendix F.1.2.1.



Step 3 (Rxp) run +Mx = Step 2 (P + Rxp) - Step 1 (P)

Figure F.1.2-10 – Step 3 membrane Rxp (run +Mx bending) tresca stresses, shown as difference of steps 2 and step 1.

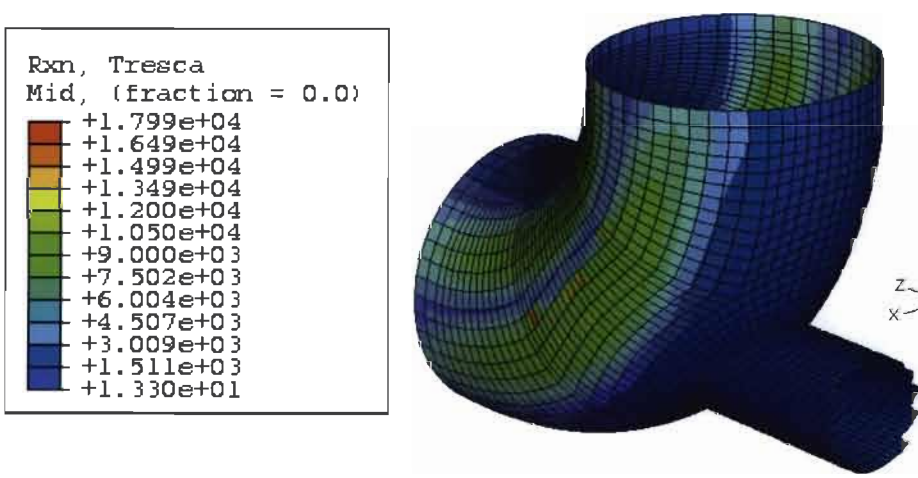


Figure F.1.2-11 – Step 3 membrane Rxn (run –Mxp bending) tresca stresses.

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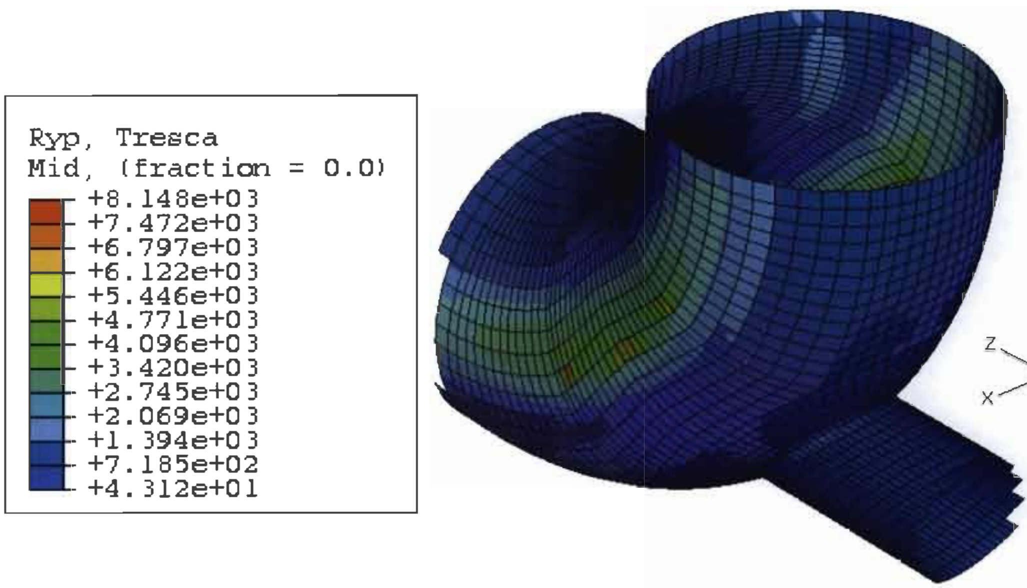

Figure F.1.2-12 – Step 3 membrane Ryp (run +Myp torsion) tresca stresses.

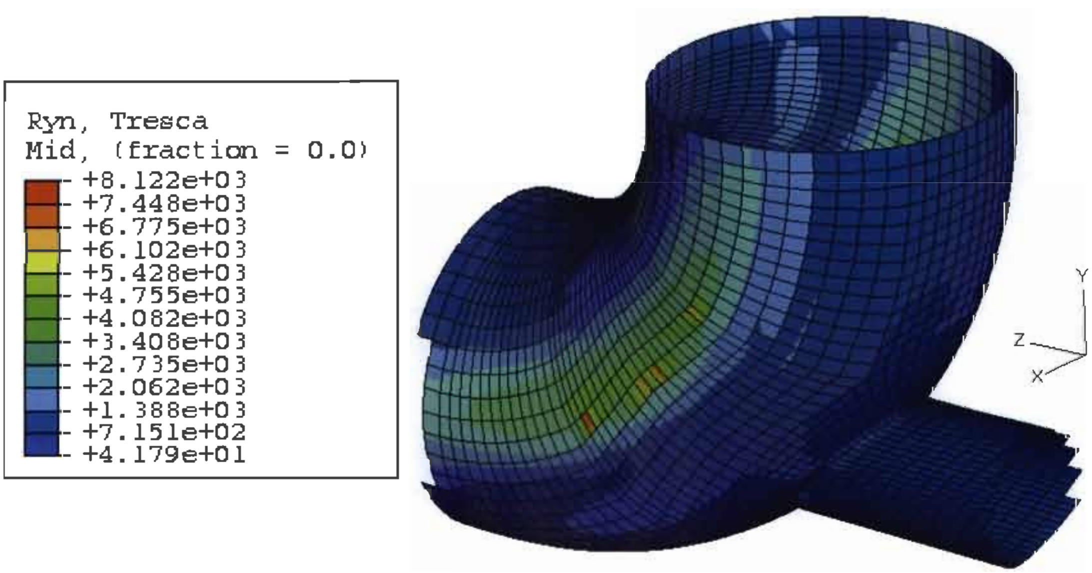

Figure F.1.2-13 – Step 3 membrane Ryn (run –Myn torsion) tresca stresses.

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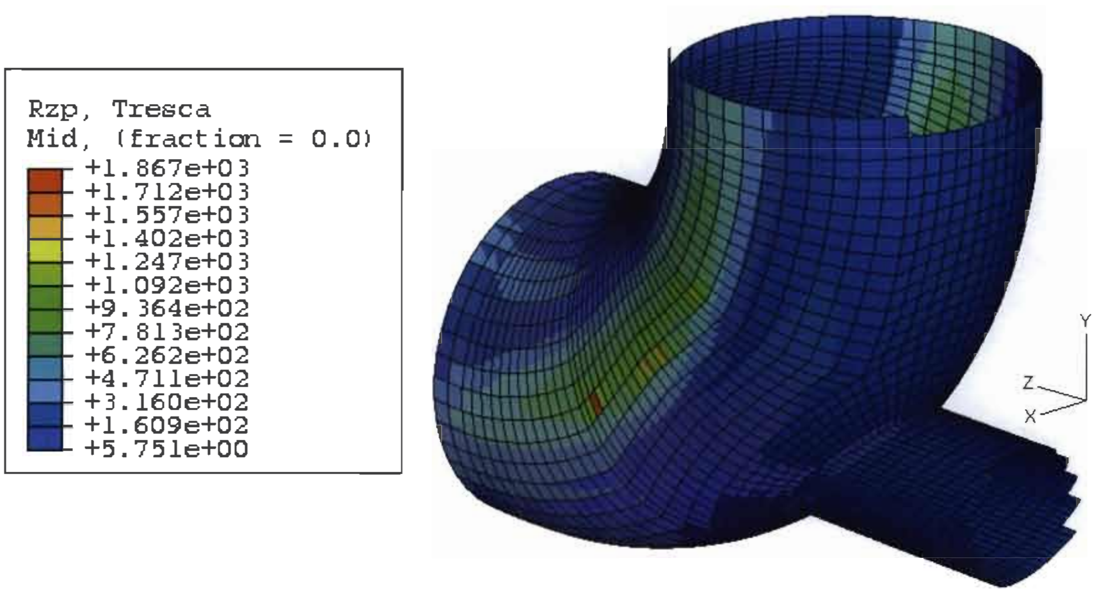
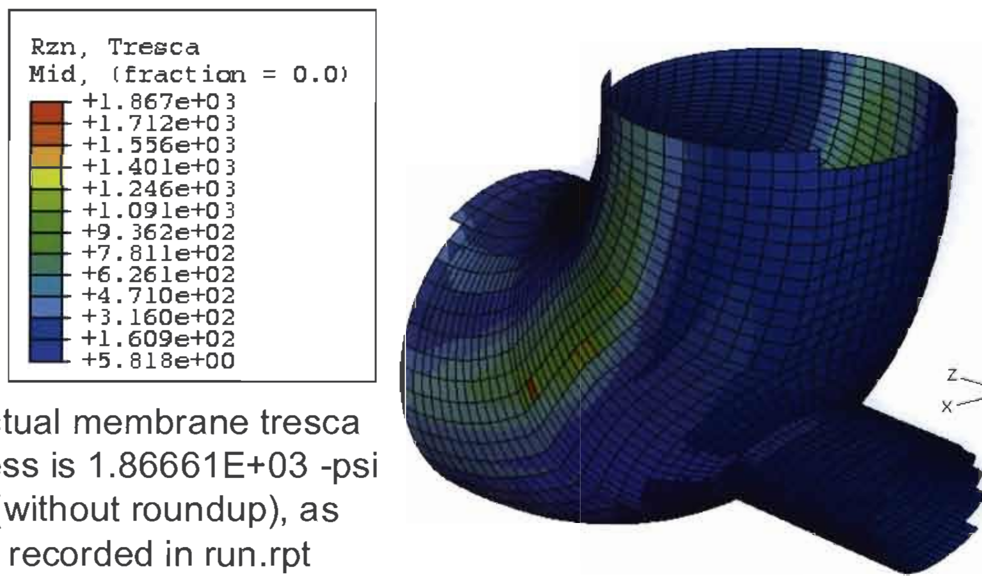


Figure F.1.2-14 – Step 3 membrane Rzp (run +Mzp bending) tresca stresses.



Actual membrane tresca stress is 1.86661E+03 -psi (without roundup), as recorded in run.rpt

Figure F.1.2-15 – Step 3 membrane Rzn (run –Mzn bending) tresca stresses.

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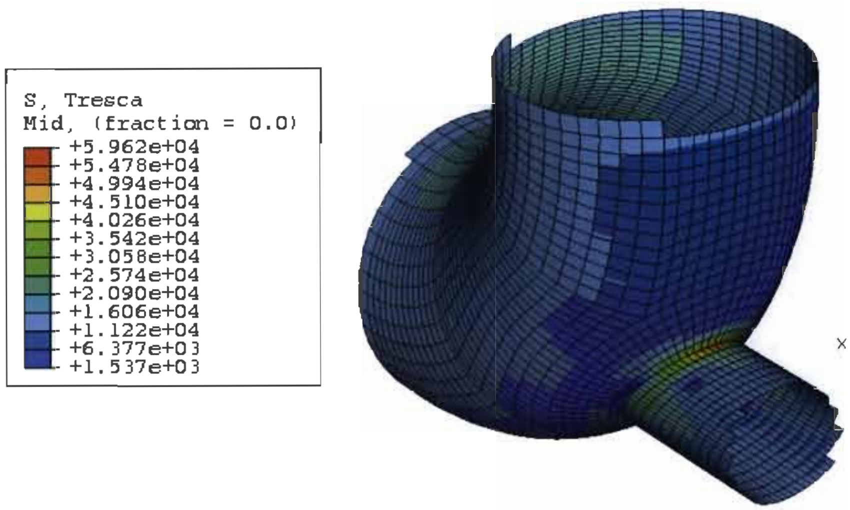

Figure F.1.2-16 – Step 1 membrane (run pressure) tresca stresses.

It should be noted that the exact width of the reinforcing plate at all locations around the branch pipe, is unknown at time of this analysis. Hence, an approximation of the reinforcement plate widths has been estimated (see Appendix 1.3). The following plot (Figure F.1.2.17) shows the tresca peak stress acting on the reinforcement plate, for branch bending about the Y-axis since this correlates to the maximum tressca state out of all of the loading scenarios.

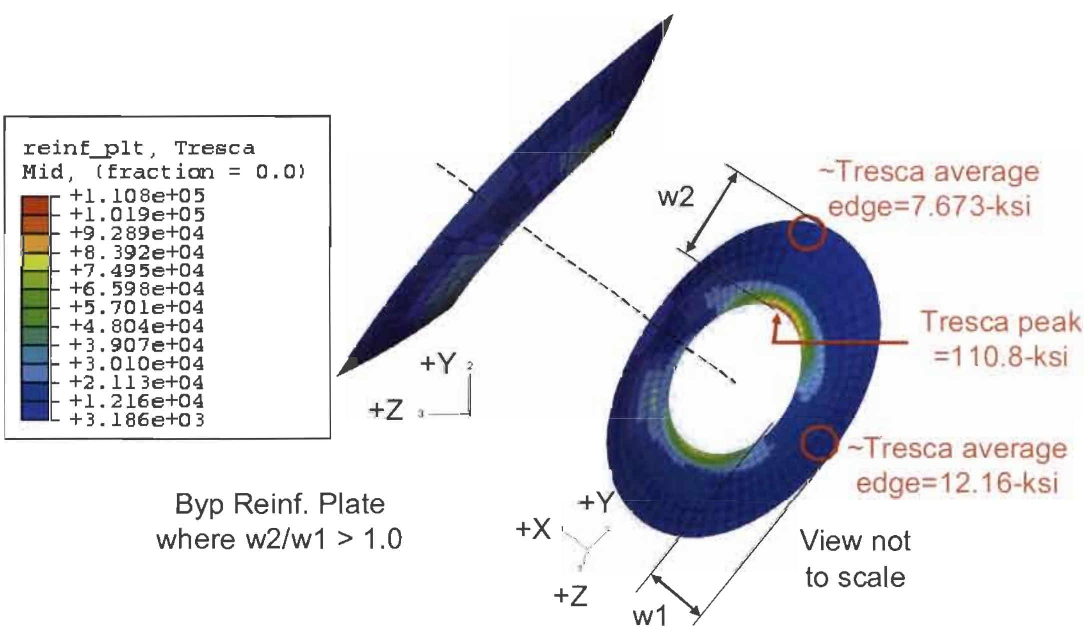

Figure F.1.2-17 – Estimated reinforcement plate's varying widths produce insignificant effects on maximum "Byp" load scenario peak stress values.

As shown in Figure F.1.2-17, the varying width effects corresponding to the reinforcement plate's estimated shape, is insignificant to the maximum Byp peak tresca stress load scenario. The difference between the two widths (w1 & w2) is approximately 4% (i.e., 7.7/111 = ~ 7% vs. 12/111 =~11%) and is considered to be insignificant. Hence, the reinforcement plate as estimated and modeled is considered to produce adequate results for this application.

F.1.2.1 – Unlisted Branch Component Maximum Tresca Stress Result Files

Two files are used to capture maximum tresca stresses for the branch and run load conditions. File "branch.rpt' contain maximum element and nodal tresca stress values for loads placed on the branch pipe end and file "run.rpt" contains corresponding data for loads placed on the top run pipe end and are reprinted following.

branch.rpt

```
*******************************************************************************
Probe Values Report, written on Wed Apr 09 11:44:52 2008

Source
-------

   ODB:
C:/pcs/pcs2/nonstandard_runs/final_runs/difference_runs/branch_diff/bx_diff/p_branc
h_si_bxA.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304 > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
-----------------------------------------------------------------------------
    PART-1-1       32326          S4       37387   23716   23717   37428


  Part Instance  Element ID        Type            Node      Bxp: Tresca
--------------------------------------------------------------------------------
    PART-1-1       32326          S4              1          511.33
    PART-1-1       32326          S4              2         629.013
    PART-1-1       32326          S4              3         625.955
    PART-1-1       32326          S4              4         513.493

*******************************************************************************
Probe Values Report, written on Wed Apr 09 11:51:02 2008

Source
-------
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:** 09/30/08	**Checker:** A. S. Siahpush	**Date:**	09/30/08

```
   ODB:
C:/pcs/pcs2/nonstandard_runs/final_runs/difference_runs/branch_diff/bx_diff/p_branc
h_si_bx0.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304 > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1       32326          S4       37387   23716   23717   37428

  Part Instance  Element ID        Type            Node      Bxn: Tresca
--------------------------------------------------------------------------------
    PART-1-1       32326          S4              1          511.097
    PART-1-1       32326          S4              2           628.99
    PART-1-1       32326          S4              3          625.938
    PART-1-1       32326          S4              4          513.255

********************************************************************************
Probe Values Report, written on Tue Jun 17 16:11:59 2008

Source
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   ODB:
C:/pcs/pcs2/nonstandard_runs/final_runs/difference_runs/branch_diff/by_diff/p_branc
h_si_byA.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304 > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type            Node      byp: Tresca
--------------------------------------------------------------------------------
    PART-1-1       31886          S4              1      29.4751E+03
    PART-1-1       31886          S4              2       28.721E+03
    PART-1-1       31886          S4              3      28.8811E+03
    PART-1-1       31886          S4              4      29.6588E+03
```

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```
********************************************************************************
Probe Values Report, written on Wed Apr 09 12:38:35 2008

Source
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   ODB:
C:/pcs/pcs2/nonstandard_runs/final_runs/difference_runs/branch_diff/by_diff/p_branc
h_si_by0.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304 > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1       33446          S4       38599   23759   2375   38640


  Part Instance  Element ID        Type            Node      Byn: Tresca
--------------------------------------------------------------------------------
    PART-1-1       33446          S4              1      29.6648E+03
    PART-1-1       33446          S4              2      28.8836E+03
    PART-1-1       33446          S4              3      28.7196E+03
    PART-1-1       33446          S4              4      29.4775E+03


********************************************************************************
Probe Values Report, written on Wed Apr 09 13:40:28 2008

Source
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   ODB:
C:/pcs/pcs2/nonstandard_runs/final_runs/difference_runs/branch_diff/bz_diff/p_branc
h_si_bzA.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304 > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1       33366          S4       38517   23773   23766   38558


  Part Instance  Element ID        Type            Node      Bzp: Tresca
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
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```
--------------------------------------------------------------------------------
    PART-1-1       33366          S4               1      5.40814E+03
    PART-1-1       33366          S4               2       6.1527E+03
    PART-1-1       33366          S4               3      6.37879E+03
    PART-1-1       33366          S4               4      5.58212E+03


********************************************************************************
Probe Values Report, written on Wed Apr 09 14:27:31 2008

Source
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   ODB:
C:/pcs/pcs2/nonstandard_runs/final_runs/difference_runs/branch_diff/bz_diff/p_branc
h_si_bz0.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304 > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type        Nodes
--------------------------------------------------------------------------------
    PART-1-1       31966          S4       37018   23707   23708   37059


  Part Instance  Element ID        Type             Node     Bzn: Tresca
--------------------------------------------------------------------------------
    PART-1-1       31966          S4               1      5.57557E+03
    PART-1-1       31966          S4               2      6.37742E+03
    PART-1-1       31966          S4               3      6.15056E+03
    PART-1-1       31966          S4               4      5.40202E+03


********************************************************************************
Probe Values Report, written on Wed Apr 09 13:50:10 2008

Source
-------

   ODB:
C:/pcs/pcs2/nonstandard_runs/final_runs/difference_runs/branch_diff/bz_diff/p_branc
h_si_bz0.odb
   Step: Step-1
   Frame: Increment     14: Step Time =    1.000

Loc 1 : Element nodal values at shell < SST304 > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes
```

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```
  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1       32966          S4       38107   38108   24006   23999


  Part Instance  Element ID        Type            Node        S: Tresca
--------------------------------------------------------------------------------
    PART-1-1       32966          S4              1      25.4862E+03
    PART-1-1       32966          S4              2      26.3805E+03
    PART-1-1       32966          S4              3      59.8824E+03
    PART-1-1       32966          S4              4      58.9505E+03


run.rpt
********************************************************************************
Probe Values Report, written on Wed Apr 09 16:34:48 2008

Source
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   ODB:
C:/pcs/pcs2/nonstandard_runs/final_runs/difference_runs/run_diff/rx_diff/p_vertrun_
si_rxA.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304 > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1       26724          S4       31556   31557   31578   31577


  Part Instance  Element ID        Type            Node      Rxp: Tresca
--------------------------------------------------------------------------------
    PART-1-1       26724          S4              1      15.6175E+03
    PART-1-1       26724          S4              2      18.6615E+03
    PART-1-1       26724          S4              3      14.3547E+03
    PART-1-1       26724          S4              4      10.1457E+03


********************************************************************************
Probe Values Report, written on Wed Apr 09 16:39:36 2008

Source
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   ODB:
C:/pcs/pcs2/nonstandard_runs/final_runs/difference_runs/run_diff/rx_diff/p_vertrun_
si_rxO.odb
   Step: Session Step
```

Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304 > < 5 section points > : Mid, (fraction = 0.0)

Probe values reported at element nodes

Part Instance	Element ID	Type	Nodes			
PART-1-1	26724	S4	31556	31557	31578	31577

Part Instance	Element ID	Type	Node	Rxn: Tresca
PART-1-1	26724	S4	1	15.0695E+03
PART-1-1	26724	S4	2	17.9863E+03
PART-1-1	26724	S4	3	13.8301E+03
PART-1-1	26724	S4	4	9.79649E+03

****
Probe Values Report, written on Wed Apr 09 16:47:49 2008

Source

ODB:
C:/pcs/pcs2/nonstandard_runs/final_runs/difference_runs/run_diff/ry_diff/p_vertrun_si_ryA.odb
Step: Session Step
Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304 > < 5 section points > : Mid, (fraction = 0.0)

Probe values reported at element nodes

Part Instance	Element ID	Type	Nodes			
PART-1-1	26724	S4	31556	31557	31578	31577

Part Instance	Element ID	Type	Node	Ryp: Tresca
PART-1-1	26724	S4	1	8.14789E+03
PART-1-1	26724	S4	2	7.46668E+03
PART-1-1	26724	S4	3	5.17087E+03
PART-1-1	26724	S4	4	6.11814E+03

****
Probe Values Report, written on Wed Apr 09 16:50:54 2008

```
Source
-------

   ODB:
C:/pcs/pcs2/nonstandard_runs/final_runs/difference_runs/run_diff/ry_diff/p_vertrun_
si_ryO.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304 > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1       26724           S4       31556   31557   31578   31577


  Part Instance  Element ID        Type              Node      Ryn: Tresca
--------------------------------------------------------------------------------
    PART-1-1       26724           S4                1      8.12167E+03
    PART-1-1       26724           S4                2      7.43331E+03
    PART-1-1       26724           S4                3      5.14357E+03
    PART-1-1       26724           S4                4      6.10099E+03


********************************************************************************
Probe Values Report, written on Wed Apr 09 16:55:47 2008

Source
-------

   ODB:
C:/pcs/pcs2/nonstandard_runs/final_runs/difference_runs/run_diff/rz_diff/p_vertrun_
si_rzA.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304 > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1       26419           S4       31216   31217   31238   31237


  Part Instance  Element ID        Type              Node      Rzp: Tresca
--------------------------------------------------------------------------------
    PART-1-1       26419           S4                1      1.66367E+03
    PART-1-1       26419           S4                2      1.86709E+03
    PART-1-1       26419           S4                3      1.42455E+03
```

```
    PART-1-1       26419          S4                 4      1.18138E+03

********************************************************************************
Probe Values Report, written on Wed Apr 09 16:59:42 2008

Source
-------

   ODB:
C:/pcs/pcs2/nonstandard_runs/final_runs/difference_runs/run_diff/rz_diff/p_vertrun_
si_rz0.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304 > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1       26419          S4       31216   31217   31238   31237

  Part Instance  Element ID        Type            Node     Rzn: Tresca
--------------------------------------------------------------------------------
    PART-1-1       26419          S4                 1      1.66272E+03
    PART-1-1       26419          S4                 2      1.86661E+03
    PART-1-1       26419          S4                 3       1.4243E+03
    PART-1-1       26419          S4                 4      1.18063E+03
```

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```
********************************************************************************
Probe Values Report, written on Wed Apr 09 16:31:35 2008

Source
-------

   ODB:
C:/pcs/pcs2/nonstandard_runs/final_runs/difference_runs/run_diff/rx_diff/p_vertrun_
si_rxA.odb
   Step: Step-1
   Frame: Increment     14: Step Time =    1.000

Loc 1 : Element nodal values at shell < SST304 > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1       32966          S4       38107   38108   24006   23999

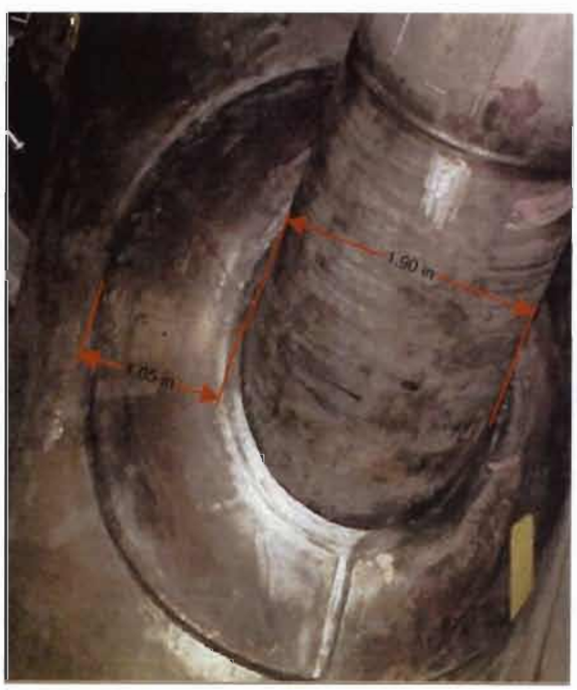

  Part Instance  Element ID        Type            Node       S: Tresca
--------------------------------------------------------------------------------
    PART-1-1       32966          S4              1      25.3432E+03
    PART-1-1       32966          S4              2      26.2351E+03
    PART-1-1       32966          S4              3      59.6236E+03
    PART-1-1       32966          S4              4      58.6949E+03
```

F.1.3 – Unlisted Branch Component FE model input and FF & SI Determination

The purpose of this section is to determine FE model input, FF, and stress indices (SI), for the Pilot model's unlisted branch component. Pertinent FE model result data are extracted from Appendices F.1.2 and F.1.2.1 for FF and SI value determinations.

FE model input:

Pilot Model unlisted branch component => 14" branch extended from 36" elbow



$S_1 := 1.90\,in$ $S_2 := 1.05\,in$

$D_{14} := 14 \cdot in$ $t_{14} := 0.25 \cdot in$ Diameter and thickness of 14-in sch. 10 branch pipe

$d_{14} := D_{14} - 2 \cdot t_{14}$ $d_{14} = 13.5 \cdot in$ Inner diameter of branch pipe

$d14_{mean} := \frac{D_{14} + d_{14}}{2}$ $d14_{mean} = 13.75\,in$ Mean diameter of branch pipe

$r14_{mean} := \frac{d14_{mean}}{2}$ $r14_{mean} = 6.875\,in$ Mean radius of branch pipe

Find reinforcement plating dimensions

$$\frac{D_{14}}{S_1} = \frac{w_{rein}}{S_2}$$

$w_{rein} := \frac{D_{14}}{S_1} \cdot S_2$ $w_{rein} = 7.737 \cdot in$ Estimated projected width of reinforcing plate ring

Let => $w_{rein} := 7.5 \cdot in$

$pD_{rein} := 2 \cdot w_{rein} + D_{14}$ $pD_{rein} = 29 \cdot in$ Estimated projected diameter of reinforcing plate

$t_{rein} := \frac{1}{2} \cdot in$ Thickness of reinforcement plate [7]

$D_{elbow} := 36 \cdot in$ $t_{elbow} := \frac{9}{16} \cdot in$ Short elbow diameter and thickness [6 & 14]

$d_{elbow} := D_{elbow} - 2 \cdot t_{elbow}$ $d_{elbow} = 34.875\,in$ Inner diameter of elbow

$de_{mean} := \frac{D_{elbow} + d_{elbow}}{2}$ $de_{mean} = 35.438\,in$ Mean elbow diameter and radius

$re_{mean} := \frac{de_{mean}}{2}$ $re_{mean} = 17.719\,in$

Determine length of FE model extension piping, for restraint and moment application:

$re_{mean} = 17.719\,in$
$r14_{mean} = 6.875\,in$
Length of piping on branch and elbow ends, based on minimum distance to flanges [1, NB-3686.2 (c)] shall be no greater than the pipe's mean radius.

Let => $Le_{min} := 5 \cdot re_{mean}$ $Le_{min} = 88.594\,in$ $Le_{min} := 89 \cdot in$

Let => $L14_{min} := 10 \cdot r14_{mean}$ $L14_{min} = 68.75\,in$ $L14_{min} := 71 \cdot in$

Extended 36-in and 14-in pipe lengths for restraint and moment application

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FE model material properties:

Operating conditions of pilot model [11, Section 7.1]:

$P := 400 \cdot psi$ $T := 125 \cdot deg$ Pilot model's operating internal pressure and temperature

$T_{70} := 70$ $T_{200} := 200$

$E_{70} := 28.3 \cdot 10^6 \cdot psi$ $E_{200} := 27.5 \cdot 10^6 \cdot psi$ Modulus of Elasticity at room & 200 °F temperatures [12, Table TM-1, mat'l group G, p. 775-776]

$$E_{125} := \left[\left(\frac{\frac{T}{deg} - T_{70}}{T_{200} - T_{70}}\right) \cdot \frac{(E_{200} - E_{70})}{psi} + \frac{E_{70}}{psi}\right] \cdot psi \qquad E_{125} = 2.8 \times 10^7 \cdot psi$$

Modulus of Elasticity at 125°F

Let => $\nu := 0.30 \cdot \frac{in}{in}$

$$G_{125} := \frac{E_{125}}{2 \cdot (1 + \nu)} \qquad G_{125} = 1.07544 \times 10^7 \cdot psi$$

Shear modulus [13, eqn 2-19]

$T_{rm} := 100$ Yield strength properties do not change within the -20 to 100°F range, thus room temperature is reset to 100°F for proper scaling purposes.

$T_{150} := 150$ $Sy\_plt_{rm} := 30 \cdot ksi$ $Sy\_plt_{150} := 26.7 \cdot ksi$ Yield strength of 304 SST plate at room & 150°F temperature [12, Table Y-1, p. 646-648, line 7]

$T_{167} := 167$ $T_{125} := \frac{T}{deg}$ $T_{125} = 125$ PCS piping system of interest operates between 125°F and 167°F [11, Sect. 7.1]

$Sm_{125} := 20 \cdot ksi$ Maximum allowable stress intensity for 304 SST plate at 125 °F [11, Table 5A, p. 428, line# 4]

$Sy\_wpipe_{rm} := 30 \cdot ksi$ $Sy\_wpipe_{150} := 26.7 \cdot ksi$ Yield strength of 304 SST welded pipe at room & 150°F temperature [12, Table Y-1, p. 646-648, line 15]

$T_{dif} := T_{150} - T_{rm}$ $T_{dif} = 50$

$$Sy\_plt_{125} := \left[\left(\frac{T_{125} - T_{rm}}{T_{150} - T_{rm}}\right) \cdot \frac{(Sy\_plt_{150} - Sy\_plt_{rm})}{ksi} + \frac{Sy\_plt_{rm}}{ksi}\right] \cdot ksi$$

Yield strength of 304 SST plate at 125°F

$Sy\_plt_{125} = 28.35 \cdot ksi$

$$Sy\_wpipe_{125} := \left[\left(\frac{T_{125} - T_{rm}}{T_{dif}}\right) \cdot \frac{(Sy\_wpipe_{150} - Sy\_wpipe_{rm})}{ksi} + \frac{Sy\_wpipe_{rm}}{ksi}\right] \cdot ksi$$

$Sy\_wpipe_{125} = 28.35\,ksi$ Yield strength of 304 SST welded pipe at 125°F

$\frac{Sy\_plt_{125}}{Sy\_wpipe_{125}} = 1$ Both plate and welded pipe yield strength properties are the same at 125°F

Let => $Sy_{125} := Sy\_plt_{125}$ $Sy_{125} = 28.35\,ksi$

Determine Flexibility Factor (FF) for Unlisted Branch Component:

Several steps are taken for determining the flexibility factor of the unlisted branch component. The first step occured within Appendix A (Section A.6) where beam modeling an elbow with 2 parabolic elements produced very good results (within 0.007%) as compared to nominal deflection of elbows specified by the code. The next step was to determine a flexibility factor for the beam model that represents the unlisted branch component. Since there is no code provision for this, an FE shell model was created to determine an appropriate FF to be applied to the beam model for the unlisted component. Another step is to determine how a shelled-mesh compares to the code. This was done by first determining the flexibility factor of a shell elbow model (without the branch) and comparing displacements based on linear material properties to see if reasonable correlations to code are obtained. The last step, was to shell model the unlisted branch component and compare displacements due to linear and plastic material properties - as compared to the linear elbow. If the difference between listed elbow and unlisted branch models are reasonable (or within 10%) and the elbow to Code is also reasonable, then the shelled model of the unlisted branch's flexibility factors may be approximated as an elbow which has already been shown in Appendix A to match closely to that of the beam elbow modeled as two parabolic elements.

FF determination followed the Code provisions as outlined in NB-3680 [1] and NB-3686.2 for "Curved Pipe & Welded Elbows" [1]. Initial FF evaluation efforts approximated the unlisted branch as a common 36-in short radius welded elbow. The elbow within the unlisted branch is fabricated from rolled plate and welded at the seam.

From NB-3686.2:

(a) R/r is not less than 1.7

R - bend radius $R := 36\,in$ Bending radius of 36-in short radius elbow

r - elbow mean radius => $re_{mean} = 17.719\,in$

$\frac{R}{re_{mean}} = 2.032$ > 1.7 OK

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(b) center line length $R\alpha$ is greater than 2r

$\alpha := \frac{\pi}{2}$ $\alpha = 90 \cdot deg$ 90-deg elbow angle sweep

$\frac{R \cdot \alpha}{2 \cdot re_{mean}} = 1.596$ OK

(c) There are no flanges or other similar stiffeners within a distance r from either end of the curved section of pipe or from the ends of welding elbows.

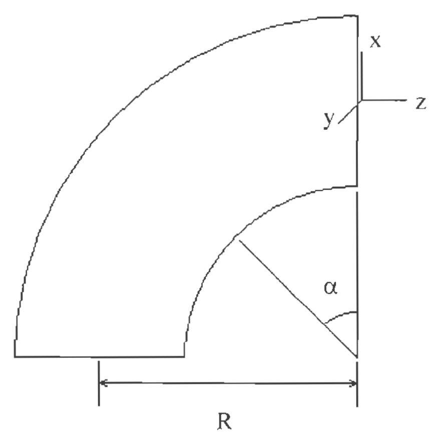
Per geometry within PCS piping, this is true.

$$\theta_{nom1} = \frac{R}{E \cdot I} \cdot \int_0^\theta M_1 \, d\alpha \qquad \theta_{ab1} = k \cdot \theta_{nom1} = \frac{k \cdot R}{E \cdot I} \cdot \int_0^\theta M_1 \, d\alpha$$

$$\theta_{nom2} = \frac{R}{E \cdot I} \cdot \int_0^\theta M_2 \, d\alpha \qquad \theta_{ab2} = k \cdot \theta_{nom2} = \frac{k \cdot R}{E \cdot I} \cdot \int_0^\theta M_2 \, d\alpha$$

$$\theta_{nom3} = \frac{R}{G \cdot J} \cdot \int_0^\theta M_3 \, d\alpha \qquad \theta_{ab3} = \theta_{nom3} = \frac{R}{G \cdot J} \cdot \int_0^\theta M_3 \, d\alpha$$

To address the flexibility factor in the finite element model, an effective area moment of inertia will be established:



$$I_e = \frac{I}{k}$$

Therefore:

$$\theta_{ab1} = \frac{R}{E \cdot I_e} \cdot \int_0^\theta M_1 \, d\alpha$$

$$\theta_{ab2} = \frac{R}{E \cdot I_e} \cdot \int_0^\theta M_2 \, d\alpha$$

$$\theta_{ab3} = \frac{R}{G \cdot J} \cdot \int_0^\theta M_3 \, d\alpha$$

Pipe 36 Inch Diameter and 9/16 Thickness

$D_{elbow} = 36 \cdot in$ $t_{elbow} = 0.563\,in$ $d_{elbow} = 34.875\,in$ Various parameters previously defined

$de_{mean} = 35.438\,in$ $re_{mean} = 17.719\,in$ $P = 400 \cdot psi$

$R = 36 \cdot in$ $E_{125} = 2.796 \times 10^{4} \cdot ksi$ $Sy_{125} = 28.35\,ksi$

$$h_{elbow} := \frac{t_{elbow} \cdot R}{re_{mean}^{\ 2}} \qquad h_{elbow} = 0.064$$

FF equations in NB-3686.2

$$X_k := 6 \cdot \left(\frac{re_{mean}}{t_{elbow}}\right)^{\frac{4}{3}} \cdot \left(\frac{R}{re_{mean}}\right)^{\frac{1}{3}} \qquad X_k = 756$$

$$k_{elbow} := \frac{1.65}{h_{elbow}} \cdot \left[\frac{1}{1 + \left(\frac{P \cdot re_{mean}}{t_{elbow} \cdot E_{125}}\right) \cdot X_k}\right] \qquad k_{elbow} = 19.081$$

Calculated FF of 36-in short radius elbow at 125ºF

$$I_{elbow} := \frac{\pi}{64} \cdot \left(D_{elbow}^{\ 4} - d_{elbow}^{\ 4}\right) = 4.093 \times 10^{-3}\,m^4$$

Moment of inertia of 36-in elbow

$$I_{elbow} = 9.833 \times 10^{3} \cdot in^4$$

$$Ie_{elbow} := \frac{I_{elbow}}{k_{elbow}} \qquad Ie_{elbow} = 515.32\,in^4$$

Effective moment of inertia for short radius

$M_o := 1.4 \cdot 10^{6} \cdot in \cdot lbf$ Moment applied to FE model meshes for FF evaluation, obtained from preliminary 80-percentile solution runs for pilot model. Moment corresponds to value less then material's yield point.

$$k = \frac{\theta_{ab}}{\theta_{nom}}$$

General definition of flexibility factor [1, NB-3682]

where θ_{ab} - rotation of end a with respect to end b, due to moment load (Mo)

θ_{nom} - nominal rogation due to moment load (Mo)

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Previously defined:

$$\theta_{nom} = \frac{R}{E_{125} I_{elbow}} \int_0^{\frac{\pi}{2}} M_o \, d\alpha = \frac{M_o \cdot R}{E_{125} I_{elbow}} \cdot \left(\frac{\pi}{2} - 0\right)$$

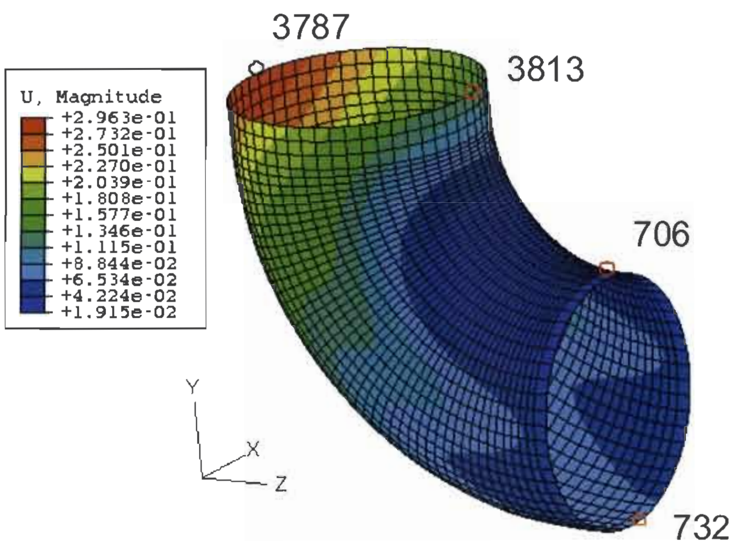
$$\theta_{nom} := \frac{\pi \cdot M_o \cdot R}{2 \cdot E_{125} I_{elbow}} \qquad \theta_{nom} = 0.016\,\text{deg}$$

Computed for 36-in short radius elbow

$$\theta_{ab} := k_{elbow} \cdot \theta_{nom} \qquad \theta_{ab} = 0.315\,\text{deg}$$

Compare above code calculated elbow values to corresponding FE model elbow mesh:

Displacement coordinate data obtained from Appendix F.1.2, corresponding to Fig. F.1.2-2.



elbow_npn.inp (-RX) with ***linear*** material properties, produces highest deflections

N3787

$$N_{1e} := (1.65\text{E-}06 \;\; 35.8066 \;\; -53.9118)^T$$

N3813

$$N_{2e} := (-1.74\text{E-}05 \;\; 36.0021 \;\; -18.3668)^T$$

$$V_{21e} := N_{2e} - N_{1e} \qquad V_{21e}^T = \left(-1.905 \times 10^{-5} \;\; 0.195 \;\; 35.545\right)$$

Top displacement vector of elbow FE model mesh

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N732 N706

$N_{3e} := (1.65E\text{-}06\ \ -17.7915\ \ 2.02E\text{-}03)^T$ $N_{4e} := (-1.74E\text{-}05\ \ 17.754\ \ -1.12E\text{-}02)^T$

$V_{43e} := N_{4e} - N_{3e}$ $V_{43e}{}^T = \left(-1.905\times 10^{-5}\ \ 35.546\ \ -0.013\right)$ Side displacement vector of elbow FE model mesh

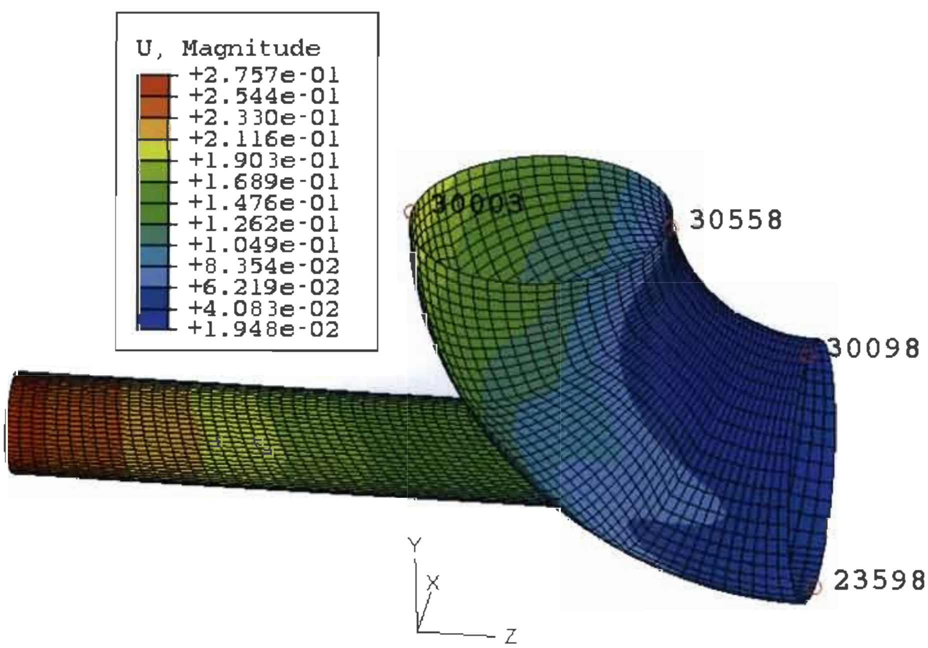
$\theta e_{ab} := \operatorname{acos}\left(\dfrac{V_{21e}\cdot V_{43e}}{|V_{21e}|\cdot|V_{43e}|}\right) - 90\cdot deg$ $\theta e_{ab} = -0.294\,deg$ Dot product between vectors V21e & V43e

$\dfrac{|\theta e_{ab}|}{\theta_{ab}} = 0.933$ Elbow FE model mesh provides reasonable correlation as compared to computed code values.

$k_e := \dfrac{|\theta e_{ab}|}{\theta_{nom}}$ $k_e = 17.809$ Flexibility Factor of elbow shelled model, based on linear material properties.

Determine FF of unlisted branch component corresponding to FE model branch mesh:

Displacement coordinate data obtained from Appendix F.1.2, corresponding to Fig. F.1.2-1.



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branch_npn.inp (-RX) with ***linear*** material properties produces highest deflections

N30003

$N_{1b} := (-7.36668E\text{-}06\ \ 35.8021\ \ -53.911)^T$

N300558

$N_{2b} := (-5.45163E\text{-}06\ \ 36.0012\ \ -18.3682)^T$

$V_{21b} := N_{2b} - N_{1b}$ $\quad V_{21b}{}^T = \left(1.915\times 10^{-6}\ \ 0.199\ \ 35.543\right)$ Top displacement vector of branch FE model mesh

N23598

$N_{3b} := (-11.8249E\text{-}06\ \ -17.7899\ \ 1.66025E\text{-}03)^T$

N30098

$N_{4b} := (-20.3925E\text{-}06\ \ 17.7537\ \ -11.3385E\text{-}03)^T$

$V_{43b} := N_{4b} - N_{3b}$ $\quad V_{43b}{}^T = \left(-8.568\times 10^{-6}\ \ 35.544\ \ -0.013\right)$ Side displacement vector of branch FE model mesh

$$\theta b_{ab} := \mathrm{acos}\left(\frac{V_{21b}\cdot V_{43b}}{\left|V_{21b}\right|\cdot\left|V_{43b}\right|}\right) - 90\cdot deg \qquad \theta b_{ab} = -0.3\cdot deg$$

Dot product between vectors V21b & V43b

$$\frac{\theta b_{ab}}{\theta e_{ab}} = 1.021$$

Subtle difference (2.1%) between FE model unlisted branch & listed elbow, based on linear material properties.

$$k_b := \frac{\left|\theta b_{ab}\right|}{\theta_{nom}} \qquad k_b = 18.184$$

FF of FE model unlisted branch mesh, based on linear material properties.

Flexibility factor of unlisted branch is similar (within 2.1%) to that of a regular elbow. Thus, the unlisted branch component may use the FF of a listed elbow.

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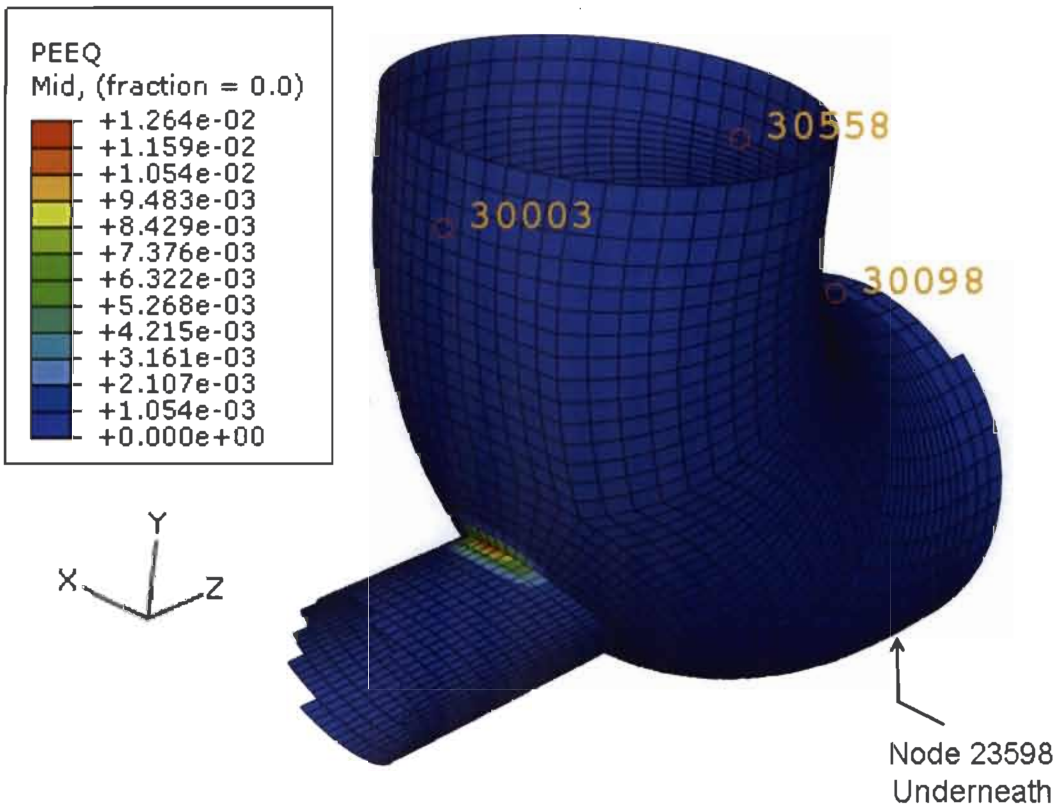
Further down in the "Unlisted Branch Component Stress Indices" section, the unlisted branch was evaluated to have a D/C value of 1.93 - significantly over unity. Thus, a plastic analysis was recommended (Appendix A.1.4). Plastic material properties used in the plastic evaluation (Appendix F.1.5) and the resultant plastic equivalent strain (0.01142) were retrieved from the plastic analysis. A scaled moment was applied to the branch end such that a similar plastic equivalent strain was generated (shown following) and the original moment (Mo) was reapplied to the plastic material unlisted branch model to determine new flexibility factors, as shown following.



ABAQUS file branch_npn.inp (-RX) with ***platicity*** incorporated within material definition, was renamed as branch_npn2_new.inp and an abbreviated listing is shown in Section F.1.6.

Nodal deflection coordinate data has been extracted from the unlisted branch plastic model and reprinted following.

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Nodal deflection coordinate data has been extracted from the unlisted branch plastic model and reprinted following.

```
********************************************************************************
Probe Values Report, written on Mon Sep 15 23:00:05 2008

Source
-------

   ODB: C:/pcs/pcs2/nonstandard_runs/branch_npn2_new.odb
   Step: Step-4
   Frame: Increment     14: Step Time =    1.000

Probe values reported at nodes

  Part Instance     Node ID                    Def. Coords
                                  X                Y                Z
----------------------------------------------------------------------------------
--------------------------------------
    PART-1-1       30003    -14.3373E-06         35.7997         -53.9059
    PART-1-1       30558    -4.55024E-06             36.         -18.3682
    PART-1-1       23598    -4.37843E-06        -17.7875       1.76346E-03
    PART-1-1       30098    -23.6801E-06         17.7528      -11.0838E-03
```

Plastic nodal displacement coordinates, taken from above file.

N30003

$N_{1bp} := (-14.3373E\text{-}06\ 35.7997\ -53.9059)^T$

N30558

$N_{2bp} := (-4.55024E\text{-}06\ 36.\ -18.3682)^T$

$V_{21bp} := N_{2bp} - N_{1bp}$ $V_{21bp}{}^T = (9.787\times 10^{-6}\ \ 0.2\ \ 35.538)$ Top displacement vector of branch FE model mesh

N23598

$N_{3bp} := (-4.37843E\text{-}06\ -17.7875\ 1.76346E\text{-}03)^T$

N30098

$N_{4bp} := (-23.6801E\text{-}06\ 17.7528\ -11.0838E\text{-}03)^T$

$V_{43bp} := N_{4bp} - N_{3bp}$ $V_{43bp}{}^T = (-1.93\times 10^{-5}\ \ 35.54\ \ -0.013)$ Side displacement vector of branch FE model mesh

$\theta b_{abp} := \operatorname{acos}\left(\frac{V_{21bp}\cdot V_{43bp}}{|V_{21bp}|\cdot|V_{43bp}|}\right) - 90\cdot deg$ $\theta b_{abp} = -0.302\cdot deg$ Dot product between vectors V21b & V43b

$\frac{\theta b_{abp}}{\theta b_{ab}} = 1.007$ No significant deflection difference between unlisted branch linear and plastic material properties.

Compare unlisted branch Run component (with plastic materials) to that of listed elbow (with linear material properties.

$\frac{\theta b_{abp}}{\theta e_{ab}} = 1.029$ Subtle difference (2.9%) between FE model unlisted branch run & listed elbow differences

$k_{bp} := \frac{|\theta b_{abp}|}{\theta_{nom}}$ $k_{bp} = 18.319$ FF of FE model unlisted branch mesh

$\frac{k_{elbow}}{k_e} = \frac{k_{new}}{k_{bp}}$ => $k_{new} := k_{elbow} \cdot \frac{k_{bp}}{k_e}$ Scaled FE model values used to determine actual FF for unlisted branch run component.

$k_{new} = 19.627$ $\frac{k_{new}}{k_{elbow}} = 1.029$ FF difference between unlisted branch and code calculated elbow (2.9%) is insignificant. Therefore, approximating unlisted branch run component (even with plastic material properties) as a common 36-in elbow is still acceptable for unlisted branch FF.

Flexibility Factor values for elastic and plastic material properties of unlisted branch closely match that of the elbow calculated code value (2.9%), thus the unlisted branch component correlation to that of a regular elbow is acceptable. Error from using parabolic curve elements (Appendix A, Section A.6) and using shelled element models is a combined 2.97% (i.e., 2.9% shell elements + 0.007% parabolic beam elements) is considered to be sufficiently close correlation between the unlisted plastic branch model and the computed elbow Code values (and hence to the elastic system model values as established in Appendix A.

Unlisted Branch Component Stress Indices

(9) $B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot M_i$ <= $1.5 \cdot S_m$ Primary SI limit is satisfied if equation 9 is met [1, NB-3652]

For stress indices determination, will approximate unlisted component as a branch fabricated normal to a straight pipe run. In this case, the 36-in elbow is approximated as the run (which has been straghtened out) and the 14-in pipe is approximated as the branch. In this configuration, the branch is normal to the run.

For straight run pipe with smaller diameter branch:

(9) $B_1 \cdot \left(\frac{P \cdot D_o}{2 \cdot T_r}\right) + \left[B_{2b} \cdot \left(\frac{M_b}{Z_b}\right) + B_{2r} \cdot \left(\frac{M_r}{Z_r}\right)\right]$ <= $1.5 \cdot S_m$ Equation 9 is modified for its moment terms [1, NB-3683.1]

where: B1 - primary stress indice for pressure
B2b - primary stress indice for branch contribution
B2r - primary stress indice for run moments contribution
Do - outside diameter of run (in)
Mb - branch moments (Mx, My, Mz) due ot a combination of mechanical loads (in*lbf)
Mr - run moments (Mx, My, Mz) due ot a combination of mechanical loads (in*lbf)
P - Design Pressure (psi)
Sm - allowable design stress intensity value (psi)
Tr - nominal wall thickness of run (in)
Zb - approximate section modulus of attached branch pipe (in^3)
Zr - approximate section modulus of designated run pipe (in^3)

$P = 400 \cdot psi$ $Sm_{125} = 20 \cdot ksi$ $Sy_{125} = 28.35 \cdot ksi$ $D_{elbow} = 36 \cdot in$ Previously defined parameters

Let => $T_r := t_{elbow}$ $T_r = 0.563\,in$

Per Section NB-3656(a): Level D Service Limits apply

(1) $P = 400 \cdot psi < 2 \cdot P_a$

(3) $P_a = \frac{2 \cdot S_m \cdot t}{D_o - 2 \cdot y \cdot t}$ [1, Section NB-3641.1]

where P_a Calculated maximum allowable internal pressure of straight pipe

$y := 0.4$ $Y := 0.4$ [1,Section NB-3641.1]

$P_a := \frac{2 \cdot Sm_{125} \cdot T_r}{D_{elbow} - 2 \cdot y \cdot T_r}$ $P_a = 632.911\,psi$ $\frac{P}{2 \cdot P_a} = 0.316$ OK

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Equation 9 adapted for level D service limits (as defined in NB-3225 [1]):

(9) $$B_1 \cdot \left(\frac{P \cdot D_o}{2 \cdot T_r}\right) + \left[B_{2b} \cdot \left(\frac{M_b}{Z_b}\right) + B_{2r} \cdot \left(\frac{M_r}{Z_r}\right)\right] \quad =< \quad \text{min(3*Sm, 2*Sy)}$$

where $3 \cdot Sm_{125} = 60 \cdot ksi$ $\quad 2 \cdot Sy_{125} = 56.7 \cdot ksi$ $\quad$ 2*Yield at 125°F governs

(9) $$B_1 \cdot \left(\frac{P \cdot D_o}{2 \cdot T_r}\right) + \left[B_{2b} \cdot \left(\frac{M_b}{Z_b}\right) + B_{2r} \cdot \left(\frac{M_r}{Z_r}\right)\right] \quad =< \quad 2 \cdot Sy_{125} = 56.7 \cdot ksi$$

$Z_b = \pi \cdot (r'_m)^2 \cdot T'_b$ Approximate branch section modulus [1, NB-3683.1]

where r'_m - mean radius of attached branch pipe (in)

T'_b - nominal wall thickness of attached branch pipe (in)

$r14_{mean} = 6.875\,in$ $\quad t_{14} = 0.25\,in$ $\quad$ Previously defined

$Z_b := \pi \cdot (r14_{mean})^2 \cdot t_{14}$ $\quad Z_b = 37.122\,in^3$

$Z_r = \pi \cdot (R_m)^2 \cdot T_r$ Approximate run section modulus [1, NB-3683-1]

where R_m - mean radius of designated run pipe (in)

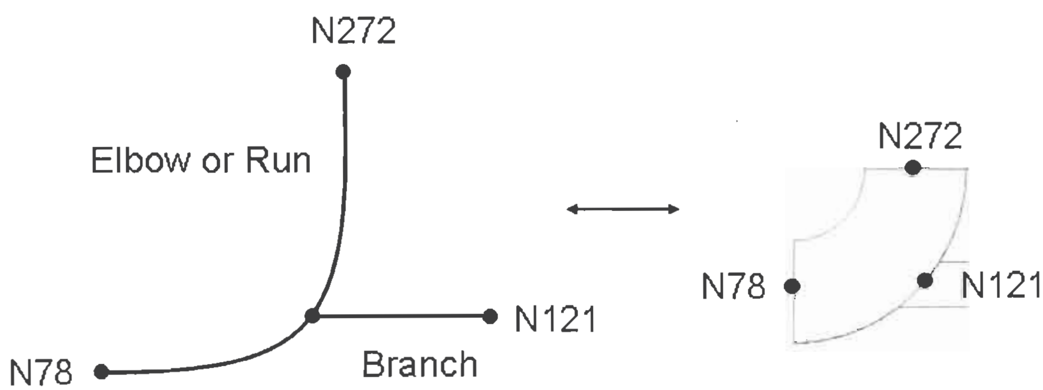
T_r - nominal wall thickness of designated run pipe (in)

$de_{mean} = 35.438\,in$ $\quad T_r = 0.563\,in$ $\quad$ Previously defined

$Z_r := \pi \cdot (de_{mean})^2 \cdot T_r$ $\quad Z_r = 2219.21\,in^3$

The following outline illustrates the pilot model's unlisted component (36-in elbow branched with 14-in pipe) for preliminary 80 percentile solution run set. The unlisted component is approximated as a standard branch with the 36-in elbow forming the run and the 24-in pipe forming the branch. Nodes 78 and 272 depict the start and end conditions of the run and node 121 depicts the end condition of the branch. The following matrix identifies the scoping nodal moment reactions for each of the run (N78 & N272) and branch (N121) conditions, obtained from Table F.1.1-4.

Preliminary 80 Percentile Nodal Moment Reactions used for Scoping Stress Indices Calculations



Mx My Mz

$n_{121} := \left(1.47417\,10^{4} \quad -5.33164\,10^{5} \quad 1.48736\,10^{5}\right)^{T}$ $\quad N_{121} := \sqrt{\sum n_{121}^{2}} \quad N_{121} = 5.537\times 10^{5}$

$n_{78} := \left(-1.5479\,10^{6} \quad -2.03468\,10^{4} \quad -1.35239\,10^{5}\right)^{T}$ $\quad N_{78} := \sqrt{\sum n_{78}^{2}} \quad N_{78} = 1.554\times 10^{6}$

$n_{272} := \left(3.94024\,10^{5} \quad 5.81897\,10^{5} \quad -3.18892\,10^{4}\right)^{T}$ $\quad N_{272} := \sqrt{\sum n_{272}^{2}} \quad N_{272} = 7.035\times 10^{5}$

The above moment reactions were obtained from one of the earlier Pilot model 80th percentile solution results and used to determine scoping FF and SI of the Pilot model unlisted components. As the Pilot model evaluation matured, final moment reactions were obtained (as listed in Appendix B) and compared to these preliminary moment reactions for final model evaluation updates.

$M_{ub} := N_{121}\cdot in\cdot lbf \quad M_{ub} = 553.718\,in\cdot kip$ Branch resultant moment at N121

$M_{ur} := if\left(N_{78} \geq N_{272}, N_{78}, N_{272}\right)\cdot in\cdot lbf \quad M_{ur} = 1553.93\,in\cdot kip$ Maximum run resultant moment

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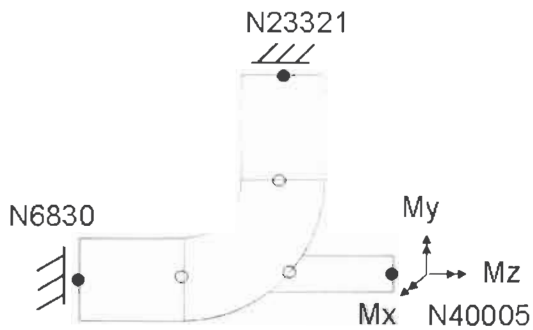
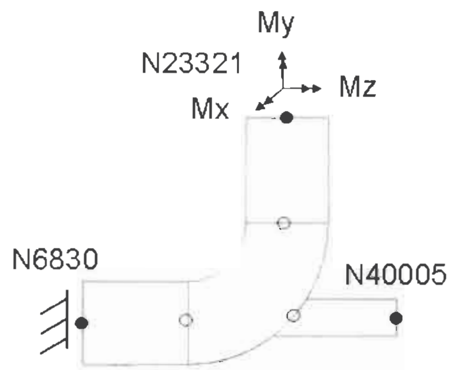
Determination of SI for the branch and run are performed similarly, excepting each model uses a different restraint configuration. As shown following, the branch FE model fully restrains the run nodes and combines an internal pressure with corresponding moment reactions (from N121) to 40005. Similarly, the run FE model fully restrains the elbow's start node and combines internal pressure with corresponding maximum moment reactions at N23321.



Branch Configuration



Run Configuration

Determine scoping SI for Branch member:

$Mub_{mxA} := \left|n121_0\right| \cdot in \cdot lbf$ $\quad Mub_{mxA} = 14.742\,in \cdot kip$ $\quad$ Branch bending moments (+/-) about X-axis

$Mub_{mxO} := -Mub_{mxA}$ $\quad Mub_{mxO} = -14.742\,in \cdot kip$

$Mub_{myA} := \left|n121_1\right| \cdot in \cdot lbf$ $\quad Mub_{myA} = 533.164\,in \cdot kip$ $\quad$ Branch bending moments (+/-) about Y-axis

$Mub_{myO} := -Mub_{myA}$ $\quad Mub_{myO} = -533.164\,in \cdot kip$

$Mub_{mzA} := \left|n121_2\right| \cdot in \cdot lbf$ $\quad Mub_{mzA} = 148.736\,in \cdot kip$ $\quad$ Branch bending moments (+/-) about Z-axis

$Mub_{mzO} := -Mub_{mzA}$ $\quad Mub_{mzO} = -148.736\,in \cdot kip$

FE branch membrane tresca stress results are reflective of three load conditions (or steps). The first step (step 1) produces results for an internal pressure (400-psi) loading. The second step (step 2) computes results for combined internal pressure and bending loading. The last step (step 3) subtracts step 1 (P) from step 2 (P+Bi) to obtain corresponding bending tresca stress results (Bi). This is done to capture the added stiffness from internal pressure reflected into Bi results. Maximum tresca stress results (extracted from FE model results) of the three moments (Mx, My, & Mz) are used to determine the branch stress indice.

$\sigma ub_{mx} := \begin{pmatrix} 629.013 \\ 628.99 \end{pmatrix} \cdot psi$ $\quad$ Mub_{mxA} (+ direction), Mub_{mxO} (- direction)

$\sigma_{ub_0} := max(\sigma ub_{mx})$ $\quad \sigma_{ub_0} = 0.629\,ksi$

Branch tresca stress for X-axis bending (+/- moment directions). FE results are shown in Figs F.1.2-3 & -4 (Appendix F.1.2) and recorded in file branch.rpt (Appendix F.1.2.1).

$\sigma ub_{my} := \begin{pmatrix} 29.6588E+03 \\ 29.6648E+03 \end{pmatrix} \cdot psi$ — Mub_{myA} (+ direction), Mub_{myO} (- direction)

Branch tresca stress for Y-axis bending (+/- moment directions). FE results are shown in Figs. F.1.2-5 & -6 (Appendix F.1.2) and recorded in file branch.rpt (Appendix F.1.2.1).

$\sigma_{ub_1} := max(\sigma ub_{my})$ $\quad \sigma_{ub_1} = 29.665\,ksi$

$\sigma ub_{mz} := \begin{pmatrix} 6.37879E+03 \\ 6.37742E+03 \end{pmatrix} \cdot psi$ — Mub_{mzA} (+ direction), Mub_{mzO} (- direction)

Branch tresca stress for Z-axis bending (+/- moment directions). FE results are shown in Figs. F.1.2.-7 & -8 (Appendix F.1.2) and recorded in file branch.rpt (Appendix F.1.2.1).

$\sigma_{ub_2} := max(\sigma ub_{mz})$ $\quad \sigma_{ub_2} = 6.379\,ksi$

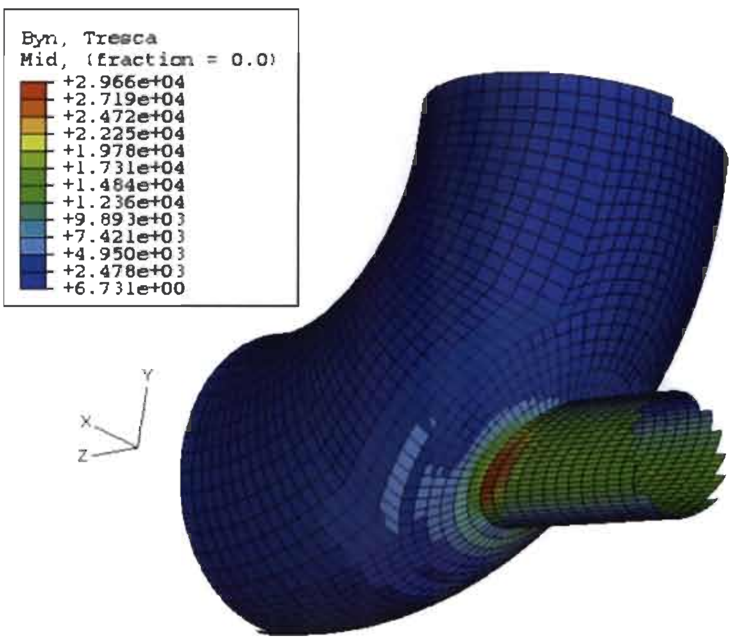
$\sigma_{ub}^{T} = (0.629 \;\; 29.665 \;\; 6.379) \cdot ksi$

Branch tresca stress results (in psi) corresponding to moments Mx, My, and Mz, is shown.

$\sigma ub_{max} := max(\sigma_{ub})$ $\quad \sigma ub_{max} = 29.665\,ksi$

Maximum branch stress occurs for negative Y-axis bending (Mub_{myO})

$Mub_{myA} = 533.164\,in \cdot kip$ $\quad \dfrac{Mub_{myA}}{M_{ub}} = 0.963$



Branch member scoping stress indice determination

$$\sigma ub_{max} = B_{2ub} \cdot \left(\frac{Mub_{myA}}{Z_b}\right) \quad => \quad B_{2ub} := \frac{\sigma ub_{max}}{\left(\frac{Mub_{myA}}{Z_b}\right)} \quad B_{2ub} = 2.065$$

Unlisted branch member scoping stress indice

Determine scoping SI for unlisted Run member:

$Mur_{mxA} := max\left(\left|n78_0\right|, \left|n272_0\right|\right)\cdot in\cdot lbf$ $Mur_{mxA} = 1.548\times 10^3\cdot in\cdot kip$ Run bending moments (+/-) about X-axis

$Mur_{mxO} := -Mur_{mxA}$ $Mur_{mxO} = -1.548\times 10^3\cdot in\cdot kip$

$Mur_{myA} := max\left(\left|n78_1\right|, \left|n272_1\right|\right)\cdot in\cdot lbf$ $Mur_{myA} = 581.897 in\cdot kip$ Run bending moments (+/-) about Y-axis

$Mur_{myO} := -Mur_{myA}$ $Mur_{myO} = -581.897 in\cdot kip$

$Mur_{mzA} := max\left(\left|n78_2\right|, \left|n272_2\right|\right)\cdot in\cdot lbf$ $Mur_{mzA} = 135.239 in\cdot kip$ Run bending moments (+/-) about Z-axis

$Mur_{mzO} := -Mur_{mzA}$ $Mur_{mzO} = -135.239 in\cdot kip$

FE run membrane tresca stress results are reflective of three load conditions (or steps), previously described for the branch member.

$\sigma ur_{mx} := \begin{pmatrix} 18.6615E+03 \\ 17.9863E+03 \end{pmatrix}\cdot psi$ Mur_{mxA} (+ direction) Mur_{mxO} (- direction) Run tresca stress for X-axis bending (+/- moment directions). FE results are shown in Figs F.1.2-10 & -11 (Appendix F.1.2) and recorded in file run.rpt (Appendix F.1.2.1).

$\sigma_{ur_0} := max(\sigma ur_{mx})$ $\sigma_{ur_0} = 18.662 ksi$

$\sigma ur_{my} := \begin{pmatrix} 8.14789E+03 \\ 8.12167E+03 \end{pmatrix}\cdot psi$ Mur_{myA} (+ direction) Mur_{myO} (- direction) Run tresca stress for Y-axis bending (+/- moment directions). FE results are shown in Figs. F.1.2-12 & -13 (Appendix F.1.2) and recorded in file run.rpt (Appendix F.1.2.1).

$\sigma_{ur_1} := max(\sigma ur_{my})$ $\sigma_{ur_1} = 8.148 ksi$

$\sigma ur_{mz} := \begin{pmatrix} 1.86709E+03 \\ 1.86661E+03 \end{pmatrix}\cdot psi$ Mur_{mzA} (+ direction) Mur_{mzO} (- direction) Run tresca stress for Z-axis bending (+/- moment directions). FE results are shown in Figs. F.1.2-14 & -15 (Appendix F.1.2) and recorded in file run.rpt (Appendix F.1.2.1).

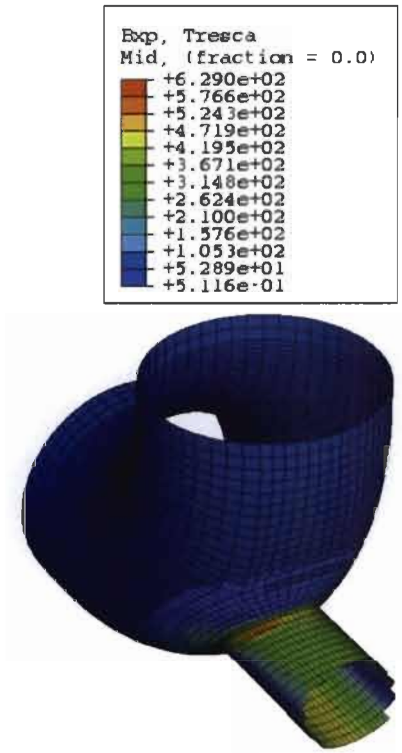
$\sigma_{ur_2} := max(\sigma ur_{mz})$ $\sigma_{ur_2} = 1.867 ksi$

$\sigma_{ur}^T = (18.662\ \ 8.148\ \ 1.867)\cdot ksi$ Run tresca stress results corresponding to scoping moments Mx, My, and Mz.

$\sigma ur_{max} := max(\sigma_{ur})$ $\sigma ur_{max} = 18.662 ksi$ Maximum scoping run stress occurs for positive X-axis bending

$Mur_{mxA} = 1.548\times 10^3\cdot in\cdot kip$ Corresponding maximum scoping unlisted run moment

$$\frac{Mur_{mxA}}{M_{ur}} = 0.996$$



Run member stress indice

$$\sigma ur_{max} = B_{2ur} \cdot \left(\frac{Mur_{rxA}}{Z_r} \right)$$

$$B_{2ur} := \frac{\sigma ur_{max}}{\left(\frac{Mur_{mxA}}{Z_r} \right)}$$ Branch member stress indice

$$B_{2ur} = 26.755$$

Determine system pressure indice:

$$\sigma up := (59.8824E+03\ 59.6236E+03)^T \cdot psi$$

Scoping branch and run tresca stresss for pressure. FE results are show in Fig. F.1.2-9 for branch pressure (Appendix F.1.2) and Fig. F.1.2-16 for run pressure (Appendix F.1.2). Both branch and run tresca stress pressure values recoreded in branch.inp and run.inp (Appendix F.1.2.1) respectively.

$\sigma_{up} := max(\sigma up)$ $\sigma_{up} = 59.882\,ksi$ Unlisted component scoping system pressure

$$\sigma_{up} = B_{1u} \cdot \left(\frac{P \cdot D_o}{2 \cdot T_r} \right)$$

$$B_{1u} := \frac{\sigma_{up}}{\left(\frac{P \cdot D_{elbow}}{2 \cdot T_r} \right)}$$ $B_{1u} = 4.678$ System pressure scoping SI

$B_{1u} = 4.678$ $B_{2ub} = 2.065$ $B_{2ur} = 26.755$ Unlisted branch component scoping SI

F.1.4 – Linear Evaluation of Unlisted Branch Component

The purpose of this section is to perform a linear evaluation of the unlisted branch component, using the stress indices and methodology defined in the previous section (Appendix F.1.3).

For unlisted elbow/pipe branch:

$$B_{1u}\cdot\left(\frac{P\cdot D_{elbow}}{2\cdot T_r}\right)+\left[B_{2b}\cdot\left(\frac{M_{ub}}{Z_b}\right)+B_{2r}\cdot\left(\frac{M_{ur}}{Z_r}\right)\right] \quad =< \quad 2\cdot Sy_{125}=56.7\cdot ksi$$

$$\frac{B_{1u}\cdot\left(\frac{P\cdot D_{elbow}}{2\cdot T_r}\right)+\left[B_{2ub}\cdot\left(\frac{M_{ub}}{Z_b}\right)+B_{2ur}\cdot\left(\frac{M_{ur}}{Z_r}\right)\right]}{2\cdot Sy_{125}}=1.93 \qquad \text{NG}$$

$$\frac{B_{1u}\cdot\left(\frac{P\cdot D_{elbow}}{2\cdot T_r}\right)}{2\cdot Sy_{125}}=1.056$$ Pressure strongly influences linear results.

$$\frac{\left[B_{2ub}\cdot\left(\frac{M_{ub}}{Z_b}\right)+B_{2ur}\cdot\left(\frac{M_{ur}}{Z_r}\right)\right]}{2\cdot Sy_{125}}=0.874$$ Seismic loading effects

$$\frac{B_{2ur}\cdot\left(\frac{M_{ur}}{Z_r}\right)}{2\cdot Sy_{125}}=0.33 \quad << \quad \frac{B_{2ub}\cdot\left(\frac{M_{ub}}{Z_b}\right)}{2\cdot Sy_{125}}=0.543$$ Scoping branch bending about Y-axis is significant.

The branch seismic loading is significant, based on scoping calculations. Thus, a plastic analysis is required to determine code acceptance. A plastic analysis of the unlisted branch component is performed in the following section (Appendix F.1.5).

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The above unlisted elbow/branch component linear evaluation was based on preliminary 80 percentile moment reactions, used for determining scoping stress indices. Following are final run moment reactions (obtained from Appendix B) for the unlisted elbow/branch component. Preliminary and final moment reactions are compared.

Preliminary 80 Percentile Nodal Moment Reactions, previously shown

Mx My Mz Magnitudes

$$n_{121}^T = \begin{pmatrix} 1.474\times 10^4 & -5.332\times 10^5 & 1.487\times 10^5 \end{pmatrix} \qquad N_{121} = 5.537\times 10^5$$

$$n_{78}^T = \begin{pmatrix} -1.548\times 10^6 & -2.035\times 10^4 & -1.352\times 10^5 \end{pmatrix} \qquad N_{78} = 1.554\times 10^6$$

$$n_{272}^T = \begin{pmatrix} 3.94\times 10^5 & 5.819\times 10^5 & -3.189\times 10^4 \end{pmatrix} \qquad N_{272} = 7.035\times 10^5$$

Final run 80 Percentile Nodal Moment Reactions for unlisted elbow/branch component

Mx My Mz

$$n_{121f} := \begin{pmatrix} -3.457\cdot 10^4 & -1.433\cdot 10^5 & 1.211\cdot 10^5 \end{pmatrix}^T \qquad N_{121f} := |n_{121f}| \qquad N_{121f} = 1.908\times 10^5$$

$$n_{78f} := \begin{pmatrix} -5.157\cdot 10^3 & 801.12 & -1.259\cdot 10^4 \end{pmatrix}^T \qquad N_{78f} := |n_{78f}| \qquad N_{78f} = 1.363\times 10^4$$

$$n_{272f} := \begin{pmatrix} 3.394\cdot 10^3 & -827.84 & 7.997\cdot 10^3 \end{pmatrix}^T \qquad N_{272f} := |n_{272f}| \qquad N_{272f} = 8.727\times 10^3$$

$$\frac{n_{121f}}{n_{121}} = \begin{pmatrix} -2.345 \\ 0.269 \\ 0.814 \end{pmatrix} \qquad \frac{n_{78f}}{n_{78}} = \begin{pmatrix} 0.0033 \\ -0.0394 \\ 0.0931 \end{pmatrix} \qquad \frac{n_{272f}}{n_{272}} = \begin{pmatrix} 0.0086 \\ -0.0014 \\ -0.2508 \end{pmatrix}$$

Most of the final reaction moments are less than the scoping moments, excepting branch bending about the x-axis. Here, the moment has a significant increase. This unlisted elbow/branch component acceptance will be decided by plastic analysis.

F.1.5 – Plastic Evaluation of Unlisted Branch Component

To run the plastic analysis for the unlisted branch component, displacement results versus time were gathered from the model 3 beam element model (shown in Figure F.1.5-1). The model selected was realization 27 based on it being the eightieth percentile run for the unlisted branch component and the displacement results (shown in Figure F.1.5-2) were taken from the nodes identified in Figure F.1.5-1. (One more model run occurred after these results were gathered. The model was rerun because five elements distant from the area of concern needed to have a gravitational load added to them. The results were not gathered again due to the insignificance of the change.)

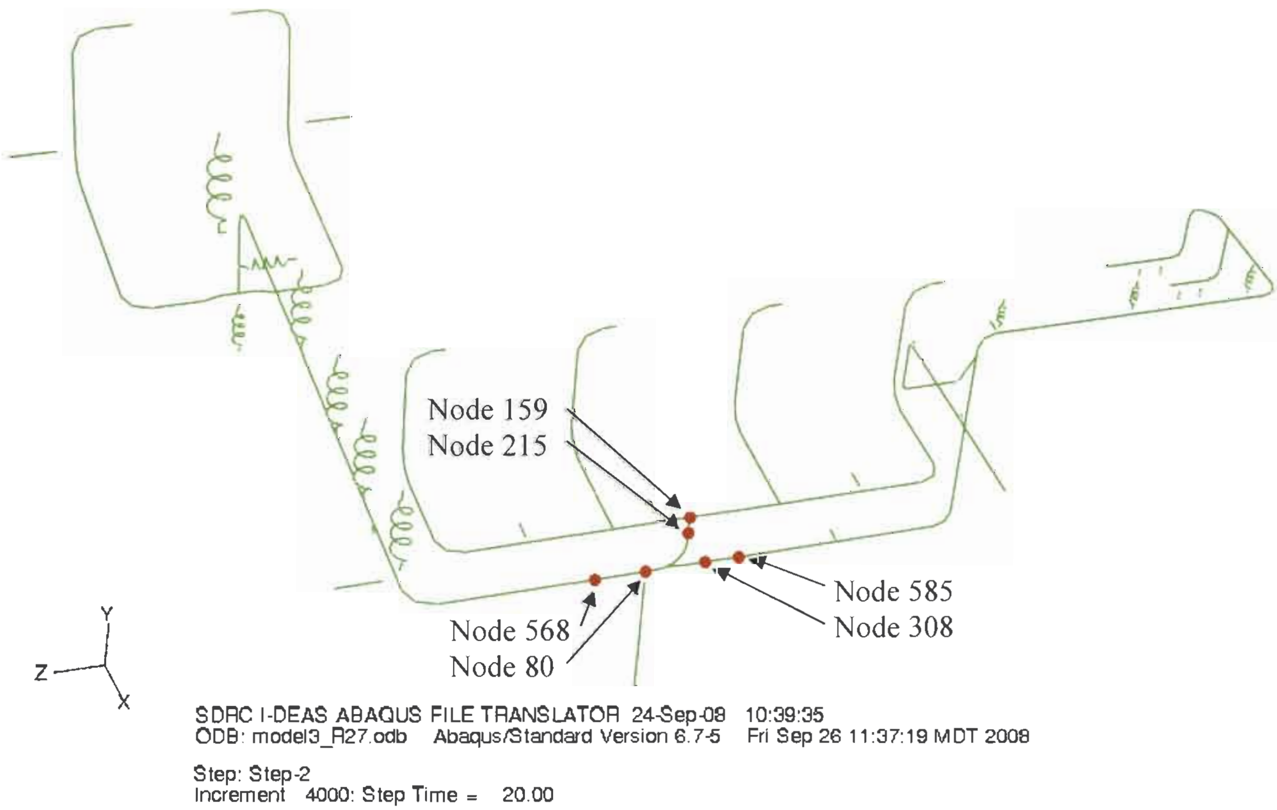

Figure F.1.5-1 – Realization 27 of the piping model.

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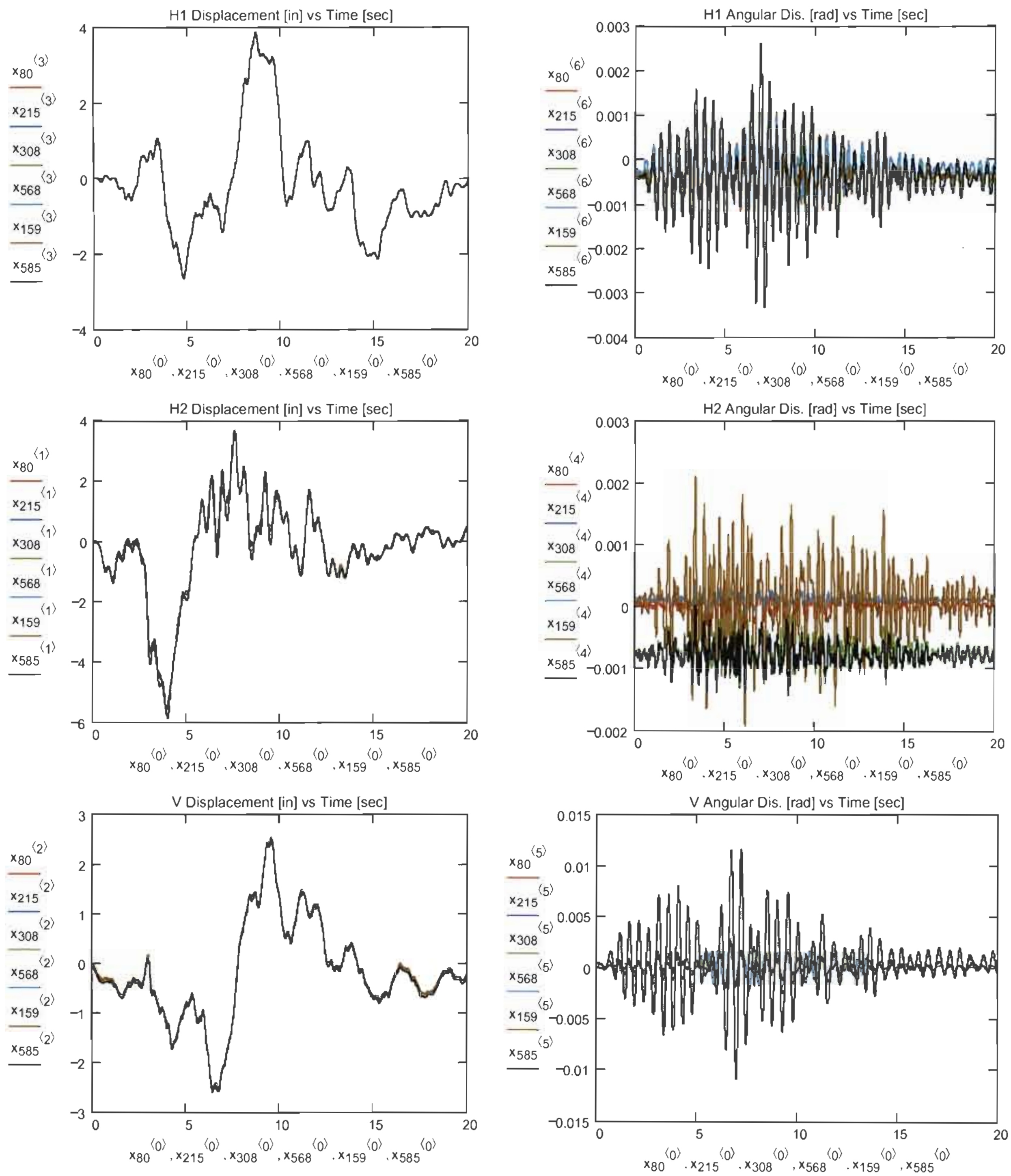

Figure F.1.5-2 – Displacement plots for nodes identified in Figure F.1.5-1.

Figure F.1.5-2 shows the translational and rotational displacement in the nodes output from realization 27 (shown in Figure F.1.5-1). In the plot variables, "x" indicates displacement and the subscript that follows is the node number from Figure F.1.5-1. H1 represents the east/west direction and it is on the z-axis in the model plots. H2 represents the north/south direction and it is on the x-axis in the model plots. V represents the vertical direction and it is on the y-axis in the model plots.

The plastic analysis for the unlisted branch component was performed by generating a continuum shell model (as shown in Figures F.1.5-3 - F.1.5-8) of the region including the nodes identified in Figure F.1.5-1. This model includes 36 inch pipe with a wall thickness of 0.562 inches, 14 inch pipe with a wall thickness of 0.25 inches, and a stiffener plate that is 0.5 inches thick.

```
NX I-deas 5 :    NX I-DEAS 5 Team : er2 : C:\er2\work\TRA-670_ 25-Sep-08  17:13:52

 Database: C:\er2\work\TRA-670_piping\Unlisted_elbow.mf1            Units    : IN
 View    : No stored Workb_View                            Display : No stored Option
   Task : Boundary Conditions                                    Model/Part Bin: Main
   Model: Fem1 Standard          Active Study: DEFAULT FE STUDY    Parent Part: elbow
```

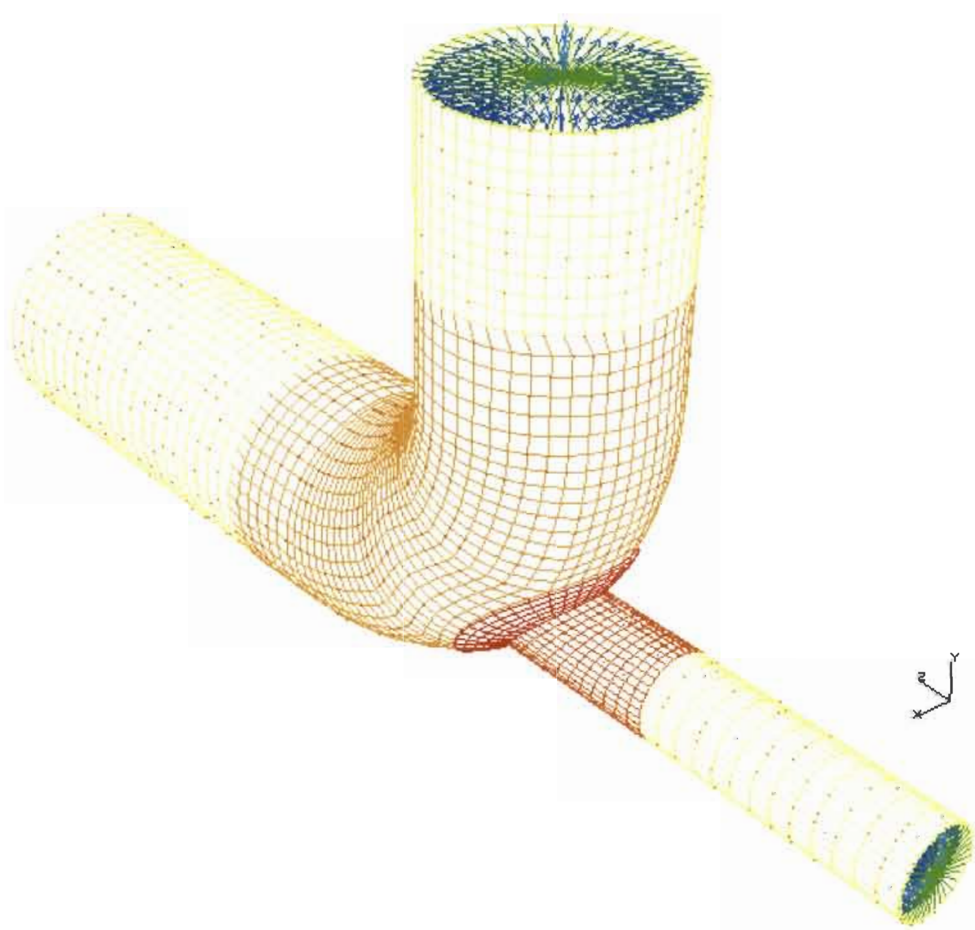

Figure F.1.5-3 – Mesh of the full model.

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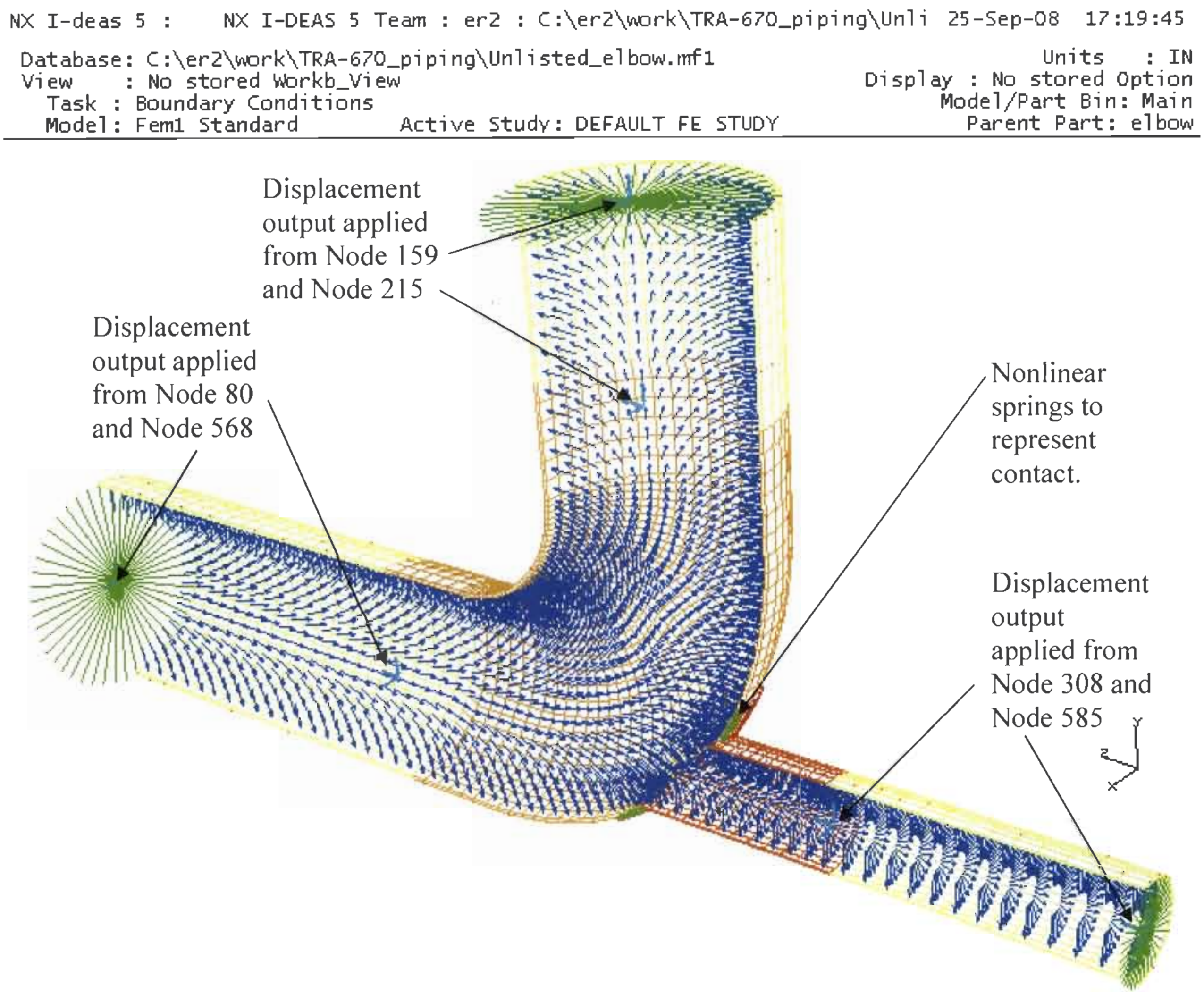

Figure F.1.5-4 – Cut-away of the model.

The displacement time histories taken from realization 27 were applied to the nodes identified in Figure F.1.5-4. Nodes 568, 159, and 585 attached to the mesh with rigid elements. Nodes 80, 215, and 308 attached to the mesh with coupling definitions. These coupling definitions caused the average motion of the slave nodes (on the plane where the yellow elements transitioned to golden orange/orange elements) to correspond with the motion of the reference node. In general, the yellow elements were added to improve the accuracy at the couplings. They are not intended to produce important results themselves. In addition to the moving restraints, the model was loaded with gravity and a 400 psi internal pressure. Finally, nonlinear springs (shown in more detail in Figure F.1.5-8) were added to provide contact between the stiffener plate and the 36 inch pipe.

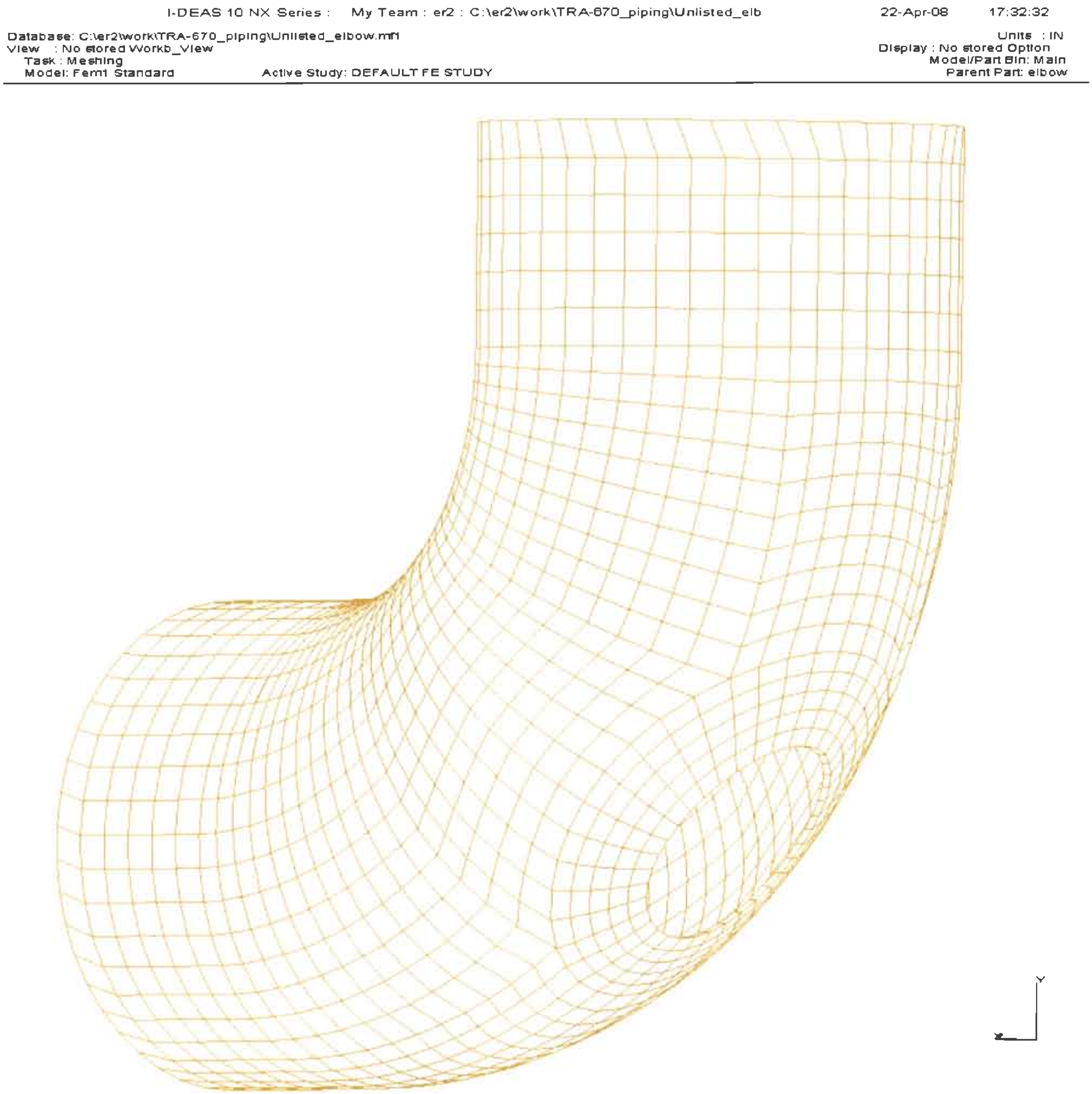

Figure F.1.5-5 – Continuum shell mesh of the 36 inch pipe with a wall thickness of 0.562 inches.

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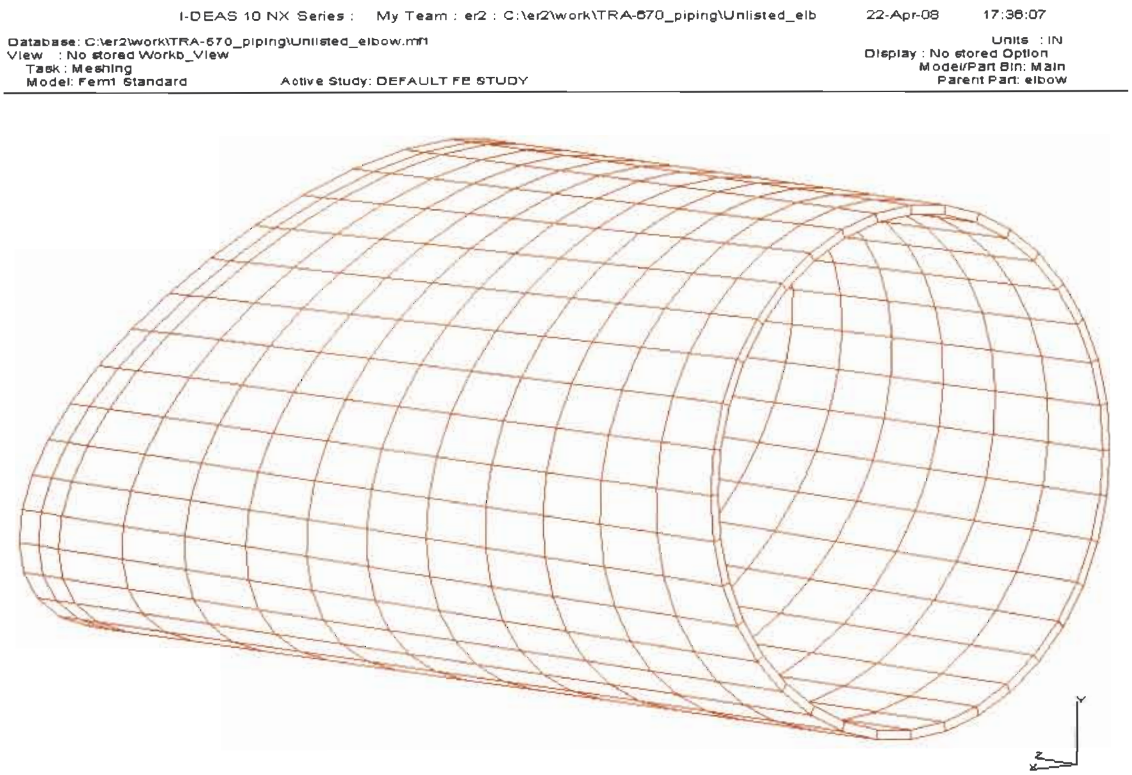

Figure F.1.5-6 – Continuum shell mesh of the 14 inch pipe with a wall thickness of 0.25 inches.

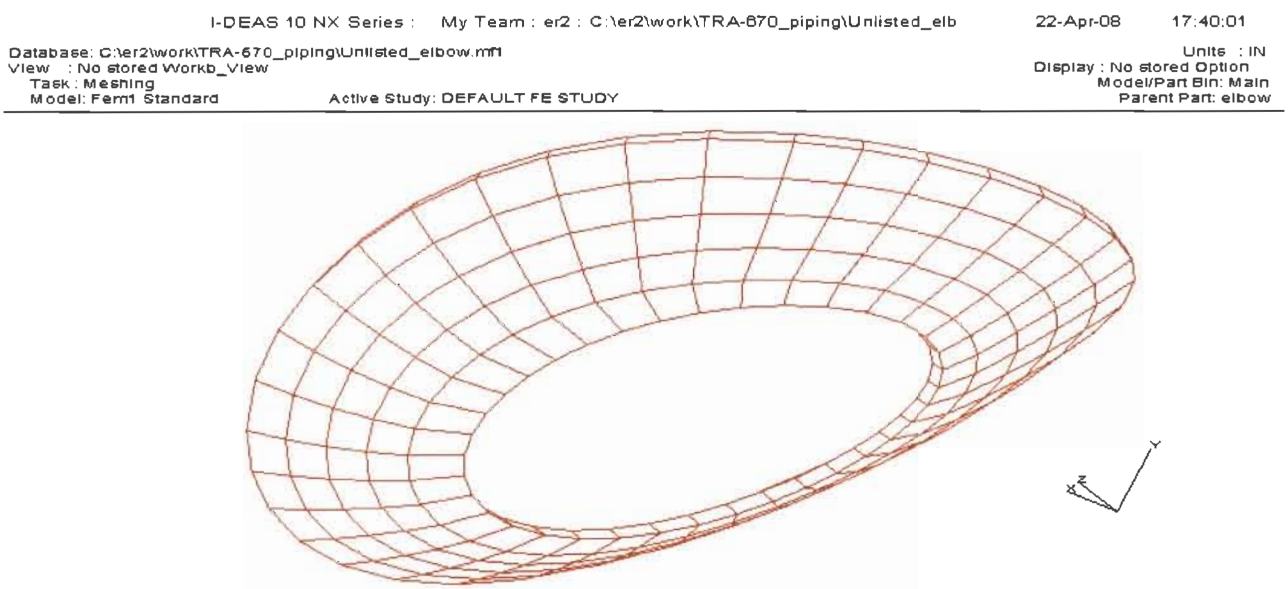

Figure F.1.5-7 – Continuum shell mesh of the 0.5 inch thick stiffener plate.

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I-DEAS 10 NX Series : My Team : er2 : C:\er2\work\TRA-670_piping\Unlisted_elb 22-Apr-08 18:27:29

Database: C:\er2\work\TRA-670_piping\Unlisted_elbow.mf1 Units : IN
View : No stored Workb_View Display : No stored Option
Task : Meshing Model/Part Bin: Main
Model: Fem1 Standard Active Study: DEFAULT FE STUDY Parent Part: elbow

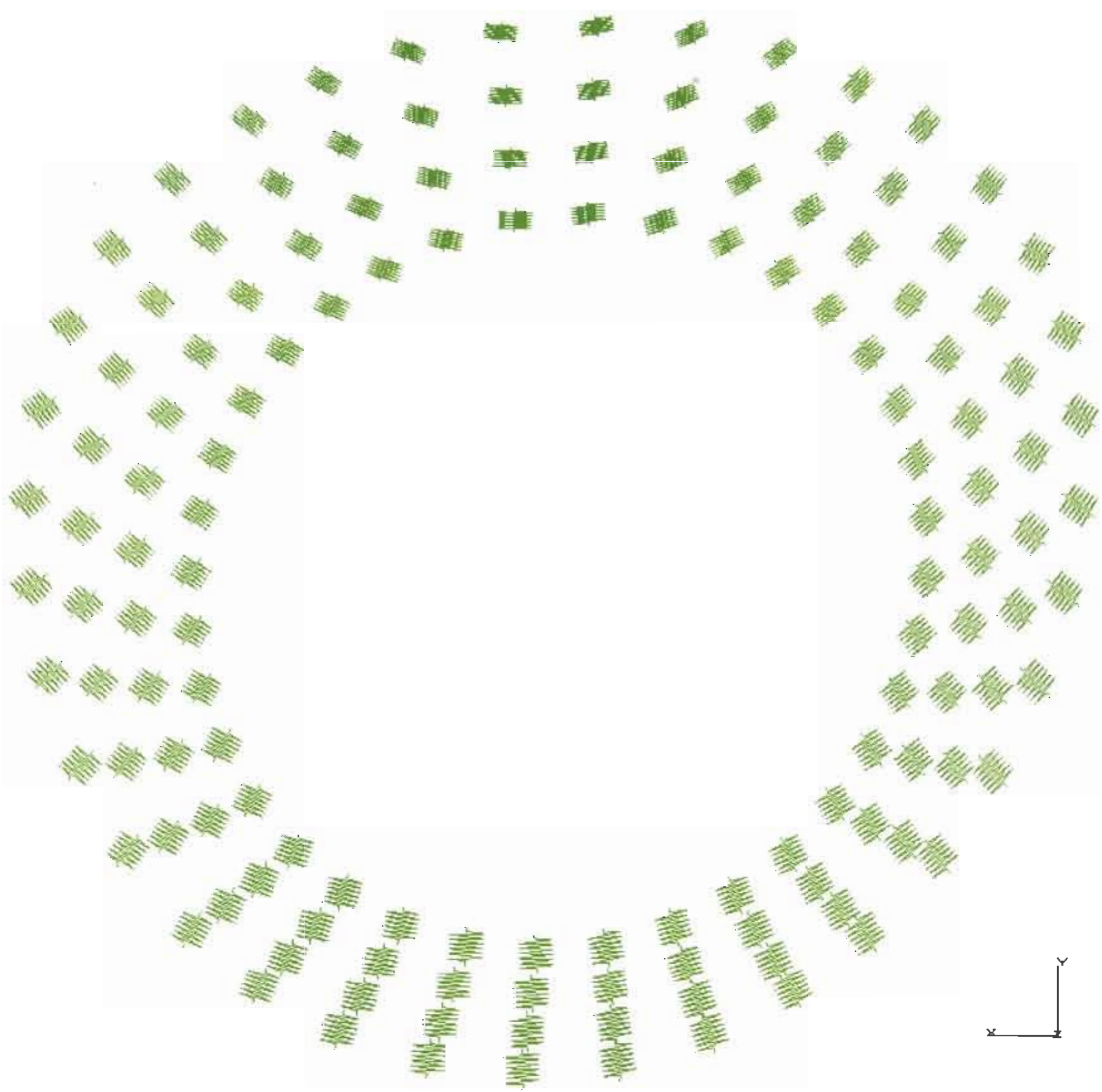

Figure F.1.5-8 – Nonlinear spring elements representing contact between the 36 inch pipe and stiffener.

This model was defined with the same elastic properties as the other models of the unlisted branch component. To run this model with plasticity, however, additional material properties were defined. To define these additional properties, ASME Section II, Part D [12] was used to define engineering yield and tensile stress values and the Nuclear Systems Materials Handbook [15] was used to determine the minimum total elongation percentage and the ratio of uniform elongation to total elongation (considering that the uniform elongation percentage is the engineering strain at the engineering tensile

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stress). Review of the Atlas of Stress-Strain Curves [16] and Tensile Stress-Strain Results for 304L and 316L Stainless Steel Plate at Temperature [17] tends to substantiate the values used from the previous two references. Presented below are the material properties and there conversion to a bilinear true stress versus true strain (using equations from Juvinall [18]) for use in ABAQUS.

$E_S := 2.8 \cdot 10^7 \cdot psi$ — Modulus of elasticity

$\nu_S := 0.30$ — Poisson's ratio

$$G_S := \frac{E_S}{2 \cdot (1 + \nu_S)}$$ Modulus of elasticity

$G_S = 1.077 \times 10^7\ psi$

$\rho_S := 0.28 \cdot \frac{lb}{in^3}$ — Mass density

$\rho_S = 7.252 \times 10^{-4} \frac{lbf \cdot sec^2}{in^4}$

$T_o := 125$ — Operating temperature

$\sigma_{ys100} := 30 \cdot ksi$ — Engineering yield stress at 100 degrees F [12, p. 644]

$\sigma_{ys150} := 26.7 \cdot ksi$ — Engineering yield stress at 150 degrees F [12, p. 644]

$$\sigma_{ys} := \frac{\sigma_{ys150} - \sigma_{ys100}}{150 - 100} \cdot (T_o - 100) + \sigma_{ys100}$$

$\sigma_{ys} = 28.35\ ksi$ — Engineering yield stress at operating temperature

$\sigma_{us100} := 75 \cdot ksi$ — Engineering tensile stress at 100 degrees F [12, p. 521]

$\sigma_{us200} := 71 \cdot ksi$ — Engineering tensile stress at 200 degrees F [12, p. 521]

$$\sigma_{us} := \frac{\sigma_{us200} - \sigma_{us100}}{200 - 100} \cdot (T_o - 100) + \sigma_{us100}$$

$\sigma_{us} = 74\ ksi$ — Engineering tensile stress at operating temperature

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$\varepsilon_{ys} := \frac{\sigma_{ys}}{E_s}$ — Engineering yield strain (0.2% offset is not considered)

$\varepsilon_{ys} = 0.001012 \frac{in}{in}$

$\varepsilon_{ts} := 0.37 \cdot \frac{in}{in}$ — Total elongation percentage [15, p. 3.1]

$R_{UE\_TE100} := 0.873$ — Ratio of total elongation to uniform elongation at 100 degrees F [15, p. 2.0]

$R_{UE\_TE200} := 0.87$ — Ratio of total elongation to uniform elongation at 200 degrees F [15, p. 2.0]

$$\varepsilon_{us} := \left[\frac{R_{UE\_TE200} - R_{UE\_TE100}}{200 - 100} \cdot (T_o - 100) + R_{UE\_TE100}\right] \cdot \varepsilon_{ts}$$

$\varepsilon_{us} = 0.323 \frac{in}{in}$ — Uniform elongation at operating temperature

$\sigma_{Tys} := \sigma_{ys} \cdot (1 + \varepsilon_{ys})$ — True yield stress [18, p. 51]

$\sigma_{Tys} = 28378.7 \text{ psi}$

$\sigma_{Tus} := \sigma_{us} \cdot (1 + \varepsilon_{us})$ — True ultimate stress [18, p. 51]

$\sigma_{Tus} = 97882.2 \text{ psi}$

$\varepsilon_{Tys} := \ln(1 + \varepsilon_{ys})$ — True yield strain [18, p. 51]

$\varepsilon_{Tys} = 0.001012 \frac{in}{in}$

$\varepsilon_{Tus} := \ln(1 + \varepsilon_{us})$ — True ultimate strain [18, p. 51]

$\varepsilon_{Tus} = 0.28 \frac{in}{in}$

$\varepsilon_{Tps} := \varepsilon_{Tus} - \frac{\sigma_{Tus}}{E_s}$ — True plastic strain [18, p. 51]

$\varepsilon_{Tps} = 0.276 \frac{in}{in}$

Having the material properties for the model, stress allowables must be found. The stress allowables are from F-1341.2 Plastic Analysis [4] which state that the stress allowable is "the greater of $0.7S_u$ and $S_y + 1/3\ (S_u - S_y)$."

$S_{allow1} := 0.7 \cdot \sigma_{us}$ First stress allowable option

$S_{allow1} = 51.8\ ksi$

$S_{allow2} := \sigma_{ys} + \frac{1}{3} \cdot (\sigma_{us} - \sigma_{ys})$ Second stress allowable option

$S_{allow2} = 43.567\ ksi$

$S_{allow} := S_{allow1} \cdot (S_{allow1} \geq S_{allow2}) + S_{allow2} \cdot (S_{allow1} < S_{allow2})$

$S_{allow} = 51.8\ ksi$ Stress allowable in engineering stress

It is desirable to put this allowable into a form easily compared to the ABAQUS output (which is based on true stress/strain). The most logical comparison with ABAQUS results is the plastic equivalent strain. This is a desirable value because it is an indicator of the maximum stress that occurred during the entire dynamic event. Considering the values of the previous section that are put into ABAQUS as a bilinear, true stress-strain curve, the following calculation was performed to find the allowable plastic equivalent strain (that is equivalent to the stress allowable in engineering stress above).

$\sigma_{Tg} := 58.5 \cdot ksi$ Allowable true stress guess for the given/find performed below

$\varepsilon_{Tg} := 0.12 \cdot \frac{in}{in}$ Allowable true strain guess for the given/find performed below

$\varepsilon_{allowg} := 0.13 \cdot \frac{in}{in}$ Allowable engineering strain guess for the given/find performed below

Given

$$\sigma_{Tg} = \sigma_{Tys} + \left(\frac{\sigma_{Tus} - \sigma_{Tys}}{\varepsilon_{Tus} - \varepsilon_{Tys}}\right)\cdot\left(\varepsilon_{Tg} - \varepsilon_{Tys}\right)$$ Plastic portion of the true stress versus true stain equation used in ABAQUS

$$\sigma_{Tg} = S_{allow}\cdot\left(1 + \varepsilon_{allowg}\right)$$ True stress versus engineering stress and engineering strain

$$\varepsilon_{Tg} = \ln\left(1 + \varepsilon_{allowg}\right)$$ True strain versus engineering strain

$$\begin{pmatrix} \sigma_{Tallow} \\ \varepsilon_{Tallow} \\ \varepsilon_{allow} \end{pmatrix} := \mathrm{Find}\left(\sigma_{Tg}, \varepsilon_{Tg}, \varepsilon_{allowg}\right)$$

$\sigma_{Tallow} = 58.5\ \mathrm{ksi}$ Stress allowable in true stress

$\varepsilon_{Tallow} = 0.122\ \frac{in}{in}$ True strain at the stress allowable

$\varepsilon_{allow} = 0.13$ Engineering strain at the stress allowable

$peeq_{allow} := \varepsilon_{Tallow} - \frac{\sigma_{Tallow}}{E_s}$ Allowable plastic equivalent strain

$peeq_{allow} = 0.120\ \frac{in}{in}$

One further material property needing definition was that for the nonlinear spring elements. ABAQUS requires force displacement data for the nonlinear spring definition. Two points were defined. The first was a million pound compressive load and its associated displacement. The second was zero load and zero displacement. This makes it so that there is no load in tension and significant stiffness in compression. The calculation for the displacement under the million pound compressive load is presented below.

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$$\sigma = E\cdot\varepsilon = \frac{P}{A} = E\cdot\frac{x}{L} \quad ==> \quad P = \frac{A\cdot E}{L}\cdot x = k\cdot x$$

$L_o := (0.562 + 0.5)\cdot in$

$L_o = 1.062\ in$

Length used for the nonlinear springs (equal to the added thickness of the 36 inch pipe and stiffener plate)

$A_o := (2\cdot in)^2$

$A_o = 4\ in^2$

Area used for the nonlinear springs (approximately equal to the area represented by a single node)

$k := \frac{A_o\cdot E_s}{L_o}$

Nonlinear spring stiffness

$k = 1.055\times 10^8\ \frac{lbf}{in}$

$x_m := \frac{-10^6\cdot lbf}{k}$

Compressive displacement for a million pound load

$x_m = -0.01\ in$

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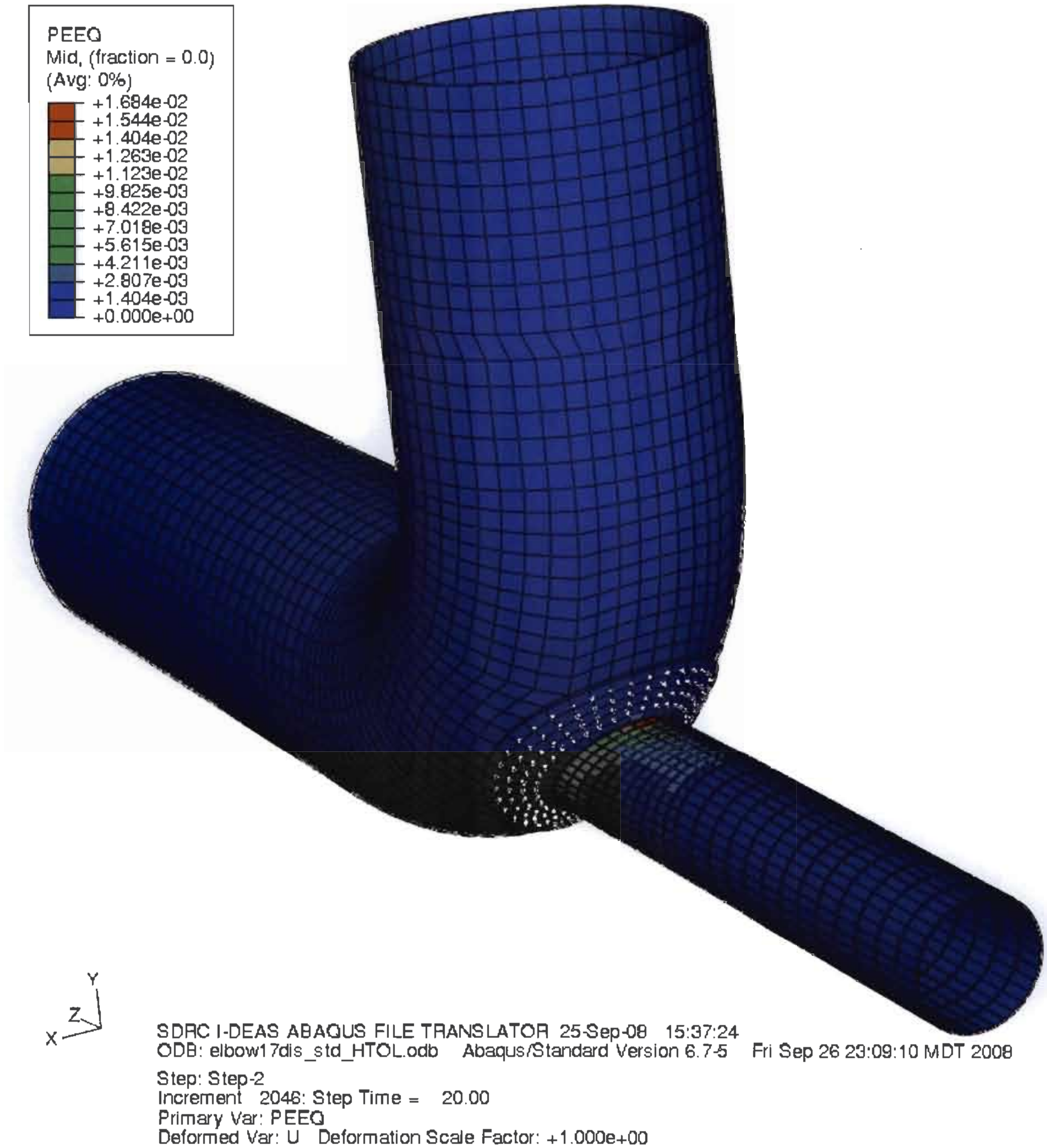

Figure F.1.5-8 – Plastic equivalent strain shown at the midplane with averaging turned off.

As shown in Figure F.1.5-8, the plastic equivalent strain is much less than the allowable 0.120 in/in. Thus, the unlisted branch component is acceptable.

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A check must now be performed to ensure that, at the load level of the plastic analysis, the beam element model responds similar to the shell model. Figure F.1.5-9 shows the beam elements from the model 3 runs.

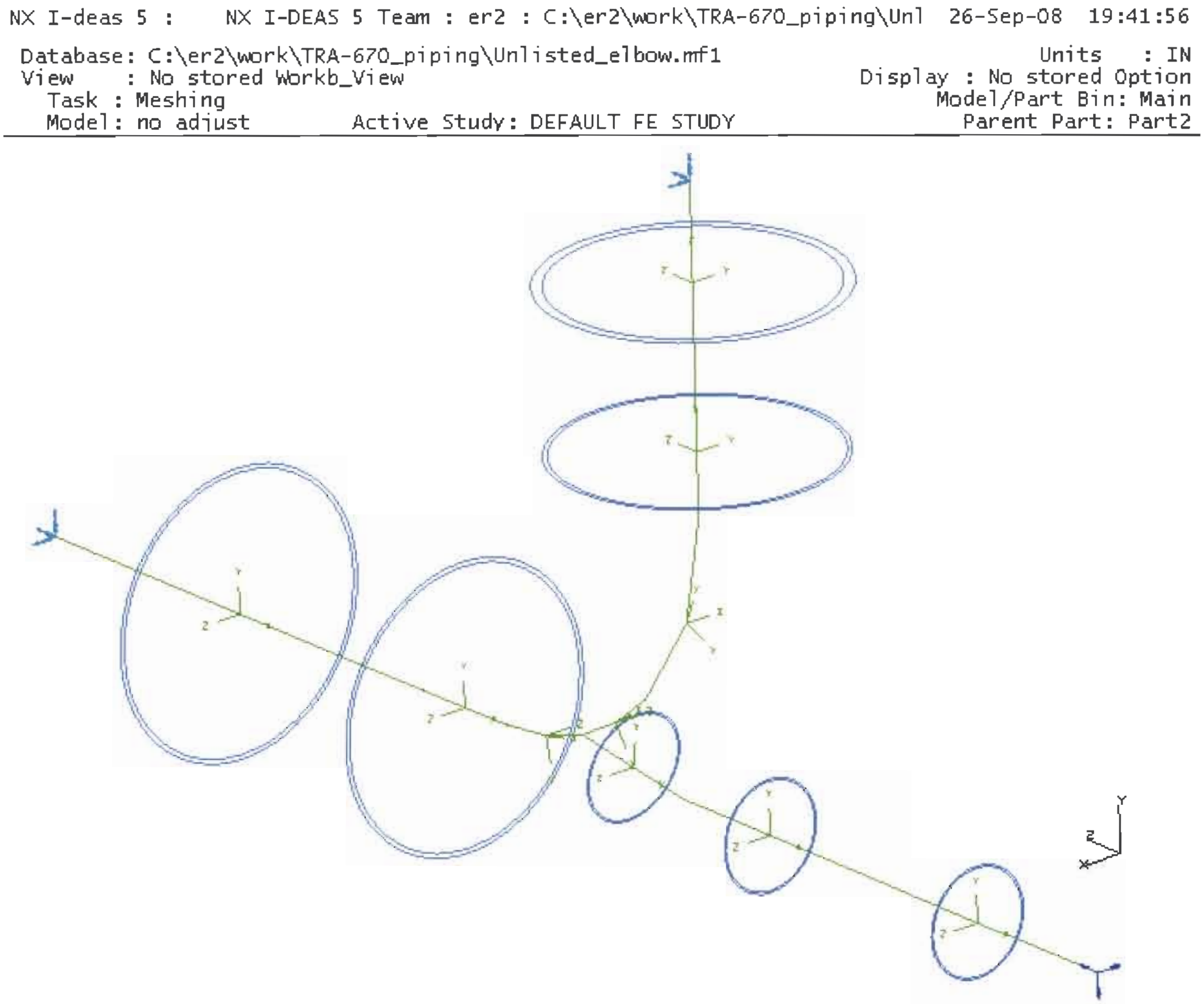

Figure F.1.5-9 – Beam model of the elbow and branch used to check flexibility.

Figure F.1.5-10 shows the shell mesh for the flexibility check. This mesh has shells at the cut points as shown in Figure F.1.5-10. This is to simplify the force balance for the model.

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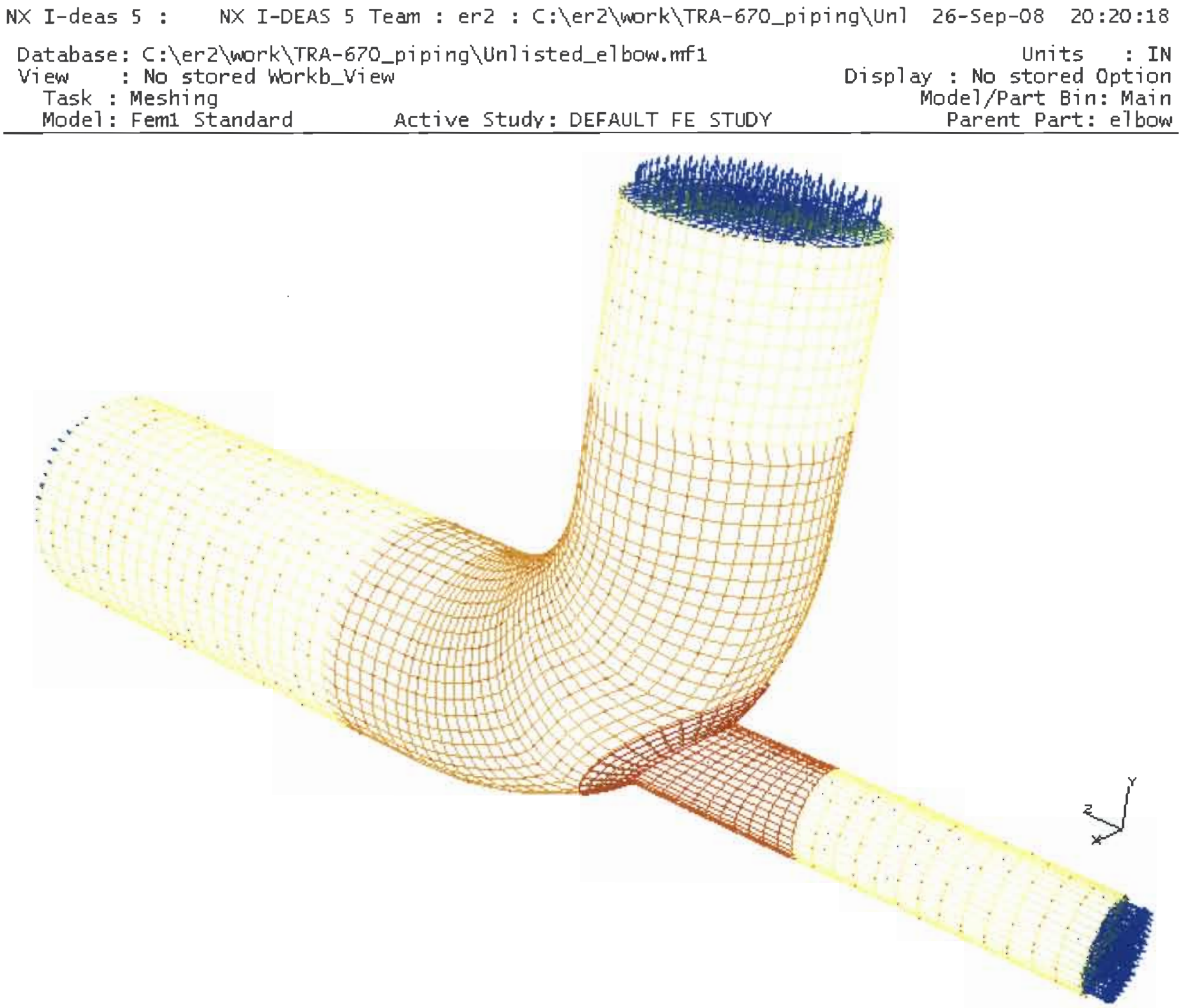

Figure F.1.5-10 – Shell model of the elbow and branch used to check flexibility.

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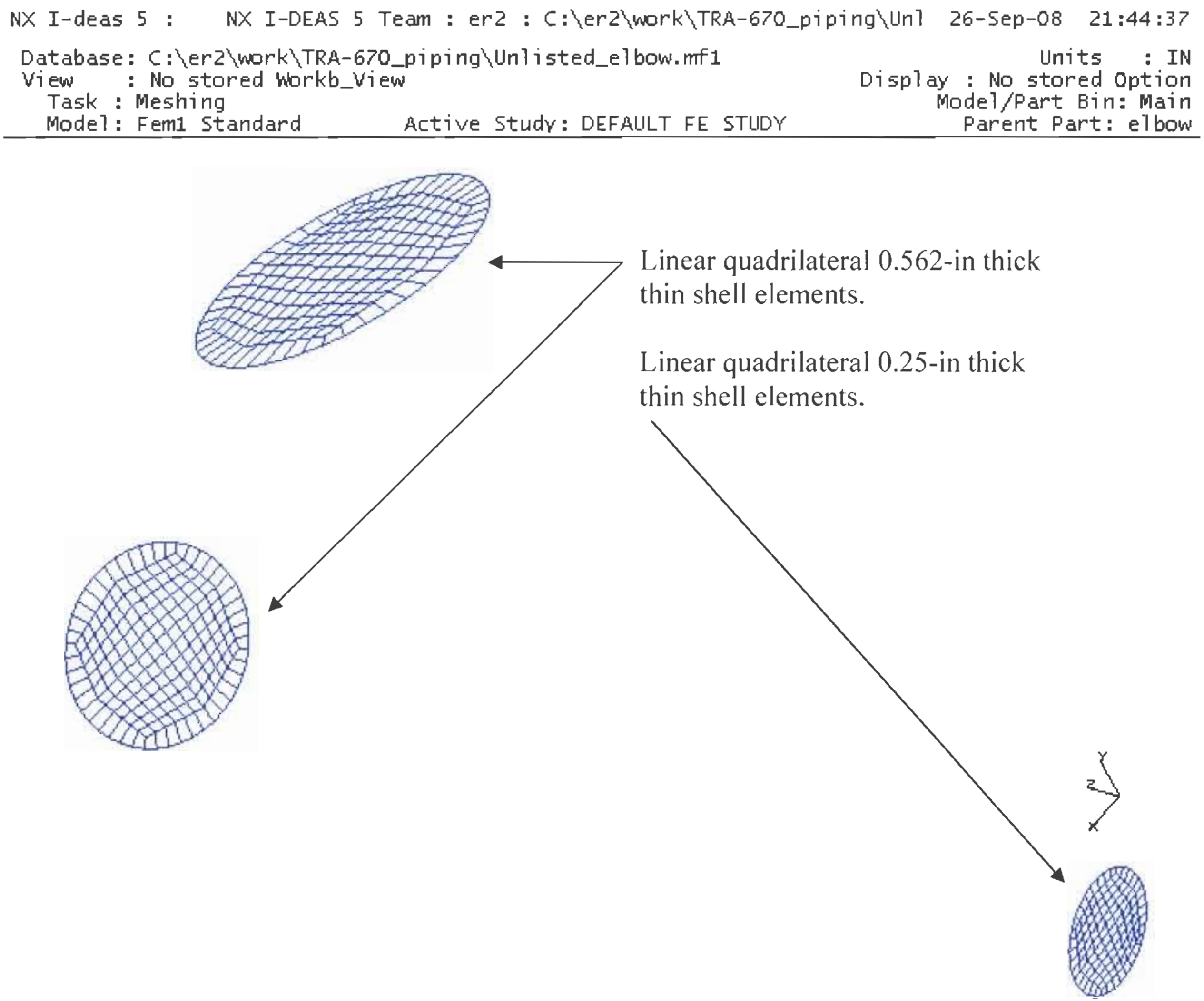

Figure F.1.5-11 – Cut end shell elements.

The next step is to establish loading. From the model 3 run, 80^{th} percentile moments are shown below.

EL 206 ND 121

$$M_{121} := \left(7.883\cdot 10^{4} \quad -8.54\cdot 10^{5} \quad 1.605\cdot 10^{5}\right)^{T}\cdot in\cdot lbf$$

Branch 80^{th} percentile moments from Appendix B

$$M'' := \left(\left|M_{121_0}\right| \quad \left|M_{121_1}\right| \quad \left|M_{121_2}\right|\right)^{T}\cdot(in\cdot lbf)^{-1}$$

Moment used to scale the plots

$$M''^{T} = \left(7.883\times 10^{4} \quad 8.54\times 10^{5} \quad 1.605\times 10^{5}\right)$$

To check the flexibility, three load cases are run with the beam and shell models. Each beam model load case consists of a single moment direction applied to its end branch node (i.e. 78,830 in•lbf in the global x-direction, -854,000 in•lbf in the global y-direction, or 160,500 in•lbf in the global z-direction). The model is fully restrained where the run pipe is cut. Each shell model is run with the same boundary conditions as its corresponding beam model. However, the shell model has an additional initial step where an internal pressure of 400 psi is applied. Figure F.1.5-12 below shows the resulting angular displacement at the end of the branch versus moment applied at the same point. The plots include the results from the shell model and the beam model. Additionally, beam results scaled plus and minus 20% are included for information. The shell model results have two steps. Displacements that occur during the first step, due to the pressure loading, are subtracted from the total curve so that only the relative displacement of caused by the moment is plotted.

The input files used for the beam models were "elbow_beam_17dis_std_STnc_1.inp", "elbow_beam_17dis_std_STnc_2.inp", and "elbow_beam_17dis_std_STnc_3.inp". The input files used for the shell models were "elbow17dis_std_ST_1.inp", "elbow17dis_std_ST_2.inp", and "elbow17dis_std_ST_3.inp". In both sets of input files, the number change of 1, 2, and 3 represent the x-axis run, the y-axis run, and the z-axis run respectively.

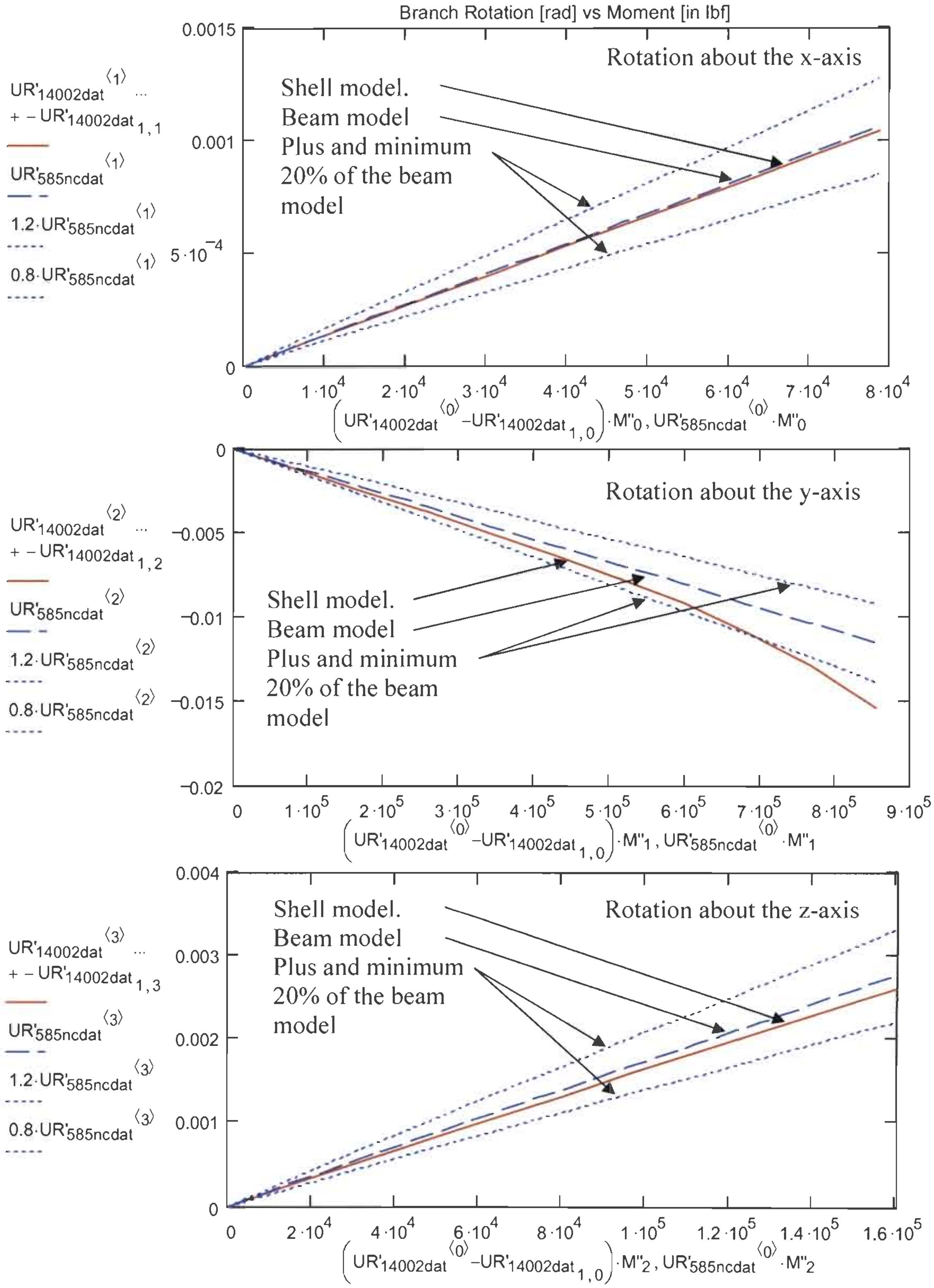

Figure F.1.5-12 – Model 3 branch rotation versus moment check.

Considering Figure F.1.5-12, the shell model gives results within 20% of the beam model for all but a small portion of the moment in the vertical direction.

F.1.6 – Abbreviated reprints of pilot model's ABAQUS input files

Input file names

1. branch_np.in
2. elbow_np.inp
3. branch_npn2_new.inp
4. p_branch_si_bxA.inp
5. p_branch_si_bxO.inp
6. p_branch_si_byA.inp
7. p_branch_si_byO.inp
8. p_branch_si_bzA.inp
9. p_branch_si_bzO.inp
10. p_run_si_rxA.inp
11. p_run_si_rxO.inp
12. p_run_si_ryA.inp
13. p_run_si_ryO.inp
14. p_run_si_rzA.inp
15. p_run_si_rzO.inp
16. elbow17dis_std_HTOL.inp
17. elbow17dis_std_ST_1.inp
18. elbow17dis_std_ST_2.inp
19. elbow17dis_std_ST_3.inp
20. elbow_beam_17dis_std_STnc_1.inp
21. elbow_beam_17dis_std_STnc_2.inp
22. elbow_beam_17dis_std_STnc_3.inp

branch_np.inp

```
**%   ============================================================
**%
**%            I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                   FOR ABAQUS VERSION 6.x
**%
**%         MODEL FILE: C:\DOCUME~1\dtclark\pilot_nonstandard.mf1
**%         INPUT FILE: C:\pcs\pcs2\nonstandard_runs\branch_np.inp
**%           EXPORTED: AT 16:24:30 ON 05-Mar-08
**%               PART: pilot_elbow_branch
**%                FEM: pilot_ns1
**%
**%              UNITS: IN-Inch (pound f)
**%                   ... LENGTH : inch
**%                   ... TIME   : sec
**%                   ... MASS   : lbf-sec**2/in
**%                   ... FORCE  : pound (lbf)
**%                   ... TEMPERATURE : deg Fahrenheit
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  05-Mar-08   16:24:30
**%=============================================
**%          MODAL DATA
**%=============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*ELEMENT, TYPE=S4      , ELSET=THK_562
*ELEMENT, TYPE=S4      , ELSET=THK_50
*MPC
 BEAM,   5758,   6830
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  2.50000E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  2.90000E-01
*DENSITY
 7.51120E-04,
***PLASTIC
** 28600.0,
*SHELL SECTION,
 ELSET=THK_562 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.62000E-01,
*SHELL SECTION,
 ELSET=THK_50,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.00000E-01,
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
 THK_562 ,
 THK_50,
**%
*NSET,NSET=BRANCH_NODES
   23598,   30003,   30098,   30558
*ELSET,ELSET=ALLELE, GENERATE
      6117,     6508,        1
     19375,    19806,        1
```

```
     19843,    19938,        1
     20011,    20106,        1
     23175,    23366,        1
     24719,    35438,        1
*ELSET,ELSET=P14, GENERATE
     31687,    34886,        1
*ELSET,ELSET=REIN_PLT, GENERATE
     34887,    35270,        1
*ELSET,ELSET=EL_TRAN, GENERATE
     19615,    19806,        1
     19843,    19938,        1
     20011,    20106,        1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
     19543,    19614,        1
     25135,    27110,        1
*ELSET,ELSET=P36, GENERATE
      6117,     6508,        1
     19375,    19542,        1
     23175,    23366,        1
     24719,    25134,        1
     27111,    31686,        1
*ELSET,ELSET=LFACE_P36, GENERATE
      6117,     6508,        1
     23175,    23366,        1
*ELSET,ELSET=TFACE_P36, GENERATE
     19375,    19542,        1
     24719,    25134,        1
*ELSET,ELSET=RFACE_P14, GENERATE
     34247,    34886,        1
*ELSET,ELSET=TOP_P36, GENERATE
     19375,    19542,        1
     24719,    25134,        1
     29399,    31686,        1
*ELSET,ELSET=LEFT_P36, GENERATE
      6117,     6508,        1
     23175,    23366,        1
     27111,    29398,        1
*ELSET,ELSET=ELBOW, GENERATE
     19543,    19704,        1
     19706,    19775,        1
     19777,    19806,        1
     19843,    19938,        1
     20011,    20106,        1
     25135,    27110,        1
*ELSET,ELSET=ALLSHELL, GENERATE
      6117,     6508,        1
     19375,    19806,        1
     19843,    19938,        1
     20011,    20106,        1
     23175,    23366,        1
     24719,    34886,        1
**%
**% ====== STEP NUMBER   1 ======
**%
```

```
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      23321,  1,,       0.00000E+00
      23321,  5, 6,      0.00000E+00
       6830,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
      23321,    4,-1.4000E+06
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*ELSET, ELSET=BS000001, GENERATE
      6117,     6508,        1
     19375,    19806,        1
     19843,    19938,        1
     20011,    20106,        1
     23175,    23366,        1
     24719,    34886,        1
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*OUTPUT, HISTORY,FREQUENCY=1
*MONITOR, NODE=23321, DOF=4
*END STEP
```

elbow_np.inp

```
**%   ===========================================================
**%
**%             I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                    FOR ABAQUS VERSION 6.x
**%
**%         MODEL FILE: C:\DOCUME~1\dtclark\pilot_nonstandard.mf1
**%         INPUT FILE: C:\pcs\pcs2\nonstandard_runs\elbow_np.inp
**%           EXPORTED: AT 14:54:26 ON 28-Feb-08
**%               PART: pilot_elbow
**%                FEM: pilot_e1
**%
**%              UNITS: IN-Inch (pound f)
**%                    ... LENGTH : inch
**%                    ... TIME   : sec
**%                    ... MASS   : lbf-sec**2/in
**%                    ... FORCE  : pound (lbf)
**%                    ... TEMPERATURE : deg Fahrenheit
**%
**%        COORDINATE SYSTEM: PART
**%
**%            SUBSET EXPORT: OFF
**%
**%      NODE ZERO TOLERANCE: OFF
**%
**%   ===========================================================
**%
**%
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  28-Feb-08   14:54:26
**%==========================================
**%           MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4       , ELSET=THK_25
*ELEMENT, TYPE=S4       , ELSET=THK_562
*ELEMENT, TYPE=S4       , ELSET=THK_50
*MPC
 BEAM,     589,       7
*SHELL SECTION,
 ELSET=THK_562 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.62000E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  2.90000E-01
*DENSITY
 7.51120E-04,
***PLASTIC
** 28600.0,
**%
*ELSET, ELSET=ALLELEMENTS
 THK_562 ,
**%
*NSET,NSET=ELBOW_NODES
     706,      732,     3787,     3813
*ELSET, ELSET=BS000001, GENERATE
        1,      8032,        1
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       3070,  1,,       0.00000E+00
       3070,  5, 6,      0.00000E+00
          7,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
       3070,    4,-1.4000E+06
*DLOAD,OP=NEW
BS000001,     P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*OUTPUT, HISTORY,FREQUENCY=1
*MONITOR, NODE=3070, DOF=4
*END STEP
```

branch_npn2_new.inp with Plastic Material Properties

```
**%   ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\pilot_nonstandard.mf1
**%          INPUT FILE: C:\pcs\pcs2\nonstandard_runs\branch_npn2_new.inp
**%            EXPORTED: AT 16:24:30 ON 05-Mar-08
**%                PART: pilot_elbow_branch
**%                 FEM: pilot_ns1
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  05-Mar-08   16:24:30
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*ELEMENT, TYPE=S4      , ELSET=THK_562
*ELEMENT, TYPE=S4      , ELSET=THK_50
*MPC
*MPC
*MPC
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  2.50000E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
** 2.80000E+07,  2.90000E-01*DENSITY
 *DENSITY
7.25200E-04,
** 7.51120E-04,
*PLASTIC
```

```
 28400.0, 0.0
 97900.0, 0.276
*SHELL SECTION,
 ELSET=THK_562 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.62000E-01,
*SHELL SECTION,
 ELSET=THK_50,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.00000E-01,
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
 THK_562 ,
 THK_50,
**%
*NSET,NSET=BRANCH_NODES
*ELSET,ELSET=ALLELE, GENERATE
*ELSET,ELSET=P14, GENERATE
*ELSET,ELSET=REIN_PLT, GENERATE
*ELSET,ELSET=EL_TRAN, GENERATE
*ELSET,ELSET=ELBOW_HOLE, GENERATE
*ELSET,ELSET=P36, GENERATE
*ELSET,ELSET=LFACE_P36, GENERATE
*ELSET,ELSET=TFACE_P36, GENERATE
*ELSET,ELSET=RFACE_P14, GENERATE
*ELSET,ELSET=TOP_P36, GENERATE
*ELSET,ELSET=LEFT_P36, GENERATE
*ELSET,ELSET=ELBOW, GENERATE
*ELSET,ELSET=ALLSHELL, GENERATE
*ELSET, ELSET=BS000001, GENERATE
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.5
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       6830,  1, 6,      0.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S, PEEQ
*END STEP
**
**
**% ====== STEP NUMBER   2 ======
```

```
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       6830,  1, 6,      0.00000E+00
**%  LOAD SET 2
*CLOAD,OP=NEW
     40005,    4, -3.5460E+05
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S, PEEQ
*END STEP
**%
**%
**% ====== STEP NUMBER   3 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       6830,  1, 6,      0.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S, PEEQ
*END STEP
**%
**%
**% ====== STEP NUMBER   4 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      23321,  1,,       0.00000E+00
      23321,  5, 6,      0.00000E+00
       6830,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
      23321,    4,-1.4000E+06
*DLOAD,OP=NEW
```

```
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S, PEEQ
*END STEP
```

p_branch_si_bxA.inp

```
**%   ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\pilot_nonstandard.mf1
**%          INPUT FILE:
C:\pcs\pcs2\nonstandard_runs\final_runs\p_branch_si_bxA.inp
**%            EXPORTED: AT 14:13:07 ON 26-Mar-08
**%                PART: pilot_elbow_branch
**%                 FEM: p_branch_si
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Mar-08   14:13:07
**%============================================
**%          MODAL DATA
**%============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_562
*ELEMENT, TYPE=S4      , ELSET=THK_50
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
 BEAM,   5758,   6830
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  2.50000E-01,
*MATERIAL,NAME=SST304
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:** 09/30/08	**Checker:** A. S. Siahpush	**Date:**	09/30/08

```
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  2.90000E-01
*DENSITY
 7.51120E-04,
***PLASTIC
** 28600.0,
*SHELL SECTION,
 ELSET=THK_562 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.62000E-01,
*SHELL SECTION,
 ELSET=THK_50,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.00000E-01,
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
 THK_562 ,
 THK_50,
**%
*NSET,NSET=RING1NDS, GENERATE
     23701,    23717,         1
     23724,    23829,         7
     23901,    24006,         7
     24200,    24214,         1
*ELSET,ELSET=P14, GENERATE
     31687,    34246,         1
*ELSET,ELSET=REIN_PLT, GENERATE
     34887,    35270,         1
*ELSET,ELSET=EL_TRAN, GENERATE
     19615,    19806,         1
     19843,    19938,         1
     20011,    20106,         1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
     19543,    19614,         1
     25135,    27110,         1
*ELSET,ELSET=P36, GENERATE
     27111,    31686,         1
*ELSET,ELSET=LFACE_P36, GENERATE
      6117,     6508,         1
     23175,    23366,         1
*ELSET,ELSET=TFACE_P36, GENERATE
     19375,    19542,         1
     24719,    25134,         1
*ELSET,ELSET=RFACE_P14, GENERATE
     34247,    34886,         1
*ELSET,ELSET=TOP_P36, GENERATE
     29399,    31686,         1
*ELSET,ELSET=LEFT_P36, GENERATE
     27111,    29398,         1
*ELSET,ELSET=ELBOW, GENERATE
     19543,    19806,         1
```

```
     19843,    19938,          1
     20011,    20106,          1
     25135,    27110,          1
*ELSET,ELSET=ELBOW_HOLE_1/2, GENERATE
     19543,    19614,          1
     25207,    25278,          1
     26231,    27110,          1
*ELSET,ELSET=ELBOW_HOLE_B1/2, GENERATE
     25135,    25206,          1
     25279,    26230,          1
*ELSET,ELSET=ALLSHELL, GENERATE
      6117,     6508,          1
     19375,    19806,          1
     19843,    19938,          1
     20011,    20106,          1
     23175,    23366,          1
     24719,    35270,          1
*ELSET,ELSET=NO_REINF, GENERATE
      6117,     6508,          1
     19375,    19806,          1
     19843,    19938,          1
     20011,    20106,          1
     23175,    23366,          1
     24719,    34886,          1
*ELSET,ELSET=RING1, GENERATE
     31726,    32326,         40
     32951,    32966,          1
     33006,    33606,         40
     33607,    34207,         40
*ELSET, ELSET=BS000001, GENERATE
      6117,     6508,          1
     19375,    19806,          1
     19843,    19938,          1
     20011,    20106,          1
     23175,    23366,          1
     24719,    34886,          1
*BOUNDARY,OP=NEW
       6830,  1, 6,      0.00000E+00
      23321,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1BX
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,     P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
```

```
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1BX
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE + BX
*CLOAD,OP=NEW
      40005,    4, 1.47417E+04
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

p_branch_si_bxO.inp

```
**%   ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\pilot_nonstandard.mf1
**%          INPUT FILE:
C:\pcs\pcs2\nonstandard_runs\final_runs\p_branch_si_bxO.inp
**%            EXPORTED: AT 14:13:07 ON 26-Mar-08
**%                PART: pilot_elbow_branch
**%                 FEM: p_branch_si
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Mar-08   14:13:07
**%========================================
**%          MODAL DATA
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
**%============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4       , ELSET=THK_562
*ELEMENT, TYPE=S4       , ELSET=THK_50
*ELEMENT, TYPE=S4       , ELSET=THK_25
*MPC
 BEAM,   5758,   6830
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  2.50000E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  2.90000E-01
*DENSITY
 7.51120E-04,
***PLASTIC
** 28600.0,
*SHELL SECTION,
 ELSET=THK_562 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.62000E-01,
*SHELL SECTION,
 ELSET=THK_50,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.00000E-01,
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
 THK_562 ,
 THK_50,
**%
*NSET,NSET=RING1NDS, GENERATE
     23701,    23717,         1
     23724,    23829,         7
     23901,    24006,         7
     24200,    24214,         1
*ELSET,ELSET=P14, GENERATE
     31687,    34246,         1
*ELSET,ELSET=REIN_PLT, GENERATE
     34887,    35270,         1
*ELSET,ELSET=EL_TRAN, GENERATE
     19615,    19806,         1
     19843,    19938,         1
     20011,    20106,         1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
     19543,    19614,         1
     25135,    27110,         1
*ELSET,ELSET=P36, GENERATE
     27111,    31686,         1
*ELSET,ELSET=LFACE_P36, GENERATE
```

```
      6117,      6508,         1
     23175,     23366,         1
*ELSET,ELSET=TFACE_P36, GENERATE
     19375,     19542,         1
     24719,     25134,         1
*ELSET,ELSET=RFACE_P14, GENERATE
     34247,     34886,         1
*ELSET,ELSET=TOP_P36, GENERATE
     29399,     31686,         1
*ELSET,ELSET=LEFT_P36, GENERATE
     27111,     29398,         1
*ELSET,ELSET=ELBOW, GENERATE
     19543,     19806,         1
     19843,     19938,         1
     20011,     20106,         1
     25135,     27110,         1
*ELSET,ELSET=ELBOW_HOLE_1/2, GENERATE
     19543,     19614,         1
     25207,     25278,         1
     26231,     27110,         1
*ELSET,ELSET=ELBOW_HOLE_B1/2, GENERATE
     25135,     25206,         1
     25279,     26230,         1
*ELSET,ELSET=ALLSHELL, GENERATE
      6117,      6508,         1
     19375,     19806,         1
     19843,     19938,         1
     20011,     20106,         1
     23175,     23366,         1
     24719,     35270,         1
*ELSET,ELSET=NO_REINF, GENERATE
      6117,      6508,         1
     19375,     19806,         1
     19843,     19938,         1
     20011,     20106,         1
     23175,     23366,         1
     24719,     34886,         1
*ELSET,ELSET=RING1, GENERATE
     31726,     32326,        40
     32951,     32966,         1
     33006,     33606,        40
     33607,     34207,        40
*ELSET, ELSET=BS000001, GENERATE
      6117,      6508,         1
     19375,     19806,         1
     19843,     19938,         1
     20011,     20106,         1
     23175,     23366,         1
     24719,     34886,         1
*BOUNDARY,OP=NEW
       6830,  1, 6,      0.00000E+00
      23321,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
```

```
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1BX
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1BX
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE + BX
*CLOAD,OP=NEW
      40005,    4,-1.47417E+04
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

p_branch_si_byA.inp

```
**%   ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\pilot_nonstandard.mf1
**%          INPUT FILE:
C:\pcs\pcs2\nonstandard_runs\final_runs\p_branch_si_byA.inp
**%            EXPORTED: AT 14:13:07 ON 26-Mar-08
**%                PART: pilot_elbow_branch
**%                 FEM: p_branch_si
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
```

```
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Mar-08   14:13:07
**%======================================
**%          MODAL DATA
**%======================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4       , ELSET=THK_562
*ELEMENT, TYPE=S4       , ELSET=THK_50
*ELEMENT, TYPE=S4       , ELSET=THK_25
*MPC
 BEAM,   5758,   6830
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  2.50000E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  2.90000E-01
*DENSITY
 7.51120E-04,
***PLASTIC
** 28600.0,
*SHELL SECTION,
 ELSET=THK_562 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.62000E-01,
*SHELL SECTION,
 ELSET=THK_50,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.00000E-01,
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
 THK_562 ,
 THK_50,
**%
*NSET,NSET=RING1NDS, GENERATE
     23701,    23717,         1
     23724,    23829,         7
     23901,    24006,         7
     24200,    24214,         1
*ELSET,ELSET=P14, GENERATE
```

```
    31687,     34246,          1
*ELSET,ELSET=REIN_PLT, GENERATE
    34887,     35270,          1
*ELSET,ELSET=EL_TRAN, GENERATE
    19615,     19806,          1
    19843,     19938,          1
    20011,     20106,          1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
    19543,     19614,          1
    25135,     27110,          1
*ELSET,ELSET=P36, GENERATE
    27111,     31686,          1
*ELSET,ELSET=LFACE_P36, GENERATE
     6117,      6508,          1
    23175,     23366,          1
*ELSET,ELSET=TFACE_P36, GENERATE
    19375,     19542,          1
    24719,     25134,          1
*ELSET,ELSET=RFACE_P14, GENERATE
    34247,     34886,          1
*ELSET,ELSET=TOP_P36, GENERATE
    29399,     31686,          1
*ELSET,ELSET=LEFT_P36, GENERATE
    27111,     29398,          1
*ELSET,ELSET=ELBOW, GENERATE
    19543,     19806,          1
    19843,     19938,          1
    20011,     20106,          1
    25135,     27110,          1
*ELSET,ELSET=ELBOW_HOLE_1/2, GENERATE
    19543,     19614,          1
    25207,     25278,          1
    26231,     27110,          1
*ELSET,ELSET=ELBOW_HOLE_B1/2, GENERATE
    25135,     25206,          1
    25279,     26230,          1
*ELSET,ELSET=ALLSHELL, GENERATE
     6117,      6508,          1
    19375,     19806,          1
    19843,     19938,          1
    20011,     20106,          1
    23175,     23366,          1
    24719,     35270,          1
*ELSET,ELSET=NO_REINF, GENERATE
     6117,      6508,          1
    19375,     19806,          1
    19843,     19938,          1
    20011,     20106,          1
    23175,     23366,          1
    24719,     34886,          1
*ELSET,ELSET=RING1, GENERATE
    31726,     32326,         40
    32951,     32966,          1
    33006,     33606,         40
```

```
    33607,    34207,       40
*ELSET, ELSET=BS000001, GENERATE
     6117,     6508,        1
    19375,    19806,        1
    19843,    19938,        1
    20011,    20106,        1
    23175,    23366,        1
    24719,    34886,        1
*BOUNDARY,OP=NEW
      6830,  1, 6,      0.00000E+00
     23321,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 2BY
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 2BY
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE + BY
*CLOAD,OP=NEW
     40005,    5, 5.33164E+05
*DLOAD,OP=NEW
BS000001,    P, 4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

p_branch_si_by0.inp

```
**%   ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\pilot_nonstandard.mf1
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
**%          INPUT FILE:
C:\pcs\pcs2\nonstandard_runs\final_runs\p_branch_si_by0.inp
**%             EXPORTED: AT 14:13:07 ON 26-Mar-08
**%                 PART: pilot_elbow_branch
**%                  FEM: p_branch_si
**%
**%                UNITS: IN-Inch (pound f)
**%                      ... LENGTH : inch
**%                      ... TIME   : sec
**%                      ... MASS   : lbf-sec**2/in
**%                      ... FORCE  : pound (lbf)
**%                      ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Mar-08   14:13:07
**%============================================
**%          MODAL DATA
**%============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_562
*ELEMENT, TYPE=S4      , ELSET=THK_50
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
 BEAM,   5758,   6830
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  2.50000E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  2.90000E-01
*DENSITY
 7.51120E-04,
***PLASTIC
** 28600.0,
*SHELL SECTION,
 ELSET=THK_562 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.62000E-01,
*SHELL SECTION,
 ELSET=THK_50,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
```

```
 5.00000E-01,
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
 THK_562 ,
 THK_50,
**%
*NSET,NSET=RING1NDS, GENERATE
     23701,    23717,         1
     23724,    23829,         7
     23901,    24006,         7
     24200,    24214,         1
*ELSET,ELSET=P14, GENERATE
     31687,    34246,         1
*ELSET,ELSET=REIN_PLT, GENERATE
     34887,    35270,         1
*ELSET,ELSET=EL_TRAN, GENERATE
     19615,    19806,         1
     19843,    19938,         1
     20011,    20106,         1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
     19543,    19614,         1
     25135,    27110,         1
*ELSET,ELSET=P36, GENERATE
     27111,    31686,         1
*ELSET,ELSET=LFACE_P36, GENERATE
      6117,     6508,         1
     23175,    23366,         1
*ELSET,ELSET=TFACE_P36, GENERATE
     19375,    19542,         1
     24719,    25134,         1
*ELSET,ELSET=RFACE_P14, GENERATE
     34247,    34886,         1
*ELSET,ELSET=TOP_P36, GENERATE
     29399,    31686,         1
*ELSET,ELSET=LEFT_P36, GENERATE
     27111,    29398,         1
*ELSET,ELSET=ELBOW, GENERATE
     19543,    19806,         1
     19843,    19938,         1
     20011,    20106,         1
     25135,    27110,         1
*ELSET,ELSET=ELBOW_HOLE_1/2, GENERATE
     19543,    19614,         1
     25207,    25278,         1
     26231,    27110,         1
*ELSET,ELSET=ELBOW_HOLE_B1/2, GENERATE
     25135,    25206,         1
     25279,    26230,         1
*ELSET,ELSET=ALLSHELL, GENERATE
      6117,     6508,         1
     19375,    19806,         1
     19843,    19938,         1
     20011,    20106,         1
```

```
     23175,     23366,         1
     24719,     35270,         1
*ELSET,ELSET=NO_REINF, GENERATE
      6117,      6508,         1
     19375,     19806,         1
     19843,     19938,         1
     20011,     20106,         1
     23175,     23366,         1
     24719,     34886,         1
*ELSET,ELSET=RING1, GENERATE
     31726,     32326,        40
     32951,     32966,         1
     33006,     33606,        40
     33607,     34207,        40
*ELSET, ELSET=BS000001, GENERATE
      6117,      6508,         1
     19375,     19806,         1
     19843,     19938,         1
     20011,     20106,         1
     23175,     23366,         1
     24719,     34886,         1
*BOUNDARY,OP=NEW
       6830,  1, 6,      0.00000E+00
      23321,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 2BY
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 2BY
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE + BY
*CLOAD,OP=NEW
      40005,    5,-5.33164E+05
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
```

```
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

p_branch_si_bzA.inp

```
**%   ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\pilot_nonstandard.mfl
**%          INPUT FILE:
C:\pcs\pcs2\nonstandard_runs\final_runs\p_branch_si_bzA.inp
**%            EXPORTED: AT 14:13:07 ON 26-Mar-08
**%                PART: pilot_elbow_branch
**%                 FEM: p_branch_si
**%
**%              UNITS: IN-Inch (pound f)
**%                    ... LENGTH : inch
**%                    ... TIME   : sec
**%                    ... MASS   : lbf-sec**2/in
**%                    ... FORCE  : pound (lbf)
**%                    ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Mar-08   14:13:07
**%===========================================
**%          MODAL DATA
**%===========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_562
*ELEMENT, TYPE=S4      , ELSET=THK_50
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
 BEAM,   5758,   6830
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  2.50000E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  2.90000E-01
*DENSITY
```

```
 7.51120E-04,
***PLASTIC
** 28600.0,
*SHELL SECTION,
 ELSET=THK_562 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.62000E-01,
*SHELL SECTION,
 ELSET=THK_50,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.00000E-01,
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
 THK_562 ,
 THK_50,
**%
*NSET,NSET=RING1NDS, GENERATE
     23701,    23717,         1
     23724,    23829,         7
     23901,    24006,         7
     24200,    24214,         1
*ELSET,ELSET=P14, GENERATE
     31687,    34246,         1
*ELSET,ELSET=REIN_PLT, GENERATE
     34887,    35270,         1
*ELSET,ELSET=EL_TRAN, GENERATE
     19615,    19806,         1
     19843,    19938,         1
     20011,    20106,         1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
     19543,    19614,         1
     25135,    27110,         1
*ELSET,ELSET=P36, GENERATE
     27111,    31686,         1
*ELSET,ELSET=LFACE_P36, GENERATE
      6117,     6508,         1
     23175,    23366,         1
*ELSET,ELSET=TFACE_P36, GENERATE
     19375,    19542,         1
     24719,    25134,         1
*ELSET,ELSET=RFACE_P14, GENERATE
     34247,    34886,         1
*ELSET,ELSET=TOP_P36, GENERATE
     29399,    31686,         1
*ELSET,ELSET=LEFT_P36, GENERATE
     27111,    29398,         1
*ELSET,ELSET=ELBOW, GENERATE
     19543,    19806,         1
     19843,    19938,         1
     20011,    20106,         1
     25135,    27110,         1
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
*ELSET,ELSET=ELBOW_HOLE_1/2, GENERATE
     19543,     19614,          1
     25207,     25278,          1
     26231,     27110,          1
*ELSET,ELSET=ELBOW_HOLE_B1/2, GENERATE
     25135,     25206,          1
     25279,     26230,          1
*ELSET,ELSET=ALLSHELL, GENERATE
      6117,      6508,          1
     19375,     19806,          1
     19843,     19938,          1
     20011,     20106,          1
     23175,     23366,          1
     24719,     35270,          1
*ELSET,ELSET=NO_REINF, GENERATE
      6117,      6508,          1
     19375,     19806,          1
     19843,     19938,          1
     20011,     20106,          1
     23175,     23366,          1
     24719,     34886,          1
*ELSET,ELSET=RING1, GENERATE
     31726,     32326,         40
     32951,     32966,          1
     33006,     33606,         40
     33607,     34207,         40
*ELSET, ELSET=BS000001, GENERATE
      6117,      6508,          1
     19375,     19806,          1
     19843,     19938,          1
     20011,     20106,          1
     23175,     23366,          1
     24719,     34886,          1
*BOUNDARY,OP=NEW
       6830,  1, 6,       0.00000E+00
      23321,  1, 6,       0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 3BZ
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,     P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**% ====== STEP NUMBER   2 ======
**%
```

Project:	ATR Life Time Extension Project	ECAR No.:	ECAR-194	Rev.:	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	Date: 09/30/08	Checker: A. S. Siahpush	Date:	09/30/08

```
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 3BZ
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE + BZ
*CLOAD,OP=NEW
      40005,    6, 1.48736E+05
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark **Date:** 09/30/08	**Checker:**	A. S. Siahpush	**Date:**	09/30/08

p_branch_si_bzO.inp

```
**%   ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\pilot_nonstandard.mf1
**%          INPUT FILE:
C:\pcs\pcs2\nonstandard_runs\final_runs\p_branch_si_bz0.inp
**%            EXPORTED: AT 14:13:07 ON 26-Mar-08
**%                PART: pilot_elbow_branch
**%                 FEM: p_branch_si
**%
**%              UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Mar-08   14:13:07
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_562
*ELEMENT, TYPE=S4      , ELSET=THK_50
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
 BEAM,   5758,   6830
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  2.50000E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  2.90000E-01
*DENSITY
 7.51120E-04,
***PLASTIC
** 28600.0,
*SHELL SECTION,
 ELSET=THK_562 ,
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark **Date:** 09/30/08	**Checker:**	A. S. Siahpush	**Date:**	09/30/08

```
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.62000E-01,
*SHELL SECTION,
 ELSET=THK_50,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.00000E-01,
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
 THK_562 ,
 THK_50,
**%
*NSET,NSET=RING1NDS, GENERATE
     23701,    23717,         1
     23724,    23829,         7
     23901,    24006,         7
     24200,    24214,         1
*ELSET,ELSET=P14, GENERATE
     31687,    34246,         1
*ELSET,ELSET=REIN_PLT, GENERATE
     34887,    35270,         1
*ELSET,ELSET=EL_TRAN, GENERATE
     19615,    19806,         1
     19843,    19938,         1
     20011,    20106,         1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
     19543,    19614,         1
     25135,    27110,         1
*ELSET,ELSET=P36, GENERATE
     27111,    31686,         1
*ELSET,ELSET=LFACE_P36, GENERATE
      6117,     6508,         1
     23175,    23366,         1
*ELSET,ELSET=TFACE_P36, GENERATE
     19375,    19542,         1
     24719,    25134,         1
*ELSET,ELSET=RFACE_P14, GENERATE
     34247,    34886,         1
*ELSET,ELSET=TOP_P36, GENERATE
     29399,    31686,         1
*ELSET,ELSET=LEFT_P36, GENERATE
     27111,    29398,         1
*ELSET,ELSET=ELBOW, GENERATE
     19543,    19806,         1
     19843,    19938,         1
     20011,    20106,         1
     25135,    27110,         1
*ELSET,ELSET=ELBOW_HOLE_1/2, GENERATE
     19543,    19614,         1
     25207,    25278,         1
     26231,    27110,         1
*ELSET,ELSET=ELBOW_HOLE_B1/2, GENERATE
```

```
     25135,    25206,         1
     25279,    26230,         1
*ELSET,ELSET=ALLSHELL, GENERATE
      6117,     6508,         1
     19375,    19806,         1
     19843,    19938,         1
     20011,    20106,         1
     23175,    23366,         1
     24719,    35270,         1
*ELSET,ELSET=NO_REINF, GENERATE
      6117,     6508,         1
     19375,    19806,         1
     19843,    19938,         1
     20011,    20106,         1
     23175,    23366,         1
     24719,    34886,         1
*ELSET,ELSET=RING1, GENERATE
     31726,    32326,        40
     32951,    32966,         1
     33006,    33606,        40
     33607,    34207,        40
*ELSET, ELSET=BS000001, GENERATE
      6117,     6508,         1
     19375,    19806,         1
     19843,    19938,         1
     20011,    20106,         1
     23175,    23366,         1
     24719,    34886,         1
*BOUNDARY,OP=NEW
       6830,  1, 6,      0.00000E+00
      23321,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 3BZ
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 3BZ
```

```
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE + BZ
*CLOAD,OP=NEW
     40005,     6, -1.48736E+05
*DLOAD,OP=NEW
BS000001,     P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

p_vertrun_si_rxA.inp

```
**%   ============================================================
**%
**%             I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                    FOR ABAQUS VERSION 6.x
**%
**%         MODEL FILE: C:\DOCUME~1\dtclark\pilot_nonstandard.mf1
**%         INPUT FILE:
C:\pcs\pcs2\nonstandard_runs\final_runs\p_vertrun_si_rxA.inp
**%           EXPORTED: AT 14:33:08 ON 26-Mar-08
**%               PART: pilot_elbow_branch
**%                FEM: p_vertrun_si
**%
**%              UNITS: IN-Inch (pound f)
**%                    ... LENGTH : inch
**%                    ... TIME   : sec
**%                    ... MASS   : lbf-sec**2/in
**%                    ... FORCE  : pound (lbf)
**%                    ... TEMPERATURE : deg Fahrenheit
**%
**%        COORDINATE SYSTEM: PART
**%
**%            SUBSET EXPORT: OFF
**%
**%      NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Mar-08   14:33:08
**%===========================================
**%         MODAL DATA
**%===========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_562
*ELEMENT, TYPE=S4      , ELSET=THK_50
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
 BEAM,   5758,   6830
*SHELL SECTION,
```

```
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  2.50000E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  2.90000E-01
*DENSITY
 7.51120E-04,
***PLASTIC
** 28600.0,
*SHELL SECTION,
 ELSET=THK_562 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.62000E-01,
*SHELL SECTION,
 ELSET=THK_50,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.00000E-01,
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
 THK_562 ,
 THK_50,
**%
*NSET,NSET=RING1NDS, GENERATE
     23701,    23717,        1
     23724,    23829,        7
     23901,    24006,        7
     24200,    24214,        1
*ELSET,ELSET=P14, GENERATE
     31687,    34246,        1
*ELSET,ELSET=REIN_PLT, GENERATE
     34887,    35270,        1
*ELSET,ELSET=EL_TRAN, GENERATE
     19615,    19806,        1
     19843,    19938,        1
     20011,    20106,        1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
     19543,    19614,        1
     25135,    27110,        1
*ELSET,ELSET=P36, GENERATE
     27111,    31686,        1
*ELSET,ELSET=LFACE_P36, GENERATE
      6117,     6508,        1
     23175,    23366,        1
*ELSET,ELSET=TFACE_P36, GENERATE
     19375,    19542,        1
     24719,    25134,        1
*ELSET,ELSET=RFACE_P14, GENERATE
     34247,    34886,        1
*ELSET,ELSET=TOP_P36, GENERATE
```

```
    29399,     31686,          1
*ELSET,ELSET=LEFT_P36, GENERATE
    27111,     29398,          1
*ELSET,ELSET=ELBOW, GENERATE
    19543,     19806,          1
    19843,     19938,          1
    20011,     20106,          1
    25135,     27110,          1
*ELSET,ELSET=ELBOW_HOLE_1/2, GENERATE
    19543,     19614,          1
    25207,     25278,          1
    26231,     27110,          1
*ELSET,ELSET=ELBOW_HOLE_B1/2, GENERATE
    25135,     25206,          1
    25279,     26230,          1
*ELSET,ELSET=ALLSHELL, GENERATE
     6117,      6508,          1
    19375,     19806,          1
    19843,     19938,          1
    20011,     20106,          1
    23175,     23366,          1
    24719,     35270,          1
*ELSET,ELSET=NO_REINF, GENERATE
     6117,      6508,          1
    19375,     19806,          1
    19843,     19938,          1
    20011,     20106,          1
    23175,     23366,          1
    24719,     34886,          1
*ELSET,ELSET=RING1, GENERATE
    31726,     32326,         40
    32951,     32966,          1
    33006,     33606,         40
    33607,     34207,         40
*ELSET, ELSET=BS000001, GENERATE
     6117,      6508,          1
    19375,     19806,          1
    19843,     19938,          1
    20011,     20106,          1
    23175,     23366,          1
    24719,     34886,          1
*BOUNDARY,OP=NEW
      6830,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1RX
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
```

```
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1RX
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + RX
*CLOAD,OP=NEW
     23321,     4, 1.5479E+06
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

p_vertrun_si_rxO.inp

```
**%   ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\pilot_nonstandard.mf1
**%          INPUT FILE:
C:\pcs\pcs2\nonstandard_runs\final_runs\p_vertrun_si_rxO.inp
**%            EXPORTED: AT 14:33:08 ON 26-Mar-08
**%                PART: pilot_elbow_branch
**%                 FEM: p_vertrun_si
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:**	09/30/08	**Checker:**	A. S. Siahpush	**Date:**	09/30/08

```
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Mar-08   14:33:08
**%========================================
**%          MODAL DATA
**%========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_562
*ELEMENT, TYPE=S4      , ELSET=THK_50
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
 BEAM,   5758,   6830
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  2.50000E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  2.90000E-01
*DENSITY
 7.51120E-04,
***PLASTIC
** 28600.0,
*SHELL SECTION,
 ELSET=THK_562 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.62000E-01,
*SHELL SECTION,
 ELSET=THK_50,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.00000E-01,
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
 THK_562 ,
 THK_50,
**%
*NSET,NSET=RING1NDS, GENERATE
     23701,    23717,         1
     23724,    23829,         7
     23901,    24006,         7
     24200,    24214,         1
*ELSET,ELSET=P14, GENERATE
     31687,    34246,         1
*ELSET,ELSET=REIN_PLT, GENERATE
     34887,    35270,         1
*ELSET,ELSET=EL_TRAN, GENERATE
     19615,    19806,         1
     19843,    19938,         1
     20011,    20106,         1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
     19543,    19614,         1
```

```
    25135,    27110,         1
*ELSET,ELSET=P36, GENERATE
    27111,    31686,         1
*ELSET,ELSET=LFACE_P36, GENERATE
     6117,     6508,         1
    23175,    23366,         1
*ELSET,ELSET=TFACE_P36, GENERATE
    19375,    19542,         1
    24719,    25134,         1
*ELSET,ELSET=RFACE_P14, GENERATE
    34247,    34886,         1
*ELSET,ELSET=TOP_P36, GENERATE
    29399,    31686,         1
*ELSET,ELSET=LEFT_P36, GENERATE
    27111,    29398,         1
*ELSET,ELSET=ELBOW, GENERATE
    19543,    19806,         1
    19843,    19938,         1
    20011,    20106,         1
    25135,    27110,         1
*ELSET,ELSET=ELBOW_HOLE_1/2, GENERATE
    19543,    19614,         1
    25207,    25278,         1
    26231,    27110,         1
*ELSET,ELSET=ELBOW_HOLE_B1/2, GENERATE
    25135,    25206,         1
    25279,    26230,         1
*ELSET,ELSET=ALLSHELL, GENERATE
     6117,     6508,         1
    19375,    19806,         1
    19843,    19938,         1
    20011,    20106,         1
    23175,    23366,         1
    24719,    35270,         1
*ELSET,ELSET=NO_REINF, GENERATE
     6117,     6508,         1
    19375,    19806,         1
    19843,    19938,         1
    20011,    20106,         1
    23175,    23366,         1
    24719,    34886,         1
*ELSET,ELSET=RING1, GENERATE
    31726,    32326,        40
    32951,    32966,         1
    33006,    33606,        40
    33607,    34207,        40
*ELSET, ELSET=BS000001, GENERATE
     6117,     6508,         1
    19375,    19806,         1
    19843,    19938,         1
    20011,    20106,         1
    23175,    23366,         1
    24719,    34886,         1
*BOUNDARY,OP=NEW
```

```
      6830,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1RX
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1RX
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + RX
*CLOAD,OP=NEW
      23321,    4, -1.5479E+06
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

p_vertrun_si_ryA.inp

```
**%   ============================================================
**%
**%               I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                      FOR ABAQUS VERSION 6.x
**%
**%           MODEL FILE: C:\DOCUME~1\dtclark\pilot_nonstandard.mf1
**%           INPUT FILE:
C:\pcs\pcs2\nonstandard_runs\final_runs\p_vertrun_si_ryA.inp
**%             EXPORTED: AT 14:33:08 ON 26-Mar-08
**%                 PART: pilot_elbow_branch
**%                  FEM: p_vertrun_si
**%
**%                UNITS: IN-Inch (pound f)
**%                      ... LENGTH : inch
**%                      ... TIME   : sec
**%                      ... MASS   : lbf-sec**2/in
**%                      ... FORCE  : pound (lbf)
```

```
**%                        ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Mar-08   14:33:08
**%============================================
**%          MODAL DATA
**%============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_562
*ELEMENT, TYPE=S4      , ELSET=THK_50
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
 BEAM,   5758,   6830
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  2.50000E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  2.90000E-01
*DENSITY
 7.51120E-04,
***PLASTIC
** 28600.0,
*SHELL SECTION,
 ELSET=THK_562 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.62000E-01,
*SHELL SECTION,
 ELSET=THK_50,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.00000E-01,
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
 THK_562 ,
 THK_50,
**%
*NSET,NSET=RING1NDS, GENERATE
     23701,    23717,        1
     23724,    23829,        7
     23901,    24006,        7
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark **Date:** 09/30/08	**Checker:**	A. S. Siahpush	**Date:**	09/30/08

```
    24200,     24214,         1
*ELSET,ELSET=P14, GENERATE
    31687,     34246,         1
*ELSET,ELSET=REIN_PLT, GENERATE
    34887,     35270,         1
*ELSET,ELSET=EL_TRAN, GENERATE
    19615,     19806,         1
    19843,     19938,         1
    20011,     20106,         1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
    19543,     19614,         1
    25135,     27110,         1
*ELSET,ELSET=P36, GENERATE
    27111,     31686,         1
*ELSET,ELSET=LFACE_P36, GENERATE
     6117,      6508,         1
    23175,     23366,         1
*ELSET,ELSET=TFACE_P36, GENERATE
    19375,     19542,         1
    24719,     25134,         1
*ELSET,ELSET=RFACE_P14, GENERATE
    34247,     34886,         1
*ELSET,ELSET=TOP_P36, GENERATE
    29399,     31686,         1
*ELSET,ELSET=LEFT_P36, GENERATE
    27111,     29398,         1
*ELSET,ELSET=ELBOW, GENERATE
    19543,     19806,         1
    19843,     19938,         1
    20011,     20106,         1
    25135,     27110,         1
*ELSET,ELSET=ELBOW_HOLE_1/2, GENERATE
    19543,     19614,         1
    25207,     25278,         1
    26231,     27110,         1
*ELSET,ELSET=ELBOW_HOLE_B1/2, GENERATE
    25135,     25206,         1
    25279,     26230,         1
*ELSET,ELSET=ALLSHELL, GENERATE
     6117,      6508,         1
    19375,     19806,         1
    19843,     19938,         1
    20011,     20106,         1
    23175,     23366,         1
    24719,     35270,         1
*ELSET,ELSET=NO_REINF, GENERATE
     6117,      6508,         1
    19375,     19806,         1
    19843,     19938,         1
    20011,     20106,         1
    23175,     23366,         1
    24719,     34886,         1
*ELSET,ELSET=RING1, GENERATE
    31726,     32326,        40
```

```
    32951,    32966,        1
    33006,    33606,       40
    33607,    34207,       40
*ELSET, ELSET=BS000001, GENERATE
     6117,     6508,        1
    19375,    19806,        1
    19843,    19938,        1
    20011,    20106,        1
    23175,    23366,        1
    24719,    34886,        1
*BOUNDARY,OP=NEW
      6830,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 2RY
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 2RY
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + RY
*CLOAD,OP=NEW
     23321,     5, 5.81897E+05
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

p_vertrun_si_ryO.inp

```
**%   ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\pilot_nonstandard.mf1
**%          INPUT FILE:
C:\pcs\pcs2\nonstandard_runs\final_runs\p_vertrun_si_ryO.inp
**%            EXPORTED: AT 14:33:08 ON 26-Mar-08
**%                PART: pilot_elbow_branch
**%                 FEM: p_vertrun_si
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%              SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Mar-08   14:33:08
**%=============================================
**%          MODAL DATA
**%=============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4       , ELSET=THK_562
*ELEMENT, TYPE=S4       , ELSET=THK_50
*ELEMENT, TYPE=S4       , ELSET=THK_25
*MPC
 BEAM,   5758,   6830
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  2.50000E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  2.90000E-01
*DENSITY
 7.51120E-04,
***PLASTIC
** 28600.0,
*SHELL SECTION,
 ELSET=THK_562 ,
```

```
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.62000E-01,
*SHELL SECTION,
 ELSET=THK_50,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.00000E-01,
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
 THK_562 ,
 THK_50,
**%
*NSET,NSET=RING1NDS, GENERATE
     23701,    23717,        1
     23724,    23829,        7
     23901,    24006,        7
     24200,    24214,        1
*ELSET,ELSET=P14, GENERATE
     31687,    34246,        1
*ELSET,ELSET=REIN_PLT, GENERATE
     34887,    35270,        1
*ELSET,ELSET=EL_TRAN, GENERATE
     19615,    19806,        1
     19843,    19938,        1
     20011,    20106,        1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
     19543,    19614,        1
     25135,    27110,        1
*ELSET,ELSET=P36, GENERATE
     27111,    31686,        1
*ELSET,ELSET=LFACE_P36, GENERATE
      6117,     6508,        1
     23175,    23366,        1
*ELSET,ELSET=TFACE_P36, GENERATE
     19375,    19542,        1
     24719,    25134,        1
*ELSET,ELSET=RFACE_P14, GENERATE
     34247,    34886,        1
*ELSET,ELSET=TOP_P36, GENERATE
     29399,    31686,        1
*ELSET,ELSET=LEFT_P36, GENERATE
     27111,    29398,        1
*ELSET,ELSET=ELBOW, GENERATE
     19543,    19806,        1
     19843,    19938,        1
     20011,    20106,        1
     25135,    27110,        1
*ELSET,ELSET=ELBOW_HOLE_1/2, GENERATE
     19543,    19614,        1
     25207,    25278,        1
     26231,    27110,        1
*ELSET,ELSET=ELBOW_HOLE_B1/2, GENERATE
```

```
     25135,    25206,         1
     25279,    26230,         1
*ELSET,ELSET=ALLSHELL, GENERATE
      6117,     6508,         1
     19375,    19806,         1
     19843,    19938,         1
     20011,    20106,         1
     23175,    23366,         1
     24719,    35270,         1
*ELSET,ELSET=NO_REINF, GENERATE
      6117,     6508,         1
     19375,    19806,         1
     19843,    19938,         1
     20011,    20106,         1
     23175,    23366,         1
     24719,    34886,         1
*ELSET,ELSET=RING1, GENERATE
     31726,    32326,        40
     32951,    32966,         1
     33006,    33606,        40
     33607,    34207,        40
*ELSET, ELSET=BS000001, GENERATE
      6117,     6508,         1
     19375,    19806,         1
     19843,    19938,         1
     20011,    20106,         1
     23175,    23366,         1
     24719,    34886,         1
*BOUNDARY,OP=NEW
       6830,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 2RY
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 2RY
**%  RESTRAINT SET 1
```

```
**%  LOAD SET PRESSURE +RY
*CLOAD,OP=NEW
      23321,     5, -5.81897E+05
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

p_vertrun_si_rzA.inp

```
**%   ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\pilot_nonstandard.mf1
**%          INPUT FILE:
C:\pcs\pcs2\nonstandard_runs\final_runs\p_vertrun_si_rzA.inp
**%            EXPORTED: AT 14:33:08 ON 26-Mar-08
**%                PART: pilot_elbow_branch
**%                 FEM: p_vertrun_si
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Mar-08   14:33:08
**%============================================
**%          MODAL DATA
**%============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_562
*ELEMENT, TYPE=S4      , ELSET=THK_50
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
 BEAM,   5758,   6830
*SHELL SECTION,
 ELSET=THK_25,
```

```
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  2.50000E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  2.90000E-01
*DENSITY
 7.51120E-04,
***PLASTIC
** 28600.0,
*SHELL SECTION,
 ELSET=THK_562 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.62000E-01,
*SHELL SECTION,
 ELSET=THK_50,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.00000E-01,
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
 THK_562 ,
 THK_50,
**%
*NSET,NSET=RING1NDS, GENERATE
     23701,    23717,        1
     23724,    23829,        7
     23901,    24006,        7
     24200,    24214,        1
*ELSET,ELSET=P14, GENERATE
     31687,    34246,        1
*ELSET,ELSET=REIN_PLT, GENERATE
     34887,    35270,        1
*ELSET,ELSET=EL_TRAN, GENERATE
     19615,    19806,        1
     19843,    19938,        1
     20011,    20106,        1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
     19543,    19614,        1
     25135,    27110,        1
*ELSET,ELSET=P36, GENERATE
     27111,    31686,        1
*ELSET,ELSET=LFACE_P36, GENERATE
      6117,     6508,        1
     23175,    23366,        1
*ELSET,ELSET=TFACE_P36, GENERATE
     19375,    19542,        1
     24719,    25134,        1
*ELSET,ELSET=RFACE_P14, GENERATE
     34247,    34886,        1
*ELSET,ELSET=TOP_P36, GENERATE
     29399,    31686,        1
```

```
*ELSET,ELSET=LEFT_P36, GENERATE
    27111,    29398,         1
*ELSET,ELSET=ELBOW, GENERATE
    19543,    19806,         1
    19843,    19938,         1
    20011,    20106,         1
    25135,    27110,         1
*ELSET,ELSET=ELBOW_HOLE_1/2, GENERATE
    19543,    19614,         1
    25207,    25278,         1
    26231,    27110,         1
*ELSET,ELSET=ELBOW_HOLE_B1/2, GENERATE
    25135,    25206,         1
    25279,    26230,         1
*ELSET,ELSET=ALLSHELL, GENERATE
     6117,     6508,         1
    19375,    19806,         1
    19843,    19938,         1
    20011,    20106,         1
    23175,    23366,         1
    24719,    35270,         1
*ELSET,ELSET=NO_REINF, GENERATE
     6117,     6508,         1
    19375,    19806,         1
    19843,    19938,         1
    20011,    20106,         1
    23175,    23366,         1
    24719,    34886,         1
*ELSET,ELSET=RING1, GENERATE
    31726,    32326,        40
    32951,    32966,         1
    33006,    33606,        40
    33607,    34207,        40
*ELSET, ELSET=BS000001, GENERATE
     6117,     6508,         1
    19375,    19806,         1
    19843,    19938,         1
    20011,    20106,         1
    23175,    23366,         1
    24719,    34886,         1
*BOUNDARY,OP=NEW
      6830,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1RX
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,     P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
```

```
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1RX
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + RZ
*CLOAD,OP=NEW
     23321,    6, 1.35239E+05
*DLOAD,OP=NEW
BS000001,    P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

p_vertrun_si_rzO.inp

```
**%   ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\pilot_nonstandard.mf1
**%          INPUT FILE:
C:\pcs\pcs2\nonstandard_runs\final_runs\p_vertrun_si_rzO.inp
**%            EXPORTED: AT 14:33:08 ON 26-Mar-08
**%                PART: pilot_elbow_branch
**%                 FEM: p_vertrun_si
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Mar-08   14:33:08
```

Project:	ATR Life Time Extension Project	ECAR No.:	ECAR-194	Rev.:	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	Date: 09/30/08	Checker: A. S. Siahpush	Date:	09/30/08

```
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_562
*ELEMENT, TYPE=S4      , ELSET=THK_50
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
 BEAM,   5758,   6830
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  2.50000E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  2.90000E-01
*DENSITY
 7.51120E-04,
***PLASTIC
** 28600.0,
*SHELL SECTION,
 ELSET=THK_562 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.62000E-01,
*SHELL SECTION,
 ELSET=THK_50,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.00000E-01,
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
 THK_562 ,
 THK_50,
**%
*NSET,NSET=RING1NDS, GENERATE
     23701,    23717,        1
     23724,    23829,        7
     23901,    24006,        7
     24200,    24214,        1
*ELSET,ELSET=P14, GENERATE
     31687,    34246,        1
*ELSET,ELSET=REIN_PLT, GENERATE
     34887,    35270,        1
*ELSET,ELSET=EL_TRAN, GENERATE
     19615,    19806,        1
     19843,    19938,        1
     20011,    20106,        1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
     19543,    19614,        1
     25135,    27110,        1
*ELSET,ELSET=P36, GENERATE
```

```
    27111,    31686,        1
*ELSET,ELSET=LFACE_P36, GENERATE
     6117,     6508,        1
    23175,    23366,        1
*ELSET,ELSET=TFACE_P36, GENERATE
    19375,    19542,        1
    24719,    25134,        1
*ELSET,ELSET=RFACE_P14, GENERATE
    34247,    34886,        1
*ELSET,ELSET=TOP_P36, GENERATE
    29399,    31686,        1
*ELSET,ELSET=LEFT_P36, GENERATE
    27111,    29398,        1
*ELSET,ELSET=ELBOW, GENERATE
    19543,    19806,        1
    19843,    19938,        1
    20011,    20106,        1
    25135,    27110,        1
*ELSET,ELSET=ELBOW_HOLE_1/2, GENERATE
    19543,    19614,        1
    25207,    25278,        1
    26231,    27110,        1
*ELSET,ELSET=ELBOW_HOLE_B1/2, GENERATE
    25135,    25206,        1
    25279,    26230,        1
*ELSET,ELSET=ALLSHELL, GENERATE
     6117,     6508,        1
    19375,    19806,        1
    19843,    19938,        1
    20011,    20106,        1
    23175,    23366,        1
    24719,    35270,        1
*ELSET,ELSET=NO_REINF, GENERATE
     6117,     6508,        1
    19375,    19806,        1
    19843,    19938,        1
    20011,    20106,        1
    23175,    23366,        1
    24719,    34886,        1
*ELSET,ELSET=RING1, GENERATE
    31726,    32326,       40
    32951,    32966,        1
    33006,    33606,       40
    33607,    34207,       40
*ELSET, ELSET=BS000001, GENERATE
     6117,     6508,        1
    19375,    19806,        1
    19843,    19938,        1
    20011,    20106,        1
    23175,    23366,        1
    24719,    34886,        1
*BOUNDARY,OP=NEW
      6830,  1, 6,      0.00000E+00
**%
```

```
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1RX
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,     P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1RX
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + RZ
*CLOAD,OP=NEW
      23321,     6, -1.35239E+05
*DLOAD,OP=NEW
BS000001,     P,-4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

elbow7dis_std.inp

```
**%   ============================================================
**%
**%              I-DEAS 10 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_elbow.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_elbow\input\elbow7dis_std.inp
**%            EXPORTED: AT 10:38:56 ON 16-Apr-08
**%                PART: elbow
**%                 FEM: Fem1 Standard
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
```

Project:	ATR Life Time Extension Project		**ECAR No.:**	ECAR-194		**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation						
Performer:	D. T. Clark	**Date:** 09/30/08	**Checker:**	A. S. Siahpush		**Date:**	09/30/08

```
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  16-Apr-08   10:38:56
**%=============================================
**%          MODAL DATA
**%=============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=SC8R, ELSET=SOLID7
*MPC
 BEAM,   9521,  14000
*ELEMENT, TYPE=SPRINGA , ELSET=SPRING1E6
*SHELL SECTION, ELSET=SOLID7, MATERIAL=SST304
 5.0,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.2520E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
*DAMPING, ALPHA=1.077, BETA=1.137E-3
*SPRING, ELSET=SPRING1E6, NONLINEAR

-1.00000E+06, -1.00000E-02
 0.00000E+00,  0.00000E+00
**%
*NSET,NSET=ALL
*NSET,NSET=CPL0ND
*NSET,NSET=CPL1ND
*NSET,NSET=CPL2ND
*ELSET,ELSET=ALL
*ELSET,ELSET=HALFYZ
*ELSET,ELSET=PIPE14
*ELSET,ELSET=STIFFENER
**%
*AMPLITUDE, NAME=R19N80D1
*AMPLITUDE, NAME=R19N80D2
*AMPLITUDE, NAME=R19N80D3
*AMPLITUDE, NAME=R19N80D4
*AMPLITUDE, NAME=R19N80D5
*AMPLITUDE, NAME=R19N80D6
*AMPLITUDE, NAME=R19N111D1
*AMPLITUDE, NAME=R19N111D2
*AMPLITUDE, NAME=R19N111D3
*AMPLITUDE, NAME=R19N111D4
```

```
*AMPLITUDE, NAME=R19N111D5
*AMPLITUDE, NAME=R19N111D6
*AMPLITUDE, NAME=R19N159D1
*AMPLITUDE, NAME=R19N159D2
*AMPLITUDE, NAME=R19N159D3
*AMPLITUDE, NAME=R19N159D4
*AMPLITUDE, NAME=R19N159D5
*AMPLITUDE, NAME=R19N159D6
*AMPLITUDE, NAME=R19N215D1
*AMPLITUDE, NAME=R19N215D2
*AMPLITUDE, NAME=R19N215D3
*AMPLITUDE, NAME=R19N215D4
*AMPLITUDE, NAME=R19N215D5
*AMPLITUDE, NAME=R19N215D6
*AMPLITUDE, NAME=R19N308D1
*AMPLITUDE, NAME=R19N308D2
*AMPLITUDE, NAME=R19N308D3
*AMPLITUDE, NAME=R19N308D4
*AMPLITUDE, NAME=R19N308D5
*AMPLITUDE, NAME=R19N308D6
*AMPLITUDE, NAME=R19N309D1
*AMPLITUDE, NAME=R19N309D2
*AMPLITUDE, NAME=R19N309D3
*AMPLITUDE, NAME=R19N309D4
*AMPLITUDE, NAME=R19N309D5
*AMPLITUDE, NAME=R19N309D6
**%
*ELSET,ELSET=BS000001
*ELSET,ELSET=BS000002
**%
*Surface, type=NODE, name=CPL0ND
 CPL0ND, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING0, REF NODE=9000, SURFACE=CPL0ND
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CPL1ND
 CPL1ND, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING1, REF NODE=9001, SURFACE=CPL1ND
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CPL2ND
 CPL2ND, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING2, REF NODE=9002, SURFACE=CPL2ND
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
**% Note: Nodes vertical is possitive z
**%       Elements vertical is possitive y
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.01
 0.005,1.0,1.0E-08,1.0
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
 9000, 1, , -5.31E-02
 9000, 2, , -2.97E-02
 9000, 3, , -3.21E-03
 9000, 4, , -1.67E-04
 9000, 5, , 1.90E-04
 9000, 6, , -1.93E-04
 9001, 1, , -4.35E-02
 9001, 2, , -5.74E-02
 9001, 3, , -2.64E-02
 9001, 4, , -1.59E-04
 9001, 5, , 4.66E-05
 9001, 6, , -4.11E-04
 9002, 1, , -7.27E-02
 9002, 2, , -8.66E-02
 9002, 3, , -2.60E-03
 9002, 4, , -1.01E-03
 9002, 5, , 3.93E-04
 9002, 6, , -3.28E-04
 14000, 1, , -4.73E-02
 14000, 2, , -2.73E-02
 14000, 3, , -3.21E-03
 14000, 4, , -6.10E-05
 14000, 5, , 1.89E-04
 14000, 6, , -1.79E-04
 14001, 1, , -3.30E-02
 14001, 2, , -5.75E-02
 14001, 3, , -3.03E-02
 14001, 4, , -1.46E-04
 14001, 5, , 4.49E-05
 14001, 6, , -4.14E-04
 14002, 1, , -8.79E-02
 14002, 2, , -1.20E-01
 14002, 3, , -2.59E-03
 14002, 4, , -9.63E-04
 14002, 5, , 5.20E-04
 14002, 6, , -4.10E-04
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
 BS000001,    P2, 4.0000E+02
 BS000002,    P5, 4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*MONITOR, NODE=893, DOF=1
*END STEP
**%
**% ====== SEISMIC WITH G-LOAD ======
**%
**% Note: Damping is address in the material properties
**%
*STEP,INC=10000000,NLGEOM
```

```
*DYNAMIC, DIRECT
 0.005,20.0,1.0E-08,0.005
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%
*BOUNDARY,AMPLITUDE=R19N80D1,OP=NEW,TYPE=DISPLACEMENT
       9000,  1, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N80D2,OP=NEW,TYPE=DISPLACEMENT
       9000,  2, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N80D3,OP=NEW,TYPE=DISPLACEMENT
       9000,  3, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N80D4,OP=NEW,TYPE=DISPLACEMENT
       9000,  4, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N80D5,OP=NEW,TYPE=DISPLACEMENT
       9000,  5, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N80D6,OP=NEW,TYPE=DISPLACEMENT
       9000,  6, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N215D1,OP=NEW,TYPE=DISPLACEMENT
       9001,  1, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N215D2,OP=NEW,TYPE=DISPLACEMENT
       9001,  2, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N215D3,OP=NEW,TYPE=DISPLACEMENT
       9001,  3, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N215D4,OP=NEW,TYPE=DISPLACEMENT
       9001,  4, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N215D5,OP=NEW,TYPE=DISPLACEMENT
       9001,  5, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N215D6,OP=NEW,TYPE=DISPLACEMENT
       9001,  6, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N308D1,OP=NEW,TYPE=DISPLACEMENT
       9002,  1, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N308D2,OP=NEW,TYPE=DISPLACEMENT
       9002,  2, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N308D3,OP=NEW,TYPE=DISPLACEMENT
       9002,  3, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N308D4,OP=NEW,TYPE=DISPLACEMENT
       9002,  4, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N308D5,OP=NEW,TYPE=DISPLACEMENT
       9002,  5, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N308D6,OP=NEW,TYPE=DISPLACEMENT
       9002,  6, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N111D1,OP=NEW,TYPE=DISPLACEMENT
       14000,  1, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N111D2,OP=NEW,TYPE=DISPLACEMENT
       14000,  2, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N111D3,OP=NEW,TYPE=DISPLACEMENT
       14000,  3, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N111D4,OP=NEW,TYPE=DISPLACEMENT
       14000,  4, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N111D5,OP=NEW,TYPE=DISPLACEMENT
       14000,  5, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N111D6,OP=NEW,TYPE=DISPLACEMENT
       14000,  6, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N159D1,OP=NEW,TYPE=DISPLACEMENT
```

```
       14001,  1, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N159D2,OP=NEW,TYPE=DISPLACEMENT
       14001,  2, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N159D3,OP=NEW,TYPE=DISPLACEMENT
       14001,  3, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N159D4,OP=NEW,TYPE=DISPLACEMENT
       14001,  4, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N159D5,OP=NEW,TYPE=DISPLACEMENT
       14001,  5, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N159D6,OP=NEW,TYPE=DISPLACEMENT
       14001,  6, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N309D1,OP=NEW,TYPE=DISPLACEMENT
       14002,  1, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N309D2,OP=NEW,TYPE=DISPLACEMENT
       14002,  2, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N309D3,OP=NEW,TYPE=DISPLACEMENT
       14002,  3, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N309D4,OP=NEW,TYPE=DISPLACEMENT
       14002,  4, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N309D5,OP=NEW,TYPE=DISPLACEMENT
       14002,  5, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R19N309D6,OP=NEW,TYPE=DISPLACEMENT
       14002,  6, ,       1.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
 BS000001,   P2, 4.0000E+02
 BS000002,   P5, 4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*MONITOR, NODE=893, DOF=1
*END STEP
```

elbow17dis_std_HTOL.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_elbow.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_elbow\input\elbow16dis_std.inp
**%            EXPORTED: AT 15:37:24 ON 25-Sep-08
**%                PART: elbow
**%                 FEM: Fem1 Standard
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
```

```
**%                      ... FORCE  : pound (lbf)
**%                      ... TEMPERATURE : deg Fahrenheit
**%
**%          COORDINATE SYSTEM: PART
**%
**%              SUBSET EXPORT: OFF
**%
**%        NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  25-Sep-08   15:37:24
**%============================================
**%           MODAL DATA
**%============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=SC8R, ELSET=SOLID7
*MPC
*ELEMENT, TYPE=SPRINGA , ELSET=SPRING1E6
*SHELL SECTION, ELSET=SOLID7, MATERIAL=SST304
 5.0,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
*SPRING, ELSET=SPRING1E6, NONLINEAR
-1.00000E+06, -1.00000E-02
 0.00000E+00,  0.00000E+00
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=CPL0ND, GENERATE
*NSET,NSET=CPL1ND, GENERATE
*NSET,NSET=CPL2ND, GENERATE
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=HALFYZ, GENERATE
*ELSET,ELSET=PIPE36, GENERATE
*ELSET,ELSET=PIPE14, GENERATE
*ELSET,ELSET=STIFFENER, GENERATE
**%
*AMPLITUDE, NAME=R27N80D1
*AMPLITUDE, NAME=R27N80D2
*AMPLITUDE, NAME=R27N80D3
*AMPLITUDE, NAME=R27N80D4
*AMPLITUDE, NAME=R27N80D5
*AMPLITUDE, NAME=R27N80D6
*AMPLITUDE, NAME=R27N159D1
*AMPLITUDE, NAME=R27N159D2
```

```
*AMPLITUDE, NAME=R27N159D3
*AMPLITUDE, NAME=R27N159D4
*AMPLITUDE, NAME=R27N159D5
*AMPLITUDE, NAME=R27N159D6
*AMPLITUDE, NAME=R27N215D1
*AMPLITUDE, NAME=R27N215D2
*AMPLITUDE, NAME=R27N215D3
*AMPLITUDE, NAME=R27N215D4
*AMPLITUDE, NAME=R27N215D5
*AMPLITUDE, NAME=R27N215D6
*AMPLITUDE, NAME=R27N308D1
*AMPLITUDE, NAME=R27N308D2
*AMPLITUDE, NAME=R27N308D3
*AMPLITUDE, NAME=R27N308D4
*AMPLITUDE, NAME=R27N308D5
*AMPLITUDE, NAME=R27N308D6
*AMPLITUDE, NAME=R27N568D1
*AMPLITUDE, NAME=R27N568D2
*AMPLITUDE, NAME=R27N568D3
*AMPLITUDE, NAME=R27N568D4
*AMPLITUDE, NAME=R27N568D5
*AMPLITUDE, NAME=R27N568D6
*AMPLITUDE, NAME=R27N585D1
*AMPLITUDE, NAME=R27N585D2
*AMPLITUDE, NAME=R27N585D3
*AMPLITUDE, NAME=R27N585D4
*AMPLITUDE, NAME=R27N585D5
*AMPLITUDE, NAME=R27N585D6
**%
*NSET,NSET=BS000001
*ELSET, ELSET=BS000002, GENERATE
*ELSET, ELSET=BS000003, GENERATE
**%
*Surface, type=NODE, name=CPL0ND
 CPL0ND, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING0, REF NODE=9000, SURFACE=CPL0ND
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CPL1ND
 CPL1ND, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING1, REF NODE=9001, SURFACE=CPL1ND
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CPL2ND
 CPL2ND, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING2, REF NODE=9002, SURFACE=CPL2ND
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.01
 0.005,1.0,1.0E-08,1.0
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
```

```
9000, 1, , -5.22E-03
9000, 2, , -1.99E-02
9000, 3, , -4.79E-04
9000, 4, , 2.85E-05
9000, 5, , 2.79E-05
9000, 6, , -2.37E-04
9001, 1, , 1.05E-02
9001, 2, , -2.91E-02
9001, 3, , -6.09E-03
9001, 4, , 6.14E-05
9001, 5, , -2.53E-05
9001, 6, , -3.75E-04
9002, 1, , -1.49E-02
9002, 2, , -5.23E-02
9002, 3, , 1.00E-04
9002, 4, , -7.60E-04
9002, 5, , 2.96E-04
9002, 6, , -3.38E-04
14000, 1, , -3.61E-03
14000, 2, , -2.73E-02
14000, 3, , -4.73E-04
14000, 4, , 1.18E-04
14000, 5, , 2.18E-05
14000, 6, , -2.18E-04
14001, 1, , 2.01E-02
14001, 2, , -2.92E-02
14001, 3, , -4.43E-03
14001, 4, , 6.91E-05
14001, 5, , -2.55E-05
14001, 6, , -3.77E-04
14002, 1, , -3.21E-02
14002, 2, , -8.83E-02
14002, 3, , 1.06E-04
14002, 4, , -7.93E-04
14002, 5, , 4.83E-04
14002, 6, , -4.23E-04
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
 BS000002,   P2, 4.0000E+02
 BS000003,   P5, 4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*MONITOR, NODE=893, DOF=1
*END STEP
**%
**% ====== SEISMIC WITH G-LOAD ======
**%
**% Note: Damping is address in the material properties
**%
*STEP,INC=10000000,NLGEOM
```

```
*DYNAMIC, HAFTOL=2.5E+05
 0.01,20.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%
*BOUNDARY,AMPLITUDE=R27N80D1,OP=NEW,TYPE=DISPLACEMENT
       9000,  1, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N80D2,OP=NEW,TYPE=DISPLACEMENT
       9000,  2, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N80D3,OP=NEW,TYPE=DISPLACEMENT
       9000,  3, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N80D4,OP=NEW,TYPE=DISPLACEMENT
       9000,  4, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N80D5,OP=NEW,TYPE=DISPLACEMENT
       9000,  5, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N80D6,OP=NEW,TYPE=DISPLACEMENT
       9000,  6, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N215D1,OP=NEW,TYPE=DISPLACEMENT
       9001,  1, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N215D2,OP=NEW,TYPE=DISPLACEMENT
       9001,  2, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N215D3,OP=NEW,TYPE=DISPLACEMENT
       9001,  3, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N215D4,OP=NEW,TYPE=DISPLACEMENT
       9001,  4, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N215D5,OP=NEW,TYPE=DISPLACEMENT
       9001,  5, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N215D6,OP=NEW,TYPE=DISPLACEMENT
       9001,  6, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N308D1,OP=NEW,TYPE=DISPLACEMENT
       9002,  1, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N308D2,OP=NEW,TYPE=DISPLACEMENT
       9002,  2, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N308D3,OP=NEW,TYPE=DISPLACEMENT
       9002,  3, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N308D4,OP=NEW,TYPE=DISPLACEMENT
       9002,  4, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N308D5,OP=NEW,TYPE=DISPLACEMENT
       9002,  5, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N308D6,OP=NEW,TYPE=DISPLACEMENT
       9002,  6, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N568D1,OP=NEW,TYPE=DISPLACEMENT
       14000,  1, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N568D2,OP=NEW,TYPE=DISPLACEMENT
       14000,  2, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N568D3,OP=NEW,TYPE=DISPLACEMENT
       14000,  3, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N568D4,OP=NEW,TYPE=DISPLACEMENT
       14000,  4, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N568D5,OP=NEW,TYPE=DISPLACEMENT
       14000,  5, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N568D6,OP=NEW,TYPE=DISPLACEMENT
       14000,  6, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R27N159D1,OP=NEW,TYPE=DISPLACEMENT
```

```
      14001,  1, ,        1.00000E+00
*BOUNDARY,AMPLITUDE=R27N159D2,OP=NEW,TYPE=DISPLACEMENT
      14001,  2, ,        1.00000E+00
*BOUNDARY,AMPLITUDE=R27N159D3,OP=NEW,TYPE=DISPLACEMENT
      14001,  3, ,        1.00000E+00
*BOUNDARY,AMPLITUDE=R27N159D4,OP=NEW,TYPE=DISPLACEMENT
      14001,  4, ,        1.00000E+00
*BOUNDARY,AMPLITUDE=R27N159D5,OP=NEW,TYPE=DISPLACEMENT
      14001,  5, ,        1.00000E+00
*BOUNDARY,AMPLITUDE=R27N159D6,OP=NEW,TYPE=DISPLACEMENT
      14001,  6, ,        1.00000E+00
*BOUNDARY,AMPLITUDE=R27N585D1,OP=NEW,TYPE=DISPLACEMENT
      14002,  1, ,        1.00000E+00
*BOUNDARY,AMPLITUDE=R27N585D2,OP=NEW,TYPE=DISPLACEMENT
      14002,  2, ,        1.00000E+00
*BOUNDARY,AMPLITUDE=R27N585D3,OP=NEW,TYPE=DISPLACEMENT
      14002,  3, ,        1.00000E+00
*BOUNDARY,AMPLITUDE=R27N585D4,OP=NEW,TYPE=DISPLACEMENT
      14002,  4, ,        1.00000E+00
*BOUNDARY,AMPLITUDE=R27N585D5,OP=NEW,TYPE=DISPLACEMENT
      14002,  5, ,        1.00000E+00
*BOUNDARY,AMPLITUDE=R27N585D6,OP=NEW,TYPE=DISPLACEMENT
      14002,  6, ,        1.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
 BS000002,   P2, 4.0000E+02
 BS000003,   P5, 4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=8
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*MONITOR, NODE=893, DOF=1
*END STEP
```

elbow17dis_std_ST_1.inp

```
**%   ==============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_elbow.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_elbow\input\elbow16dis_std_ST.inp
**%            EXPORTED: AT 09:16:20 ON 26-Sep-08
**%                PART: elbow
**%                 FEM: Fem1 Standard
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
```

```
**%                        ... FORCE   : pound (lbf)
**%                        ... TEMPERATURE : deg Fahrenheit
**%
**%          COORDINATE SYSTEM: PART
**%
**%              SUBSET EXPORT: OFF
**%
**%        NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Sep-08   09:16:20
**%===========================================
**%          MODAL DATA
**%===========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*ELEMENT, TYPE=S4      , ELSET=THK_562
*ELEMENT, TYPE=SC8R, ELSET=SOLID7
*MPC
*ELEMENT, TYPE=SPRINGA , ELSET=SPRING1E6
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  2.50000E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
*SHELL SECTION,
 ELSET=THK_562 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.62000E-01,
*SHELL SECTION, ELSET=SOLID7, MATERIAL=SST304
 5.0,
*SPRING, ELSET=SPRING1E6, NONLINEAR

-1.00000E+06, -1.00000E-02
 0.00000E+00,  0.00000E+00
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=CPL0ND, GENERATE
*NSET,NSET=CPL1ND, GENERATE
*NSET,NSET=CPL2ND, GENERATE
*ELSET,ELSET=ALL, GENERATE
```

```
*ELSET,ELSET=HALFYZ, GENERATE
*ELSET,ELSET=PIPE36, GENERATE
*ELSET,ELSET=PIPE14, GENERATE
*ELSET,ELSET=STIFFENER, GENERATE
**%
*ELSET, ELSET=BS000002, GENERATE
*ELSET, ELSET=BS000003, GENERATE
*ELSET, ELSET=BS000004, GENERATE
*NSET,NSET=OUT
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.01
 0.005,1.0,1.0E-08,1.0
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
14000,    1, 6,      0.00000E+00
14001,    1, 6,      0.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
BS000002,    P, 4.0000E+02
BS000003,   P2, 4.0000E+02
BS000004,   P5, 4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=6626, DOF=1
*END STEP
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  PRESSURE_MX
*CLOAD,OP=NEW
       14002,    4, 7.883E+4
**       14002,    5, -8.54E+5
**       14002,    6, 1.605E+5
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
```

```
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=6626, DOF=1
*END STEP
```

elbow17dis_std_ST_2.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_elbow.mfl
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_elbow\input\elbow16dis_std_ST.inp
**%            EXPORTED: AT 09:16:20 ON 26-Sep-08
**%                PART: elbow
**%                 FEM: Fem1 Standard
**%
**%               UNITS: IN-Inch (pound f)
**%                      ... LENGTH : inch
**%                      ... TIME   : sec
**%                      ... MASS   : lbf-sec**2/in
**%                      ... FORCE  : pound (lbf)
**%                      ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Sep-08   09:16:20
**%=============================================
**%          MODAL DATA
**%=============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*ELEMENT, TYPE=S4      , ELSET=THK_562
*ELEMENT, TYPE=SC8R, ELSET=SOLID7
*MPC
*ELEMENT, TYPE=SPRINGA , ELSET=SPRING1E6
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
```

```
 MATERIAL=SST304
  2.50000E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
*SHELL SECTION,
 ELSET=THK_562 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.62000E-01,
*SHELL SECTION, ELSET=SOLID7, MATERIAL=SST304
 5.0,
*SPRING, ELSET=SPRING1E6, NONLINEAR

-1.00000E+06, -1.00000E-02
 0.00000E+00,  0.00000E+00
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=CPL0ND, GENERATE
*NSET,NSET=CPL1ND, GENERATE
*NSET,NSET=CPL2ND, GENERATE
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=PIPE36, GENERATE
*ELSET,ELSET=PIPE14, GENERATE
*ELSET,ELSET=STIFFENER, GENERATE
**%
*ELSET, ELSET=BS000002, GENERATE
*ELSET, ELSET=BS000003, GENERATE
*ELSET, ELSET=BS000004, GENERATE
*NSET,NSET=OUT
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.01
 0.005,1.0,1.0E-08,1.0
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
14000,    1, 6,      0.00000E+00
14001,    1, 6,      0.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
BS000002,    P, 4.0000E+02
BS000003,   P2, 4.0000E+02
BS000004,   P5, 4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
```

```
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=6626, DOF=1
*END STEP
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  PRESSURE_MX
*CLOAD,OP=NEW
**       14002,    4, 7.883E+4
       14002,    5, -8.54E+5
**       14002,    6, 1.605E+5
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=6626, DOF=1
*END STEP
```

elbow17dis_std_ST_3.inp

```
**%   ===========================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_elbow.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_elbow\input\elbow16dis_std_ST.inp
**%            EXPORTED: AT 09:16:20 ON 26-Sep-08
**%                PART: elbow
**%                 FEM: Fem1 Standard
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
```

```
**%                        ... MASS    : lbf-sec**2/in
**%                        ... FORCE   : pound (lbf)
**%                        ... TEMPERATURE : deg Fahrenheit
**%
**%          COORDINATE SYSTEM: PART
**%
**%              SUBSET EXPORT: OFF
**%
**%        NODE ZERO TOLERANCE: OFF
**%
**%    ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Sep-08   09:16:20
**%========================================
**%          MODAL DATA
**%========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*ELEMENT, TYPE=S4      , ELSET=THK_562
*ELEMENT, TYPE=SC8R, ELSET=SOLID7
*MPC
*ELEMENT, TYPE=SPRINGA , ELSET=SPRING1E6
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  2.50000E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
*DAMPING, ALPHA=0.9492, BETA=1.421E-3
*SHELL SECTION,
 ELSET=THK_562 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  5.62000E-01,
*SHELL SECTION, ELSET=SOLID7, MATERIAL=SST304
 5.0,
*SPRING, ELSET=SPRING1E6, NONLINEAR

-1.00000E+06, -1.00000E-02
 0.00000E+00,  0.00000E+00
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=CPL0ND, GENERATE
*NSET,NSET=CPL1ND, GENERATE
*NSET,NSET=CPL2ND, GENERATE
```

```
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=HALFYZ, GENERATE
*ELSET,ELSET=PIPE36, GENERATE
*ELSET,ELSET=PIPE14, GENERATE
*ELSET,ELSET=STIFFENER, GENERATE
**%
*ELSET, ELSET=BS000002, GENERATE
*ELSET, ELSET=BS000003, GENERATE
*ELSET, ELSET=BS000004, GENERATE
*NSET,NSET=OUT
9000,9001,9002,14000,14001,14002
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.01
 0.005,1.0,1.0E-08,1.0
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
14000,    1, 6,      0.00000E+00
14001,    1, 6,      0.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
BS000002,    P, 4.0000E+02
BS000003,   P2, 4.0000E+02
BS000004,   P5, 4.0000E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=6626, DOF=1
*END STEP
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  PRESSURE_MX
*CLOAD,OP=NEW
**        14002,    4, 7.883E+4
**        14002,    5, -8.54E+5
        14002,    6, 1.605E+5
*OUTPUT, FIELD ,FREQUENCY=1
```

```
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=6626, DOF=1
*END STEP
```

elbow_beam_17dis_std_STnc_1.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_elbow.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_elbow\input\elbow_beam_16dis_std_STnc_1.inp
**%            EXPORTED: AT 10:26:29 ON 26-Sep-08
**%                PART: Part2
**%                 FEM: no adjust
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Sep-08   10:26:29
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
*ELEMENT, TYPE=B31     , ELSET=PIPE_3
*ELEMENT, TYPE=B32     , ELSET=ELBOW
*ELEMENT, TYPE=B32     , ELSET=ELBOW_1
```

```
*ELEMENT, TYPE=B32     , ELSET=ELBOW_2
**%
**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5625
**%
*BEAM SECTION,
 MATERIAL=SST304_36X05625 ,
 ELSET=PIPE,
 SECTION=PIPE
 0.18000E+02, 0.56250E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_36X05625
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5625
**%
*BEAM SECTION,
 MATERIAL=SST304_36X05625 ,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.18000E+02, 0.56250E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE14_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_14X025 ,
 ELSET=PIPE_2,
 SECTION=PIPE
 0.70000E+01, 0.25000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_14X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.96300E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: TEE37_75X1_375
**%
*BEAM SECTION,
 MATERIAL=SST304_T3775X1375 ,
 ELSET=PIPE_3,
 SECTION=PIPE
 0.18875E+02, 0.13750E+01
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:** 09/30/08	**Checker:** A. S. Siahpush	**Date:**	09/30/08

```
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_T3775X1375
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.29700E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW36_0X0_5625R36P400_FAB
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW ,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.62623E+02, 0.51820E+03, 0.00000E+00, 0.51820E+03, 0.19666E+05, 0, 0.00000E+00
-0.20000E-04,-0.98078E+00,-0.19510E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW36_0X0_5625R36P400_FAB
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_1 ,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.62623E+02, 0.51820E+03, 0.00000E+00, 0.51820E+03, 0.19666E+05, 0, 0.00000E+00
 0.00000E+00,-0.38268E+00,-0.92387E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW36_0X0_5625R36P400_FAB
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_2 ,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.62623E+02, 0.51820E+03, 0.00000E+00, 0.51820E+03, 0.19666E+05, 0, 0.00000E+00
 0.00000E+00,-0.83146E+00,-0.55557E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
*ELSET, ELSET=ALLELEMENTS
```

```
 PIPE,
 PIPE_1,
 PIPE_2,
 PIPE_3,
 ELBOW ,
 ELBOW_1 ,
 ELBOW_2 ,
**%
*NSET,NSET=OUT
 159,568,585
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       159,  1, 6,      0.00000E+00
       568,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
      585,    4, 7.883E+4
**      585,    5, -8.54E+5
**      585,    6, 1.605E+5
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=272, DOF=1
*END STEP
```

elbow_beam_17dis_std_STnc_2.inp

```
**%  ============================================================
**%
**%             NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                    FOR ABAQUS VERSION 6.x
**%
**%         MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_elbow.mf1
**%         INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_elbow\input\elbow_beam_16dis_std_STnc_1.inp
**%           EXPORTED: AT 10:26:29 ON 26-Sep-08
**%               PART: Part2
**%                FEM: no adjust
**%
**%              UNITS: IN-Inch (pound f)
```

```
**%                        ... LENGTH : inch
**%                        ... TIME   : sec
**%                        ... MASS   : lbf-sec**2/in
**%                        ... FORCE  : pound (lbf)
**%                        ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Sep-08   10:26:29
**%========================================
**%          MODAL DATA
**%========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31      , ELSET=PIPE
*ELEMENT, TYPE=B31      , ELSET=PIPE_1
*ELEMENT, TYPE=B31      , ELSET=PIPE_2
*ELEMENT, TYPE=B31      , ELSET=PIPE_3
*ELEMENT, TYPE=B32      , ELSET=ELBOW
*ELEMENT, TYPE=B32      , ELSET=ELBOW_1
*ELEMENT, TYPE=B32      , ELSET=ELBOW_2
**%
**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5625
**%
*BEAM SECTION,
 MATERIAL=SST304_36X05625 ,
 ELSET=PIPE,
 SECTION=PIPE
 0.18000E+02, 0.56250E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_36X05625
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5625
**%
*BEAM SECTION,
 MATERIAL=SST304_36X05625 ,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.18000E+02, 0.56250E+00
```

```
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE14_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_14X025 ,
 ELSET=PIPE_2,
 SECTION=PIPE
 0.70000E+01, 0.25000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_14X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.96300E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: TEE37_75X1_375
**%
*BEAM SECTION,
 MATERIAL=SST304_T3775X1375 ,
 ELSET=PIPE_3,
 SECTION=PIPE
 0.18875E+02, 0.13750E+01
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_T3775X1375
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.29700E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW36_0X0_5625R36P400_FAB
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW ,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.62623E+02, 0.51820E+03, 0.00000E+00, 0.51820E+03, 0.19666E+05, 0, 0.00000E+00
-0.20000E-04,-0.98078E+00,-0.19510E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW36_0X0_5625R36P400_FAB
**%
```

```
*BEAM GENERAL SECTION,
 ELSET=ELBOW_1 ,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.62623E+02, 0.51820E+03, 0.00000E+00, 0.51820E+03, 0.19666E+05, 0, 0.00000E+00
 0.00000E+00,-0.38268E+00,-0.92387E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW36_0X0_5625R36P400_FAB
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_2 ,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.62623E+02, 0.51820E+03, 0.00000E+00, 0.51820E+03, 0.19666E+05, 0, 0.00000E+00
 0.00000E+00,-0.83146E+00,-0.55557E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE,
 PIPE_1,
 PIPE_2,
 PIPE_3,
 ELBOW ,
 ELBOW_1 ,
 ELBOW_2 ,
**%
*NSET,NSET=OUT
 159,568,585
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
        159,  1, 6,      0.00000E+00
        568,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
**        585,    4, 7.883E+4
       585,    5, -8.54E+5
**        585,    6, 1.605E+5
*OUTPUT, FIELD ,FREQUENCY=1
```

```
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 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=272, DOF=1
*END STEP
```

elbow_beam_17dis_std_STnc_3.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_elbow.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_elbow\input\elbow_beam_16dis_std_STnc_1.inp
**%            EXPORTED: AT 10:26:29 ON 26-Sep-08
**%                PART: Part2
**%                 FEM: no adjust
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Sep-08   10:26:29
**%===========================================
**%          MODAL DATA
**%===========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
*ELEMENT, TYPE=B31     , ELSET=PIPE_3
*ELEMENT, TYPE=B32     , ELSET=ELBOW
*ELEMENT, TYPE=B32     , ELSET=ELBOW_1
```

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```
*ELEMENT, TYPE=B32     , ELSET=ELBOW_2
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**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5625
**%
*BEAM SECTION,
 MATERIAL=SST304_36X05625 ,
 ELSET=PIPE,
 SECTION=PIPE
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-0.10000E+01, 0.00000E+00, 0.00000E+00
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*ELASTIC,TYPE=ISOTROPIC
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*DENSITY
 2.15000E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE36_0X0_5625
**%
*BEAM SECTION,
 MATERIAL=SST304_36X05625 ,
 ELSET=PIPE_1,
 SECTION=PIPE
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 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE14_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_14X025 ,
 ELSET=PIPE_2,
 SECTION=PIPE
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-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_14X025
*ELASTIC,TYPE=ISOTROPIC
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*DENSITY
 1.96300E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: TEE37_75X1_375
**%
*BEAM SECTION,
 MATERIAL=SST304_T3775X1375 ,
 ELSET=PIPE_3,
 SECTION=PIPE
 0.18875E+02, 0.13750E+01
```

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```
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_T3775X1375
*ELASTIC,TYPE=ISOTROPIC
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*DENSITY
 1.29700E-03,
*EXPANSION,TYPE=ISO
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*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW36_0X0_5625R36P400_FAB
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW ,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.62623E+02, 0.51820E+03, 0.00000E+00, 0.51820E+03, 0.19666E+05, 0, 0.00000E+00
-0.20000E-04,-0.98078E+00,-0.19510E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW36_0X0_5625R36P400_FAB
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_1 ,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.62623E+02, 0.51820E+03, 0.00000E+00, 0.51820E+03, 0.19666E+05, 0, 0.00000E+00
 0.00000E+00,-0.38268E+00,-0.92387E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW36_0X0_5625R36P400_FAB
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW_2 ,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.62623E+02, 0.51820E+03, 0.00000E+00, 0.51820E+03, 0.19666E+05, 0, 0.00000E+00
 0.00000E+00,-0.83146E+00,-0.55557E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
*ELSET, ELSET=ALLELEMENTS
```

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```
 PIPE,
 PIPE_1,
 PIPE_2,
 PIPE_3,
 ELBOW ,
 ELBOW_1 ,
 ELBOW_2 ,
**%
*NSET,NSET=OUT
 159,568,585
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
        159,  1, 6,      0.00000E+00
        568,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
**        585,     4, 7.883E+4
**        585,     5, -8.54E+5
       585,    6, 1.605E+5
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=272, DOF=1
*END STEP
```

Appendix F.2
Unlisted Component Evaluations Associated with Model 256

Model 256 contains two unlisted components within its piping boundary.

The first unlisted component [5, Table 6] is a 16-in x 0.25-in thick elbow (line 1-30) that has a 10-in x 0.25-in thick pipe (line 8-14) that extends out its back radius, forming a branch connection [20, 21]. The 16-in elbow is reinforced to the elbow with a 1/4-in thick plate [22, Section 5.1]. Figure F.2-1 illustrates model 256's unlisted branch component, as viewed from below. The unlisted branch component is fabricated from 304 stainless steel materials.

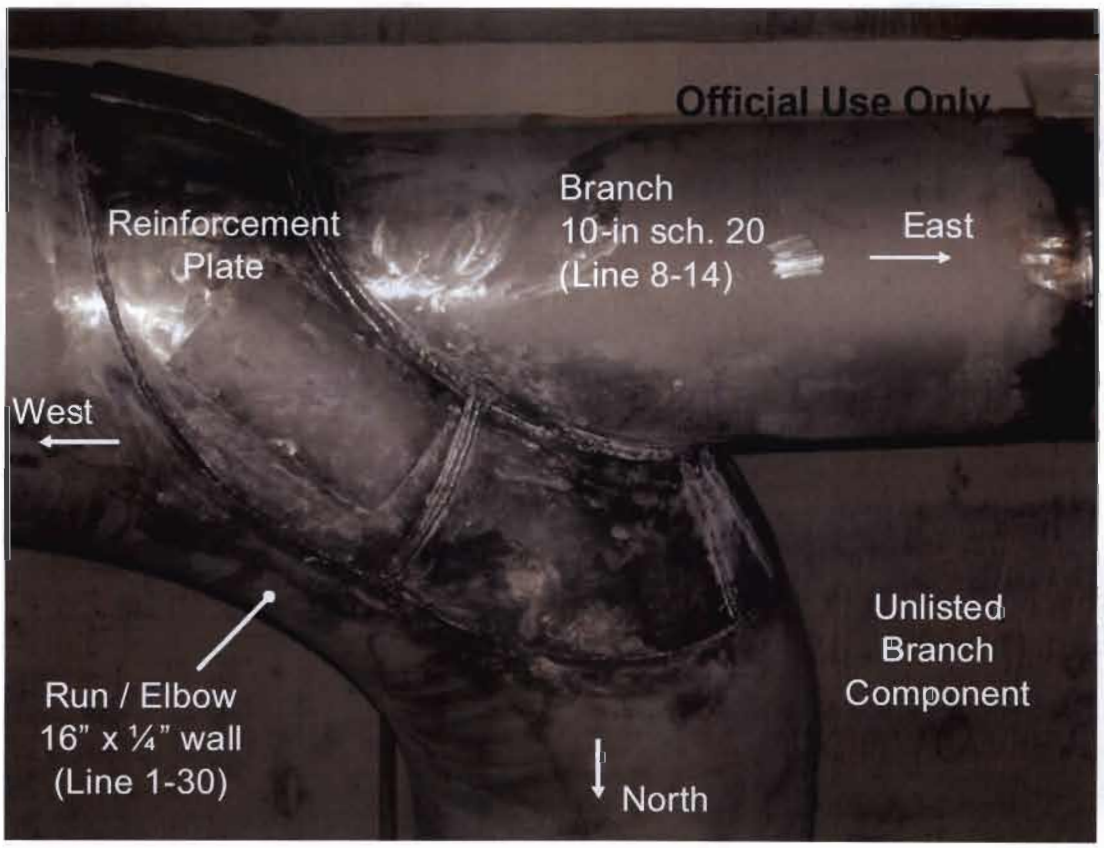

Figure F.2-1 – Model 256's unlisted branch component is shown, as viewed from below

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The second unlisted component [5, Figure 22] is a 30-in x 7/16-in wall cap (line 1-17) [23] that has a 10-in schedule 20 pipe (line 1-43) [24] stubbed into the cap end. Figure F.2-2 illustrates model 256's unlisted cap component, as viewed looking in the south direction. The unlisted cap component is fabricated from 304 stainless steel materials. The unlisted cap acts as a reducer between the cap and stub are heavily reinforced by layers of weld.

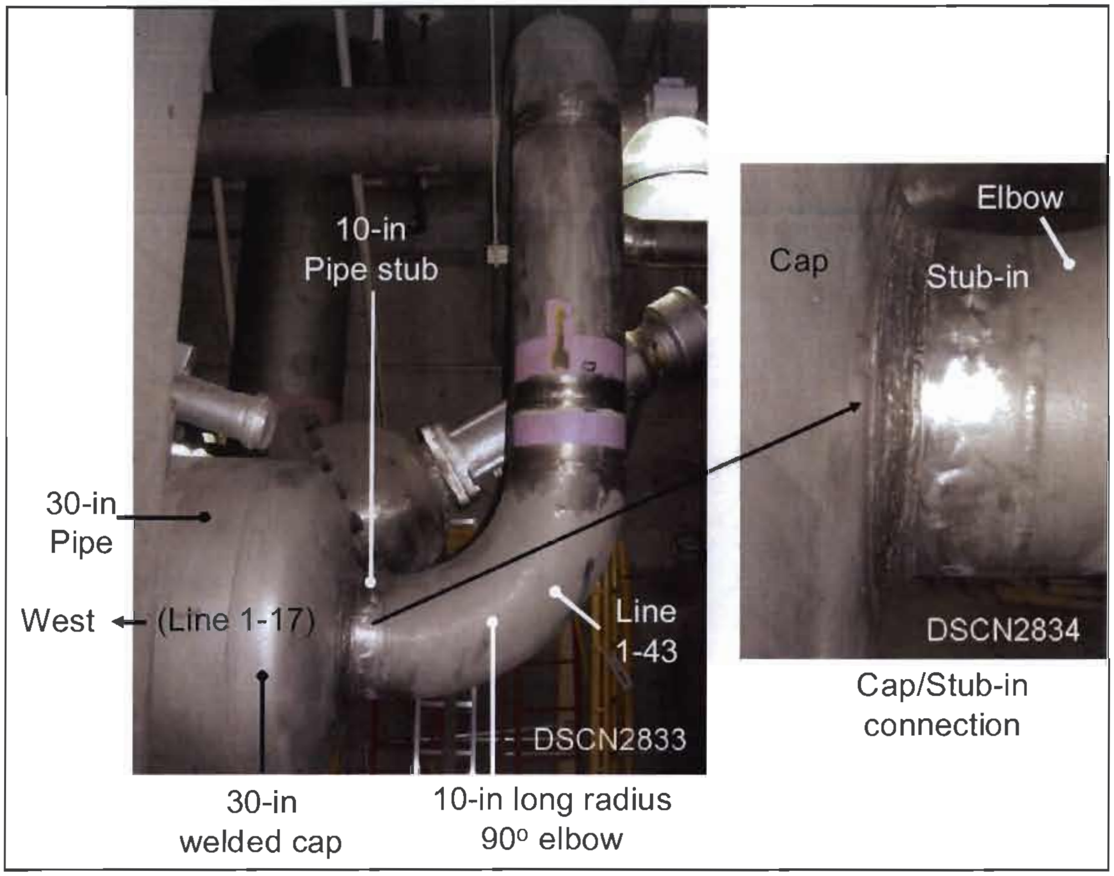

Figure F.2-2 – Model 256's unlisted cap component is shown.

The following sections (listed below) contain information used to evaluate Model 256's unlisted branch and unlisted cap components.

Contents Page

F.2.1 – FE Model Description of Unlisted Branch Component

Model 256's unlisted branch component was solid-modeled and meshed within I-DEAS Master Series, Simulation, Version 12 [9]. With the meshing complete, input files were written for ABAQUS [10]. Final editing of the input files was performed in a text editor and then solution runs were performed with ABAQUS Standard, Version 6.7-5. Results of the FE models are displayed with ABAQUS Viewer, Version 6.7-5, and are shown in Appendix F.2.2.

The unlisted branch component was meshed primarily with four-node quadrilateral elements and some rigid beam elements. The quadrilateral elements support six degrees of freedom (3-translations, 3 rotations) at each node and were used to model the 16-in elbow, 10-in pipe, and 1/4-in thick reinforcement plate. The rigid beams were used as an aid in defining boundary conditions (i.e., applying loads and defining restraints) to the meshed unlisted branch component. Figures F.2.1-1 through F.2.1-3 illustrates the unlisted branch component as meshed with the quadrilateral elements. Table F.2.1-1 correlates element color to member name and thickness.

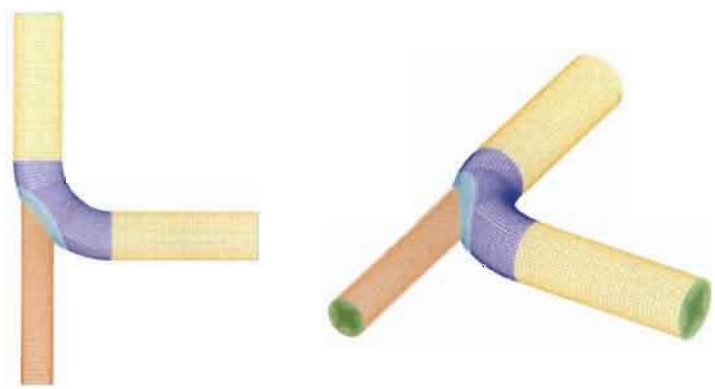

Figure F.2.1-1 – Quadrilateral shell mesh of 256 model's unlisted branch component is shown.

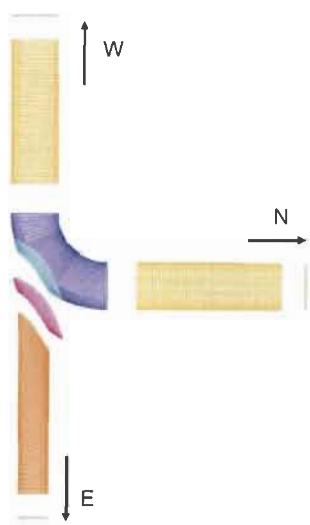

Figure F.2.1-2 – Top view of unlisted branch component showing member meshes.

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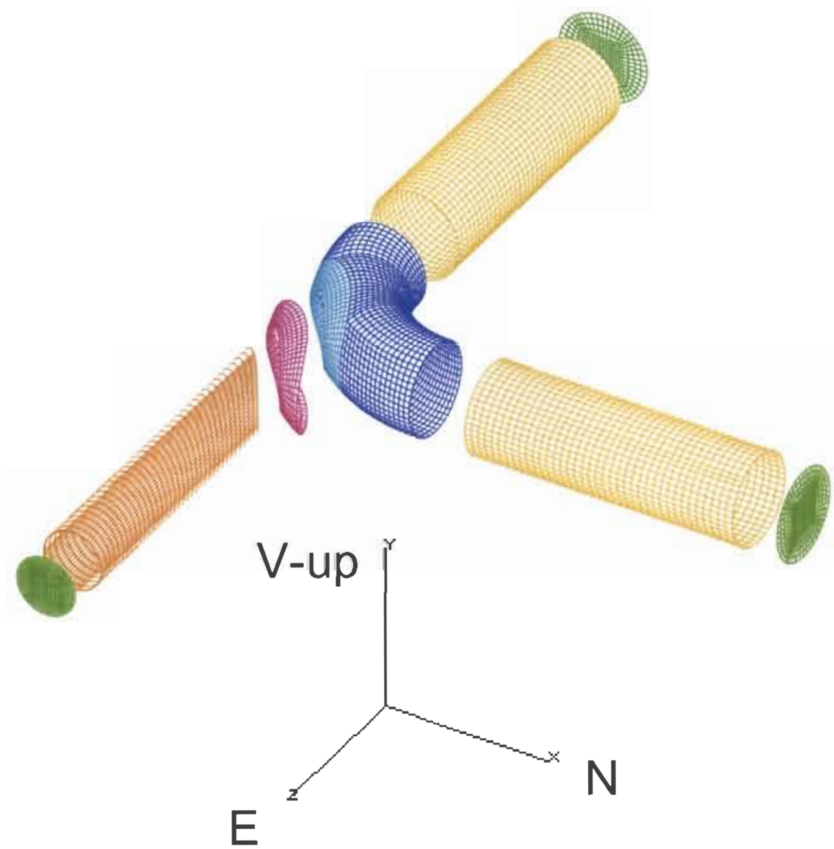

Figure F.2.1-3 – Isometric view of unlisted branch component showing member meshes.

Table F.2.1-1 – Mesh color, thickness, and component member correlation

Member Name	Mesh Color(s)	Element Thickness
16" Long Radius Elbow	Dark Blue & Cyan	¼" (0.25-in)
Reinforcement Plate	Magenta	¼" (0.25-in)
Branch (10" Pipe)	Redish-orange	¼" (0.25-in)
*Run (16" Pipe) extended from both ends of elbow	Gold	¼" (0.25-in)
*Run/Branch Ends	Dark Green	¼" (0.25-in)

*These component members were used as an aid to apply boundary conditions to unlisted branch.

As shown in Figures F.2.1-1 through F.2.1-3 and in Table F.2.1-1, the unlisted branch component's reinforced plate is oriented right next to the elbow's back surface (part of run) and surrounds the 10-in piping (forming the branch). The combined thickness in the reinforced plate region is 0.5-inches (0.25-in elbow thickness + 0.25-in reinforcement plate thickness). The run portion of this "branch component" is comprised of the elbow and two 16-in pipe extensions. The two 16-in pipe extensions were used as an aid to apply boundary conditions to the unlisted branch component.

The unlisted branch component is fabricated with 304 stainless steel [6] and operates at 125°F while maintaining a constant internal gauge pressure of 253-psi [11, Section 7.1]. Material properties of the unlisted branch component are shown in Table F.2.2 (see following), where property values are taken from ASME Section II, Subpart D, "Materials" [12].

Table F.2.1-2 – 304 Stainless Steel Material Properties at 125°F.

Symbol	Property Value	Property Description
μ	0.30 in/in	Poisson's Ration [1, Section NB-3683.1(b)]
E	28.0E+6	Modulus of Elasticity at 125°F Temperature [12, Table TM]
Sy	28.35 ksi	Material Yield Strength at 125°F Temperature [12, Table Y-1]
Sm	20 ksi	Maximum allowable Stress Intensity at 125°F Temperature [12, Table 2A]

FE Boundary Conditions

A total of twelve (14) ABAQUS solution runs were used to determine the unlisted branch component's flexibility factor (FF) and preliminary stress indices (SI) values. The FF runs used one model mesh with one boundary condition – but with differing (+/-) load appications. The preliminary SI runs utilized one model, with six different boundary conditions and differing (+/-) load applications.

FF Models & Boundary Conditions

One FE model mesh was used to determine deflection information necessary for computing the unlisted branch component's FF. The single shell model utilized rigid beams at the pipe ends to transmit applied moments and restraints from pipe section center nodes to perimeter nodes. The first model mesh (shown in Figure F.2.1-4) reflects boundary condition 1 and indicates how restraints and applied moments are placed on the unlisted branch component mesh. The picture on the left shows a hidden line removal view of the unlisted branch. The picture on the right shows a better view of the unlisted branch model's restraints and applied moment, with the hidden line remove featues turned off. The second FF boundary condition is exactly the same as first boundary condition (Figure F.2.1-4), except its applied moment is applied in the opposite direction. The maximum angular deflection results (within the X-Z plane) of these two FF unlisted branch solution runs are compared to that of the angular deflection of a regular elbow (without branch or reinforcement plate) model, as calculated based on code requirements [1, NB-3680 & NB-3683.2 Both FF solution runs provide differing angular deflections - which information is used to determine the unlisted branch component's flexibility factor (in Appendix F.2.3). Table F.2.1-3 summaries the boundary condition placed on the two FF solution models. A brief listing (without nodal and element definitions) of each ABAQUS boundary condition model is reprinted in Appendix F.2.11.

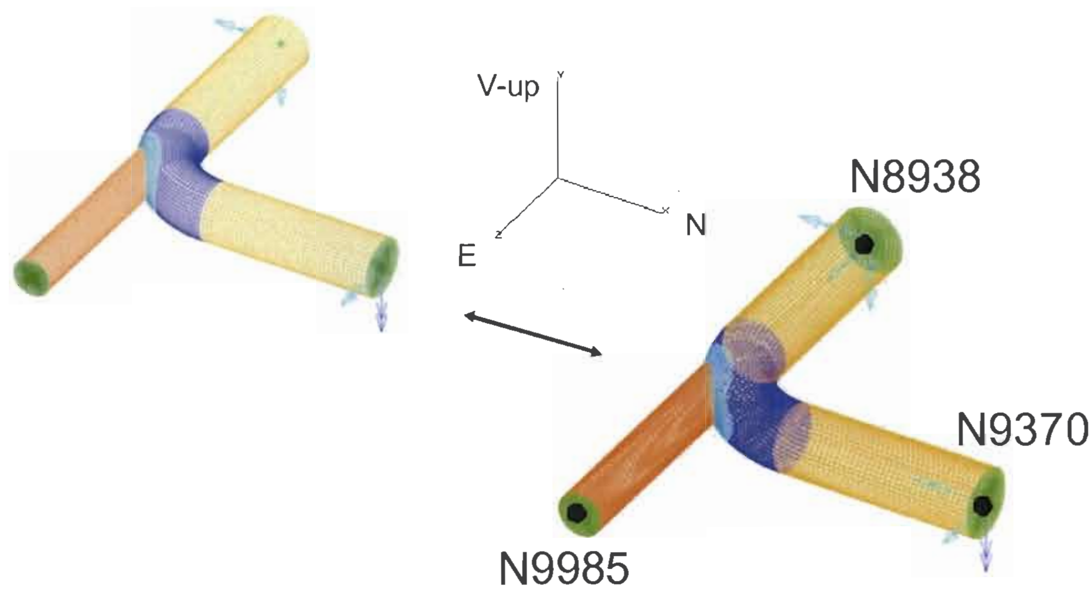

Figure F.2.1-4 – Isometric view of FF unlisted branch model mesh showing first applied boundary condition.

Table F.2.1-3 – FF Models Boundary Conditions.

FE Model Boundary Conditions	Restraint Nodes & Degrees of Freedom (DOF)	Applied Loads (IP-internal pressure) (Mx – applied moment)	ABAQUS model (Appendix F.1.11)
BC-1 Elbow/Branch (unlisted branch)	N8938: 6 dof fixed (X, Y, Z, RX, RY, RZ) N9370: 3 dof fixed: (Y, RX, RZ)	IP = 253 psi N9370: Mx = 4.671E+4 in*lbf	ff_mt_ubranchp.inp
BC-2 " "	" "	" " N9370: Mx = -4.671E+4 in*lbf	ff_mt_ubranchn.inp

Note that the applied moment of each FF model boundary conditon has a different sign. The applied moment direction that produces the maximum angular displacement for each FF model mesh is used.

SI Model & Boundary Conditions

As previously described, the SI model mesh matches that of the unlisted branch component mesh for which the physical properties (Table F.2.1-1) and material properties (Table F.2.1-2) apply. Twelve boundary conditions corresponding to twelve solution runs were used to apply corresponding results for determining the unlisted branch component's stress indices. The twelve boundary conditions stem from two restraint sets that apply a single nodal moment at six different locations. Six additional nodal moments are applied, with opposing signs, bringing the total boundary conditions (or ABAQUS models) to twelve. As was shown for the FF model meshes, rigid beams were used at pipe ends for restraint and moment application.

Applied moments were extracted from a preliminary set of 32 pilot model's piping system runs (Appendix B), in which the 80 percentile run pertaining to corresponding moments incurred within the unlisted branch component final set are identified. Figure F.2.1-5 shows a representation of corresponding system beam nodes in which nodal moments are extracted.

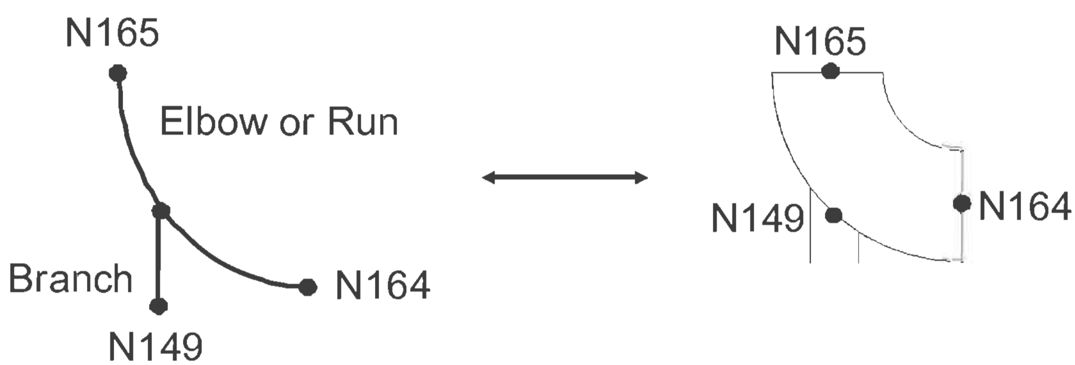

Figure F.2.1-5 – Corresponding nodes in which moments are extracted for 80 percentile run.

As can be seen in figure F.2.1-5, moments (Mx, My, Mz) extracted at node 149 correspond to the branch segment and moments (Mx, My, Mz) extracted at nodes N164 and N165 correspond to the run segment. Table F.2.1-4 lists the nodal moment values extracted from a preliminary 80 percentile run at these nodes that were used for scoping stress indices calculations.

Table F.2.1-4 – Unlisted Branch Component's Scoping Stress Indices Moment Extractions.

Node Number	MX (in*lbf)	MY (in*lbf)	MZ (in*lbf)
N149 (branch)	2.778E+4	7.788E+4	-4.084E+3
N164 (N-run)	528.946	4.357E+4	-3.091E+4
N165 (W-run)	9.978E+3	-5.874E+4	8.298E+4

From Table F.2.1-4, the maximum moment magnitude values and their opposite negative magnitudes were used to define the twelve boundary conditions at the extended branch and run pipe ends. Figure F.2.1-6 illustrates a single boundary condition where restraint set 1 is used along with a single positive (+) moment applied at the branch (or 10-in Pipe) end. Six boundary conditions utilize restraint set 1, where varying positive and negative moments are applied at the branch pipe end. Figure F.2.1-7 shows a single boundary condition where restraint set 2 is used along with a single positive (+) moment applied at the right pipe end of run (or 16-in Pipe) end. Six boundary conditions utilize restraint set 2, where varying positive and negative moments are applied at the run's right pipe end. Table F.2.1-5 summaries boundary conditions placed on the twelve SI solution runs and identify corresponding ABAQUS models. A brief listing (without nodal and element definitions) of each SI ABAQUS model file is reprinted in Appendix F.2.9.

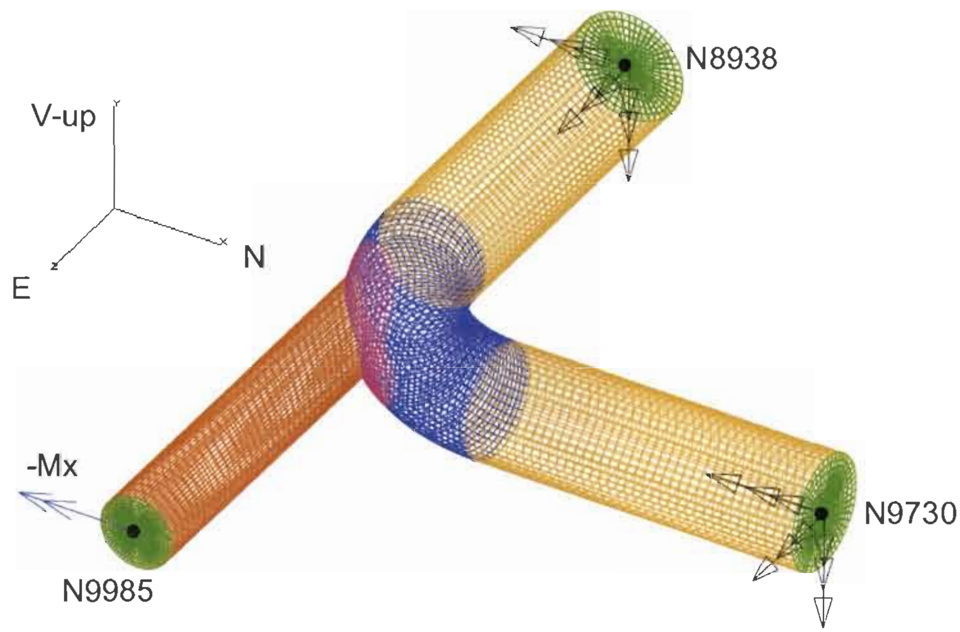

Figure F.2.1-6 – Isometric wireframe view of unlisted e/bow/branch example mesh showing restraint set-1 boundary condition applied to branch (N9985).

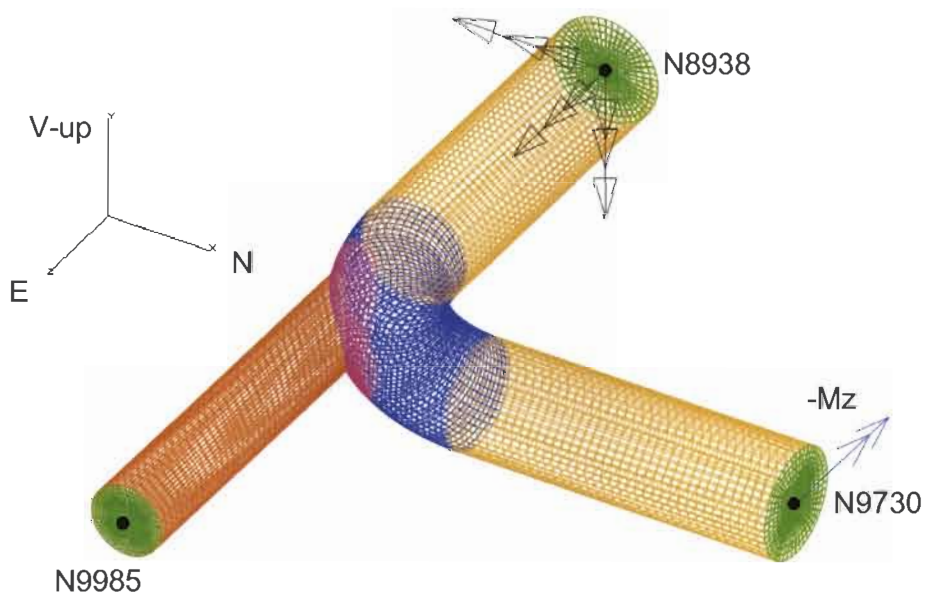

Figure F.2.1-7 – Isometric wireframe view of unlisted e/bow/branch example mesh showing restraint set-2 boundary condition applied to run (N9730 moment).

Table F.2.1-5 – SI Boundary Conditions.

ABAQUS Model (Appendix F.2.11)	**Restraint Set Degrees of Freedom (DOF)**	**Applied Loads (IP – internal pressure) (Mx, My, Mz – applied moments)**
si_mt_ubranch_mxp.inp	Set 1 N8938 & N9730 - 6 dof fixed: (X, Y, Z, RX, RY, RZ)	IP = 253 psi N9985: Mx = +2.778E+4 in*lbf
si_mt_ubranch_mxn.inp	" "	" " N9985: Mx = -2.778E+4 in*lbf
si_mt_ubranch_myp.inp	" "	" " N9985: My = +7.788E+4 in*lbf
si_mt_ubranch_myn.inp	" "	" " N9985: My = -7.788E+4 in*lbf
si_mt_ubranch_mzp.inp	" "	" " N9985: Mz = +4.084E+3 in*lbf
si_mt_ubranch_mzn.inp	" "	" " N9985: Mz = -4.084E+3 in*lbf
si_mt_urun_mxp.inp	Set 2 N8938 - 6 dof fixed: (X, Y, Z, RX, RY, RZ)	IP = 253 psi N9370: Mx = +9.978E+3 in*lbf
si_mt_urun_mxn.inp	" "	" " N9370: Mx = -9.978E+3 in*lbf
si_mt_urun_myp.inp	" "	" " N9370: My = +5.874E+4 in*lbf
si_mt_urun_myn.inp	" "	" " N9370: My = -5.874E+4 in*lbf
si_mt_urun_mzp.inp	" "	" " N9370: Mz = +8.298E+3 in*lbf
si_mt_urun_mzn.inp	" "	" " N9370: Mz = -8.298E+3 in*lbf

F.2.2 – FE Model Results of Unlisted Branch Component

ABAQUS post processing results for the fourteen (14) preliminary 80 percentile solution runs are shown within this section.

The first two FF solution results extract deflection nodal coordinate values which are then used (in Appendix F.2.3) to determine angular displacements and a flexibility factor. Figure F.2.2-1 shows displacement magnitude results of the unlisted branch mesh (1st FF model mesh) and identifies nodes that are used for FF determination (within Appendix F.2.3).

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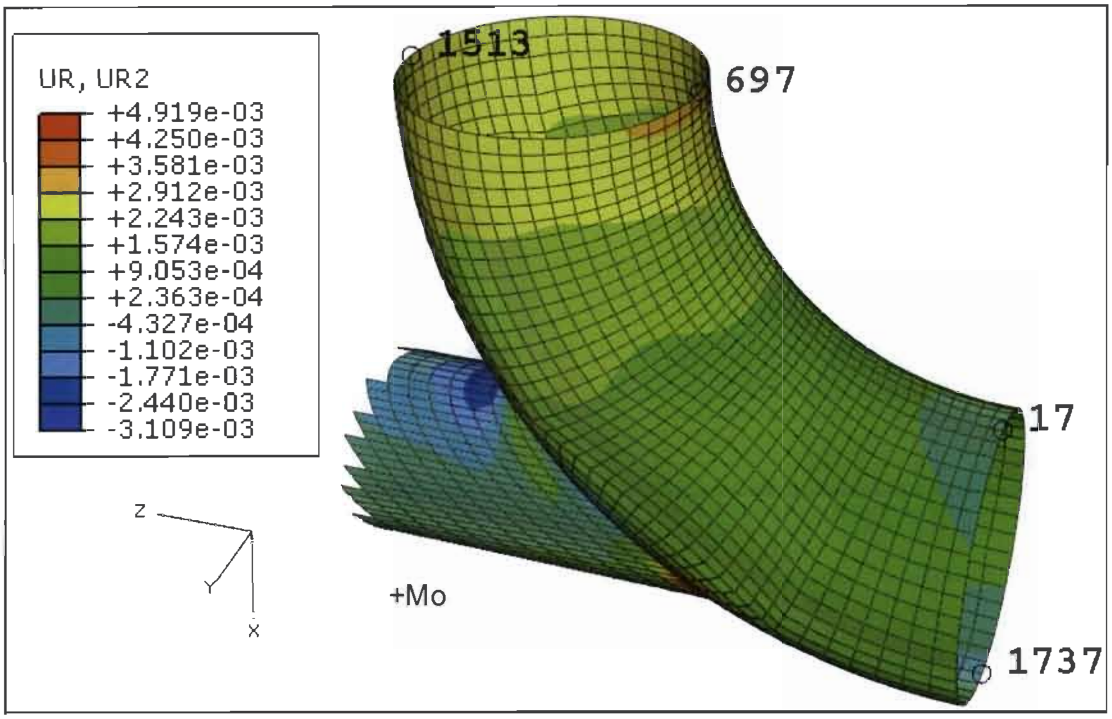

Figure F.2.2-1 – Unlisted branch component angular displacement (+Mo), identifying governing nodes.

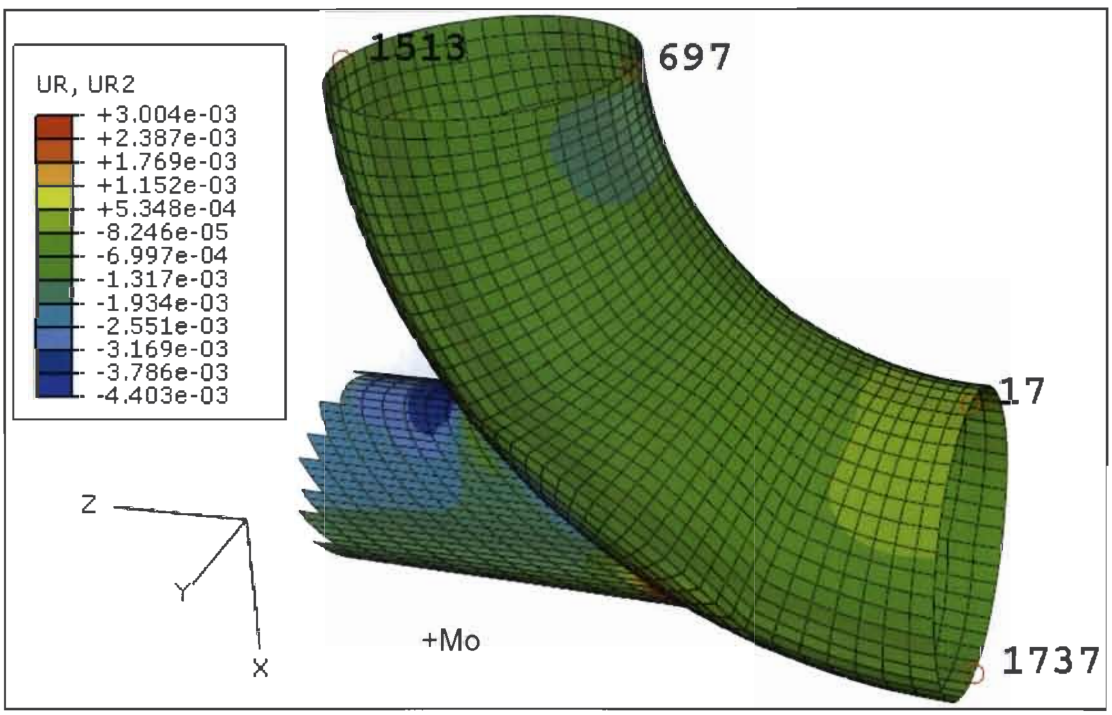

Figure F.2.2-2 – Unlisted branch component angular displacement (-Mo), identifying governing nodes.

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Maximum angular rotation occurs with +Mo, as compared between Figures F.2.2-1 and F.2.2-2. Nodal coordinate data (from Figure F.2.2-1) has been extracted from the unlisted branch post processing results and reprinted following.

```
********************************************************************************
Probe Values Report, written on Wed Aug 20 10:22:50 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/ff_multiple_time_histories/ff_mt_branch/ff_mt_ubranchp.odb
   Step: Step-1
   Frame: Increment     14: Step Time =    1.000

Probe values reported at nodes

  Part Instance     Node ID                   Def. Coords
                                   X                Y               Z
---------------------------------------------------------------------------------
--------------------------------------
    PART-1-1         1513      53.246E-03    -19.8328E-06         7.92843
    PART-1-1          697     11.5988E-03     614.875E-09        -7.84164
    PART-1-1         1737         31.8849     34.2039E-06        -23.9981
    PART-1-1           17         16.1233     547.159E-09        -23.9958
```

The next twelve SI solution results extract maximum membrane tresca stresses from each SI result model. The input file for each SI input file creates two resultant steps in which a third step is generated to obtain the tresca stress state needed. As shown in the following run bending moment example, at the bottom of each SI input file the first step (step 1) produces results for an internal pressure (253-psi) loading. The second step (step 2) computes results for combined internal pressure and bending loading.

```
**% ====== STEP NUMBER    1 ======
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1MX
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S
*END STEP
**% ====== STEP NUMBER    2 ======
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1MX
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + MX
*CLOAD,OP=NEW
     9985,    4, 3.142E+04
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S
*END STEP
```

A third step (step 3) is created within ABAQUS Viewer that subtracts step 1 (P) from step 2 (P+Mi) to obtain corresponding bending tresca stress results (Mi). This is done to capture the added stiffness from internal pressure reflected into the Mi results [Mi = (P+Mi) – (P)]. Maximum tresca stress results (extracted from the twelve SI result models) for the three moments (Mx, My, & Mz) are used to determine branch and run stress indices computed in Appendix F.2.3.

Figures F.2.2-3 through F.2.2-8 show maximum membrane tresca stress plots corresponding to +/- bending moment results applied to the branch pipe end. Figure F.2.2-9 shows the corresponding maximum membrane tresca stress plot due to branch pressure. The corresponding maximum tresca stress values for each load case (+Mx, -Mx, +My, -My, +Mz, -Mz, P) are contained in file "si_mt_ubranch_08_26_08.rpt" reprinted in Appendix F.2.2.1.

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

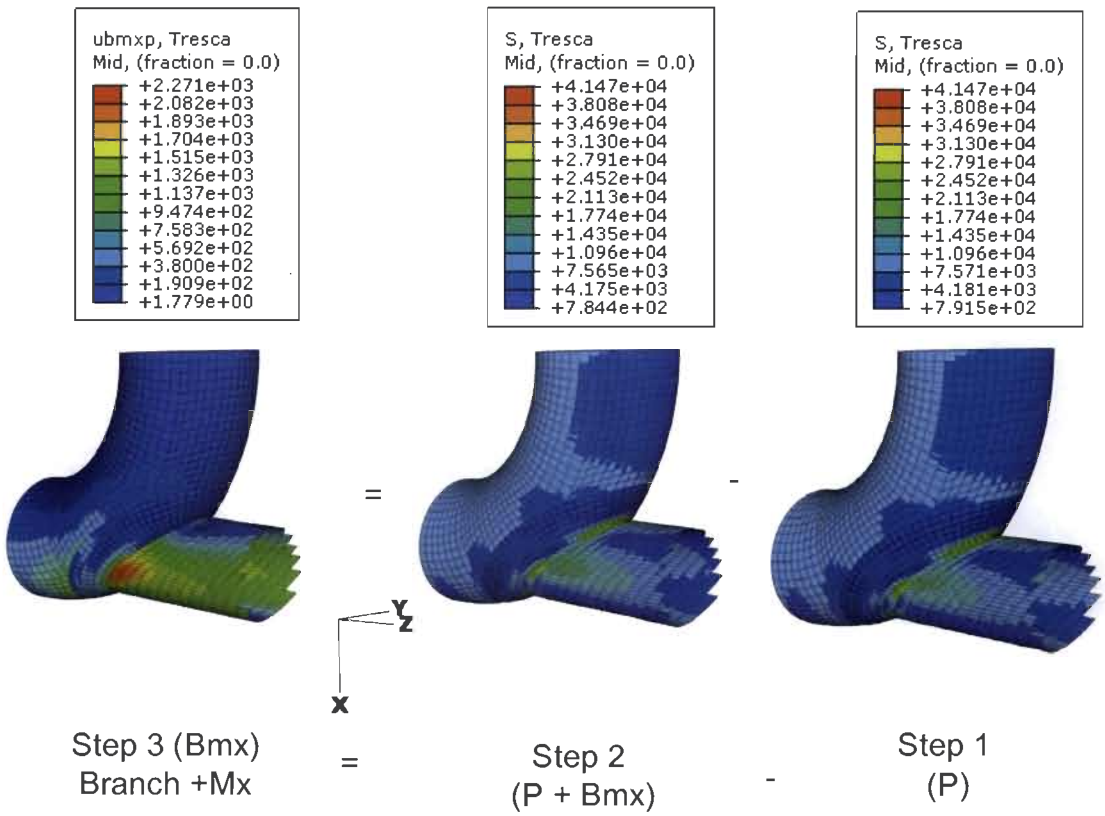

Figure F.2.2-3 – Step 3 membrane Bxp (branch +Mx bending) tresca stresses, determined as difference of steps 2 and step 1.

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

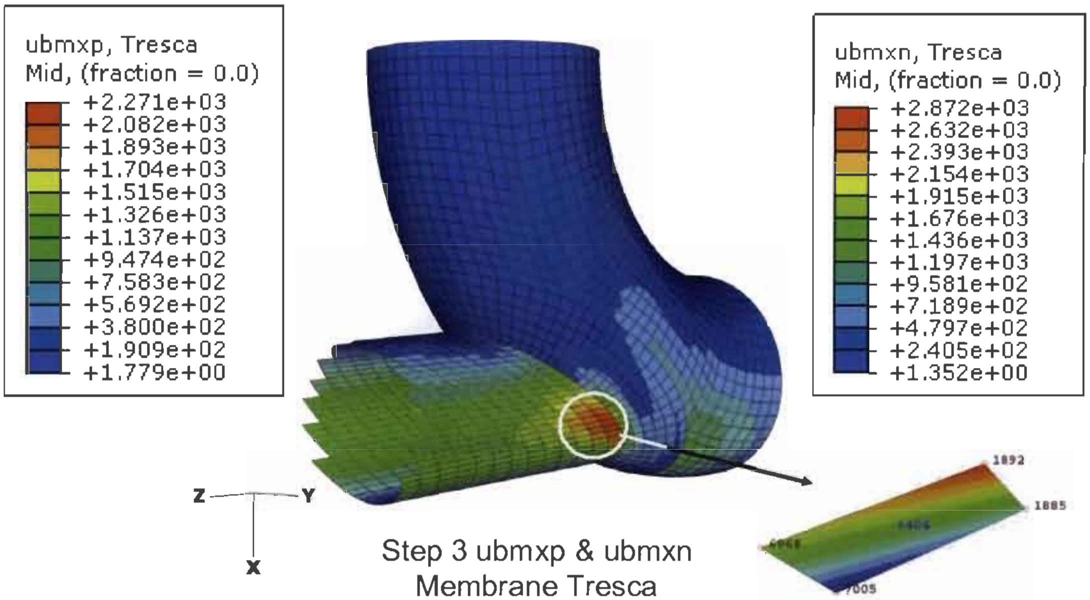

Figure F.2.2-4 – Step 3 membrane Bxp (branch +Mx bending) & Bxn (branch –Mx bending) tresca stresses are at same element, but have different values.

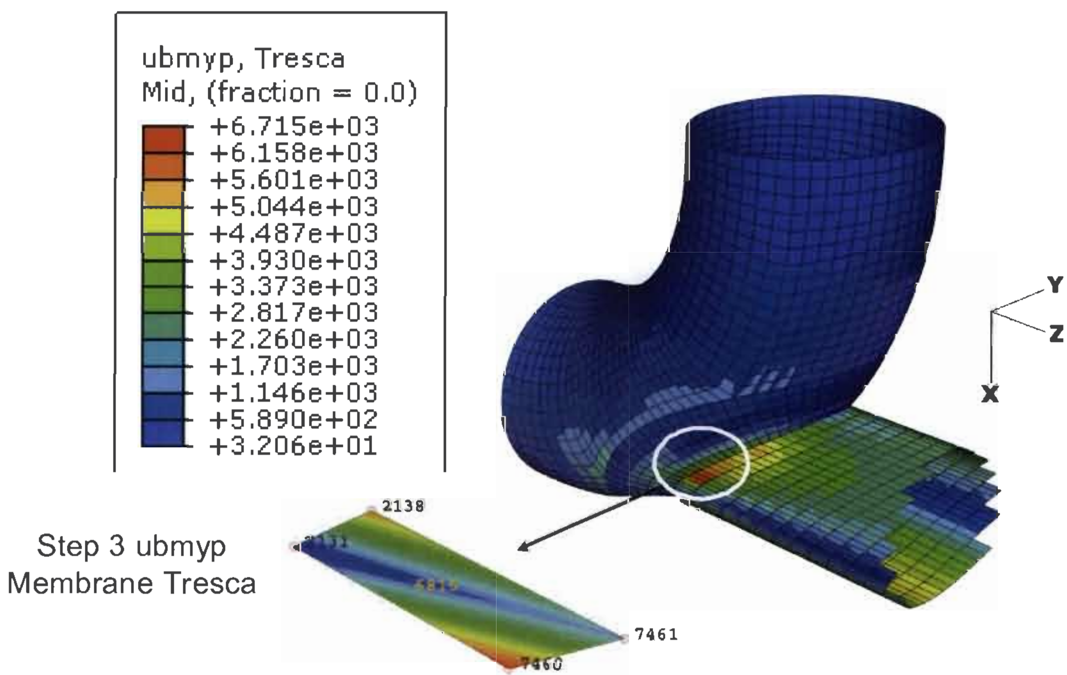

Figure F.2.2-5 – Step 3 membrane Byp (branch +My bending) tresca stresses.

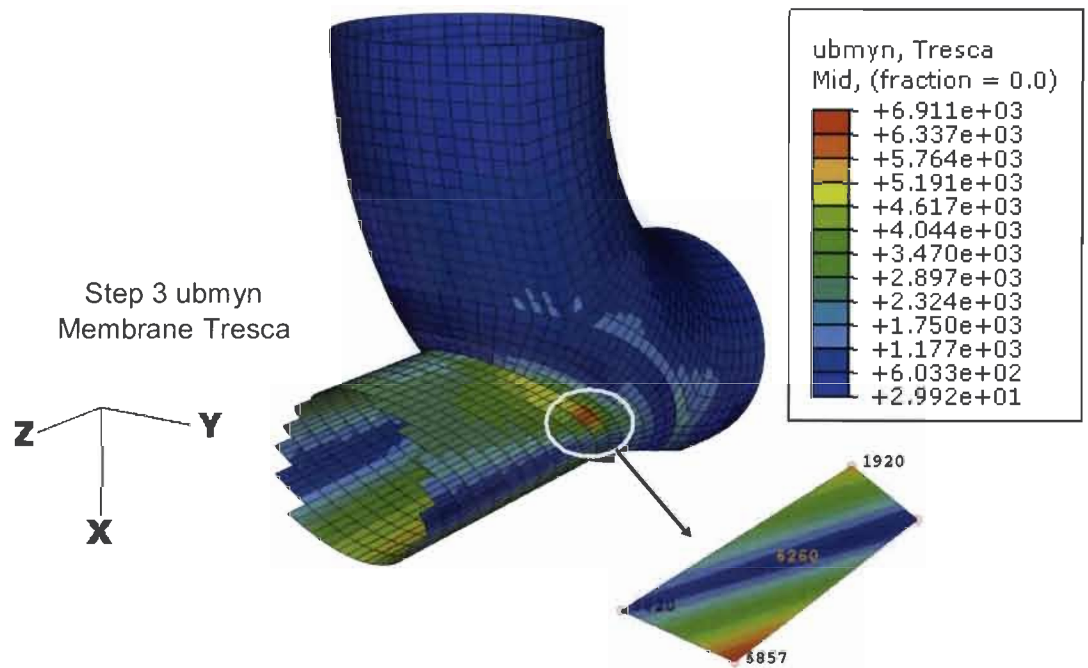

Figure F.2.2-6 – Step 3 membrane Byn (branch –My bending) tresca stresses.

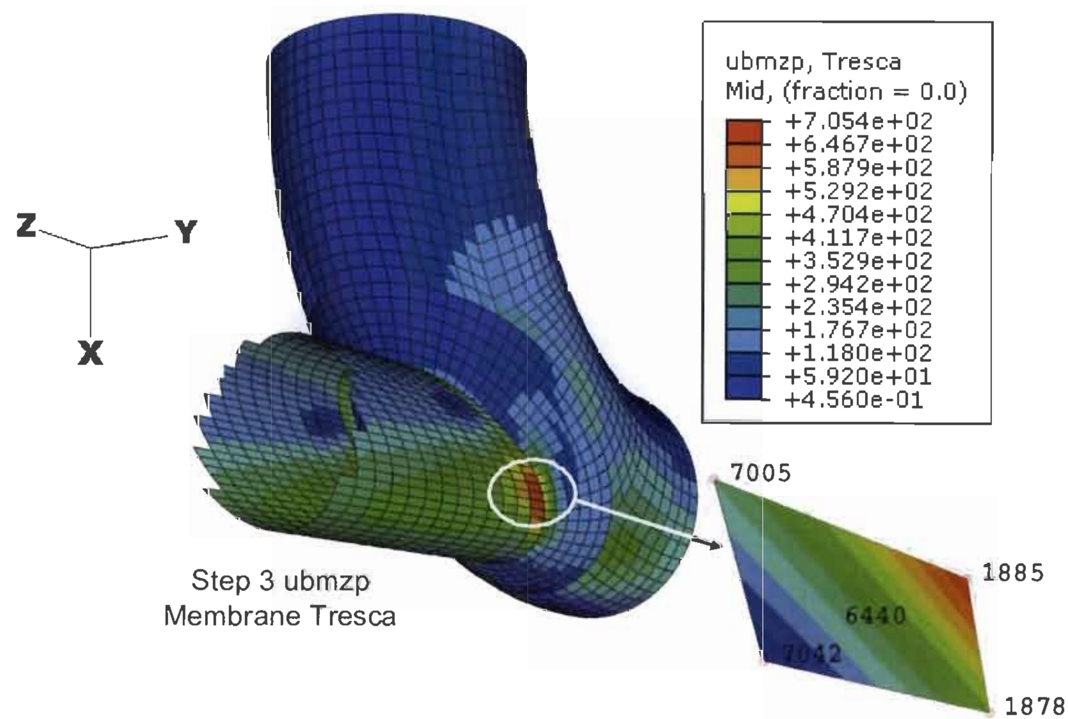

Figure F.2.2-7 – Step 3 membrane Bzp (branch +Mz torsion) tresca stresses.

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

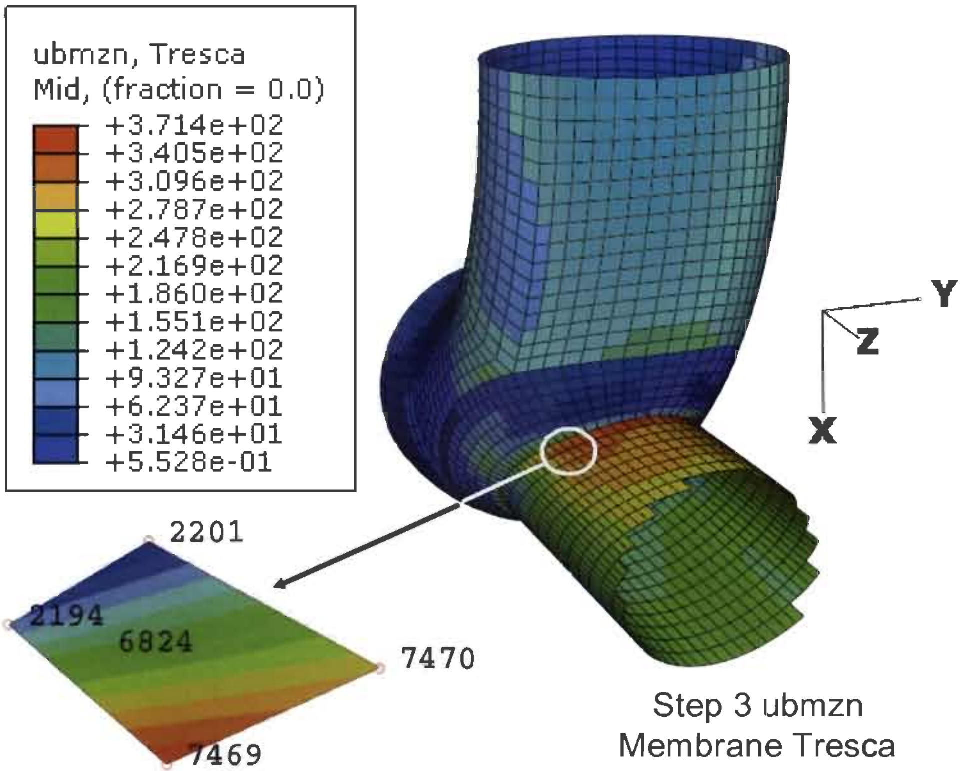

Figure F.2.2-8 – Step 3 membrane Bzn (branch –Mz torsion) tresca stresses.

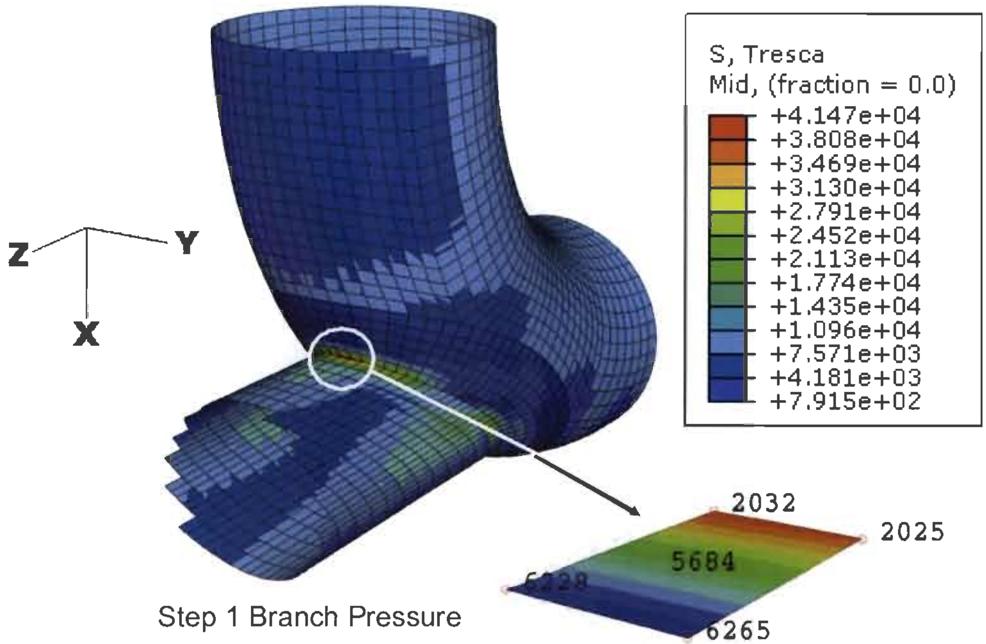

Figure F.2.2-9 – Step 1 membrane (branch pressure) tresca stresses.

Figures F.2.2-10 through F.2.2-15 show maximum membrane tresca stress plots corresponding to +/- bending moment results applied to the top run pipe end. Figure F.2.2-16 shows the corresponding maximum membrane tresca stress plot due to run pressure. The corresponding maximum tresca stress values for each load case (+Mx, -Mx, +My, -My, +Mz, -Mz, P) are contained in file "mt_urun_08_26_08.rpt" reprinted in Appendix F.2.2.1.

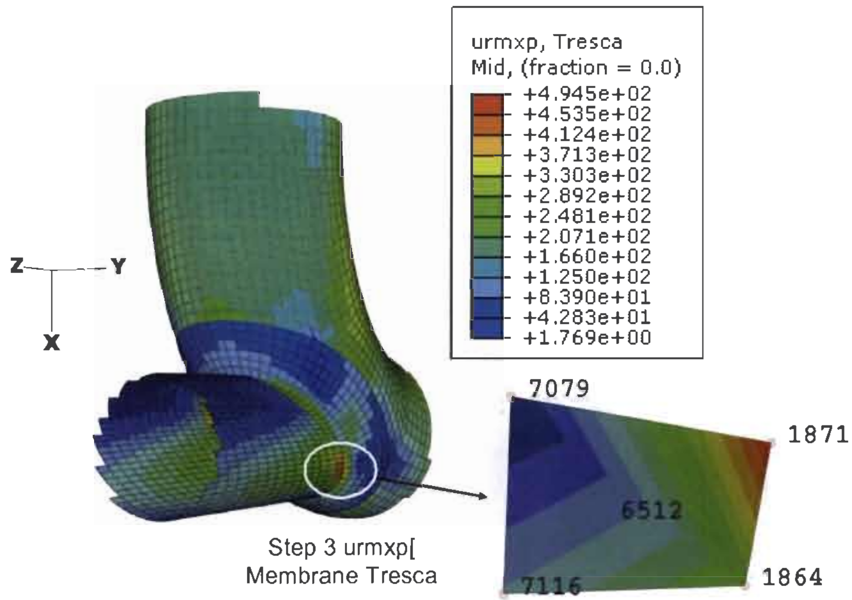

Figure F.2.2-10 – Step 3 membrane Rxp (run +Mx torsion) tresca stresses.

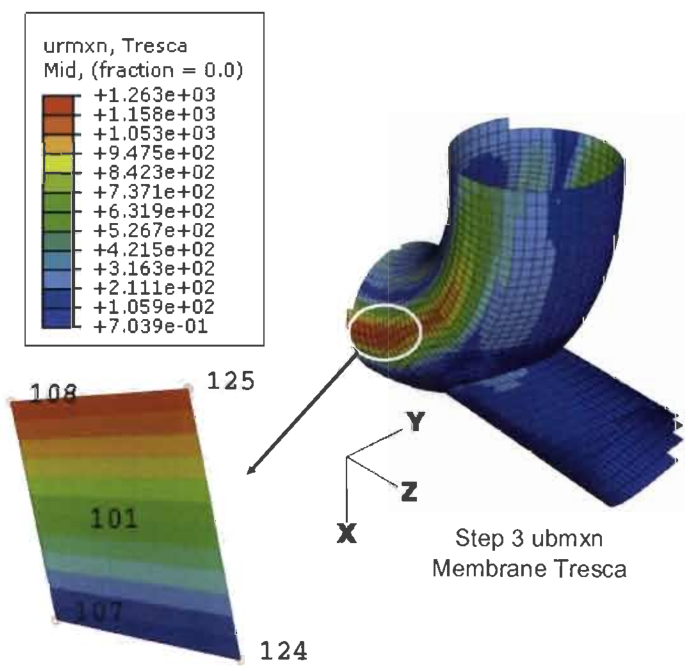

Figure F.2.2-11 – Step 3 membrane Rxn (run -Mx torsion) tresca stresses

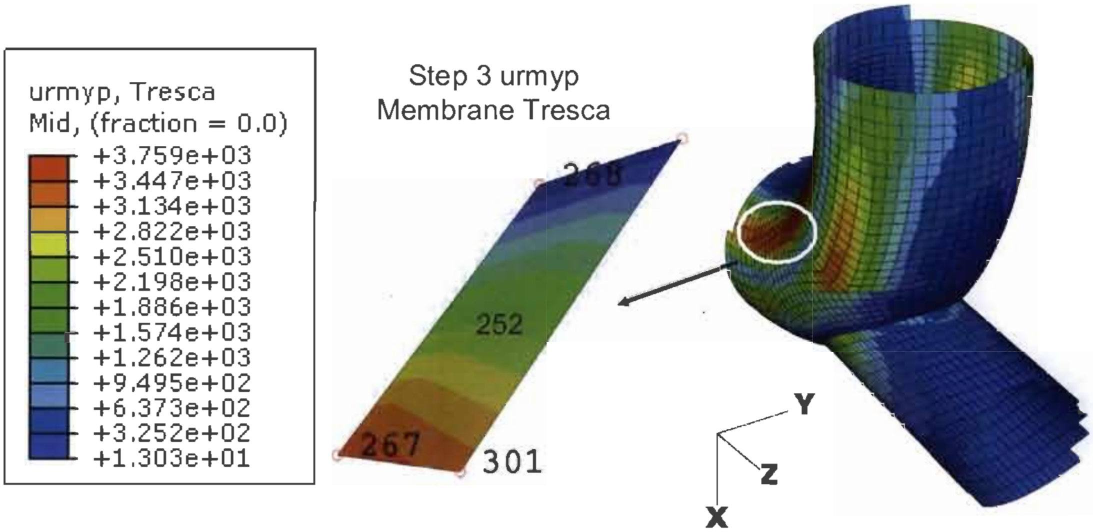

Figure F.2.2-12 – Step 3 membrane Ryp (run +My bending) tresca stresses.

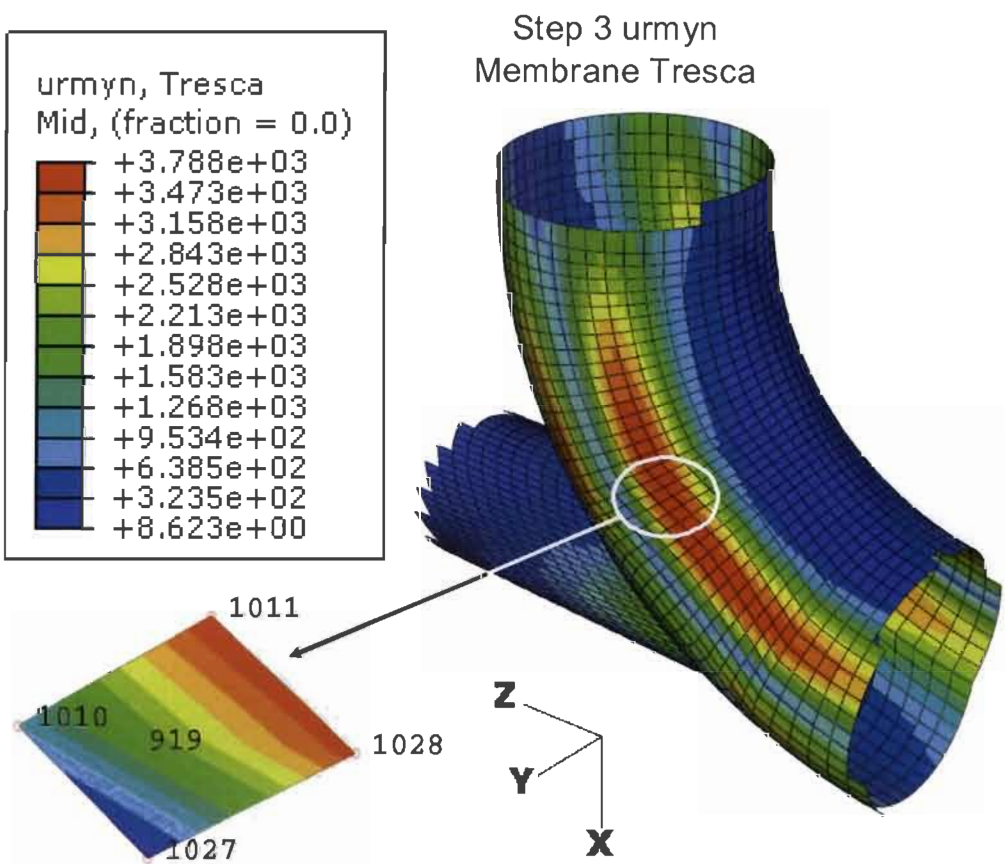

Figure F.2.2-13 – Step 3 membrane Ryn (run -My bending) tresca stresses.

Project:	ATR Life Time Extension Project	ECAR No.:	ECAR-194	Rev.:	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	Date: 09/30/08	Checker: A. S. Siahpush	Date:	09/30/08

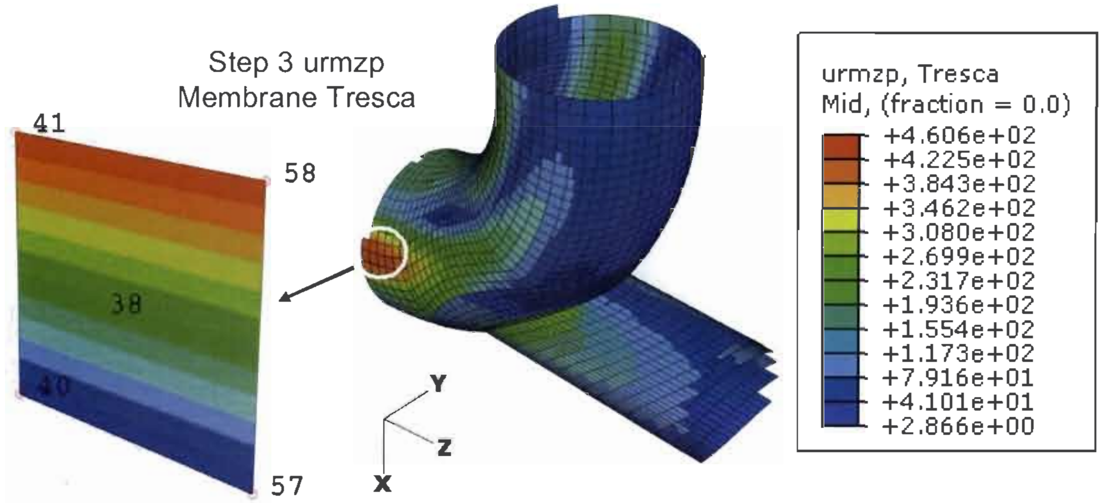

Figure F.2.2-14 – Step 3 membrane Rzp (run +Mz bending) tresca stresses.

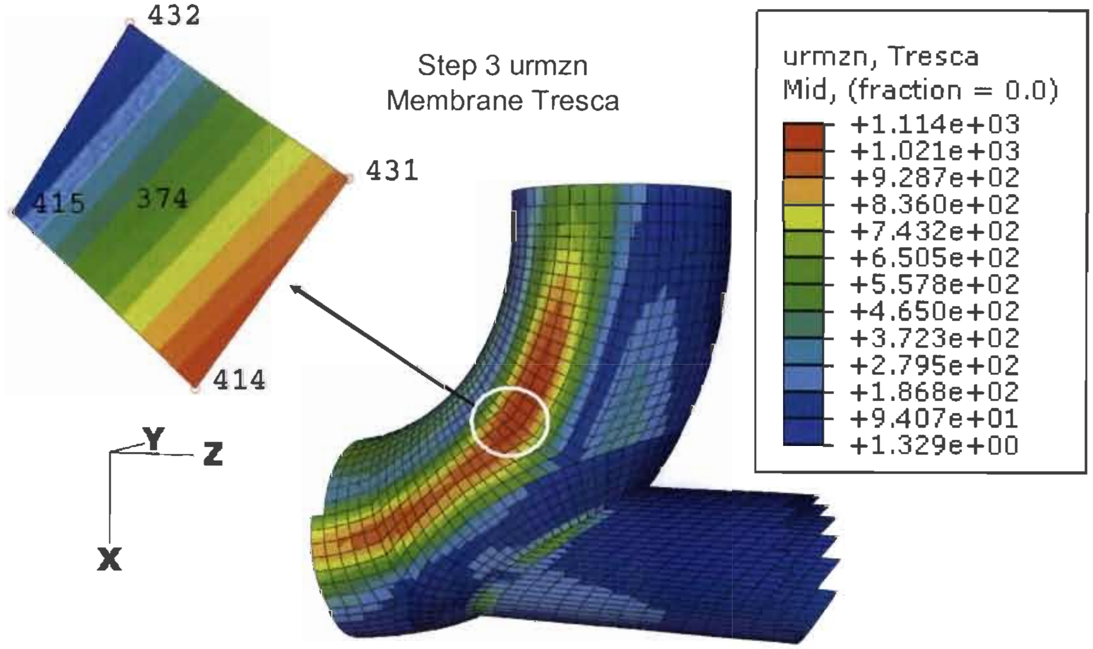

Figure F.2.2-15 – Step 3 membrane Rzn (run –Mz bending) tresca stresses.

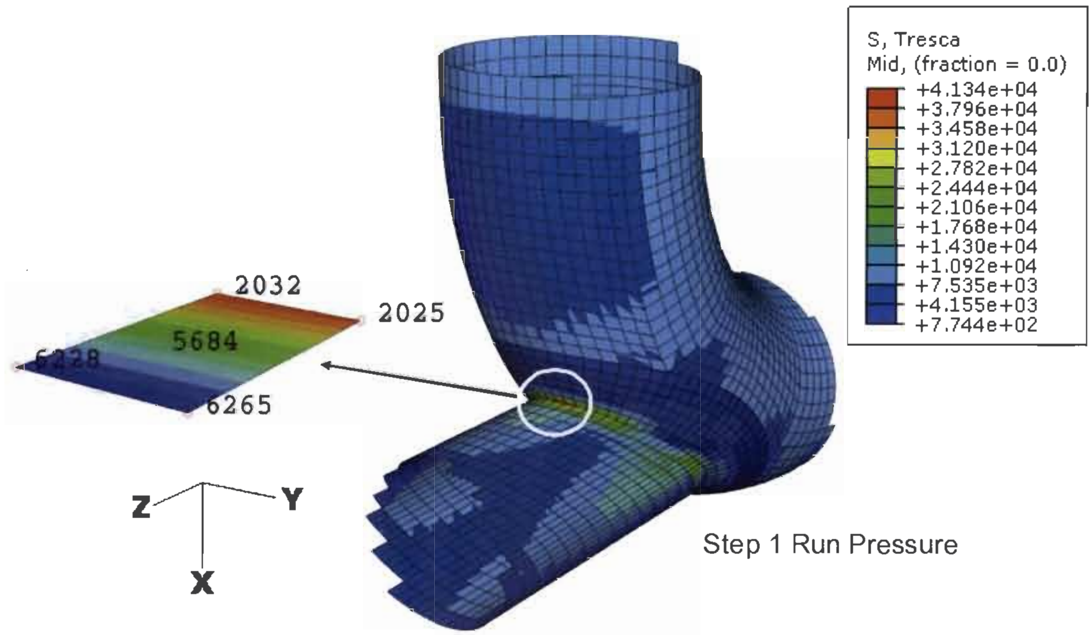

Figure F.2.2-16 - Step 1 membrane (run pressure) tresca stresses is shown.

Project:	ATR Life Time Extension Project	ECAR No.:	ECAR-194	Rev.:	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	Date:	09/30/08	Checker:	A. S. Siahpush	Date:	09/30/08

F.2.2.1 – Unlisted Branch Component Maximum Tresca Stress Result Files

Two files are used to capture maximum tresca stresses for the branch and run load conditions. File "si_mt_run_08_26_08.rpt' contain maximum element and nodal tresca stress values for loads placed on the branch pipe end and file "mt_urun.rpt" contains corresponding data for loads placed on the top run pipe end.

si_mt_ubranch_08_26_08.rpt

```
********************************************************************************
Probe Values Report, written on Wed Sep 03 13:37:41 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_branch_08_26_08_diff/si_mt_
ubranch_08_26_08_mxp.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1        6404          S4        6968        1892        1885
7005


  Part Instance  Element ID        Type            Node   ubmxp: Tresca
--------------------------------------------------------------------------------
    PART-1-1        6404          S4               1       2.2332E+03
    PART-1-1        6404          S4               2       2.2713E+03
    PART-1-1        6404          S4               3      2.20066E+03
    PART-1-1        6404          S4               4      2.16353E+03


********************************************************************************
Probe Values Report, written on Wed Sep 03 14:47:44 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_branch_08_26_08_diff/si_mt_
ubranch_08_26_08_mxn.odb
   Step: Session Step
   Frame: Session Frame
```

```
Loc 1 : Element nodal values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1        6404          S4       6968        1892        1885
7005

  Part Instance  Element ID        Type            Node   ubmxn: Tresca
--------------------------------------------------------------------------------
    PART-1-1        6404          S4               1      2.82569E+03
    PART-1-1        6404          S4               2      2.87158E+03
    PART-1-1        6404          S4               3      2.78194E+03
    PART-1-1        6404          S4               4      2.73716E+03

********************************************************************************
Probe Values Report, written on Wed Sep 03 15:00:31 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_branch_08_26_08_diff/si_mt_
ubranch_08_26_08_myp.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1        6815          S4       2131        2138        7461
7460

  Part Instance  Element ID        Type            Node   ubmyp: Tresca
--------------------------------------------------------------------------------
    PART-1-1        6815          S4               1      5.36578E+03
    PART-1-1        6815          S4               2      6.48548E+03
    PART-1-1        6815          S4               3      5.70404E+03
    PART-1-1        6815          S4               4       6.7149E+03

********************************************************************************
Probe Values Report, written on Wed Sep 03 15:14:31 2008
```

```
Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_branch_08_26_08_diff/si_mt_
ubranch_08_26_08_myn.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1        6260           S4       6820        1920        1913
6857


  Part Instance  Element ID        Type            Node   ubmyn: Tresca
--------------------------------------------------------------------------------
    PART-1-1        6260           S4               1      5.89427E+03
    PART-1-1        6260           S4               2      6.64107E+03
    PART-1-1        6260           S4               3      5.72856E+03
    PART-1-1        6260           S4               4      6.91082E+03


********************************************************************************
Probe Values Report, written on Wed Sep 03 15:30:35 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_branch_08_26_08_diff/si_mt_
ubranch_08_26_08_mzp.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1        6440           S4       7005        1885        1878
7042


  Part Instance  Element ID        Type            Node   ubmzp: Tresca
--------------------------------------------------------------------------------
    PART-1-1        6440           S4               1         663.711
```

```
    PART-1-1        6440          S4              2          705.428
    PART-1-1        6440          S4              3          677.776
    PART-1-1        6440          S4              4          641.662


*********************************************************************************
Probe Values Report, written on Wed Sep 03 15:44:07 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_branch_08_26_08_diff/si_mt_
ubranch_08_26_08_mzn.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
---------------------------------------------------------------------------------
    PART-1-1        6824          S4        2194        2201        7470
7469


  Part Instance  Element ID        Type            Node   ubmzn: Tresca
---------------------------------------------------------------------------------
    PART-1-1        6824          S4              1          298.312
    PART-1-1        6824          S4              2          282.196
    PART-1-1        6824          S4              3          347.147
    PART-1-1        6824          S4              4           371.44


*********************************************************************************
Probe Values Report, written on Wed Sep 03 16:07:14 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_branch_08_26_08_diff/si_mt_
ubranch_08_26_08_mzn.odb
   Step: Step-1
   Frame: Increment     14: Step Time =    1.000

Loc 1 : Element nodal values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
--------------------------------------------------------------------------------
    PART-1-1        5684          S4         6228         2032         2025
6265

  Part Instance  Element ID        Type             Node        S: Tresca
--------------------------------------------------------------------------------
    PART-1-1        5684          S4                1      12.9028E+03
    PART-1-1        5684          S4                2      41.4681E+03
    PART-1-1        5684          S4                3      40.1888E+03
    PART-1-1        5684          S4                4      12.3366E+03
```

si_mt_urun_08_26_08.rpt

```
********************************************************************************
Probe Values Report, written on Wed Sep 03 16:31:41 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_run_08_26_08_diff/si_mt_uru
n_08_26_08_mxp.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1        6512          S4        7079        1871         1864
7116

  Part Instance  Element ID        Type             Node   urmxp: Tresca
--------------------------------------------------------------------------------
    PART-1-1        6512          S4                1          395.646
    PART-1-1        6512          S4                2          494.529
    PART-1-1        6512          S4                3          447.525
    PART-1-1        6512          S4                4          421.343

********************************************************************************
Probe Values Report, written on Wed Sep 03 16:47:45 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_run_08_26_08_diff/si_mt_uru
n_08_26_08_mxn.odb
   Step: Session Step
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:**	09/30/08	**Checker:**	A. S. Siahpush	**Date:**	09/30/08

```
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1          101          S4         107          108          125
124


  Part Instance  Element ID        Type            Node   urmxn: Tresca
--------------------------------------------------------------------------------
    PART-1-1          101          S4              1      1.15242E+03
    PART-1-1          101          S4              2      1.26304E+03
    PART-1-1          101          S4              3      1.26173E+03
    PART-1-1          101          S4              4      1.15095E+03


********************************************************************************
Probe Values Report, written on Wed Sep 03 17:40:17 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_run_08_26_08_diff/si_mt_uru
n_08_26_08_myp.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1          262          S4         295          296          313
312


  Part Instance  Element ID        Type            Node   urmyp: Tresca
--------------------------------------------------------------------------------
    PART-1-1          262          S4              1      3.42311E+03
    PART-1-1          262          S4              2      3.72157E+03
    PART-1-1          262          S4              3       3.7458E+03
    PART-1-1          262          S4              4      3.45865E+03


********************************************************************************
Probe Values Report, written on Wed Sep 03 17:51:30 2008
```

Project:	ATR Life Time Extension Project	ECAR No.:	ECAR-194	Rev.:	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	Date: 09/30/08	Checker: A. S. Siahpush	Date:	09/30/08

```
Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_run_08_26_08_diff/si_mt_uru
n_08_26_08_myn.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1          919          S4        1010         1011         1028
1027


  Part Instance  Element ID        Type             Node   urmyn: Tresca
--------------------------------------------------------------------------------
    PART-1-1          919          S4                1      3.57782E+03
    PART-1-1          919          S4                2      3.78763E+03
    PART-1-1          919          S4                3      3.77667E+03
    PART-1-1          919          S4                4      3.50685E+03

********************************************************************************
Probe Values Report, written on Wed Sep 03 18:00:13 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_run_08_26_08_diff/si_mt_uru
n_08_26_08_mzp.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1           38          S4          40           41           58
57


  Part Instance  Element ID        Type             Node   urmzp: Tresca
--------------------------------------------------------------------------------
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
    PART-1-1           38           S4                1          442.837
    PART-1-1           38           S4                2           460.61
    PART-1-1           38           S4                3          460.428
    PART-1-1           38           S4                4          442.524


********************************************************************************
Probe Values Report, written on Wed Sep 03 18:18:25 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_run_08_26_08_diff/si_mt_uru
n_08_26_08_mzn.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1          374          S4         414         415         432
431


  Part Instance  Element ID        Type            Node   urmzn: Tresca
--------------------------------------------------------------------------------
    PART-1-1          374          S4                1       1.1142E+03
    PART-1-1          374          S4                2          972.163
    PART-1-1          374          S4                3          952.094
    PART-1-1          374          S4                4      1.09502E+03


********************************************************************************
Probe Values Report, written on Wed Sep 03 18:23:14 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_run_08_26_08_diff/si_mt_uru
n_08_26_08_mzn.odb
   Step: Step-1
   Frame: Increment     14: Step Time =    1.000

Loc 1 : Element nodal values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

Part Instance	Element ID	Type	Nodes			
PART-1-1	5684	S4	6228	2032	2025	6265

Part Instance	Element ID	Type	Node	S: Tresca
PART-1-1	5684	S4	1	12.6935E+03
PART-1-1	5684	S4	2	41.3383E+03
PART-1-1	5684	S4	3	40.0537E+03
PART-1-1	5684	S4	4	12.1282E+03

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F.2.3 – Unlisted Branch Component FE model input and FF & SI Determination

The purpose of this section is to determine FE model input, flexibility factor (FF), and stress indices (SI), for Model 256's unlisted elbow/branch component. Pertinent FE model result data are extracted from Appendices F.2.2 and F.2.2.1 for FF and SI value determinations.

FE model input:

Model (256) unlisted branch component => 10" branch extended from 16" elbow

$S_1 := 3.14\,in$ $S_2 := 2.32\,in$

$S_3 := 1.26\,in$

Model 256 Unlisted Branch Component Dimensions:

Branch [21]:

$D_{10} := 10.75\,in$ $t_{10} := 0.25\,in$ Diameter & thickness of 10-in, sch. 20 branch pipe

$d_{10} := D_{10} - 2 \cdot t_{10}$ $d_{10} = 10.25\,in$ Inner diameter of branch pipe

$d10_{mean} := \frac{D_{10} + d_{10}}{2}$ $d10_{mean} = 10.5\,in$ Mean diameter of branch pipe

$r10_{mean} := \frac{d10_{mean}}{2}$ $r10_{mean} = 5.25\,in$ Mean radius of branch pipe

Elbow [20]:

$D_e := 16\,in$ $t_e := \frac{1}{4} \cdot in$ Light weight 90º elbow diameter and thickness [14]

$d_e := D_e - 2 \cdot t_e$ $d_e = 15.5\,in$ Inner diameter of elbow

$de_{mean} := \frac{D_e + d_e}{2}$ $de_{mean} = 15.75\,in$ Mean elbow diameter and radius

$re_{mean} := \frac{de_{mean}}{2}$ $re_{mean} = 7.875\,in$

Find reinforcement plating dimensions

$t_{rein} := \frac{1}{4} \cdot in$ Thickness of reinforcement plate [22]

$$\frac{D_{10}}{S_1} = \frac{w3_{rein}}{S_3} = \frac{w2_{rein}}{S_2}$$

$w3_{rein} := D_{10} \cdot \left(\frac{S_3}{S_1}\right)$ $w3_{rein} = 4.314\,in$ Estimated projected width at S3 of reinforcing plate ring

$w2_{rein} := D_{10} \cdot \left(\frac{S_2}{S_1}\right)$ $w2_{rein} = 7.943\,in$ Estimated projected width at S2 of reinforcing plate ring

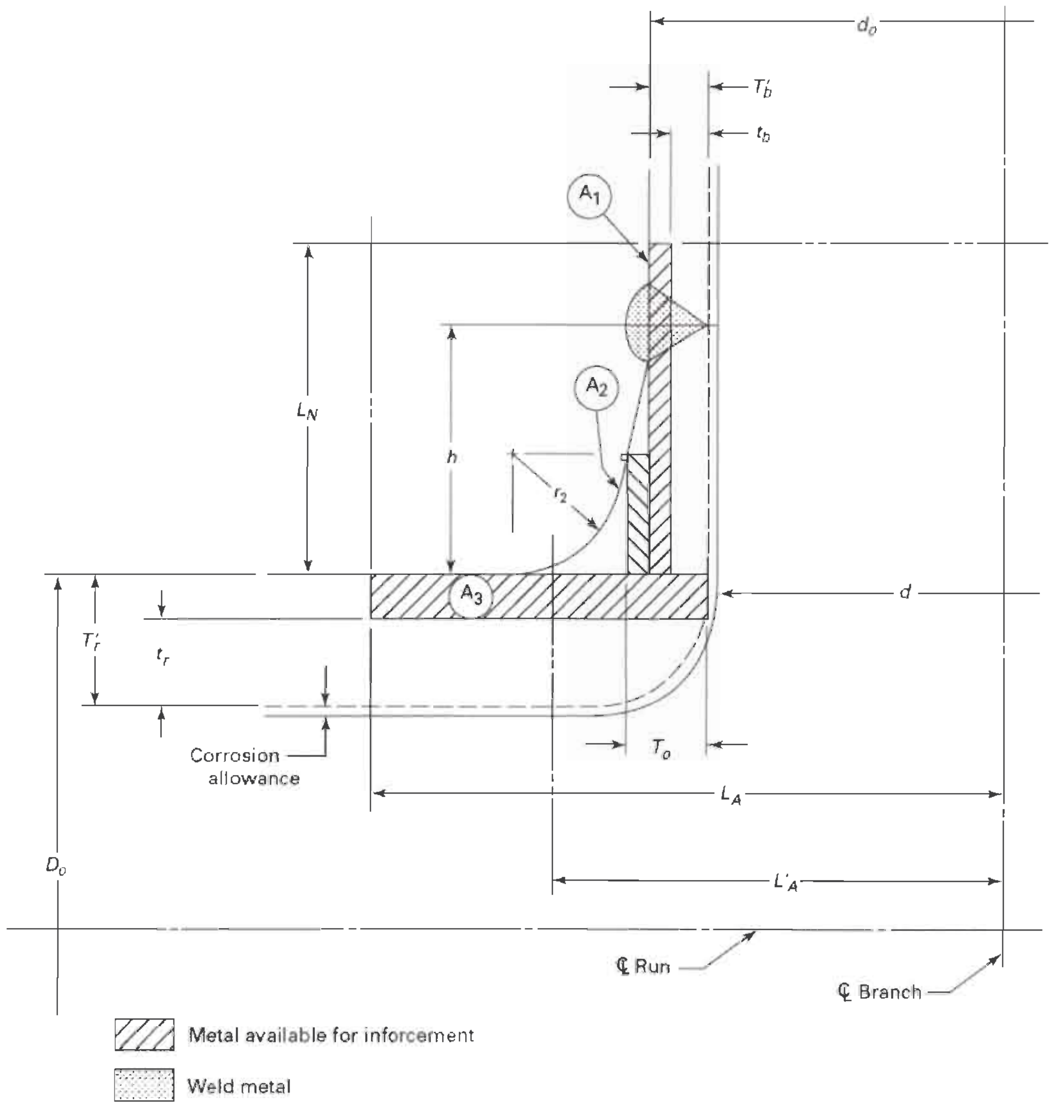
$$wm_{rein} := \frac{w3_{rein} + w2_{rein}}{2} \qquad wm_{rein} = 6.128\,in$$

Estimated projected width at mid point (between S3 & S2) of reinforcing plate ring

It is suspected that the measurement for S2 is incorrect. S2 appears to be dimensioned on the back side of the elbow (due to parallax error) and should have been dimensioned along the plate's welded seam, as was done for S1. Thus, there appears to be a discrepancy between reinforcing plate widths at different locations.

Check these scaled lengths according to code [1, NB-3643.3] and adjust accordingly.

FIG. NB-3643.3(a)-3 TYPICAL REINFORCED EXTRUDED OUTLET



The unlisted branch is reinforced on the run (or elbow) only. Therefore, the maximum reinforcement plate width (per code) corresponds to L_A and the maximum reinforcement area corresponds to A_3. The PCS piping has insignificant corrosion, thus corrosion is approximated to be zero within the following definitions and equations.

$d := d_{10}$ $\quad d = 10.25\,in$ Diameter in the given plane of the finished opening in its corroded condition. For this application, d corresponds to the inner diameter of the branch.

$L_A := d$ $\quad L_A = 10.25\,in$ Half width of the reinforcement zone [1, NB-3643.3(f)(2)(b)]

Thus => $L_A = w_{max} + \frac{D_{10}}{2} = d$

$w_{max} := d - \frac{D_{10}}{2}$ $\quad w_{max} = 4.875\,in$

$\frac{w_{max}}{w2_{rein}} = 0.614$ $\quad \frac{w_{max}}{w3_{rein}} = 1.13$ $\quad \frac{w_{max}}{wm_{rein}} = 0.796$

$A_3 = d \cdot (T'_r - t_r)$ Area A3 is the area lying within the reinforcement zone that results from any excess thickness in the run (or elbow) pipe wall [1, NB-3643.3(f)(3)(c)]

where t_r - minimum required thickness of the run pipe

T'_r - Minimum thickness of the run pipe after extrusion of the opening

$t_r := t_e$ $\quad t_r = 0.25\,in$ Thickness of run (or elbow)

$T'_r := t_r + t_{rein}$ $\quad T'_r = 0.5\,in$ Combined run wall and reinforcement plate thickness

$A_3 := d \cdot (T'_r - t_r)$ $\quad A_3 = 2.563\,in^2$ Maximum cross-sectional area (per code) of reinforcement plate

$A_3 = d \cdot (T'_r - t_r) = \left(w_{rein} + \frac{D_{10}}{2}\right) \cdot t_{rein}$

$wA_{rein} := \frac{A_3}{t_{rein}} - \frac{D_{10}}{2}$ $\quad wA_{rein} = 4.875\,in = w_{max} = 4.875\,in$ Based on area and half width, the reinforcement plate's largest width shall be modeled with a 4.875-in width.

$A_{min} = d \cdot t_r \cdot (2 - \sin(\alpha))$ Minimum cross-sectional area of reinforcement [1, NB-3643.3(b)(2)]

where $\alpha := 90 \cdot deg$ In this application, elbow is approximated as straight run with branch positioned normal to run.

$A_{min} := d \cdot t_r \cdot (2 - \sin(\alpha))$ $A_{min} = 2.563\,in^2$ $\frac{A_{min}}{A_3} = 1$ Minimum area correlates to that of A_3. Thus, (per code) the reinforcement plate is modeled with a uniform width of 4.875-in.

Let => $w_{rein} := w_{max}$ $w_{rein} = 4.875\,in$

Determine length of FE model extension piping, for restraint and moment application:

$re_{mean} = 7.875\,in$

$r10_{mean} = 5.25\,in$

Length of piping on elbow and branch ends, based on minimum distance to flanges [1, NB-3686.2 (c)] shall be no greater than the pipe's mean radius.

Let => $Le_{min} := 6 \cdot re_{mean}$ $Le_{min} = 47.25\,in$ $Le_{min} := 48 \cdot in$

Let => $L10_{min} := 10 \cdot r10_{mean}$ $L10_{min} = 52.5\,in$ $L10_{min} := 53 \cdot in$

Extended 16-in and 10-in pipe lengths for restraint and moment application

FE model material properties:

Operating conditions of pilot model [11, Section 7.1]:

$P := 253 \cdot psi$ $T := 125\,deg$ Pilot model's operating internal pressure and temperature

Let => $\nu := 0.30 \cdot \frac{in}{in}$ $E_{125} := 2.8 \cdot 10^7 \cdot psi$ $G_{125} := 1.075 \cdot 10^7 \cdot psi$ $Sy_{125} := 28.35\,ksi$

$Sm_{125} := 20 \cdot ksi$

Poisson's ratio, Modulus of Elasticity , Section Modulus , & Material Yield Strength at 125 °F, and Allowable Stress Intensity, already computed and retrieved from Appendix F.1.3 and Table 2, from the main report body..

Determine Flexibility Factor (FF) for Unlisted Branch Component:

FF determination shall follow the provisions as outlined in NB-3680 [1] and NB-3686.2 for "Curved Pipe & Welded Elbows" [1]. Initial FF evaluation efforts approximate the unlisted branch to that of a common 16-in light weight 90° welded elbow. The elbow within the unlisted branch is fabricated from rolled plate and welded at the seam. From Section F.1.2, it has been shown that FE results match closely to that of a regular elbow.

From NB-686.2 [1]:

(a) R/r is not less than 1.7

R - bend radius $R := 24 \cdot in$ Bending radius of 16-in elbow [14, p. 8]

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r - elbow mean radius => $re_{mean} = 7.875\,in$

$\frac{R}{re_{mean}} = 3.048$ > 1.7 OK

(b) center line length Rα is greater than 2r

$\alpha := \frac{\pi}{2}$ $\alpha = 90\cdot deg$ 90-deg elbow angle sweep

$\frac{R\cdot\alpha}{2\cdot re_{mean}} = 2.394$ OK

(c) There are no flanges or other similar stiffeners within a distance r from either end of the curved section of pipe or from the ends of welding elbows.

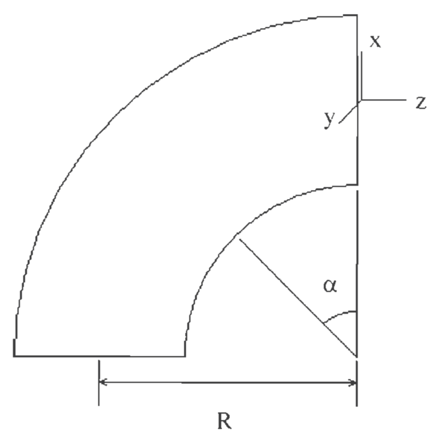
Per geometry with PCS piping, this is true.

$$\theta_{nom1} = \frac{R}{E\cdot I}\cdot\int_0^\theta M_1\,d\alpha \qquad \theta_{ab1} = k\cdot\theta_{nom1} = \frac{k\cdot R}{E\cdot I}\cdot\int_0^\theta M_1\,d\alpha$$

$$\theta_{nom2} = \frac{R}{E\cdot I}\cdot\int_0^\theta M_2\,d\alpha \qquad \theta_{ab2} = k\cdot\theta_{nom2} = \frac{k\cdot R}{E\cdot I}\cdot\int_0^\theta M_2\,d\alpha$$

$$\theta_{nom3} = \frac{R}{G\cdot J}\cdot\int_0^\theta M_3\,d\alpha \qquad \theta_{ab3} = \theta_{nom3} = \frac{R}{G\cdot J}\cdot\int_0^\theta M_3\,d\alpha$$

To address the flexibility factor in the finite element model, an effective area moment of inertia will be established:



$$I_e = \frac{I}{k}$$

Therefore:

$$\theta_{ab1} = \frac{R}{E\cdot I_e}\cdot\int_0^\theta M_1\,d\alpha$$

$$\theta_{ab2} = \frac{R}{E\cdot I_e}\cdot\int_0^\theta M_2\,d\alpha \qquad \theta_{ab3} = \frac{R}{G\cdot J}\cdot\int_0^\theta M_3\,d\alpha$$

Pipe 16 Inch Diameter and 1/4 Thickness

$D_e = 16 \cdot in$ $\quad t_e = 0.25 \cdot in$ $\quad d_e = 15.5 \cdot in$ — Various parameters previously defined

$de_{mean} = 15.75\,in$ $\quad re_{mean} = 7.875\,in$ $\quad P = 253 \cdot psi$

$R = 24 \cdot in$ $\quad E_{125} = 2.8 \times 10^4 \cdot ksi$ $\quad Sy_{125} = 28.35\,ksi$

$$h_e := \frac{t_e \cdot R}{re_{mean}^2} \qquad h_e = 0.097$$

FF equations in NB-3683.2 [1]

$$X_k := 6 \cdot \left(\frac{re_{mean}}{t_e}\right)^{\frac{4}{3}} \cdot \left(\frac{R}{re_{mean}}\right)^{\frac{1}{3}} \qquad X_k = 865$$

$$k_e := \frac{1.65}{h_e} \cdot \left[\frac{1}{1 + \left(\frac{P \cdot re_{mean}}{t_e \cdot E_{125}}\right) \cdot X_k}\right] \qquad k_e = 13.684$$

Calculated FF of 16-in 90° long radius elbow at 125°F

$$I_e := \frac{\pi}{64} \cdot \left(D_e^4 - d_e^4\right) = 383.664\,in^4$$

Moment of inertia of 16-in elbow

$$Ie_{elbow} := \frac{I_e}{k_e} \qquad Ie_{elbow} = 28.038\,in^4$$

Effective moment of inertia for 16-in elbow

$$M_o := 4.671 \cdot 10^4 \cdot in \cdot lbf$$

$$\frac{M_o \cdot \frac{D_e}{2}}{I_e} = 0.974\,ksi$$

Moment (My) extracted from unlisted branch component preliminary runs and applied to FE model meshes for FF evaluation. Moment corresponds to value less then material's yield point.

$$k = \frac{\theta_{ab}}{\theta_{nom}}$$

General definition of flexibility factor [1, NB-3682]

where θ_{ab} - rotation of end "a" with respect to end "b", due to moment load (Mo)

θ_{nom} - nominal rotation due to moment load (Mo)

Previously defined:

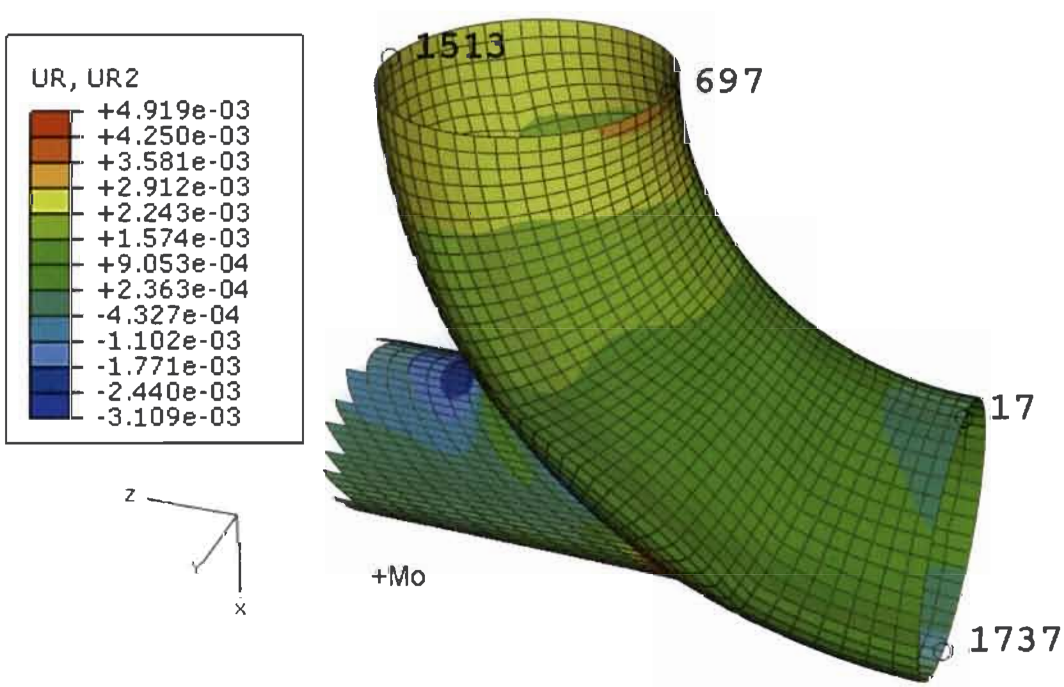
$$\theta_{nom} = \frac{R}{E_{125} \cdot I_{elbow}} \int_0^{\frac{\pi}{2}} M_o \, d\alpha = \frac{M_o \cdot R}{E_{125} \cdot I_{elbow}} \cdot \left(\frac{\pi}{2} - 0\right)$$

$\theta_{nom} := \dfrac{\pi \cdot M_o \cdot R}{2 \cdot E_{125} \cdot I_e}$ $\theta_{nom} = 9.392 \times 10^{-3} \cdot deg$ Computed for 16-in elbow

$\theta_{ab} := k_e \cdot \theta_{nom}$ $\theta_{ab} = 0.129\,deg$ Angular deflection for regular 16-in elbow.

Compare above calculated elbow values to corresponding unlisted branch FE model.

Displacement coordinate data obtained from Appendix F.2.2, corresponding to Fig. F.2.2-1. 16x10 unlisted branch displacements shown below for +Mo.



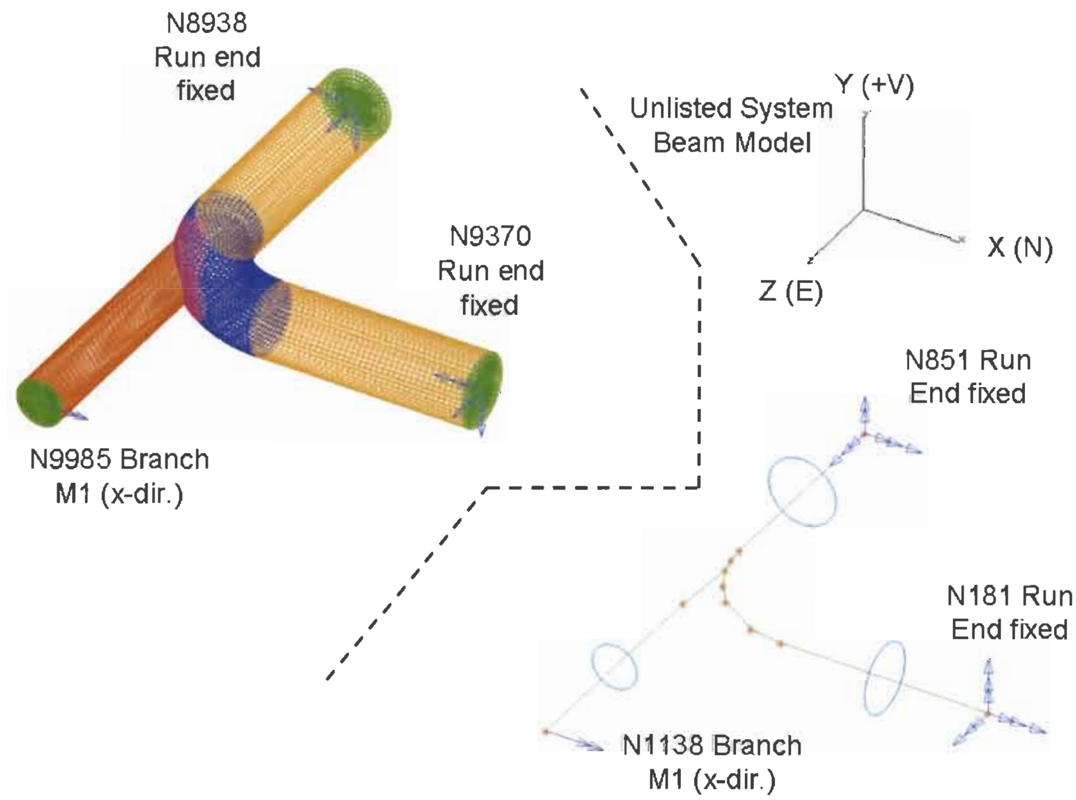
Displacement coordinate data obtained from Appendix F.2.2, corresponding to Fig. F.2.2-2. 16x10 unlisted branch displacements shown following for -Mo.

$\frac{|\theta bu_{ab}|}{\theta_{ab}} = 1.112$ Unlisted branch FE model mesh of elbow/branch has more flexibility (or is less stiff) than that of a regular 16-in elbow

$kb_{ue} := \frac{|\theta bu_{ab}|}{\theta_{nom}}$ $kb_{ue} = 15.221$ Flexibility factor for unlisted branch component

$Ib_{ue} := \frac{I_e}{kb_{ue}}$ $Ib_{ue} = 25.207\,in^4$ Corresponding unlisted branch net effective moment of inertia

Compare flexibilities between shell and beam models of Model 256 elbow/branch unlisted component:

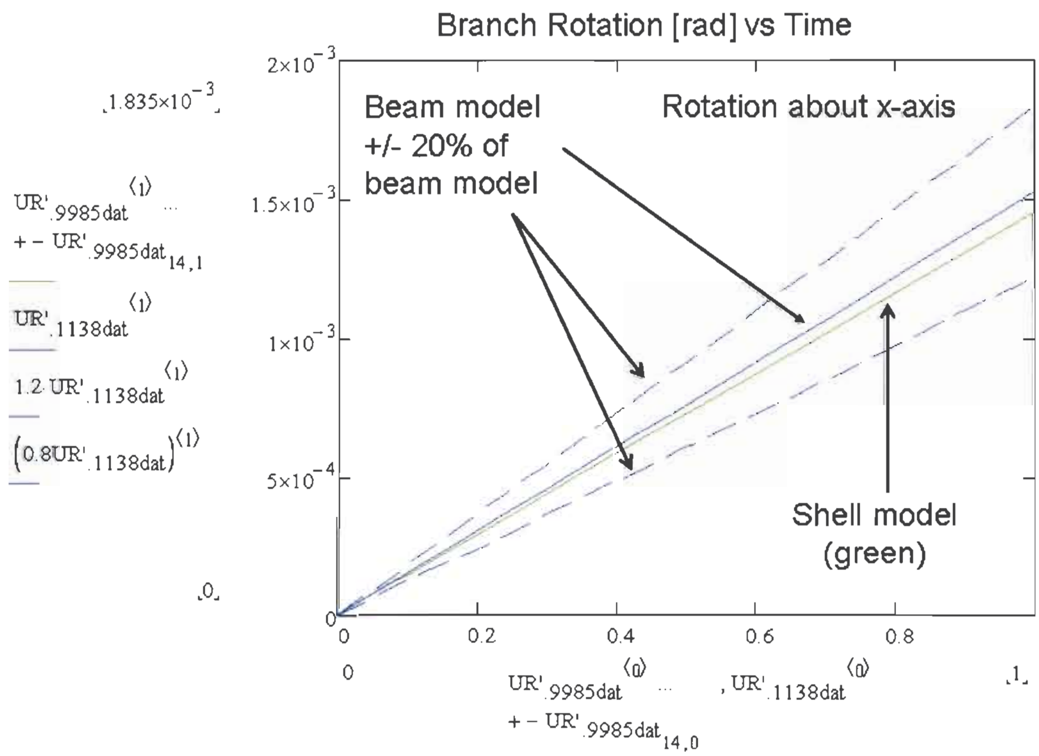


Mx My Mz

$n_{149} := \left(5.144\cdot 10^4 \quad 9.801\cdot 10^4 \quad -1.036\cdot 10^4\right)^T$

To check the flexibility, three load cases are run with the beam and shell models with the most recent 80 percentile solution runs. Each beam model load case consists of a single moment direction applied to its end branch node (i.e. 51,440 inlbf in the global x-direction, 98,010 inlbf in global y-direction, or -10,360 inlbf in the global z-direction). The model is fully restrained where the run pipe is cut. Each shell model is run with the same boundary conditions as its corresponding beam model. However, the shell model has an additional initial step where an internal pressure of 253 psi is applied. The following plots include the results from the shell model and the beam model. Additionally, beam results scaled plus and minus 20% are included for information. The shell model results have two steps. Displacements that occur during the first step, due to the pressure loading, are subtracted from the total curve so that only the relative displacement of caused by the moment is plotted.

The input files used for the beam models were "beam_mt_branch_16x10_m1.inp", "beam_mt_branch_16x10_m2.inp", and "beam_mt_branch_16x10_m3.inp". The input files used for the shell models were "shell_mt_branch_16x10_m1.inp", "shell_mt_branch_16x10_m2.inp", and "shell_mt_branch_16x10_m3.inp". In both sets of input files, the number change of 1, 2, and 3 represent the x-axis run, the y-axis run, and the z-axis run respectivel



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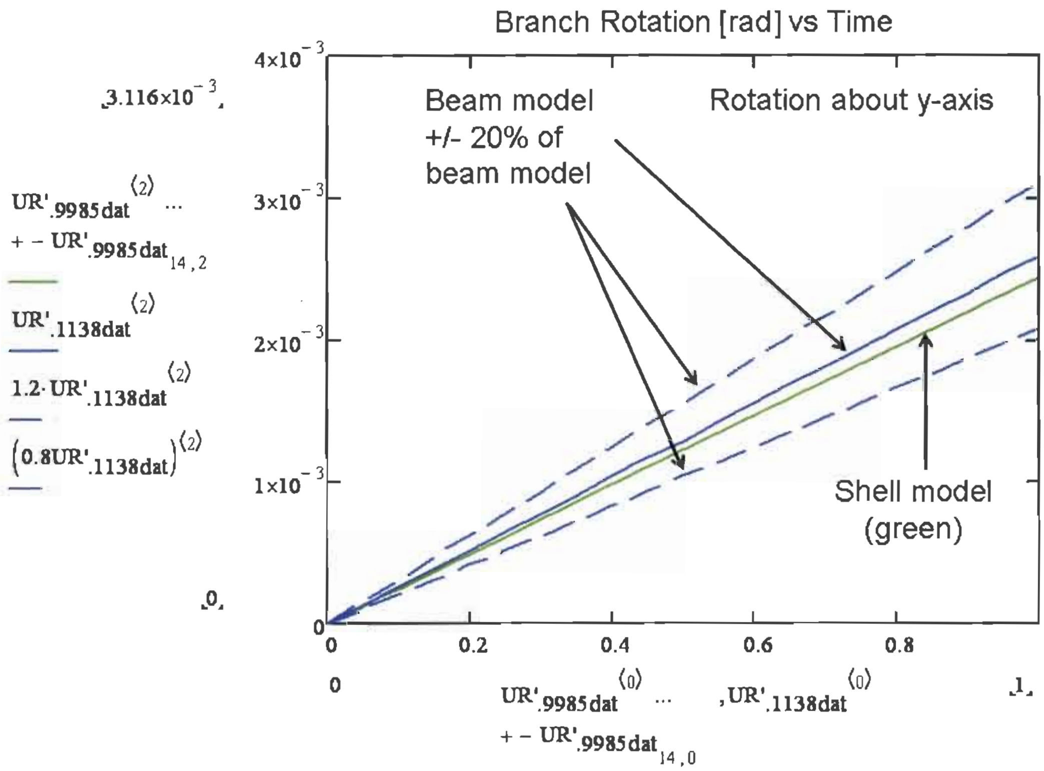

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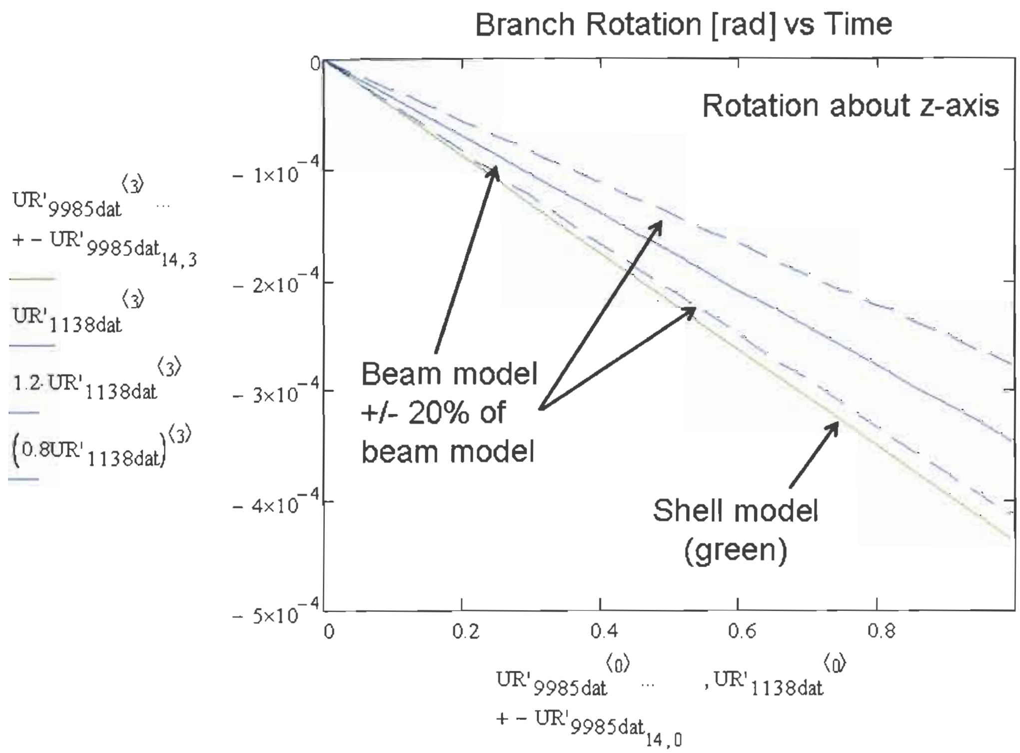

The x-direction and y-direction flexibility shell and beam models show good correlation. As see in the z-direction graph, flexibility of shell model is outside the +/- 20% range of the beam model. Will determine new flexibility factor of beam model for z-direction.

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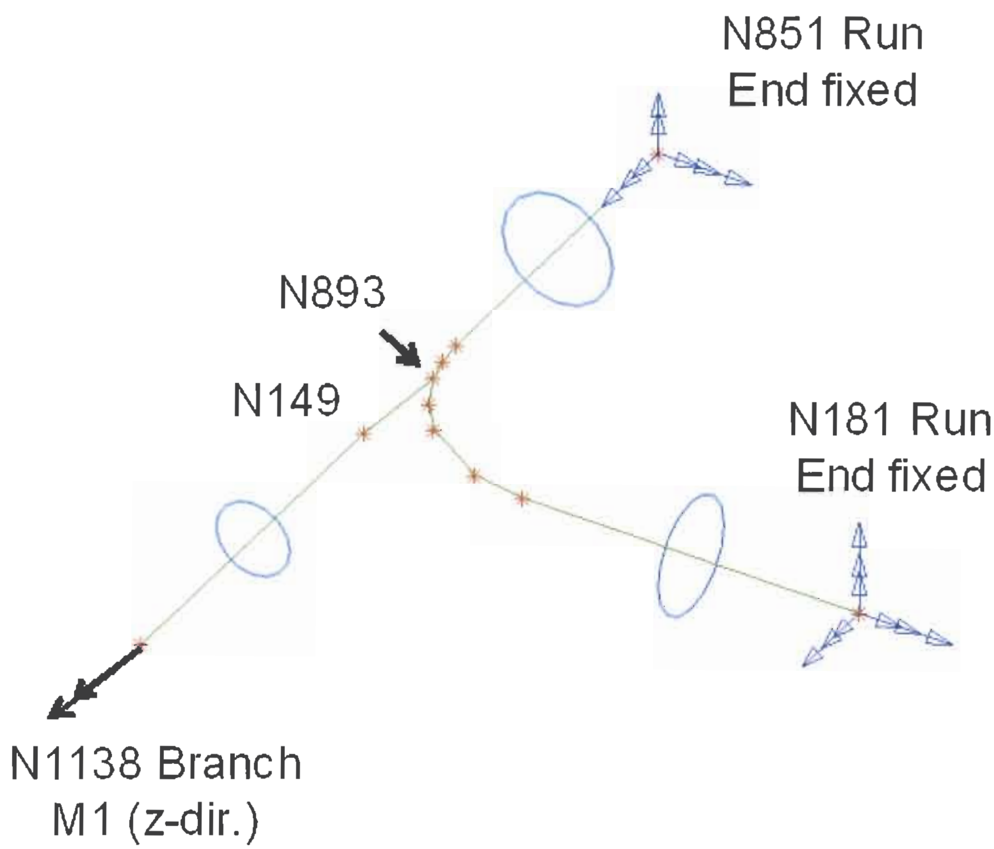
Global 3 (z-direction)



The beam model has two intermediate nodes (N149 & N893) along its branch segment. Node 149 corresonds to the run's outer diameter surface and node 893 correlates to the center intersection between the branch and run neutral axis. The shell model does not have these nodes, for it models the exterior branch/run surface of this intersection. Following are the rotations about the z-direction for these interior beam branch nodes.

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$UR'_{beam\_mt\_ur3\_ncdat} :=$

$UR'_{beam\_mt\_ur3\_ncdat} =$

Time	N149	N893	N1138
0	0	0	0
0.05	−0.00000567	−0.0000025	−0.00001729
0.1	−0.00001133	−0.000005	−0.00003459
0.15	−0.000017	−0.0000075	−0.00005188
0.2	−0.00002266	−0.00000999	−0.00006917
0.25	−0.00002833	−0.00001249	−0.00008647
0.3	−0.000034	−0.00001499	−0.00010376
0.35	−0.00003966	−0.00001749	−0.00012105
0.4	−0.00004533	−0.00001999	−0.00013834
0.45	−0.00005099	−0.00002249	−0.00015564
0.5	−0.00005666	−0.00002498	−0.00017293
0.55	−0.00006233	−0.00002748	−0.00019022
0.6	−0.00006799	−0.00002998	−0.00020752
0.65	−0.00007366	−0.00003248	−0.00022481
0.7	−0.00007932	−0.00003498	−0.0002421
0.75	−0.00008499	−0.00003748	−0.0002594
0.8	−0.00009066	−0.00003998	−0.00027669
0.85	−0.00009632	−0.00004247	−0.00029398
0.9	−0.00010199	−0.00004497	−0.00031128
0.95	−0.00010765	−0.00004747	−0.00032857
1	−0.00011332	−0.00004997	−0.00034586

$UR'_{149\_ur3\_ncdat} := UR'^{\langle 1 \rangle}_{beam\_mt\_ur3\_ncdat}$ Creation of array for node 149

$UR'_{893\_ur3\_ncdat} := UR'^{\langle 2 \rangle}_{beam\_mt\_ur3\_ncdat}$ Creation of array for node 893

$UR'_{1138\_ur3\_ncdat} := UR'^{\langle 3 \rangle}_{beam\_mt\_ur3\_ncdat}$ Creation of array for node 1138

The next step is to determine a new beam flexibility factor (in z-direction) for the beam model that correlates to the shell model.

$\theta3\_n1138b\_nc := UR'1138\_ur3\_ncdat_{rows(UR'1138\_ur3\_ncdat)-1}$ — Maximum rotation at N1138 (end of branch) for beam model

$\theta3\_n1138b\_nc = -3.459\times 10^{-4}$

$\theta3\_n149b\_nc := UR'149\_ur3\_ncdat_{rows(UR'149\_ur3\_ncdat)-1}$ — Maximum rotation at N149 (edge of run surface) for beam model

$\theta3\_n149b\_nc = -1.133\times 10^{-4}$

$\theta3\_n893b\_nc := UR'893\_ur3\_ncdat_{rows(UR'893\_ur3\_ncdat)-1}$ — Maximum rotation at N893 (intersection between run and branch) for beam model

$\theta3\_n893b\_nc = -4.997\times 10^{-5}$

$\theta3\_n9985s := UR'9985dat_{rows(UR'9985dat)-1,3}$ — Maximum rotation at N9985 (end of branch) for shell model

$\theta3\_n9985s = -4.214\times 10^{-4}$

$\theta3\_n1138b\_nc_{ctr} := \theta3\_n149b\_nc - \theta3\_n893b\_nc$ — Rotation of center tee portion of beam (between nodes 149 & 893)

$\theta3\_n1138b\_nc_{ctr} = -6.335\times 10^{-5}$

$\theta3\_n9985s_{ctr} := \theta3\_n9985s - (\theta3\_n1138b\_nc - \theta3\_n1138b\_nc_{ctr})$ — Correlated rotation of center tee portion of shell

$\theta3\_n9985s_{ctr} = -1.389\times 10^{-4}$

$k3_{branch} := \dfrac{\theta3\_n9985s_{ctr}}{\theta3\_n1138b\_nc_{ctr}}$ $k3_{branch} = 2.192$ — Flexibility in global 3 (z-direction)

$D_{10} = 10.75\,in$ $d_{10} = 10.25\,in$ $t_{10} = 0.25\,in$ — Outside diamter, inside diameter and thickness of branch pipe, previously defined.

$A_{10} := \frac{\pi}{4}\cdot\left(D_{10}^{2} - d_{10}^{2}\right)$ $A_{10} = 8.247\,in^{2}$ — Branch area

$I_{10} := \frac{\pi}{64}\cdot\left(D_{10}^{4} - d_{10}^{4}\right)$ $I_{10} = 113.714\,in^{4}$ — Branch moment of inertia

$J_{10} := \frac{\pi}{32}\cdot\left(D_{10}^{4} - d_{10}^{4}\right)$ $J_{10} = 227.428\,in^{4}$ — Branch polar moment of inertia

$I_e = \frac{I}{k}$ Net effective moment of inertia

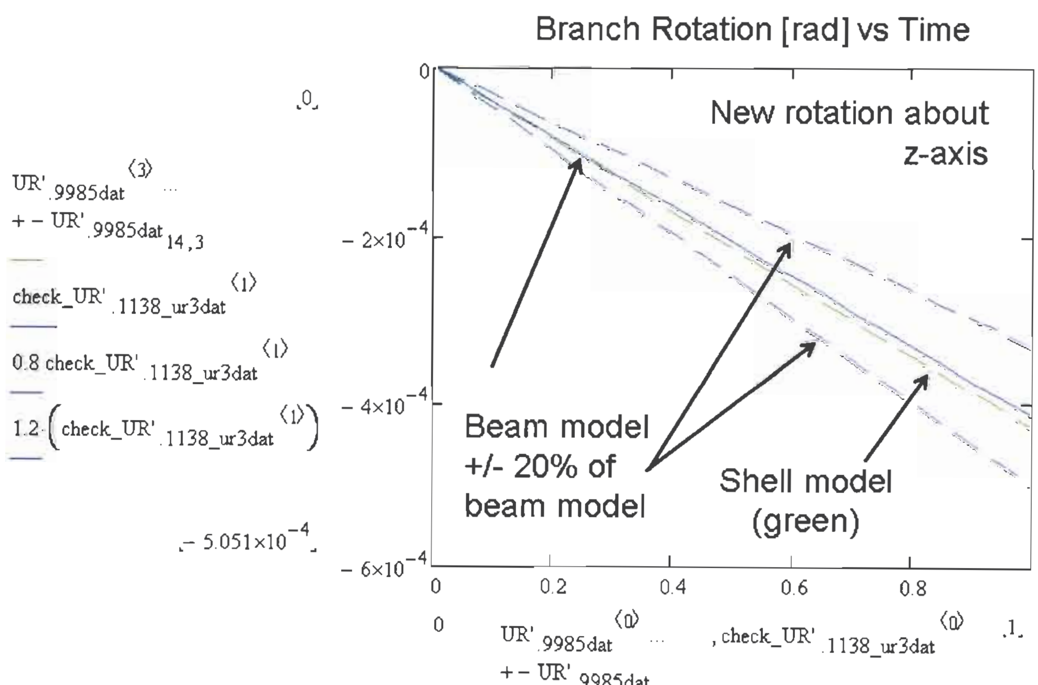
$J_e = \frac{J}{k}$ Net effective polar moment of inertia

$J3_{branch} := \frac{J_{10}}{k3_{branch}}$ $J3_{branch} = 103.736\,in^4$

A check is performed by changing the beam section properties (at its center, between nodes 149 & 893) and obtaining results for z-direction. Results of this check were derived from ABAQUS file "check_beam_mt_branch_16x10_m3.inp," and an abbreviated listing of it is in Appendix F.2.9.

$check\_UR'_{1138\_ur3dat} :=$

$$\frac{check\_UR'_{1138\_ur3dat_{rows(check\_UR'_{1138\_ur3dat})-1,1}}}{UR'_{9985dat_{rows(UR'_{9985dat})-1,3}}} = 0.999$$



With new flexibility factor applied in the z-direction, the check shows that there is now excellent correlation between the beam and shell models.

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Unlisted Branch Component Stress Indices

(9) $B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot M_i$ <= $1.5 \cdot S_m$ — Primary SI limit is satisfied if equation 9 is met [1, NB-36-3652]

For SI determination, will approximate unlisted component as a branch fabricated normal to a straight pipe run. In this case, the 16-in elbow is approximated as the run (which has been straightened out) and the 10-in pipe is approximated as the branch. In this configuration, the branch is normal to the run.

For straight run pipe with smaller diameter branch:

(9) $B_1 \cdot \left(\frac{P \cdot D_o}{2 \cdot T_r}\right) + \left[B_{2b} \cdot \left(\frac{M_b}{Z_b}\right) + B_{2r} \cdot \left(\frac{M_r}{Z_r}\right)\right]$ <= $1.5 \cdot S_m$ — Equation 9 is modified for its moment terms [1, NB-3683.1]

B_1 - primary stress indice for pressure
B_{2b} - primary stress indice for branch contribution
B_{2r} - primary stress indice for run moments contribution
D_o - outside diameter of run (in)
M_b - branch moments (Mx, My, Mz) due to a combination of mechanical loads (in*lbf)
M_r - run moments (Mx, My, Mz) due to a combination of mechanical loads (in*lbf)
P - Design Pressure (psi)
S_m - allowable design stress intensity value (psi)
T_r - nominal wall thickness of run (in)
Z_b - approximate section modulus of attached branch pipe (in^3)
Z_r - approximate section modulus of designated run pipe (in^3)

$P = 253 \cdot psi$ $\quad Sm_{125} = 20 \cdot ksi$ $\quad Sy_{125} = 28.35\,ksi$ — Previously defined parameters $t_e = 0.25 \cdot in$

where: Let => $T_r := t_e$ $\quad T_r = 0.25\,in$ $\quad D_e = 16 \cdot in$

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Per Section NB-3656(a) [1]: Level D Service Limits apply

(1) $P = 253 \cdot psi < 2 \cdot P_a$

$$P_a = \frac{2 \cdot S_m \cdot t}{D_o - 2 \cdot y \cdot t}$$ (3) [1, Section NB-3641.1]

where P_a Calculated maximum allowable internal pressure of straight pipe

$y := 0.4$ $Y := 0.4$ [1,Section NB-3641.1]

$P_a := \frac{2 \cdot Sm_{125} \cdot T_r}{D_e - 2 \cdot y \cdot T_r}$ $P_a = 632.911 \, psi$ $\frac{2P_a}{P} = 5.003$ OK

Equation 9 adapted for level D service limits

(9) $B_1 \cdot \left(\frac{P \cdot D_o}{2 \cdot T_r}\right) + \left[B_{2b} \cdot \left(\frac{M_b}{Z_b}\right) + B_{2r} \cdot \left(\frac{M_r}{Z_r}\right)\right]$ =< min(3*Sm, 2*Sy)

where $3 \cdot Sm_{125} = 60 \cdot ksi$ $2 \cdot Sy_{125} = 56.7 \cdot ksi$ 2*Yield at 125°F governs

(9) $B_1 \cdot \left(\frac{P \cdot D_o}{2 \cdot T_r}\right) + \left[B_{2b} \cdot \left(\frac{M_b}{Z_b}\right) + B_{2r} \cdot \left(\frac{M_r}{Z_r}\right)\right]$ =< $2 \cdot Sy_{125} = 56.7 \cdot ksi$

$Z_b = \pi \cdot (r'_m)^2 \cdot T'_b$ Approximate branch section modulus [1, NB-3683.1]

where r'_m - mean radius of attached branch pipe (in)

T'_b - nominal wall thickness of attached branch pipe (in)

$r10_{mean} = 5.25 \cdot in$ $t_{10} = 0.25 \cdot in$ Previously defined

$Z_b := \pi \cdot (r10_{mean})^2 \cdot t_{10}$ $Z_b = 21.648 \, in^3$

$Z_r = \pi \cdot (R_m)^2 \cdot T_r$ Approximate run section modulus [1, NB-3683-1]

where R_m - mean radius of designated run pipe (in)

T_r - nominal wall thickness of designated run pipe (in)

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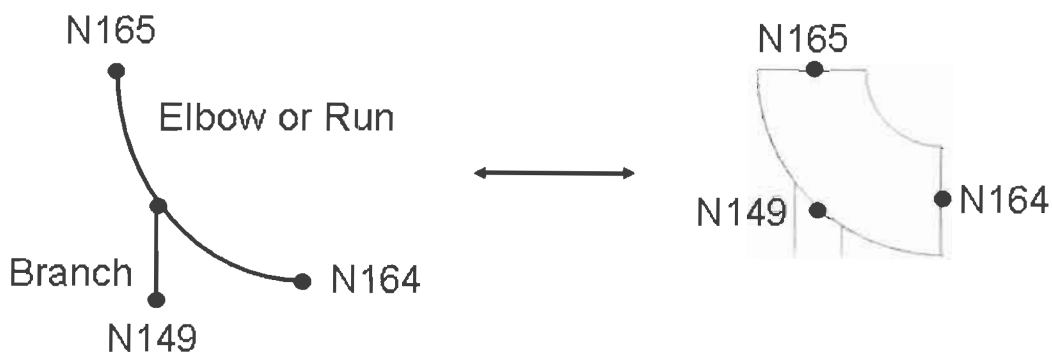
$re_{mean} = 7.875 \cdot in$ $T_r = 0.25 \cdot in$ Previously defined

$Z_r := \pi \cdot (re_{mean})^2 \cdot T_r$ $Z_r = 48.71 \cdot in^3$

The following outline illustrates ;Model 256's unlisted component (16-in elbow branched with 10-in pipe) for preliminary 80 percentile solution run set. The unlisted component is approximated as a standard branch with the 16-in elbow forming the run and the 10-in pipe forming the branch. Nodes 165 and 164 depict the start and end conditions of the run and node 149 depicts the end condition of the branch. The following matrix identifies the scoping nodal moment reactions for each of the run (N165 & N164) and branch (N149) conditions, obtained from Table F.2.1-4 (Appendix F).

Preliminary 80 Percentile Nodal Moment Reactions used for Scoping Stress Indices Calculations



Mx My Mz

$n_{149} := (2.778 \cdot 10^4 \quad 7.788 \cdot 10^4 \quad -4.084 \cdot 10^3)^T$ $N_{149} := |n_{149}|$ $N_{149} = 8.279 \times 10^4$

$n_{164} := (528.946 \quad 4.357 \cdot 10^4 \quad -3.091 \cdot 10^4)^T$ $N_{164} := |n_{164}|$ $N_{164} = 5.342 \times 10^4$

$n_{165} := (9.978 \cdot 10^3 \quad -5.874 \cdot 10^4 \quad 8.298 \cdot 10^3)^T$ $N_{165} := |n_{165}|$ $N_{165} = 6.016 \times 10^4$

$M_{ub} := N_{149} \cdot in \cdot lbf$ $M_{ub} = 82.787 \cdot in \cdot kip$ Branch resultant moment at N149

$M_{ur} := if(N_{164} \geq N_{165}, N_{164}, N_{165}) \cdot in \cdot lbf$ $M_{ur} = 60.157 \cdot in \cdot kip$ Maximum run resultant moment based on N165

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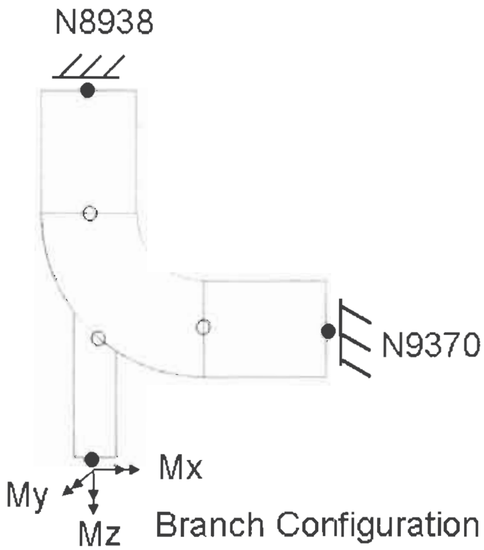
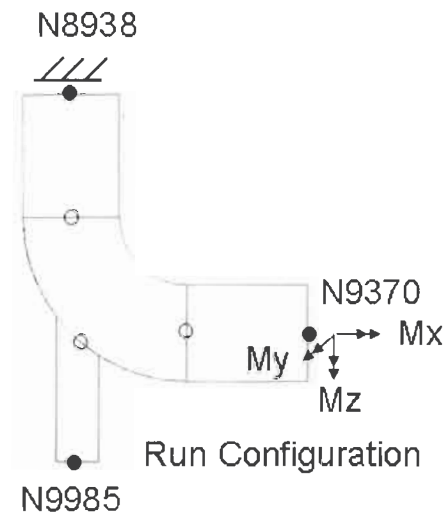
Determination of stress indices for the branch and run are performed similarly, excepting each model uses a different restraint configuration. As shown following, the branch FE model fully restrains the run nodes and combines an internal pressure with corresponding moment reactions (from N149) to N9985. Similarly, the run FE model fully restrains the elbow's start node and combines internal pressure with corresponding maximum moment reactions at N9370.





Determine scoping stress indice for Branch member:

$Mub_{mxp} := \left|n149_0\right| \cdot in \cdot lbf$ $\quad Mub_{mxp} = 27.78\, in \cdot kip$ $\quad$ Branch bending moments (+/-) about X-axis

$Mub_{mxn} := -Mub_{mxp}$ $\quad Mub_{mxn} = -27.78\, in \cdot kip$

$Mub_{myp} := \left|n149_1\right| \cdot in \cdot lbf$ $\quad Mub_{myp} = 77.88\, in \cdot kip$ $\quad$ Branch bending moments (+/-) about Y-axis

$Mub_{myn} := -Mub_{myp}$ $\quad Mub_{myn} = -77.88\, in \cdot kip$

$Mub_{mzp} := \left|n149_2\right| \cdot in \cdot lbf$ $\quad Mub_{mzp} = 4.084\, in \cdot kip$ $\quad$ Branch torsion (+/-) about Z-axis

$Mub_{mzn} := -Mub_{mzp}$ $\quad Mub_{mzn} = -4.084\, in \cdot kip$

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FE branch membrane tresca stress results are reflective of three load conditions (or steps). The first step (step 1) produces results for an internal pressure (253-psi) loading. The second step (step 2) computes results for combined internal pressure and bending loading. The last step (step 3) subtracts step 1 (P) from step 2 (P+Bi) to obtain corresponding bending tresca stress results (Bi). This is done to capture the added stiffness from internal pressure reflected into Bi results. Maximum tresca stress results (extracted from FE model results) of the three moments (Mx, My, & Mz) are used to determine the branch stress indice (B_{2b}).

$$\sigma ub_{mx} := \begin{pmatrix} 2.2713E+03 \\ 2.87158E+03 \end{pmatrix} \cdot psi \qquad \begin{matrix} Mub_{mxp} \text{ (+ direction)} \\ Mub_{mxn} \text{ (- direction)} \end{matrix}$$

$$\sigma_{ub_0} := max(\sigma ub_{mx}) \qquad \sigma_{ub_0} = 2.872 \cdot ksi$$

Branch tresca stress for X-axis bending (+/- moment directions). FE results are shown in Figs F.1.2-4 (Appendix F.2.2) and recorded in file mt_ubranch.rpt (Appendix F.2.2.1).

$$\sigma ub_{my} := \begin{pmatrix} 6.7149E+03 \\ 6.91082E+03 \end{pmatrix} \cdot psi \qquad \begin{matrix} Mub_{myp} \text{ (+ direction)} \\ Mub_{myn} \text{ (- direction)} \end{matrix}$$

$$\sigma_{ub_1} := max(\sigma ub_{my}) \qquad \sigma_{ub_1} = 6.911 \cdot ksi$$

Branch tresca stress for Y-axis bending (+/- moment directions). FE results are shown in Figs. F.2.2-5 & -6 (Appendix F.2.2) and recorded in file mt_ubranch.rpt (Appendix F.2.2.1).

$$\sigma ub_{mz} := \begin{pmatrix} 705.428 \\ 371.44 \end{pmatrix} \cdot psi \qquad \begin{matrix} Mub_{mzp} \text{ (+ direction)} \\ Mub_{mzn} \text{ (- direction)} \end{matrix}$$

$$\sigma_{ub_2} := max(\sigma ub_{mz}) \qquad \sigma_{ub_2} = 0.705 ksi$$

Branch tresca stress for Z-axis torsion (+/- moment directions). FE results are shown in Figs. F.2.2.-7 & -8 (Appendix F.2.2) and recorded in file mt_ubranch.rpt (Appendix F.2.2.1).

$$\sigma_{ub}^{T} = (2.872 \;\; 6.911 \;\; 0.705) \cdot ksi$$

Branch tresca stress results corresponding to moments Mx, My, and Mz.

$$\sigma ub_{max} := max(\sigma_{ub}) \qquad \sigma ub_{max} = 6.911 \cdot ksi$$

Maximum branch stress occurs for negative Y-axis bending

$$Mub_{myn} = -77.88 \, in \cdot kip \qquad \frac{|Mub_{myn}|}{M_{ub}} = 0.941$$

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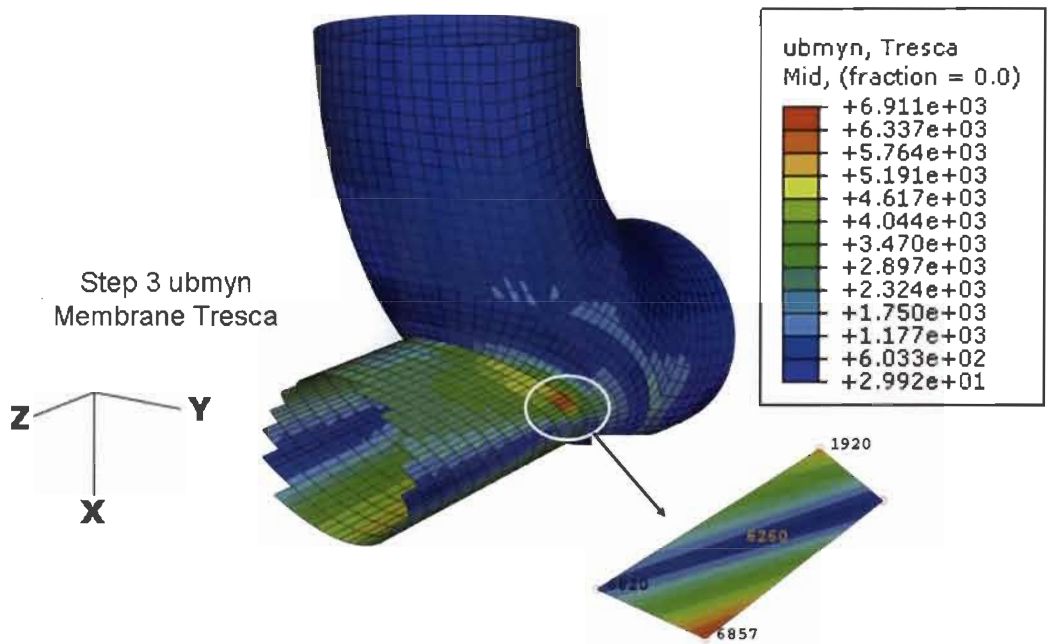

Branch member scoping SI determination

$$\sigma ub_{max} = B_{2ub} \cdot \left(\frac{|Mub_{myn}|}{Z_b} \right)$$

$$B_{2ub} := \frac{\sigma ub_{max}}{\left(\frac{|Mub_{myn}|}{Z_b} \right)} \qquad B_{2ub} = 1.921$$ Unlisted branch member scoping SI

Determine scoping SI for unlisted Run member:

$Mur_{mxp} := max\left(\left| {}^{n}164_0 \right|, \left| {}^{n}165_0 \right| \right) \cdot in \cdot lbf$ $\quad Mur_{mxp} = 9.978\, in \cdot kip$ Run torsion moments (+/-) about X-axis

$Mur_{mxn} := -Mur_{mxp}$ $\quad Mur_{mxn} = -9.978\, in \cdot kip$

$Mur_{myp} := max\left(\left| {}^{n}164_1 \right|, \left| {}^{n}165_1 \right| \right) \cdot in \cdot lbf$ $\quad Mur_{myp} = 58.74\, in \cdot kip$ Run bending moments (+/-) about Y-axis

$Mur_{myn} := -Mur_{myp}$ $\quad Mur_{myn} = -58.74\, in \cdot kip$

$Mur_{mzp} := max\left(\left| {}^{n}164_2 \right|, \left| {}^{n}165_2 \right| \right) \cdot in \cdot lbf$ $\quad Mur_{mzp} = 30.91\, in \cdot kip$ Run bending moments (+/-) about Z-axis

$Mur_{mzn} := -Mur_{mzp}$ $\quad Mur_{mzn} = -30.91\, in \cdot kip$

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FE run membrane tresca stress results are reflective of three load conditions (or steps), previously described for the branch member.

$$\sigma ur_{mx} := \begin{pmatrix} 494.529 \\ 1.26304E+03 \end{pmatrix} \cdot psi$$ Mur_{mxp} (+ direction), Mur_{mxn} (- direction)

$$\sigma_{ur_0} := max(\sigma ur_{mx}) \qquad \sigma_{ur_0} = 1.263\,ksi$$

Run tresca stress for X-axis torsion (+/- moment directions). FE results are shown in Figs F.2.2-10, -11, & -12 (Appendix F.2.2) and recorded in file mt_urun.rpt (Appendix F.2.2.1).

$$\sigma ur_{my} := \begin{pmatrix} 3.7458E+03 \\ 3.78763E+03 \end{pmatrix} \cdot psi$$ Mur_{myp} (+ direction), Mur_{myn} (- direction)

$$\sigma_{ur_1} := max(\sigma ur_{my}) \qquad \sigma_{ur_1} = 3.78763\,ksi$$

Run tresca stress for Y-axis bending (+/- moment directions). FE results are shown in Figs. F.2.2-13 & -14 (Appendix F.2.2) and recorded in file mt_urun.rpt (Appendix F.2.2.1).

$$\sigma ur_{mz} := \begin{pmatrix} 460.61 \\ 1.1142E+03 \end{pmatrix} \cdot psi$$ Mur_{mzp} (+ direction), Mur_{mzn} (- direction)

$$\sigma_{ur_2} := max(\sigma ur_{mz}) \qquad \sigma_{ur_2} = 1.114\,ksi$$

Run tresca stress for Z-axis bending (+/- moment directions). FE results are shown in Figs. F.1.2-15 & -16 (Appendix F.5.2) and recorded in file urun.rpt (Appendix F.2.2.1).

$$\sigma_{ur}^T = (1.263 \quad 3.788 \quad 1.114) \cdot ksi$$

Run tresca stress results corresponding to scoping moments Mx, My, and Mz.

$$\sigma ur_{max} := max(\sigma_{ur}) \qquad \sigma ur_{max} = 3.788\,ksi$$

Maximum scoping run tresca stress occurs for negative Y-axis bending and positive X-axis bending.

$$Mur_{myn} = -58.74\,in \cdot kip$$

Corresponding maximum scoping unlisted run moment

$$\frac{|Mur_{myn}|}{M_{ur}} = 0.976$$

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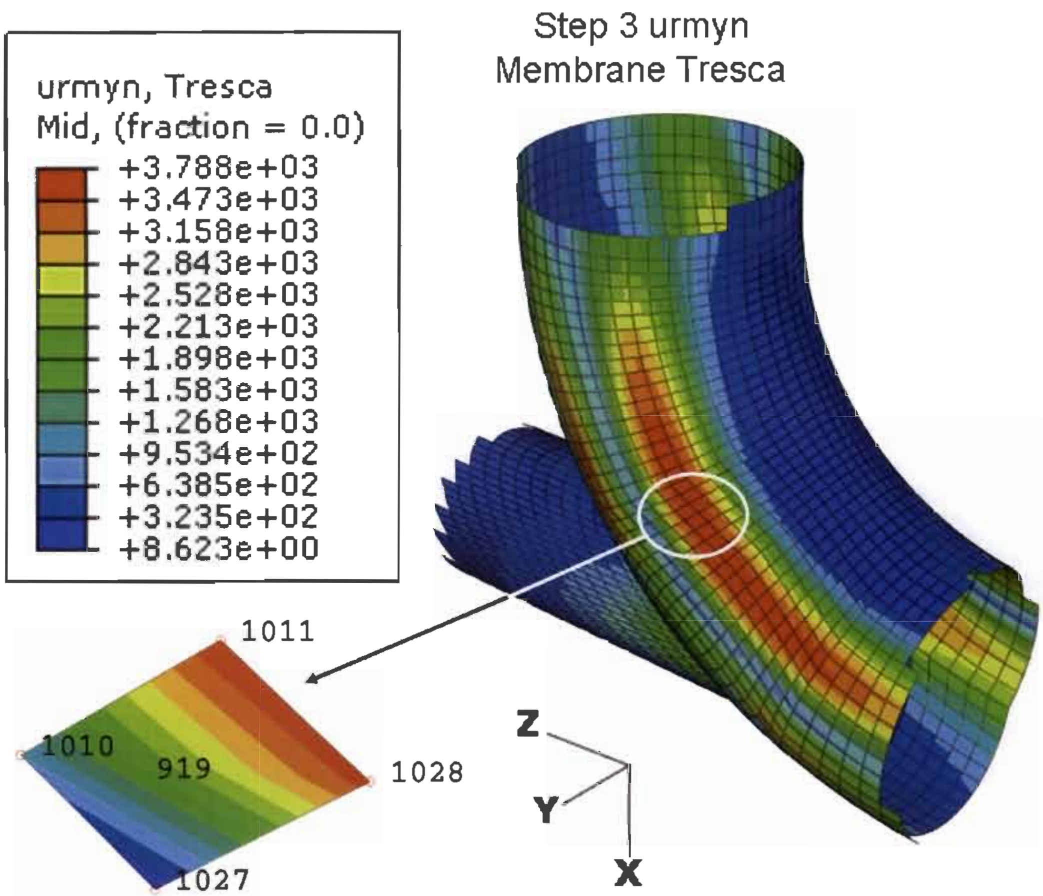


Run member SI

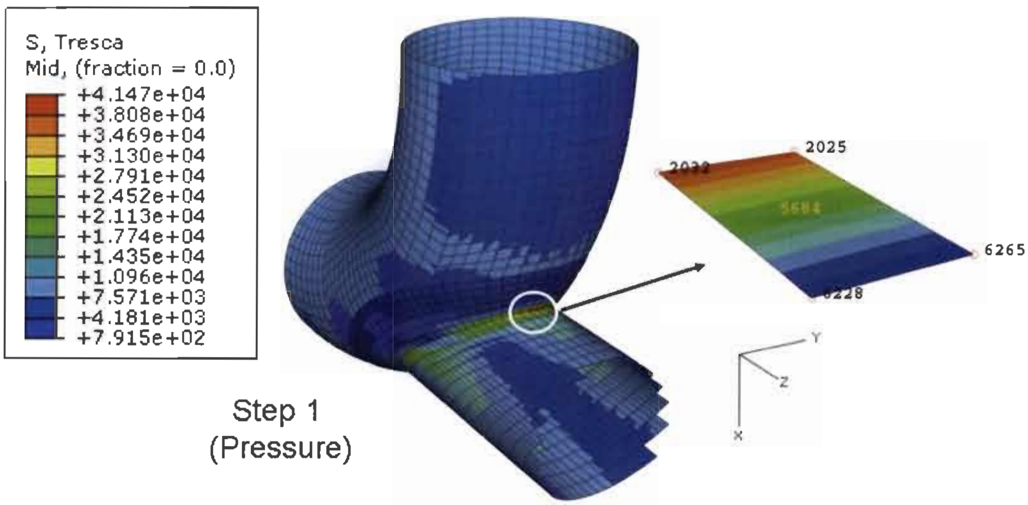
$$\sigma ur_{max} = B_{2ur} \cdot \left(\frac{|Mur_{myn}|}{Z_r} \right)$$

$$B_{2ur} := \frac{\sigma ur_{max}}{\left(\frac{|Mur_{myn}|}{Z_r} \right)} \qquad B_{2ur} = 3.141 \quad \text{Run member SI}$$

Determine system pressure indice:

$\sigma up := (41.4681E+03\ 41.3383E+03)^T \cdot psi$ $\qquad \sigma_{up} := max(\sigma up)$

$\sigma_{up} = 41.468\,ksi$ Unlisted component scoping system pressure



Step 1
(Pressure)

Scoping branch and run tresca stresses for pressure. FE results are show in Fig. F.2.2-9 for branch pressure (Appendix F.2.2) and Fig. F.1.2-16 for run pressure (Appendix F.2.2). Both branch and run tresca stress pressure values recorded in si_mt_ubranch_08_26_08.rpt and si_mt_urun_08_26_08.rpt (Appendix F.2.2.1) respectively.

$$\sigma_{up} = B_{1u} \cdot \left(\frac{P \cdot D_o}{2 \cdot T_r}\right) \quad => \quad B_{1u} := \frac{\sigma_{up}}{\left(\frac{P \cdot D_e}{2 \cdot T_r}\right)} \qquad B_{1u} = 5.122$$

System pressure scoping SI

$B_{1u} = 5.122$ $\quad B_{2ub} = 1.921$ $\quad B_{2ur} = 3.141$ Unlisted branch component scoping SI

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F.2.4 – Linear Evaluation of Unlisted Branch Component

The purpose of this section is to perform a linear evaluation of the unlisted branch component, using the SI and methodology defined in the previous section (Appendix F.2.3).

For unlisted elbow/pipe branch:

$$B_I \cdot \left(\frac{P \cdot D_o}{2 \cdot T_r}\right) + \left[B_{2b} \cdot \left(\frac{M_b}{Z_b}\right) + B_{2r} \cdot \left(\frac{M_r}{Z_r}\right)\right] \quad =< \quad 2 \cdot Sy_{125} = 56.7 \cdot ksi$$

$$\frac{B_{1u} \cdot \left(\frac{P \cdot D_e}{2 \cdot T_r}\right) + \left[B_{2ub} \cdot \left(\frac{M_{ub}}{Z_b}\right) + B_{2ur} \cdot \left(\frac{M_{ur}}{Z_r}\right)\right]}{2 \cdot Sy_{125}} = 0.929$$

256 Model Unlisted Elbow/Branch Component is Acceptable

$$\frac{B_{1u} \cdot \left(\frac{P \cdot D_e}{2 \cdot T_r}\right)}{2 \cdot Sy_{125}} = 0.731$$

Pressure strongly influences linear results

$$\frac{\left[B_{2ub} \cdot \left(\frac{M_{ub}}{Z_b}\right) + B_{2ur} \cdot \left(\frac{M_{ur}}{Z_r}\right)\right]}{2 \cdot Sy_{125}} = 0.198$$

Seismic loading effects

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The above unlisted elbow/branch component linear evaluation was based on preliminary 80 percentile moment reactions, used for determining approximate scoping indices. Following are final run moment reactions (as of 09-25-08) for the unlisted cap component. Preliminary and final moment reactions are compared.

Preliminary 80 Percentile Nodal Moment Reactions, previously shown

Mx My Mz

$$n_{149}^{T} = \begin{pmatrix} 2.778\times 10^{4} & 7.788\times 10^{4} & -4.084\times 10^{3} \end{pmatrix}$$

$$n_{164}^{T} = \begin{pmatrix} 528.946 & 4.357\times 10^{4} & -3.091\times 10^{4} \end{pmatrix}$$

$$n_{165}^{T} = \begin{pmatrix} 9.978\times 10^{3} & -5.874\times 10^{4} & 8.298\times 10^{3} \end{pmatrix}$$

Final run 80 Percentile Nodal Moment Reactions for unlisted elbow/branch component

Mx My Mz

$$n_{149f} := \begin{pmatrix} 5.144\cdot 10^{4} & 9.801\cdot 10^{4} & -1.036\cdot 10^{4} \end{pmatrix}^{T}$$

$$n_{164f} := \begin{pmatrix} 3.801\cdot 10^{4} & 6.048\cdot 10^{4} & -6.431\cdot 10^{4} \end{pmatrix}^{T}$$

$$n_{165f} := \begin{pmatrix} -9.021\cdot 10^{3} & -9.884\cdot 10^{4} & 621.902 \end{pmatrix}^{T}$$

$$\frac{n_{149f}}{n_{149}} = \begin{pmatrix} 1.852 \\ 1.258 \\ 2.537 \end{pmatrix} \qquad \frac{n_{164f}}{n_{164}} = \begin{pmatrix} 71.86 \\ 1.388 \\ 2.081 \end{pmatrix} \qquad \frac{n_{165f}}{n_{165}} = \begin{pmatrix} -0.904 \\ 1.683 \\ 0.075 \end{pmatrix}$$

Final reaction moments, in general, are significantly higher than the preliminary set of moments used to determine SI. The 16-in x 10-in branch already has a high D/C value of approximiately 1.93. Therefore, a plastic analysis is recommended to determine acceptance of 16-in x 10-in unlisted elbow/branch component.

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Date:	09/30/08				

F.2.4.1 - Plastic Evaluation of Unlisted Branch Component

The purpose of this section is to perform a plastic evaluation on a 16 inch elbow with a 10 inch branch (called the 16x10 branch from here forward). To perform the plastic analysis, displacement results versus time are gathered from realization 22 of the beam element model 265 (shown in Figure F.2.4.1-1). These displacement results are then applied to a shell modeled cutout of the 16x10 branch. This realization of model 265 is the 80th percentile realization for the 16x10 branch.

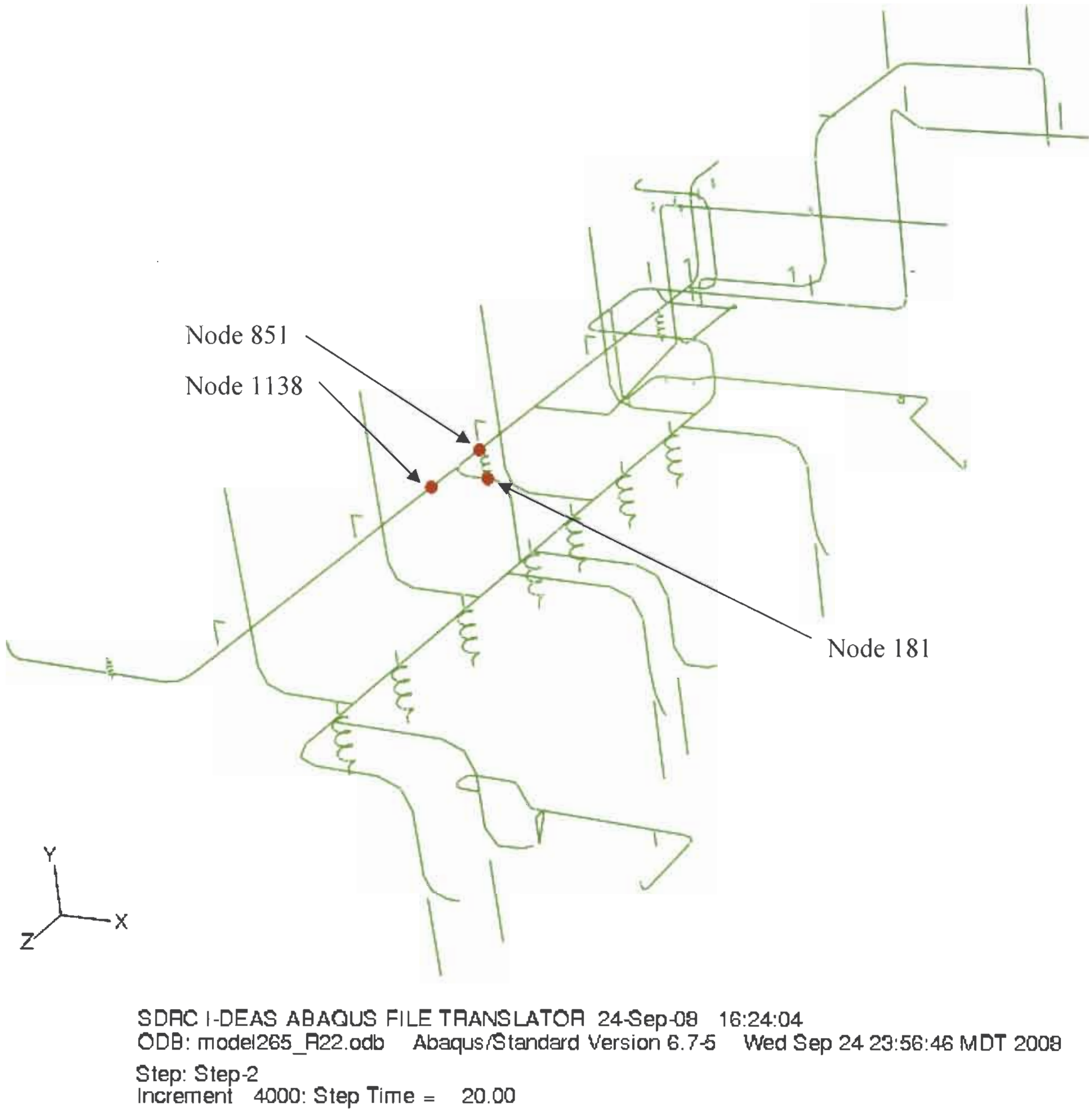

Figure F.2.4.1-1 – Realization 22 of the piping model.

The displacement results from Model 265 nodes 851, 181, and 1138 are shown in Figure F.2.4.1-2.

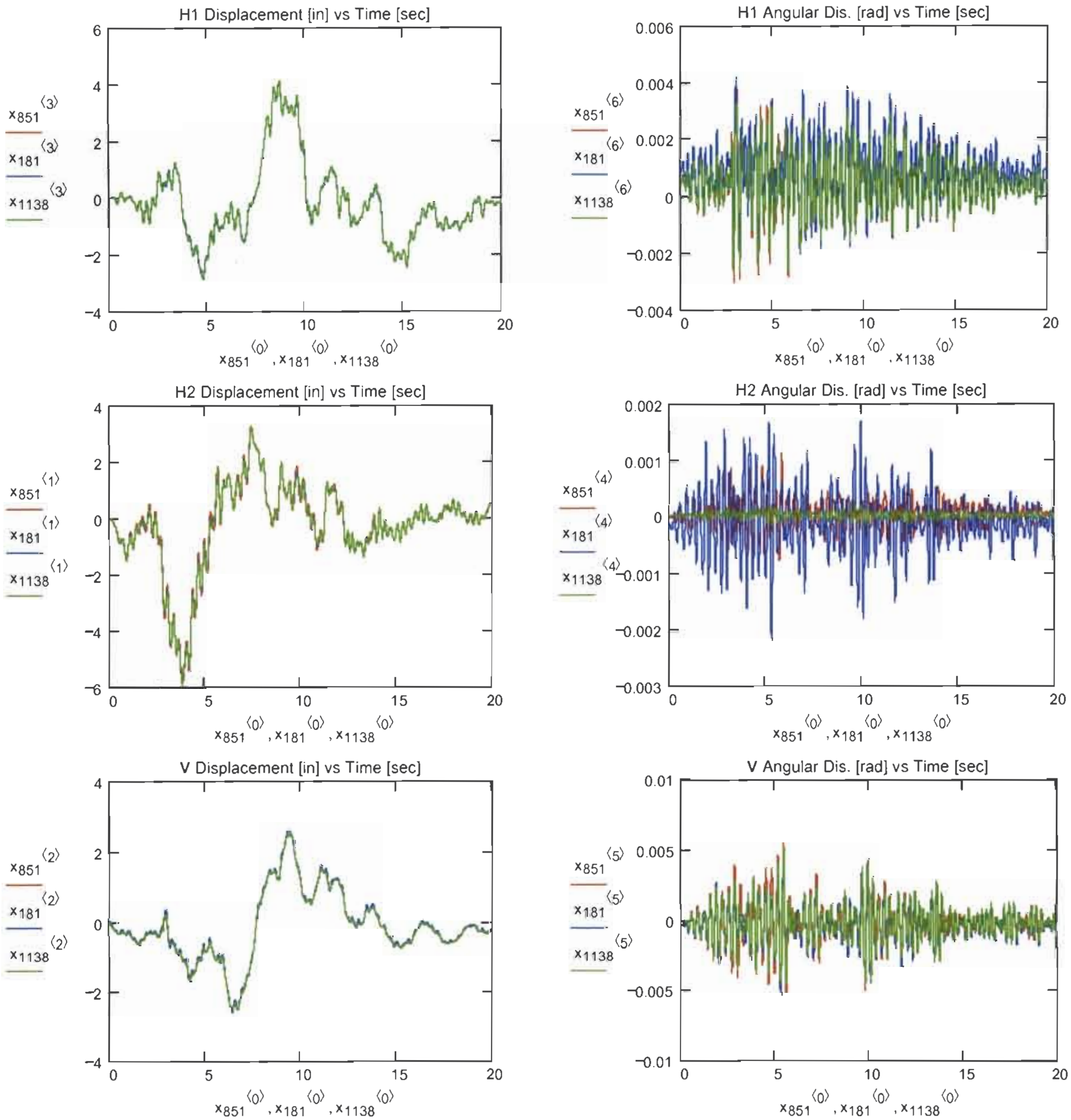

Figure F.2.4.1-2 – Displacement plots for nodes identified in Figure F.2.4.1-1.

Figure F.2.4.1-2 shows the translational and rotational displacement in the nodes output from realization 22 (shown in Figure F.2.4.1-1). In the plot variables, "x" indicates displacement and the subscript that follows is the node number from Figure F.2.4.1-1. H1 represents the east/west direction and it is on the z-axis in the model plots. H2 represents the north/south direction and it is on the x-axis in the model plots. V represents the vertical direction and it is on the y-axis in the model plots.

The plastic analysis for the 16x10 branch was performed by generating a linear quadrilateral shell model (as shown in Figures F.2.4.1-3 - F.2.4.1-8) of the region including the nodes identified in Figure F.2.4.1-1. This model includes a 16 inch schedule 10 run pipe, a 10 inch schedule 20 branch pipe, and a 0.25 inch thick stiffener plate. The model is meshed with linear quadrilateral shells. The cut ends of the pipes are covered with 0.25 inch thick linear quadrilateral shells that contain the pressure.

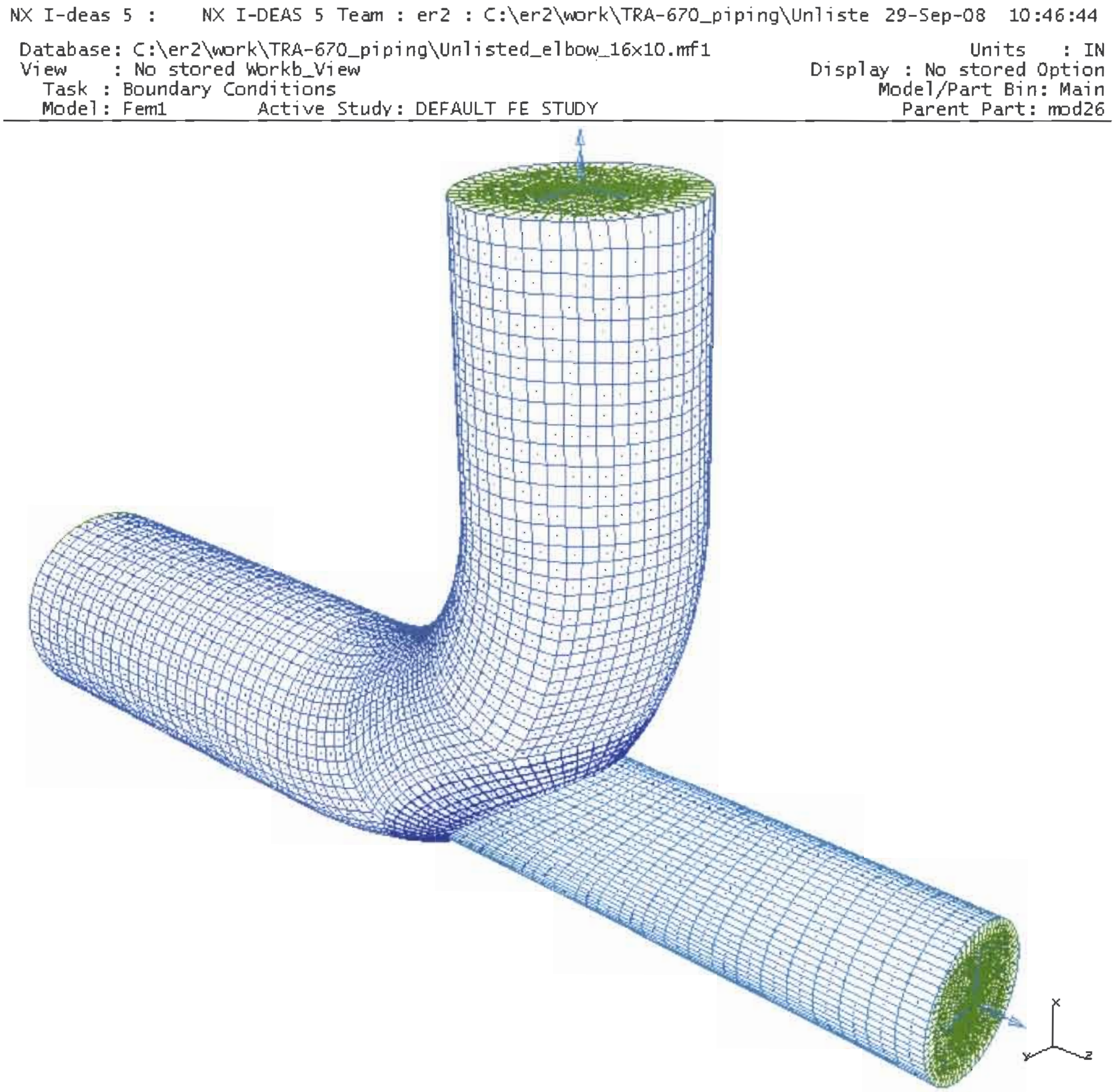

Figure F.2.4.1-3 – Mesh of the full model.

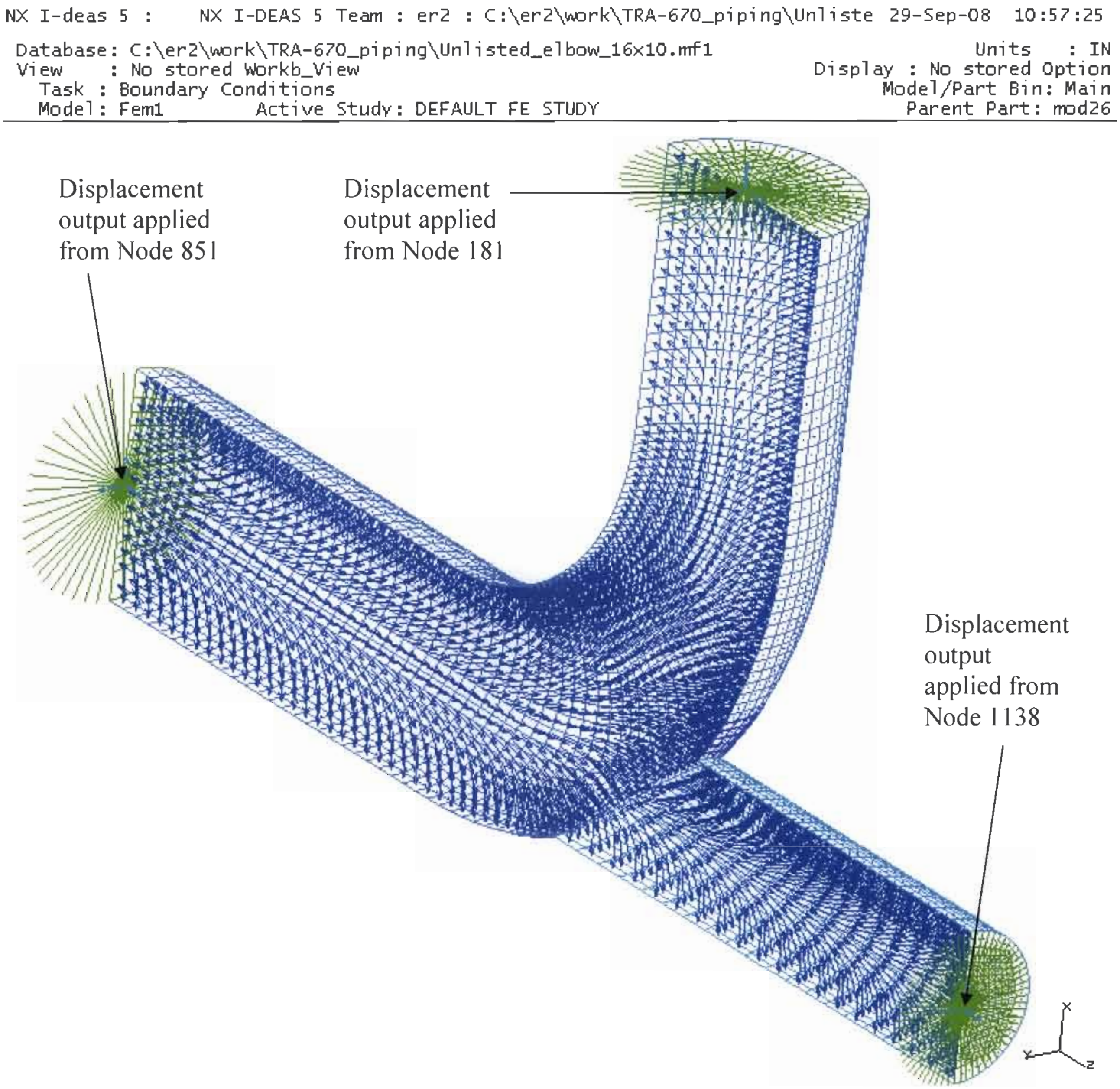

Figure F.2.4.1-4 – Cut-away of the model.

The displacement time histories taken from realization 22 were applied to the nodes identified in Figure F.2.4.1-4. Nodes 851, 181, and 1138 are attached with rigid elements to the nodes in the linear quadrilateral shells at the section where the pipe is cut. In addition to the moving restraints, the model was loaded with gravity and a 253 psi internal pressure.

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NX I-deas 5 : NX I-DEAS 5 Team : er2 : C:\er2\work\TRA-670_piping\Unliste 29-Sep-08 11:14:40

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Task : Boundary Conditions Model/Part Bin: Main
Model: Fem1 Active Study: DEFAULT FE STUDY Parent Part: mod26

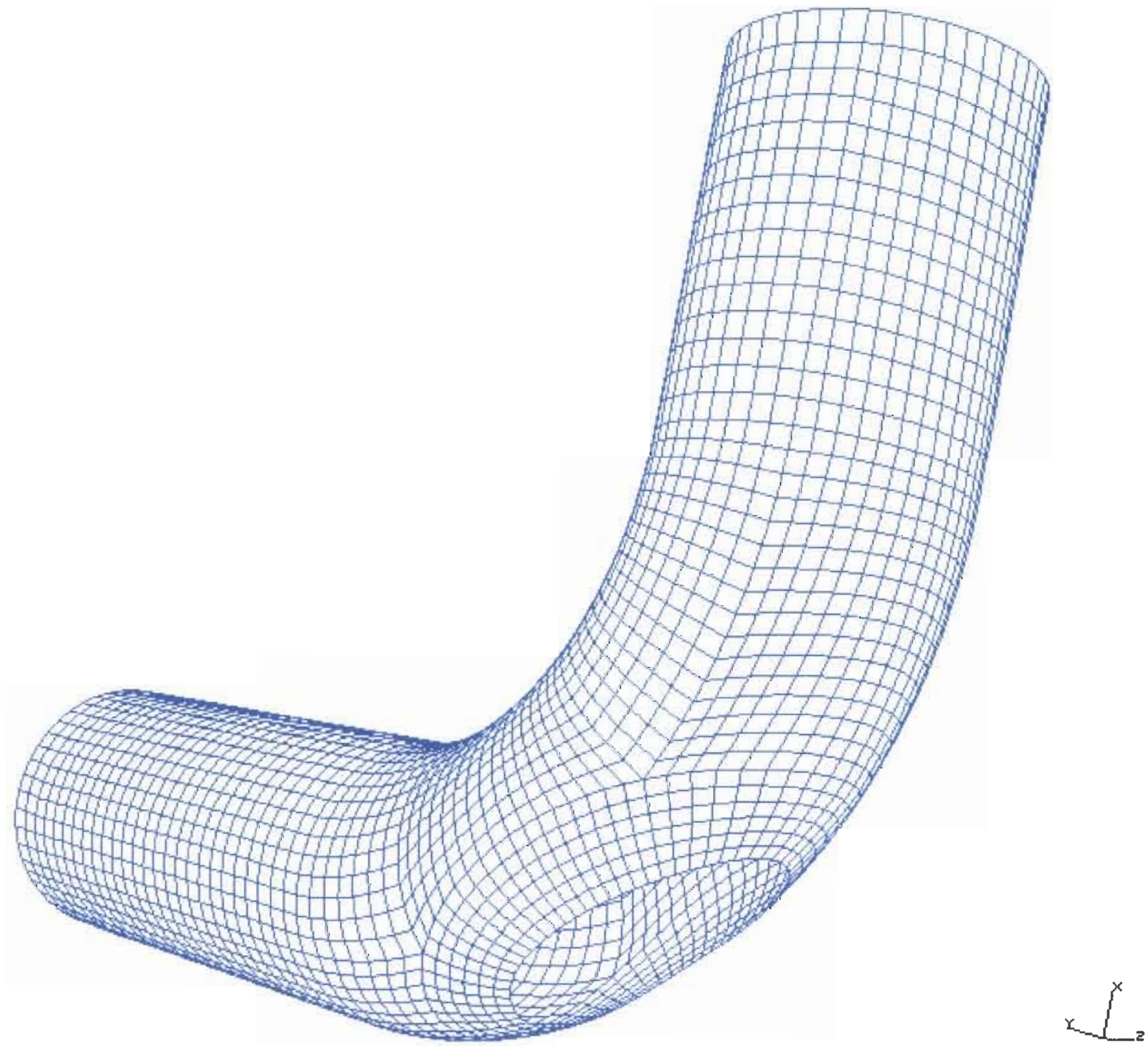

Figure F.2.4.1-5 – Linear quadrilateral shell mesh of the 16 inch schedule 20 pipe.

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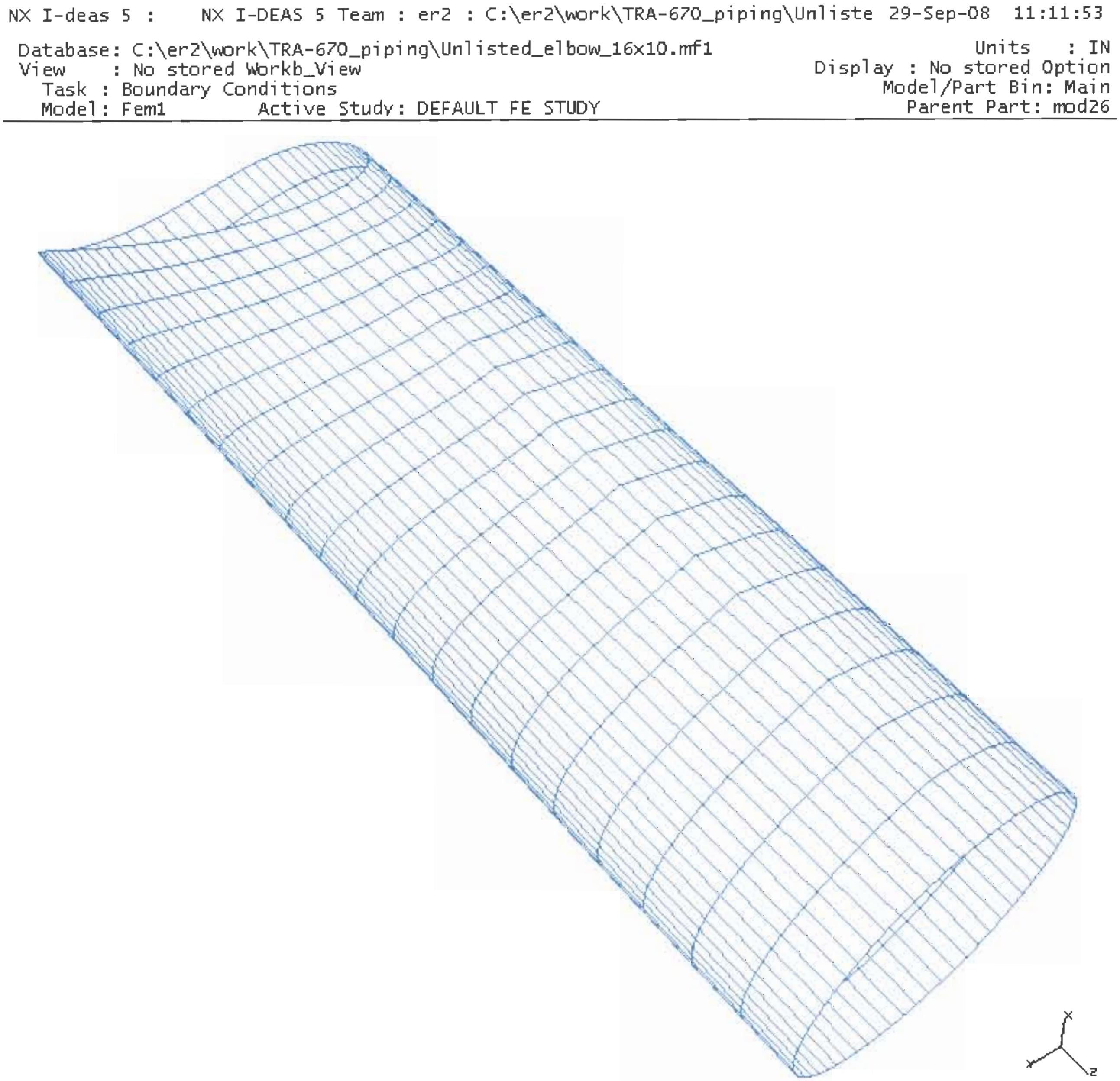

Figure F.2.4.1-6 – Linear quadrilateral shell mesh of the 10 inch schedule 40 pipe.

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  Model: Fem1         Active Study: DEFAULT FE STUDY                            Parent Part: mod26
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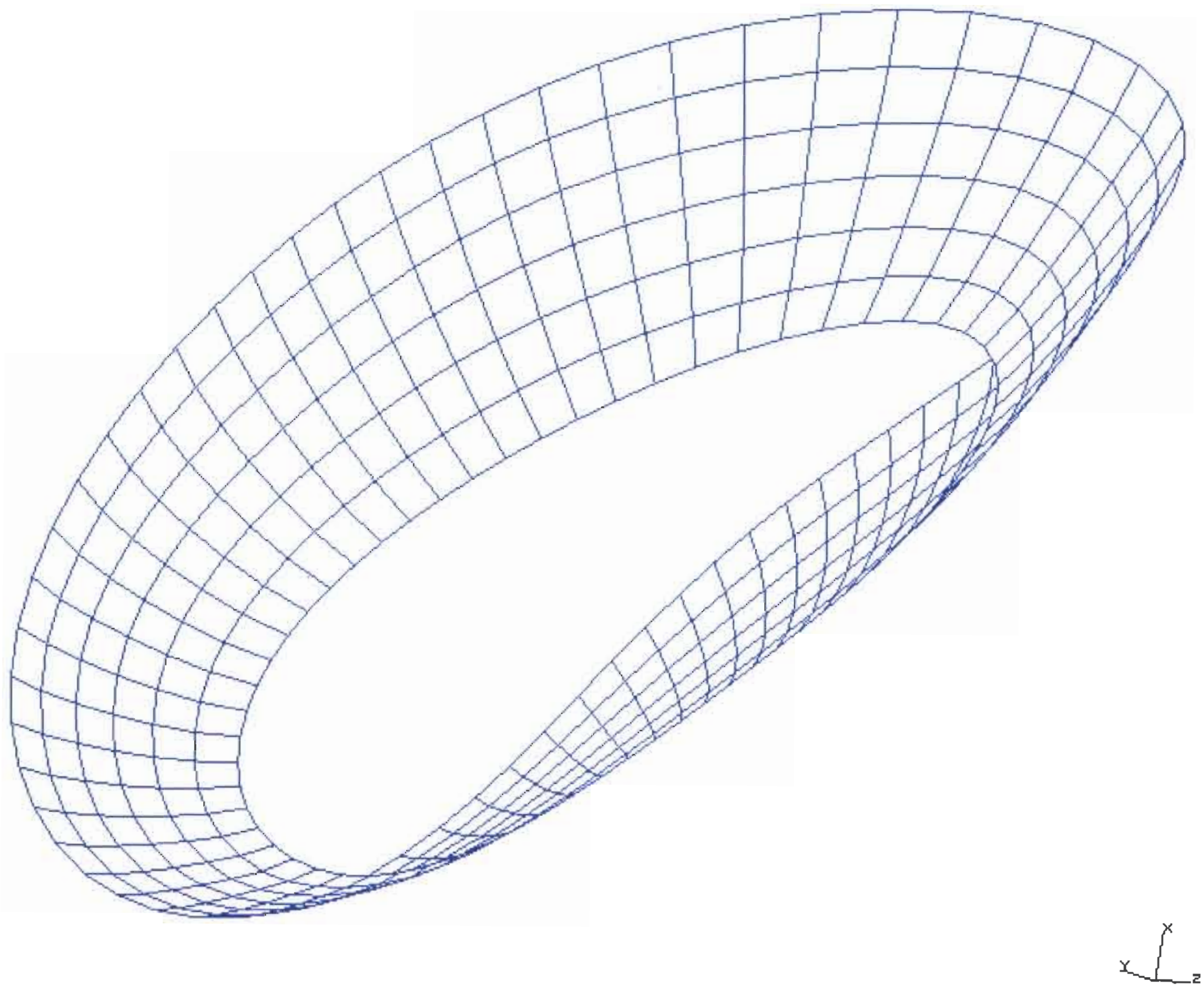

Figure F.2.4.1-7 – Linear quadrilateral shell mesh of the 0.25 inch thick stiffener plate.

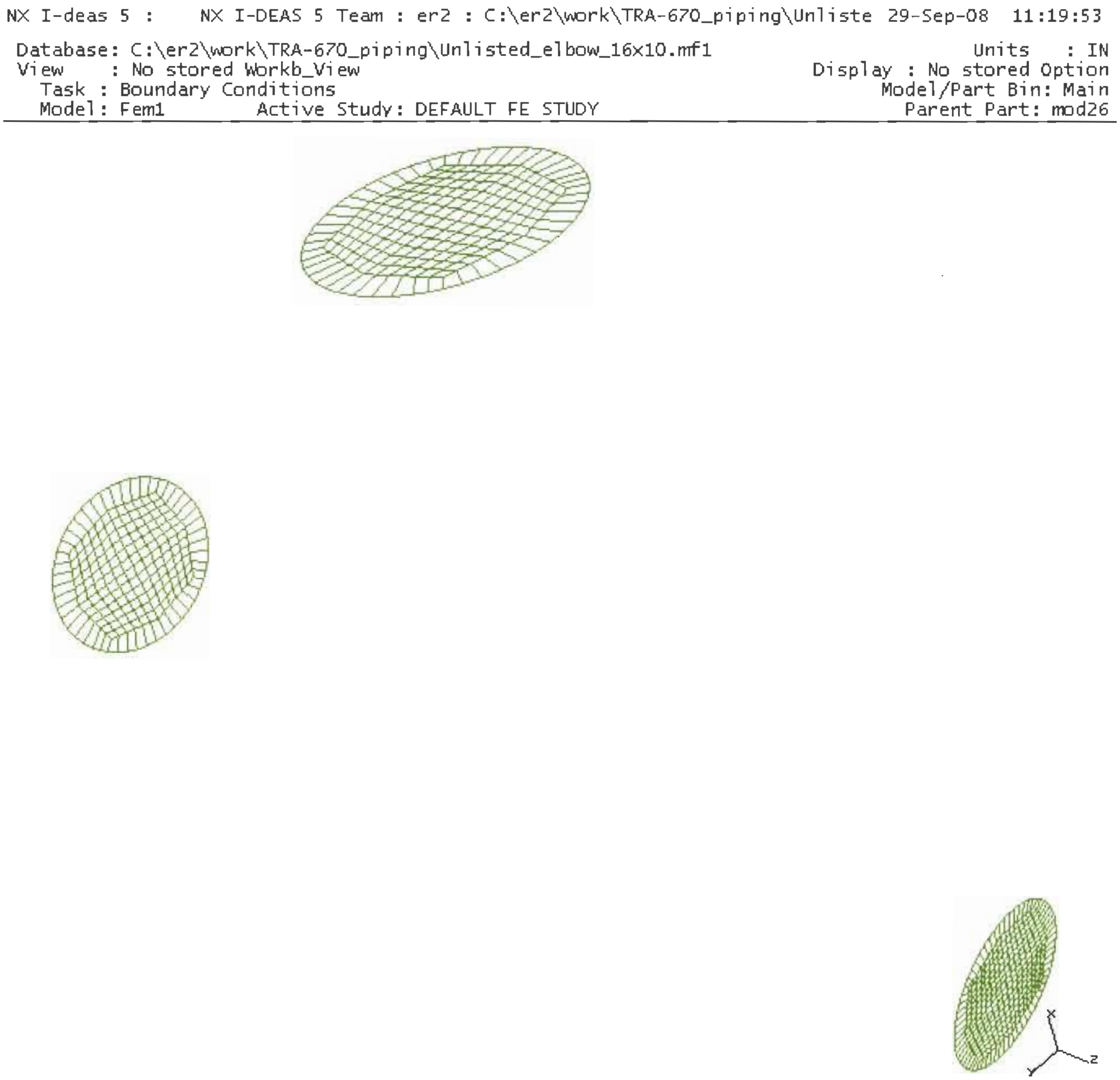

Figure F.2.4.1-8 – Linear quadrilateral thin shell mesh of the 0.312 inch thick end plates.

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This model was defined with the same material properties as the unlisted branch in Section F.1.5. Consequently, the allowable plastic equivalent strain is 0.120 in/in. Figure F.2.4.1-9 shows the plastic equivalent strain at the shell midplane with averaging turned off.

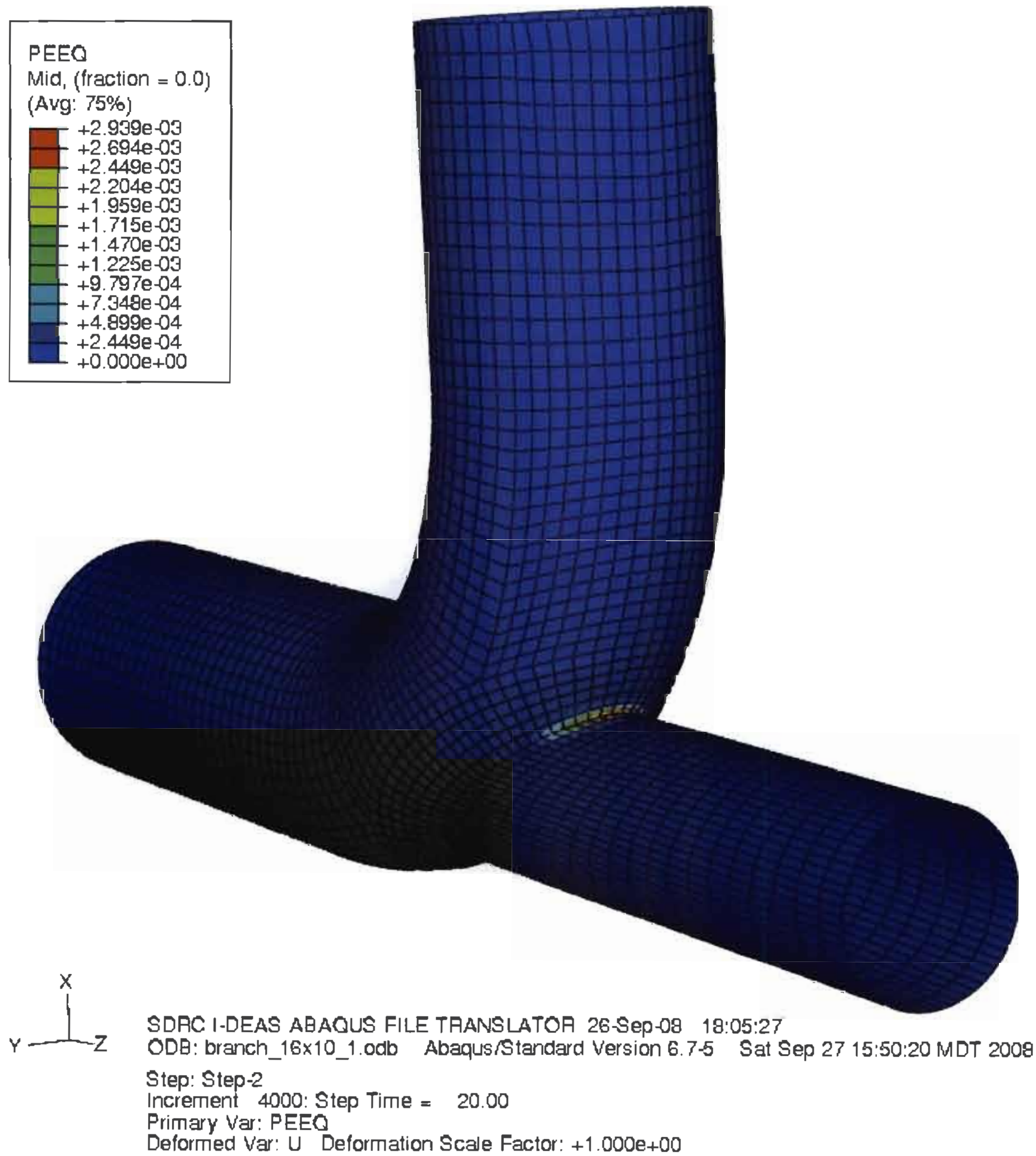

Figure F.2.4.1-9 – Plastic equivalent strain shown at the midplane with averaging turned off.

As shown in Figure F.2.4.1-9, the maximum plastic equivalent strain is much less than the allowable 0.120 in/in. Thus, the unlisted branch component is acceptable.

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Before FE analysis was performed on model 265, scoping calculations were performed to provide flexibility adjusted section properties. These adjustments were for the first branch element of the 16x10 branch occurring in model 265. A check must now be performed to ensure that, at the load level of the plastic analysis, the beam element model responds similar to the shell model. Figure F.2.4.1-10 shows the beam element model from the 16x10 branch in model 265.

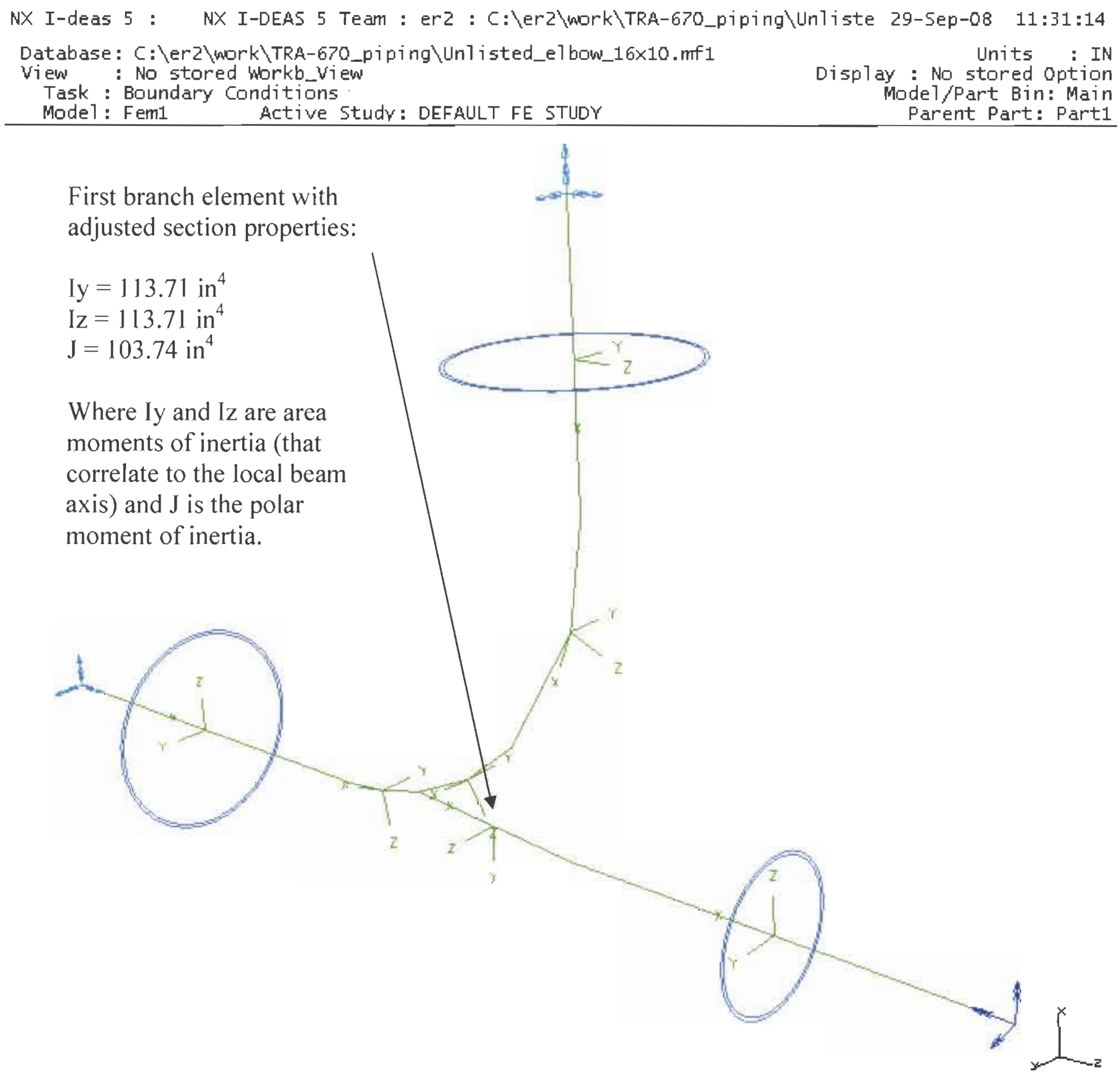

Figure F.2.4.1-10 – Beam model of the 16x10 branch used to check flexibility.

Figure F.2.4.1-11 shows the shell mesh for the flexibility check.

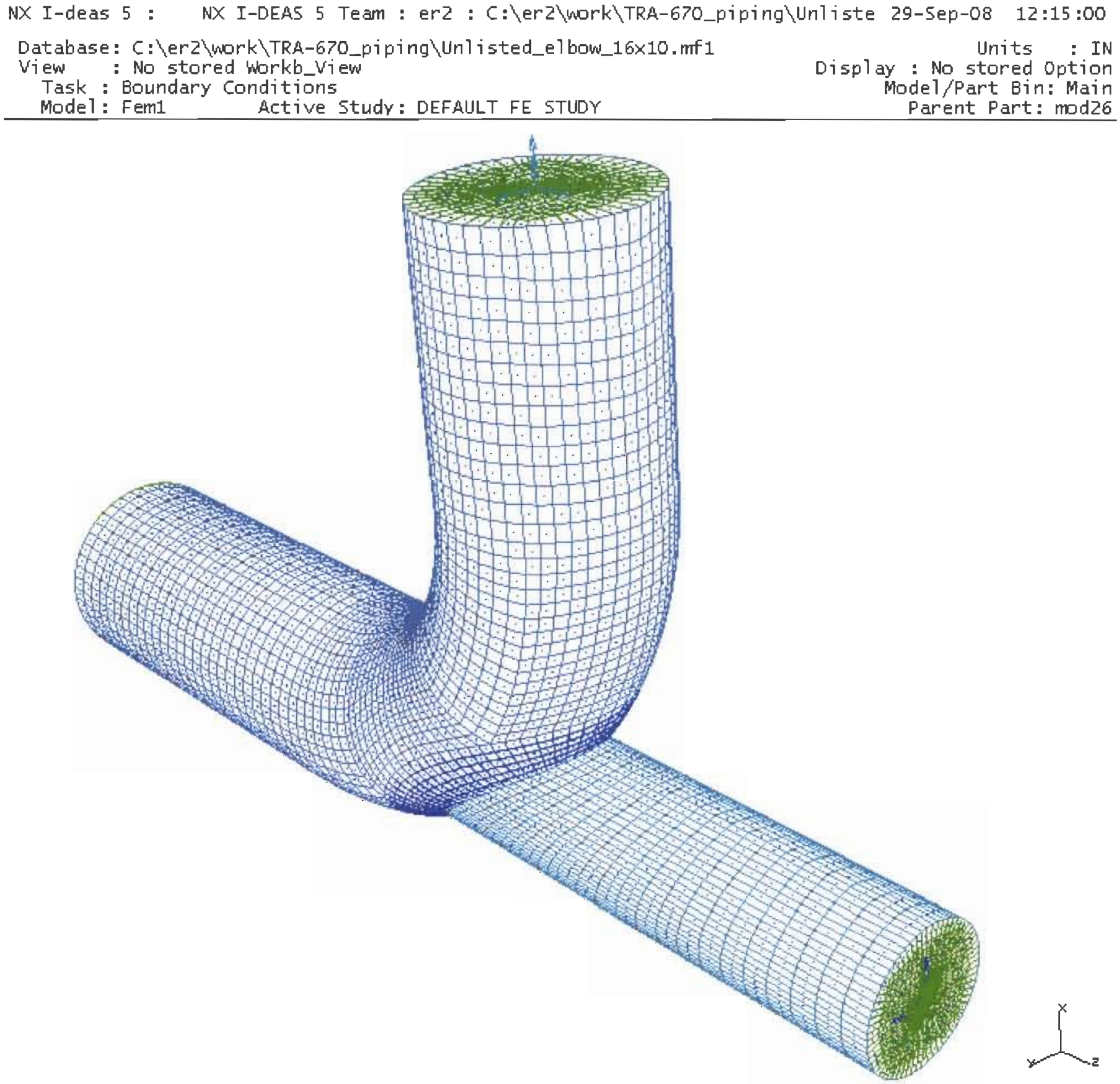

Figure F.2.4.1-11 – Shell model of the 16x10 branch used to check flexibility.

The next step is to establish loading. From the model 265 run, 80th percentile moments are shown below. These loads include 80th percentile data for the branch.

EL 489 ND 149

$M_{149} := \left(8.114 \cdot 10^4 \;\; 7.96 \cdot 10^4 \;\; -1.049 \cdot 10^4\right)^T \cdot in \cdot lbf$

Tee 1-43 80th percentile branch moments from Appendix C.

$M'' := \left(\left|M_{149_0}\right| \;\; \left|M_{149_1}\right| \;\; \left|M_{149_2}\right|\right)^T \cdot (in \cdot lbf)^{-1}$

Moment used to scale the plots.

$M''^T = \left(8.114 \times 10^4 \;\; 7.96 \times 10^4 \;\; 1.049 \times 10^4\right)$

To check the flexibility, three load cases are evaluated with the beam and shell models. Each beam model load case consists of a single moment direction applied to its end branch node (i.e. 81,140 in•lbf in the global x-direction, 79,600 in•lbf in the global y-direction, or -10,490 in•lbf in the global z-direction). The model is fully restrained where the run pipe is cut. Each shell model is evaluated with the same boundary conditions as its corresponding beam model. However, the shell model has an additional initial step where an internal pressure of 253 psi is applied. Figure F.2.4.1-13 below shows the resulting angular displacement at the end of the branch versus moment applied at the same point. The plots include the results from the shell model and the beam model. Additionally, beam results scaled plus and minus 20% are included for information. The shell model results have two steps. Displacements that occur during the first step, due to the pressure loading, are subtracted from the total curve so that only the relative displacement caused by the moment is plotted.

The input files used for the beam models were "branch_beam_16x10_ST_1.inp", "branch_beam_16x10_ST_2.inp", and "branch_beam_16x10_ST_3.inp". The input files used for the shell models were "branch_16x10_ST_1.inp", "branch_16x10_ST_2.inp", and "branch_16x10_ST_3.inp". In both sets of input files, the number change of 1, 2, and 3 represent the x-axis run, the y-axis run, and the z-axis run respectively.

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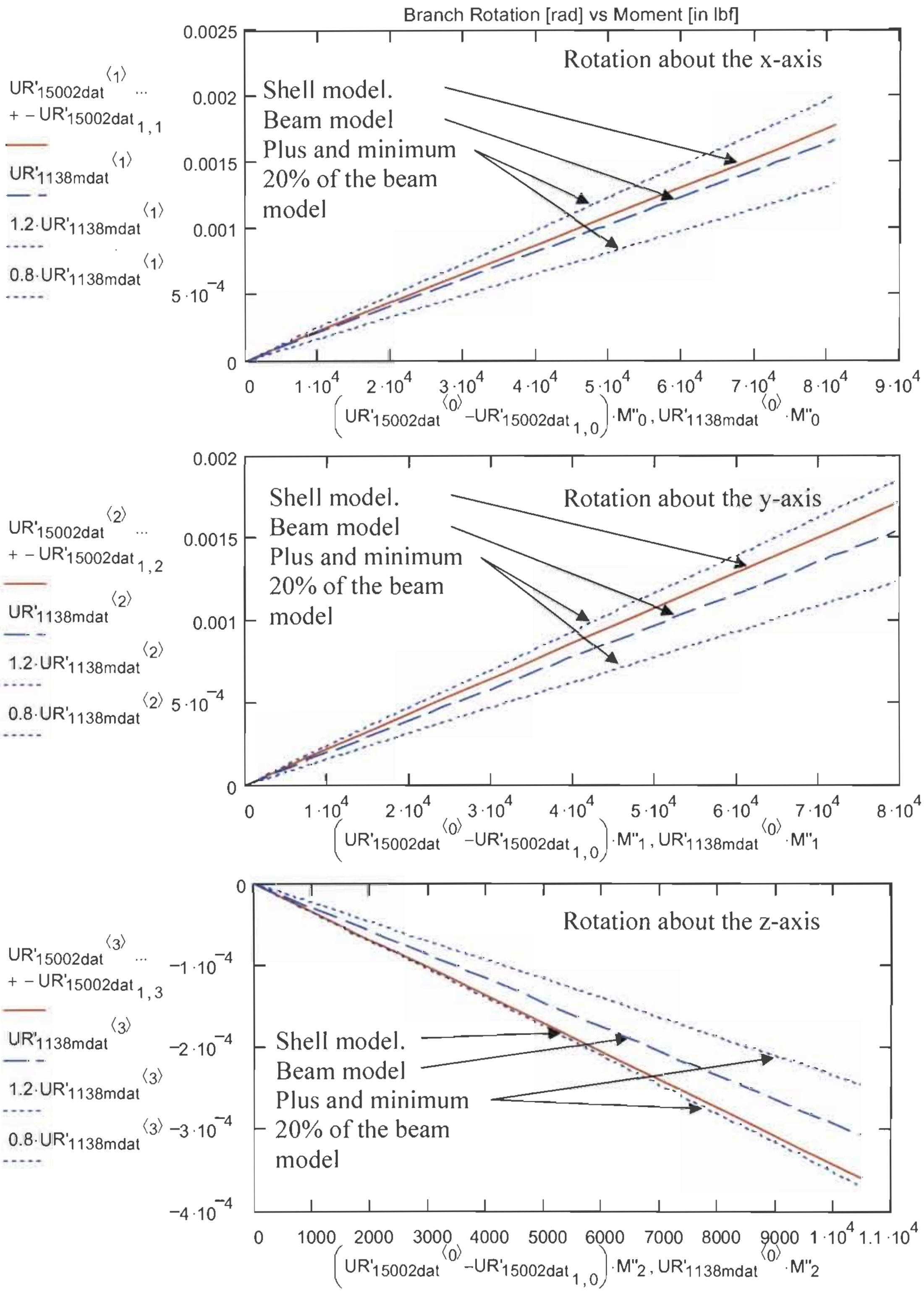

Figure F.2.4.1-13 – Model 265 16x10 branch rotation versus moment check.

Figure F.2.4.1-13 shows that all of the shell model plots are within the plus and minus 20% of the beam element results plots.

F.2.5 – FE Model Description of Unlisted Cap Component

The 256 model's unlisted cap component was solid-modeled and meshed within I-DEAS Master Series, Simulation, Version 12 [9]. With the meshing complete, input files were written for ABAQUS [10]. Final editing of the input files were performed in a text editor and then solution runs were performed with ABAQUS Standard, Version 6.7-5. Results of the FE models are displayed with ABAQUS Viewer, Version 6.7-5, and are shown in Appendix F.2.6.

The unlisted cap component was meshed primarily with eight-node continuum shell elements and some rigid beam elements. The quadrilateral elements support six degrees of freedom (3-translations, 3 rotations) at each node and were used to model the 30-in cap, 30-in extended pipe, 10-in pipe stub-in, and 10-in long radius 90° elbow. The rigid beams were used as an aid in defining boundary conditions (i.e., applying loads and defining restraints) to the meshed unlisted capcomponent. Figures F.2.5-1 through F.2.5-3 illustrates the unlisted cap component as meshed with the quadrilateral elements. Table F.2.5-1 correlates element color to member name and thickness.

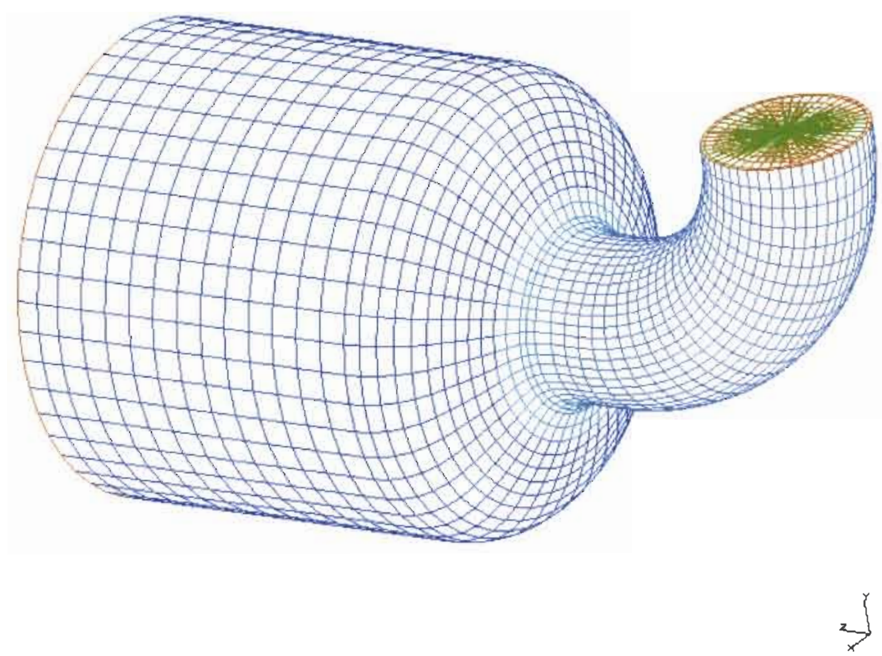

Figure F.2.5-1 – Linear continuum shell mesh of 256 model's unlisted cap component is shown.

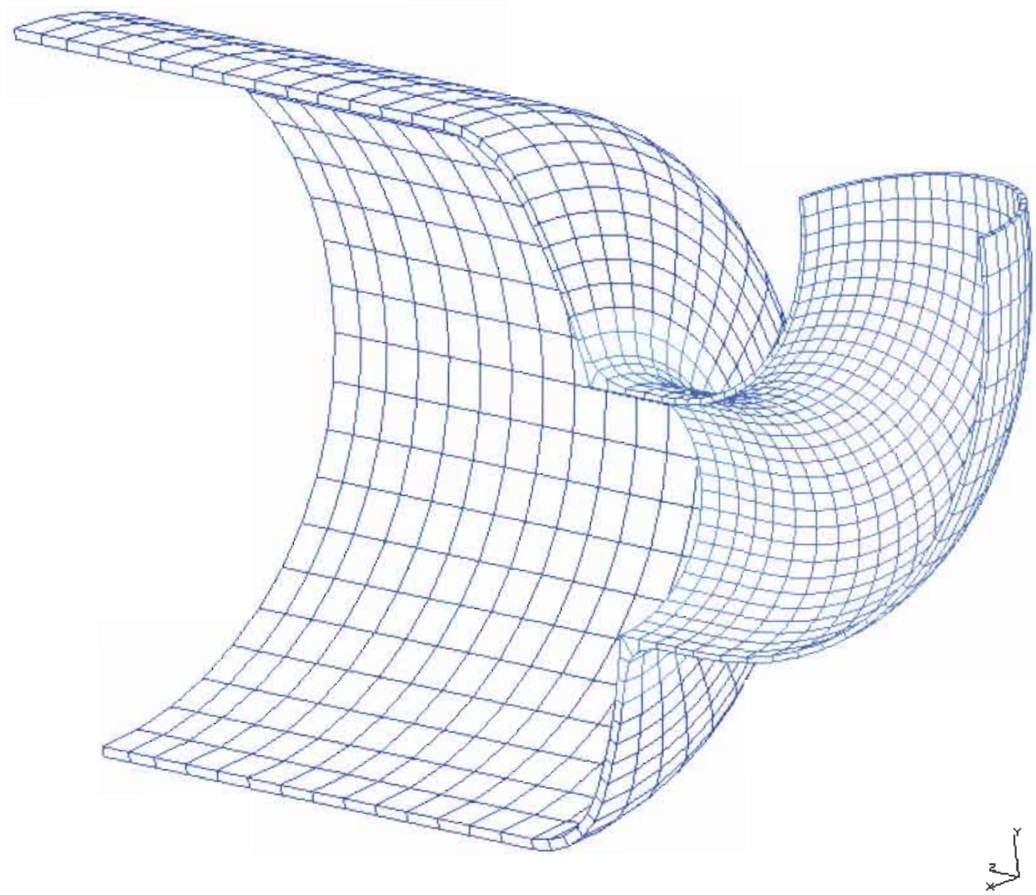

Figure F.2.5-2 – Cut-away of the continuum shell mesh.

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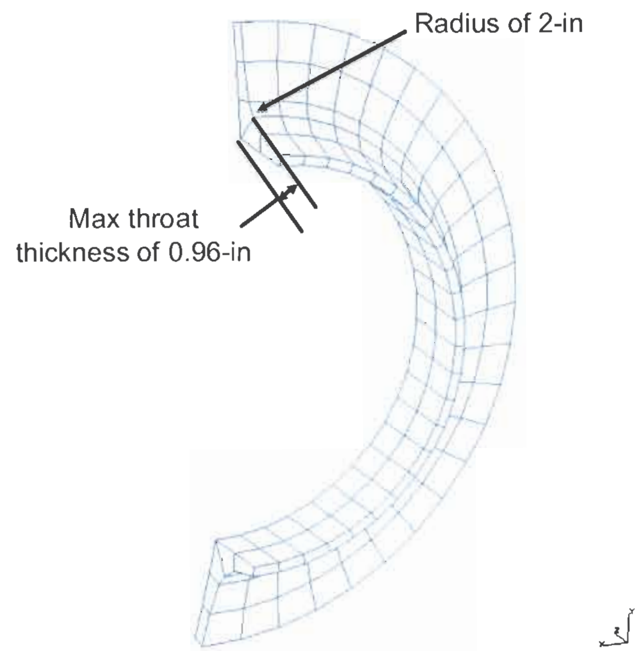

Figure F.2.5-3 – Continuum shell mesh in the region of the weld.

Figure F.2.5-4 – Cap mesh closely matches that of physical conditions, shown overlaid on picture.

Figure F.2.5-5 – End caps of 30-in pipe and top of 10-in elbow.

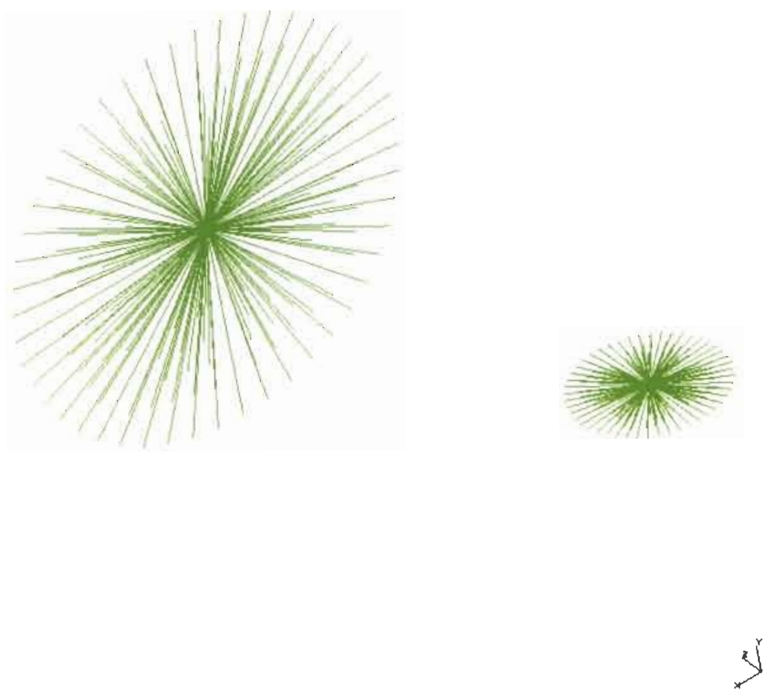

Figure F.2.5-6 – Rigid elements attached to end caps and used to apply boundary condtions.

Table F.2.5-1 – Mesh color, thickness, and component member correlation

Member Name	Mesh Color(s)	Element Thickness
30" Cap	Cyan	7/16" (0.4375-in)
10-in sch. 20 Stub	Cyan	¼" (0.25-in)
10-in long radius 90° Elbow	Light Blue	¼" (0.25-in)
*30-in Pipe extended from cap	Dark Blue	¼" (0.25-in)
*30-in Pipe/Elbow Ends	Orange	7/16" (0.4375-in) / ¼" (0.25-in)

*These component members were used as an aid to apply boundary conditions to unlisted cap.

As shown in Figure F.2.5-1 through F.2.5-6 and in Table F.2.5-1, the unlisted cap component's 30-in cap has been machined to accomdate a 10-in pipe stub-in. This connection area is heavily welded and acts as built-up reinforcement to both the cap and stub-in. All other piping weld connections are fully penetrating.

The unlisted cap component is fabricated with 304 stainless steel [6] and operates at 125°F while maintaining a constant internal gauge pressure of 253-psi [11, Section 7.1]. Applicable material properties of the unlisted cap component are shown in Table F.2.5-2, as retrieved from Table 2 from the main report body.

Table F.2.5-2 – 304 Stainless Steel Material Properties at 125°F .

Symbol	Property Value	Property Description
μ	0.30 in/in	Poisson's Ration [1, Section NB-3683.1(b)]
E	28.0E+6	Modulus of Elasticity at 125°F Temperature [12, Table TM]
Sy	28.35 ksi	Material Yield Strength at 125°F Temperature [12, Table Y-1]
Sm	20 ksi	Maximum allowable Stress Intensity at 125°F Temperature [12, Table 2A]

FE Boundary Conditions

A total of ten (10) ABAQUS solution runs were used to determine the unlisted cap component's FF and preliminary SI values. The FF runs used one model mesh with one boundary condition, but with differing (+/-) load appications. The preliminary SI runs utilized one model, with eight different boundary conditions and differing load applications.

FF Models & Boundary Conditions

One FE model mesh was used to determine deflection information necessary for computing the unlisted cap component's FF. An internal pressure of 253-psi is also applied. Figure F.2.5-7 shows a cut-away of the cap model showing how the internal pressure is appied on the element faces.

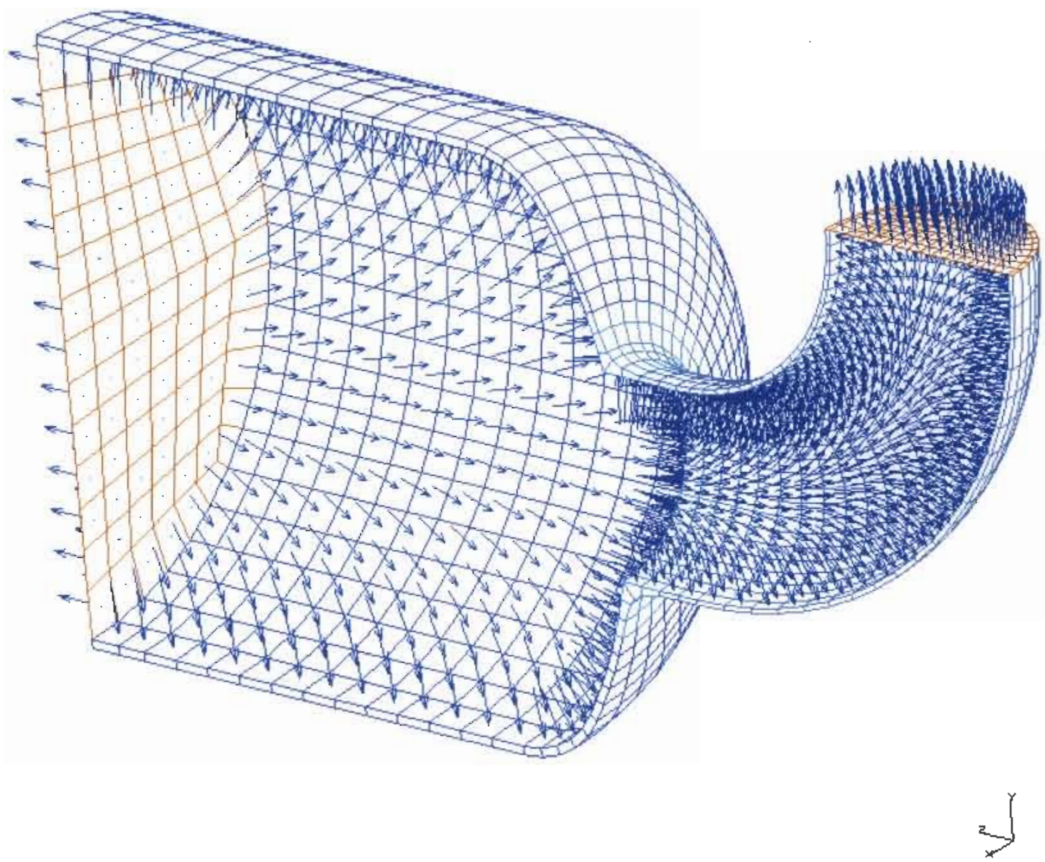

Figure F.2.5-7 – Cut-away of cap mesh showing applied internal pressure.

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The unlisted cap model utilizes rigid beams at the pipe and elbow top ends to transmit applied moments and restraints from the center nodes of the unlisted cap ends to the center nodes of 30-in pipe and elbow top ends. For illustration purposes only, the following figures show the unlisted cap mesh is contracting colors, to assist with identification of applied boundary conditions. The first model mesh (shown in Figure F.2.5-8) reflects how restraints and applied moments are placed on the unlisted cap component mesh. The angular deflection results (within the Y-Z plane) of this FF cap is used to determine cap deflection and then its flexibility factor. Table F.2.5-3 summaries the boundary condition placed on the two FF model meshes and identifies corresponding ABAQUS input files. A brief listing (without nodal and element definitions) of each input file is reprinted in Appendix F.2.10.

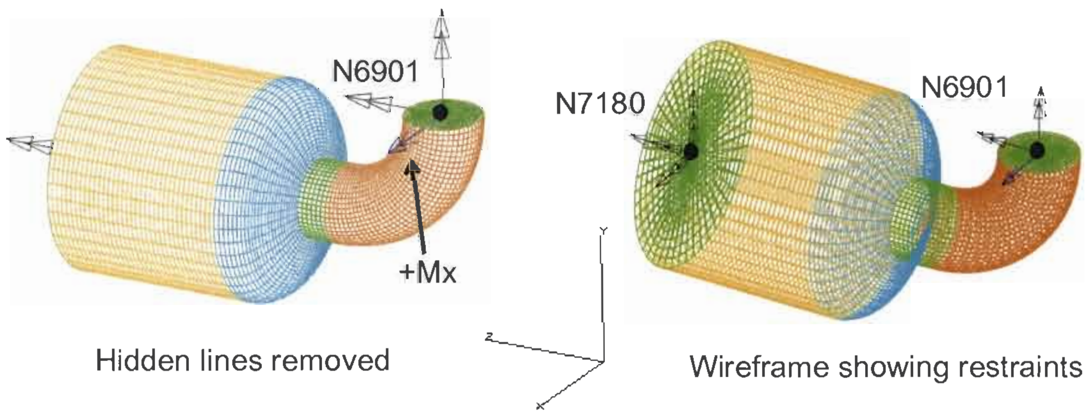


Figure F.2.5-8 – Isometric view of FF cap model mesh showing applied boundary condition.

Table F.2.5-3 – FF Models Boundary Conditions.

Model Meshes	**Restraint Nodes & Degrees of Freedom (DOF)**	**Applied Loads (IP-internal pressure) (Rx – applied moment)**	**Input File Name (Appendix F.1.11)**
Unlisted Cap	N7180: 6 dof fixed (X, Y, Z, RX, RY, RZ) N6901: 3 dof fixed: (X, RY, RZ)	IP = 253 psi N6901: MX = 9.886E+4 in*lbf	unlisted_end_cap_stp.inp
" "	" "	" " N6901: MX = -9.886E+4 in*lbf	unlisted_end_cap_stn.inp

Note that the applied moment of each FF model mesh has a different sign. The applied moment direction that produces the maximum angular displacement for each FF model mesh is used.

SI Model & Boundary Conditions

As previously described, the SI model mesh matches that of the cap (or unlisted cap component) mesh for which the physical properties (Table F.2.5-1) and material properties (Table F.2.5-2) apply. Eight boundary conditions corresponding to eight solution runs were used to apply corresponding results for determining the unlisted cap component's stress indices. The eight boundary conditions stem from two applied moment signs (+/-) and applied for three rotational directions (Mx, My, Mz), providing for eight different load combinations. As was shown for the FF model meshes, rigid beams were used at pipe and elbow top ends for restraint and moment application.

Applied moments were extracted from the final set of 32 Model 256's piping system runs (Appendix C), in which the 80 percentile run pertaining to corresponding moments incurred within the unlisted cap component final set are identified. Figure F.2.5-9 shows a representation of corresponding system beam nodes in which nodal moments are extracted.

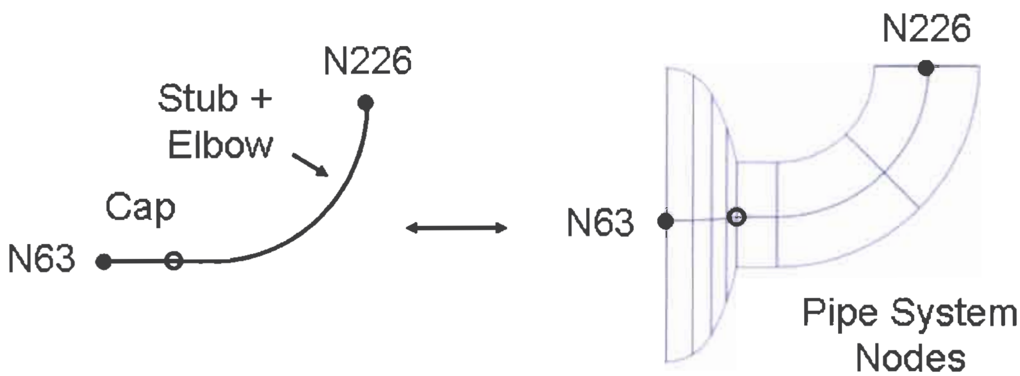


Figure F.2.5-9 – Corresponding nodes in which moments are extracted for 80 percentile solution.

As can be seen in figure F.2.5-9, moments (Mx, My, Mz) extracted at node 226 correspond to the cap's smaller opening and moments (Mx, My, Mz) extracted at node N63 are applied to the extended 30-in pipe end. Table F.2.5-4 lists the nodal moment values extracted from a preliminary 80 percentile run at these nodes that were used for scoping stress indices calculations.

Table F.2.5-4 – Unlisted Cap Component's Scoping Stress Indices Moment Extractions.

Node Number	MX (in*lbf)	MY (in*lbf)	MZ (in*lbf)
N226 (elbow top)	1.023E+5	1.435E+5	-7.598E+5
N63 (30" cap end)	-1.37E+5	-3.598E+4	1.387E+5

From Table F.2.5-4, the eight combination moment values were used to define the eight boundary conditions at the extended 30-in pipe and elbow top ends. Figure F.2.5-10 illustrates a single boundary condition where restraint set 1 is used along with the first of eight combinations applied at the elbow top end. Eight boundary conditions utilize restraint set 1, where varying moment combinations are applied at the elbow top end. Table F.2.5-5 summaries boundary conditions placed on the eight SI solutions and identify corresponding ABAQUS input files. A brief listing (without nodal and element definitions) of each SI input file is reprinted in Appendix F.2.10.

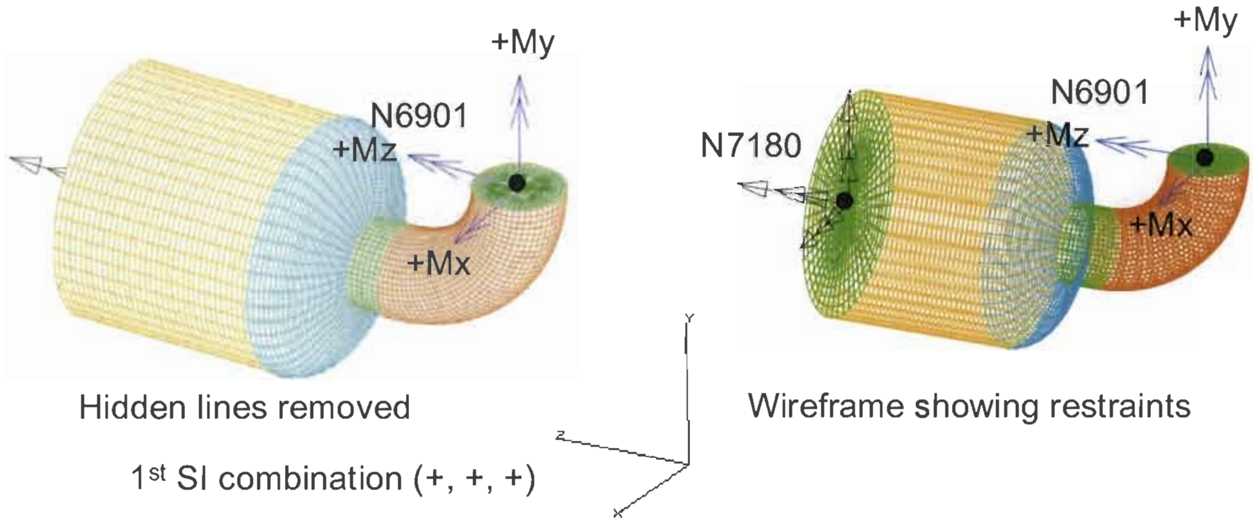


Figure F.2.5-10 – Isometric view of unlisted cap mesh showing restraint set 1 boundary condition applied.

Table F.2.5-5 – SI Model Boundary Conditions.

Input File Name (Appendix F.2.11)	Restraint Set Degrees of Freedom (DOF)	Applied Loads (IP – internal pressure) (Mx, My, Mz – applied moments)
si_mt_ucap_ce_ppp.inp	Set 1 N7180 - 6 dof fixed: (X, Y, Z, RX, RY, RZ)	IP = 253 psi N6901: Mx = +1.37E+5 in*lbf My = +3.598E+4 in*lbf Mz = +1.387E+5 in*lbf
si_mt_ucap_ce_ppn.inp	" "	" " N6901: Mx = +1.37E+5 in*lbf My = +3.598E+4 in*lbf Mz = -1.387E+5 in*lbf
si_mt_ucap_cd_pnp.inp	" "	" " N6901: Mx = +1.37E+5 in*lbf My = -3.598E+4 in*lbf Mz = +1.387E+5 in*lbf
si_mt_ucap_ce_npp.inp	" "	" " N6901: Mx = -1.37E+5 in*lbf My = +3.598E+4 in*lbf Mz = +1.387E+5 in*lbf
si_mt_ucap_ce_nnn.inp	" "	" " N6901: Mx = -1.37E+5 in*lbf My = -3.598E+4 in*lbf Mz = -1.387E+5 in*lbf
si_mt_ucap_ce_nnp.inp	" "	" " N6901: Mx = -1.37E+5 in*lbf My = -3.598E+4 in*lbf Mz = +1.387E+5 in*lbf
si_mt_ucap_ce_npn.inp	" "	" " N6901: Mx = -1.37E+5 in*lbf My = +3.598E+4 in*lbf Mz = -1.387E+5 in*lbf
si_mt_ucap__ce_pnn.inp	" "	" " N6901: Mx = +1.37E+5 in*lbf My = -3.598E+4 in*lbf Mz = -1.387E+5 in*lbf

F.2.6 – FE Model Results of Unlisted Cap Component

ABAQUS post processing results for the ten preliminary 80 percentile solution runs are shown within this section.

The first two FF solution results extract nodal coordinate values which are then used (in Appendix F.2.3) to determine angular displacements and a flexibility factor. Figure F.2.6-1 and F.2.6-2 shows displacement magnitude results of the positive and negative moments (Mx) for the unlisted cap mesh (1st and 2nd FF model mesh) and identifies nodes that are used for FF determination (within Appendix F.2.3).

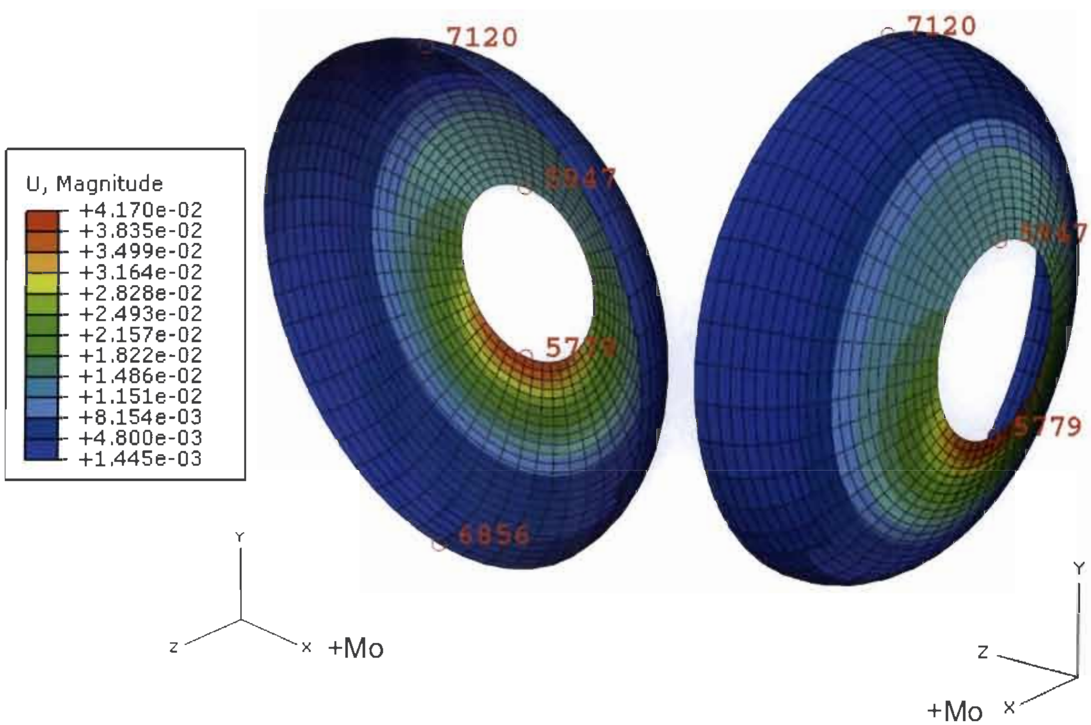


Figure F.2.6-1 – Isometric view of FF unlisted cap mesh +Mx results identifying displaced nodes.

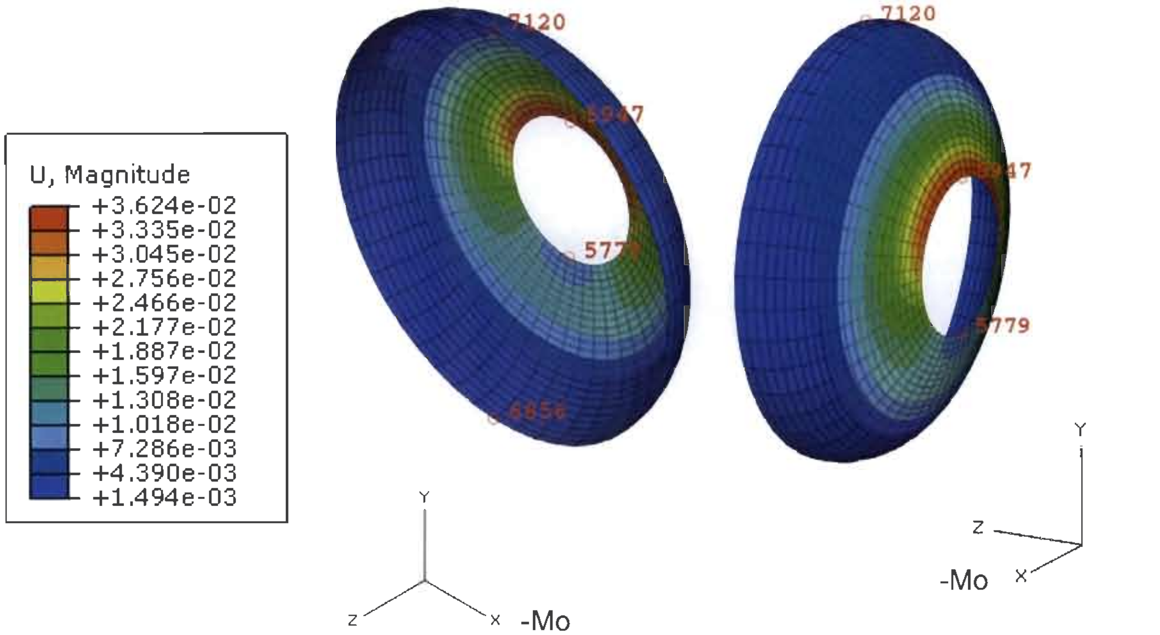


Figure F.2.6-2 – Isometric view of FF unlisted cap mesh -Mx results identifying displaced nodes.

Maximum nodal coordinate data (from Figure F.2.6-1) using linear material properties has been extracted from the unlisted cap post processing results and reprinted following.

```
****************************************************************************
Probe Values Report, written on Mon Aug 25 15:13:46 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/ff_multiple_time_histories/ff_mt_bob_cap/ff_mt_ucapp_ce.odb
   Step: Step-2
   Frame: Increment     14: Step Time =    1.000

Probe values reported at nodes

  Part Instance     Node ID                      Def. Coords
                                      X               Y               Z
-------------------------------------------------------------------------------------
--------------------------------------
    PART-1-1        6856     3.26037E-06      -14.5624         -2.34401
    PART-1-1        7120     1.85745E-06       14.5637         -2.34352
    PART-1-1        5779     6.82929E-03      -5.13016         -9.16882
    PART-1-1        5957    -7.17828E-03       5.12911         -9.15622
```

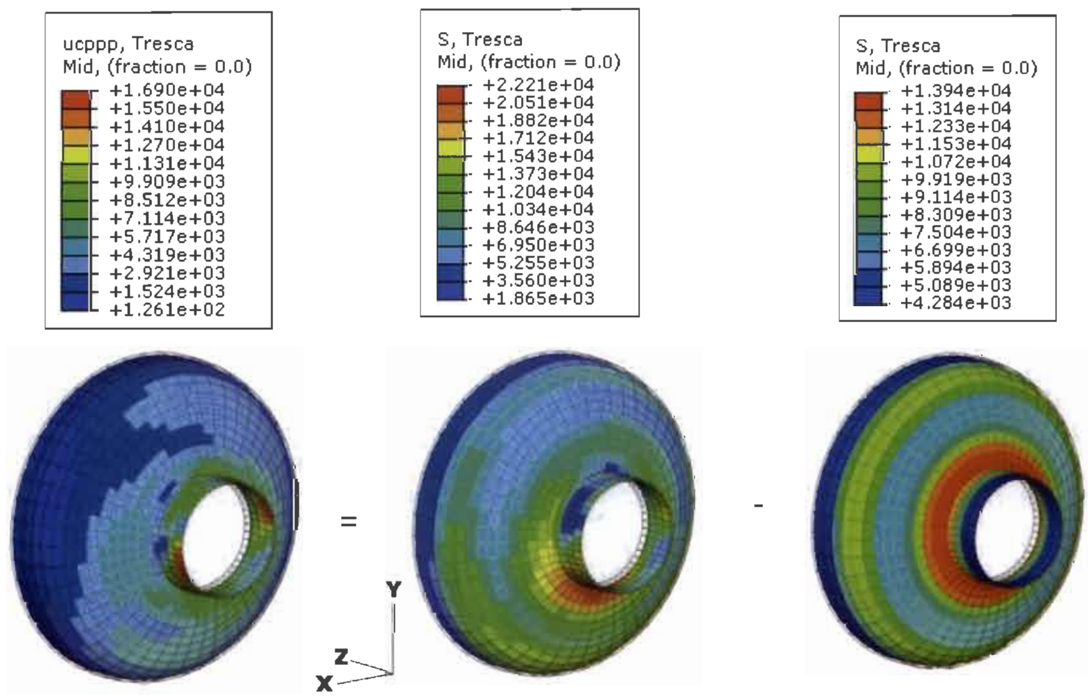
Note: Nodes corresponding to thin shell element model (shown in Figures F.2.6-1 and F.2.6-2) are used to match that of nodes corresponding to continuum element model that was run to generate results. Actual continuum shell node labels are 1637, 338, 7524, and 7503, organized from top down, in place of node labels shown.

The next eight SI solution results extract maximum membrane tresca stresses from each SI result model. The input file for each SI input file creates two resultant steps in which a third step is generated to obtain the tresca stress state needed. As shown in the first combination boundary condition (shown following), at the bottom of each SI input file the first step (step 1) produces results for an internal pressure (253-psi) loading. The second step (step 2) computes results for combined internal pressure plus moment combination loading.

```
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET Mppp
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET Mppp
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE + Cppp
**%  RESTRAINT SET 1
**%  LOAD SET 1
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00,-0.10000E+01, 0.00000E+00
*CLOAD,OP=NEW
      11680,     4, 9.886E+04
      11680,     5, 1.529E+05
      11680,     6, 9.927E+04
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

A third step (step 3) is created within ABAQUS Viewer that subtracts step 1 (P) from step 2 (P+Ri) to obtain corresponding bending tresca stress results (Ri). This is done to capture the added stiffness from internal pressure reflected into the Ri results [Ri = (P+Ri) – (P)]. Maximum tresca stress results (extracted from the eight SI result combinations) for the three moments (Mx, My, & Mz) are used to determine branch and run stress indices computed in Appendix F.2.7.

Figures F.2.6-3 through F.2.6-7 show maximum membrane tresca stress plots corresponding to eight moment combination results applied to the elbow top end. Figure F.2.3-8 shows the corresponding maximum membrane tresca stress plot due to unlisted cap pressure. The corresponding maximum tresca stress values for each load combination case are contained in file "mt_ucap_ce.rpt" reprinted in Appendix F.2.6.1.



Step 3 (Cppp) Cap +Mx +My +Mz = Step 2 (P + Cppp) - Step 1 (P)

Figure F.2.6-3 – Step 3 membrane Cppp (cap + Mx +My +Mz) tresca stresses, shown as difference of steps 2 and step 1.

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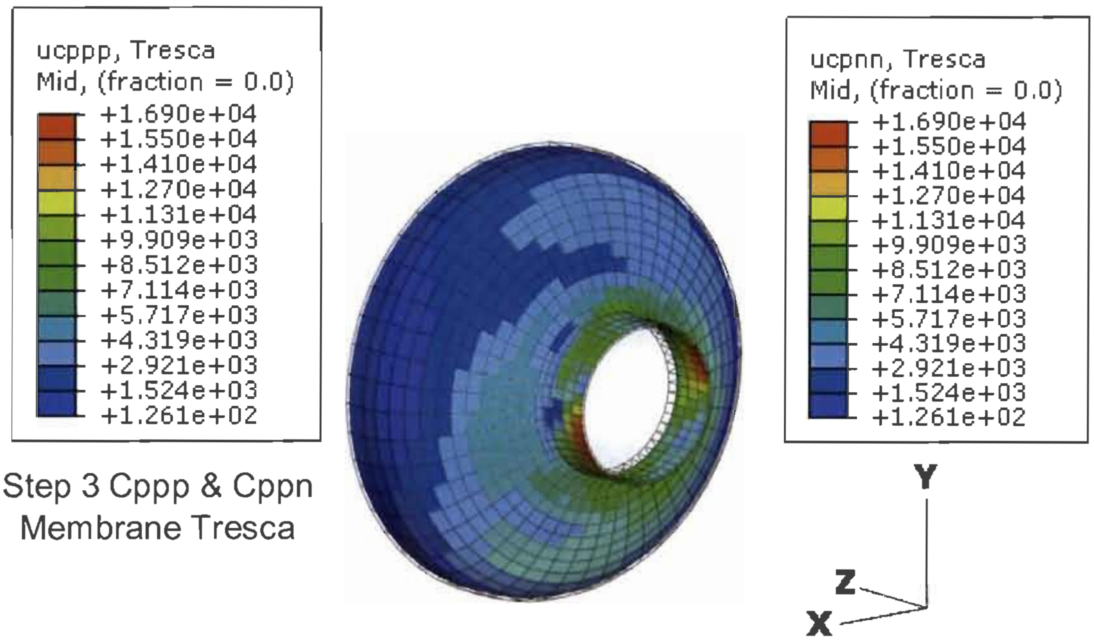

Figure F.2.6-4 – Step 3 membrane Cppp (cap +Mx +My +Mz) and Cppn (cap +Mx +My –Mz) tresca stresses share the same maximum values.

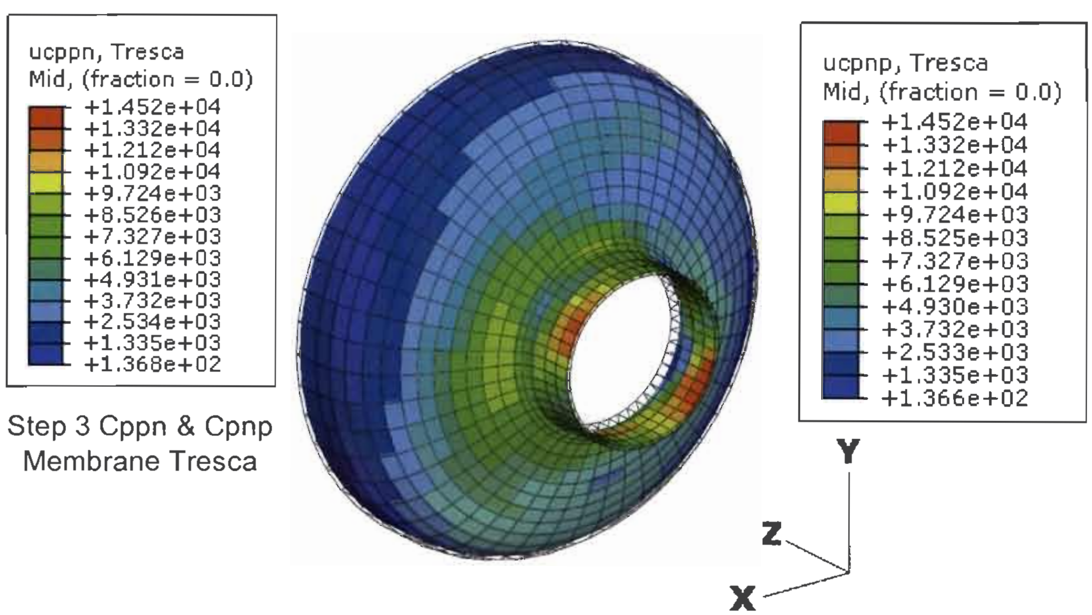

Figure F.2.6-5 – Step 3 membrane Cppn (cap +My +My -Mz) and Cpnp (+Mx -My +Mz) tresca stresses share the same maximum values.

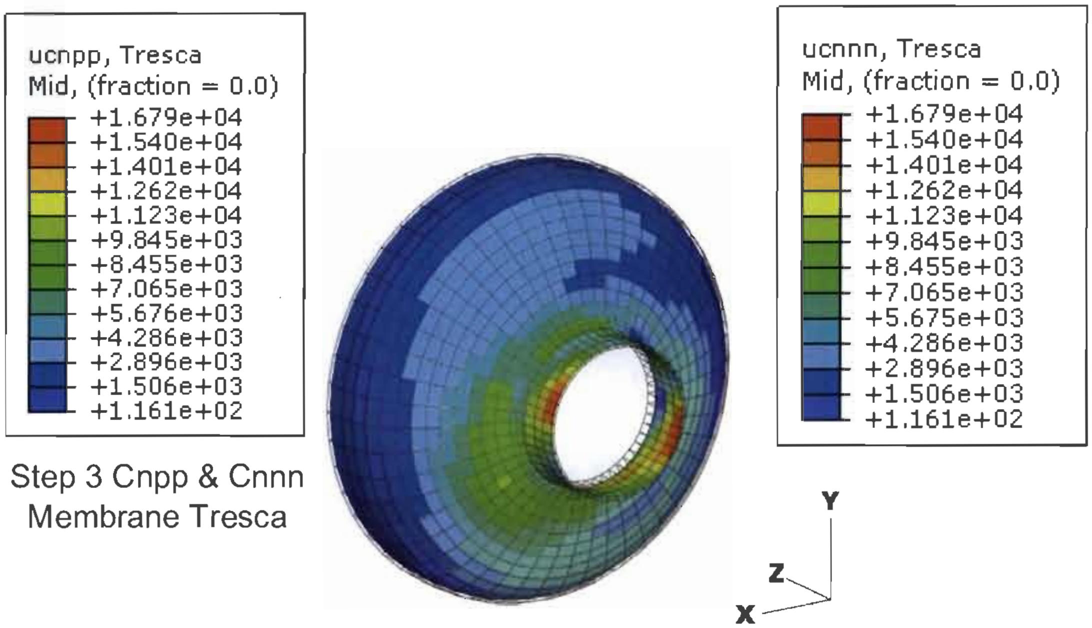

Figure F.2.6-6 – Step 3 membrane Cnpp (cap –Mx +My +Mz) and Cnpp (cap -Mx +My +Mz) tresca stresses share the same maximum values..

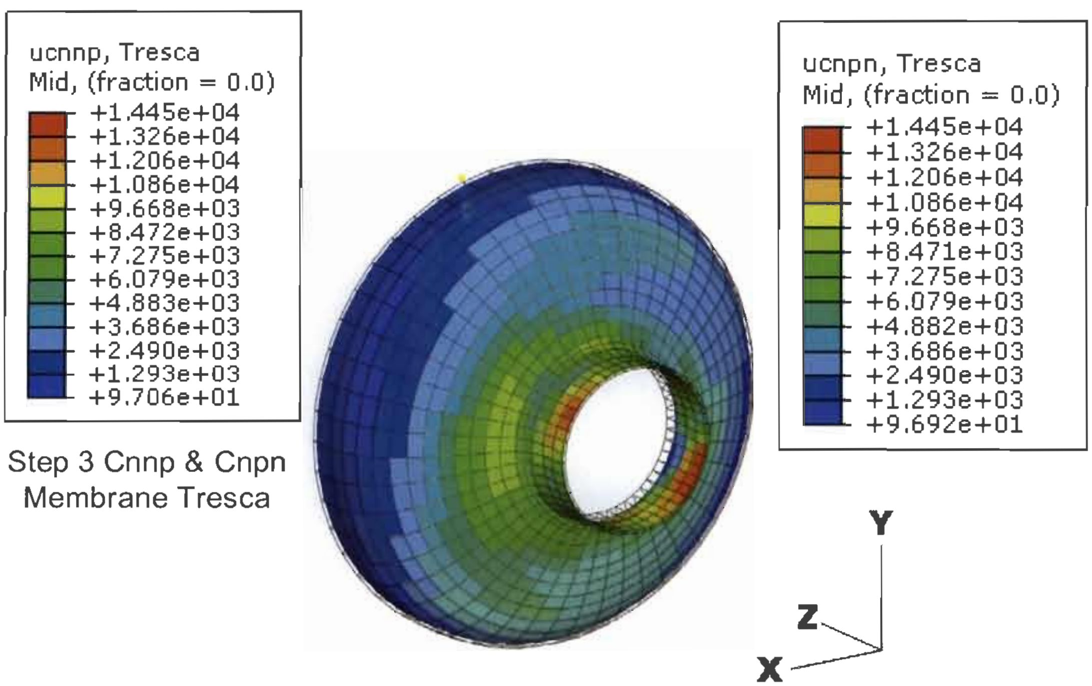

Figure F.2.6-7 – Step 3 membrane Cnnp (cap –Mx -My +Mz) and Cnpn (cap -Mx +My -Mz) tresca stresses share the same maximum values.

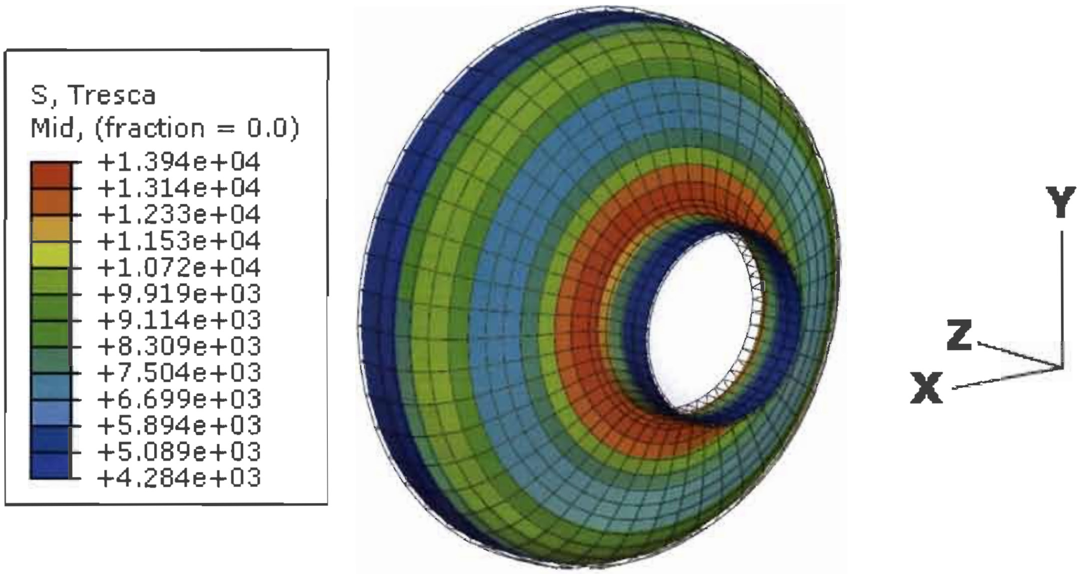

Figure F.2.6-8 – Step 1 membrane Pressure (P) tresca stresses.

F.2.6.1 – Unlisted Cap Component Maximum Tresca Stress Result Files

A file is used to capture maximum tresca stresses for the eight cap combination load conditions and the cap pressure. File "mt_ucap_ce.rpt' contain maximum element and integration point tresca stress values for loads placed on the unlisted cap's elbow top end.

mt_ucap_ce.rpt

```
********************************************************************************
Probe Values Report, written on Tue Sep 02 22:07:50 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_cap_cont_ele/si_mt_ucap_ce_
ppp.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Integration point values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at integration points

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
```

```
    PART-1-1        6357        SC8R        4240        4219        5124
5169        5555        5534        6713        6716


  Part Instance  Element ID        Type       Int. Pt.  ucppp: Tresca
--------------------------------------------------------------------------------
    PART-1-1        6357        SC8R               1     16.897E+03


********************************************************************************
Probe Values Report, written on Tue Sep 02 22:28:48 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_cap_cont_ele/si_mt_ucap_ce_
ppn.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Integration point values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at integration points

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1        3241        SC8R        577         598         1981
1976        2405        2426        3675        3672


  Part Instance  Element ID        Type       Int. Pt.  ucppn: Tresca
--------------------------------------------------------------------------------
    PART-1-1        3241        SC8R               1     14.518E+03


********************************************************************************
Probe Values Report, written on Tue Sep 02 22:32:26 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_cap_cont_ele/si_mt_ucap_ce_
pnp.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Integration point values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at integration points
```

```
  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1        6361        SC8R        4261        4240        5169
5206        5576        5555        6716        6719


  Part Instance  Element ID        Type       Int. Pt.  ucpnp: Tresca
--------------------------------------------------------------------------------
    PART-1-1        6361        SC8R                1     14.517E+03


********************************************************************************
Probe Values Report, written on Tue Sep 02 22:47:48 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_cap_cont_ele/si_mt_ucap_ce_
npp.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Integration point values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at integration points

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1        3237        SC8R         556         577        1976
1971        2384        2405        3672        3669


  Part Instance  Element ID        Type       Int. Pt.  ucnpp: Tresca
--------------------------------------------------------------------------------
    PART-1-1        3237        SC8R                1     16.794E+03


********************************************************************************

Probe Values Report, written on Tue Sep 02 22:46:23 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_cap_cont_ele/si_mt_ucap_ce_
nnn.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Integration point values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)
```

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Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
Probe values reported at integration points

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1        6357        SC8R        4240        4219        5124
5169        5555        5534        6713        6716

  Part Instance  Element ID        Type       Int. Pt.  ucnnn: Tresca
--------------------------------------------------------------------------------
    PART-1-1        6357        SC8R                1     16.794E+03


********************************************************************************
Probe Values Report, written on Tue Sep 02 22:51:47 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_cap_cont_ele/si_mt_ucap_ce_
nnp.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Integration point values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at integration points

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1        3241        SC8R        577         598         1981
1976        2405        2426        3675        3672

  Part Instance  Element ID        Type       Int. Pt.  ucnnp: Tresca
--------------------------------------------------------------------------------
    PART-1-1        3241        SC8R                1     14.454E+03


********************************************************************************
Probe Values Report, written on Tue Sep 02 22:55:27 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_cap_cont_ele/si_mt_ucap_ce_
npn.odb
   Step: Session Step
   Frame: Session Frame
```

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```
Loc 1 : Integration point values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at integration points

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1        6361        SC8R        4261        4240        5169
5206        5576        5555        6716        6719

  Part Instance  Element ID        Type       Int. Pt.  ucnpn: Tresca
--------------------------------------------------------------------------------
    PART-1-1        6361        SC8R              1     14.453E+03

********************************************************************************
Probe Values Report, written on Tue Sep 02 23:06:15 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_cap_cont_ele/si_mt_ucap_ce_
pnn.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Integration point values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at integration points

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1        3237        SC8R         556         577        1976
1971        2384        2405        3672        3669

  Part Instance  Element ID        Type       Int. Pt.  ucpnn: Tresca
--------------------------------------------------------------------------------
    PART-1-1        3237        SC8R              1     16.897E+03

********************************************************************************
Probe Values Report, written on Tue Sep 02 23:07:21 2008

Source
-------

   ODB:
C:/pcs/pcs2/model_(26)/si_multiple_time_histories/si_mt_cap_cont_ele/si_mt_ucap_ce_
pnn.odb
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
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```
Step: Step-1
Frame: Increment     14: Step Time =    1.000

Loc 1 : Integration point values at shell < SST304_P > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at integration points

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1        6332        SC8R        5194        5185        5186
5195        6696        6688        6689        6697

  Part Instance  Element ID        Type       Int. Pt.      S: Tresca
--------------------------------------------------------------------------------
    PART-1-1        6332        SC8R              1     13.938E+03
```

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F.2.7 – Unlisted Cap Component FE model input and FF & SI Determination

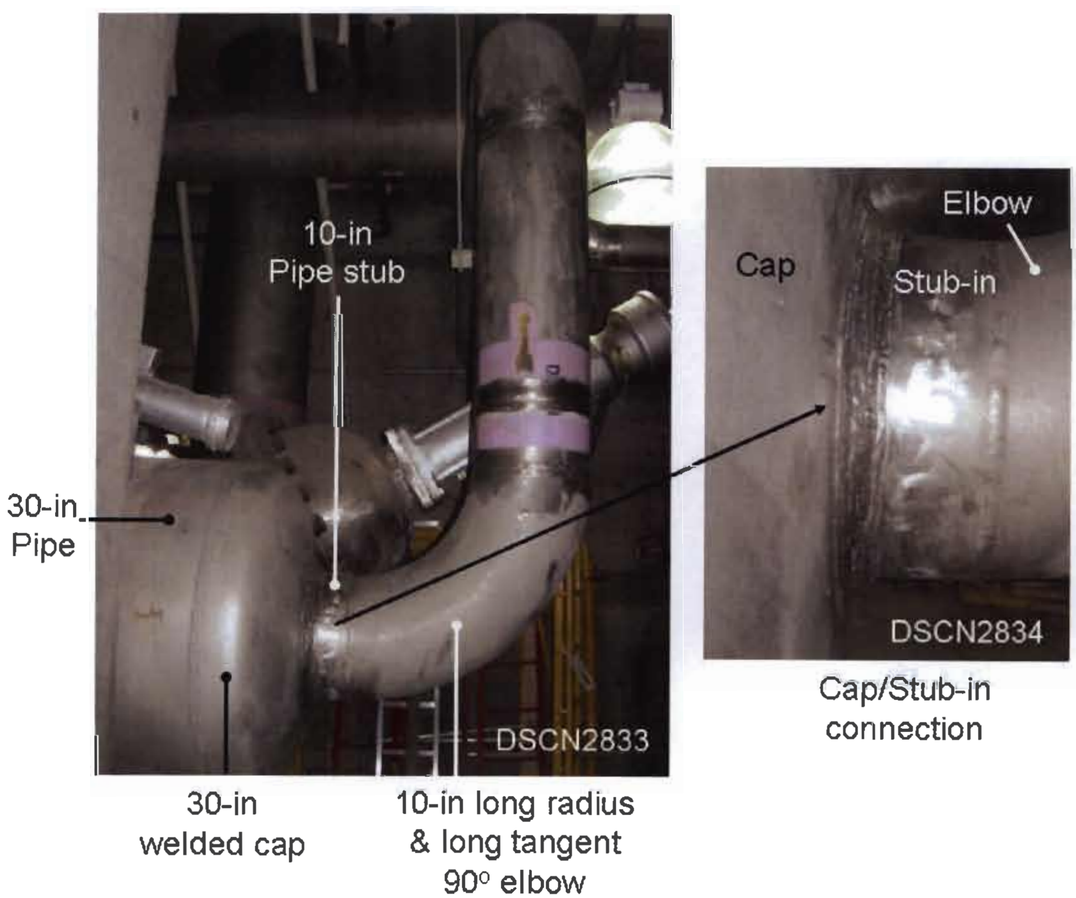
The purpose of this section is to determine FE model input, FF, and SI, for Model 256's unlisted cap component. Pertinent FE model result data are extracted from Appendices F.2.6 and F.2.6.1 for FF and SI value determinations.

FE model input:

Model 256 unlisted cap component [23] is an 30-in pipe cap stubbed with short 10-in straight pipe extension.

The unlisted component is actually the cap that has been breached. The stub-in (short straight pipe extension) and follow-on elbow, are listed components. To determine the breached cap's flexibility factor, the listed components surrounding the unlisted cap are modeled.

Per its drawing [23], the elbow is listed as a 90-deg 10-in schedule 20 long radius & long tangent. As depicted in the following picture, the tangent section of the elbow appears to be a 10-in pipe segment that is welded to the top of a listed long radius elbow. Thus, the elbow (used in this construction) is a 90-deg long radius 10-in sch. 20 listed elbow.



Project:	ATR Life Time Extension Project			**ECAR No.:**	ECAR-194	**Rev.:**	0
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Model 256 Unlisted Cap & surrounding listed component dimensions:

Capped Pipe [23]:

$D_{30} := 30 \cdot in$ $\quad t_{30} := \frac{7}{16} \cdot in$ Outside diameter and thickness of 30-in pipe (line 1-17)

$d_{30} := D_{30} - 2 \cdot t_{30}$ $\quad d_{30} = 29.125\, in$ Inner diameter of capped pipe

$d30_{mean} := \frac{D_{30} + d_{30}}{2}$ $\quad d30_{mean} = 29.563\, in$ Mean diameter of capped pipe

$r30_{mean} := \frac{d30_{mean}}{2}$ $\quad r30_{mean} = 14.781\, in$ Mean radius of capped pipe

Cap [14, p. 68, 69]:

$E_{cap} := 10.5 \cdot in$ Cap overall length

$IEn_{cap} := E_{cap} - \frac{t_{30}}{2}$ $\quad IEn_{cap} = 10.281\, in$ Inside length of cap at neutral axis

$S_{cap} := \frac{2.81 + 2.75}{2} \cdot in$ $\quad S_{cap} = 2.78\, in$ Tangent length averaged between 3/8-in and 1/2-in thick caps

$R_{cap} := \frac{25.6 + 25.38}{2} \cdot in$ $\quad R_{cap} = 25.49\, in$ Inside dish radius of cap averaged between 3/8-in and 1/2-in thick caps

$Rn_{cap} := R_{cap} + \frac{t_{30}}{2}$ $\quad Rn_{cap} = 25.709\, in$ Inside dish radius of cap at neutral axis

$r_{cap} := \frac{4.88 + 4.83}{2} \cdot in$ $\quad r_{cap} = 4.855\, in$ Inside knuckle radius of cap averaged between 3/8-in and 1/2-in thick caps

$r_{ncap} := r_{cap} + \frac{t_{30}}{2}$ $\quad r_{ncap} = 5.074\, in$ Inside knuckle radius of cap at neutral axis

10-in schedule 20 pipe & long radius 90° elbow [14, p. 8-9]:

$D_{10} := 10.75\,in$ $t_{10} := \frac{1}{4}\cdot in$ Outside diameter and thickness of 10-in schedule 20 pipe & elbow (line 1-17)

$d_{10} := D_{10} - 2\cdot t_{10}$ $d_{10} = 10.25\,in$ Inner diameter of 10-in sch 20 pipe & elbow

$d10_{mean} := \frac{D_{10} + d_{10}}{2}$ $d10_{mean} = 10.5\,in$ Mean diameter of 10-in pipe & elbow

$r10_{mean} := \frac{d10_{mean}}{2}$ $r10_{mean} = 5.25\,in$ Mean radius of 10-in pipe & elbow

$L_{10e} := 15\cdot in$ Center to elbow face distance

$L_{10} := 4\cdot in$ The length of the 10-in pipe stub is approximately 4-inches, as determined from I-DEAS model and dimension stack up noted in its drawing [23].

Determine length of FE model 30-in extension piping, for restraint application:

$r30_{mean} = 14.781\,in$ Length of piping on capped pipe end, based on minimum distance to flanges [1, NB-3686.2 (c)] shall be no greater than the pipe's mean radius.

Let => $L30_{min} := 22\cdot in$ $\frac{L30_{min}}{r30_{mean}} = 1.488$ Extended 30-in pipe length used for applying restraint to unlisted cap model.

FE model material properties:

Operating conditions of pilot model [11, Section 7.1]:

$P := 253\cdot psi$ $T := 125\cdot deg$ Model 256's operating internal pressure and temperature

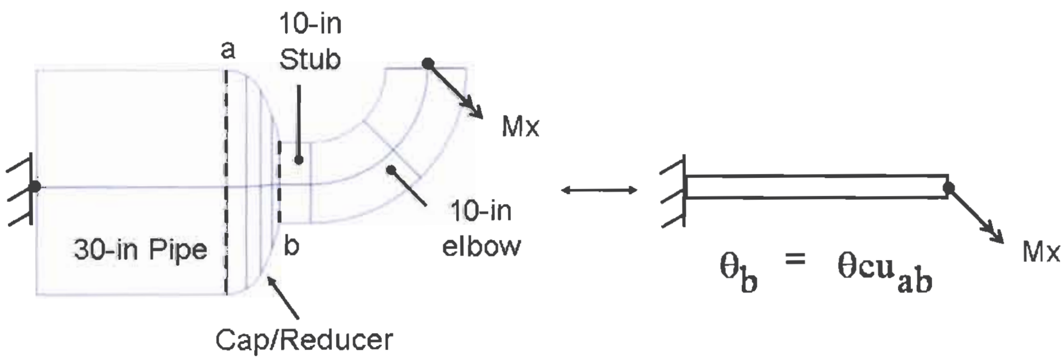
Let => $\nu := 0.30\,\frac{in}{in}$ $E_{125} := 2.8\cdot 10^{7}\cdot psi$ $G_{125} := 1.075\cdot 10^{7}\cdot psi$ $Sy_{125} := 28.35\,ksi$

Poisson's ratio, Modulus of Elasticity at 125 °F, Section Modulus at 125°F, & Material Yield Strength at 125°F, already computed and retrieved from Table F.2.1.-2.

Determine Effective Moment of Inertia (EMI) for Unlisted Cap Component

The unlisted cap component's EMI is approximated as a listed piping reducer. Normally, the EMI is calculated by first determining the listed reducer's flexibility factor (FF). Unfortunately, there are no provisions for determining FF for a listed reducer. Hence, the EMI is determined directly.

Find effective moment of inertia for cap.



$\theta_b = \dfrac{M_o \cdot L}{E \cdot I}$ Deflection angle of fixed cantilever beam with applied moment at its end [24, App. G, Case 6]

=> $\theta cu_{ab} = \dfrac{M_o \cdot L_{cap}}{E_{125} \cdot Icap_{eff}}$

where θcu_{ab} Angular deflection of unlisted cap, between planes "a" & "b"

M_o Applied moment at cantilever end (Mx)

L_{cap} Length of cap/reducer

E_{125} Material stiffness at 125° F

$Icap_{eff}$ EMI of cap/reducer

=> $Icap_{eff} = \dfrac{M_o \cdot L_{cap}}{E_{125} \cdot \theta cu_{ab}}$

$M_o := 9.886 \cdot 10^4 \cdot in \cdot lbf$ Moment (Mx) extracted from unlisted cap component preliminary runs and applied to FE model meshes for EMI evaluation. Moment corresponds to value less then material's yield point.

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$L_{cap} := 6.95\cdot in$ Cap length $E_{125} = 28000\,ksi$ Modulus of Elasticity at 125 ° F

Cap is connected to 30-in pipe on large end and 10-in sch. 20 pipe on small end.

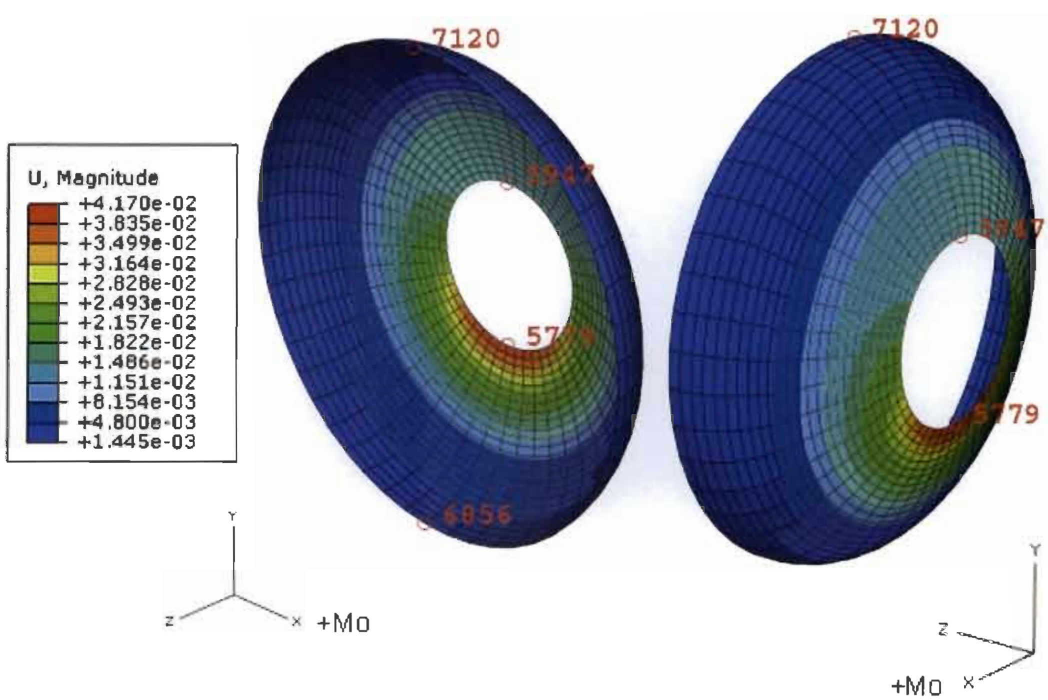
$Do_{30} := 30\cdot in$ $t30_{cap} := \frac{7}{16}\cdot in$ $Di_{30} := Do_{30} - 2\cdot t30_{cap}$ $Di_{30} = 29.125\,in$

$Dm_{30} := Do_{30} - t30_{cap}$ $Dm_{30} = 29.5625\,in$

$Do_{10} := 10.75\,in$ $t10_{cap} := \frac{1}{4}\cdot in$ $Di_{10} := Do_{10} - 2\cdot t10_{cap}$ $Di_{10} = 10.25\,in$

$Dm_{10} := Do_{10} - t10_{cap}$ $Dm_{10} = 10.5\,in$

Displacement coordinate data obtained from Appendix F.2.6, corresponding to Fig. F.2.6-1.
30-in x10-in unlisted cap displacements shown below for +Mo.



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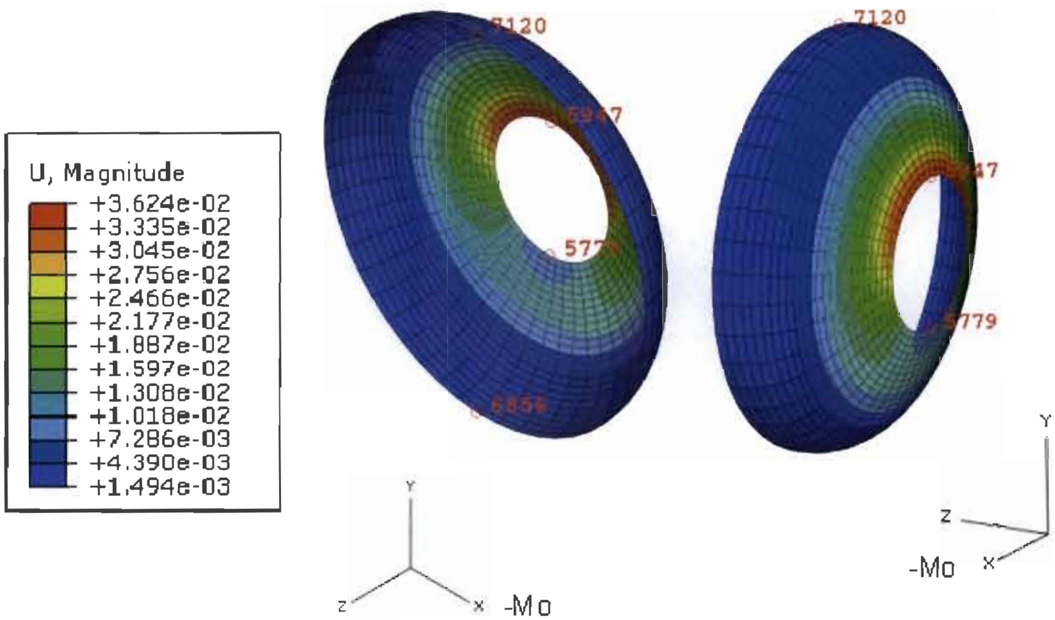
Displacement coordinate data obtained from Appendix F.2.6, corresponding to Fig. F.2.6-2. 30-in x10-in unlisted cap displacements shown below for -Mo.



Unlisted_end_cap_stp.inp (+Mx) with ***linear*** material properties, produces highest cap deflections. Deflection node coordinates of cap openings, are shown following and Section F.2.6.

N6856 N7120

$$Nc_{1u} := (3.26037E\text{-}06\ \ -14.5624\ \ -2.34401)^T \qquad Nc_{2u} := (1.85745E\text{-}06\ \ 14.5637\ \ -2.34352)^T$$

$$Vc_{21u} := Nc_{2u} - Nc_{1u} \qquad Vc_{21u}^T = \left(-1.40292\times 10^{-6}\ \ 29.1261\ \ 0.00049\right)$$

Back plane displacement vector of unlisted cap FE model mesh

N5779 N5947

$$Nc_{3u} := (6.82929E\text{-}03\ \ -5.13016\ \ -9.16882)^T \qquad Nc_{4u} := (-7.17828E\text{-}03\ \ 5.12911\ \ -9.15622)^T$$

$$Vc_{43u} := Nc_{4u} - Nc_{3u} \qquad Vc_{43u}^T = (-0.01401\ \ 10.25927\ \ 0.0126)$$

Front plane displacement vector of unlisted cap FE model mesh

$$\theta cu_{ab} := \text{acos}\left(\frac{Vc_{21u}\cdot Vc_{43u}}{|Vc_{21u}|\cdot|Vc_{43u}|}\right) \qquad \theta cu_{ab} = 0.10458\,\text{deg}$$

Dot product between vectors Vc21cu & Vc43u

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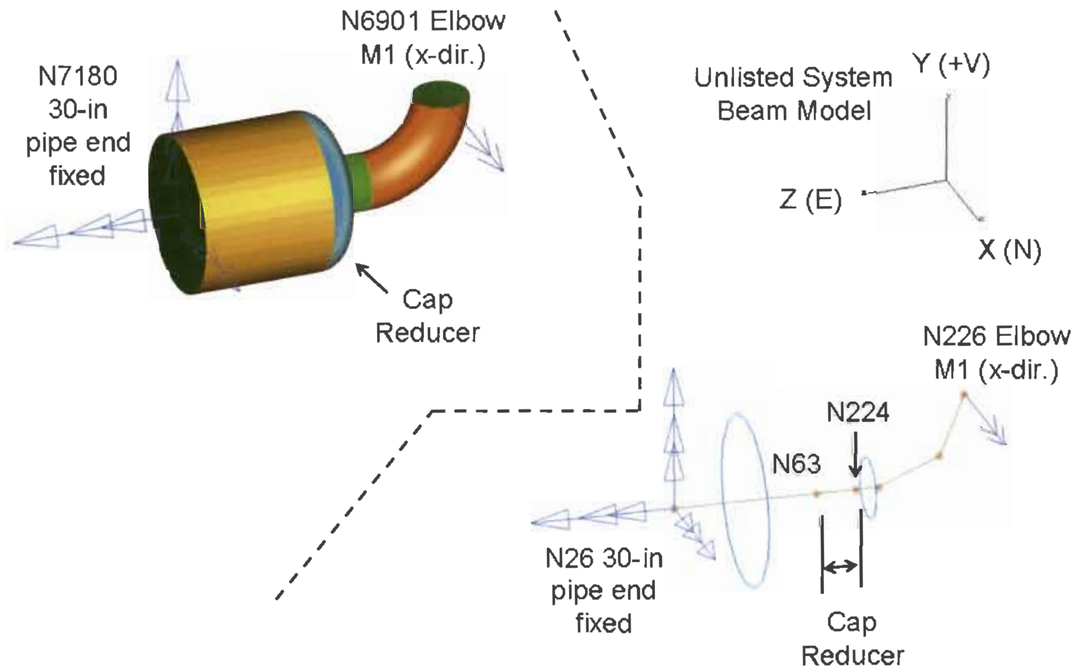
$Icap_{eff} := \frac{|M_o| \cdot L_{cap}}{E_{125} \cdot \theta cu_{ab}}$ $Icap_{eff} = 13.44419 in^4$ Unlisted cap's EMI

$Jcu_{eff} := 2 \cdot Icap_{eff}$ $Jcu_{eff} = 26.88837 in^4$ Unlisted cap's effective polar moment of inertia

Compare flexibilities between shell and beam models of Model 256 cap unlisted component:



Mx My Mz

$n_{226s} := \begin{pmatrix} 9.516\ 10^4 & 1.315\ 10^5 & -5.064\ 10^4 \end{pmatrix}^T$

Check flexibility of cap shell model to that of cap beam model using 09/24/08 scoping solution moment reactions.

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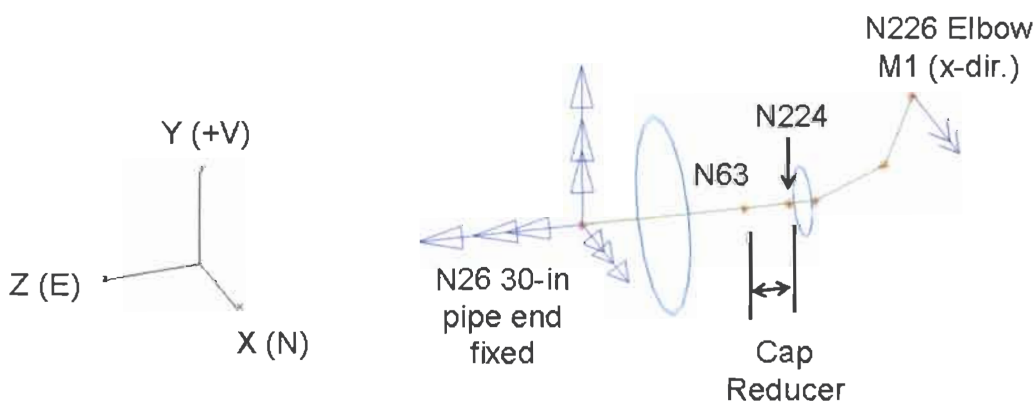
To check the flexibility, three load cases are run with the beam and shell models with the most recent 80 percentile solution runs. Each beam model load case consists of a single moment direction applied to its end elbow node (i.e. 95,160 in-lbf in the global x-direction, 131,500 in-lbf in global y-direction, or -50,640 in-lbf in the global z-direction). The model is fully restrained where the 30-in diameter pipe (behind the cap) is cut. Each shell model is run with the same boundary conditions as its corresponding beam model. However, the shell model has an additional initial step where an internal pressure of 253 psi is applied. The following plots include the results from the shell model and the beam model. Additionally, beam results scaled plus and minus 20% are included for information. The shell model results have two steps. Displacements that occur during the first step, due to the pressure loading, are subtracted from the total curve so that only the relative displacement of caused by the moment is plotted.

The input files used for the beam models were "beam_mt_cap_m1.inp", 'beam_mt_cap_m2.inp", and "beam_mt_cap_m3.inp". The input files used for the shell models were "shell_mt_cap_ce_m1.inp", "shell_mt_cap_ce_m2.inp", and "shell_mt_cap_ce_m3.inp". In both sets of input files, the number change of 1, 2, and 3 represent the x-axis run, the y-axis run, and the z-axis run respectivel

Angular displacements are obtained from the beam model between the cap (reducer) section, between nodes N224 and N63. This reducer section is the unlisted compoent and remaining piping items are listed components. Determine beam model reducer deflections about the Global 1 (x-direction).



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Start with beam model angular deflections. Following are the angular rotations of the cap nodes N63 and N226.

$UR'_{beam\_cap\_m1dat} :=$

Time	N63	N225
0	0	0
0.05	0	0.00009
0.1	0	0.00018
0.15	0	0.00027
0.2	0	0.00036
0.25	0	0.00044
0.3	0.00001	0.00053
0.35	0.00001	0.00062
0.4	0.00001	0.00071
0.45	0.00001	0.0008
0.5	0.00001	0.00089
0.55	0.00001	0.00098
0.6	0.00001	0.00107
0.65	0.00001	0.00115
0.7	0.00001	0.00124
0.75	0.00001	0.00133
0.8	0.00002	0.00142
0.85	0.00002	0.00151
0.9	0.00002	0.0016
0.95	0.00002	0.00169
1	0.00002	0.00178

$UR'_{beam\_cap\_m1dat} =$ (matrix above)

Separate angular rotation of nodes into their own arrays, take a difference, and add time increment column so that it may be plotted.

$UR1\_beam\_cap_{n63} := UR'^{\langle 1 \rangle}_{beam\_cap\_m1dat}$ $\qquad UR1\_beam\_cap_{n225} := UR'^{\langle 2 \rangle}_{beam\_cap\_m1dat}$

$\theta 1^{\langle 0 \rangle}_{beam\_cap\_n225\_n63} := UR'^{\langle 0 \rangle}_{beam\_cap\_m1dat}$

$\theta 1^{\langle 1 \rangle}_{beam\_cap\_n225\_n63} := UR1\_beam\_cap_{n225} - UR1\_beam\_cap_{n63}$

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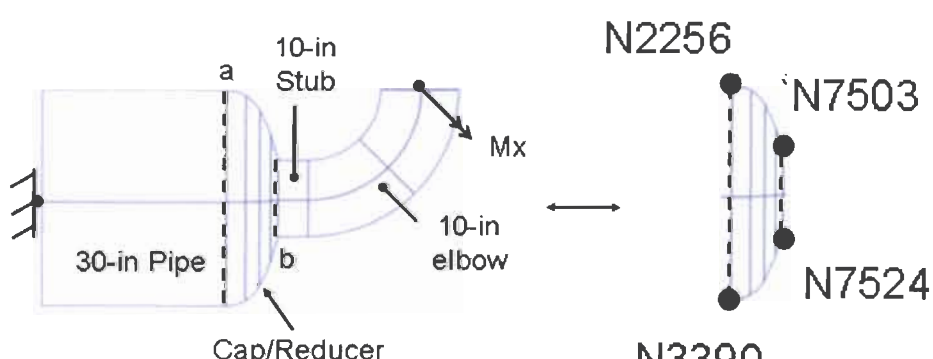
$$\theta 1_{beam\_cap\_n225\_n63} = \begin{pmatrix} 0 & 0 \\ 0.05 & 0.00009 \\ 0.1 & 0.00018 \\ 0.15 & 0.00026 \\ 0.2 & 0.00035 \\ 0.25 & 0.00044 \\ 0.3 & 0.00053 \\ 0.35 & 0.00061 \\ 0.4 & 0.0007 \\ 0.45 & 0.00079 \\ 0.5 & 0.00088 \\ 0.55 & 0.00097 \\ 0.6 & 0.00105 \\ 0.65 & 0.00114 \\ 0.7 & 0.00123 \\ 0.75 & 0.00132 \\ 0.8 & 0.00141 \\ 0.85 & 0.00149 \\ 0.9 & 0.00158 \\ 0.95 & 0.00167 \\ 1 & 0.00176 \end{pmatrix}$$

Rotation of beam mode reducerl in global 1 (x-direction)

Check flexibility of cap shell model to that of cap beam model using 09/24/08 scoping solution moment reactions.

Compare to shell cap model angular deflections in Global 1 (x-direction):



Side view

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Unlike the cap (reducer) beam model, angular displacements may not be extracted directly from the shell model. The front and rear surfaces of the reducer are approximated as vectors (in planes a & b of previous sketch) and their vector displacements with respect to each other determine the amount of angular displacement that has occured within the shell model.

Instead of angular displacements, nodal translations are added to original coordinates to define vectors by the specifying nodes (shown in the previous sketch).

shell_cap_ce_oc_m1dat :=

Node	X	Y	Z
2256	−0.029	15	−2.366
3390	−0.029	−15	−2.366
7503	−0.007	5.125	−9.143
7524	0.007	−5.125	−9.143

shell_cap_ce_oc_m1dat =

$$\begin{pmatrix} 2256 & -0.029 & 15 & -2.366 \\ 3390 & -0.029 & -15 & -2.366 \\ 7503 & -0.007 & 5.125 & -9.143 \\ 7524 & 0.007 & -5.125 & -9.143 \end{pmatrix}$$

$U'_{shell\_cap\_ce\_m1dat}$:=

Nodal displacements (dx, dy, dz) are extracted from shell model for each vector node.

$$graph_s(a,b) := \left| \begin{array}{l} \theta 1cu_{ab}^{\langle 0 \rangle} \leftarrow a^{\langle 0 \rangle} \\ \text{for } i \in 0..\text{rows}(a)-1 \\ \quad \left| \begin{array}{l} Nc_{1u} \leftarrow \left(a_{i,4}\ a_{i,8}\ a_{i,12}\right)^T + \left(b_{3,1}\ b_{3,2}\ b_{3,3}\right)^T \\ Nc_{2u} \leftarrow \left(a_{i,3}\ a_{i,7}\ a_{i,11}\right)^T + \left(b_{2,1}\ b_{2,2}\ b_{2,3}\right)^T \\ Nc_{3u} \leftarrow \left(a_{i,2}\ a_{i,6}\ a_{i,10}\right)^T + \left(b_{1,1}\ b_{1,2}\ b_{1,3}\right)^T \\ Nc_{4u} \leftarrow \left(a_{i,1}\ a_{i,5}\ a_{i,9}\right)^T + \left(b_{0,1}\ b_{0,2}\ b_{0,3}\right)^T \\ Vc_{21u} \leftarrow Nc_{2u} - Nc_{1u} \\ Vc_{43u} \leftarrow Nc_{4u} - Nc_{3u} \\ \theta 1cu_{ab_{i,1}} \leftarrow \text{acos}\left(\dfrac{Vc_{21u} \cdot Vc_{43u}}{\left|Vc_{21u}\right| \cdot \left|Vc_{43u}\right|}\right) \end{array} \right. \\ \theta 1cu_{ab} \end{array} \right.$$

Each of the displaced nodes (dx,dy, dz) is summed with original nodal coordinates, forming ends of two vectors.

Two vectors are formed and their displacement relative to each other, is determined about the x-direction.

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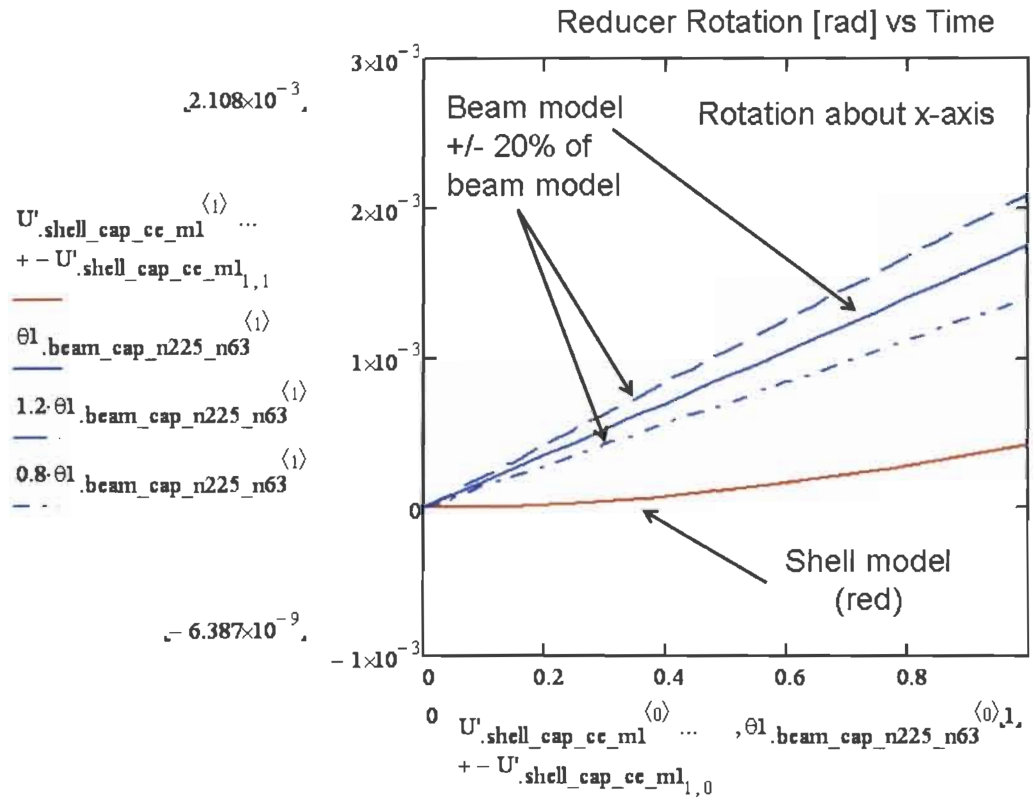
$U'_{shell\_cap\_ce\_m1} := graph_s(U'_{shell\_cap\_ce\_m1dat}, shell\_cap\_ce\_oc\_m1dat)$



The shell and beam reducer models have poor correlation in the x-direction. Will determine another flexibility factor for beam, such that shell and beam models correlate.

$\theta 1_{shell\_cap\_ce} := U'_{shell\_cap\_ce\_m1\, rows(U'_{shell\_cap\_ce\_m1})-1,1} + -U'_{shell\_cap\_ce\_m1\, 1,1}$ Reducer deflection of shell model

$\theta 1_{shell\_cap\_ce} = 0.0244deg$

$\theta 1_{beam\_cap} := \theta 1_{beam\_cap\_n225\_n63\, rows(\theta 1_{beam\_cap\_n225\_n63})-1,1}$ Rotational deflections of beam reducer model

$\theta 1_{beam\_cap} = 0.10066deg$

$k1_{cap} := \frac{\theta 1_{shell\_cap\_ce}}{\theta 1_{beam\_cap}}$ $k1_{cap} = 0.24238$ Flexibility factor of cap in Global 1 (x-direction)

$Ib_{10} := 13.444\,in^4$ Moment of inertia taken from beam model cap (reducer) - previously determined.

$Ie = \frac{I}{k}$ $\quad$ $Ieff_{cap} := \frac{Ib_{10}}{k1_{cap}}$ $\quad$ $Ieff_{cap} = 55.46703 in^4$

New effective moment of inertia. This moment of inertia applies for x and y-directions, since the reducer is symmetric.

Due to symmetry, the net effective moment of inertia for the Global 1 (x-direction) will be the same for the Global 2 (y-direction). Will compare beam angular displacements to that of the shell model about the Global 3 (z-direction).

Start of beam model angular displacements of reducer:

$UR'_{beam\_cap\_m3dat} :=$

$UR'_{beam\_cap\_m3dat} =$

Time	N63	N225
0	0	0
0.05	−0.00000066	−0.00006143
0.1	−0.00000131	−0.00012286
0.15	−0.00000197	−0.00018429
0.2	−0.00000262	−0.00024572
0.25	−0.00000328	−0.00030715
0.3	−0.00000393	−0.00036857
0.35	−0.00000459	−0.00043
0.4	−0.00000524	−0.00049143
0.45	−0.0000059	−0.00055286
0.5	−0.00000656	−0.00061429
0.55	−0.00000721	−0.00067572
0.6	−0.00000787	−0.00073715
0.65	−0.00000852	−0.00079858
0.7	−0.00000918	−0.00086001
0.75	−0.00000983	−0.00092144
0.8	−0.00001049	−0.00098287
0.85	−0.00001114	−0.00104429
0.9	−0.0000118	−0.00110572
0.95	−0.00001246	−0.00116715
1	−0.00001311	−0.00122858

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$UR3\_beam\_cap_{n63} := UR'_{beam\_cap\_m3dat}{}^{\langle 1 \rangle}$ $\quad UR3\_beam\_cap_{n225} := UR'_{beam\_cap\_m3dat}{}^{\langle 2 \rangle}$

$\theta 3_{beam\_cap\_n225\_n63} := UR3\_beam\_cap_{n225} - UR3\_beam\_cap_{n63}$

$$\theta 3_{beam\_cap\_n225\_n63} = \begin{pmatrix} 0 \\ -0.00006 \\ -0.00012 \\ -0.00018 \\ -0.00024 \\ -0.0003 \\ -0.00036 \\ -0.00043 \\ -0.00049 \\ -0.00055 \\ -0.00061 \\ -0.00067 \\ -0.00073 \\ -0.00079 \\ -0.00085 \\ -0.00091 \\ -0.00097 \\ -0.00103 \\ -0.00109 \\ -0.00115 \\ -0.00122 \end{pmatrix}$$

Rotation of beam model in global 3 (z-direction)

$\theta 3_{beam\_cap\_n225\_n63} := augment\left(UR'_{beam\_cap\_m3dat}{}^{\langle 0 \rangle}, \theta 3_{beam\_cap\_n225\_n63}{}^{\langle 0 \rangle}\right)$

Compare to shell cap model angular deflections in Global 3 (z-direction):

Node X Y Z

$$shell\_cap\_ce\_oc\_m1dat = \begin{pmatrix} 2256 & -0.029 & 15 & -2.366 \\ 3390 & -0.029 & -15 & -2.366 \\ 7503 & -0.007 & 5.125 & -9.143 \\ 7524 & 0.007 & -5.125 & -9.143 \end{pmatrix}$$

$U'_{shell\_cap\_ce\_m3dat} :=$

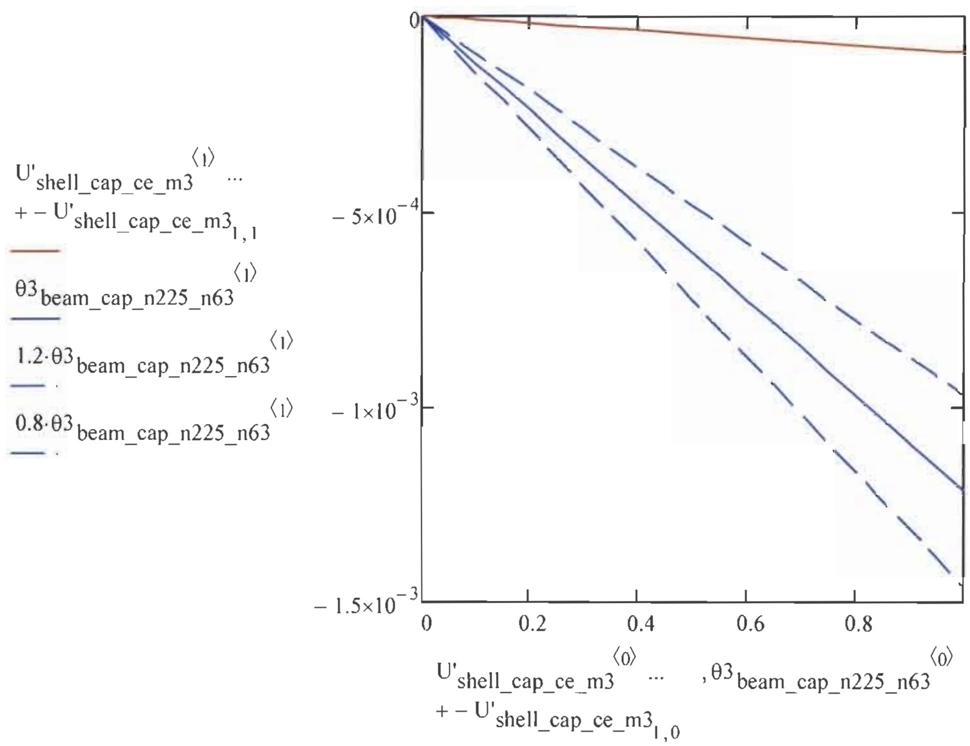
Nodal displacements about z-direction (dx, dy, dz) are extracted from shell model for each vector node.

$$graph_s(a,b) := \left| \begin{array}{l} \theta3cu_{ab}^{\langle 0 \rangle} \leftarrow a^{\langle 0 \rangle} \\ \text{for } i \in 0..rows(a)-1 \\ \quad \left| \begin{array}{l} Nc_{1u} \leftarrow \left(a_{i,4} \;\; a_{i,8} \;\; a_{i,12}\right)^T + \left(b_{3,1} \;\; b_{3,2} \;\; b_{3,3}\right)^T \\ Nc_{2u} \leftarrow \left(a_{i,3} \;\; a_{i,7} \;\; a_{i,11}\right)^T + \left(b_{2,1} \;\; b_{2,2} \;\; b_{2,3}\right)^T \\ Nc_{3u} \leftarrow \left(a_{i,2} \;\; a_{i,6} \;\; a_{i,10}\right)^T + \left(b_{1,1} \;\; b_{1,2} \;\; b_{1,3}\right)^T \\ Nc_{4u} \leftarrow \left(a_{i,1} \;\; a_{i,5} \;\; a_{i,9}\right)^T + \left(b_{0,1} \;\; b_{0,2} \;\; b_{0,3}\right)^T \\ Vc_{21u} \leftarrow Nc_{2u} - Nc_{1u} \\ Vc_{43u} \leftarrow Nc_{4u} - Nc_{3u} \\ \theta3cu_{ab_{i,1}} \leftarrow acos\left(\frac{Vc_{21u} \cdot Vc_{43u}}{\left|Vc_{21u}\right| \cdot \left|Vc_{43u}\right|}\right) \end{array} \right. \\ \theta3cu_{ab} \end{array} \right.$$

Each of the displaced nodes (dx,dy, dz) is summed with original nodal coordinates, forming ends of two vectors.

Two vectors are formed and their displacement relative to each other, is determined about the z-direction.

$$U'_{shell\_cap\_ce\_m3} := graph_s\left(U'_{shell\_cap\_ce\_m3dat}, shell\_cap\_ce\_oc\_m1dat\right)$$



The shell and beam reducer models have poor correlation in the z-direction. Will determine another flexibility factor for beam, such that shell and beam models correlate.

$$\theta 3_{shell\_cap\_ce} := U'_{shell\_cap\_ce\_m3_{rows(U'_{shell\_cap\_ce\_m3})-1,1}} \cdots + -U'_{shell\_cap\_ce\_m3_{1,1}}$$

Reducer deflection of shell model

$$\theta 3_{shell\_cap\_ce} = -0.00539 deg$$

$$\theta 3_{beam\_cap} := \theta 3_{beam\_cap\_n225\_n63_{rows(\theta 3_{beam\_cap\_n225\_n63})-1,1}}$$

Rotational deflections of beam reducer model

$$\theta 3_{beam\_cap} = -0.06964 deg$$

$$k3_{cap} := \frac{\theta 3_{shell\_cap\_ce}}{\theta 3_{beam\_cap}} \qquad k3_{cap} = 0.07738$$

Flexibility factor of reducer in Global 3 (z-direction)

$$Jb_{10} := 26.888\, in^4$$

Polar moment of inertia taken from beam model cap (reducer), previously defined.

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$Je = \frac{J}{k}$ $\quad J3eff_{cap} := \frac{Jb_{10}}{k3_{cap}}$ $\quad J3eff_{cap} = 347.47141 in^4$

$I1eff_{cap} = 55.46703 in^4$

A check is performed by changing the beam reducer section properties (at its center, between nodes 225 & 63) and obtaining results for both x and z-directions. ABAQUS files "check_beam_mt_cap_m1.inp" and "check_beam_mt_cap_m3.inp" to calcule the solution results.

$UR'_{check\_beam\_cap\_m1dat} :=$ Global 1 (x-direction)

$UR'_{check\_beam\_cap\_m1dat} =$

Time	N63	N225
0	0	0
0.05	0.000000948	0.00002224
0.1	0.000001895	0.000044479
0.15	0.000002843	0.000066719
0.2	0.00000379	0.000088958
0.25	0.000004738	0.000111198
0.3	0.000005686	0.000133438
0.35	0.000006633	0.000155677
0.4	0.000007581	0.000177917
0.45	0.000008529	0.000200156
0.5	0.000009476	0.000222396
0.55	0.000010424	0.000244636
0.6	0.000011371	0.000266875
0.65	0.000012319	0.000289115
0.7	0.000013267	0.000311354
0.75	0.000014214	0.000333594
0.8	0.000015162	0.000355834
0.85	0.000016109	0.000378073
0.9	0.000017057	0.000400313
0.95	0.000018005	0.000422553
1	0.000018952	0.000444792

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$$UR1\_check\_beam\_cap_{n63} := UR'_{check\_beam\_cap\_m1dat}{}^{\langle 1 \rangle}$$

$$UR1\_check\_beam\_cap_{n225} := UR'_{check\_beam\_cap\_m1dat}{}^{\langle 2 \rangle}$$

Separate nodes N63 and N225 into separate arrays

$$\theta1_{check\_beam\_cap\_n225\_n63} := UR1\_check\_beam\_cap_{n225} - UR1\_check\_beam\_cap_{n63}$$

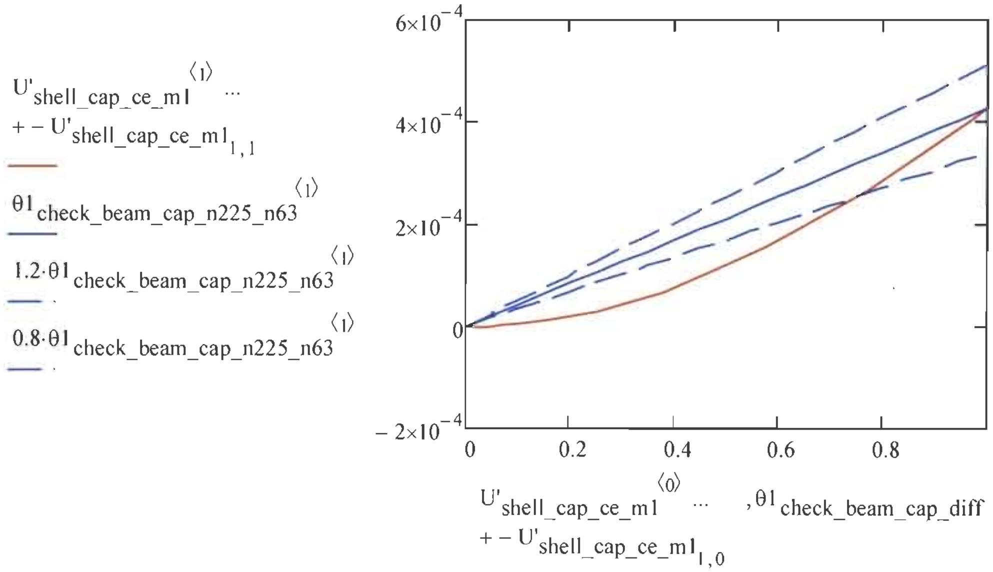
Let => $A := \theta1_{check\_beam\_cap\_n225\_n63}$

$$\theta1_{check\_beam\_cap\_n225\_n63} := \text{augment}\left(UR'_{check\_beam\_cap\_m1dat}{}^{\langle 0 \rangle}, A^{\langle 0 \rangle}\right)$$

$$\theta1_{check\_beam\_cap\_n225\_n63} = \begin{pmatrix} 0 & 0 \\ 0.05 & 0.00002 \\ 0.1 & 0.00004 \\ 0.15 & 0.00006 \\ 0.2 & 0.00009 \\ 0.25 & 0.00011 \\ 0.3 & 0.00013 \\ 0.35 & 0.00015 \\ 0.4 & 0.00017 \\ 0.45 & 0.00019 \\ 0.5 & 0.00021 \\ 0.55 & 0.00023 \\ 0.6 & 0.00026 \\ 0.65 & 0.00028 \\ 0.7 & 0.0003 \\ 0.75 & 0.00032 \\ 0.8 & 0.00034 \\ 0.85 & 0.00036 \\ 0.9 & 0.00038 \\ 0.95 & 0.0004 \\ 1 & 0.00043 \end{pmatrix}$$

Rotation of beam model in global 1 (x-direction)

Let => $\theta1_{check\_beam\_cap\_diff} := \theta1_{check\_beam\_cap\_n225\_n63}{}^{\langle 0 \rangle}$



Shell model experiences large displacements, but returns within acceptable beam correlation at time end.

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$UR'_{check\_beam\_cap\_m3dat} :=$ Global 3 (z-direction)

Time	N63	N225
0	0	0
0.05	−0.000000656	−0.000005358
0.1	−0.000001311	−0.000010717
0.15	−0.000001967	−0.000016075
0.2	−0.000002622	−0.000021433
0.25	−0.000003278	−0.000026792
0.3	−0.000003933	−0.00003215
0.35	−0.000004589	−0.000037508
0.4	−0.000005245	−0.000042867
0.45	−0.0000059	−0.000048225
0.5	−0.000006556	−0.000053583
0.55	−0.000007211	−0.000058942
0.6	−0.000007867	−0.0000643
0.65	−0.000008522	−0.000069658
0.7	−0.000009178	−0.000075017
0.75	−0.000009833	−0.000080375
0.8	−0.000010489	−0.000085733
0.85	−0.000011145	−0.000091092
0.9	−0.0000118	−0.00009645
0.95	−0.000012456	−0.000101808
1	−0.000013111	−0.000107167

$UR'_{check\_beam\_cap\_m3dat} =$ (matrix above)

$UR3\_check\_beam\_cap_{n63} := UR'^{\langle 1 \rangle}_{check\_beam\_cap\_m3dat}$ Separate nodes N63 and N225 into separate arrays

$UR3\_check\_beam\_cap_{n225} := UR'^{\langle 2 \rangle}_{check\_beam\_cap\_m3dat}$

$\theta3_{check\_beam\_cap\_n225\_n63} := UR3\_check\_beam\_cap_{n225} - UR3\_check\_beam\_cap_{n63}$

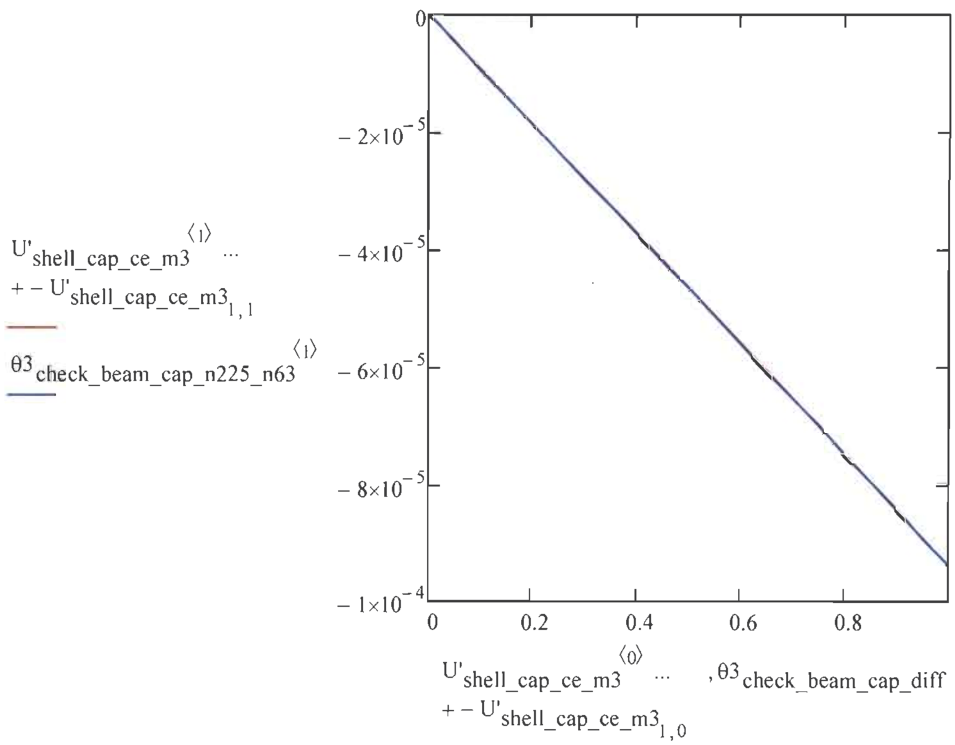
Let => $B := \theta3_{check\_beam\_cap\_n225\_n63}$

$\theta3_{check\_beam\_cap\_n225\_n63} := \text{augment}\left(UR'^{\langle 0 \rangle}_{check\_beam\_cap\_m3dat}, B^{\langle 0 \rangle}\right)$

$$\theta3_{check\_beam\_cap\_n225\_n63} = \begin{pmatrix} 0 & 0 \\ 0.05 & -0 \\ 0.1 & -0.00001 \\ 0.15 & -0.00001 \\ 0.2 & -0.00002 \\ 0.25 & -0.00002 \\ 0.3 & -0.00003 \\ 0.35 & -0.00003 \\ 0.4 & -0.00004 \\ 0.45 & -0.00004 \\ 0.5 & -0.00005 \\ 0.55 & -0.00005 \\ 0.6 & -0.00006 \\ 0.65 & -0.00006 \\ 0.7 & -0.00007 \\ 0.75 & -0.00007 \\ 0.8 & -0.00008 \\ 0.85 & -0.00008 \\ 0.9 & -0.00008 \\ 0.95 & -0.00009 \\ 1 & -0.00009 \end{pmatrix}$$

Rotation of beam model in global 3 (z-direction)

Let => $\theta3_{check\_beam\_cap\_diff} := \theta3_{check\_beam\_cap\_n225\_n63}^{\langle 0 \rangle}$



Shell and beam model flexibility are the same. Hence, good correlation in the z-direction exists with refined beam section properties.

Summary:

$k1_{cap} = 0.24238$ $k3_{cap} = 0.07738$ Flexibility factors in x, y (due to symmetry) and z-directions.

$I1eff_{cap} = 55.46703 in^4$ $J3eff_{cap} = 347.47141 in^4$ Beam reducer section properties.

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Unlisted Cap Stress Indices

For SI determination, will approximate unlisted cap component as a listed reducer. After listed reducer stress indices are determined, will solve stress indices for unlisted cap directly - using the reducer format.

(9) $B_1 \cdot \left(\frac{P \cdot D_o}{2 \cdot t}\right) + B_2 \cdot \left(\frac{D_o \cdot M_i}{2 \cdot I}\right)$ =< $1.5 \cdot S_m$ Primary stress intensity [1, NB-3652]

Determine listed reducer stress indices:

$B_2 := 1.0$ Stress indice 2 [1, Table NB-3681(a)-1 for reducers]

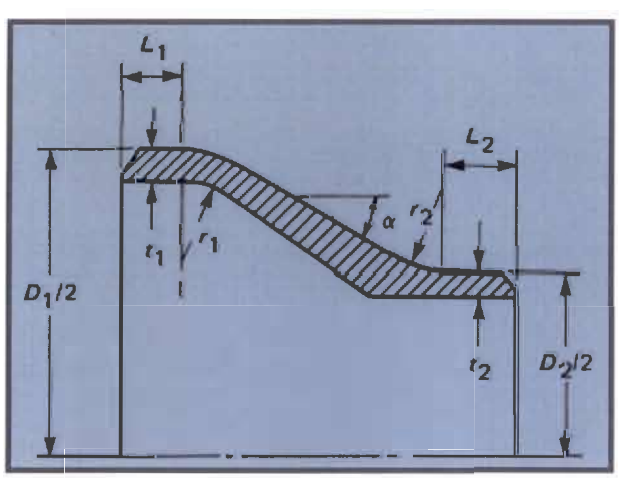

FIG. NB-3683.6-1

$$\tan(\alpha) = \frac{\left(\frac{Do_{30} - Do_{10}}{2}\right)}{L_{cap}}$$

$$\alpha := \operatorname{atan}\left[\frac{\left(\frac{Do_{30} - Do_{10}}{2}\right)}{L_{cap}}\right]$$

$\alpha = 54.16778 deg$

$B_1 := \text{if}(\alpha \le 30 \cdot deg, 0.5, 1.0)$ $B_1 = 1$ B1 SI [1, NB-3683.6]

$P = 253 \cdot psi$ $Sy_{125} = 28.35 ksi$ $Do_{30} = 30 \cdot in$ $t30_{cap} = 0.4375 in$ Previously defined

$Sm_{125} := 20 \cdot ksi$ Maximum allowable stress intensity for 304 SST at 125 °F

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Per Section NB-3656(a) [1]: Level D Service Limits apply

(1) $P = 253 \cdot psi \quad < \quad 2 \cdot P_a$

$$P_a \quad = \quad \frac{2 \cdot S_m \cdot t}{D_o - 2 \cdot y \cdot t}$$ (3) [1, Section NB-3641.1]

where P_a Calculated maximum allowable internal pressure of straight pipe

$y := 0.4 \qquad Y := 0.4$ [1,Section NB-3641.1]

$$P_a := \frac{2 \cdot Sm_{125} \cdot t30_{cap}}{Do_{30} - 2 \cdot y \cdot t30_{cap}} \qquad P_a = 590.21922 psi \qquad \frac{2 \cdot P_a}{P} = 4.66576$$ OK

Equation 9 adapted for level D service limits

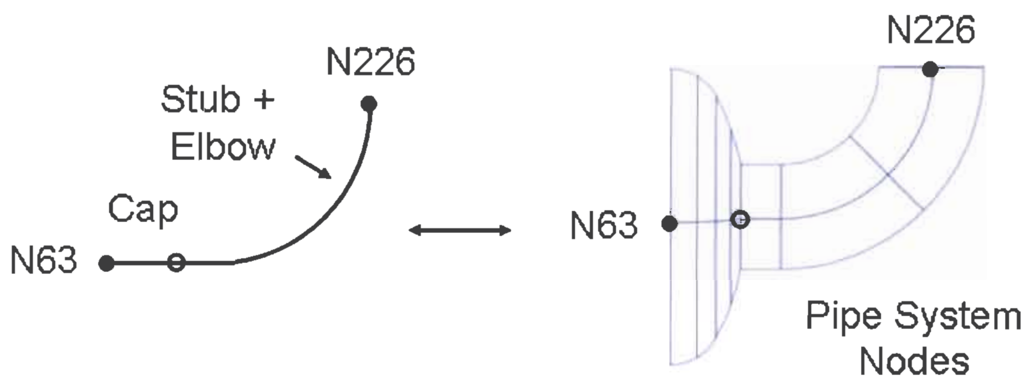
(9) $$B_1 \cdot \left(\frac{P \cdot D_o}{2 \cdot t} \right) + B_2 \cdot \left(\frac{D_o \cdot M_i}{2 \cdot I} \right)$$ =< min(3*Sm, 2*Sy)

where $3 \cdot Sm_{125} = 60 \cdot ksi \qquad 2 \cdot Sy_{125} = 56.7 \cdot ksi$ 2*Yield at 125°F governs

(9) $$B_1 \cdot \left(\frac{P \cdot D_o}{2 \cdot t} \right) + B_2 \cdot \left(\frac{D_o \cdot M_i}{2 \cdot I} \right) \quad =< \quad 2 \cdot Sy_{125} = 56.7 \cdot ksi$$

The following outline illustrates 256 model's unlisted cap component (30-in cap extended from its center with 10-in pipe) for preliminary 80 percentile solution run set. The unlisted cap component is approximated as a listed reducer. Node 63 forms the cap's back plate and node 226 reflects where moments are applied to the 10-in pipe and elbow end. The 10-in pipe and elbow are listed components, where only the cap is unlisted. The following matrixes identify the scoping nodal moment reactions for the cap's back plane and corresponding extension elbow end. These cap node (N63 & N226) reflect the piping system node numbers and reactions have been retrieved from Table F. 2.5-4.

Preliminary 80 Percentile Nodal Moment Reactions used for Scoping Stress Indices Calculations



Mx My Mz

$n_{226} := \left(1.023 \cdot 10^{5} \quad 1.435 \cdot 10^{5} \quad -7.598 \cdot 10^{4}\right)^{T}$ $N_{226} := \left|n_{226}\right|$ $N_{226} = 191912.74163$

$n_{63} := \left(-1.37 \cdot 10^{5} \quad -3.598 \cdot 10^{4} \quad 1.387 \cdot 10^{5}\right)^{T}$ $N_{63} := \left|n_{63}\right|$ $N_{63} = 198245.42971$

$M_{uc} := N_{63} \cdot in \cdot lbf$ $M_{uc} = 198.24543 in \cdot kip$ Cap resultant moment at N63

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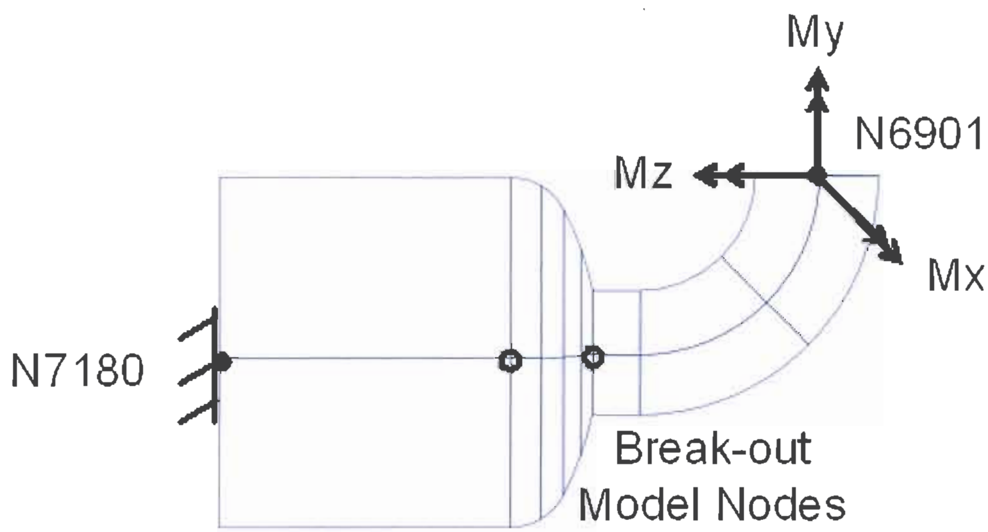
Determination of SI for the unlisted cap are performed with several separate break-out models that are used to mimic "Mi" as determined for the bending term of equation (9), previously defined. Mi defines a Mx, My, Mz vector where each variable has a positive or negative sign that requires a total of 8 models (i.e., $2^3 = 8$ models) that must be solved to determine the maximum tresca stress and thus, appropriate B2 stress indice. The unlisted cap break-out models use differing nodes than that of the piping system nodes. N7180 extends out the back of the unlisted cap and it is fully restrained. N6901 replaces system note N226 and is used to apply Mi moment Mi vectors combined with internal pressure (253-psi).



Determine scoping stress indice for unlisted cap:

$n_{uc} := 2$ Two signs (+/-) $v_{uc} := 3$ Three variables (Mx, My, Mz)

$Tcap_{models} := n_{uc}^{v_{uc}}$ $Tcap_{models} = 8$ A total of 8 moment combination models are required to determine maximum tresca stresses action on unlisted cap.

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Let =>

Muc_{ppp}	= + + +	Mi moment vector for +Mx, +My, +Mz
Muc_{ppn}	= + + -	Mi moment vector for +Mx, +My, -Mz
Muc_{pnp}	= + - +	Mi moment vector for +Mx, -My, +Mz
Muc_{npp}	= - + +	Mi moment vector for -Mx, +My, +Mz
Muc_{nnn}	= - - -	Mi moment vector for -Mx, -My, -Mz
Muc_{nnp}	= - - +	Mi moment vector for -Mx, -My, +Mz
Muc_{npn}	= - + -	Mi moment vector for -Mx, +My, -Mz
Muc_{pnn}	= + - -	Mi moment vector for +Mx, -My, -Mz

Mx My Mz

$Muc_{ppp} := \left(\left|{}^{n}63_0\right| \quad \left|{}^{n}63_1\right| \quad \left|{}^{n}63_2\right| \right)^T \cdot in \cdot lbf$ $\qquad Muc_{ppp}^T = (137 \quad 35.98 \quad 138.7) \cdot in \cdot kip$

$Muc_{ppn} := \left(\left|{}^{n}63_0\right| \quad \left|{}^{n}63_1\right| \quad -\left|{}^{n}63_2\right| \right)^T \cdot in \cdot lbf$ $\qquad Muc_{ppn}^T = (137 \quad 35.98 \quad -138.7) \cdot in \cdot kip$

$Muc_{pnp} := \left(\left|{}^{n}63_0\right| \quad -\left|{}^{n}63_1\right| \quad \left|{}^{n}63_2\right| \right)^T \cdot in \cdot lbf$ $\qquad Muc_{pnp}^T = (137 \quad -35.98 \quad 138.7) \cdot in \cdot kip$

$Muc_{npp} := \left(-\left|{}^{n}63_0\right| \quad \left|{}^{n}63_1\right| \quad \left|{}^{n}63_2\right| \right)^T \cdot in \cdot lbf$ $\qquad Muc_{npp}^T = (-137 \quad 35.98 \quad 138.7) \cdot in \cdot kip$

$Muc_{nnn} := \left(-\left|{}^{n}63_0\right| \quad -\left|{}^{n}63_1\right| \quad -\left|{}^{n}63_2\right| \right)^T \cdot in \cdot lbf$ $\qquad Muc_{nnn}^T = (-137 \quad -35.98 \quad -138.7) \cdot in \cdot kip$

$Muc_{nnp} := \left(-\left|{}^{n}63_0\right| \quad -\left|{}^{n}63_1\right| \quad \left|{}^{n}63_2\right| \right)^T \cdot in \cdot lbf$ $\qquad Muc_{nnp}^T = (-137 \quad -35.98 \quad 138.7) \cdot in \cdot kip$

$Muc_{npn} := \left(-\left|{}^{n}63_0\right| \quad \left|{}^{n}63_1\right| \quad -\left|{}^{n}63_2\right| \right)^T \cdot in \cdot lbf$ $\qquad Muc_{npn}^T = (-137 \quad 35.98 \quad -138.7) \cdot in \cdot kip$

$Muc_{pnn} := \left(\left|{}^{n}63_0\right| \quad -\left|{}^{n}63_1\right| \quad -\left|{}^{n}63_2\right| \right)^T \cdot in \cdot lbf$ $\qquad Muc_{pnn}^T = (137 \quad -35.98 \quad -138.7) \cdot in \cdot kip$

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:** 09/30/08	**Checker:** A. S. Siahpush	**Date:**	09/30/08

FE unlisted cap membrane tresca stress results are reflective of three load conditions (or steps). The first step (step 1) produces results for an internal pressure (253-psi) loading. The second step (step 2) computes results for combined internal pressure and moment combination loading. The last step (step 3) subtracts step 1 (P) from step 2 (P+Ci) to obtain corresponding tresca stress results (Ci). This is performed to capture the added stiffness from internal pressure reflected into B2 results. Maximum tresca stress results (extracted from FE model results) of the eight Mi moment combinations (Muc_{ppp}, Muc_{ppn}, Muc_{pnp}, Muc_{npp}, Muc_{nnn}, Muc_{nnp}, Muc_{npn}, Muc_{pnn}) are used to determine the unlisted cap component stress indice (B2). Maximum Tresca stress values (per each of the eight models), are extracted from the "mt_ucap_ce.rpt" file.

Membrane Tresca Stresses	Applied Loads
	Muc_{ppp}
16.897E+03	Muc_{ppn}
14.518E+03	Muc_{pnp}
14.517E+03	Muc_{npp}
16.794E+03	Muc_{nnn}
16.794E+03	Muc_{nnp}
14.454E+03	Muc_{npn}
14.453E+03	Muc_{pnn}
16.897E+03	$P = 253 \cdot psi$
13.938E+03	

$$\sigma_{uc} := \begin{pmatrix} 16.897E+03 \\ 14.518E+03 \\ 14.517E+03 \\ 16.794E+03 \\ 16.794E+03 \\ 14.454E+03 \\ 14.453E+03 \\ 16.897E+03 \\ 13.938E+03 \end{pmatrix} \cdot psi$$

$\sigma uc_p := \sigma_{uc_8}$ $\quad \sigma uc_p = 13.938\,ksi$ Pressure tresca stress

$\sigma uc_{max} := max(\sigma_{uc}) = 16.897\,ksi$ Maximum tresca stress occurs for both Muc_{ppp} & Muc_{pnn}

(9) $$B_1 \cdot \left(\frac{P \cdot D_o}{2 \cdot t}\right) + B_2 \cdot \left(\frac{D_o \cdot M_i}{2 \cdot I}\right) \quad =< \quad 2 \cdot Sy_{125} = 56.7 \cdot ksi$$

Let => $t_p := t_{30} = 0.4375\,in$ Pressure tresca stress occurs on 7/16-in wall cap.

$M_i := |Muc_{ppp}|$ $\quad M_i = 198.24543\,in \cdot kip$

Solve for unlisted cap SI:

$$Buc_1 \cdot \left(\frac{P \cdot D_o}{2 \cdot t}\right) = \sigma uc_p = 13.938 \text{ksi}$$

=> $Buc_1 := \dfrac{\sigma uc_p}{\left(\dfrac{P \cdot Do_{10}}{2 \cdot t_p}\right)} = 4.48414$ SI 1 for pressure membrane tresca, where the smallest diameter (Do_{10}) is when the maximum stress occurs on the cap.

$\dfrac{Buc_1}{B_1} = 4.48414$ Unlisted Cap SI 1 significantly larger than listed reducer.

$$Buc_2 \cdot \left(\frac{D_o \cdot M_i}{2 \cdot I}\right) = \sigma uc_{max} = 16.897 \text{ksi}$$

=> $Buc_2 := \dfrac{\sigma uc_{max}}{\left(\dfrac{Do_{10} \cdot M_i}{2 \cdot Icap_{eff}}\right)} = 0.21319$ SI 2 for moment (Mucnnn) membrane tresca, where the smallest diameter (Do_{10}) is where the maximum stress occurs on the stub pipe.

$\dfrac{Buc_2}{B_2} = 0.21319$ Unlisted Cap sI 2 significantly less than listed reducer.

$Buc_1 = 4.48414$ $Buc_2 = 0.21319$

F.2.8 – Linear Evaluation of Unlisted Cap Component

The purpose of this section is to perform a linear evaluation of the unlisted cap component, using the stress indices and methodology defined in the previous section (Appendix F.2.7).

For unlisted cap component

(9) $$B_1 \cdot \left(\frac{P \cdot D_o}{2 \cdot t}\right) + B_2 \cdot \left(\frac{D_o \cdot M_i}{2 \cdot I}\right) \quad =< \quad 2 \cdot Sy_{125} = 56.7 \cdot ksi$$

$$\frac{Buc_1 \cdot \left(\frac{P \cdot Do_{10}}{2 \cdot t_p}\right) + Buc_2 \cdot \left(\frac{Do_{10} \cdot M_i}{2 \cdot Icap_{eff}}\right)}{2 \cdot Sy_{125}} = 0.54383$$ Unlisted cap is acceptable.

$$\frac{Buc_1 \cdot \left(\frac{P \cdot Do_{10}}{2 \cdot t_p}\right)}{2 \cdot Sy_{125}} = 0.24582 \quad < \quad \frac{Buc_2 \cdot \left(\frac{Do_{10} \cdot M_i}{2 \cdot Icap_{eff}}\right)}{2 \cdot Sy_{125}} = 0.29801$$ Moment and pressure effects are similar

The above unlisted cap component linear evaluation was based on scoping 80 percentile moment reactions, used for determining approximate SI. Following are final run moment reactions (as of 09-25-08) for the unlisted cap component. Preliminary and final moment reactions are compared.

Preliminary 80 Percentile Nodal Moment Reactions, previously shown

Mx My Mz Magnitudes

$n_{226} := \left(1.023\cdot10^{5} \quad 1.435\cdot10^{5} \quad -7.598\cdot10^{4}\right)^{T}$ $\quad N_{226} := \left|n_{226}\right|$ $\quad N_{226} = 191912.74163$

$n_{63} := \left(-1.37\cdot10^{5} \quad -3.598\cdot10^{4} \quad 1.387\cdot10^{5}\right)^{T}$ $\quad N_{63} := \left|n_{63}\right|$ $\quad N_{63} = 198245.42971$

Final run 80 Percentile Nodal Moment Reactions for unlisted cap component

Mx My Mz

$n_{226f} := \left(6.168\cdot10^{3} \quad -2.009\cdot10^{4} \quad 4.113\cdot10^{3}\right)^{T}$

$n_{63f} := \left(-3.514\cdot10^{4} \quad 1.834\cdot10^{4} \quad -4.997\cdot10^{3}\right)^{T}$

$$\frac{n_{226f}}{n_{226}} = \begin{pmatrix} 0.06029 \\ -0.14 \\ -0.05413 \end{pmatrix} \qquad \frac{n_{63f}}{n_{63}} = \begin{pmatrix} 0.2565 \\ -0.50973 \\ -0.03603 \end{pmatrix}$$

Final reaction moments are significantly lower than those used to calculate unlisted cap component stress indices. Thus, the unlisted cap comonent SI are conservative demonstrating that the cap is still acceptable.

Project:	ATR Life Time Extension Project	ECAR No.:	ECAR-194	Rev.:	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	Date: 09/30/08	Checker: A. S. Siahpush	Date:	09/30/08

F.2.9 – Abbreviated reprints of pilot model's ABAQUS input files

Input file names

1. ff_mt_ubranchp.inp
2. ff_mt_ubranchn.inp
3. si_mt_ubranch_08_26_08_mxp.inp
4. si_mt_ubranch_08_26_08_mxn.inp
5. si_mt_ubranch_08_26_08_myp.inp
6. si_mt_ubranch_08_26_08_myn.inp
7. si_mt_ubranch_08_26_08_mzp.inp
8. si_mt_ubranch_08_26_08_mzn.inp
9. si_mt_urun_08_26_08_mxp.inp
10. si_mt_urun_08_26_08_mxn.inp
11. si_mt_urun_08_26_08_myp.inp
12. si_mt_urun_08_26_08_myn.inp
13. si_mt_urun_08_26_08_mzp.inp
14. si_mt_urun_08_26_08_mzn.inp
15. Unlisted_end_cap_stp.inp
16. Unlisted_end_cap_stn.inp
17. si_mt_ucap_ce_ppp.inp
18. si_mt_ucap_ce_ppn.inp
19. si_mt_ucap_ce_pnp.inp
20. si_mt_ucap_ce_npp.inp
21. si_mt_ucap_ce_nnn.inp
22. si_mt_ucap_ce_nnp.inp
23. si_mt_ucap_ce_npn.inp
24. si_mt_ucap_ce_pnn.inp
25. beam_mt_branch_16x10_m1.inp
26. beam_mt_branch_16x10_m2.inp
27. beam_mt_branch_16x10_m3.inp
28. shell_mt_branch_16x10_m1.inp
29. shell_mt_branch_16x10_m2.inp
30. shell_mt_branch_16x10_m3.inp
31. check_beam_mt+16x10_m3.inp
32. branch_beam_16x10_ST_1.inp
33. branch_beam_16x10_ST_2.inp
34. branch_beam_16x10_ST_3.inp
35. branch_16x10_ST_1.inp
36. branch_16x10_ST_2.inp
37. branch_16x10_ST_3.inp
38. beam_mt_cap_m1.inp
39. beam_mt_cap_m2.inp
40. beam_mt_cap_m3.inp
41. shell_mt_cap_ce_m1.inp

42. shell_mt_cap_ce_m2.inp
43. shell_mt_cap_ce_m3.inp
44. check_beam_mt_cap_m1.inp
45. check_beam_mt_cap_m2.inp

ff_mt_ubranchp.inp

```
**%   ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\mod2_unlisted_last5.mf1
**%          INPUT FILE: C:\pcs\pcs2\model_(26)\ff_files\ff_ubranchp.inp
**%            EXPORTED: AT 10:02:34 ON 20-Aug-08
**%                PART: mod26
**%                 FEM: ff_ubranch26
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  20-Aug-08   10:02:34
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
*MPC
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
```

```
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=RESNDS
    8938,    9370,    9985
*NSET,NSET=ANGNDS
      17,     697,    1513,    1737
*NSET,NSET=RESTRAINTS
    8938,    9370,    9985
*ELSET,ELSET=ALLELE, GENERATE
         1,     9200,        1
*ELSET,ELSET=TRANS_PLT, GENERATE
      1617,     2000,        1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
         1,     1616,        1
*ELSET,ELSET=RIGID
    9201,    9202,    9203
*ELSET,ELSET=ELBOW, GENERATE
         1,     2000,        1
*ELSET,ELSET=BRANCH, GENERATE
      5649,     7952,        1
*ELSET,ELSET=BRANCH_CAP, GENERATE
      8625,     9200,        1
*ELSET,ELSET=CAPPED_BRANCH, GENERATE
      5649,     7952,        1
      8625,     9200,        1
*ELSET,ELSET=SIDE_RUN, GENERATE
      2001,     3824,        1
*ELSET,ELSET=SIDE_CAP, GENERATE
      8289,     8624,        1
*ELSET,ELSET=CAPPED_SIDERUN, GENERATE
      2001,     3824,        1
      8289,     8624,        1
*ELSET,ELSET=BOT_RUN, GENERATE
      3825,     5648,        1
*ELSET,ELSET=BOT_CAP, GENERATE
      7953,     8288,        1
*ELSET,ELSET=CAPPED_BOTRUN, GENERATE
      3825,     5648,        1
      7953,     8288,        1
*ELSET,ELSET=REINPLT
*ELSET,ELSET=SECT, GENERATE
*ELSET,ELSET=RESTRAINTS, GENERATE
         1,     9200,        1
*ELSET,ELSET=PRESSURE_ELE, GENERATE
         1,     9200,        1
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
```

```
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       9370,  2,,       0.00000E+00
       9370,  4,,       0.00000E+00
       9370,  6,,       0.00000E+00
       8938,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
       9370,    5, 4.671E+4
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*ELSET, ELSET=BS000001, GENERATE
         1,     9200,        1
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*OUTPUT, HISTORY,FREQUENCY=1
*END STEP
```

ff_mt_ubranchn.inp

```
**%   ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\mod2_unlisted_last5.mf1
**%          INPUT FILE: C:\pcs\pcs2\model_(26)\ff_files\ff_ubranchn.inp
**%            EXPORTED: AT 10:02:34 ON 20-Aug-08
**%                PART: mod26
**%                 FEM: ff_ubranch26
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  20-Aug-08   10:02:34
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
```

```
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
*MPC
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=RESNDS
    8938,     9370,     9985
*NSET,NSET=ANGNDS
      17,      697,     1513,     1737
*NSET,NSET=RESTRAINTS
    8938,     9370,     9985
*ELSET,ELSET=ALLELE, GENERATE
         1,      9200,         1
*ELSET,ELSET=TRANS_PLT, GENERATE
      1617,      2000,         1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
         1,      1616,         1
*ELSET,ELSET=RIGID
    9201,     9202,     9203
*ELSET,ELSET=ELBOW, GENERATE
         1,      2000,         1
*ELSET,ELSET=BRANCH, GENERATE
      5649,      7952,         1
*ELSET,ELSET=BRANCH_CAP, GENERATE
      8625,      9200,         1
*ELSET,ELSET=CAPPED_BRANCH, GENERATE
      5649,      7952,         1
      8625,      9200,         1
*ELSET,ELSET=SIDE_RUN, GENERATE
      2001,      3824,         1
*ELSET,ELSET=SIDE_CAP, GENERATE
      8289,      8624,         1
*ELSET,ELSET=CAPPED_SIDERUN, GENERATE
      2001,      3824,         1
      8289,      8624,         1
*ELSET,ELSET=BOT_RUN, GENERATE
      3825,      5648,         1
*ELSET,ELSET=BOT_CAP, GENERATE
```

```
      7953,     8288,        1
*ELSET,ELSET=CAPPED_BOTRUN, GENERATE
      3825,     5648,        1
      7953,     8288,        1
*ELSET,ELSET=REINPLT
*ELSET,ELSET=SECT, GENERATE
*ELSET,ELSET=RESTRAINTS, GENERATE
         1,     9200,        1
*ELSET,ELSET=PRESSURE_ELE, GENERATE
         1,     9200,        1
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       9370,  2,,       0.00000E+00
       9370,  4,,       0.00000E+00
       9370,  6,,       0.00000E+00
       8938,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
       9370,    5,-4.671E+4
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*ELSET, ELSET=BS000001, GENERATE
         1,     9200,        1
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*OUTPUT, HISTORY,FREQUENCY=1
*END STEP
```

si_mt_ubranch_08_26_08_mxp.inp

```
**%    ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\mod2_unlisted_last5.mf1
**%          INPUT FILE: si_mt_ubranch_08_26_08_mxp.inp
**%            EXPORTED: AT 18:19:52 ON 20-Aug-08
**%                PART: mod26
**%                 FEM: si_ubranch26
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
```

```
**%
**%            SUBSET EXPORT: OFF
**%
**%      NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  20-Aug-08   18:19:52
**%==========================================
**%         MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4       , ELSET=THK_25
*MPC
*MPC
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=RESNDS
    8938,     9370,     9985
*NSET,NSET=ANGNDS
      17,      697,     1513,     1737
*NSET,NSET=RESTRAINTS
    8938,     9370,     9985
*ELSET,ELSET=ALLELE, GENERATE
         1,      9200,        1
*ELSET,ELSET=TRANS_PLT, GENERATE
      1617,      2000,        1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
         1,      1616,        1
*ELSET,ELSET=RIGID
    9201,     9202,     9203
*ELSET,ELSET=ELBOW, GENERATE
         1,      2000,        1
*ELSET,ELSET=BRANCH, GENERATE
      5649,      7952,        1
*ELSET,ELSET=BRANCH_CAP, GENERATE
```

```
      8625,      9200,          1
*ELSET,ELSET=CAPPED_BRANCH, GENERATE
      5649,      7952,          1
      8625,      9200,          1
*ELSET,ELSET=SIDE_RUN, GENERATE
      2001,      3824,          1
*ELSET,ELSET=SIDE_CAP, GENERATE
      8289,      8624,          1
*ELSET,ELSET=CAPPED_SIDERUN, GENERATE
      2001,      3824,          1
      8289,      8624,          1
*ELSET,ELSET=BOT_RUN, GENERATE
      3825,      5648,          1
*ELSET,ELSET=BOT_CAP, GENERATE
      7953,      8288,          1
*ELSET,ELSET=CAPPED_BOTRUN, GENERATE
      3825,      5648,          1
      7953,      8288,          1
*ELSET,ELSET=REINPLT
*ELSET,ELSET=RESTRAINTS, GENERATE
         1,      9200,          1
*ELSET,ELSET=PRESSURE_ELE, GENERATE
         1,      9200,          1
*ELSET,ELSET=SECT, GENERATE
*ELSET, ELSET=BS000001, GENERATE
         1,      9200,          1
*ELSET, ELSET=ACCL_ELM
 THK_25,
*BOUNDARY,OP=NEW
       8938,  1, 6,       0.00000E+00
       9370,  1, 6,       0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,     P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
```

```
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + Bxp
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00, 0.10000E+01, 0.00000E+00
*CLOAD,OP=NEW
       9985,    4, 2.778E+04
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

si_mt_ubranch_08_26_08_mxn.inp

```
**%   ============================================================
**%
**%             I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                    FOR ABAQUS VERSION 6.x
**%
**%         MODEL FILE: C:\DOCUME~1\dtclark\mod2_unlisted_last5.mf1
**%         INPUT FILE: si_mt_ubranch__08_26_08_mxn.inp
**%           EXPORTED: AT 18:19:52 ON 20-Aug-08
**%               PART: mod26
**%                FEM: si_ubranch26
**%
**%              UNITS: IN-Inch (pound f)
**%                    ... LENGTH : inch
**%                    ... TIME   : sec
**%                    ... MASS   : lbf-sec**2/in
**%                    ... FORCE  : pound (lbf)
**%                    ... TEMPERATURE : deg Fahrenheit
**%
**%        COORDINATE SYSTEM: PART
**%
**%            SUBSET EXPORT: OFF
**%
**%      NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  20-Aug-08   18:19:52
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
*MPC
*MPC
*SHELL SECTION,
```

```
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=RESNDS
    8938,     9370,     9985
*NSET,NSET=ANGNDS
      17,      697,     1513,     1737
*NSET,NSET=RESTRAINTS
    8938,     9370,     9985
*ELSET,ELSET=ALLELE, GENERATE
       1,     9200,        1
*ELSET,ELSET=TRANS_PLT, GENERATE
    1617,     2000,        1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
       1,     1616,        1
*ELSET,ELSET=RIGID
    9201,     9202,     9203
*ELSET,ELSET=ELBOW, GENERATE
       1,     2000,        1
*ELSET,ELSET=BRANCH, GENERATE
    5649,     7952,        1
*ELSET,ELSET=BRANCH_CAP, GENERATE
    8625,     9200,        1
*ELSET,ELSET=CAPPED_BRANCH, GENERATE
    5649,     7952,        1
    8625,     9200,        1
*ELSET,ELSET=SIDE_RUN, GENERATE
    2001,     3824,        1
*ELSET,ELSET=SIDE_CAP, GENERATE
    8289,     8624,        1
*ELSET,ELSET=CAPPED_SIDERUN, GENERATE
    2001,     3824,        1
    8289,     8624,        1
*ELSET,ELSET=BOT_RUN, GENERATE
    3825,     5648,        1
*ELSET,ELSET=BOT_CAP, GENERATE
    7953,     8288,        1
*ELSET,ELSET=CAPPED_BOTRUN, GENERATE
    3825,     5648,        1
    7953,     8288,        1
*ELSET,ELSET=REINPLT
```

```
*ELSET,ELSET=RESTRAINTS, GENERATE
         1,      9200,         1
*ELSET,ELSET=PRESSURE_ELE, GENERATE
         1,      9200,         1
*ELSET,ELSET=SECT, GENERATE
*ELSET, ELSET=BS000001, GENERATE
         1,      9200,         1
*ELSET, ELSET=ACCL_ELM
 THK_25,
*BOUNDARY,OP=NEW
       8938,  1, 6,      0.00000E+00
       9370,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + Bxp
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00, 0.10000E+01, 0.00000E+00
*CLOAD,OP=NEW
       9985,    4,-2.778E+04
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

si_mt_ubranch_08_26_08_myp.inp

```
**%   =============================================================
**%
**%                I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:** 09/30/08	**Checker:** A. S. Siahpush	**Date:**	09/30/08

```
**%                      FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\mod2_unlisted_last5.mf1
**%          INPUT FILE: si_mt_ubranch_08_26_08_myp.inp
**%            EXPORTED: AT 18:19:52 ON 20-Aug-08
**%                PART: mod26
**%                 FEM: si_ubranch26
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  20-Aug-08   18:19:52
**%============================================
**%          MODAL DATA
**%============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
*MPC
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=RESNDS
    8938,    9370,    9985
*NSET,NSET=ANGNDS
```

```
      17,      697,     1513,     1737
*NSET,NSET=RESTRAINTS
    8938,     9370,     9985
*ELSET,ELSET=ALLELE, GENERATE
         1,      9200,          1
*ELSET,ELSET=TRANS_PLT, GENERATE
      1617,      2000,          1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
         1,      1616,          1
*ELSET,ELSET=RIGID
    9201,     9202,     9203
*ELSET,ELSET=ELBOW, GENERATE
         1,      2000,          1
*ELSET,ELSET=BRANCH, GENERATE
      5649,      7952,          1
*ELSET,ELSET=BRANCH_CAP, GENERATE
      8625,      9200,          1
*ELSET,ELSET=CAPPED_BRANCH, GENERATE
      5649,      7952,          1
      8625,      9200,          1
*ELSET,ELSET=SIDE_RUN, GENERATE
      2001,      3824,          1
*ELSET,ELSET=SIDE_CAP, GENERATE
      8289,      8624,          1
*ELSET,ELSET=CAPPED_SIDERUN, GENERATE
      2001,      3824,          1
      8289,      8624,          1
*ELSET,ELSET=BOT_RUN, GENERATE
      3825,      5648,          1
*ELSET,ELSET=BOT_CAP, GENERATE
      7953,      8288,          1
*ELSET,ELSET=CAPPED_BOTRUN, GENERATE
      3825,      5648,          1
      7953,      8288,          1
*ELSET,ELSET=REINPLT
*ELSET,ELSET=RESTRAINTS, GENERATE
         1,      9200,          1
*ELSET,ELSET=PRESSURE_ELE, GENERATE
         1,      9200,          1
*ELSET,ELSET=SECT, GENERATE
*ELSET, ELSET=BS000001, GENERATE
         1,      9200,          1
*ELSET, ELSET=ACCL_ELM
 THK_25,
*BOUNDARY,OP=NEW
       8938,  1, 6,      0.00000E+00
       9370,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
```

```
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + Bxp
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00, 0.10000E+01, 0.00000E+00
*CLOAD,OP=NEW
      9985,    5, 7.788E+04
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

si_mt_ubranch_08_26_08_myn.inp

```
**%    ============================================================
**%
**%             I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                    FOR ABAQUS VERSION 6.x
**%
**%         MODEL FILE: C:\DOCUME~1\dtclark\mod2_unlisted_last5.mf1
**%         INPUT FILE: si_mt_ubranch_08_26)08_myn.inp
**%           EXPORTED: AT 18:19:52 ON 20-Aug-08
**%               PART: mod26
**%                FEM: si_ubranch26
**%
**%              UNITS: IN-Inch (pound f)
**%                    ... LENGTH : inch
**%                    ... TIME   : sec
**%                    ... MASS   : lbf-sec**2/in
**%                    ... FORCE  : pound (lbf)
**%                    ... TEMPERATURE : deg Fahrenheit
**%
**%        COORDINATE SYSTEM: PART
**%
**%            SUBSET EXPORT: OFF
**%
```

```
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  20-Aug-08   18:19:52
**%============================================
**%          MODAL DATA
**%============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
*MPC
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=RESNDS
    8938,    9370,    9985
*NSET,NSET=ANGNDS
      17,     697,    1513,    1737
*NSET,NSET=RESTRAINTS
    8938,    9370,    9985
*ELSET,ELSET=ALLELE, GENERATE
         1,     9200,        1
*ELSET,ELSET=TRANS_PLT, GENERATE
      1617,     2000,        1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
         1,     1616,        1
*ELSET,ELSET=RIGID
    9201,    9202,    9203
*ELSET,ELSET=ELBOW, GENERATE
         1,     2000,        1
*ELSET,ELSET=BRANCH, GENERATE
      5649,     7952,        1
*ELSET,ELSET=BRANCH_CAP, GENERATE
      8625,     9200,        1
*ELSET,ELSET=CAPPED_BRANCH, GENERATE
      5649,     7952,        1
```

```
      8625,      9200,         1
*ELSET,ELSET=SIDE_RUN, GENERATE
      2001,      3824,         1
*ELSET,ELSET=SIDE_CAP, GENERATE
      8289,      8624,         1
*ELSET,ELSET=CAPPED_SIDERUN, GENERATE
      2001,      3824,         1
      8289,      8624,         1
*ELSET,ELSET=BOT_RUN, GENERATE
      3825,      5648,         1
*ELSET,ELSET=BOT_CAP, GENERATE
      7953,      8288,         1
*ELSET,ELSET=CAPPED_BOTRUN, GENERATE
      3825,      5648,         1
      7953,      8288,         1
*ELSET,ELSET=REINPLT
*ELSET,ELSET=RESTRAINTS, GENERATE
         1,      9200,         1
*ELSET,ELSET=PRESSURE_ELE, GENERATE
         1,      9200,         1
*ELSET,ELSET=SECT, GENERATE
*ELSET, ELSET=BS000001, GENERATE
         1,      9200,         1
*ELSET, ELSET=ACCL_ELM
 THK_25,
*BOUNDARY,OP=NEW
       8938,  1, 6,      0.00000E+00
       9370,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + Bxp
```

```
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00, 0.10000E+01, 0.00000E+00
*CLOAD,OP=NEW
       9985,    5,-7.788E+04
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

si_mt_ubranch_08_26_08_mzp.inp

```
**%   ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\mod2_unlisted_last5.mf1
**%          INPUT FILE: si_mt_ubranch_08_26_08_mzp.inp
**%            EXPORTED: AT 18:19:52 ON 20-Aug-08
**%                PART: mod26
**%                 FEM: si_ubranch26
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%        COORDINATE SYSTEM: PART
**%
**%            SUBSET EXPORT: OFF
**%
**%      NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  20-Aug-08   18:19:52
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
*MPC
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
```

```
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=RESNDS
    8938,    9370,    9985
*NSET,NSET=ANGNDS
      17,     697,    1513,    1737
*NSET,NSET=RESTRAINTS
    8938,    9370,    9985
*ELSET,ELSET=ALLELE, GENERATE
         1,     9200,          1
*ELSET,ELSET=TRANS_PLT, GENERATE
      1617,     2000,          1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
         1,     1616,          1
*ELSET,ELSET=RIGID
    9201,    9202,    9203
*ELSET,ELSET=ELBOW, GENERATE
         1,     2000,          1
*ELSET,ELSET=BRANCH, GENERATE
      5649,     7952,          1
*ELSET,ELSET=BRANCH_CAP, GENERATE
      8625,     9200,          1
*ELSET,ELSET=CAPPED_BRANCH, GENERATE
      5649,     7952,          1
      8625,     9200,          1
*ELSET,ELSET=SIDE_RUN, GENERATE
      2001,     3824,          1
*ELSET,ELSET=SIDE_CAP, GENERATE
      8289,     8624,          1
*ELSET,ELSET=CAPPED_SIDERUN, GENERATE
      2001,     3824,          1
      8289,     8624,          1
*ELSET,ELSET=BOT_RUN, GENERATE
      3825,     5648,          1
*ELSET,ELSET=BOT_CAP, GENERATE
      7953,     8288,          1
*ELSET,ELSET=CAPPED_BOTRUN, GENERATE
      3825,     5648,          1
      7953,     8288,          1
*ELSET,ELSET=REINPLT
*ELSET,ELSET=RESTRAINTS, GENERATE
         1,     9200,          1
*ELSET,ELSET=PRESSURE_ELE, GENERATE
```

```
         1,     9200,        1
*ELSET,ELSET=SECT, GENERATE
*ELSET, ELSET=BS000001, GENERATE
         1,     9200,        1
*ELSET, ELSET=ACCL_ELM
 THK_25,
*BOUNDARY,OP=NEW
       8938,  1, 6,      0.00000E+00
       9370,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + Bxp
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00, 0.10000E+01, 0.00000E+00
*CLOAD,OP=NEW
       9985,    6, 4.084E+03
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

si_mt_ubranch_08_26_08_mzn.inp

```
**%    ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\mod2_unlisted_last5.mf1
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
**%          INPUT FILE: si_mt_ubranch_08_26_08_mzn.inp
**%            EXPORTED: AT 18:19:52 ON 20-Aug-08
**%                PART: mod26
**%                 FEM: si_ubranch26
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  20-Aug-08   18:19:52
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
*MPC
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=RESNDS
    8938,    9370,    9985
*NSET,NSET=ANGNDS
      17,     697,    1513,    1737
*NSET,NSET=RESTRAINTS
    8938,    9370,    9985
```

```
*ELSET,ELSET=ALLELE, GENERATE
         1,     9200,         1
*ELSET,ELSET=TRANS_PLT, GENERATE
      1617,     2000,         1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
         1,     1616,         1
*ELSET,ELSET=RIGID
    9201,    9202,    9203
*ELSET,ELSET=ELBOW, GENERATE
         1,     2000,         1
*ELSET,ELSET=BRANCH, GENERATE
      5649,     7952,         1
*ELSET,ELSET=BRANCH_CAP, GENERATE
      8625,     9200,         1
*ELSET,ELSET=CAPPED_BRANCH, GENERATE
      5649,     7952,         1
      8625,     9200,         1
*ELSET,ELSET=SIDE_RUN, GENERATE
      2001,     3824,         1
*ELSET,ELSET=SIDE_CAP, GENERATE
      8289,     8624,         1
*ELSET,ELSET=CAPPED_SIDERUN, GENERATE
      2001,     3824,         1
      8289,     8624,         1
*ELSET,ELSET=BOT_RUN, GENERATE
      3825,     5648,         1
*ELSET,ELSET=BOT_CAP, GENERATE
      7953,     8288,         1
*ELSET,ELSET=CAPPED_BOTRUN, GENERATE
      3825,     5648,         1
      7953,     8288,         1
*ELSET,ELSET=REINPLT
*ELSET,ELSET=RESTRAINTS, GENERATE
         1,     9200,         1
*ELSET,ELSET=PRESSURE_ELE, GENERATE
         1,     9200,         1
*ELSET,ELSET=SECT, GENERATE
*ELSET, ELSET=BS000001, GENERATE
         1,     9200,         1
*ELSET, ELSET=ACCL_ELM
 THK_25,
*BOUNDARY,OP=NEW
       8938,  1, 6,      0.00000E+00
       9370,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
```

```
BS000001,    P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + Bxp
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00, 0.10000E+01, 0.00000E+00
*CLOAD,OP=NEW
       9985,    6,-4.084E+03
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

si_mt_urun_08_26_08_mxp.inp

```
**%    ============================================================
**%
**%               I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                      FOR ABAQUS VERSION 6.x
**%
**%           MODEL FILE: C:\DOCUME~1\dtclark\mod2_unlisted_last5.mf1
**%           INPUT FILE: C:\pcs\pcs2\model_(26)\si_mt_urun_08_26_08_mxp.inp
**%             EXPORTED: AT 09:28:40 ON 21-Aug-08
**%                 PART: mod26
**%                  FEM: si_urun26
**%
**%                UNITS: IN-Inch (pound f)
**%                      ... LENGTH : inch
**%                      ... TIME   : sec
**%                      ... MASS   : lbf-sec**2/in
**%                      ... FORCE  : pound (lbf)
**%                      ... TEMPERATURE : deg Fahrenheit
**%
**%          COORDINATE SYSTEM: PART
**%
**%              SUBSET EXPORT: OFF
**%
**%        NODE ZERO TOLERANCE: OFF
**%
**%    ============================================================
**%
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  21-Aug-08   09:28:40
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
*MPC
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=RESNDS
    8938,     9370,     9985
*NSET,NSET=ANGNDS
      17,      697,     1513,     1737
*NSET,NSET=RESTRAINTS
    8938,     9370,     9985
*ELSET,ELSET=ALLELE, GENERATE
         1,      9200,        1
*ELSET,ELSET=TRANS_PLT, GENERATE
      1617,      2000,        1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
         1,      1616,        1
*ELSET,ELSET=RIGID
    9201,     9202,     9203
*ELSET,ELSET=ELBOW, GENERATE
         1,      2000,        1
*ELSET,ELSET=BRANCH, GENERATE
      5649,      7952,        1
*ELSET,ELSET=BRANCH_CAP, GENERATE
      8625,      9200,        1
*ELSET,ELSET=CAPPED_BRANCH, GENERATE
      5649,      7952,        1
      8625,      9200,        1
*ELSET,ELSET=SIDE_RUN, GENERATE
      2001,      3824,        1
*ELSET,ELSET=SIDE_CAP, GENERATE
```

```
      8289,      8624,         1
*ELSET,ELSET=CAPPED_SIDERUN, GENERATE
      2001,      3824,         1
      8289,      8624,         1
*ELSET,ELSET=BOT_RUN, GENERATE
      3825,      5648,         1
*ELSET,ELSET=BOT_CAP, GENERATE
      7953,      8288,         1
*ELSET,ELSET=CAPPED_BOTRUN, GENERATE
      3825,      5648,         1
      7953,      8288,         1
*ELSET,ELSET=REINPLT
*ELSET,ELSET=RESTRAINTS, GENERATE
         1,      9200,         1
*ELSET,ELSET=PRESSURE_ELE, GENERATE
         1,      9200,         1
*ELSET, ELSET=BS000001, GENERATE
         1,      9200,         1
*BOUNDARY,OP=NEW
       8938,  1, 6,       0.00000E+00
*ELSET, ELSET=ACCL_ELM
 THK_25,
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 2
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,     P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 2
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE + MX
*CLOAD,OP=NEW
       9370,     4, 9.978E+03
*DLOAD,OP=NEW
BS000001,     P,-2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00, 0.10000E+01, 0.00000E+00
```

```
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

si_mt_urun_08_26_08_mxn.inp

```
**%    ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\mod2_unlisted_last5.mf1
**%          INPUT FILE: C:\pcs\pcs2\model_(26)\si_mt_urun_08_26_08_mxn.inp
**%            EXPORTED: AT 09:28:40 ON 21-Aug-08
**%                PART: mod26
**%                 FEM: si_urun26
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%    ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  21-Aug-08   09:28:40
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
*MPC
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=RESNDS
    8938,    9370,    9985
*NSET,NSET=ANGNDS
      17,     697,    1513,    1737
*NSET,NSET=RESTRAINTS
    8938,    9370,    9985
*ELSET,ELSET=ALLELE, GENERATE
         1,      9200,         1
*ELSET,ELSET=TRANS_PLT, GENERATE
      1617,      2000,         1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
         1,      1616,         1
*ELSET,ELSET=RIGID
    9201,    9202,    9203
*ELSET,ELSET=ELBOW, GENERATE
         1,      2000,         1
*ELSET,ELSET=BRANCH, GENERATE
      5649,      7952,         1
*ELSET,ELSET=BRANCH_CAP, GENERATE
      8625,      9200,         1
*ELSET,ELSET=CAPPED_BRANCH, GENERATE
      5649,      7952,         1
      8625,      9200,         1
*ELSET,ELSET=SIDE_RUN, GENERATE
      2001,      3824,         1
*ELSET,ELSET=SIDE_CAP, GENERATE
      8289,      8624,         1
*ELSET,ELSET=CAPPED_SIDERUN, GENERATE
      2001,      3824,         1
      8289,      8624,         1
*ELSET,ELSET=BOT_RUN, GENERATE
      3825,      5648,         1
*ELSET,ELSET=BOT_CAP, GENERATE
      7953,      8288,         1
*ELSET,ELSET=CAPPED_BOTRUN, GENERATE
      3825,      5648,         1
      7953,      8288,         1
*ELSET,ELSET=REINPLT
*ELSET,ELSET=RESTRAINTS, GENERATE
         1,      9200,         1
*ELSET,ELSET=PRESSURE_ELE, GENERATE
         1,      9200,         1
*ELSET, ELSET=BS000001, GENERATE
         1,      9200,         1
*BOUNDARY,OP=NEW
       8938,  1, 6,      0.00000E+00
*ELSET, ELSET=ACCL_ELM
```

```
 THK_25,
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 2
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 2
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE + MX
*CLOAD,OP=NEW
       9370,    4,-9.978E+03
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00, 0.10000E+01, 0.00000E+00
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

si_mt_urun_08_26_08_myp.inp

```
**%    ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\mod2_unlisted_last5.mf1
**%          INPUT FILE: C:\pcs\pcs2\model_(26)\si_mt_urun_08_26_08_myn.inp
**%            EXPORTED: AT 09:28:40 ON 21-Aug-08
**%                PART: mod26
**%                 FEM: si_urun26
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
```

```
**%                       ... MASS    : lbf-sec**2/in
**%                       ... FORCE   : pound (lbf)
**%                       ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  21-Aug-08   09:28:40
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
*MPC
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=RESNDS
    8938,    9370,    9985
*NSET,NSET=ANGNDS
      17,      697,    1513,    1737
*NSET,NSET=RESTRAINTS
    8938,    9370,    9985
*ELSET,ELSET=ALLELE, GENERATE
         1,     9200,        1
*ELSET,ELSET=TRANS_PLT, GENERATE
      1617,     2000,        1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
         1,     1616,        1
*ELSET,ELSET=RIGID
    9201,    9202,    9203
```

```
*ELSET,ELSET=ELBOW, GENERATE
       1,     2000,        1
*ELSET,ELSET=BRANCH, GENERATE
    5649,     7952,        1
*ELSET,ELSET=BRANCH_CAP, GENERATE
    8625,     9200,        1
*ELSET,ELSET=CAPPED_BRANCH, GENERATE
    5649,     7952,        1
    8625,     9200,        1
*ELSET,ELSET=SIDE_RUN, GENERATE
    2001,     3824,        1
*ELSET,ELSET=SIDE_CAP, GENERATE
    8289,     8624,        1
*ELSET,ELSET=CAPPED_SIDERUN, GENERATE
    2001,     3824,        1
    8289,     8624,        1
*ELSET,ELSET=BOT_RUN, GENERATE
    3825,     5648,        1
*ELSET,ELSET=BOT_CAP, GENERATE
    7953,     8288,        1
*ELSET,ELSET=CAPPED_BOTRUN, GENERATE
    3825,     5648,        1
    7953,     8288,        1
*ELSET,ELSET=REINPLT
*ELSET,ELSET=RESTRAINTS, GENERATE
       1,     9200,        1
*ELSET,ELSET=PRESSURE_ELE, GENERATE
       1,     9200,        1
*ELSET, ELSET=BS000001, GENERATE
       1,     9200,        1
*BOUNDARY,OP=NEW
     8938,  1, 6,      0.00000E+00
*ELSET, ELSET=ACCL_ELM
 THK_25,
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 2
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**%
**% ====== STEP NUMBER   2 ======
**%
```

```
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 2
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE + MY
*CLOAD,OP=NEW
       9370,    5,-5.874E+04
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00, 0.10000E+01, 0.00000E+00
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

si_mt_urun_08_26_08_myn.inp

```
**%   ============================================================
**%
**%             I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                    FOR ABAQUS VERSION 6.x
**%
**%         MODEL FILE: C:\DOCUME~1\dtclark\mod2_unlisted_last5.mf1
**%         INPUT FILE: C:\pcs\pcs2\model_(26)\si_mt_urun_08_26_08_myn.inp
**%           EXPORTED: AT 09:28:40 ON 21-Aug-08
**%               PART: mod26
**%                FEM: si_urun26
**%
**%              UNITS: IN-Inch (pound f)
**%                    ... LENGTH : inch
**%                    ... TIME   : sec
**%                    ... MASS   : lbf-sec**2/in
**%                    ... FORCE  : pound (lbf)
**%                    ... TEMPERATURE : deg Fahrenheit
**%
**%        COORDINATE SYSTEM: PART
**%
**%            SUBSET EXPORT: OFF
**%
**%      NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  21-Aug-08   09:28:40
**%===========================================
**%         MODAL DATA
**%===========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
```

```
*MPC
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=RESNDS
    8938,     9370,     9985
*NSET,NSET=ANGNDS
      17,      697,     1513,     1737
*NSET,NSET=RESTRAINTS
    8938,     9370,     9985
*ELSET,ELSET=ALLELE, GENERATE
         1,     9200,         1
*ELSET,ELSET=TRANS_PLT, GENERATE
      1617,     2000,         1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
         1,     1616,         1
*ELSET,ELSET=RIGID
    9201,     9202,     9203
*ELSET,ELSET=ELBOW, GENERATE
         1,     2000,         1
*ELSET,ELSET=BRANCH, GENERATE
      5649,     7952,         1
*ELSET,ELSET=BRANCH_CAP, GENERATE
      8625,     9200,         1
*ELSET,ELSET=CAPPED_BRANCH, GENERATE
      5649,     7952,         1
      8625,     9200,         1
*ELSET,ELSET=SIDE_RUN, GENERATE
      2001,     3824,         1
*ELSET,ELSET=SIDE_CAP, GENERATE
      8289,     8624,         1
*ELSET,ELSET=CAPPED_SIDERUN, GENERATE
      2001,     3824,         1
      8289,     8624,         1
*ELSET,ELSET=BOT_RUN, GENERATE
      3825,     5648,         1
*ELSET,ELSET=BOT_CAP, GENERATE
      7953,     8288,         1
*ELSET,ELSET=CAPPED_BOTRUN, GENERATE
```

```
      3825,      5648,          1
      7953,      8288,          1
*ELSET,ELSET=REINPLT
*ELSET,ELSET=RESTRAINTS, GENERATE
         1,      9200,          1
*ELSET,ELSET=PRESSURE_ELE, GENERATE
         1,      9200,          1
*ELSET, ELSET=BS000001, GENERATE
         1,      9200,          1
*BOUNDARY,OP=NEW
       8938,. 1, 6,       0.00000E+00
*ELSET, ELSET=ACCL_ELM
 THK_25,
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 2
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 2
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE + MY
*CLOAD,OP=NEW
       9370,     5,-5.874E+04
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00, 0.10000E+01, 0.00000E+00
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

si_mt_urun_08_26_08_mzp.inp

```
**%    ============================================================
**%
```

Project:	ATR Life Time Extension Project		**ECAR No.:**	ECAR-194		**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation						
Performer:	D. T. Clark	**Date:**	09/30/08	**Checker:**	A. S. Siahpush	**Date:**	09/30/08

```
**%               I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                      FOR ABAQUS VERSION 6.x
**%
**%           MODEL FILE: C:\DOCUME~1\dtclark\mod2_unlisted_last5.mf1
**%           INPUT FILE: C:\pcs\pcs2\model_(26)\si_mt_urun_08_26_08_mzp.inp
**%             EXPORTED: AT 09:28:40 ON 21-Aug-08
**%                 PART: mod26
**%                  FEM: si_urun26
**%
**%               UNITS: IN-Inch (pound f)
**%                      ... LENGTH : inch
**%                      ... TIME   : sec
**%                      ... MASS   : lbf-sec**2/in
**%                      ... FORCE  : pound (lbf)
**%                      ... TEMPERATURE : deg Fahrenheit
**%
**%          COORDINATE SYSTEM: PART
**%
**%              SUBSET EXPORT: OFF
**%
**%        NODE ZERO TOLERANCE: OFF
**%
**%    ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  21-Aug-08   09:28:40
**%=========================================
**%          MODAL DATA
**%=========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
*MPC
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=RESNDS
    8938,     9370,     9985
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
*NSET,NSET=ANGNDS
      17,      697,     1513,     1737
*NSET,NSET=RESTRAINTS
    8938,     9370,     9985
*ELSET,ELSET=ALLELE, GENERATE
        1,      9200,         1
*ELSET,ELSET=TRANS_PLT, GENERATE
      1617,      2000,         1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
        1,      1616,         1
*ELSET,ELSET=RIGID
    9201,     9202,     9203
*ELSET,ELSET=ELBOW, GENERATE
        1,      2000,         1
*ELSET,ELSET=BRANCH, GENERATE
      5649,      7952,         1
*ELSET,ELSET=BRANCH_CAP, GENERATE
      8625,      9200,         1
*ELSET,ELSET=CAPPED_BRANCH, GENERATE
      5649,      7952,         1
      8625,      9200,         1
*ELSET,ELSET=SIDE_RUN, GENERATE
      2001,      3824,         1
*ELSET,ELSET=SIDE_CAP, GENERATE
      8289,      8624,         1
*ELSET,ELSET=CAPPED_SIDERUN, GENERATE
      2001,      3824,         1
      8289,      8624,         1
*ELSET,ELSET=BOT_RUN, GENERATE
      3825,      5648,         1
*ELSET,ELSET=BOT_CAP, GENERATE
      7953,      8288,         1
*ELSET,ELSET=CAPPED_BOTRUN, GENERATE
      3825,      5648,         1
      7953,      8288,         1
*ELSET,ELSET=REINPLT
*ELSET,ELSET=RESTRAINTS, GENERATE
        1,      9200,         1
*ELSET,ELSET=PRESSURE_ELE, GENERATE
        1,      9200,         1
*ELSET, ELSET=BS000001, GENERATE
        1,      9200,         1
*BOUNDARY,OP=NEW
       8938,  1, 6,      0.00000E+00
*ELSET, ELSET=ACCL_ELM
 THK_25,
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 2
**%  RESTRAINT SET 2
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,     P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 2
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE + MZ
*CLOAD,OP=NEW
       9370,     6, 8.298E+03
*DLOAD,OP=NEW
BS000001,     P,-2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00, 0.10000E+01, 0.00000E+00
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

si_mt_urun_08_26_08_mzn.inp

```
**%    ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\mod2_unlisted_last5.mf1
**%          INPUT FILE: C:\pcs\pcs2\model_(26)\si_mt_urun_08_26_08_mzn.inp
**%            EXPORTED: AT 09:28:40 ON 21-Aug-08
**%                PART: mod26
**%                 FEM: si_urun26
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  21-Aug-08   09:28:40
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
*MPC
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=RESNDS
    8938,    9370,    9985
*NSET,NSET=ANGNDS
      17,      697,    1513,    1737
*NSET,NSET=RESTRAINTS
    8938,    9370,    9985
*ELSET,ELSET=ALLELE, GENERATE
         1,     9200,        1
*ELSET,ELSET=TRANS_PLT, GENERATE
      1617,     2000,        1
*ELSET,ELSET=ELBOW_HOLE, GENERATE
         1,     1616,        1
*ELSET,ELSET=RIGID
    9201,    9202,    9203
*ELSET,ELSET=ELBOW, GENERATE
         1,     2000,        1
*ELSET,ELSET=BRANCH, GENERATE
      5649,     7952,        1
*ELSET,ELSET=BRANCH_CAP, GENERATE
      8625,     9200,        1
*ELSET,ELSET=CAPPED_BRANCH, GENERATE
      5649,     7952,        1
      8625,     9200,        1
```

```
*ELSET,ELSET=SIDE_RUN, GENERATE
      2001,     3824,         1
*ELSET,ELSET=SIDE_CAP, GENERATE
      8289,     8624,         1
*ELSET,ELSET=CAPPED_SIDERUN, GENERATE
      2001,     3824,         1
      8289,     8624,         1
*ELSET,ELSET=BOT_RUN, GENERATE
      3825,     5648,         1
*ELSET,ELSET=BOT_CAP, GENERATE
      7953,     8288,         1
*ELSET,ELSET=CAPPED_BOTRUN, GENERATE
      3825,     5648,         1
      7953,     8288,         1
*ELSET,ELSET=REINPLT
*ELSET,ELSET=RESTRAINTS, GENERATE
         1,     9200,         1
*ELSET,ELSET=PRESSURE_ELE, GENERATE
         1,     9200,         1
*ELSET, ELSET=BS000001, GENERATE
         1,     9200,         1
*BOUNDARY,OP=NEW
       8938,  1, 6,      0.00000E+00
*ELSET, ELSET=ACCL_ELM
 THK_25,
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 2
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 2
**%  RESTRAINT SET 2
**%  LOAD SET PRESSURE + MZ
*CLOAD,OP=NEW
       9370,    6,-8.298E+03
*DLOAD,OP=NEW
```

```
BS000001,     P,-2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00, 0.10000E+01, 0.00000E+00
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

Unlisted_end_cap_stp.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_end_cap.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_end_cap\input\Unlisted_end_cap_stp.inp
**%            EXPORTED: AT 14:09:22 ON 25-Aug-08
**%                PART: End cap continuum shell
**%                 FEM: Fem2
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  25-Aug-08   14:09:22
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL1
*ELEMENT, TYPE=SC8R, ELSET=SOLID4
*MPC
*MPC
*SHELL SECTION,
 ELSET=SHELL1,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  1.00000E+00,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
*SHELL SECTION, ELSET=SOLID4, MATERIAL=SST304_P
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
 5.0,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=ANGPTS
     338,    1637,    7503,    7524
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=HALFYZ, GENERATE
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=BS000002, GENERATE
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       7180,  1, 6,      0.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       7180,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
      6901,    4, 9.886E+04
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
```

Unlisted_end_cap_stn.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_end_cap.mfl
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_end_cap\input\Unlisted_end_cap_stn.inp
**%            EXPORTED: AT 14:09:22 ON 25-Aug-08
**%                PART: End cap continuum shell
**%                 FEM: Fem2
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  25-Aug-08   14:09:22
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL1
*ELEMENT, TYPE=SC8R, ELSET=SOLID4
*MPC
*MPC
*SHELL SECTION,
 ELSET=SHELL1,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  1.00000E+00,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
```

```
*SHELL SECTION, ELSET=SOLID4, MATERIAL=SST304_P
 5.0,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=ANGPTS
     338,    1637,    7503,    7524
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=HALFYZ, GENERATE
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=BS000002, GENERATE
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      7180,  1, 6,      0.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      7180,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
     6901,    4,-9.886E+04
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
```

si_mt_ucap_ce_ppp.inp

```
**%   ============================================================
**%
**%             NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                    FOR ABAQUS VERSION 6.x
**%
**%         MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_end_cap.mf1
**%         INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_end_cap\input\si_mt_ucap_ce_ppp.inp
**%           EXPORTED: AT 14:09:22 ON 25-Aug-08
**%               PART: End cap continuum shell
**%                FEM: Fem2
**%
**%              UNITS: IN-Inch (pound f)
**%                    ... LENGTH : inch
**%                    ... TIME   : sec
**%                    ... MASS   : lbf-sec**2/in
**%                    ... FORCE  : pound (lbf)
**%                    ... TEMPERATURE : deg Fahrenheit
**%
**%        COORDINATE SYSTEM: PART
**%
**%            SUBSET EXPORT: OFF
**%
**%      NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  25-Aug-08   14:09:22
**%============================================
**%         MODAL DATA
**%============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL1
*ELEMENT, TYPE=SC8R, ELSET=SOLID4
*MPC
*MPC
*SHELL SECTION,
 ELSET=SHELL1,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  1.00000E+00,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
*SHELL SECTION, ELSET=SOLID4, MATERIAL=SST304_P
```

```
 5.0,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=ANGPTS
     338,    1637,    7503,    7524
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=HALFYZ, GENERATE
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=BS000002, GENERATE
*ELSET, ELSET=ACCL_ELM
 ALL,
*BOUNDARY,OP=NEW
       7180,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1, VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + Mppp
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00,-0.10000E+01, 0.00000E+00
*CLOAD,OP=NEW
      6901,    4, 1.37E+05
      6901,    5, 3.598E+04
      6901,    6, 1.387E+05
*OUTPUT, FIELD ,FREQUENCY=1, VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
```

si_mt_ucap_ce_ppn.inp

```
**%   ============================================================
**%
**%             NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                    FOR ABAQUS VERSION 6.x
**%
**%         MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_end_cap.mf1
**%         INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_end_cap\input\si_mt_ucap_ce_ppn.inp
**%           EXPORTED: AT 14:09:22 ON 25-Aug-08
**%               PART: End cap continuum shell
**%                FEM: Fem2
**%
**%              UNITS: IN-Inch (pound f)
**%                    ... LENGTH : inch
**%                    ... TIME   : sec
**%                    ... MASS   : lbf-sec**2/in
**%                    ... FORCE  : pound (lbf)
**%                    ... TEMPERATURE : deg Fahrenheit
**%
**%        COORDINATE SYSTEM: PART
**%
**%            SUBSET EXPORT: OFF
**%
**%      NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  25-Aug-08   14:09:22
**%=============================================
**%          MODAL DATA
**%=============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL1
*ELEMENT, TYPE=SC8R, ELSET=SOLID4
*MPC
*MPC
*SHELL SECTION,
 ELSET=SHELL1,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  1.00000E+00,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
*SHELL SECTION, ELSET=SOLID4, MATERIAL=SST304_P
 5.0,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=ANGPTS
     338,     1637,     7503,     7524
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=HALFYZ, GENERATE
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=BS000002, GENERATE
*ELSET, ELSET=ACCL_ELM
 ALL,
*BOUNDARY,OP=NEW
       7180,  1, 6,       0.00000E+00
**%
**% ====== STEP NUMBER    1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,     P, 2.5300E+02
BS000002,    P1, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1, VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
**%
**% ====== STEP NUMBER    2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + Mppn
*DLOAD,OP=NEW
BS000001,     P, 2.5300E+02
BS000002,    P1, 2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00,-0.10000E+01, 0.00000E+00
*CLOAD,OP=NEW
      6901,     4, 1.37E+05
      6901,     5, 3.598E+04
      6901,     6,-1.387E+05
*OUTPUT, FIELD ,FREQUENCY=1, VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
```

si_mt_ucap_ce_pnp.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_end_cap.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_end_cap\input\si_mt_ucap_ce_pnp.inp
**%            EXPORTED: AT 14:09:22 ON 25-Aug-08
**%                PART: End cap continuum shell
**%                 FEM: Fem2
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  25-Aug-08   14:09:22
**%=========================================
**%          MODAL DATA
**%=========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL1
*ELEMENT, TYPE=SC8R, ELSET=SOLID4
*MPC
*MPC
*SHELL SECTION,
 ELSET=SHELL1,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  1.00000E+00,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
*SHELL SECTION, ELSET=SOLID4, MATERIAL=SST304_P
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
 5.0,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=ANGPTS
     338,     1637,     7503,     7524
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=HALFYZ, GENERATE
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=BS000002, GENERATE
*ELSET, ELSET=ACCL_ELM
 ALL,
*BOUNDARY,OP=NEW
       7180,  1, 6,       0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,     P, 2.5300E+02
BS000002,    P1, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1, VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + Mpnp
*DLOAD,OP=NEW
BS000001,     P, 2.5300E+02
BS000002,    P1, 2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00,-0.10000E+01, 0.00000E+00
*CLOAD,OP=NEW
      6901,     4, 1.37E+05
      6901,     5,-3.598E+04
      6901,     6, 1.387E+05
*OUTPUT, FIELD ,FREQUENCY=1, VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:**	09/30/08	**Checker:**	A. S. Siahpush	**Date:**	09/30/08

si_mt_ucap_ce_npp.inp

```
**%   ==============================================================
**%
**%             NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                    FOR ABAQUS VERSION 6.x
**%
**%         MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_end_cap.mf1
**%         INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_end_cap\input\si_mt_ucap_ce_npp.inp
**%           EXPORTED: AT 14:09:22 ON 25-Aug-08
**%               PART: End cap continuum shell
**%                FEM: Fem2
**%
**%              UNITS: IN-Inch (pound f)
**%                    ... LENGTH : inch
**%                    ... TIME   : sec
**%                    ... MASS   : lbf-sec**2/in
**%                    ... FORCE  : pound (lbf)
**%                    ... TEMPERATURE : deg Fahrenheit
**%
**%        COORDINATE SYSTEM: PART
**%
**%            SUBSET EXPORT: OFF
**%
**%      NODE ZERO TOLERANCE: OFF
**%
**%   ==============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  25-Aug-08   14:09:22
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL1
*ELEMENT, TYPE=SC8R, ELSET=SOLID4
*MPC
*MPC
*SHELL SECTION,
 ELSET=SHELL1,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  1.00000E+00,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
*SHELL SECTION, ELSET=SOLID4, MATERIAL=SST304_P
 5.0,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=ANGPTS
     338,     1637,     7503,     7524
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=HALFYZ, GENERATE
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=BS000002, GENERATE
*ELSET, ELSET=ACCL_ELM
 ALL,
*BOUNDARY,OP=NEW
      7180,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1, VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + Mnpp
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00,-0.10000E+01, 0.00000E+00
*CLOAD,OP=NEW
      6901,     4,-1.37E+05
      6901,     5, 3.598E+04
      6901,     6, 1.387E+05
*OUTPUT, FIELD ,FREQUENCY=1, VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
```

si_mt_ucap_ce_nnn.inp

```
**%   ============================================================
**%
**%             NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                    FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_end_cap.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_end_cap\input\si_mt_ucap_ce_nnn.inp
**%            EXPORTED: AT 14:09:22 ON 25-Aug-08
**%                PART: End cap continuum shell
**%                 FEM: Fem2
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%              SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  25-Aug-08   14:09:22
**%============================================
**%          MODAL DATA
**%============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL1
*ELEMENT, TYPE=SC8R, ELSET=SOLID4
*MPC
*MPC
*SHELL SECTION,
 ELSET=SHELL1,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  1.00000E+00,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
*SHELL SECTION, ELSET=SOLID4, MATERIAL=SST304_P
```

```
 5.0,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=ANGPTS
     338,     1637,     7503,     7524
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=HALFYZ, GENERATE
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=BS000002, GENERATE
*ELSET, ELSET=ACCL_ELM
 ALL,
*BOUNDARY,OP=NEW
       7180,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1, VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + Mnnn
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00,-0.10000E+01, 0.00000E+00
*CLOAD,OP=NEW
      6901,    4,-1.37E+05
      6901,    5,-3.598E+04
      6901,    6,-1.387E+05
*OUTPUT, FIELD ,FREQUENCY=1, VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

si_mt_ucap_ce_nnp.inp

```
**%   ============================================================
**%
**%             NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                    FOR ABAQUS VERSION 6.x
**%
**%         MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_end_cap.mfl
**%         INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_end_cap\input\si_mt_ucap_ce_nnp.inp
**%           EXPORTED: AT 14:09:22 ON 25-Aug-08
**%               PART: End cap continuum shell
**%                FEM: Fem2
**%
**%              UNITS: IN-Inch (pound f)
**%                    ... LENGTH : inch
**%                    ... TIME   : sec
**%                    ... MASS   : lbf-sec**2/in
**%                    ... FORCE  : pound (lbf)
**%                    ... TEMPERATURE : deg Fahrenheit
**%
**%        COORDINATE SYSTEM: PART
**%
**%            SUBSET EXPORT: OFF
**%
**%      NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  25-Aug-08   14:09:22
**%==========================================
**%         MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL1
*ELEMENT, TYPE=SC8R, ELSET=SOLID4
*MPC
*MPC
*SHELL SECTION,
 ELSET=SHELL1,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  1.00000E+00,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
*SHELL SECTION, ELSET=SOLID4, MATERIAL=SST304_P
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
 5.0,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=ANGPTS
     338,    1637,    7503,    7524
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=HALFYZ, GENERATE
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=BS000002, GENERATE
*ELSET, ELSET=ACCL_ELM
 ALL,
*BOUNDARY,OP=NEW
       7180,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1, VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + Mnnp
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00,-0.10000E+01, 0.00000E+00
*CLOAD,OP=NEW
      6901,    4,-1.37E+05
      6901,    5,-3.598E+04
      6901,    6, 1.387E+05
*OUTPUT, FIELD ,FREQUENCY=1, VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
```

si_mt_ucap_ce_npn.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_end_cap.mfl
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_end_cap\input\si_mt_ucap_ce_npn.inp
**%            EXPORTED: AT 14:09:22 ON 25-Aug-08
**%                PART: End cap continuum shell
**%                 FEM: Fem2
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  25-Aug-08   14:09:22
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL1
*ELEMENT, TYPE=SC8R, ELSET=SOLID4
*MPC
*MPC
*SHELL SECTION,
 ELSET=SHELL1,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  1.00000E+00,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
*SHELL SECTION, ELSET=SOLID4, MATERIAL=SST304_P
```

```
 5.0,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=ANGPTS
     338,     1637,     7503,     7524
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=HALFYZ, GENERATE
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=BS000002, GENERATE
*ELSET, ELSET=ACCL_ELM
 ALL,
*BOUNDARY,OP=NEW
       7180,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1, VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + Mnpn
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00,-0.10000E+01, 0.00000E+00
*CLOAD,OP=NEW
      6901,    4,-1.37E+05
      6901,    5, 3.598E+04
      6901,    6,-1.387E+05
*OUTPUT, FIELD ,FREQUENCY=1, VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
```

si_mt_ucap_ce_npp.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_end_cap.mfl
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_end_cap\input\si_mt_ucap_ce_npp.inp
**%            EXPORTED: AT 14:09:22 ON 25-Aug-08
**%                PART: End cap continuum shell
**%                 FEM: Fem2
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  25-Aug-08   14:09:22
**%=========================================
**%          MODAL DATA
**%=========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL1
*ELEMENT, TYPE=SC8R, ELSET=SOLID4
*MPC
*MPC
*SHELL SECTION,
 ELSET=SHELL1,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  1.00000E+00,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
***PLASTIC
** 28400.0, 0.0
** 97900.0, 0.276
*SHELL SECTION, ELSET=SOLID4, MATERIAL=SST304_P
```

```
 5.0,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=ANGPTS
     338,    1637,    7503,    7524
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=HALFYZ, GENERATE
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=BS000002, GENERATE
*ELSET, ELSET=ACCL_ELM
 ALL,
*BOUNDARY,OP=NEW
       7180,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1, VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + Mnpp
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*DLOAD,OP=NEW
 ACCL_ELM, GRAV, 0.38600E+03, 0.00000E+00,-0.10000E+01, 0.00000E+00
*CLOAD,OP=NEW
      6901,    4,-1.37E+05
      6901,    5, 3.598E+04
      6901,    6, 1.387E+05
*OUTPUT, FIELD ,FREQUENCY=1, VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
```

beam_mt_branch_16x10_m1.inp

```
**%  ==============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\mod2_unlisted_last5.mf1
**%          INPUT FILE: si_mt_ubranch_mxp.inp
**%            EXPORTED: AT 18:19:52 ON 20-Aug-08
**%                PART: mod26
**%                 FEM: si_ubranch26
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%  ==============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  20-Aug-08   18:19:52
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
*NSET,NSET=RESNDS
*NSET,NSET=ANGNDS
*NSET,NSET=RESTRAINTS
*ELSET,ELSET=ALLELE, GENERATE
*ELSET,ELSET=TRANS_PLT, GENERATE
*ELSET,ELSET=ELBOW_HOLE, GENERATE
*ELSET,ELSET=RIGID
*ELSET,ELSET=ELBOW, GENERATE
*ELSET,ELSET=BRANCH, GENERATE
*ELSET,ELSET=BRANCH_CAP, GENERATE
*ELSET,ELSET=SIDE_RUN, GENERATE
*ELSET,ELSET=SIDE_CAP, GENERATE
*ELSET,ELSET=CAPPED_SIDERUN, GENERATE
*ELSET,ELSET=BOT_RUN, GENERATE
*ELSET,ELSET=BOT_CAP, GENERATE
*ELSET,ELSET=CAPPED_BOTRUN, GENERATE
*ELSET,ELSET=REINPLT
*ELSET,ELSET=RESTRAINTS, GENERATE
*ELSET,ELSET=PRESSURE_ELE, GENERATE
*ELSET,ELSET=SECT, GENERATE
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=ACCL_ELM
 THK_25,
*BOUNDARY,OP=NEW
       8938,  1, 6,      0.00000E+00
       9370,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + Bxp
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
```

```
*CLOAD,OP=NEW
       9985,    4, 5.388E+04
**       9985,    5, 9.736E+04
**       9985,    6,-1.074E+04
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

beam_mt_branch_16x10_m2.inp

```
**%   ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\mod2_unlisted_last5.mf1
**%          INPUT FILE: si_mt_ubranch_mxp.inp
**%            EXPORTED: AT 18:19:52 ON 20-Aug-08
**%                PART: mod26
**%                 FEM: si_ubranch26
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  20-Aug-08   18:19:52
**%===========================================
**%          MODAL DATA
**%===========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=RESNDS
*NSET,NSET=ANGNDS
*NSET,NSET=RESTRAINTS
*ELSET,ELSET=ALLELE, GENERATE
*ELSET,ELSET=TRANS_PLT, GENERATE
*ELSET,ELSET=ELBOW_HOLE, GENERATE
*ELSET,ELSET=RIGID
*ELSET,ELSET=ELBOW, GENERATE
*ELSET,ELSET=BRANCH, GENERATE
*ELSET,ELSET=BRANCH_CAP, GENERATE
*ELSET,ELSET=CAPPED_BRANCH, GENERATE
*ELSET,ELSET=SIDE_RUN, GENERATE
*ELSET,ELSET=SIDE_CAP, GENERATE
*ELSET,ELSET=CAPPED_SIDERUN, GENERATE
*ELSET,ELSET=BOT_RUN, GENERATE
*ELSET,ELSET=BOT_CAP, GENERATE
*ELSET,ELSET=CAPPED_BOTRUN, GENERATE
*ELSET,ELSET=REINPLT
*ELSET,ELSET=RESTRAINTS, GENERATE
*ELSET,ELSET=PRESSURE_ELE, GENERATE
*ELSET,ELSET=SECT, GENERATE
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=ACCL_ELM
 THK_25,
*BOUNDARY,OP=NEW
      8938,  1, 6,      0.00000E+00
      9370,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**%
```

```
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + Bxp
*DLOAD,OP=NEW
BS000001,     P,-2.5300E+02
*CLOAD,OP=NEW
**        9985,     4, 5.388E+04
       9985,     5, 9.736E+04
**        9985,     6,-1.074E+04
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

beam_mt_branch_16x10_m3.inp

```
**%   ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\mod2_unlisted_last5.mf1
**%          INPUT FILE: si_mt_ubranch_mxp.inp
**%            EXPORTED: AT 18:19:52 ON 20-Aug-08
**%                PART: mod26
**%                 FEM: si_ubranch26
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  20-Aug-08   18:19:52
**%=========================================
**%         MODAL DATA
**%=========================================
*NODE, NSET=ALLNODES, SYSTEM=R
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=RESNDS
*NSET,NSET=ANGNDS
*NSET,NSET=RESTRAINTS
*ELSET,ELSET=ALLELE, GENERATE
*ELSET,ELSET=TRANS_PLT, GENERATE
*ELSET,ELSET=ELBOW_HOLE, GENERATE
*ELSET,ELSET=RIGID
*ELSET,ELSET=ELBOW, GENERATE
*ELSET,ELSET=BRANCH, GENERATE
*ELSET,ELSET=BRANCH_CAP, GENERATE
*ELSET,ELSET=CAPPED_BRANCH, GENERATE
*ELSET,ELSET=SIDE_RUN, GENERATE
*ELSET,ELSET=SIDE_CAP, GENERATE
*ELSET,ELSET=CAPPED_SIDERUN, GENERATE
*ELSET,ELSET=BOT_RUN, GENERATE
*ELSET,ELSET=BOT_CAP, GENERATE
*ELSET,ELSET=CAPPED_BOTRUN, GENERATE
*ELSET,ELSET=REINPLT
*ELSET,ELSET=RESTRAINTS, GENERATE
*ELSET,ELSET=PRESSURE_ELE, GENERATE
*ELSET,ELSET=SECT, GENERATE
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=ACCL_ELM
 THK_25,
*BOUNDARY,OP=NEW
      8938,  1, 6,      0.00000E+00
      9370,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + Bxp
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*CLOAD,OP=NEW
**       9985,    4, 5.388E+04
**       9985,    5, 9.736E+04
       9985,    6,-1.074E+04
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

shell_mt_branch_16x10_m1.inp

```
**%   ============================================================
**%
**%              I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\mod2_unlisted_last5.mf1
**%          INPUT FILE: si_mt_ubranch_mxp.inp
**%            EXPORTED: AT 18:19:52 ON 20-Aug-08
**%                PART: mod26
**%                 FEM: si_ubranch26
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:**	09/30/08	**Checker:**	A. S. Siahpush	**Date:**	09/30/08

```
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  20-Aug-08   18:19:52
**%========================================
**%          MODAL DATA
**%========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=RESNDS
*NSET,NSET=ANGNDS
*NSET,NSET=RESTRAINTS
*ELSET,ELSET=ALLELE, GENERATE
*ELSET,ELSET=TRANS_PLT, GENERATE
*ELSET,ELSET=ELBOW_HOLE, GENERATE
*ELSET,ELSET=RIGID
*ELSET,ELSET=ELBOW, GENERATE
*ELSET,ELSET=BRANCH, GENERATE
*ELSET,ELSET=BRANCH_CAP, GENERATE
*ELSET,ELSET=SIDE_RUN, GENERATE
*ELSET,ELSET=SIDE_CAP, GENERATE
*ELSET,ELSET=CAPPED_SIDERUN, GENERATE
*ELSET,ELSET=BOT_RUN, GENERATE
*ELSET,ELSET=BOT_CAP, GENERATE
*ELSET,ELSET=CAPPED_BOTRUN, GENERATE
*ELSET,ELSET=REINPLT
*ELSET,ELSET=RESTRAINTS, GENERATE
*ELSET,ELSET=PRESSURE_ELE, GENERATE
*ELSET,ELSET=SECT, GENERATE
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=ACCL_ELM
 THK_25,
*BOUNDARY,OP=NEW
      8938,  1, 6,       0.00000E+00
```

```
      9370,  1, 6,       0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,     P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + Bxp
*DLOAD,OP=NEW
BS000001,     P,-2.5300E+02
*CLOAD,OP=NEW
      9985,     4, 5.388E+04
**       9985,     5, 9.736E+04
**       9985,     6,-1.074E+04
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

shell_mt_branch_16x10_m2.inp

```
**%  ==============================================================
**%
**%           I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                  FOR ABAQUS VERSION 6.x
**%
**%         MODEL FILE: C:\DOCUME~1\dtclark\mod2_unlisted_last5.mf1
**%         INPUT FILE: si_mt_ubranch_mxp.inp
**%           EXPORTED: AT 18:19:52 ON 20-Aug-08
**%               PART: mod26
**%                FEM: si_ubranch26
**%
**%              UNITS: IN-Inch (pound f)
**%                  ... LENGTH : inch
**%                  ... TIME   : sec
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
**%                   ... MASS   : lbf-sec**2/in
**%                   ... FORCE  : pound (lbf)
**%                   ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  20-Aug-08   18:19:52
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=RESNDS
*NSET,NSET=ANGNDS
*NSET,NSET=RESTRAINTS
*ELSET,ELSET=ALLELE, GENERATE
*ELSET,ELSET=TRANS_PLT, GENERATE
*ELSET,ELSET=ELBOW_HOLE, GENERATE
*ELSET,ELSET=RIGID
*ELSET,ELSET=ELBOW, GENERATE
*ELSET,ELSET=BRANCH, GENERATE
*ELSET,ELSET=BRANCH_CAP, GENERATE
*ELSET,ELSET=CAPPED_BRANCH, GENERATE
*ELSET,ELSET=SIDE_RUN, GENERATE
*ELSET,ELSET=SIDE_CAP, GENERATE
*ELSET,ELSET=CAPPED_SIDERUN, GENERATE
*ELSET,ELSET=BOT_RUN, GENERATE
*ELSET,ELSET=BOT_CAP, GENERATE
```

```
*ELSET,ELSET=CAPPED_BOTRUN, GENERATE
*ELSET,ELSET=REINPLT
*ELSET,ELSET=RESTRAINTS, GENERATE
*ELSET,ELSET=PRESSURE_ELE, GENERATE
*ELSET,ELSET=SECT, GENERATE
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=ACCL_ELM
 THK_25,
*BOUNDARY,OP=NEW
      8938,  1, 6,      0.00000E+00
      9370,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + Bxp
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*CLOAD,OP=NEW
**       9985,    4, 5.388E+04
      9985,    5, 9.736E+04
**       9985,    6,-1.074E+04
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

shell_mt_branch_16x10_m3.inp

```
**%   ============================================================
**%
**%                I-DEAS 12M1 ABAQUS STANDARD TRANSLATOR
**%                       FOR ABAQUS VERSION 6.x
```

```
**%
**%          MODEL FILE: C:\DOCUME~1\dtclark\mod2_unlisted_last5.mf1
**%          INPUT FILE: si_mt_ubranch_mxp.inp
**%            EXPORTED: AT 18:19:52 ON 20-Aug-08
**%                PART: mod26
**%                 FEM: si_ubranch26
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  20-Aug-08   18:19:52
**%========================================
**%          MODAL DATA
**%========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4       , ELSET=THK_25
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=RESNDS
*NSET,NSET=ANGNDS
*NSET,NSET=RESTRAINTS
*ELSET,ELSET=ALLELE, GENERATE
*ELSET,ELSET=TRANS_PLT, GENERATE
*ELSET,ELSET=ELBOW_HOLE, GENERATE
```

```
*ELSET,ELSET=RIGID
*ELSET,ELSET=ELBOW, GENERATE
*ELSET,ELSET=BRANCH, GENERATE
*ELSET,ELSET=BRANCH_CAP, GENERATE
*ELSET,ELSET=CAPPED_BRANCH, GENERATE
*ELSET,ELSET=SIDE_RUN, GENERATE
*ELSET,ELSET=SIDE_CAP, GENERATE
*ELSET,ELSET=CAPPED_SIDERUN, GENERATE
*ELSET,ELSET=BOT_RUN, GENERATE
*ELSET,ELSET=BOT_CAP, GENERATE
*ELSET,ELSET=CAPPED_BOTRUN, GENERATE
*ELSET,ELSET=REINPLT
*ELSET,ELSET=RESTRAINTS, GENERATE
*ELSET,ELSET=PRESSURE_ELE, GENERATE
*ELSET,ELSET=SECT, GENERATE
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=ACCL_ELM
 THK_25,
*BOUNDARY,OP=NEW
      8938,  1, 6,      0.00000E+00
      9370,  1, 6,      0.00000E+00
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
**%
**%
**% ====== STEP NUMBER   2 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + Bxp
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*CLOAD,OP=NEW
**       9985,    4, 5.388E+04
**       9985,    5, 9.736E+04
      9985,    6,-1.074E+04
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
```

```
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
S
*END STEP
```

check_beam_mt_16x10_m3.inp

```
**%   ============================================================
**%
**%             NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                    FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE:
C:\pcs\pcs2\model_(26)\elbow_branch_16x10\m256_beam_branch.mf1
**%          INPUT FILE:
C:\pcs\pcs2\model_(26)\elbow_branch_16x10\check_beam_mt_branch_16x10_m3.inp
**%            EXPORTED: AT 13:09:03 ON 24-Sep-08
**%                PART: Part1
**%                 FEM: Fem2
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  24-Sep-08   13:09:03
**%========================================
**%          MODAL DATA
**%========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
*ELEMENT, TYPE=B31     , ELSET=PIPE_3
*ELEMENT, TYPE=B32     , ELSET=ELBOW
**%
**% I-DEAS BEAM CROSS SECTION: PIPE16_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_16X025 ,
 ELSET=PIPE,
 SECTION=PIPE
 0.80000E+01, 0.25000E+00
```

```
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_16X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE16_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_16X025 ,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.80000E+01, 0.25000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE10_75X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_10X025 ,
 ELSET=PIPE_2,
 SECTION=PIPE
 0.53750E+01, 0.25000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_10X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.66000E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: JE10_BEAM
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_3,
 DENSITY= 0.16600E-02,
 ZERO= 0.00000E+00
 0.82467E+01, 0.11371E+03, 0.00000E+00, 0.11371E+03, 0.10374E+03, 0, 0.00000E+00
-0.99636E+00, 0.00000E+00,-0.85150E-01
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: FAB_BRANCH16_0X0_25LR24P253
**%
```

```
*BEAM GENERAL SECTION,
 ELSET=ELBOW ,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.25207E+02, 0.00000E+00, 0.25207E+02, 0.76730E+03, 0, 0.00000E+00
 0.00000E+00,-0.10000E+01, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE,
 PIPE_1,
 PIPE_2,
 PIPE_3,
 ELBOW ,
**%
**%
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION TOTAL
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
        181,  1, 6,      0.00000E+00
        851,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
**       1138,    4, 5.3880E+04
**       1138,    5, 9.7360E+04
       1138,    6,-1.0740E+04
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*END STEP
```

branch_beam_16x10_ST_1.inp

```
**%  ============================================================
**%
**%             NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                    FOR ABAQUS VERSION 6.x
**%
**%         MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_elbow_16x10.mf1
```

```
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_elbow_16x10\input\branch_16x10_ST_1.inp
**%            EXPORTED: AT 18:13:03 ON 27-Sep-08
**%                PART: Part1
**%                 FEM: Fem1
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%        COORDINATE SYSTEM: PART
**%
**%            SUBSET EXPORT: OFF
**%
**%      NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  27-Sep-08   18:13:03
**%========================================
**%          MODAL DATA
**%========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31      , ELSET=PIPE
*ELEMENT, TYPE=B31      , ELSET=PIPE_1
*ELEMENT, TYPE=B31      , ELSET=PIPE_2
*ELEMENT, TYPE=B31      , ELSET=PIPE_3
*ELEMENT, TYPE=B32      , ELSET=ELBOW
**%
**% I-DEAS BEAM CROSS SECTION: PIPE16_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_16X025 ,
 ELSET=PIPE,
 SECTION=PIPE
 0.80000E+01, 0.25000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_16X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE16_0X0_25
**%
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:** 09/30/08	**Checker:** A. S. Siahpush	**Date:**	09/30/08

```
*BEAM SECTION,
 MATERIAL=SST304_16X025 ,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.80000E+01, 0.25000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE10_75X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_10X025 ,
 ELSET=PIPE_2,
 SECTION=PIPE
 0.53750E+01, 0.25000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_10X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.66000E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: BR_16X10_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_3,
 DENSITY= 0.16600E-02,
 ZERO= 0.00000E+00
 0.82470E+01, 0.11371E+03, 0.00000E+00, 0.11371E+03, 0.10374E+03, 0, 0.00000E+00
-0.99636E+00, 0.00000E+00,-0.85150E-01
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: FAB_BRANCH16_0X0_25LR24P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW ,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.25207E+02, 0.00000E+00, 0.25207E+02, 0.76730E+03, 0, 0.00000E+00
 0.00000E+00,-0.10000E+01, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
*ELSET, ELSET=ALLELEMENTS
```

```
 PIPE,
 PIPE_1,
 PIPE_2,
 PIPE_3,
 ELBOW ,
**%
*NSET,NSET=OUT
181,851,1138
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       181,  1, 6,      0.00000E+00
       851,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
      1138,    4, 8.114E+4
**      1138,    5, 7.96E+4
**      1138,    6, -1.049E+4
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=893, DOF=1
*END STEP
```

branch_beam_16x10_ST_2.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_elbow_16x10.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_elbow_16x10\input\branch_16x10_ST_1.inp
**%            EXPORTED: AT 18:13:03 ON 27-Sep-08
**%                PART: Part1
**%                 FEM: Fem1
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
```

```
**%                        ... MASS     : lbf-sec**2/in
**%                        ... FORCE    : pound (lbf)
**%                        ... TEMPERATURE : deg Fahrenheit
**%
**%          COORDINATE SYSTEM: PART
**%
**%              SUBSET EXPORT: OFF
**%
**%        NODE ZERO TOLERANCE: OFF
**%
**% .  ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  27-Sep-08   18:13:03
**%========================================
**%          MODAL DATA
**%========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
*ELEMENT, TYPE=B31     , ELSET=PIPE_3
*ELEMENT, TYPE=B32     , ELSET=ELBOW
**%
**% I-DEAS BEAM CROSS SECTION: PIPE16_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_16X025 ,
 ELSET=PIPE,
 SECTION=PIPE
 0.80000E+01, 0.25000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_16X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE16_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_16X025 ,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.80000E+01, 0.25000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE10_75X0_25
**%
```

```
*BEAM SECTION,
 MATERIAL=SST304_10X025 ,
 ELSET=PIPE_2,
 SECTION=PIPE
 0.53750E+01, 0.25000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_10X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.66000E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: BR_16X10_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_3,
 DENSITY= 0.16600E-02,
 ZERO= 0.00000E+00
 0.82470E+01, 0.11371E+03, 0.00000E+00, 0.11371E+03, 0.10374E+03, 0, 0.00000E+00
-0.99636E+00, 0.00000E+00,-0.85150E-01
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: FAB_BRANCH16_0X0_25LR24P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW ,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.25207E+02, 0.00000E+00, 0.25207E+02, 0.76730E+03, 0, 0.00000E+00
 0.00000E+00,-0.10000E+01, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE,
 PIPE_1,
 PIPE_2,
 PIPE_3,
 ELBOW ,
**%
*NSET,NSET=OUT
181,851,1138
**%
```

```
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
        181,  1, 6,       0.00000E+00
        851,  1, 6,       0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
**        1138,     4, 8.114E+4
       1138,     5, 7.96E+4
**        1138,     6, -1.049E+4
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=893, DOF=1
*END STEP
```

branch_beam_16x10_ST_3.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_elbow_16x10.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_elbow_16x10\input\branch_16x10_ST_1.inp
**%            EXPORTED: AT 18:13:03 ON 27-Sep-08
**%                PART: Part1
**%                 FEM: Fem1
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
```

```
**%
**%   ===========================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  27-Sep-08   18:13:03
**%=========================================
**%          MODAL DATA
**%=========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
*ELEMENT, TYPE=B31     , ELSET=PIPE_3
*ELEMENT, TYPE=B32     , ELSET=ELBOW
**%
**% I-DEAS BEAM CROSS SECTION: PIPE16_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_16X025 ,
 ELSET=PIPE,
 SECTION=PIPE
 0.80000E+01, 0.25000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_16X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE16_0X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_16X025 ,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.80000E+01, 0.25000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
**%
**% I-DEAS BEAM CROSS SECTION: PIPE10_75X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_10X025 ,
 ELSET=PIPE_2,
 SECTION=PIPE
 0.53750E+01, 0.25000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_10X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
*DENSITY
 1.66000E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: BR_16X10_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_3,
 DENSITY= 0.16600E-02,
 ZERO= 0.00000E+00
 0.82470E+01, 0.11371E+03, 0.00000E+00, 0.11371E+03, 0.10374E+03, 0, 0.00000E+00
-0.99636E+00, 0.00000E+00,-0.85150E-01
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: FAB_BRANCH16_0X0_25LR24P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW ,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.25207E+02, 0.00000E+00, 0.25207E+02, 0.76730E+03, 0, 0.00000E+00
 0.00000E+00,-0.10000E+01, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE,
 PIPE_1,
 PIPE_2,
 PIPE_3,
 ELBOW ,
**%
*NSET,NSET=OUT
181,851,1138
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
        181,  1, 6,      0.00000E+00
```

```
       851,  1, 6,       0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
**        1138,     4, 8.114E+4
**        1138,     5, 7.96E+4
       1138,     6, -1.049E+4
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=893, DOF=1
*END STEP
```

branch_16x10_ST_1.inp

```
**%   ============================================================
**%
**%             NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                    FOR ABAQUS VERSION 6.x
**%
**%         MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_elbow_16x10.mf1
**%         INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_elbow_16x10\input\branch_16x10_1.inp
**%           EXPORTED: AT 18:05:27 ON 26-Sep-08
**%               PART: mod26
**%                FEM: Fem1
**%
**%              UNITS: IN-Inch (pound f)
**%                    ... LENGTH : inch
**%                    ... TIME   : sec
**%                    ... MASS   : lbf-sec**2/in
**%                    ... FORCE  : pound (lbf)
**%                    ... TEMPERATURE : deg Fahrenheit
**%
**%        COORDINATE SYSTEM: PART
**%
**%            SUBSET EXPORT: OFF
**%
**%      NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Sep-08   18:05:27
**%============================================
**%         MODAL DATA
**%============================================
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=ALL, GENERATE
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=RUN, GENERATE
*ELSET,ELSET=STIFFENER
*ELSET,ELSET=BRANCH, GENERATE
*ELSET,ELSET=ENDS, GENERATE
**%
*ELSET, ELSET=BS000001, GENERATE
*NSET,NSET=OUT
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.01
 0.005,1.0,1.0E-08,1.0
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
15000, 1, 6, 0.00000E+00
15001, 1, 6, 0.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
```

```
 RF,U
*MONITOR, NODE=259, DOF=1
*END STEP
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  PRESSURE_MX
*CLOAD,OP=NEW
      15002,    4, 8.114E+4
**      15002,    5, 7.96E+4
**      15002,    6, -1.049E+4
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=259, DOF=1
*END STEP
```

branch_16x10_ST_2.inp

```
**%  ============================================================
**%
**%            NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                   FOR ABAQUS VERSION 6.x
**%
**%        MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_elbow_16x10.mf1
**%        INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_elbow_16x10\input\branch_16x10_1.inp
**%          EXPORTED: AT 18:05:27 ON 26-Sep-08
**%              PART: mod26
**%               FEM: Fem1
**%
**%             UNITS: IN-Inch (pound f)
**%                   ... LENGTH : inch
**%                   ... TIME   : sec
**%                   ... MASS   : lbf-sec**2/in
**%                   ... FORCE  : pound (lbf)
**%                   ... TEMPERATURE : deg Fahrenheit
**%
**%       COORDINATE SYSTEM: PART
**%
**%           SUBSET EXPORT: OFF
**%
```

```
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Sep-08   18:05:27
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=ALL, GENERATE
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=RUN, GENERATE
*ELSET,ELSET=STIFFENER
*ELSET,ELSET=BRANCH, GENERATE
*ELSET,ELSET=ENDS, GENERATE
**%
*ELSET, ELSET=BS000001, GENERATE
*NSET,NSET=OUT
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.01
 0.005,1.0,1.0E-08,1.0
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
15000, 1, 6, 0.00000E+00
15001, 1, 6, 0.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
```

```
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=259, DOF=1
*END STEP
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  PRESSURE_MX
*CLOAD,OP=NEW
**       15002,     4, 8.114E+4
       15002,     5, 7.96E+4
**       15002,     6, -1.049E+4
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=259, DOF=1
*END STEP
```

branch_16x10_ST_3.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Unlisted_elbow_16x10.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Unlisted_elbow_16x10\input\branch_16x10_1.inp
**%            EXPORTED: AT 18:05:27 ON 26-Sep-08
**%                PART: mod26
**%                 FEM: Fem1
**%
**%               UNITS: IN-Inch (pound f)
```

```
**%                        ... LENGTH : inch
**%                        ... TIME   : sec
**%                        ... MASS   : lbf-sec**2/in
**%                        ... FORCE  : pound (lbf)
**%                        ... TEMPERATURE : deg Fahrenheit
**%
**%          COORDINATE SYSTEM: PART
**%
**%              SUBSET EXPORT: OFF
**%
**%        NODE ZERO TOLERANCE: OFF
**%
**%    ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  26-Sep-08   18:05:27
**%=========================================
**%           MODAL DATA
**%=========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_25
*MPC
*SHELL SECTION,
 ELSET=THK_25,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  2.50000E-01,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
*DAMPING, ALPHA=0.4295, BETA=2.894E-3
**%
*ELSET, ELSET=ALLELEMENTS
 THK_25,
**%
*NSET,NSET=ALL, GENERATE
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=RUN, GENERATE
*ELSET,ELSET=STIFFENER
*ELSET,ELSET=BRANCH, GENERATE
*ELSET,ELSET=ENDS, GENERATE
**%
*ELSET, ELSET=BS000001, GENERATE
*NSET,NSET=OUT
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
```

```
*STATIC, STABILIZE, FACTOR=0.01
 0.005,1.0,1.0E-08,1.0
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
15000, 1, 6, 0.00000E+00
15001, 1, 6, 0.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
BS000001,     P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=259, DOF=1
*END STEP
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  PRESSURE_MX
*CLOAD,OP=NEW
**        15002,     4, 8.114E+4
**        15002,     5, 7.96E+4
       15002,     6, -1.049E+4
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=259, DOF=1
*END STEP
```

beam_mt_cap_m1.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
```

```
**%                    FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\pcs\pcs2\model_(26)\ff_cap_shell_beam\m256_beam_cap.mfl
**%          INPUT FILE:
C:\pcs\pcs2\model_(26)\ff_cap_shell_beam\beam_mt_cap_m1.inp
**%            EXPORTED: AT 19:11:24 ON 23-Sep-08
**%                PART: Part1
**%                 FEM: Fem1
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%    ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  23-Sep-08   19:11:24
**%========================================
**%          MODAL DATA
**%========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
*ELEMENT, TYPE=B32     , ELSET=ELBOW
**%
**% I-DEAS BEAM CROSS SECTION: FABREDUCER30_0TO10_75
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE,
 DENSITY= 0.22500E-02,
 ZERO= 0.00000E+00
 0.82470E+01, 0.13444E+02, 0.00000E+00, 0.13444E+02, 0.26888E+02, 0, 0.00000E+00
 0.00000E+00, 0.10000E+01, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE10_75X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_10X025 ,
```

```
 ELSET=PIPE_1,
 SECTION=PIPE
 0.53750E+01, 0.25000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_10X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.66000E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_438
**%
*BEAM SECTION,
 MATERIAL=SST304_B30X0438_R ,
 ELSET=PIPE_2,
 SECTION=PIPE
 0.15000E+02, 0.43800E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_B30X0438_R
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.25500E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW10_75X0_25LR15P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW ,
 DENSITY= 0.16600E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.10254E+02, 0.00000E+00, 0.10254E+02, 0.22740E+03, 0, 0.00000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE,
 PIPE_1,
 PIPE_2,
 ELBOW ,
**%
*NSET,NSET=ALL
      26,      63,     224,     225,     226,     758
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:** 09/30/08	**Checker:** A. S. Siahpush	**Date:**	09/30/08

```
*NSET,NSET=LINE_17
      26,       63,      224,      225
*NSET,NSET=LINES_43_47
     224,      225,      226,      758
*NSET,NSET=UNLIST_COMPS
      26,       63,      224,      225,      226
*ELSET,ELSET=ALL
      78,      166,      167,      516
*ELSET,ELSET=LINE_17
      78,      166,      167
*ELSET,ELSET=LINES_43_47
     167,      516
*ELSET,ELSET=UNLIST_COMPS
      78,      166,      167,      516
**%
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION TOTAL
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
        26,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
       226,    4, 9.5160E+04
**        226,    5, 1.3150E+05
**        226,    6,-5.0640E+04
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*END STEP
```

beam_mt_cap_m2.inp

```
**%   ===========================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\pcs\pcs2\model_(26)\ff_cap_shell_beam\m256_beam_cap.mf1
**%          INPUT FILE:
C:\pcs\pcs2\model_(26)\ff_cap_shell_beam\beam_mt_cap_m1.inp
**%            EXPORTED: AT 19:11:24 ON 23-Sep-08
**%                PART: Part1
**%                 FEM: Fem1
**%
```

```
**%                UNITS: IN-Inch (pound f)
**%                       ... LENGTH : inch
**%                       ... TIME   : sec
**%                       ... MASS   : lbf-sec**2/in
**%                       ... FORCE  : pound (lbf)
**%                       ... TEMPERATURE : deg Fahrenheit
**%
**%          COORDINATE SYSTEM: PART
**%
**%              SUBSET EXPORT: OFF
**%
**%        NODE ZERO TOLERANCE: OFF
**%
**%    ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  23-Sep-08   19:11:24
**%============================================
**%          MODAL DATA
**%============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
*ELEMENT, TYPE=B32     , ELSET=ELBOW
**%
**% I-DEAS BEAM CROSS SECTION: FABREDUCER30_0TO10_75
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE,
 DENSITY= 0.22500E-02,
 ZERO= 0.00000E+00
 0.82470E+01, 0.13444E+02, 0.00000E+00, 0.13444E+02, 0.26888E+02, 0, 0.00000E+00
 0.00000E+00, 0.10000E+01, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE10_75X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_10X025 ,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.53750E+01, 0.25000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_10X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.66000E-03,
```

```
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_438
**%
*BEAM SECTION,
 MATERIAL=SST304_B30X0438_R ,
 ELSET=PIPE_2,
 SECTION=PIPE
 0.15000E+02, 0.43800E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_B30X0438_R
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.25500E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW10_75X0_25LR15P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW ,
 DENSITY= 0.16600E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.10254E+02, 0.00000E+00, 0.10254E+02, 0.22740E+03, 0, 0.00000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE,
 PIPE_1,
 PIPE_2,
 ELBOW ,
**%
*NSET,NSET=ALL
      26,      63,     224,     225,     226,     758
*NSET,NSET=LINE_17
      26,      63,     224,     225
*NSET,NSET=LINES_43_47
     224,     225,     226,     758
*NSET,NSET=UNLIST_COMPS
      26,      63,     224,     225,     226
*ELSET,ELSET=ALL
      78,     166,     167,     516
*ELSET,ELSET=LINE_17
```

```
      78,      166,      167
*ELSET,ELSET=LINES_43_47
     167,      516
*ELSET,ELSET=UNLIST_COMPS
      78,      166,      167,      516
**%
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION TOTAL
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
         26,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
**         226,    4, 9.5160E+04
        226,    5, 1.3150E+05
**         226,    6,-5.0640E+04
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*END STEP
```

beam_mt_cap_m3.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\pcs\pcs2\model_(26)\ff_cap_shell_beam\m256_beam_cap.mf1
**%          INPUT FILE:
C:\pcs\pcs2\model_(26)\ff_cap_shell_beam\beam_mt_cap_m1.inp
**%            EXPORTED: AT 19:11:24 ON 23-Sep-08
**%                PART: Part1
**%                 FEM: Fem1
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
```

```
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  23-Sep-08   19:11:24
**%============================================
**%          MODAL DATA
**%============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
*ELEMENT, TYPE=B32     , ELSET=ELBOW
**%
**% I-DEAS BEAM CROSS SECTION: FABREDUCER30_0TO10_75
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE,
 DENSITY= 0.22500E-02,
 ZERO= 0.00000E+00
 0.82470E+01, 0.13444E+02, 0.00000E+00, 0.13444E+02, 0.26888E+02, 0, 0.00000E+00
 0.00000E+00, 0.10000E+01, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE10_75X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_10X025 ,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.53750E+01, 0.25000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_10X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.66000E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_438
**%
*BEAM SECTION,
 MATERIAL=SST304_B30X0438_R ,
```

```
 ELSET=PIPE_2,
 SECTION=PIPE
 0.15000E+02, 0.43800E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_B30X0438_R
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.25500E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW10_75X0_25LR15P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW ,
 DENSITY= 0.16600E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.10254E+02, 0.00000E+00, 0.10254E+02, 0.22740E+03, 0, 0.00000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE,
 PIPE_1,
 PIPE_2,
 ELBOW ,
**%
*NSET,NSET=ALL
      26,       63,      224,      225,      226,      758
*NSET,NSET=LINE_17
      26,       63,      224,      225
*NSET,NSET=LINES_43_47
     224,      225,      226,      758
*NSET,NSET=UNLIST_COMPS
      26,       63,      224,      225,      226
*ELSET,ELSET=ALL
      78,      166,      167,      516
*ELSET,ELSET=LINE_17
      78,      166,      167
*ELSET,ELSET=LINES_43_47
     167,      516
*ELSET,ELSET=UNLIST_COMPS
      78,      166,      167,      516
**%
**%
**% ====== STEP NUMBER   1 ======
**%
```

```
*STEP,INC=1000000,NLGEOM
*STATIC
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION TOTAL
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
         26,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
**        226,     4, 9.5160E+04
**        226,     5, 1.3150E+05
        226,    6,-5.0640E+04
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*END STEP
```

shell_mt_cap_ce_m1.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\pcs\pcs2\model_(26)\ff_cap_shell_beam\m256_cap.mf1
**%          INPUT FILE:
C:\pcs\pcs2\model_(26)\ff_cap_shell_beam\shell_mt_cap_ce_m1.inp
**%            EXPORTED: AT 17:20:00 ON 23-Sep-08
**%                PART: End cap continuum shell
**%                 FEM: Fem2
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  23-Sep-08   17:20:00
```

```
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL1
*ELEMENT, TYPE=SC8R    , ELSET=SOLID4
*MPC
*SHELL SECTION,
 ELSET=SHELL1,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  1.00000E+00,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
*SHELL SECTION, ELSET=SOLID4, MATERIAL=SST304_P
 5.0,
**%
**%
*ELSET, ELSET=ALLELEMENTS
**%
*NSET,NSET=SIDEPTS
*NSET,NSET=TOPPTS
*ELSET,ELSET=ALL, GENERATE
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=BS000002, GENERATE
**%
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      7180,  1, 6,      0.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
**%
```

```
**% ====== STEP NUMBER   2 ======
**
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      7180,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
      6901,    4, 9.5160E+04
**      6901,    5, 1.3150E+05
**      6901,    6,-5.0640E+04
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
```

shell_mt_cap_ce_m2.inp

```
**%   ============================================================
**%
**%               NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                      FOR ABAQUS VERSION 6.x
**%
**%           MODEL FILE: C:\pcs\pcs2\model_(26)\ff_cap_shell_beam\m256_cap.mf1
**%           INPUT FILE:
C:\pcs\pcs2\model_(26)\ff_cap_shell_beam\shell_mt_cap_ce_m1.inp
**%             EXPORTED: AT 17:20:00 ON 23-Sep-08
**%                 PART: End cap continuum shell
**%                  FEM: Fem2
**%
**%                UNITS: IN-Inch (pound f)
**%                      ... LENGTH : inch
**%                      ... TIME   : sec
**%                      ... MASS   : lbf-sec**2/in
**%                      ... FORCE  : pound (lbf)
**%                      ... TEMPERATURE : deg Fahrenheit
**%
**%          COORDINATE SYSTEM: PART
**%
**%              SUBSET EXPORT: OFF
**%
**%        NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  23-Sep-08   17:20:00
**%========================================
**%          MODAL DATA
**%========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL1
*ELEMENT, TYPE=SC8R    , ELSET=SOLID4
*MPC
*SHELL SECTION,
 ELSET=SHELL1,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  1.00000E+00,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
*SHELL SECTION, ELSET=SOLID4, MATERIAL=SST304_P
 5.0,
**%
**%
*ELSET, ELSET=ALLELEMENTS
 SOLID4,
 SHELL1,
**%
*NSET,NSET=SIDEPTS
*NSET,NSET=TOPPTS
*ELSET,ELSET=ALL, GENERATE
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=BS000002, GENERATE
**%
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      7180,  1, 6,      0.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
```

```
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      7180,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
**        6901,     4, 9.5160E+04
      6901,     5, 1.3150E+05
**        6901,     6,-5.0640E+04
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
```

shell_mt_cap_ce_m3.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\pcs\pcs2\model_(26)\ff_cap_shell_beam\m256_cap.mf1
**%          INPUT FILE:
C:\pcs\pcs2\model_(26)\ff_cap_shell_beam\shell_mt_cap_ce_m1.inp
**%            EXPORTED: AT 17:20:00 ON 23-Sep-08
**%                PART: End cap continuum shell
**%                 FEM: Fem2
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%        COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  23-Sep-08   17:20:00
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL1
*ELEMENT, TYPE=SC8R    , ELSET=SOLID4
*MPC
*SHELL SECTION,
 ELSET=SHELL1,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304_P
  1.00000E+00,
*MATERIAL,NAME=SST304_P
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
*SHELL SECTION, ELSET=SOLID4, MATERIAL=SST304_P
 5.0,
**%
**%
*ELSET, ELSET=ALLELEMENTS
**%
*NSET,NSET=SIDEPTS
*NSET,NSET=TOPPTS
*ELSET,ELSET=ALL, GENERATE
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=BS000002, GENERATE
**%
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      7180,  1, 6,      0.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P1, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
```

```
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
**%
**% ====== STEP NUMBER   2 ======
**
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,0.2
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      7180,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
**       6901,     4, 9.5160E+04
**       6901,     5, 1.3150E+05
      6901,     6,-5.0640E+04
*DLOAD,OP=NEW
BS000001,     P, 2.5300E+02
BS000002,    P1, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*END STEP
```

check_beam_mt_cap_m1.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\pcs\pcs2\model_(26)\ff_cap_shell_beam\m256_beam_cap.mf1
**%          INPUT FILE:
C:\pcs\pcs2\model_(26)\ff_cap_shell_beam\beam_mt_cap_m1.inp
**%            EXPORTED: AT 19:11:24 ON 23-Sep-08
**%                PART: Part1
**%                 FEM: Fem1
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%              SUBSET EXPORT: OFF
```

```
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  23-Sep-08   19:11:24
**%===========================================
**%          MODAL DATA
**%===========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
*ELEMENT, TYPE=B32     , ELSET=ELBOW
**%
**% I-DEAS BEAM CROSS SECTION: FABREDUCER30_0TO10_75
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE,
 DENSITY= 0.22500E-02,
 ZERO= 0.00000E+00
 0.82470E+01, 0.5546703E+02, 0.00000E+00, 0.5546703E+02, 0.34747141E+03, 0,
0.00000E+00
 0.00000E+00, 0.10000E+01, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE10_75X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_10X025 ,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.53750E+01, 0.25000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_10X025
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.66000E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_438
**%
*BEAM SECTION,
 MATERIAL=SST304_B30X0438_R ,
```

```
 ELSET=PIPE_2,
 SECTION=PIPE
 0.15000E+02, 0.43800E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_B30X0438_R
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.25500E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: ELBOW10_75X0_25LR15P253
**%
*BEAM GENERAL SECTION,
 ELSET=ELBOW ,
 DENSITY= 0.16600E-02,
 ZERO= 0.00000E+00
 0.27832E+02, 0.10254E+02, 0.00000E+00, 0.10254E+02, 0.22740E+03, 0, 0.00000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE,
 PIPE_1,
 PIPE_2,
 ELBOW ,
**%
*NSET,NSET=ALL
      26,       63,      224,      225,      226,      758
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**% ====== STEP NUMBER   1 ======
**%
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Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark **Date:** 09/30/08	**Checker:**	A. S. Siahpush	**Date:**	09/30/08

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**        226,    5, 1.3150E+05
**        226,    6,-5.0640E+04
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*ELEMENT OUTPUT, DIRECTIONS=YES
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*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
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check_beam_mt_cap_m3.inp

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**%                 FEM: Fem1
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  23-Sep-08   19:11:24
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**%========================================
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*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
*ELEMENT, TYPE=B32     , ELSET=ELBOW
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0.00000E+00
 0.00000E+00, 0.10000E+01, 0.00000E+00
 0.28000E+08, 0.10769E+08, 0.10000E-34
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 SECTION=PIPE
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 2.80000E+07,  3.00000E-01
*DENSITY
```

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 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
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 0.28000E+08, 0.10769E+08, 0.10000E-34
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*SHEAR CENTER
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 PIPE_1,
 PIPE_2,
 ELBOW ,
**%
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      26,      63,     224,     225
*NSET,NSET=LINES_43_47
     224,     225,     226,     758
*NSET,NSET=UNLIST_COMPS
      26,      63,     224,     225,     226
*ELSET,ELSET=ALL
      78,     166,     167,     516
*ELSET,ELSET=LINE_17
      78,     166,     167
*ELSET,ELSET=LINES_43_47
     167,     516
*ELSET,ELSET=UNLIST_COMPS
      78,     166,     167,     516
**%
**%
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**%
*STEP,INC=1000000,NLGEOM
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```

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**        226,    5, 1.3150E+05
      226,    6,-5.0640E+04
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 U,V,A,RF
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*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
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Appendix F.3
Unlisted Component Evaluations Associated with Model 14

Model 14 contains two unlisted components within its piping boundary.

The first unlisted component [5, Figure 20] is a lateral wye that is constructed from 24-in diameter x 1.0-in thick pipe (line 1-5L) that is welded at both ends forming a straight run and a branch section (line 1-2L) which intersects the run at a 45° angle [25], forming a branch connection. Opposite of the straight run, the nominal diameter 18-in schedule 20 (0.312-in wall) pipe is welded to a short spool piping piece followed by a 45° elbow of the same same dimensions [26]. The straight run is placed between nominal diameter 24-in schedule 20 (0.325-in wall) piping and reducer [26]. The wye (here after referred to as the unlisted branch connection) is fabricated from 304L stainless steel. Figure F.3-1 illustrates model 14's unlisted branch component, as viewed from the East side. There are two wyes, one on the East and West side of the reactor vessel.

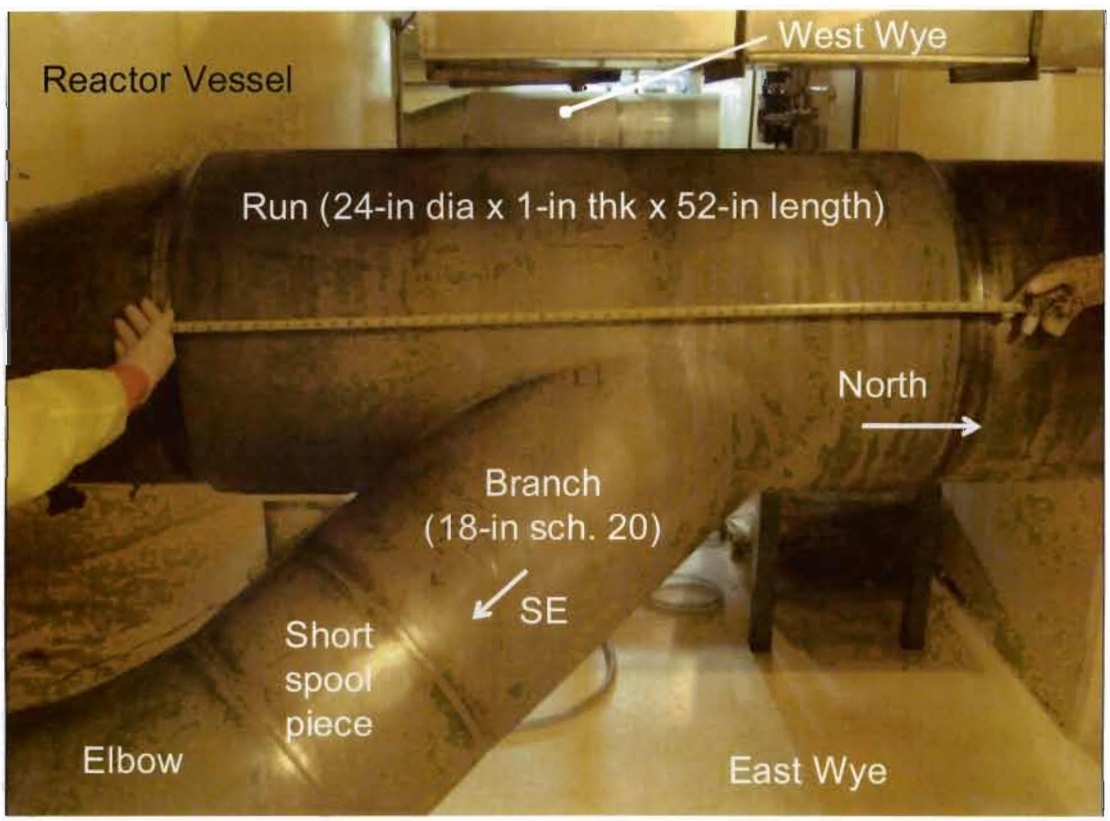

Figure F.3-1 – Model 14's unlisted branch component is shown, as viewed from the East side.

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The second unlisted component is a 36-in x 1/2-in wall elbow (line 1-7) [27] that has a 6-in schedule 40 (0.28-in) pipe (line 1-40) [28] that extends out the back radius rotated by 45° from the elbow plane. The elbow is reinforced to the branch with a 5/8-in thick pad [22]. Figure F.3-2 illustrates model 14's unlisted elbow/branch component, as viewed looking in the south direction between two Heat Exchangers. Figure.3-3 shows the unlisted elbow/branch component, as viewed from above. The unlisted elbow/branchcomponent is fabricated from 304 stainless steel materials.

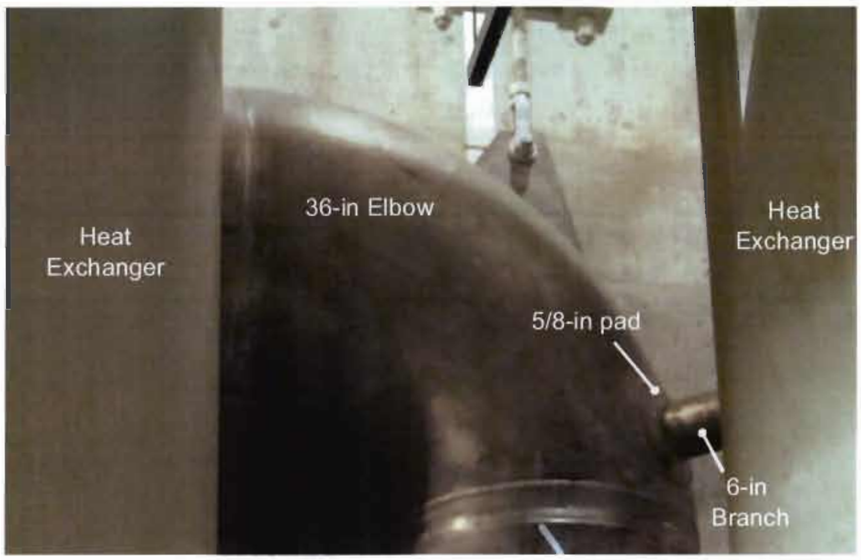

Figure F.3-2 – Model 14's unlisted elbow/branch component is shown, viewed looking South.

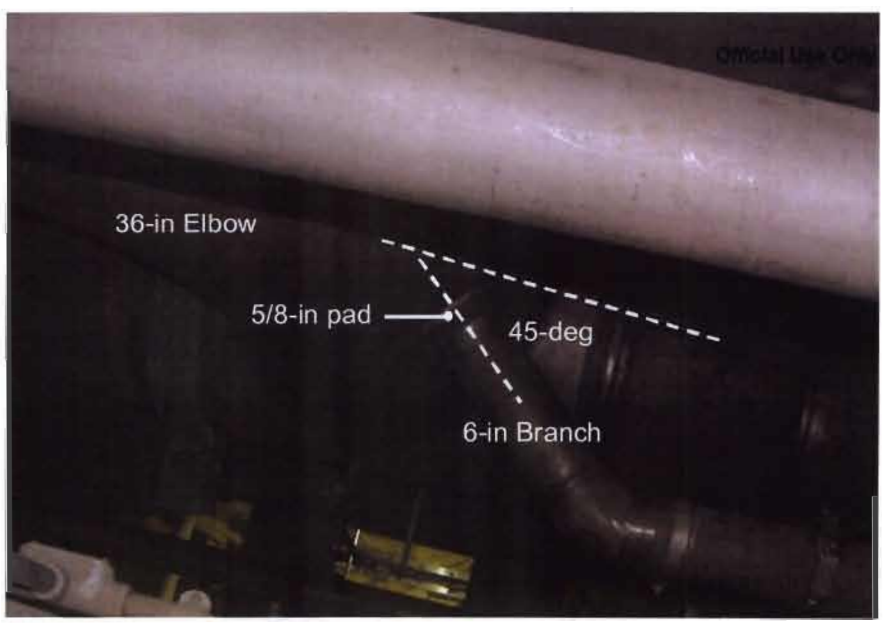

Figure F.3-3 – Model 14's unlisted elbow/branch component is shown, viewed from above.

The following sections (listed below) contain information used to evaluate Model 14's unlisted branch and elbow/branch components.

Contents　　　　Page

F.3.1 – FE Model Description of Unlisted Branch Component

Model 14's unlisted branch component was solid-modeled and meshed within I-DEAS Master Series, Simulation, Version 12 [9]. With the meshing complete, input files were written for ABAQUS [10]. Final editing of the input files was performed in a text editor and then solution runs were performed with ABAQUS Standard, Version 6.7-5. Results of the FE models are displayed with ABAQUS Viewer, Version 6.7-5, and are shown in Appendix F.3.2.

The unlisted branch component was meshed primarily with four-node quadrilateral elements and some rigid beam elements. The quadrilateral elements support six degrees of freedom (3-translations, 3 rotations) at each node and were used to model the 24-in straight run and 18-in branch. End caps for each opening of the unlisted branch component were as an aid in defining boundary conditions (i.e., applying loads and defining restraints) to the meshed unlisted branch component. Figures F.3.1-1 through F.3.1-3 illustrates the unlisted branch component as meshed with the quadrilateral elements. Table F.3.1-1 correlates element color to member name and thickness.

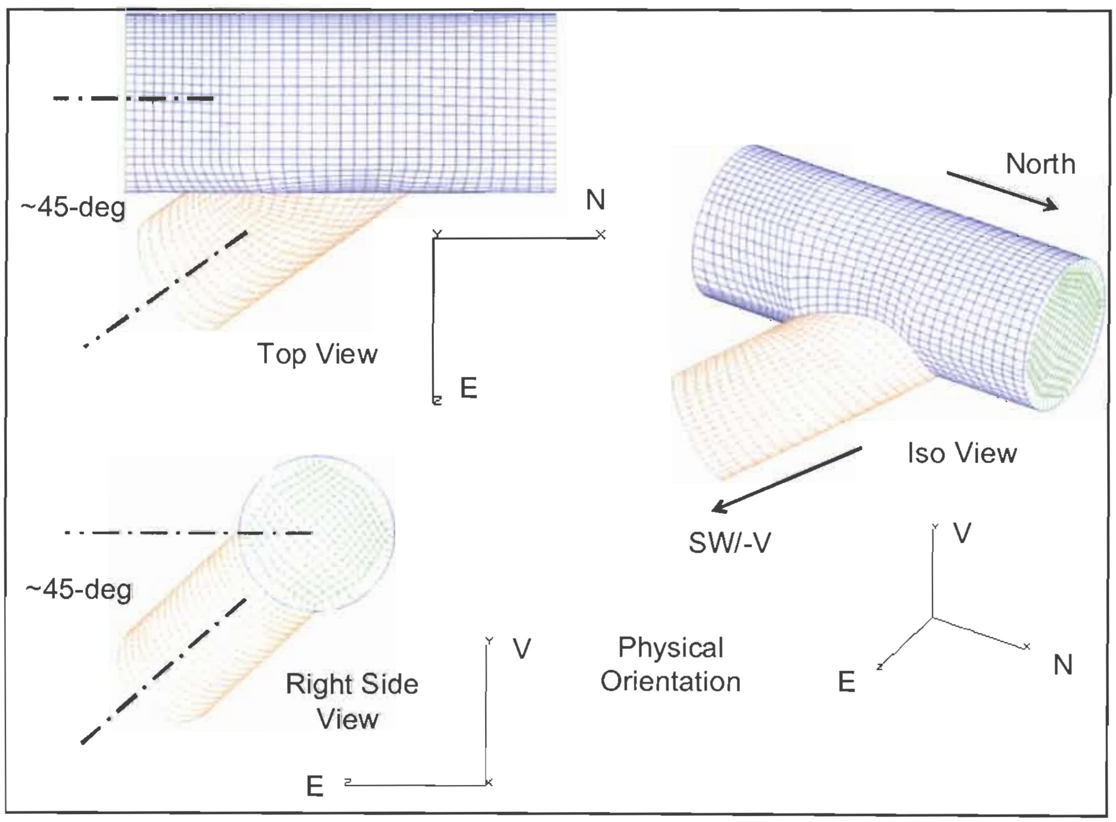

Figure F.3.1-1 – Quadrilateral shell mesh of 14 model's unlisted branch component is shown.

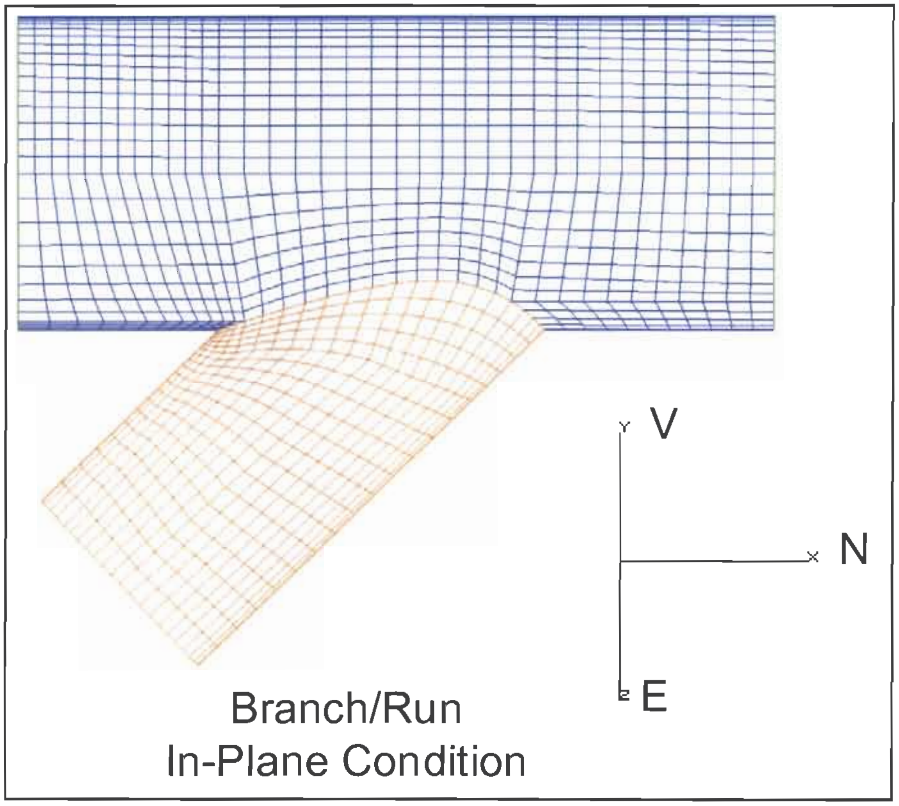

Figure F.3.1-2 – In-plane view of unlisted branch component.

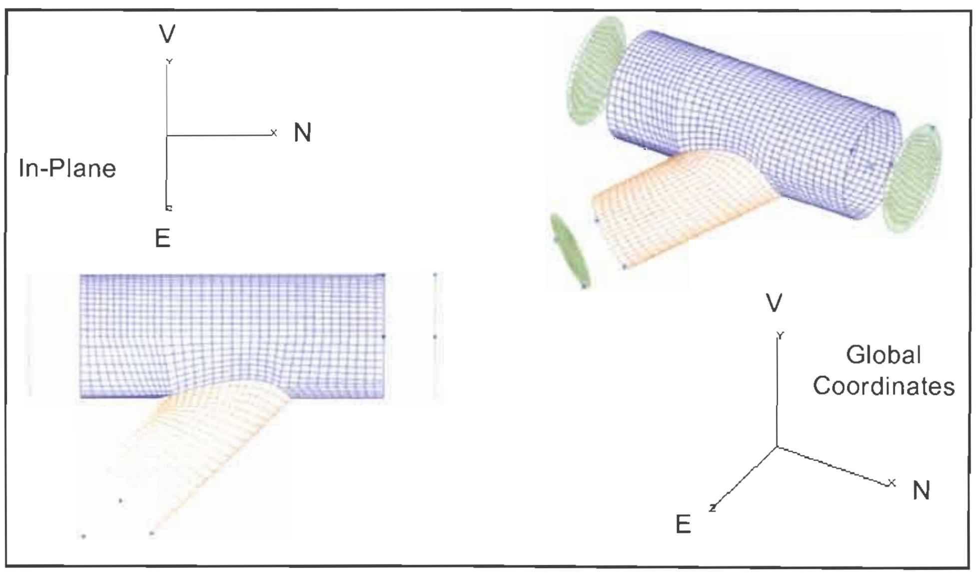

Figure F.3.1-3 – Isometric and in-plane views of unlisted branch component showing member meshes.

Table F.3.1-1 – Mesh color, thickness, and component member correlation.

Member Name	**Mesh Color(s)**	**Element Thickness**
Run (28-in Pipe)	Dark Blue	1.0-in
Branch (18-in Pipe)	Orange	Schedule 20 (0.28-in)
*Run/Branch Ends	Dark Greene	(0.28-in)

*These component members were used as an aid to apply boundary conditions to unlisted branch..

The unlisted branch component is fabricated with 304L stainless steel [27] and operates at 167°F while maintaining a constant internal gauge pressure of 272-psi [11, Section 7.1]. Material properties of the unlisted branch component are shown in Table F.3.1 (retrieved from Table 1 of report's main body).

Table F.3.1-2 – 304L Stainless Steel Material Properties at 167°F.

Symbol	**Property Value**	**Property Description**
μ	0.30 in/in	Poisson's Ration [1, Section NB-3683.1(b)]
E	27.7E+6	Modulus of Elasticity [12, Table TM]
Sy	22.26 ksi	Material Yield Strength [12, Table Y-1]
Sm	16.7 ksi	Maximum allowable Stress Intensity [12, Table 2A]

FE Boundary Conditions

A total of four (4) ABAQUS solution runs were used to determine the unlisted branch component's preliminary stress indices (SI) values. Determination of the stress indices for the unlisted branch component, uses four boundary conditions. Due to unlisted branch component's symmetry, stress indicies are determined by in-plane and out-of-plane bending moments placed on branch and North run ends. Torsion about axis of branch and run are enveloped by bend loading and hence, are not performed.

The unlisted branch component's flexibility factor closely approximates a listed component, but has a 45° angle between the branch axis and the run axis where a minimum of 60° is specified [1, NB-3643.1 (e)]. Exceptions to the angle rule is given, such that the angle may be smaller provided that a reinforment plate meets specified weld requirements [1, NB-3643.2(b)]. The unlisted branch, in this case, does not have a reinforcement plate, but has a fully-penetrating weld that attaches to a straight run – which acts like a reinforcement plate that is 3.2 times thicker than the branch. Thus, based on this reasoning, the flexibility factor for the unlisted branch is provided for that of a listed branch, already computed and used for the piping beam model..

SI Models & Boundary Conditions

One FE model mesh was used to determine stress indices for the unlisted branch component. The model mesh (shown in Figure F.3.1-4) reflects boundary condition 1 and indicates how restraints and applied moments are placed on the unlisted branch component mesh. A second boundary condition applies an out-of-plane bending on the branch end. The picture on the left shows a hidden line removal view of the unlisted branch. The picture on the right shows a better view of the unlisted branch model's restraints and applied moment, with the hidden line remove featues turned off. The third and fourth stress indice boundary conditions are similar to the branch end loading, but with similar loading placed on the run's north end shown in Figure 3.1-5. Table F.3.1-3 summaries the boundary condition placed on the four SI solution models. A brief listing (without nodal and element definitions) of each ABAQUS boundary condition model is reprinted in Appendix F.3.7

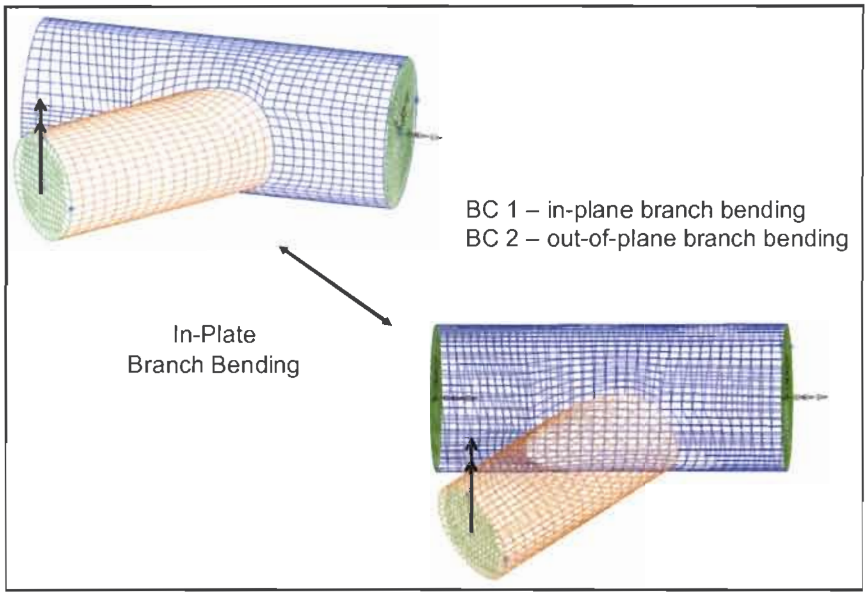

Figure F.3.1-4 – Isometric view of SI unlisted branch model mesh showing first (branch in-plane) applied boundary condition.

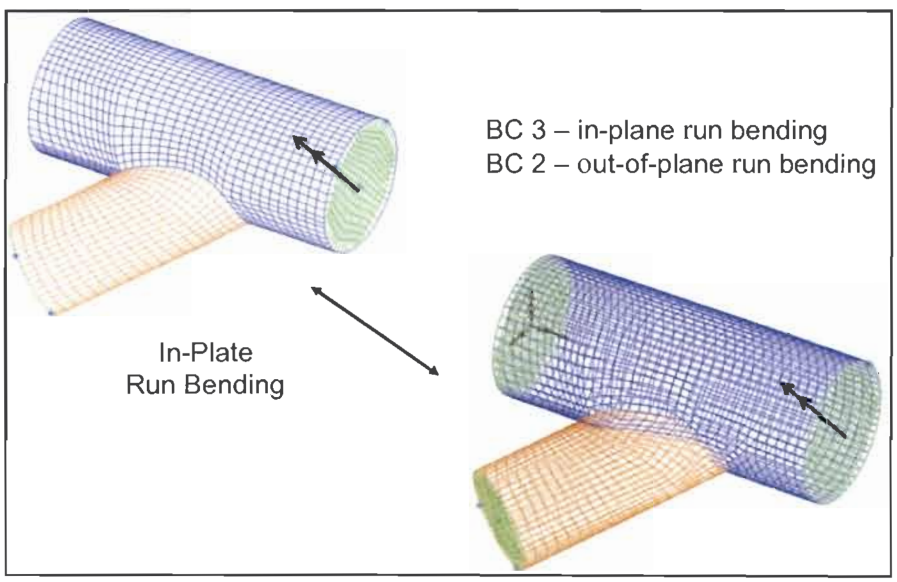

Figure F.3.1-5 – Isometric view of SI unlisted branch model mesh showing third (run in-plane) applied boundary condition.

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Applied moments were extracted from a preliminary set of 32 pilot model's piping system runs (Appendix D), in which the 80 percentile run pertaining to corresponding moments incurred within the unlisted branch component final set are identified. Figure F.3.1-6 shows a representation of corresponding system beam nodes in which nodal moments are extracted.

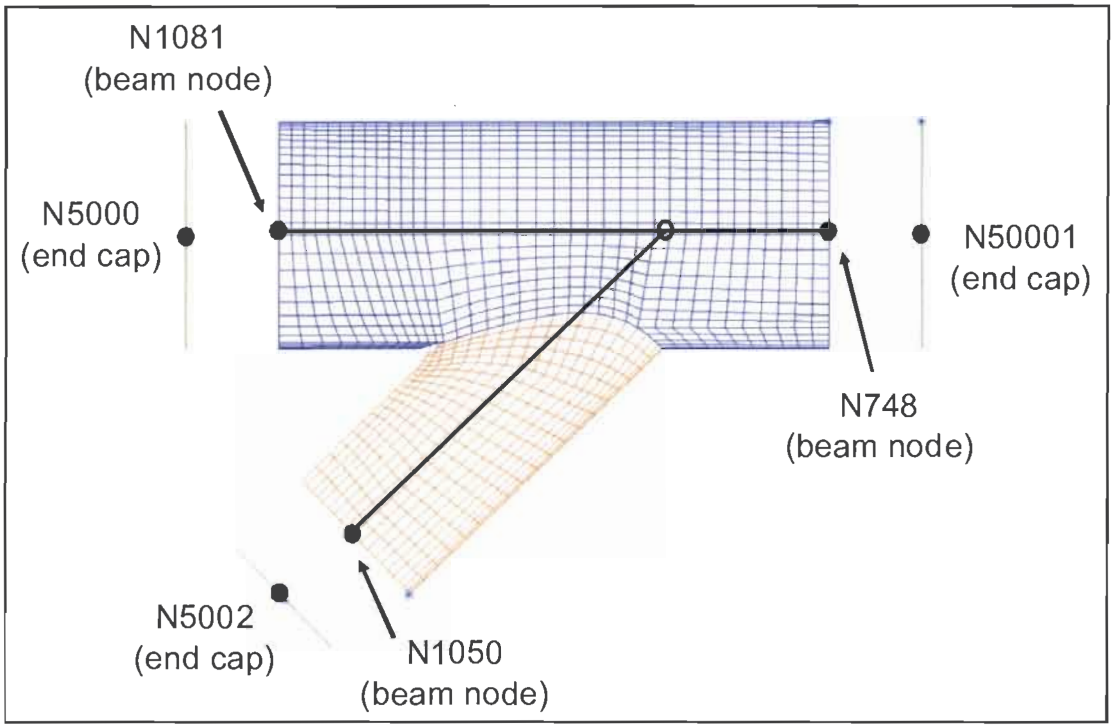

Figure F.3.1-6 – Corresponding nodes in which moments are extracted for 80 percentile run.

As can be seen in figure F.3.1-6, moments (Mx, My, Mz) extracted at node 1050 correspond to the branch end cap (node 5000) and moments (Mx, My, Mz) extracted at nodes N5000 and N5001 correspond to the run end caps. Table F.3.1-3 lists the nodal moment values extracted from a preliminary 80 percentile run at these nodes that were used for scoping stress indices calculations.

Table F.3.1-3 – Unlisted branch component's global coordinate stress indices moment extractions.

Node Number	MX (in*lbf)	MY (in*lbf)	MZ (in*lbf)
N1050 (branch)	-2.886E+4	3.752E+4	8.636E+4
N748 (N-run)	-9.171E+3	2.302E+5	-2.587E+5
N1081 (S-run)	6.274E+4	-2.804E+5	4.737E+4

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From Table F.3.1-3, in-plane and out-of-plane bending moments are in global coordinates. Applied moments must be scaled to be in-plane (and out-of-plane) for application to the unlisted branch component. This moment reaction global coordinate to in-plane scaling is performed in Appendix F.3.3. Table F.3.1-4 summaries boundary conditions, including in-plane (and out-of-plane) applied moments placed on the four SI solution runs and also identifies corresponding ABAQUS models. A brief listing (without nodal and element definitions) of each SI ABAQUS model file is reprinted in Appendix F.2.6.

Table F.3.1-4 – SI Boundary Conditions.

ABAQUS Model (Appendix F.3.7)	**Restraint Set Degrees of Freedom (DOF)**	**Applied Loads (IP – internal pressure) (Mx, My, Mz – applied moments)**
si_mt_branch_ip.inp	BC-1 N5000 & N5001 – 6 dof fixed: (X, Y, Z, RX, RY, RZ)	IP = 272 psi N5002: Mx = +0 in*lbf ⇨ My=+7.1872E+4 in*lbf ⇨ Mz=+6.7328E+4 in*lbf
si_mt_branch_op.inp	BC-2 " "	" " N5002: Mx = +6.8182E+4 in*lbf ⇨ My=-4.8584E+4 in*lbf ⇨ Mz=+5.1861E+4 in*lbf
si_mt_nrun_ip.inp	BC-3 N5000 – 6 dof fixed: (X, Y, Z, RX, RY, RZ)	IP = 272 psi N5001: Mx = +0 in*lbf ⇨ My=+2.52811E+5 in*lbf ⇨ Mz=+2.36830E+5 in*lbf
si_mt_nrun_op.inp	BC-4 " "	" " N5001: Mx = +0 in*lbf ⇨ My=+2.36830E+5 in*lbf ⇨ Mz=-2.52811E+5 in*lbf

F.3.2 – FE Model Results of Unlisted Branch Component

ABAQUS post processing results for the four preliminary 80 percentile solution runs are shown within this section.

The next four SI solution results extract maximum membrane tresca stresses from each SI result model. The input file for each SI input file creates two resultant steps in which a third step is generated to obtain the tresca stress state needed. As shown in the following run bending moment example, at the bottom of each SI input file the first step (step 1) produces results for an internal pressure (272-psi) loading. The second step (step 2) computes results for combined internal pressure and bending loading and is presented following.

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**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE
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*END STEP
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*STATIC
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**%  RESTRAINT SET 1
**%  LOAD SET PRESSURE + MX
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*DLOAD,OP=NEW
BS000001,    P,-2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1,VARIABLE=ALL
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S
*END STEP
```

A third step (step 3) is created within ABAQUS Viewer that subtracts step 1 (P) from step 2 (P+Mi) to obtain corresponding bending tresca stress results (Mi). This is done to capture the added stiffness from internal pressure reflected into the Mi results [Mi = (P+Mi) – (P)]. Maximum tresca stress results (extracted from the four SI result models) for the three moments (Mx, My, & Mz) are used to determine branch and run stress indices computed in Appendix F.3.3.

Figures F.3.2-1 and F3.2-2 show maximum membrane tresca stress plots corresponding to in-plane and out-of-plane bending moment results applied to the branch pipe end. Figures F.3.2-3 and F.3.2-4 show maximum in-plane and out-of-plane beding moment results applied to the North run end. Figure F.3.2-5 shows the corresponding maximum membrane tresca stress plot due to run pressure.

The corresponding maximum tresca stress values (in psi) for each load case (BC-1, BC-2, P, BC-3, and BC-4) are contained in files "Y_branch.rpt" and "Y_run.rpt," reprinted in Appendix F.3.2.1.

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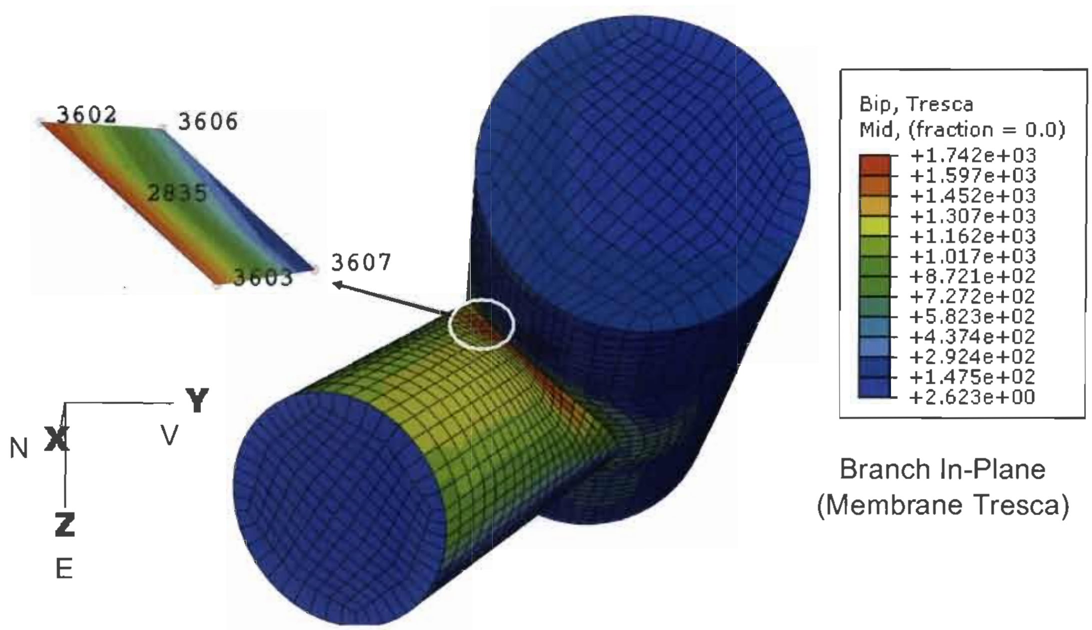

Figure F.3.2-1 – Step 3 membrane Bip (branch +In-plane bending) tresca stresses, determined as difference of steps 2 and step 1.

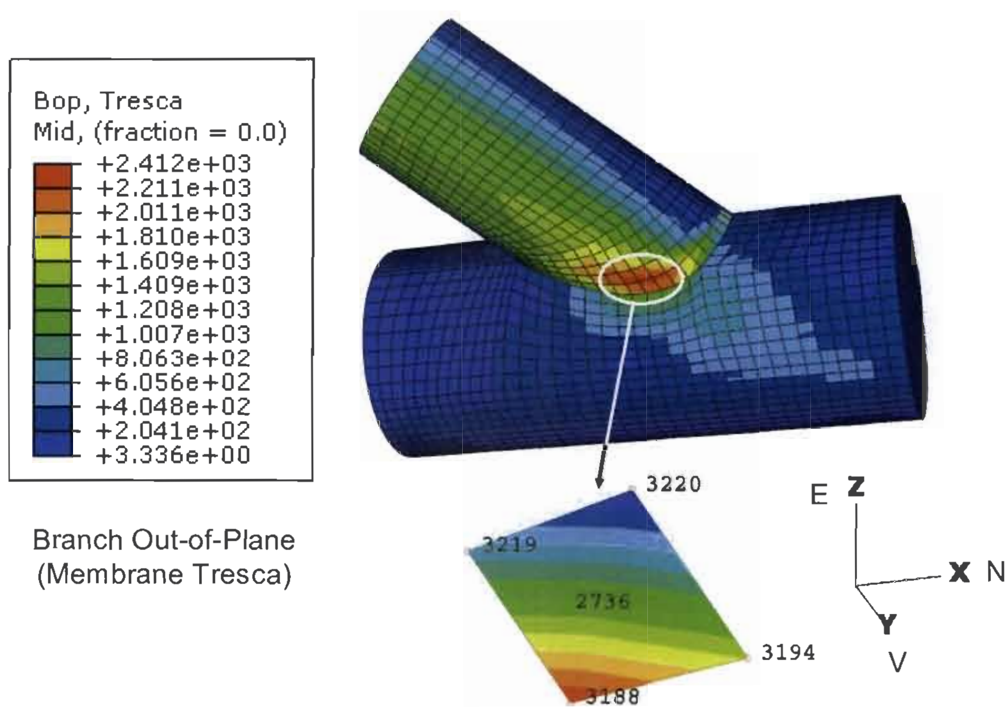

Figure F.3.2-2 – Step 3 membrane Bop (branch +Out-of-plane bending) tresca stresses.

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
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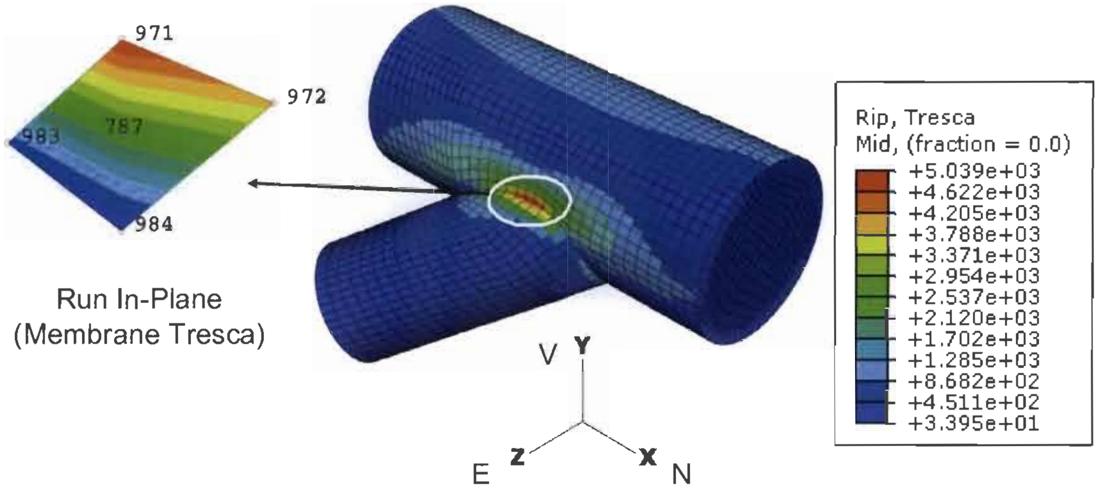

Figure F.3.2-3 – Step 3 membrane Rip (run +In-plane bending) tresca stresses.

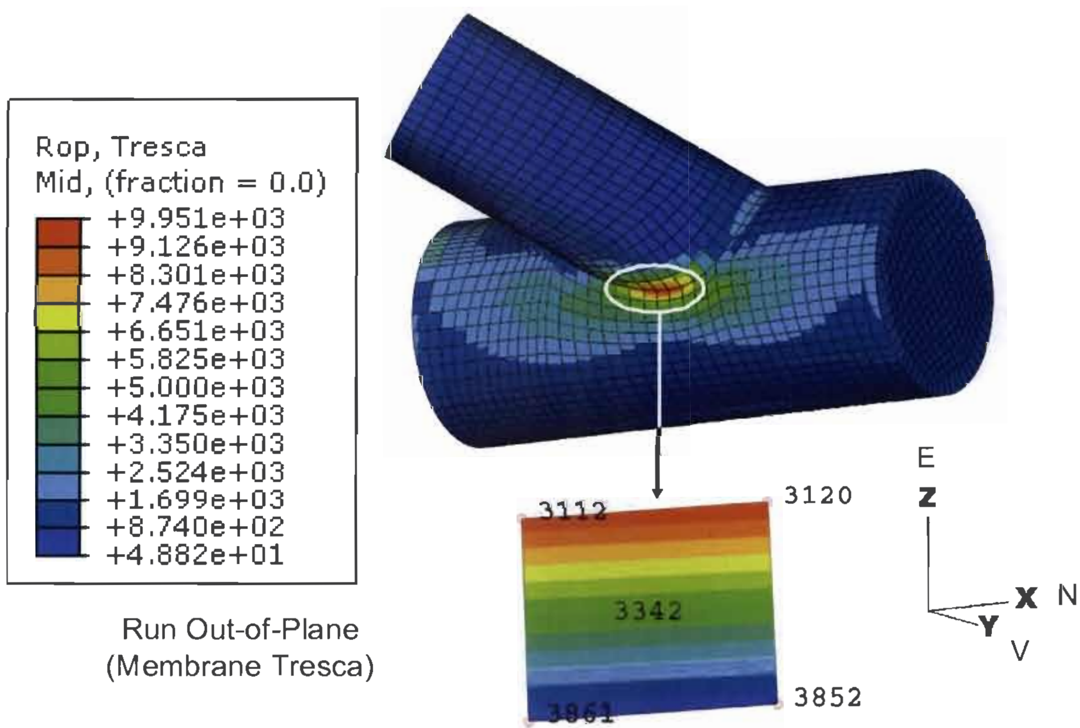

Figure F.3.2-4 – Step 3 membrane Rop (run +Out-of-plane bending) tresca stresses.

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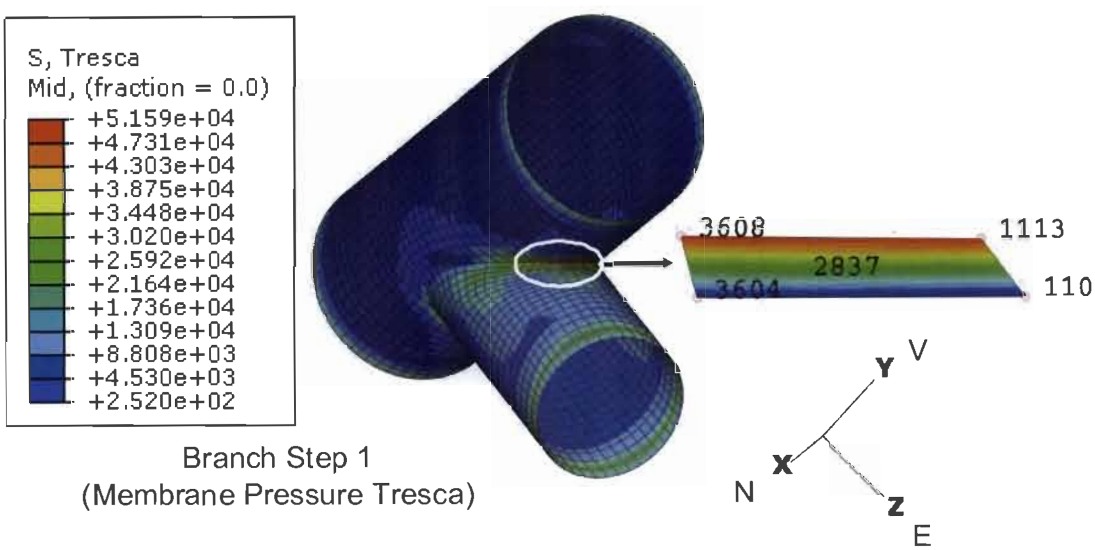

Figure F.3.2-5 – Step 3 membrane Step 1 Pressure tresca stresses.

F.3.2.1 – Unlisted Branch Component Maximum Tresca Stress Result Files

Two files are used to capture maximum tresca stresses for the branch and run load conditions. File "Y_branch.rpt' contain maximum element and nodal tresca stress values for in-plane and out-of-plane bending moments placed on the branch pipe end and file "Y_run.rpt" contains corresponding data for moments placed on the North run pipe end.

Y_branch.rpt

```
********************************************************************************
Probe Values Report, written on Sat Sep 06 23:16:24 2008

Source
-------

   ODB: C:/pcs/pcs2/model_14/wye/si_mt_branch_ip.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304L > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
```

PART-1-1	2835	S4	3607	3603	3602	3606

Part Instance	Element ID	Type	Node	Bip: Tresca
PART-1-1	2835	S4	1	1.60939E+03
PART-1-1	2835	S4	2	1.73034E+03
PART-1-1	2835	S4	3	1.74158E+03
PART-1-1	2835	S4	4	1.64035E+03

****
Probe Values Report, written on Sat Sep 06 23:37:09 2008

Source

ODB: C:/pcs/pcs2/model_14/wye/si_mt_branch_op.odb
Step: Session Step
Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304L > < 5 section points > : Mid, (fraction = 0.0)

Probe values reported at element nodes

Part Instance	Element ID	Type	Nodes			
PART-1-1	2736	S4	3220	3194	3188	3219

Part Instance	Element ID	Type	Node	Bop: Tresca
PART-1-1	2736	S4	1	1.93451E+03
PART-1-1	2736	S4	2	2.25053E+03
PART-1-1	2736	S4	3	2.41219E+03
PART-1-1	2736	S4	4	2.07288E+03

****
Probe Values Report, written on Sun Sep 07 00:07:19 2008

Source

ODB: C:/pcs/pcs2/model_14/wye/si_mt_nrun_ip.odb
Step: Step-1
Frame: Increment 13: Step Time = 1.000

Loc 1 : Element nodal values at shell < SST304L > < 5 section points > : Mid, (fraction = 0.0)

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Performer:	D. T. Clark	Date: 09/30/08	Checker: A. S. Siahpush	Date:	09/30/08

```
Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1        2837          S4        1113         1107         3604
3608


  Part Instance  Element ID        Type              Node        S: Tresca
--------------------------------------------------------------------------------
    PART-1-1        2837          S4                1      51.5868E+03
    PART-1-1        2837          S4                2      42.6724E+03
    PART-1-1        2837          S4                3      42.8699E+03
    PART-1-1        2837          S4                4      51.4722E+03
```

Y_run.rpt

```
********************************************************************************
Probe Values Report, written on Sat Sep 06 23:40:01 2008

Source
-------

   ODB: C:/pcs/pcs2/model_14/wye/si_mt_nrun_ip.odb
   Step: Session Step
   Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304L > < 5 section points > : Mid,
(fraction = 0.0)

Probe values reported at element nodes

  Part Instance  Element ID        Type       Nodes
--------------------------------------------------------------------------------
    PART-1-1         787          S4         971          972          984
983


  Part Instance  Element ID        Type              Node      Rip: Tresca
--------------------------------------------------------------------------------
    PART-1-1         787          S4                1      5.03937E+03
    PART-1-1         787          S4                2      4.63755E+03
    PART-1-1         787          S4                3      3.18454E+03
    PART-1-1         787          S4                4      3.39826E+03


********************************************************************************
Probe Values Report, written on Sun Sep 07 00:21:31 2008

Source
-------

   ODB: C:/pcs/pcs2/model_14/wye/si_mt_nrun_op.odb
   Step: Session Step
```

Project: ATR Life Time Extension Project	**ECAR No.:** ECAR-194	**Rev.:** 0	
Title: ATR Primary Coolant System Seismic Evaluation			
Performer: D. T. Clark	**Date:** 09/30/08	**Checker:** A. S. Siahpush	**Date:** 09/30/08

Frame: Session Frame

Loc 1 : Element nodal values at shell < SST304L > < 5 section points > : Mid, (fraction = 0.0)

Probe values reported at element nodes

Part Instance	Element ID	Type	Nodes			
PART-1-1	3342	S4	3112	3120	3852	3861

Part Instance	Element ID	Type	Node	Rop: Tresca
PART-1-1	3342	S4	1	9.86701E+03
PART-1-1	3342	S4	2	9.95146E+03
PART-1-1	3342	S4	3	6.66499E+03
PART-1-1	3342	S4	4	6.59152E+03

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F.3.3 – Unlisted Branch Component FE model input and SI Determination

The purpose of this section is to determine SI) for Model 14's unlisted branch component. Pertinent FE model result data are extracted from Appendices F.3.2 and F.3.2.1 for SI value determinations.

Wye In-plane & Out-of-Plane Coordinate Load Determination

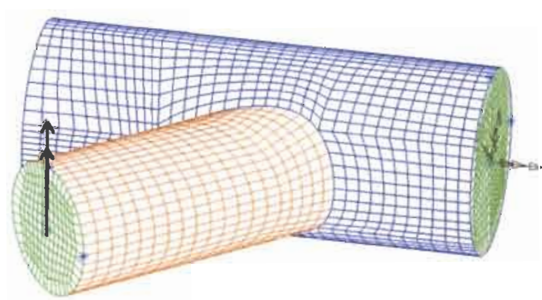
09/06/08 moment reactions

$V_{1050} := \left(-2.886 \cdot 10^4 \;\; 3.752 \cdot 10^4 \;\; 8.636 \cdot 10^4\right)^T$ $\quad |V_{1050}| = 9.848 \times 10^4$

$V_{748} := \left(-9.171 \cdot 10^3 \;\; 2.302 \cdot 10^5 \;\; -2.587 \cdot 10^5\right)^T$ $\quad |V_{748}| = 3.464 \times 10^5$

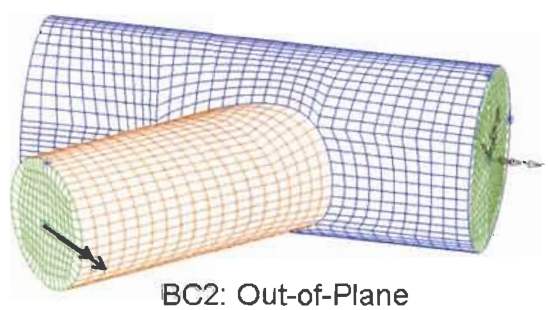
$V_{1081} := \left(6.274 \cdot 10^4 \;\; -2.804 \cdot 10^5 \;\; 4.737 \cdot 10^4\right)^T$ $\quad |V_{1081}| = 2.912 \times 10^5$

Global coordinate moment reactions & magnitudes from Model 14's piping beam results (Appendix D)



BC1: In-Plane Branch Bending

BC 1 – in-plane branch bending
BC 2 – out-of-plane branch bending



BC2: Out-of-Plane Branch Bending

$P_{5002} := (1.912044 \;\; -21.70391 \;\; 23.16844)^T$ Start branch point (N5002) coordinate

$P_{bip} := (1.91204 \;\; -20.97411 \;\; 23.85210)^T$ Branch in-plane end point (unit Y-direction) coordinate

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$Vbip_{5002} := P_{bip} - P_{5002}$ $Vbip_{5002}^{T} = \left(-4\times10^{-6}\ \ 0.73\ \ 0.684\right)$ Unit vector of branch in-plane, as measured from within wye I-DEAS model.

$M := 100000$

$VBip_{5002} := M\cdot Vbip_{5002}$ $VBip_{5002}^{T} = (-0\ \ 72980\ \ 68366)$ Scaled branch in-plane bending vector

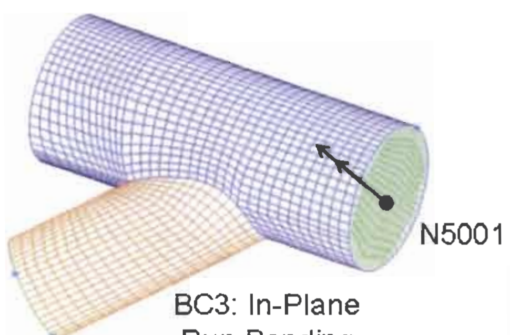
$MBip_{5002} := VBip_{5002}\dfrac{|V_{1050}|}{|VBip_{5002}|}$ $MBip_{5002}^{T} = (-0\ \ 71872\ \ 67328)$ Scaled branch in-plane moment

$P_{bop} := (2.604368\ \ -22.19724\ \ 23.69504)^{T}$ Branch out-of-plane end point (unit X-direction) coordinate

$Vbop_{5002} := P_{bop} - P_{5002}$ $Vbop_{5002}^{T} = (0.692\ \ -0.493\ \ 0.527)$ Unit vector of branch out-of-plane, as measured from within wye I-DEAS model.

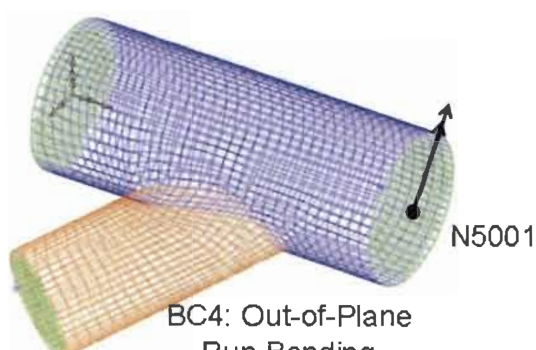
$VBop_{5002} := M\cdot Vbop_{5002}$ $VBop_{5002}^{T} = (69232\ \ -49333\ \ 52660)$ Scaled branch out-of-plane bending vector

$MBop_{5002} := VBop_{5002}\dfrac{|V_{1050}|}{|VBop_{5002}|}$ $MBop_{5002}^{T} = (68182\ \ -48584\ \ 51861)$ Scaled branch out-of-plane moment



BC3: In-Plane Run Bending

BC 3 – in-plane run bending
BC 4 – out-of-plane run bending



BC4: Out-of-Plane Run Bending

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$P_{5001} := (53.0000\ \ 0\ \ 0)^T$ Start run point (N5001) coordinate

$P_{nrip} := (53.0000\ \ 0.7297967\ \ 0.6836647)^T$ Run in-plane North end point (unit Y-direction) coordinate

$Vnrip_{5001} := P_{nrip} - P_{5001}$ $Vnrip_{5001}^T = (0\ \ 0.73\ \ 0.684)$ Unit vector of North run end in-plane, as measured from within wye I-DEAS model.

$VnRip_{5001} := M \cdot Vnrip_{5001}$ $VnRip_{5001}^T = (0\ \ 72980\ \ 68366)$ Scaled branch North in-plane bending vector

$MnRip_{5001} := VnRip_{5001} \cdot \frac{|V_{748}|}{|VnRip_{5001}|}$ $MnRip_{5001}^T = (0\ \ 252811\ \ 236830)$ Scaled North Run in-plane moment

$|MnRip_{5001}| = 3.464 \times 10^5$

$P_{nrop} := (53.00\ \ 0.6836644\ \ -0.7297964)^T$ Run out-of-plane North end point (unit Z-direction) coordinate

$Vnrop_{5001} := P_{nrop} - P_{5001}$ $Vnrop_{5001}^T = (0\ \ 0.684\ \ -0.73)$ Unit vector of North run end out-of-plane, as measured from within wye I-DEAS model.

$VnRop_{5001} := M \cdot Vnrop_{5001}$ $VnRop_{5001}^T = (0\ \ 68366\ \ -72980)$ Scaled branch North out-of-plane bending vector

$MnRop_{5001} := VnRop_{5001} \cdot \frac{|V_{748}|}{|VnRop_{5001}|}$ $MnRop_{5001}^T = (0\ \ 236830\ \ -252811)$ Scaled run North out-of-plane moment

$|MnRop_{5001}| = 3.464 \times 10^5$

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Unlisted Branch Component Stress Indices

(9) $B_1 \cdot \frac{P \cdot D_o}{2 \cdot t} + B_2 \cdot \frac{D_o}{2 \cdot I} \cdot M_i$ <= $1.5 \cdot S_m$ Primary SI limit is satisfied if equation 9 is met [1, NB-36-3652]

For SI determination, will approximate unlisted component as a branch fabricated normal to a straight pipe run. In this case, the 18-in pipe branch is approximated as being normal to the 24-in pipe run.

For straight run pipe with smaller diameter branch:

(9) $B_1 \cdot \left(\frac{P \cdot D_o}{2 \cdot T_r}\right) + \left[B_{2b} \cdot \left(\frac{M_b}{Z_b}\right) + B_{2r} \cdot \left(\frac{M_r}{Z_r}\right)\right]$ <= $1.5 \cdot S_m$ Equation 9 is modified for its moment terms [1, NB-3683.1]

where: B_1 - primary stress indice for pressure
B_{2b} - primary stress indice for branch contribution
B_{2r} - primary stress indice for run moments contribution
D_o - outside diameter of run (in)
M_b - branch moments (Mip, Mop) due to a combination of mechanical loads (in*lbf)
M_r - run moments (Mip, Mop) due to a combination of mechanical loads (in*lbf)
P - Design Pressure (psi)
S_m - allowable design stress intensity value (psi)
T_r - nominal wall thickness of run (in)
Z_b - approximate section modulus of attached branch pipe (in^3)
Z_r - approximate section modulus of designated run pipe (in^3)

$P := 272 \cdot psi$ Internal Pressure

$Sy_{167} := 22.26\,ksi$ $Sm_{167} := 16.7 \cdot ksi$ Material yield strength and Maximum allowable stress intensity at 167° F, for 304L stainless steel.

$Do_{run} := 24 \cdot in$ $Tr_{run} := 1 \cdot in$ Outside diameter and thickness of straight run

Per Section NB-3656(a) [1]: Level D Service Limits apply

(1) $P = 272 \cdot psi$ < $2 \cdot P_a$

(3) $P_a = \frac{2 \cdot S_m \cdot t}{D_o - 2 \cdot y \cdot t}$ [1, Section NB-3641.1]

where P_a Calculated maximum allowable internal pressure of straight pipe

$y := 0.4$ $Y := 0.4$ [1,Section NB-3641.1]

$$P_a := \frac{2 \cdot Sm_{167} \cdot Tr_{run}}{Do_{run} - 2 \cdot y \cdot Tr_{run}} \qquad P_a = 1440\,psi \qquad \frac{2P_a}{P} = 10.586$$ OK

Equation 9 adapted for level D service limits

(9) $$B_1 \cdot \left(\frac{P \cdot D_o}{2 \cdot T_r}\right) + \left[B_{2b} \cdot \left(\frac{M_b}{Z_b}\right) + B_{2r} \cdot \left(\frac{M_r}{Z_r}\right)\right]$$ =< min(3*Sm, 2*Sy)

where $3 \cdot Sm_{167} = 50.1 \cdot ksi$ $2 \cdot Sy_{167} = 44.52\,ksi$ 2*Yield at 167°F governs

(9) $$B_1 \cdot \left(\frac{P \cdot D_o}{2 \cdot T_r}\right) + \left[B_{2b} \cdot \left(\frac{M_b}{Z_b}\right) + B_{2r} \cdot \left(\frac{M_r}{Z_r}\right)\right] =< 2 \cdot Sy_{167} = 44.52\,ksi$$

$Z_b = \pi \cdot (r'_m)^2 \cdot T'_b$ Approximate branch section modulus [1, NB-3683.1]

where r'_m - mean radius of attached branch pipe (in)

T'_b - nominal wall thickness of attached branch pipe (in)

$T18_b := 0.312\,in$ $Do_{branch} := 18 \cdot in$ Thickness & outside diameter of branch pipe

$$r18_m := \frac{Do_{branch} - T18_b}{2} \qquad r18_m = 8.844\,in$$ Mean radius of attached branch pipe

$$Z_b := \pi \cdot (r18_m)^2 \cdot T18_b \qquad Z_b = 76.666\,in^3$$

$Z_r = \pi \cdot (R_m)^2 \cdot T_r$ Approximate run section modulus [1, NB-3683-1]

where R_m - mean radius of designated run pipe (in)

T_r - nominal wall thickness of designated run pipe (in)

$T24_r := 1 \cdot in$ $Do_{run} = 24\,in$ Thickness and outside diameter of straight run pipe

$r24_m := \frac{Do_{run} - T24_r}{2}$ $r24_m = 11.5\,in$ Mean radius of straight run pipe

$Z_r := \pi \cdot (r18_m)^2 \cdot T24_r$ $Z_r = 245.72\,in^3$

$NB_{ip} := |MBip_{5002}|$ $NB_{ip} = 9.848\times 10^4$

$NB_{op} := |MBop_{5002}|$ $NB_{op} = 9.848\times 10^4$

$NnR_{ip} := |MnRip_{5001}|$ $NnR_{ip} = 3.464\times 10^5$

$NnR_{op} := |MnRop_{5001}|$ $NnR_{op} = 3.464\times 10^5$

$M_{ub} := |NB_{ip}| \cdot in \cdot lbf$ $M_{ub} = 98.482\,in \cdot kip$ Branch in-plane resultant moment at N5002

$M_{ur} := |NnR_{ip}| \cdot in \cdot lbf$ $M_{ur} = 346.413\,in \cdot kip$ Run in-plane resultant moment at N5001

FE branch membrane tresca stress results are reflective of three load conditions (or steps). The first step (step 1) produces results for an internal pressure (253-psi) loading. The second step (step 2) computes results for combined internal pressure and bending loading. The last step (step 3) subtracts step 1 (P) from step 2 (P+Bi) to obtain corresponding bending tresca stress results (Bi). This is done to capture the added stiffness from internal pressure reflected into Bi & Ri results. Maximum tresca stress results (extracted from FE model results) of the in-plane and out-of-plane moments are used to determine the branch stress indice (B_{2b}) and the run stress indice (B_{2r}).

$\sigma T_b := \begin{pmatrix} 1.74158E{+}03 \\ 2.25053E{+}03 \end{pmatrix} \cdot psi$ In-plane bending / Out-of-plane bending — Maximum branch tresca stress occurs for out-of-plane bending.

$\sigma_{ub} := \max(\sigma T_b)$ $\sigma_{ub} = 2.251 \cdot ksi$

$\sigma T_r := \begin{pmatrix} 5.03937E{+}03 \\ 9.95146E{+}03 \end{pmatrix} \cdot psi$ In-plane bending / Out-of-plane bending — Maximum run tresca stress occurs for out-of-plane bending.

$\sigma_{ur} := \max(\sigma T_r)$ $\sigma_{ur} = 9.951 \cdot ksi$

$\sigma_{up} := 51.5868E{+}03 psi$ Unlisted branch component tresca stress due to internal pressure

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SI determination for unlisted branch component:

$$\sigma_{ub} = B_{2ub} \cdot \left(\frac{|M_{ub}|}{Z_b} \right)$$

$$B_{2ub} := \frac{\sigma_{ub}}{\left(\frac{M_{ub}}{Z_b} \right)} \qquad B_{2ub} = 1.752$$ Unlisted branch member SI

$$\sigma_{ur} = B_{2ur} \cdot \left(\frac{|M_{ur}|}{Z_r} \right)$$

$$B_{2ur} := \frac{\sigma_{ur}}{\left(\frac{|M_{ur}|}{Z_r} \right)} \qquad B_{2ur} = 7.059$$ Run member SI

$\sigma_{up} = 51.587\,ksi$ Unlisted component system pressure

$$\sigma_{up} = B_{1u} \cdot \left(\frac{P \cdot D_o}{2 \cdot T_r} \right) \Rightarrow B_{1u} := \frac{\sigma_{up}}{\left(\frac{P \cdot Do_{run}}{2 \cdot T24_r} \right)} \qquad B_{1u} = 15.805$$ System pressure SI

$B_{1u} = 15.805$ $B_{2ub} = 1.752$ $B_{2ur} = 7.059$ Unlisted branch component (wye) SI

F.3.4 Elastic Evaluation of Unlisted Branch Component

For unlisted branch component:

$$B_1 \cdot \left(\frac{P \cdot D_o}{2 \cdot T_r}\right) + \left[B_{2b} \cdot \left(\frac{M_b}{Z_b}\right) + B_{2r} \cdot \left(\frac{M_r}{Z_r}\right)\right] \quad =< \quad 2 \cdot Sy_{167} = 44.52\,ksi$$

$$\frac{B_{1u} \cdot \left(\frac{P \cdot Do_{run}}{2 \cdot T24_r}\right) + \left[B_{2ub} \cdot \left(\frac{M_{ub}}{Z_b}\right) + B_{2ur} \cdot \left(\frac{M_{ur}}{Z_r}\right)\right]}{2 \cdot Sy_{167}} = 1.433$$

14 Model Unlisted Branch Component unacceptable.

$$\frac{B_{1u} \cdot \left(\frac{P \cdot Do_{run}}{2 \cdot T24_r}\right)}{2 \cdot Sy_{167}} = 1.159$$

Pressure strongly influences linear results.

$$\frac{\left[B_{2ub} \cdot \left(\frac{M_{ub}}{Z_b}\right) + B_{2ur} \cdot \left(\frac{M_{ur}}{Z_r}\right)\right]}{2 \cdot Sy_{167}} = 0.274$$

Seismic loading effects

The unlisted branch component (or wye) is significantly over unity. As show above, pressure dominates the linear results and is 4.2 times larger (1.159/0.274) than the seismic response. Thus, a plastic analysis on the unlisted branch component is recommended to determine acceptance.

The above unlisted branch component linear evaluation was based on preliminary 80 percentile moment reactions, used for determining scoping SI. Following are final run moment reactions (as of 09-25-08) for the unlisted branch component. Preliminary and final moment reactions are compared.

Preliminary 80 Percentile Nodal Moment Reactions, previously shown

Mx My Mz

$$V_{1050}^{T} = \begin{pmatrix} -2.886\times 10^{4} & 3.752\times 10^{4} & 8.636\times 10^{4} \end{pmatrix}$$

$$V_{748}^{T} = \begin{pmatrix} -9.171\times 10^{3} & 2.302\times 10^{5} & -2.587\times 10^{5} \end{pmatrix}$$

$$V_{1081}^{T} = \begin{pmatrix} 6.274\times 10^{4} & -2.804\times 10^{5} & 4.737\times 10^{4} \end{pmatrix}$$

Final run 80 Percentile Nodal Moment Reactions for unlisted elbow/branch component

Mx My Mz

$$V_{1050f} := \begin{pmatrix} 1.589\cdot 10^{4} & -2.801\cdot 10^{4} & 6.91\cdot 10^{4} \end{pmatrix}^{T}$$

$$V_{748f} := \begin{pmatrix} 9.735\cdot 10^{4} & -2.675\cdot 10^{5} & 2.251\cdot 10^{5} \end{pmatrix}^{T}$$

$$V_{1081f} := \begin{pmatrix} 9.638\cdot 10^{4} & -2.798\cdot 10^{5} & 2.246\cdot 10^{5} \end{pmatrix}^{T}$$

$$\frac{V_{1050f}}{V_{1050}} = \begin{pmatrix} -0.551 \\ -0.747 \\ 0.8 \end{pmatrix} \qquad \frac{V_{748f}}{V_{748}} = \begin{pmatrix} -10.615 \\ -1.162 \\ -0.87 \end{pmatrix} \qquad \frac{V_{1081f}}{V_{1081}} = \begin{pmatrix} 1.536 \\ 0.998 \\ 4.741 \end{pmatrix}$$

The branch final moments are less than the prelimary moments, but the run ratios are both up and down. This unlisted elbow/branch component acceptance will be decided by plastic analysis in the next section.

F.3.5 – Plastic Evaluation of Unlisted Branch Component (Wye)

There are two nonstandard wye components that must be evaluated. To run the plastic analysis for the unlisted wye components, displacement results versus time were gathered from realization 28 of the beam element model 14 (shown in Figure F.3.5-1). These displacement results were then applied to a shell modeled cutout of the east-side wye. This realization of model 14 (applied only to a cutout model of the east-side wye) was selected as enveloping for the east- and west-side wyes. This is because realization 28 produces D/C results higher than that of the 80th percentile realization for the wye on the east-side. It also caused loads in the east-side wye that are greater than those in the west-side wye under its 80th percentile realization.

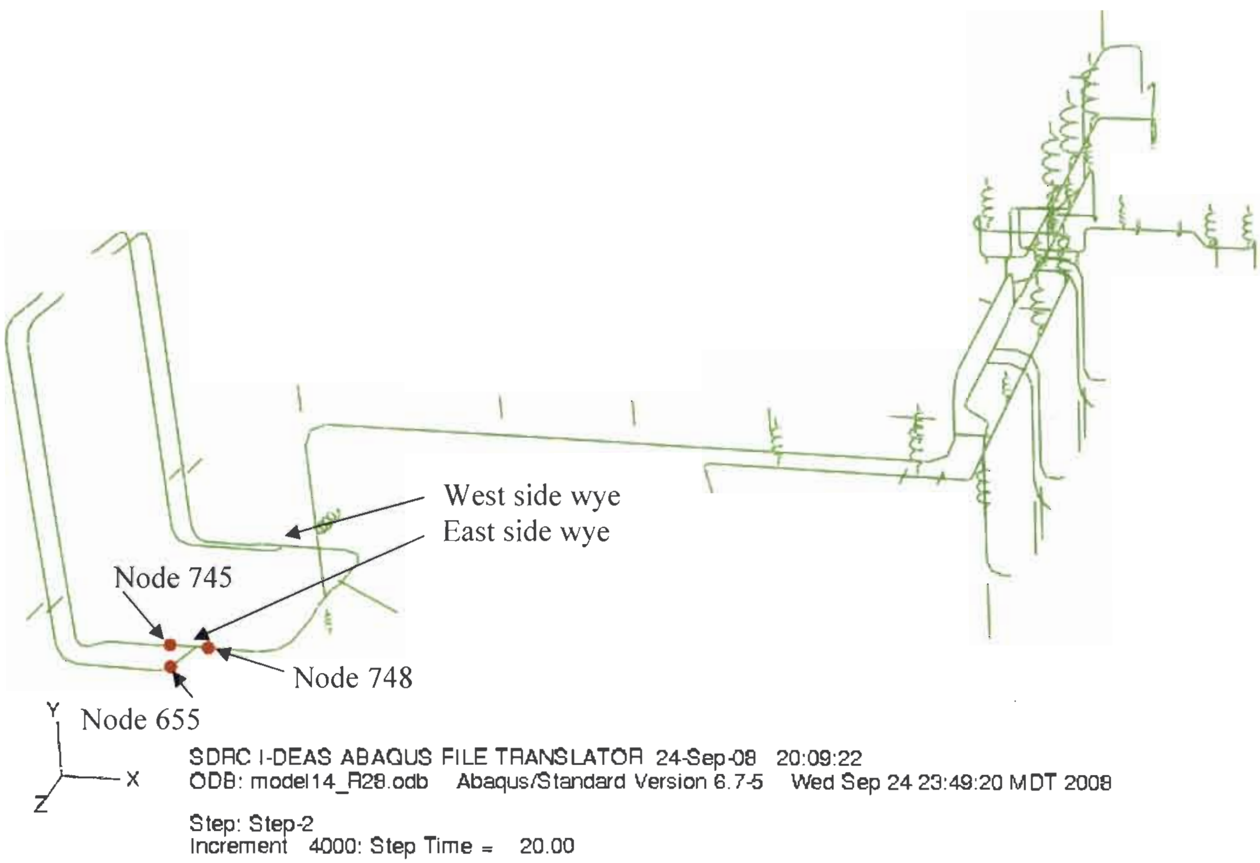

Figure F.3.5-1 – Realization 28 of the piping model and east-side wye nodes used for evaluation.

The displacement results from Model 14 nodes 655, 745, and 748 are shown in Figure F.3.5-2.

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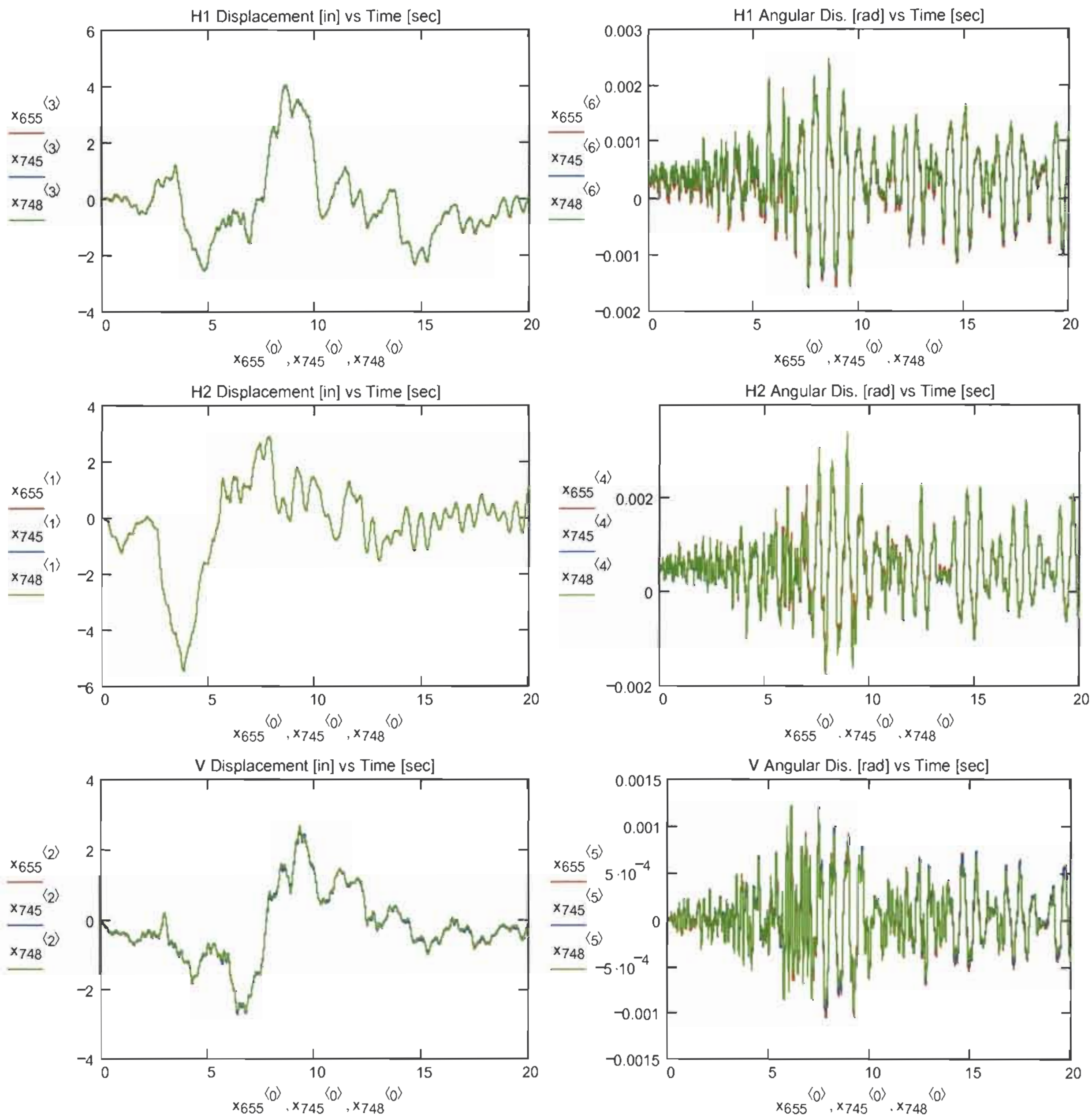

Figure F.3.5-2 – Displacement plots for nodes identified in Figure F.3.5-1.

Figure F.3.5-2 shows the translational and rotational displacement in the nodes output from realization 28 (shown in Figure F.3.5-1). In the plot variables, "x" indicates displacement and the subscript that follows is the node number from Figure F.3.5-1. H1 represents the east/west direction and it is on the z-axis in the model plots. H2 represents the north/south direction and it is on the x-axis in the model plots. V represents the vertical direction and it is on the y-axis in the model plots.

The plastic analysis for the unlisted wyes was performed by generating a linear quadrilateral and continuum shell model (as shown in Figures F.3.5-3 - F.3.5-8) of the region including the nodes identified in Figure F.3.5-1. This model includes a run pipe with a outside diameter of 25.25 inches and a wall thickness of 1 inch and a branch pipe with a cross sectional diameter of 18 inches and a wall thickness of 0.312 inch. These pipes are modeled with linear continuum shells and a 0.312 inch fillet weld is added at the connection of the pipes. The cut ends of the pipes are covered with 0.312 inch thick linear quadrilateral shells that contain the pressure.

```
NX I-deas 5 :    NX I-DEAS 5 Team : er2 : C:\er2\work\TRA-670_piping\Y_mode  15-Sep-08  18:16:53
 Database: C:\er2\work\TRA-670_piping\Y_model\Y_model.mf1                     Units   : IN
 View    : No stored Workb_View                                     Display : No stored Option
   Task : Boundary Conditions                                            Model/Part Bin: Main
   Model: East Y          Active Study: DEFAULT FE STUDY             Parent Part: Y fe continuum
```

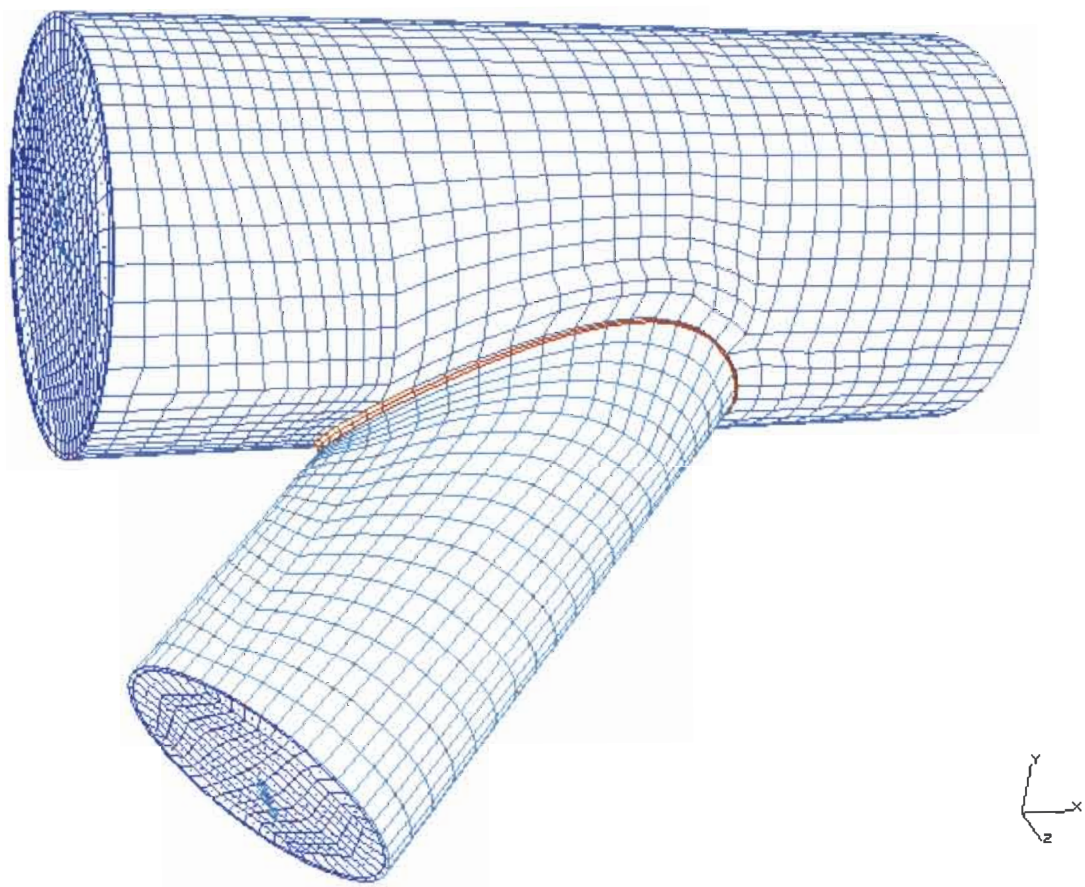

Figure F.3.5-3 – Mesh of the full model.

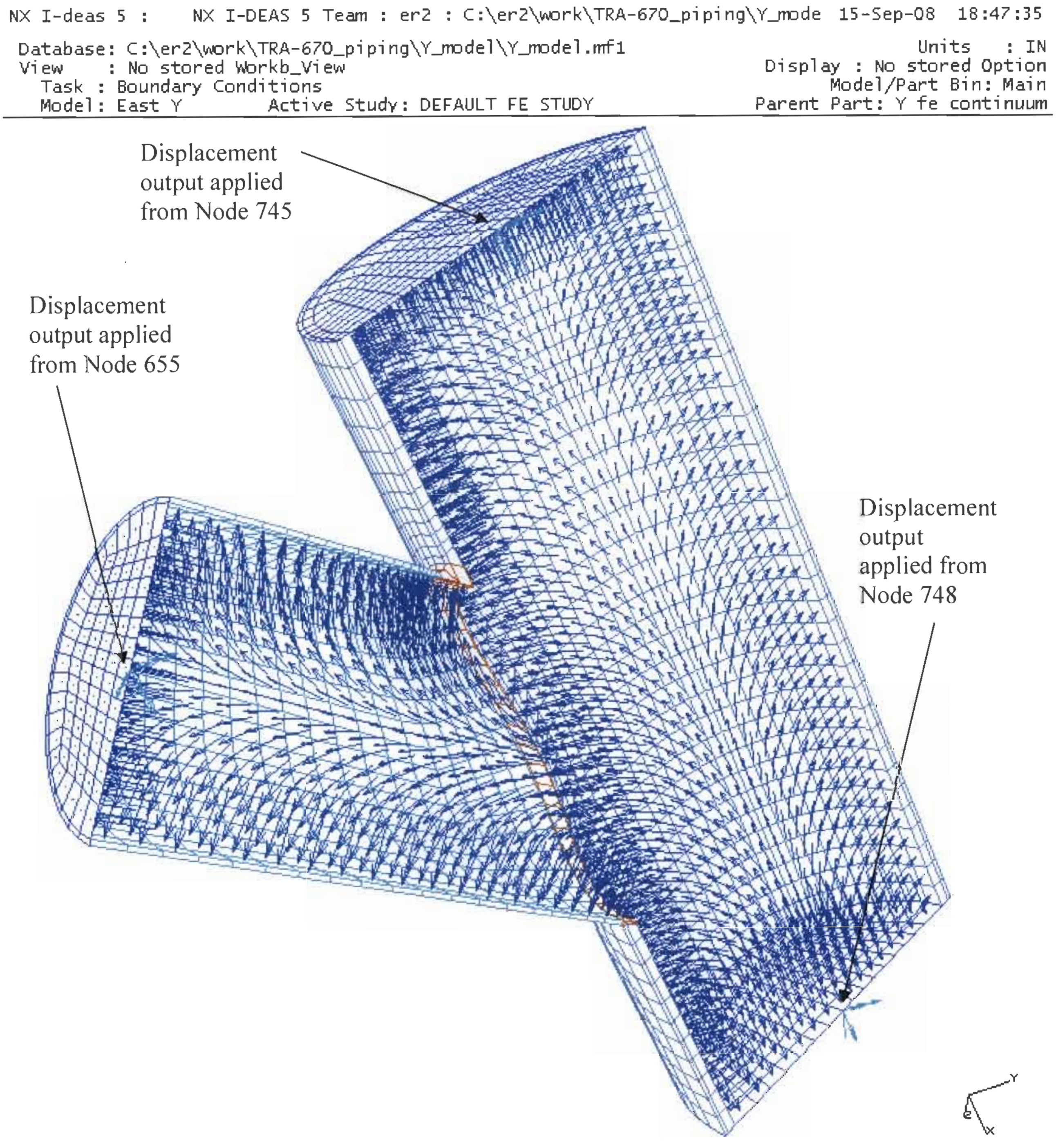

Figure F.3.5-4 – Cut-away of the model.

The displacement time histories taken from realization 28 were applied to the nodes identified in Figure F.3.5-4. Nodes 655, 745, and 748 are attached with a coupling definition to the nodes in the continuum shells at the section where the pipe is cut. These coupling definitions caused the average motion of the slave nodes to correspond with the motion of the reference node. In addition to the moving restraints, the model was loaded with gravity and a 272 psi internal pressure.

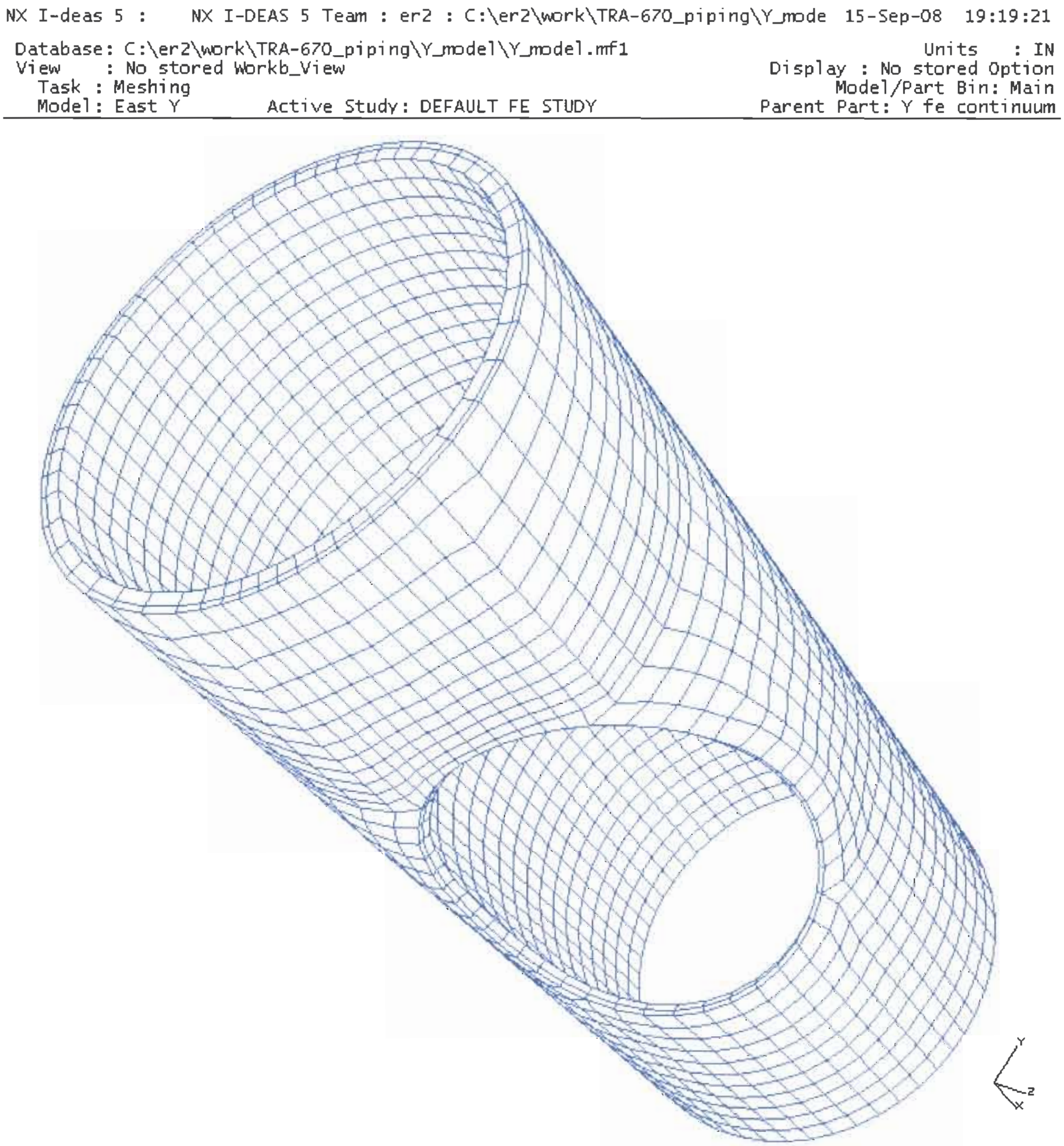

Figure F.3.5-5 – Continuum shell mesh of the 25.25 inch pipe with a wall thickness of 1 inch.

NX I-deas 5 : NX I-DEAS 5 Team : er2 : C:\er2\work\TRA-670_piping\Y_mode 15-Sep-08 19:51:33

Database: C:\er2\work\TRA-670_piping\Y_model\Y_model.mf1 Units : IN
View : No stored Workb_View Display : No stored Option
Task : Meshing Model/Part Bin: Main
Model: East Y Active Study: DEFAULT FE STUDY Parent Part: Y fe continuum

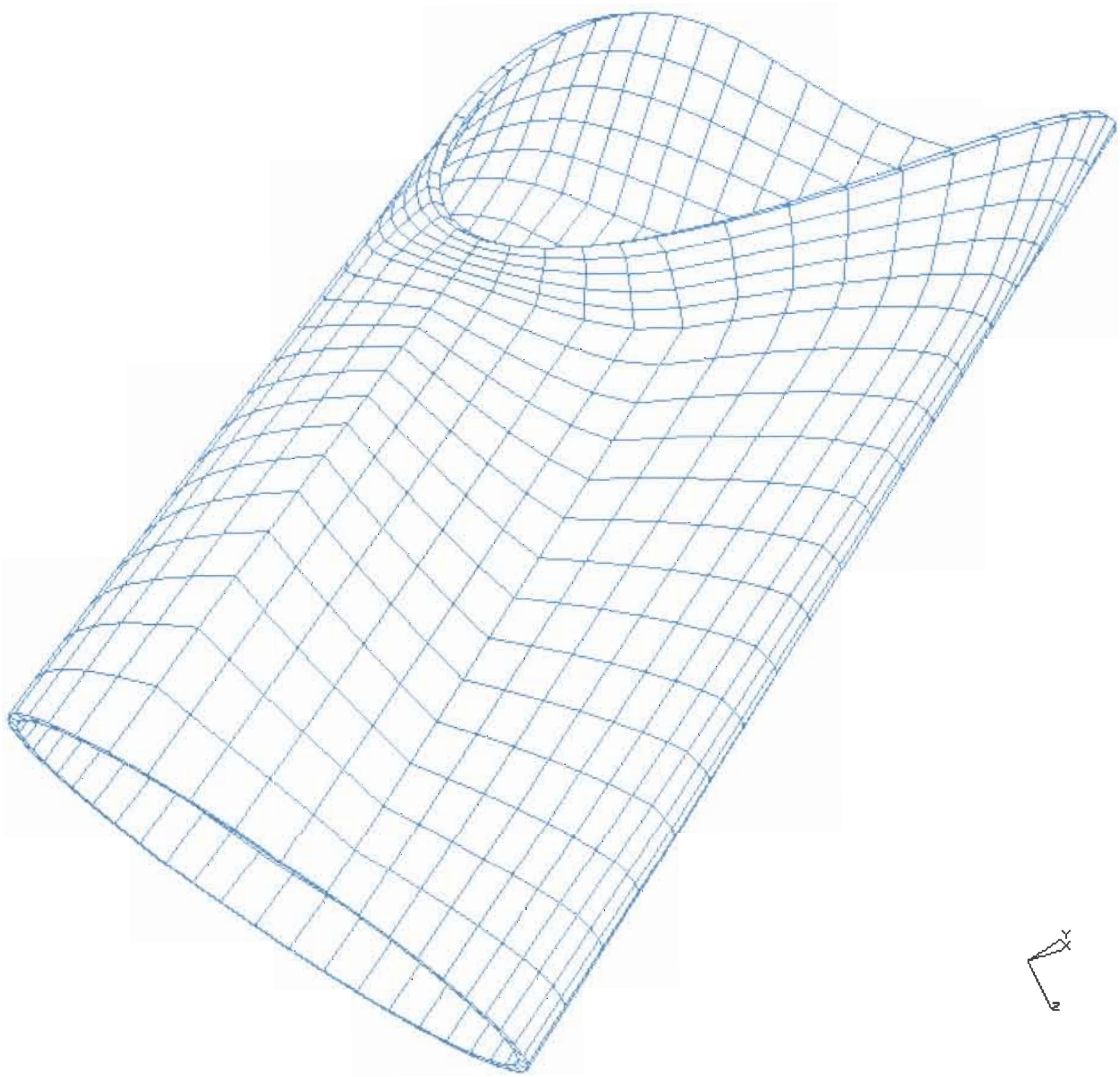

Figure F.3.5-6 – Continuum shell mesh of the 18 inch branch pipe with a wall thickness of 0.312 inches.

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```
NX I-deas 5 :    NX I-DEAS 5 Team : er2 : C:\er2\work\TRA-670_piping\Y_mode 15-Sep-08  19:57:09
 Database: C:\er2\work\TRA-670_piping\Y_model\Y_model.mf1                    Units    : IN
 View    : No stored Workb_View                                    Display : No stored Option
   Task : Meshing                                                       Model/Part Bin: Main
   Model: East Y         Active Study: DEFAULT FE STUDY            Parent Part: Y fe continuum
```

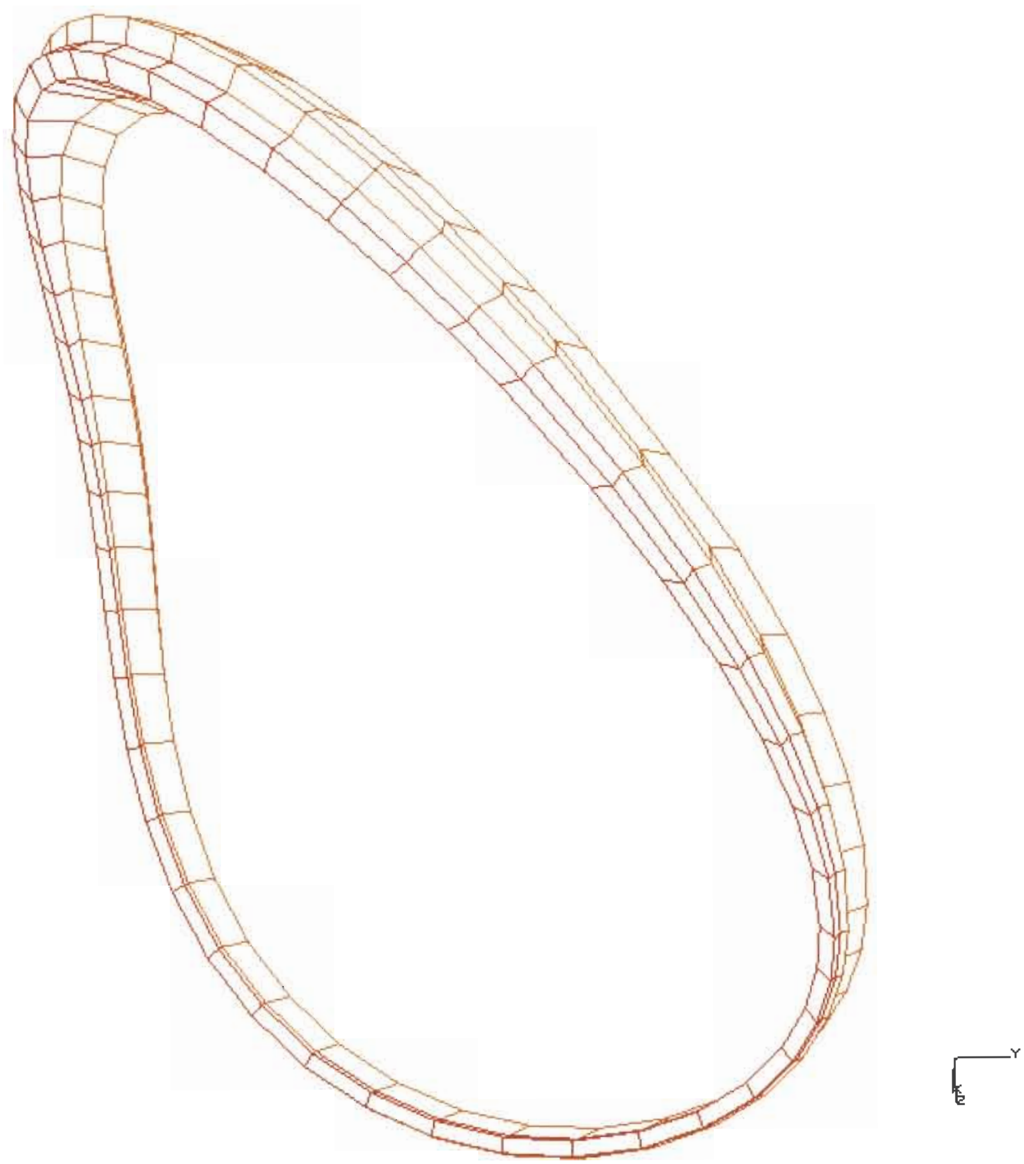

Figure F.3.5-7 – Continuum shell weld mesh.

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```
NX I-deas 5 :    NX I-DEAS 5 Team : er2 : C:\er2\work\TRA-670_piping\Y_mode  15-Sep-08  19:46:51
 Database: C:\er2\work\TRA-670_piping\Y_model\Y_model.mf1                    Units   : IN
 View    : No stored Workb_View                                    Display : No stored Option
   Task : Meshing                                                       Model/Part Bin: Main
   Model: East Y        Active Study: DEFAULT FE STUDY             Parent Part: Y fe continuum
```

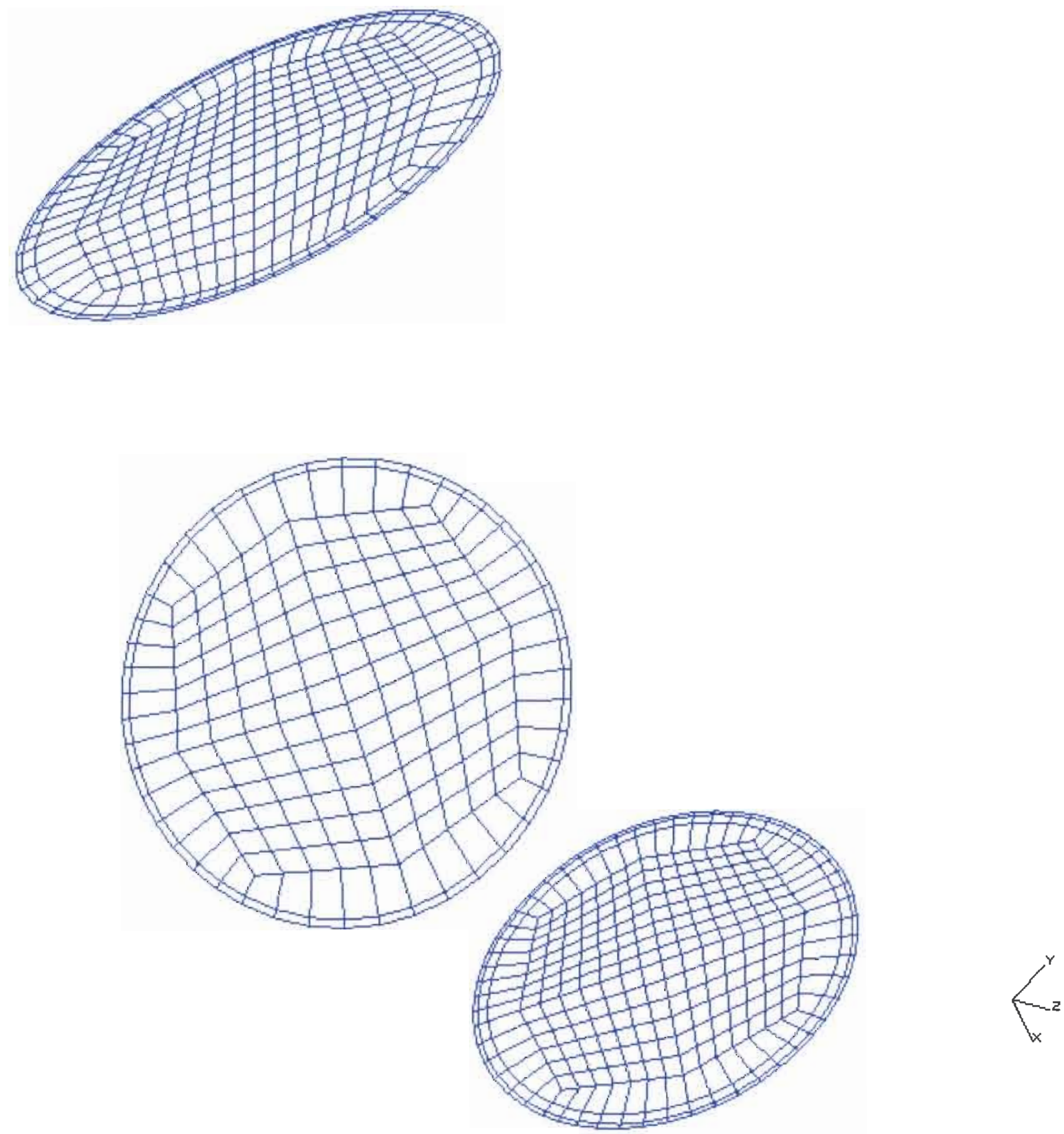

Figure F.3.5-8 – Linear quadrilateral thin shell mesh of the 0.312 inch thick end plates.

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This model was defined with the same elastic properties as the other models of the unlisted branch component. To run this model with plasticity, however, additional material properties were defined. To define these additional properties, ASME Section II, Part D [12] was used to define engineering yield and tensile stress values and the Nuclear Systems Materials Handbook [15] was used to determine the minimum total elongation percentage and the ratio of uniform elongation to total elongation (considering that the uniform elongation percentage is the engineering strain at the engineering tensile stress). Review of the Atlas of Stress-Strain Curves [16] and Tensile Stress-Strain Results for 304L and 316L Stainless Steel Plate at Temperature [17] tends to substantiate the values used from the previous two references. Below are the material properties and there conversion to a bilinear true stress versus true strain (using equations from Juvinall [18]) for use in ABAQUS.

$E_s := 2.77 \cdot 10^7 \cdot psi$ — Modulus of elasticity

$\nu_s := 0.30$ — Poisson's ratio

$G_s := \dfrac{E_s}{2 \cdot (1 + \nu_s)}$ — Modulus of elasticity

$G_s = 1.065 \times 10^7 \, psi$

$\rho_s := 0.28 \cdot \dfrac{lb}{in^3}$ — Mass density

$\rho_s = 7.252 \times 10^{-4} \, \dfrac{lbf \cdot sec^2}{in^4}$

$T_o := 167$ — Operating temperature

$\sigma_{ys} := 22.26 \cdot ksi$ — Engineering yield stress at operating temperature

$\sigma_{us100} := 70 \cdot ksi$ — Engineering tensile stress at 100 degrees F [12, p. 521]

$\sigma_{us200} := 66.1 \cdot ksi$ — Engineering tensile stress at 200 degrees F [12, p. 521]

$$\sigma_{us} := \frac{\sigma_{us200} - \sigma_{us100}}{200 - 100} \cdot (T_o - 100) + \sigma_{us100}$$

$\sigma_{us} = 67.387 \, ksi$ — Engineering tensile stress at operating temperature

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$\varepsilon_{ys} := \frac{\sigma_{ys}}{E_s}$ Engineering yield strain (0.2% offset is not considered)

$\varepsilon_{ys} = 0.000804 \frac{in}{in}$

Note: The referenced data for elongation (calculated below) is based on 304 stainless steel values. This is considered acceptable considering ASTM A312/A312M-03 provides identical elongation values for 304 and 304L stainless steel.

$\varepsilon_{ts} := 0.37 \cdot \frac{in}{in}$ Total elongation percentage [15, p. 3.1]

$R_{UE\_TE100} := 0.873$ Ratio of total elongation to uniform elongation at 100 degrees F [15, p. 2.0]

$R_{UE\_TE200} := 0.87$ Ratio of total elongation to uniform elongation at 200 degrees F [15, p. 2.0]

$$\varepsilon_{us} := \left[\frac{R_{UE\_TE200} - R_{UE\_TE100}}{200 - 100} \cdot (T_o - 100) + R_{UE\_TE100}\right] \cdot \varepsilon_{ts}$$

$\varepsilon_{us} = 0.322 \frac{in}{in}$ Uniform elongation at operating temperature

$\sigma_{Tys} := \sigma_{ys} \cdot (1 + \varepsilon_{ys})$ True yield stress [18, p. 51]

$\sigma_{Tys} = 22277.9$ psi

$\sigma_{Tus} := \sigma_{us} \cdot (1 + \varepsilon_{us})$ True ultimate stress [18, p. 51]

$\sigma_{Tus} = 89103.6$ psi

$\varepsilon_{Tys} := \ln(1 + \varepsilon_{ys})$ True yield strain [18, p. 51]

$\varepsilon_{Tys} = 0.0008033 \frac{in}{in}$

$\varepsilon_{Tus} := \ln(1 + \varepsilon_{us})$ True ultimate strain [18, p. 51]

$\varepsilon_{Tus} = 0.279 \frac{in}{in}$

$\varepsilon_{Tps} := \varepsilon_{Tus} - \frac{\sigma_{Tus}}{E_s}$ True plastic strain [18, p. 51]

$\varepsilon_{Tps} = 0.276 \frac{in}{in}$

Having the material properties for the model, stress allowables must be found. The stress allowables are from F-1341.2 Plastic Analysis [4] which state that the stress allowable is "the greater of 0.7S*u* and S*y* + 1/3 (S*u* - S*y*)."

$S_{allow1} := 0.7 \cdot \sigma_{us}$ First stress allowable option

$S_{allow1} = 47.171\ ksi$

$S_{allow2} := \sigma_{ys} + \frac{1}{3} \cdot (\sigma_{us} - \sigma_{ys})$ Second stress allowable option

$S_{allow2} = 37.302\ ksi$

$S_{allow} := S_{allow1} \cdot (S_{allow1} \geq S_{allow2}) + S_{allow2} \cdot (S_{allow1} < S_{allow2})$

$S_{allow} = 47.171\ ksi$ Stress allowable in engineering stress

It is desirable to present this allowable stress into a form easily compared to the ABAQUS output (which is based on true stress/strain). The most logical comparison with ABAQUS results is the plastic equivalent strain. This is a desirable value because it is an indicator of the maximum stress that occurred during the entire dynamic event. Considering the values of the previous section that are put into ABAQUS as a bilinear, true stress-strain curve, the following calculation was performed to find the allowable plastic equivalent strain (that is equivalent to the stress allowable in engineering stress above).

$\sigma_{Tg} := 53.8 \cdot ksi$ Allowable true stress guess for the given/find performed below

$\varepsilon_{Tg} := 0.132 \cdot \frac{in}{in}$ Allowable true strain guess for the given/find performed below

$\varepsilon_{allowg} := 0.142 \cdot \frac{in}{in}$ Allowable engineering strain guess for the given/find performed below

Given

$\sigma_{Tg} = \sigma_{Tys} + \left(\frac{\sigma_{Tus} - \sigma_{Tys}}{\varepsilon_{Tus} - \varepsilon_{Tys}}\right) \cdot (\varepsilon_{Tg} - \varepsilon_{Tys})$ Plastic portion of the true stress versus true stain equation used in ABAQUS

$\sigma_{Tg} = S_{allow} \cdot (1 + \varepsilon_{allowg})$ True stress versus engineering stress and engineering strain

$\varepsilon_{Tg} = \ln(1 + \varepsilon_{allowg})$ True strain versus engineering strain

$$\begin{pmatrix} \sigma_{Tallow} \\ \varepsilon_{Tallow} \\ \varepsilon_{allow} \end{pmatrix} := \text{Find}(\sigma_{Tg}, \varepsilon_{Tg}, \varepsilon_{allowg})$$

$\sigma_{Tallow} = 53.8\ \text{ksi}$ Stress allowable in true stress

$\varepsilon_{Tallow} = 0.132\ \frac{in}{in}$ True strain at the stress allowable

$\varepsilon_{allow} = 0.142$ Engineering strain at the stress allowable

$peeq_{allow} := \varepsilon_{Tallow} - \frac{\sigma_{Tallow}}{E_s}$ Allowable plastic equivalent strain

$peeq_{allow} = 0.130\ \frac{in}{in}$

Figure F.3.5-9 shows the plastic equivalent strain at the shell midplane with averaging turned off

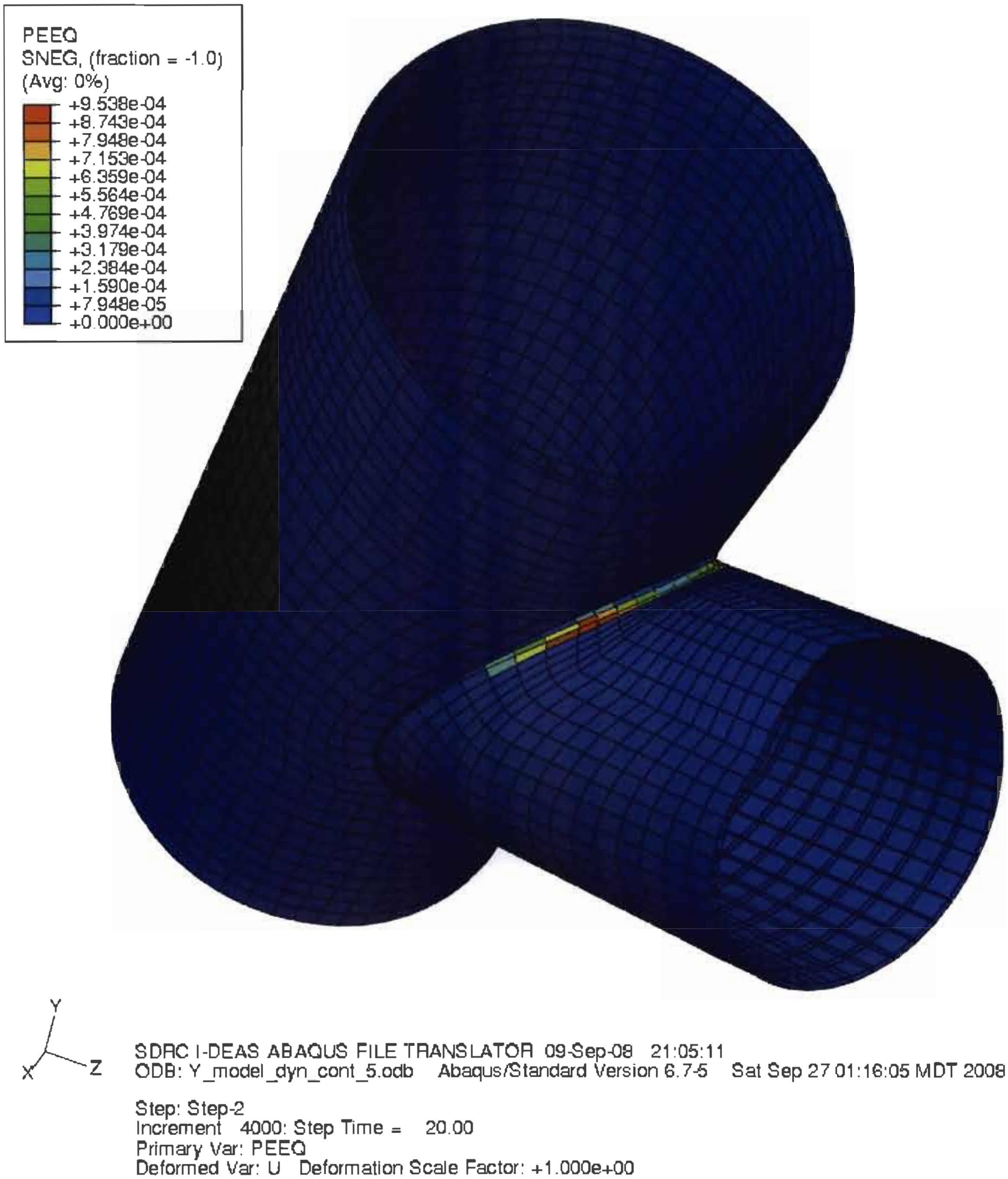

Figure F.3.5-9 – Plastic equivalent strain shown at the midplane with averaging turned off.

As shown in Figure F.3.5-9, the plastic equivalent strain is much less than the allowable 0.130 in/in. Thus, the unlisted branch component is acceptable.

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Before FE analysis was performed on model 14, scoping calculations were performed to provide flexibility adjusted section properties for the first branch element on each wye. A check must now be performed to ensure that, at the load level of the plastic analysis, the beam element model responds similar to the shell model. Figure F.3.5-10 shows the beam elements from the model 14 results. (The beams are reoriented from model 14 to align the branch with the global axis. This is done to simplify the test loading. The local axis of the first branch element is oriented relatively the same as in model 14.)

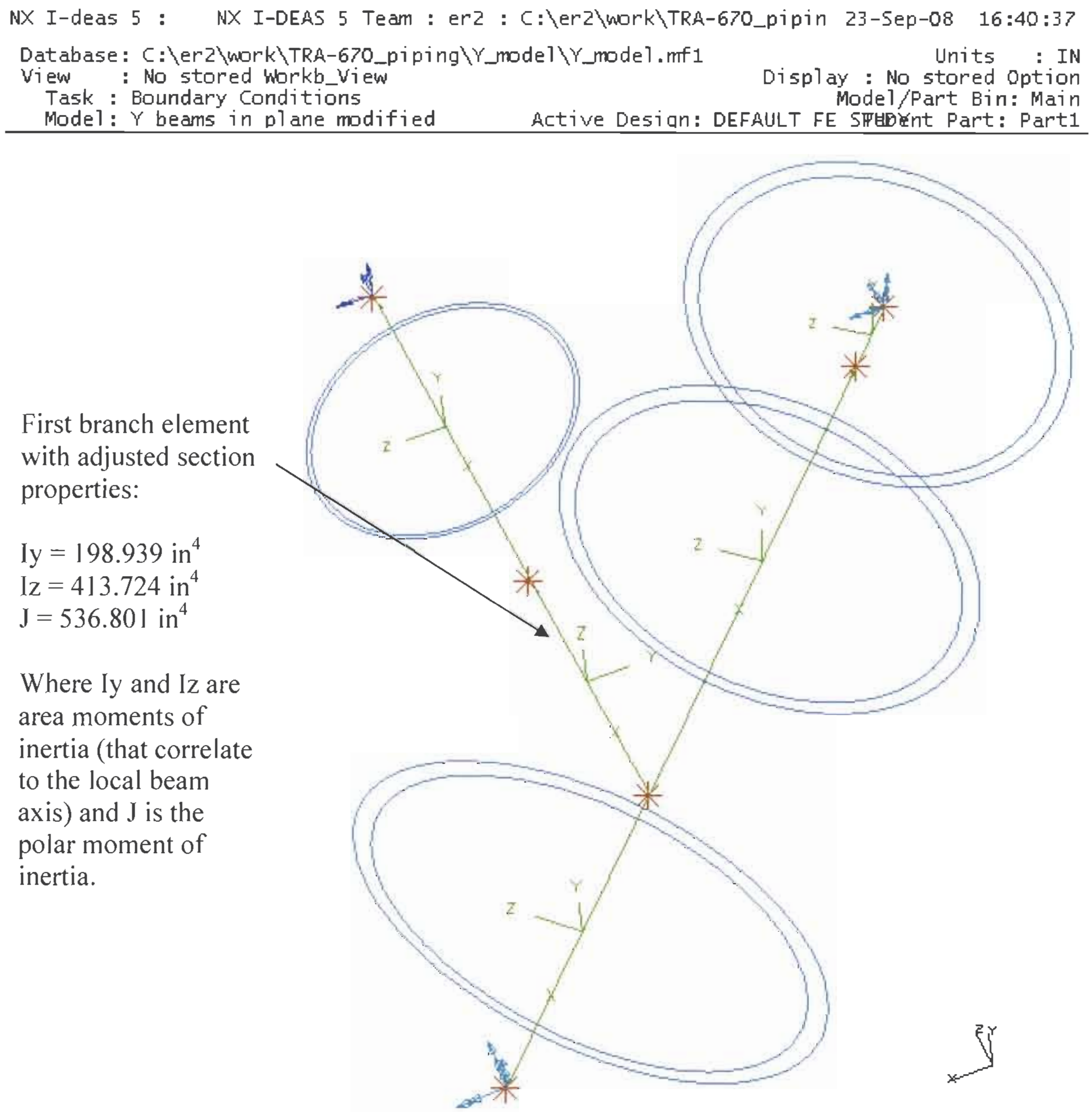

Figure F.3.5-10 – Beam model of the wye used to check flexibility.

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Figure F.3.5-11 shows the reoriented shell mesh for the flexibility check. (This reoriented to correlate with the beam model).

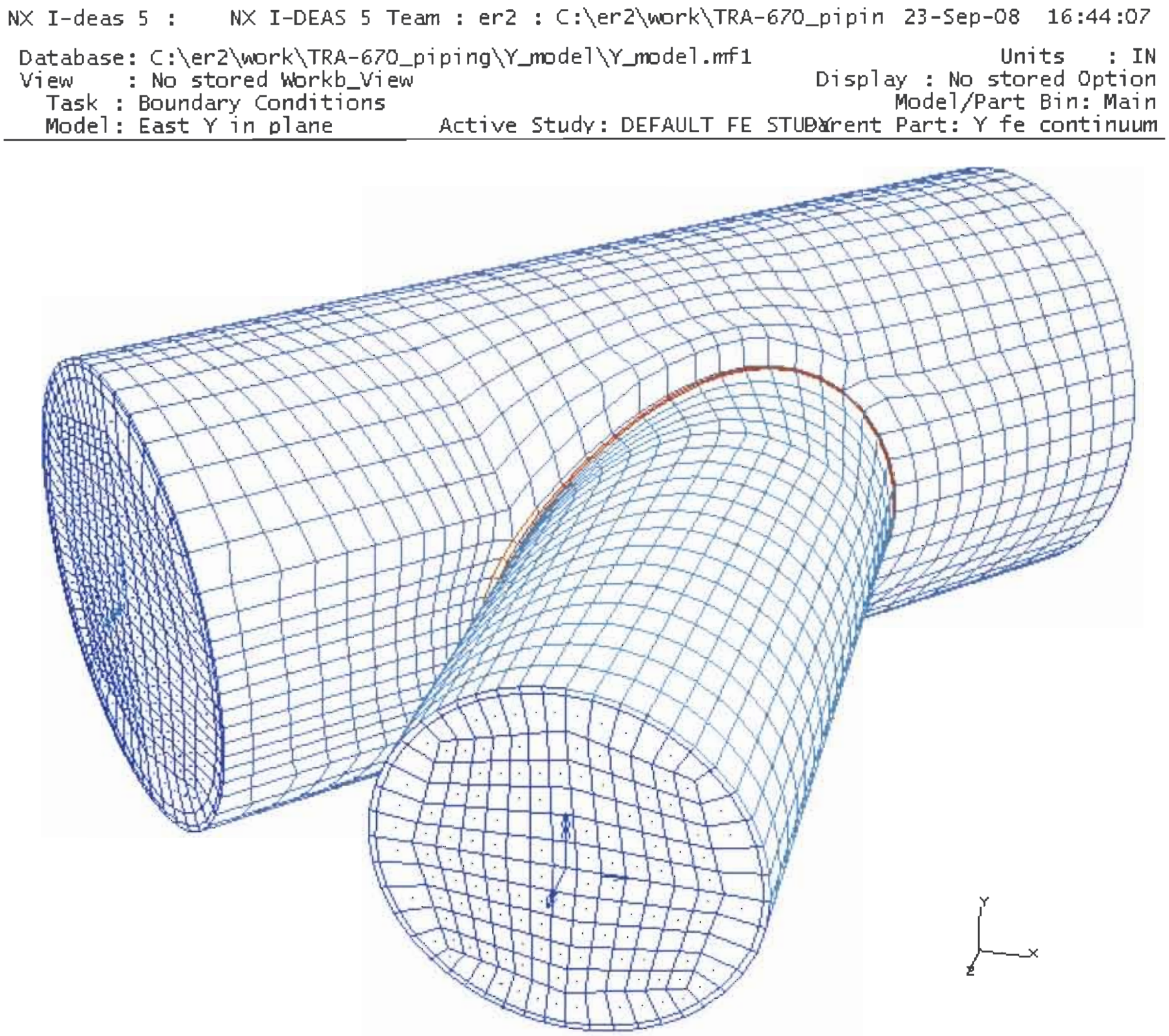

Figure F.3.5-11 – Shell model of the wye used to check flexibility.

The next step is to establish loading. From the model 14 results, 80th percentile moments are shown below.

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EL 387 ND 1050 (Real 12, Time 9.89)

$$M_{1050} := \left(1.707 \cdot 10^4 \quad -1.298 \cdot 10^4 \quad 6.734 \cdot 10^4\right)^T \cdot in \cdot lbf$$

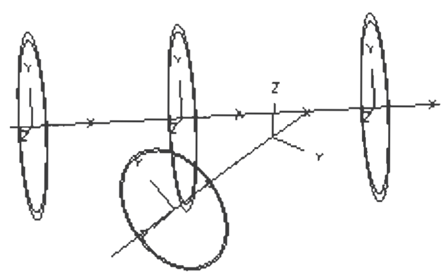
East wye 80th percentile branch moments from Appendix D

EL 389 ND 1051 (Real 6, Time 10.23)

$$M_{1051} := \left(-1.055 \cdot 10^4 \quad 5.768 \cdot 10^3 \quad 6.64 \cdot 10^4\right)^T \cdot in \cdot lbf$$

East wye 80th percentile branch moments from Appendix D

These moments are in the global axis of the model 14 run. Consequently, they need to be transformed into the global coordinates of the meshes used to check flexibility. Figure F.3.5-12 shows the two wyes as they are oriented in model 14. Using Figure F.3.5-12, measurements can be made to generate orthogonal transforms for each wye.



West wye

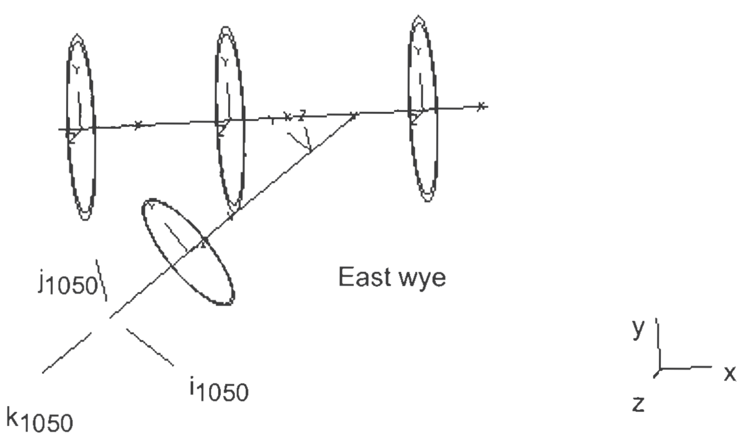


Figure F.3.5-12 – Model 14 wye orientation.

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$$i'_{1050} := \begin{pmatrix} 9.110175 \\ -6.111955 \\ 6.605443 \end{pmatrix} \quad i_{1050} := \frac{i'_{1050}}{|i'_{1050}|} \quad i_{1050} = \begin{pmatrix} 0.711 \\ -0.477 \\ 0.516 \end{pmatrix}$$

Unit i-direction vector for node 1050

$$k'_{1050} := \begin{pmatrix} -8.999326 \\ -6.187239 \\ 6.686805 \end{pmatrix} \quad k_{1050} := \frac{k'_{1050}}{|k'_{1050}|} \quad k_{1050} = \begin{pmatrix} -0.703 \\ -0.483 \\ 0.522 \end{pmatrix}$$

Unit k-direction vector for node 1050

$$j_{1050} := k_{1050} \times i_{1050} \quad j_{1050} = \begin{pmatrix} -2.005 \times 10^{-8} \\ 0.734 \\ 0.679 \end{pmatrix}$$

Unit j-direction vector for node 1050

$$Q_{1050} := \text{augment}(i_{1050}, j_{1050}, k_{1050})$$

Orthogonal transform for the east wye moment vector

$$Q_{1050} = \begin{pmatrix} 0.711 & -2.005 \times 10^{-8} & -0.703 \\ -0.477 & 0.734 & -0.483 \\ 0.516 & 0.679 & 0.522 \end{pmatrix}$$

$$i'_{1051} := \begin{pmatrix} -9.110175 \\ 6.111955 \\ 6.605443 \end{pmatrix} \quad i_{1051} := \frac{i'_{1051}}{|i'_{1051}|} \quad i_{1051} = \begin{pmatrix} -0.711 \\ 0.477 \\ 0.516 \end{pmatrix}$$

Unit i-direction vector for node 1050

$$k'_{1051} := \begin{pmatrix} -8.999326 \\ -6.187239 \\ -6.686805 \end{pmatrix} \quad k_{1051} := \frac{k'_{1051}}{|k'_{1051}|} \quad k_{1051} = \begin{pmatrix} -0.703 \\ -0.483 \\ -0.522 \end{pmatrix}$$

Unit k-direction vector for node 1050

$$j_{1051} := k_{1051} \times i_{1051} \quad j_{1051} = \begin{pmatrix} -2.005 \times 10^{-8} \\ 0.734 \\ -0.679 \end{pmatrix}$$

Unit j-direction vector for node 1050

$$Q_{1051} := \text{augment}(i_{1051}, j_{1051}, k_{1051})$$

Orthogonal transform for the east wye moment vector

$$Q_{1051} = \begin{pmatrix} -0.711 & -2.005 \times 10^{-8} & -0.703 \\ 0.477 & 0.734 & -0.483 \\ 0.516 & -0.679 & -0.522 \end{pmatrix}$$

Having the orthogonal transforms, the moments can be transformed and the maximum amplitude for each direction can be found.

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$M'_{1050} := Q_{1050} \cdot M_{1050}$ Transformed east wye moment

$$M'_{1050} = \begin{pmatrix} -3.518 \times 10^4 \\ -5.021 \times 10^4 \\ 3.515 \times 10^4 \end{pmatrix} in \cdot lbf$$

$M'_{1051} := Q_{1051} \cdot M_{1051}$ Transformed west wye moment

$$M'_{1051} = \begin{pmatrix} -3.916 \times 10^4 \\ -3.288 \times 10^4 \\ -4.403 \times 10^4 \end{pmatrix} in \cdot lbf$$

$$M' := \begin{bmatrix} \max\left(\left(\left|M'_{1050_0}\right| \quad \left|M'_{1051_0}\right|\right)\right) \\ \max\left(\left(\left|M'_{1050_1}\right| \quad \left|M'_{1051_1}\right|\right)\right) \\ \max\left(\left(\left|M'_{1050_2}\right| \quad \left|M'_{1051_2}\right|\right)\right) \end{bmatrix}$$

Maximum transformed moment in each direction

$$M' = \begin{pmatrix} 3.916 \times 10^4 \\ 5.021 \times 10^4 \\ 4.403 \times 10^4 \end{pmatrix} in \cdot lbf$$

To check the flexibility, three load cases are run with the beam and shell models. These models are run with the moments below because the moments below envelope those above (and they were completed in the scoping phase making reruns unnecessary).

$$M'' := \begin{pmatrix} 3.937 \times 10^4 \\ 5.067 \times 10^4 \\ 4.421 \times 10^4 \end{pmatrix} in \cdot lbf$$

Load applied to models

Each beam model load case consists of a single moment direction applied to its end branch node (i.e. 39,370 in•lbf in the Figure F.3.5-10 global x-direction, 50,670 in•lbf in the Figure F.3.5-10 global y-direction, or 44,210 in•lbf in the Figure F.3.5-10 global z-direction). The model is fully restrained where the run pipe is cut. Each shell model is run with the same boundary conditions as its corresponding beam model. However, the shell model has an additional initial step where an internal pressure of 272 psi is applied. Figure F.3.5-13 below shows the resulting angular displacement at the end of the branch versus moment applied at the same point. The plots include the results from the shell model and the beam model. Additionally, beam results scaled plus and minus 20% are included for information. The shell model results have two steps. Displacements that occur during the first step, due to the pressure loading, are subtracted from the total curve so that only the relative displacement of caused by the moment is plotted.

The input files used for the beam models were "Y_beam_model_4_STpm_1_mod.inp", "Y_beam_model_4_STpm_2_mod.inp", and "Y_beam_model_4_STpm_3_mod.inp". The input files used for the shell models were "Y_model_cont_4_STpm_1.inp", "Y_model_cont_4_STpm_2.inp", and "Y_model_cont_4_STpm_3.inp". In both sets of input files, the number change of 1, 2, and 3 represent the x-axis run, the y-axis run, and the z-axis run respectively.

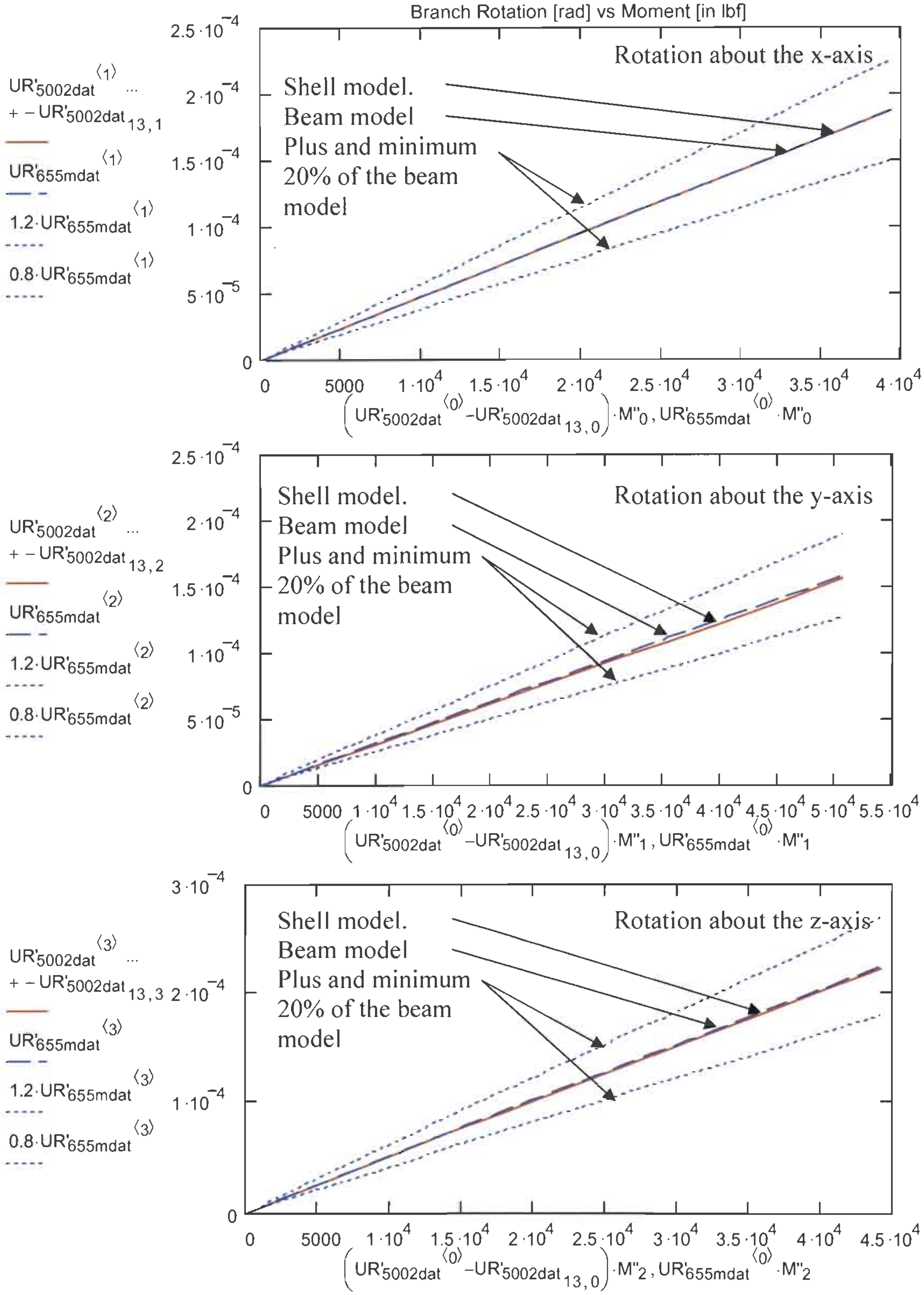

Figure F.3.5-13 – Model 14 wye branch rotation versus moment check.

Considering Figure F.3.5-13, the beam model is accurately modeling the two wyes.

F.3.6 – Elastic Evaluation of Unlisted Elbow/Branch Component

The second unlisted component (referred to as the unlisted elbow/branch component) is a 36-in x 1/2-in wall elbow (line 1-7) [27] that has a 6-in schedule 40 (0.28-in) pipe (line 1-40) [28] that extends out the back radius rotated by 45° from the elbow plane. The elbow is reinforced to the branch with a 5/8-in thick pad [22]. Figure F.3.6-1 illustrates model 14's unlisted elbow/branch component, as viewed looking in the south direction between two Heat Exchangers. The unlisted elbow/branchcomponent is fabricated from 304 stainless steel materials.

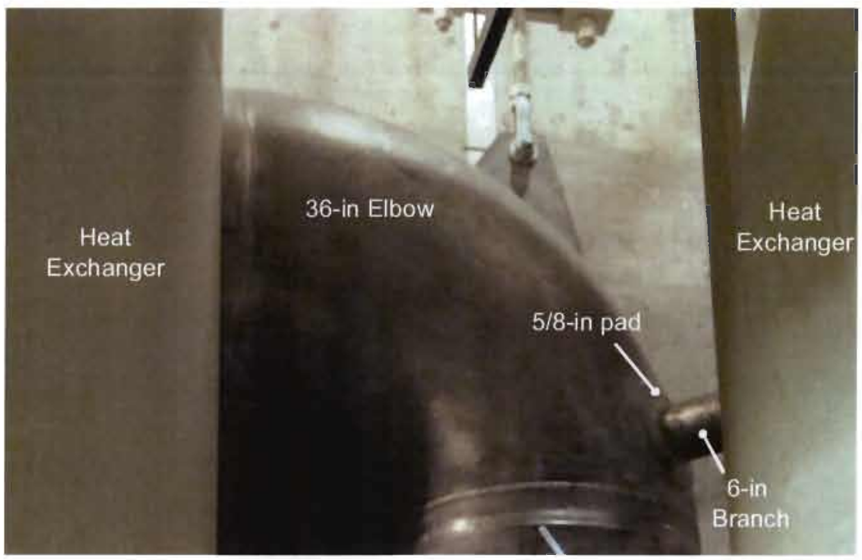

Figure F.3.6-1 – Model 14's unlisted elbow/branch component is shown, viewed looking South.

The unlisted elbow/branch component is a unique combination of a elbow and a branch, which in turn could be evaluated as two separate listed components. Figure F.3.6-2 shows a sketch of this situation. Note that the branch plane view (within Figure F.3.6-2) is inprecise, for it does not show the elbow curvature at 45°, but is sufficient for demonsration purposes.

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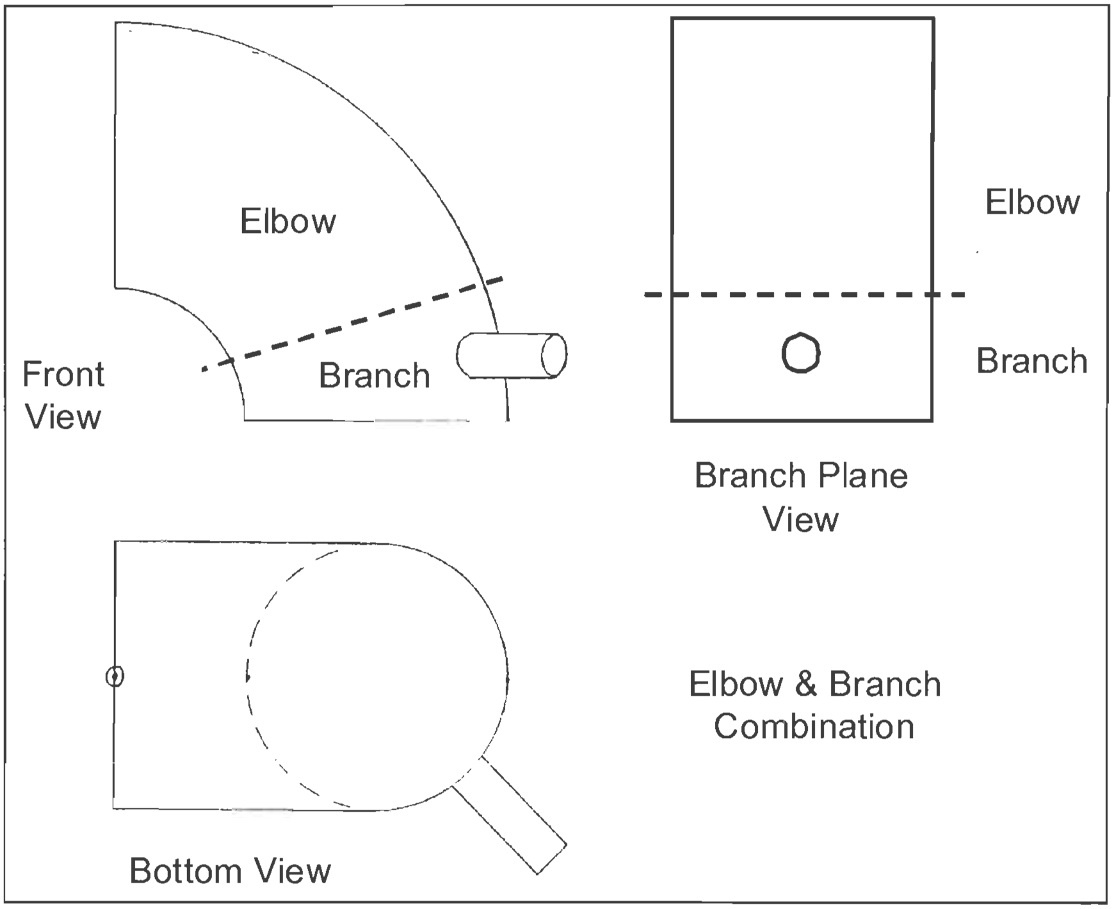

Figure F.3.6-2 – Illustration of Model 14's unlisted elbow and branch combination.

As can be seen in Figure 3.6-2, the 6-in branch is position very low on the elbow where internal and external elbow surface tangents are similar. Thus, the lower portion of the unlisted elbow/branch component could be approximated as a standard branch connected to a straight run. Likewise, because the branch is so low within the elbow, the upper elbow body could be evaluated as a listed elbow component separate from the lower listed branch. Previously evaluated unlisted elbow/branch components from Models 3 and 256, indicate that the branch has insignificant influence on the flexibility factor and has been treated like an elbow. Hence, this unlisted elbow/branch component is devided into two listed components and evaluated.

The listed branch component has a D/C = 0.342 result value, which is significantly under unity. Likewise, the listed elbow component has a maximum D/C value of 0.291 – also significantly under unity. The two listed branch and elbow components have a combined D/C = 0.633, when summed together. The actual D/C result for this unlisted elbow/branch component is somewhere between the branch's D/C= 0.342 and D/C= 0.633 maximum. Therefore, the unlisted elbow/branch component for Model 14 is acceptable.

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F.3.7 – Abbreviated Reprints of Model 14's ABAQUS Input Files

Input file names

1. si_mt_branch_ip.inp
2. si_mt_branch_op.inp
3. si_mt_nrun_ip.inp
4. si_mt_nrun_op.inp
5. Y_beam_model_5_STpm_1_mod.inp
6. Y_beam_model_5_STpm_2_mod.inp
7. Y_beam_model_5_STpm_3_mod.inp
8. Y_model_5_ST_1.inp
9. Y_model_5_ST_2.inp
10. Y_model_5_ST_3.inp
11. Y_model_dyn_cont_5.inp

si_mt_branch_ip.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Y_model\Y_model.mf1
**%          INPUT FILE: C:\er2\work\TRA-670_piping\Y_model\si_mt_branch_ip.inp
**%            EXPORTED: AT 14:07:54 ON 20-Aug-08
**%                PART: Y fe
**%                 FEM: Fem1
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  20-Aug-08   14:07:54
**%=========================================
**%          MODAL DATA
**%=========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL1_0
```

```
*ELEMENT, TYPE=S4      , ELSET=SHELL0_312
*SHELL SECTION,
 ELSET=SHELL1_0,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304L
  1.00000E+00,
*MATERIAL,NAME=SST304L
*ELASTIC,TYPE=ISOTROPIC
 2.7700E+07,  3.0000E-01
*DENSITY
 7.2520E-04,
*SHELL SECTION,
 ELSET=SHELL0_312,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304L
  3.12000E-01,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=CP0
*NSET,NSET=CP1
*NSET,NSET=CP2
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=Y, GENERATE
*ELSET,ELSET=HALF, GENERATE
**%
*ELSET, ELSET=BS000001, GENERATE
       205,      292,        1
       786,     1277,        1
      1338,     1473,        1
      1570,     1947,        1
      2011,     4352,        1
**%
*Surface, type=NODE, name=CP0
 CP0, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING0, REF NODE=5000, SURFACE=CP0
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP1
 CP1, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING1, REF NODE=5001, SURFACE=CP1
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP2
 CP2, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING2, REF NODE=5002, SURFACE=CP2
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,1.0
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      5001,  1, 6,      0.00000E+00
```

```
       5000,  1, 6,       0.00000E+00
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
BS000001,     P,-2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*MONITOR, NODE=1778, DOF=1
*END STEP
**%
**% ====== STATIC PRESSURE + Y-MOMENT ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,1.0
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       5001,  1, 6,       0.00000E+00
       5000,  1, 6,       0.00000E+00
**%  PRESSURE_MY
***CLOAD,OP=NEW
** 08/26/08 global coordinate moment reactions
**        5002,     4, 0.00000E+00
**        5002,     5, 8.4210E+04
**        5002,     6, 7.8886E+04
*CLOAD,OP=NEW
** 09/06/08 global coordinate moment reactions
       5002,     4, 0.00000E+00
       5002,     5, 7.2980E+04
       5002,     6, 6.7328E+04
*DLOAD,OP=NEW
BS000001,     P,-2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*MONITOR, NODE=1778, DOF=1
*END STEP
```

si_mt_branch_op.inp

```
**%   ============================================================
**%
**%               NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                      FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Y_model\Y_model.mf1
**%          INPUT FILE: C:\er2\work\TRA-670_piping\Y_model\si_mt_branch_op.inp
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:**	09/30/08	**Checker:** A. S. Siahpush	**Date:** 09/30/08

```
**%           EXPORTED: AT 14:07:54 ON 20-Aug-08
**%               PART: Y fe
**%                FEM: Fem1
**%
**%              UNITS: IN-Inch (pound f)
**%                    ... LENGTH : inch
**%                    ... TIME   : sec
**%                    ... MASS   : lbf-sec**2/in
**%                    ... FORCE  : pound (lbf)
**%                    ... TEMPERATURE : deg Fahrenheit
**%
**%        COORDINATE SYSTEM: PART
**%
**%            SUBSET EXPORT: OFF
**%
**%      NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  20-Aug-08   14:07:54
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL1_0
*ELEMENT, TYPE=S4      , ELSET=SHELL0_312
*SHELL SECTION,
 ELSET=SHELL1_0,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304L
  1.00000E+00,
*MATERIAL,NAME=SST304L
*ELASTIC,TYPE=ISOTROPIC
 2.7700E+07,  3.0000E-01
*DENSITY
 7.2520E-04,
*SHELL SECTION,
 ELSET=SHELL0_312,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304L
  3.12000E-01,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=CP0
*NSET,NSET=CP1
*NSET,NSET=CP2
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=Y, GENERATE
*ELSET,ELSET=HALF, GENERATE
**%
*ELSET, ELSET=BS000001, GENERATE
       205,       292,         1
```

```
      786,      1277,         1
     1338,      1473,         1
     1570,      1947,         1
     2011,      4352,         1
**%
*Surface, type=NODE, name=CP0
 CP0, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING0, REF NODE=5000, SURFACE=CP0
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP1
 CP1, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING1, REF NODE=5001, SURFACE=CP1
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP2
 CP2, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING2, REF NODE=5002, SURFACE=CP2
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,1.0
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       5001,  1, 6,      0.00000E+00
       5000,  1, 6,      0.00000E+00
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
BS000001,    P,-2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*MONITOR, NODE=1778, DOF=1
*END STEP
**%
**% ====== STATIC PRESSURE + X-MOMENT ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,1.0
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       5001,  1, 6,      0.00000E+00
       5000,  1, 6,      0.00000E+00
**%  PRESSURE_MX
***CLOAD,OP=NEW
** 08/26/08 global coordinate moment reactions
**       5002,    4, 7.9886E+04
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
**      5002,    5,-5.6924E+04
**      5002,    6, 6.0763E+04
*CLOAD,OP=NEW
** 09/06/08 global coordinate moment reactions
      5002,    4, 6.8182E+04
      5002,    5,-4.8584E+04
      5002,    6, 5.1861E+04
*DLOAD,OP=NEW
BS000001,    P,-2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*MONITOR, NODE=1778, DOF=1
*END STEP
```

si_mt_nrun_ip.inp

```
**%   ============================================================
**%
**%             NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                    FOR ABAQUS VERSION 6.x
**%
**%         MODEL FILE: C:\er2\work\TRA-670_piping\Y_model\Y_model.mf1
**%         INPUT FILE: C:\er2\work\TRA-670_piping\Y_model\si_mt_nrun_ip.inp
**%           EXPORTED: AT 14:07:54 ON 20-Aug-08
**%               PART: Y fe
**%                FEM: Fem1
**%
**%              UNITS: IN-Inch (pound f)
**%                    ... LENGTH : inch
**%                    ... TIME   : sec
**%                    ... MASS   : lbf-sec**2/in
**%                    ... FORCE  : pound (lbf)
**%                    ... TEMPERATURE : deg Fahrenheit
**%
**%        COORDINATE SYSTEM: PART
**%
**%            SUBSET EXPORT: OFF
**%
**%      NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  20-Aug-08   14:07:54
**%========================================
**%         MODAL DATA
**%========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL1_0
```

```
*ELEMENT, TYPE=S4      , ELSET=SHELL0_312
*SHELL SECTION,
 ELSET=SHELL1_0,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304L
  1.00000E+00,
*MATERIAL,NAME=SST304L
*ELASTIC,TYPE=ISOTROPIC
 2.7700E+07,  3.0000E-01
*DENSITY
 7.2520E-04,
*SHELL SECTION,
 ELSET=SHELL0_312,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304L
  3.12000E-01,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=CP0
*NSET,NSET=CP1
*NSET,NSET=CP2
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=Y, GENERATE
*ELSET,ELSET=HALF, GENERATE
**%
*ELSET, ELSET=BS000001, GENERATE
       205,       292,         1
       786,      1277,         1
      1338,      1473,         1
      1570,      1947,         1
      2011,      4352,         1
**%
*Surface, type=NODE, name=CP0
 CP0, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING0, REF NODE=5000, SURFACE=CP0
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP1
 CP1, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING1, REF NODE=5001, SURFACE=CP1
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP2
 CP2, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING2, REF NODE=5002, SURFACE=CP2
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,1.0
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       5001,  1, 6,      0.00000E+00
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
       5000,  1, 6,       0.00000E+00
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
BS000001,    P,-2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*MONITOR, NODE=1778, DOF=1
*END STEP
**%
**% ====== STATIC PRESSURE + Y-MOMENT ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,1.0
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
**       5001,  1, 6,       0.00000E+00
       5000,  1, 6,       0.00000E+00
**%  PRESSURE_MY
***CLOAD,OP=NEW
** 08/26/08 global coordinate moment reactions
**       5001,     4, 0.00000E+00
**       5001,     5, 3.45431E+05
**       5001,     6, 3.23521E+05
*CLOAD,OP=NEW
** 09/06/08 global coordinate moment reactions
       5001,     4, 0.00000E+00
       5001,     5, 2.52811E+05
       5001,     6, 2.36830E+05
*DLOAD,OP=NEW
BS000001,    P,-2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*MONITOR, NODE=1778, DOF=1
*END STEP
```

si_mt_nrun_op.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Y_model\Y_model.mf1
**%          INPUT FILE: C:\er2\work\TRA-670_piping\Y_model\si_mt_nrun_op.inp
```

```
**%           EXPORTED: AT 14:07:54 ON 20-Aug-08
**%               PART: Y fe
**%                FEM: Fem1
**%
**%              UNITS: IN-Inch (pound f)
**%                    ... LENGTH : inch
**%                    ... TIME   : sec
**%                    ... MASS   : lbf-sec**2/in
**%                    ... FORCE  : pound (lbf)
**%                    ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  20-Aug-08   14:07:54
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL1_0
*ELEMENT, TYPE=S4      , ELSET=SHELL0_312
*SHELL SECTION,
 ELSET=SHELL1_0,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304L
  1.00000E+00,
*MATERIAL,NAME=SST304L
*ELASTIC,TYPE=ISOTROPIC
 2.7700E+07,  3.0000E-01
*DENSITY
 7.2520E-04,
*SHELL SECTION,
 ELSET=SHELL0_312,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304L
  3.12000E-01,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=CP0
*NSET,NSET=CP1
*NSET,NSET=CP2
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=Y, GENERATE
*ELSET,ELSET=HALF, GENERATE
**%
*ELSET, ELSET=BS000001, GENERATE
      205,      292,        1
```

```
       786,     1277,        1
      1338,     1473,        1
      1570,     1947,        1
      2011,     4352,        1
**%
*Surface, type=NODE, name=CP0
 CP0, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING0, REF NODE=5000, SURFACE=CP0
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP1
 CP1, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING1, REF NODE=5001, SURFACE=CP1
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP2
 CP2, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING2, REF NODE=5002, SURFACE=CP2
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,1.0
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       5001,  1, 6,      0.00000E+00
       5000,  1, 6,      0.00000E+00
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
BS000001,    P,-2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*MONITOR, NODE=1778, DOF=1
*END STEP
**%
**% ====== STATIC PRESSURE + Y-MOMENT ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.005,1.0,1.0E-08,1.0
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
**       5001,  1, 6,      0.00000E+00
       5000,  1, 6,      0.00000E+00
**%  PRESSURE_MY
***CLOAD,OP=NEW
** 08/26/08 global coordinate moment reactions
**       5001,    4, 0.00000E+00
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:** 09/30/08	**Checker:** A. S. Siahpush	**Date:**	09/30/08

```
**       5001,    5, 3.23521E+05
**       5001,    6,-3.45351E+05
*CLOAD,OP=NEW
** 09/06/08 global coordinate moment reactions
       5001,    4, 0.00000E+00
       5001,    5, 2.36830E+05
       5001,    6,-2.52811E+05
*DLOAD,OP=NEW
BS000001,    P,-2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*MONITOR, NODE=1778, DOF=1
*END STEP
```

Y_beam_model_5_STpm_1_mod.inp

```
**%   ============================================================
**%
**%             NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                    FOR ABAQUS VERSION 6.x
**%
**%         MODEL FILE: C:\er2\work\TRA-670_piping\Y_model\Y_model.mf1
**%         INPUT FILE: C:\er2\work\TRA-
670_piping\Y_model\input\Y_beam_model_3_STpm_1_mod.inp
**%           EXPORTED: AT 12:44:04 ON 17-Sep-08
**%               PART: Part1
**%                FEM: Y beams in plane modified
**%
**%              UNITS: IN-Inch (pound f)
**%                    ... LENGTH : inch
**%                    ... TIME   : sec
**%                    ... MASS   : lbf-sec**2/in
**%                    ... FORCE  : pound (lbf)
**%                    ... TEMPERATURE : deg Fahrenheit
**%
**%        COORDINATE SYSTEM: PART
**%
**%            SUBSET EXPORT: OFF
**%
**%      NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  17-Sep-08   12:44:04
**%==========================================
**%         MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
```

```
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
**%
**% I-DEAS BEAM CROSS SECTION: BRANCH25_25X1_0
**%
*BEAM SECTION,
 MATERIAL=SST304L_24,
 ELSET=PIPE,
 SECTION=PIPE
 0.12625E+02, 0.10000E+01
-0.70275E+00, 0.00000E+00,-0.71143E+00
*MATERIAL,NAME=SST304L_24
*ELASTIC,TYPE=ISOTROPIC
 2.73600E+07,  2.90000E-01
*DENSITY
 2.17600E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE18_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304L_18,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.90000E+01, 0.31200E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304L_18
*ELASTIC,TYPE=ISOTROPIC
 2.73600E+07,  2.90000E-01
*DENSITY
 2.17600E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: WYE_KBH3_409_KBV1_639_KT2_527
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_2,
 DENSITY= 0.21760E-02,
 ZERO= 0.00000E+00
 0.17337E+02, 0.19894E+03, 0.00000E+00, 0.41372E+03, 0.53680E+03, 0, 0.00000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
 0.27360E+08, 0.10605E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% ====== Z-ROTATION ======
```

```
**%
*NSET,NSET=OUT
 655,745,748
*STEP,INC=1000000,NLGEOM
*STATIC
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       745,  1, 6,      0.00000E+00
       748,  1, 6,      0.00000E+00
*CLOAD,OP=NEW
      655,    4, 3.9160E+04
**       655,    5, 5.0210E+04
**       655,    6, 4.4030E+04
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=572, DOF=1
*END STEP
```

Y_beam_model_5_STpm_2_mod.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Y_model\Y_model.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Y_model\input\Y_beam_model_3_STpm_1_mod.inp
**%            EXPORTED: AT 12:44:04 ON 17-Sep-08
**%                PART: Part1
**%                 FEM: Y beams in plane modified
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
```

```
**%
**%    ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  17-Sep-08   12:44:04
**%=============================================
**%          MODAL DATA
**%=============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
**%
**% I-DEAS BEAM CROSS SECTION: BRANCH25_25X1_0
**%
*BEAM SECTION,
 MATERIAL=SST304L_24,
 ELSET=PIPE,
 SECTION=PIPE
 0.12625E+02, 0.10000E+01
-0.70275E+00, 0.00000E+00,-0.71143E+00
*MATERIAL,NAME=SST304L_24
*ELASTIC,TYPE=ISOTROPIC
 2.73600E+07,  2.90000E-01
*DENSITY
 2.17600E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE18_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304L_18,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.90000E+01, 0.31200E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304L_18
*ELASTIC,TYPE=ISOTROPIC
 2.73600E+07,  2.90000E-01
*DENSITY
 2.17600E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: WYE_KBH3_409_KBV1_639_KT2_527
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_2,
```

```
 DENSITY= 0.21760E-02,
 ZERO= 0.00000E+00
 0.17337E+02, 0.19894E+03, 0.00000E+00, 0.41372E+03, 0.53680E+03, 0, 0.00000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
 0.27360E+08, 0.10605E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% ====== Z-ROTATION ======
**%
*NSET,NSET=OUT
 655,745,748
*STEP,INC=1000000,NLGEOM
*STATIC
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       745,  1, 6,      0.00000E+00
       748,  1, 6,      0.00000E+00
*CLOAD,OP=NEW
**       655,    4, 3.9160E+04
       655,    5, 5.0210E+04
**       655,    6, 4.4030E+04
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=572, DOF=1
*END STEP
```

Y_beam_model_5_STpm_3_mod.inp

```
**%   ============================================================
**%
**%             NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                    FOR ABAQUS VERSION 6.x
**%
**%         MODEL FILE: C:\er2\work\TRA-670_piping\Y_model\Y_model.mf1
**%         INPUT FILE: C:\er2\work\TRA-
670_piping\Y_model\input\Y_beam_model_3_STpm_1_mod.inp
**%           EXPORTED: AT 12:44:04 ON 17-Sep-08
**%               PART: Part1
**%                FEM: Y beams in plane modified
**%
**%              UNITS: IN-Inch (pound f)
```

```
**%                    ... LENGTH : inch
**%                    ... TIME   : sec
**%                    ... MASS   : lbf-sec**2/in
**%                    ... FORCE  : pound (lbf)
**%                    ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  17-Sep-08   12:44:04
**%=========================================
**%          MODAL DATA
**%=========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
**%
**% I-DEAS BEAM CROSS SECTION: BRANCH25_25X1_0
**%
*BEAM SECTION,
 MATERIAL=SST304L_24,
 ELSET=PIPE,
 SECTION=PIPE
 0.12625E+02, 0.10000E+01
-0.70275E+00, 0.00000E+00,-0.71143E+00
*MATERIAL,NAME=SST304L_24
*ELASTIC,TYPE=ISOTROPIC
 2.73600E+07,  2.90000E-01
*DENSITY
 2.17600E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE18_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304L_18,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.90000E+01, 0.31200E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304L_18
*ELASTIC,TYPE=ISOTROPIC
 2.73600E+07,  2.90000E-01
```

```
*DENSITY
 2.17600E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: WYE_KBH3_409_KBV1_639_KT2_527
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_2, .
 DENSITY= 0.21760E-02,
 ZERO= 0.00000E+00
 0.17337E+02, 0.19894E+03, 0.00000E+00, 0.41372E+03, 0.53680E+03, 0, 0.00000E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
 0.27360E+08, 0.10605E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% ====== Z-ROTATION ======
**%
*NSET,NSET=OUT
 655,745,748
*STEP,INC=1000000,NLGEOM
*STATIC
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       745,  1, 6,      0.00000E+00
       748,  1, 6,      0.00000E+00
*CLOAD,OP=NEW
**       655,    4, 3.9160E+04
**       655,    5, 5.0210E+04
       655,    6, 4.4030E+04
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=572, DOF=1
*END STEP
```

Y_model_5_ST_1.inp

```
**%   ============================================================
**%
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:** 09/30/08	**Checker:** A. S. Siahpush	**Date:**	09/30/08

```
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Y_model\Y_model.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Y_model\input\Y_model_5_ST_1.inp
**%            EXPORTED: AT 00:10:04 ON 27-Sep-08
**%                PART: Y fe
**%                 FEM: East Y in plane
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  27-Sep-08   00:10:04
**%========================================
**%          MODAL DATA
**%========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL1_0
*ELEMENT, TYPE=S4      , ELSET=SHELL0_312
*SHELL SECTION,
 ELSET=SHELL1_0,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304L
  1.00000E+00,
*MATERIAL,NAME=SST304L
*ELASTIC,TYPE=ISOTROPIC
 2.73600E+07,  2.90000E-01
*DENSITY
 7.51100E-04,
*PLASTIC
 22277.9, 0.0
 89103.6, 0.276
*SHELL SECTION,
 ELSET=SHELL0_312,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304L
  3.12000E-01,
**%
*ELSET, ELSET=ALLELEMENTS
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:** 09/30/08	**Checker:** A. S. Siahpush	**Date:**	09/30/08

```
 SHELL1_0,
 SHELL0_312,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=CP0
*NSET,NSET=CP1
*NSET,NSET=CP2
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=Y, GENERATE
*ELSET,ELSET=HALF, GENERATE
**%
*ELSET, ELSET=BS000001, GENERATE
*NSET,NSET=BS000002
3894,3896,3897,3898,3909,3910,3911,3912,3923,3924,3925,3926
*NSET,NSET=OUT
 5000,5001,5002
**%
*Surface, type=NODE, name=CP0
 CP0, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING0, REF NODE=5000, SURFACE=CP0
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP1
 CP1, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING1, REF NODE=5001, SURFACE=CP1
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP2
 CP2, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING2, REF NODE=5002, SURFACE=CP2
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.005,1.0,1.0E-08,1.0
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       5001,  1, 6,      0.00000E+00
       5000,  1, 6,      0.00000E+00
**%  PRESSURE_
*DLOAD,OP=NEW
BS000001,    P,-2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
```

```
*MONITOR, NODE=1973, DOF=1
*END STEP
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  PRESSURE_MX
*CLOAD,OP=NEW
      5002,     4, 3.9160E+04
**        5002,     5, 5.0210E+04
**        5002,     6, 4.4030E+04
*DLOAD,OP=NEW
BS000001,    P,-2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=1973, DOF=1
*END STEP
```

Y_model_5_ST_2.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Y_model\Y_model.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Y_model\input\Y_model_5_ST_1.inp
**%            EXPORTED: AT 00:10:04 ON 27-Sep-08
**%                PART: Y fe
**%                 FEM: East Y in plane
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%        COORDINATE SYSTEM: PART
**%
**%            SUBSET EXPORT: OFF
```

```
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  27-Sep-08   00:10:04
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL1_0
*ELEMENT, TYPE=S4      , ELSET=SHELL0_312
*SHELL SECTION,
 ELSET=SHELL1_0,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304L
  1.00000E+00,
*MATERIAL,NAME=SST304L
*ELASTIC,TYPE=ISOTROPIC
 2.73600E+07,  2.90000E-01
*DENSITY
 7.51100E-04,
*PLASTIC
 22277.9, 0.0
 89103.6, 0.276
*SHELL SECTION,
 ELSET=SHELL0_312,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304L
  3.12000E-01,
**%
*ELSET, ELSET=ALLELEMENTS
 SHELL1_0,
 SHELL0_312,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=CP0
*NSET,NSET=CP1
*NSET,NSET=CP2
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=Y, GENERATE
*ELSET,ELSET=HALF, GENERATE
**%
*ELSET, ELSET=BS000001, GENERATE
*NSET,NSET=BS000002
3894,3896,3897,3898,3909,3910,3911,3912,3923,3924,3925,3926
*NSET,NSET=OUT
 5000,5001,5002
**%
*Surface, type=NODE, name=CP0
 CP0, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING0, REF NODE=5000, SURFACE=CP0
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP1
 CP1, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING1, REF NODE=5001, SURFACE=CP1
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP2
 CP2, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING2, REF NODE=5002, SURFACE=CP2
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.005,1.0,1.0E-08,1.0
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       5001,  1, 6,      0.00000E+00
       5000,  1, 6,      0.00000E+00
**%  PRESSURE_
*DLOAD,OP=NEW
BS000001,    P,-2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=1973, DOF=1
*END STEP
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  PRESSURE_MX
*CLOAD,OP=NEW
**       5002,    4, 3.9160E+04
       5002,    5, 5.0210E+04
**       5002,    6, 4.4030E+04
*DLOAD,OP=NEW
BS000001,    P,-2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
```

```
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=1973, DOF=1
*END STEP
```

Y_model_5_ST_3.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Y_model\Y_mode1.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Y_model\input\Y_model_5_ST_1.inp
**%            EXPORTED: AT 00:10:04 ON 27-Sep-08
**%                PART: Y fe
**%                 FEM: East Y in plane
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  27-Sep-08   00:10:04
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4       , ELSET=SHELL1_0
*ELEMENT, TYPE=S4       , ELSET=SHELL0_312
*SHELL SECTION,
 ELSET=SHELL1_0,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304L
  1.00000E+00,
*MATERIAL,NAME=SST304L
```

```
*ELASTIC,TYPE=ISOTROPIC
 2.73600E+07,  2.90000E-01
*DENSITY
 7.51100E-04,
*PLASTIC
 22277.9, 0.0
 89103.6, 0.276
*SHELL SECTION,
 ELSET=SHELL0_312,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304L
  3.12000E-01,
**%
*ELSET, ELSET=ALLELEMENTS
 SHELL1_0,
 SHELL0_312,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=CP0
*NSET,NSET=CP1
*NSET,NSET=CP2
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=Y, GENERATE
*ELSET,ELSET=HALF, GENERATE
**%
*ELSET, ELSET=BS000001, GENERATE
*NSET,NSET=BS000002
3894,3896,3897,3898,3909,3910,3911,3912,3923,3924,3925,3926
*NSET,NSET=OUT
 5000,5001,5002
**%
*Surface, type=NODE, name=CP0
 CP0, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING0, REF NODE=5000, SURFACE=CP0
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP1
 CP1, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING1, REF NODE=5001, SURFACE=CP1
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP2
 CP2, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING2, REF NODE=5002, SURFACE=CP2
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.005,1.0,1.0E-08,1.0
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       5001,  1, 6,      0.00000E+00
       5000,  1, 6,      0.00000E+00
```

```
**%  PRESSURE_
*DLOAD,OP=NEW
BS000001,    P,-2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=1973, DOF=1
*END STEP
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%  PRESSURE_MX
*CLOAD,OP=NEW
**       5002,     4, 3.9160E+04
**       5002,     5, 5.0210E+04
       5002,     6, 4.4030E+04
*DLOAD,OP=NEW
BS000001,    P,-2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=1973, DOF=1
*END STEP
```

Y_model_dyn_cont_5.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Y_model\Y_model.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Y_model\input\Y_model_dyn_cont_e_2.inp
```

```
**%            EXPORTED: AT 21:05:11 ON 09-Sep-08
**%                PART: Y fe continuum
**%                 FEM: Fem1
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  09-Sep-08   21:05:11
**%============================================
**%           MODAL DATA
**%============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL0_312
*ELEMENT, TYPE=SC8R, ELSET=SOLID40
*SHELL SECTION,
 ELSET=SHELL0_312,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304L
  3.12000E-01,
*MATERIAL,NAME=SST304L
*ELASTIC,TYPE=ISOTROPIC
 2.73600E+07,  2.90000E-01
*DENSITY
 7.51100E-04,
*PLASTIC
 22277.9, 0.0
 89103.6, 0.276
*DAMPING, ALPHA=0.7486, BETA=1.693E-3
*SHELL SECTION, ELSET=SOLID40, MATERIAL=SST304L
 5.0,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=CP0
*NSET,NSET=CP1
*NSET,NSET=CP2, GENERATE
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=Y, GENERATE
*ELSET,ELSET=HALF, GENERATE
**%
*AMPLITUDE, NAME=R28N655D1
```

```
*AMPLITUDE, NAME=R28N655D2
*AMPLITUDE, NAME=R28N655D3
*AMPLITUDE, NAME=R28N655D4
*AMPLITUDE, NAME=R28N655D5
*AMPLITUDE, NAME=R28N655D6
*AMPLITUDE, NAME=R28N745D1
*AMPLITUDE, NAME=R28N745D2
*AMPLITUDE, NAME=R28N745D4
*AMPLITUDE, NAME=R28N745D5
*AMPLITUDE, NAME=R28N745D6
*AMPLITUDE, NAME=R28N748D1
*AMPLITUDE, NAME=R28N748D2
*AMPLITUDE, NAME=R28N748D3
*AMPLITUDE, NAME=R28N748D4
*AMPLITUDE, NAME=R28N748D5
*AMPLITUDE, NAME=R28N748D6
**%
*NSET,NSET=BS000001
19712,19713,19714,19715,19725,19726,19727,19728,19737,19738,19739,19740
*ELSET, ELSET=BS000002, GENERATE
*ELSET, ELSET=BS000003, GENERATE
*ELSET, ELSET=BS000004, GENERATE
*ELSET, ELSET=BS000005, GENERATE
*NSET,NSET=OUT
 5000,5001,5002
**%
*Surface, type=NODE, name=CP0
 CP0, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING0, REF NODE=5000, SURFACE=CP0
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP1
 CP1, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING1, REF NODE=5001, SURFACE=CP1
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP2
 CP2, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING2, REF NODE=5002, SURFACE=CP2
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
**%
**% ====== STATIC PRESSURE ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.005,1.0,1.0E-08,1.0
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
5000, 1, , -1.33E-02
5000, 2, , -9.42E-02
5000, 3, , 1.71E-02
5000, 4, , 5.33E-04
5000, 5, , 9.70E-06
5000, 6, , 3.35E-04
5001, 1, , -1.33E-02
```

```
5001, 2, , -7.41E-02
5001, 3, , 1.66E-02
5001, 4, , 5.55E-04
5001, 5, , 7.28E-06
5001, 6, , 3.63E-04
5002, 1, , -5.85E-03
5002, 2, , -1.05E-01
5002, 3, , 4.20E-03
5002, 4, , 5.70E-04
5002, 5, , 4.37E-06
5002, 6, , 2.89E-04
*CLOAD,OP=NEW
BS000001,    2, 5.0000E+02
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
BS000002,    P,-2.7200E+02
BS000003,   P2, 2.7200E+02
BS000004,   P4, 2.7200E+02
BS000005,   P6, 2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*MONITOR, NODE=6626, DOF=1
*END STEP
**%
**% ====== SEISMIC WITH G-LOAD ======
**%
**% Note: Damping is address in the material properties
**%
*STEP,INC=10000000,NLGEOM
*DYNAMIC, DIRECT
 0.005,20.0,1.0E-08,0.005
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%
*BOUNDARY,AMPLITUDE=R28N655D1,OP=NEW,TYPE=DISPLACEMENT
      5002,  1, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R28N655D2,OP=NEW,TYPE=DISPLACEMENT
      5002,  2, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R28N655D3,OP=NEW,TYPE=DISPLACEMENT
      5002,  3, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R28N655D4,OP=NEW,TYPE=DISPLACEMENT
      5002,  4, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R28N655D5,OP=NEW,TYPE=DISPLACEMENT
      5002,  5, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R28N655D6,OP=NEW,TYPE=DISPLACEMENT
      5002,  6, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R28N745D1,OP=NEW,TYPE=DISPLACEMENT
      5000,  1, ,      1.00000E+00
*BOUNDARY,AMPLITUDE=R28N745D2,OP=NEW,TYPE=DISPLACEMENT
      5000,  2, ,      1.00000E+00
```

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```
*BOUNDARY,AMPLITUDE=R28N745D3,OP=NEW,TYPE=DISPLACEMENT
       5000,  3, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R28N745D4,OP=NEW,TYPE=DISPLACEMENT
       5000,  4, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R28N745D5,OP=NEW,TYPE=DISPLACEMENT
       5000,  5, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R28N745D6,OP=NEW,TYPE=DISPLACEMENT
       5000,  6, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R28N748D1,OP=NEW,TYPE=DISPLACEMENT
       5001,  1, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R28N748D2,OP=NEW,TYPE=DISPLACEMENT
       5001,  2, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R28N748D3,OP=NEW,TYPE=DISPLACEMENT
       5001,  3, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R28N748D4,OP=NEW,TYPE=DISPLACEMENT
       5001,  4, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R28N748D5,OP=NEW,TYPE=DISPLACEMENT
       5001,  5, ,       1.00000E+00
*BOUNDARY,AMPLITUDE=R28N748D6,OP=NEW,TYPE=DISPLACEMENT
       5001,  6, ,       1.00000E+00
*CLOAD,OP=NEW
BS000001,    2, 5.0000E+02
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
BS000002,    P,-2.7200E+02
BS000003,   P2, 2.7200E+02
BS000004,   P4, 2.7200E+02
BS000005,   P6, 2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=6626, DOF=1
*END STEP
```

Appendix F.4
Select Plastic Evaluations and Flexibility Factors of Over-Unity Components

Contents — Page

F.4.1 – Plastic Evaluation of Tee with Maximum D/C

There are several tee components that have D/Cs greater than one. The purpose of this section is to perform a plastic evaluation on the tee with the highest D/C. To perform the plastic analysis, displacement results versus time are gathered from realization 17 of the beam element model 265 (shown in Figure F.4.1-1). These displacement results are then applied to a shell modeled cutout of the tee. This realization of model 265 the 80th percentile realization for this tee.

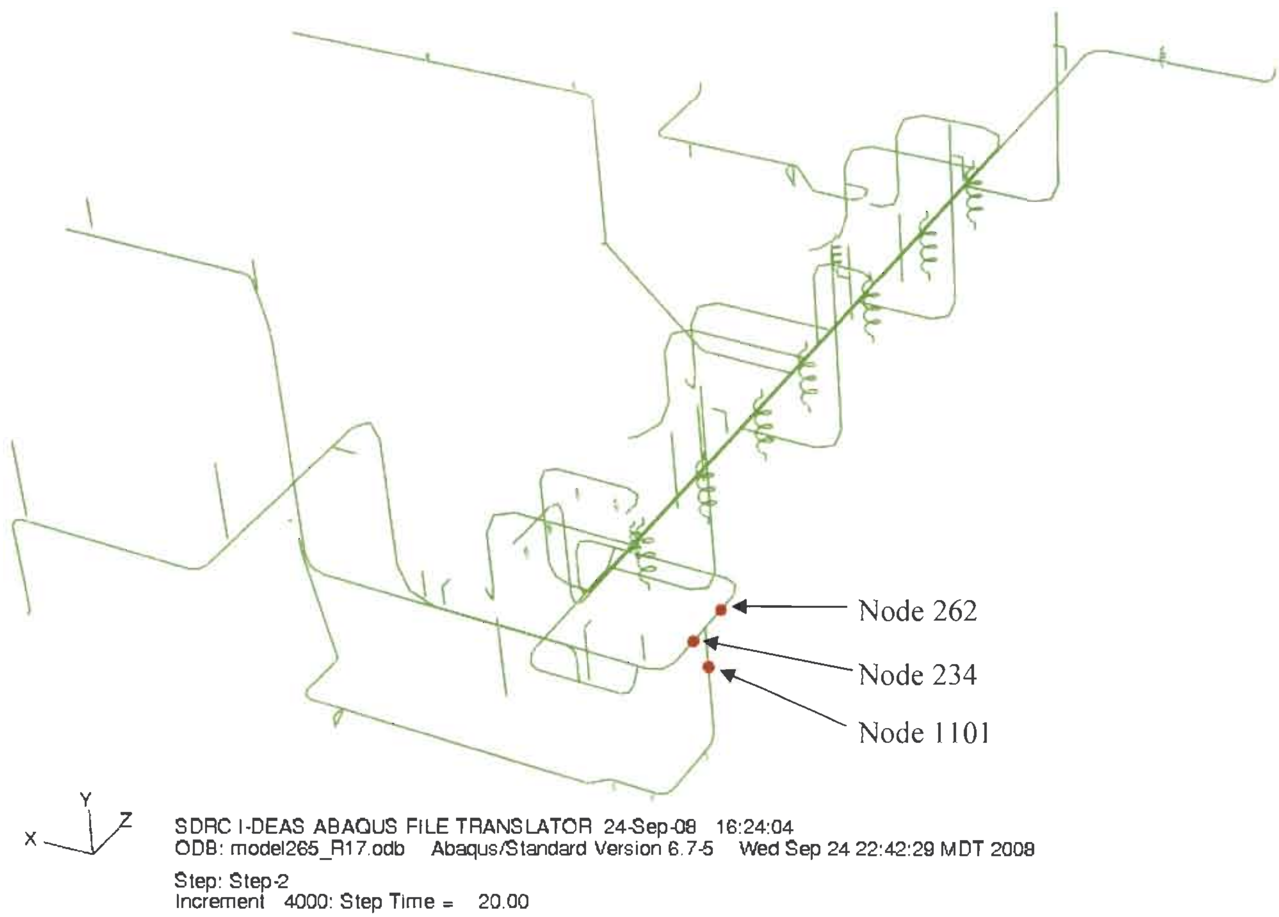

Figure F.4.1-1 – Realization 17 of the piping model.

The displacement results from Model 265 nodes 234, 262, and 1101 are shown in Figure F.4.1-2.

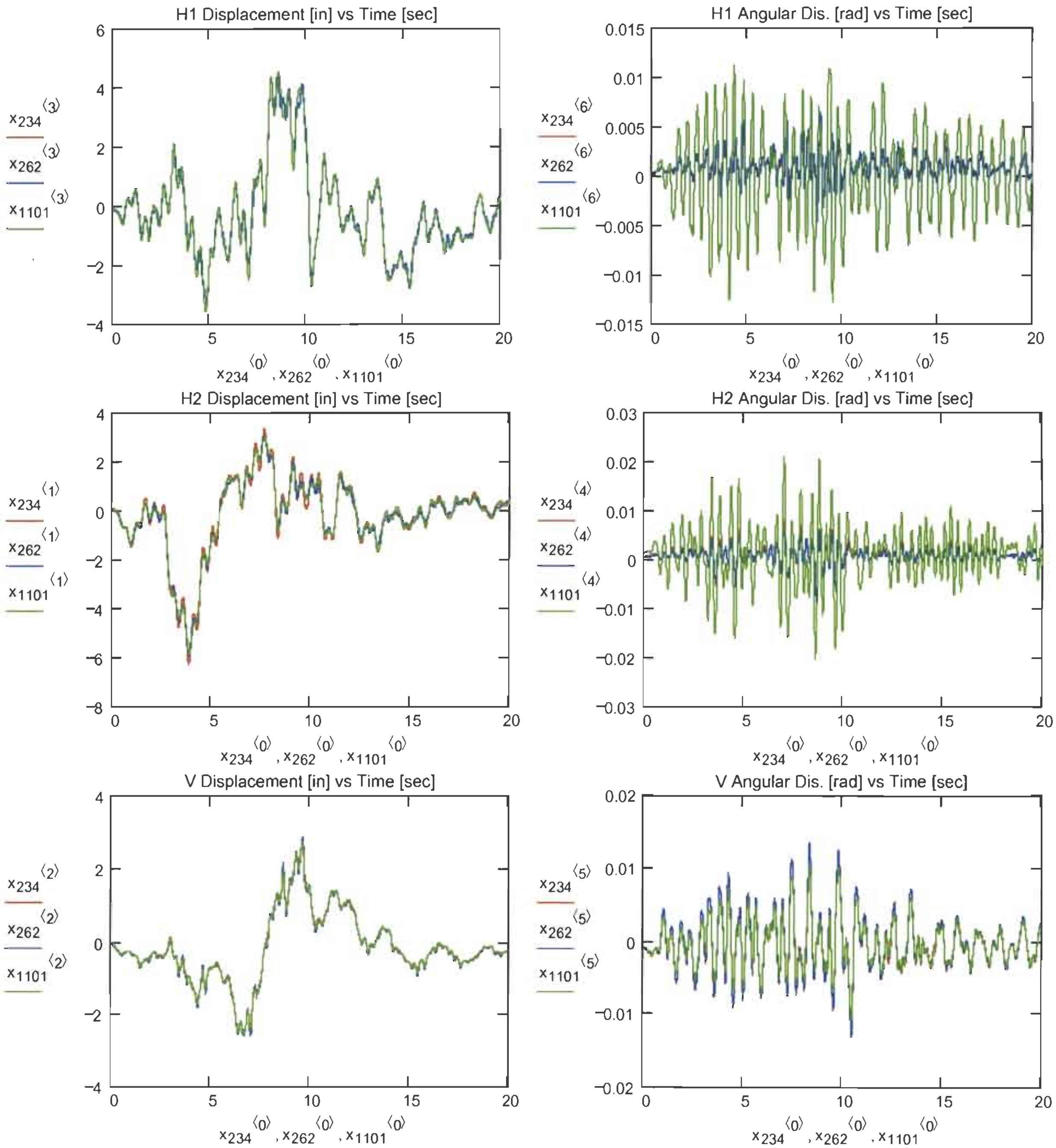

Figure F.4.1-2 – Displacement plots for nodes identified in Figure F.4.1-1.

Figure F.4.1-2 shows the translational and rotational displacement in the nodes output from realization 17 (shown in Figure F.4.1-1). In the plot variables, "x" indicates displacement and the subscript that follows is the node number from Figure F.4.1-1. H1 represents the east/west direction and it is on the z-

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axis in the model plots.. H2 represents the north/south direction and it is on the x-axis in the model plots. V represents the vertical direction and it is on the y-axis in the model plots.

The plastic analysis for the tee was performed by generating a linear quadrilateral and continuum shell model (as shown in Figures F.4.1-3 - F.4.1-8) of the region including the nodes identified in Figure F.4.1-1. This model includes a 10 schedule 20 run pipe with a 6 inch schedule 40 branch pipe. These pipes are modeled with linear continuum shells and a 0.25 inch fillet weld is added at the connection of the pipes. The cut ends of the pipes are covered with 0.25 inch thick linear quadrilateral shells that contain the pressure.

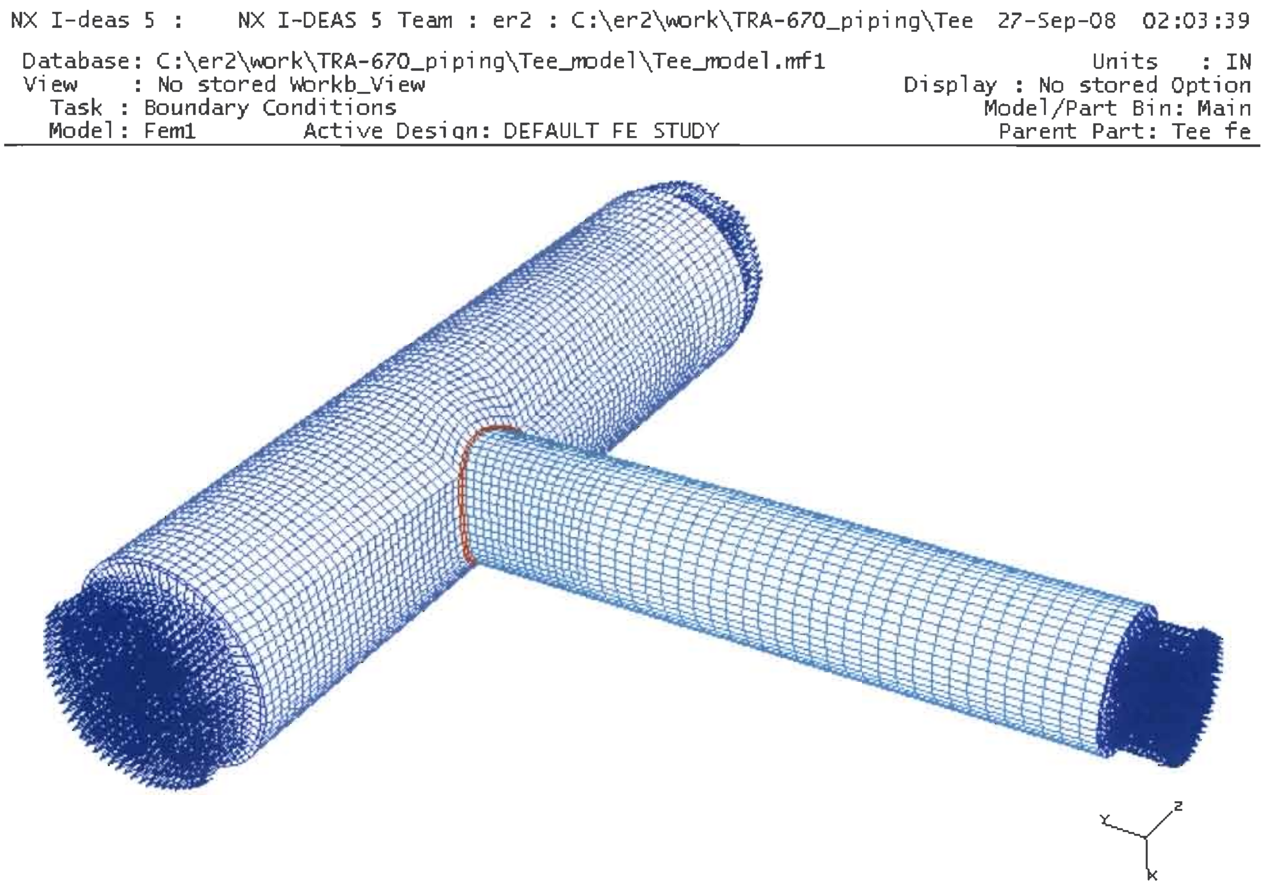

Figure F.4.1-3 – Mesh of the full model.

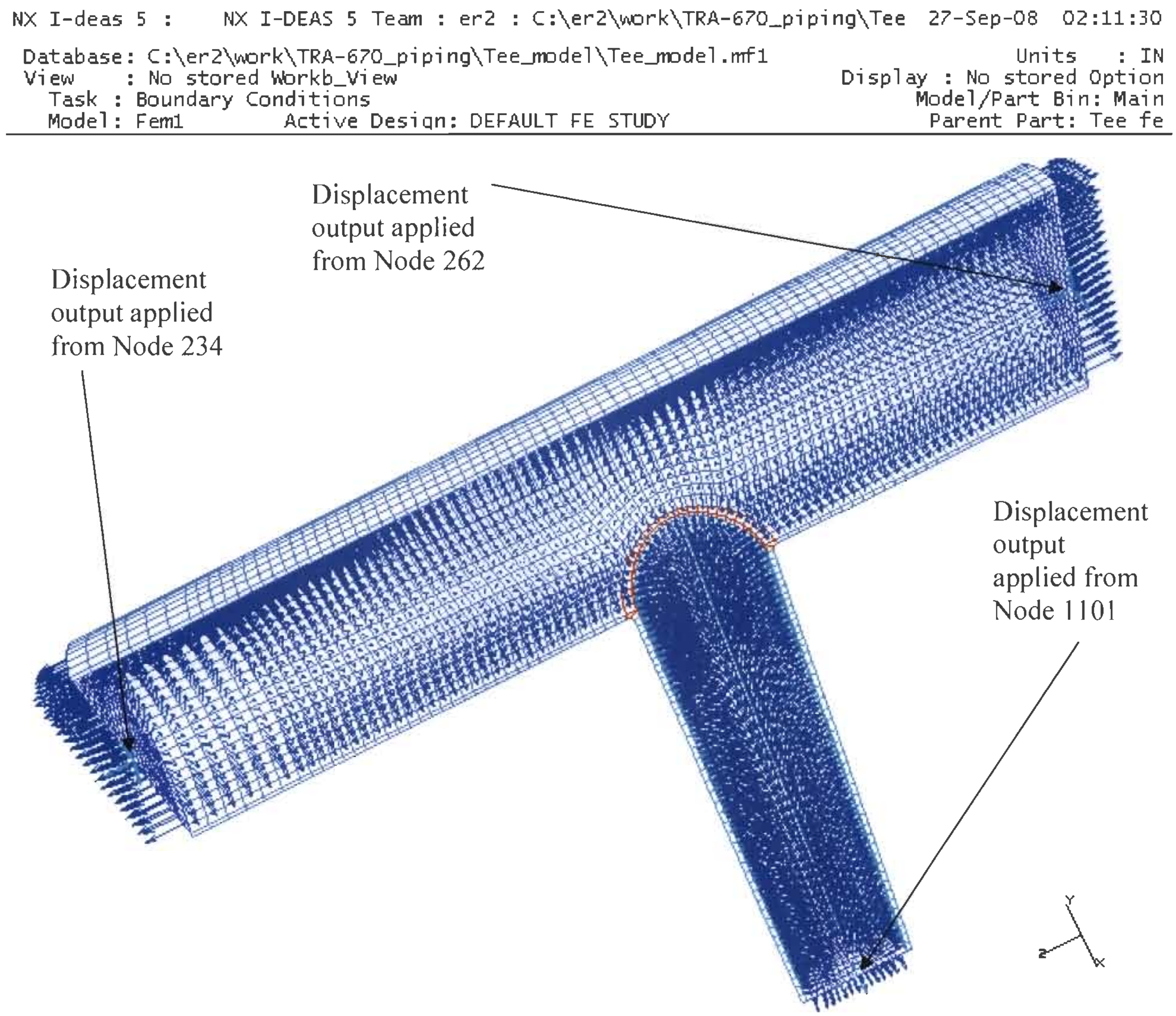

Figure F.4.1-4 – Cut-away of the model.

The displacement time histories taken from realization 17 were applied to the nodes identified in Figure F.4.1-4. Nodes 234, 262, and 1101 are attached with a coupling definition to the nodes in the continuum shells at the section where the pipe is cut. These coupling definitions caused the average motion of the slave nodes to correspond with the motion of the reference node. In addition to the moving restraints, the model was loaded with gravity and a 253 psi internal pressure.

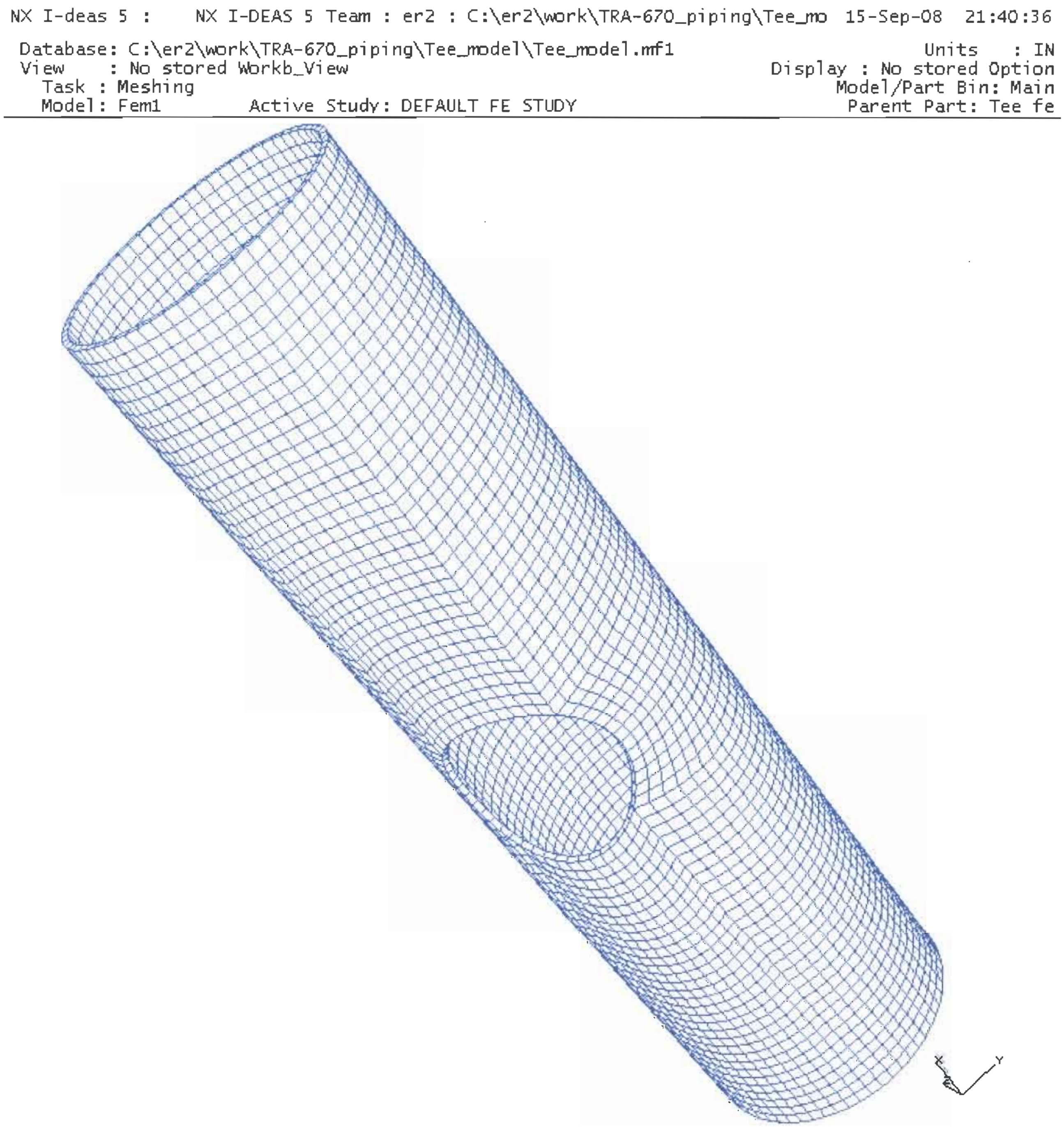

Figure F.4.1-5 – Continuum shell mesh of the 10 schedule 20 pipe.

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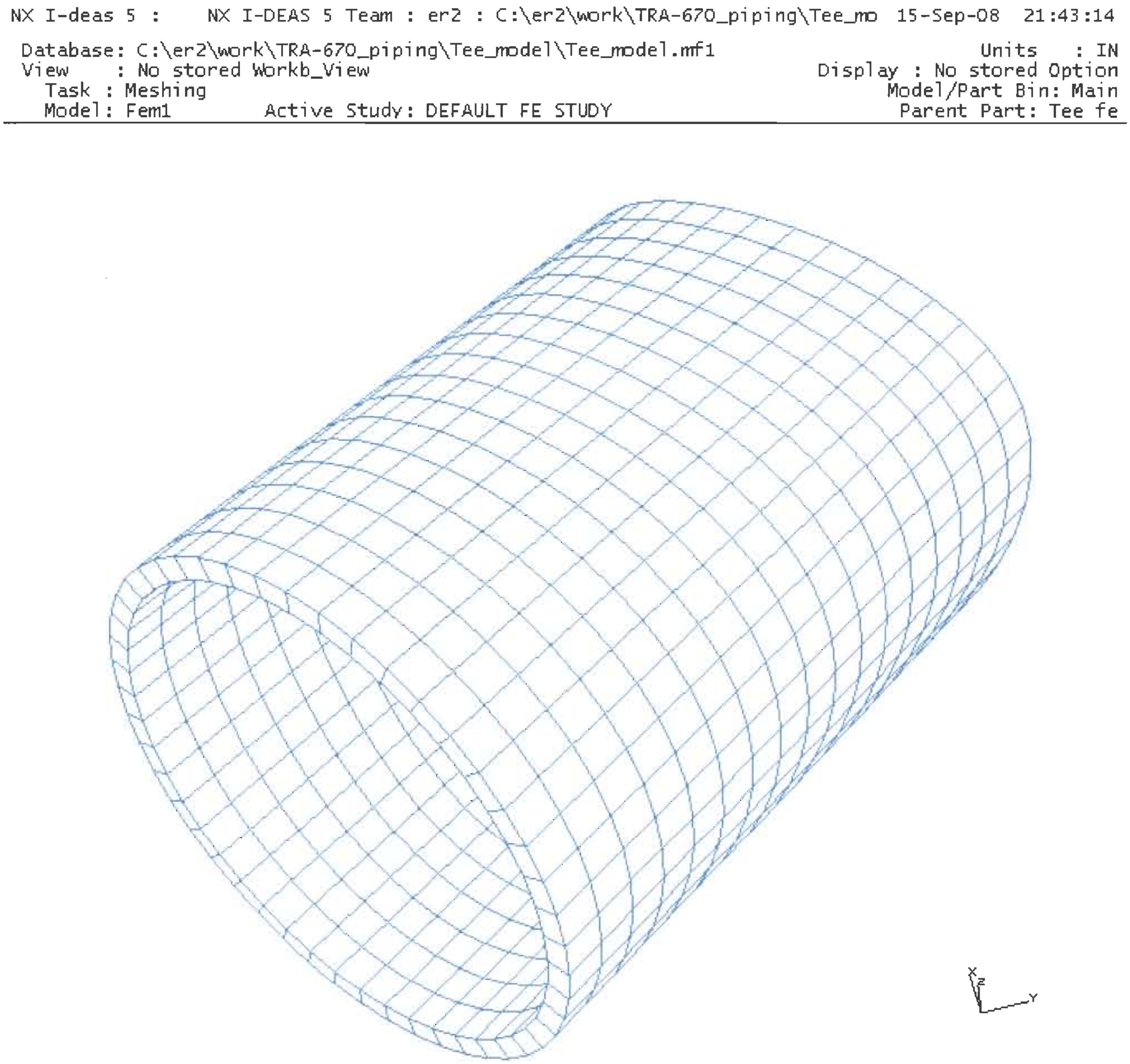

Figure F.4.1-6 – Continuum shell mesh of the 6 schedule 40 pipe.

```
NX I-deas 5 :    NX I-DEAS 5 Team : er2 : C:\er2\work\TRA-670_piping\Tee_mo  15-Sep-08  21:45:26
 Database: C:\er2\work\TRA-670_piping\Tee_model\Tee_model.mf1                    Units   : IN
 View    : No stored Workb_View                                       Display : No stored Option
   Task : Meshing                                                          Model/Part Bin: Main
   Model: Fem1        Active Study: DEFAULT FE STUDY                        Parent Part: Tee fe
```

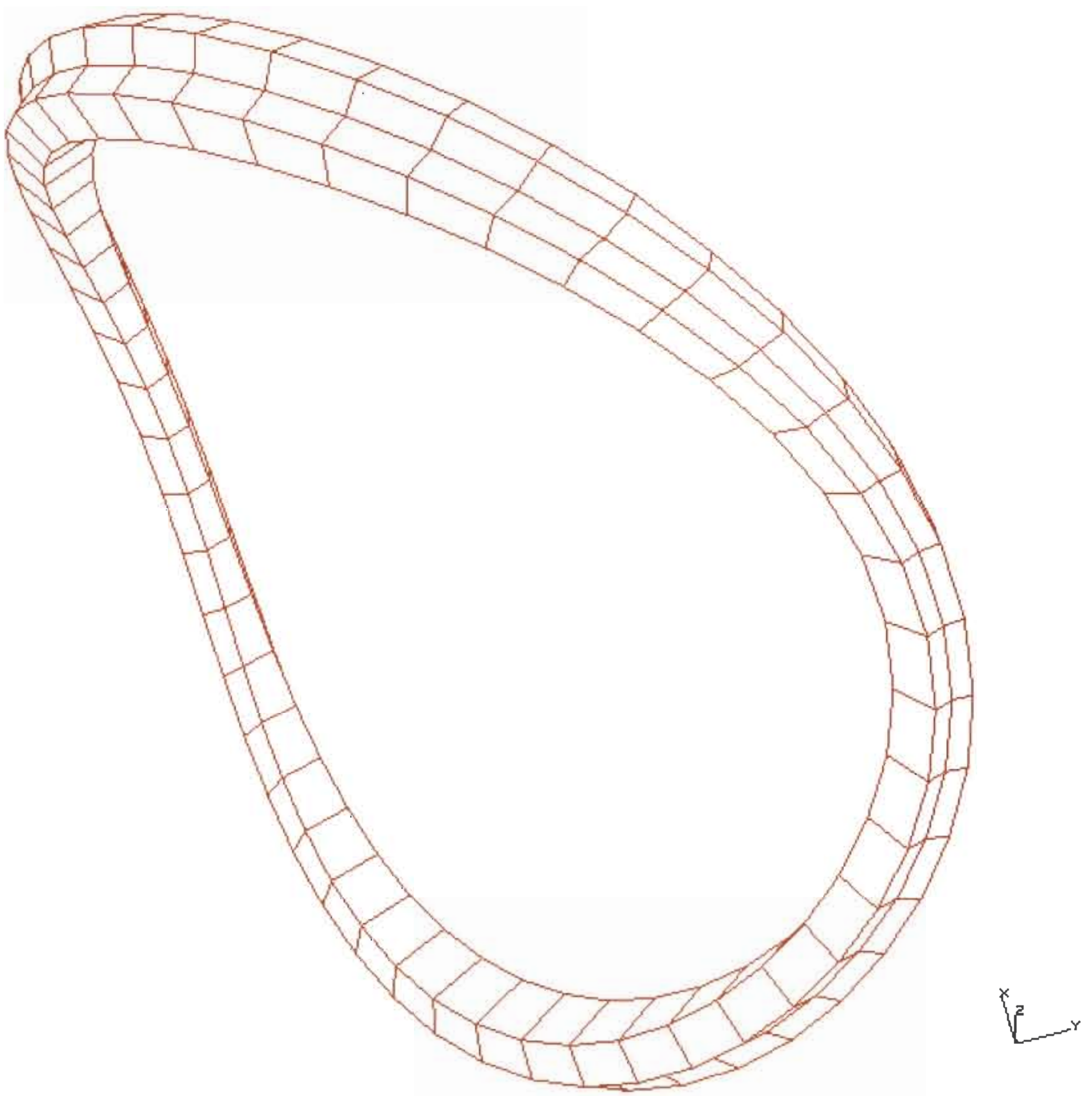

Figure F.4.1-7 – Continuum shell weld mesh.

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```
NX I-deas 5 :    NX I-DEAS 5 Team : er2 : C:\er2\work\TRA-670_piping\Tee_mo  15-Sep-08  21:47:08

Database: C:\er2\work\TRA-670_piping\Tee_model\Tee_model.mf1                  Units    : IN
View    : No stored Workb_View                                         Display : No stored Option
  Task : Meshing                                                        Model/Part Bin: Main
  Model: Fem1        Active Study: DEFAULT FE STUDY                      Parent Part: Tee fe
```

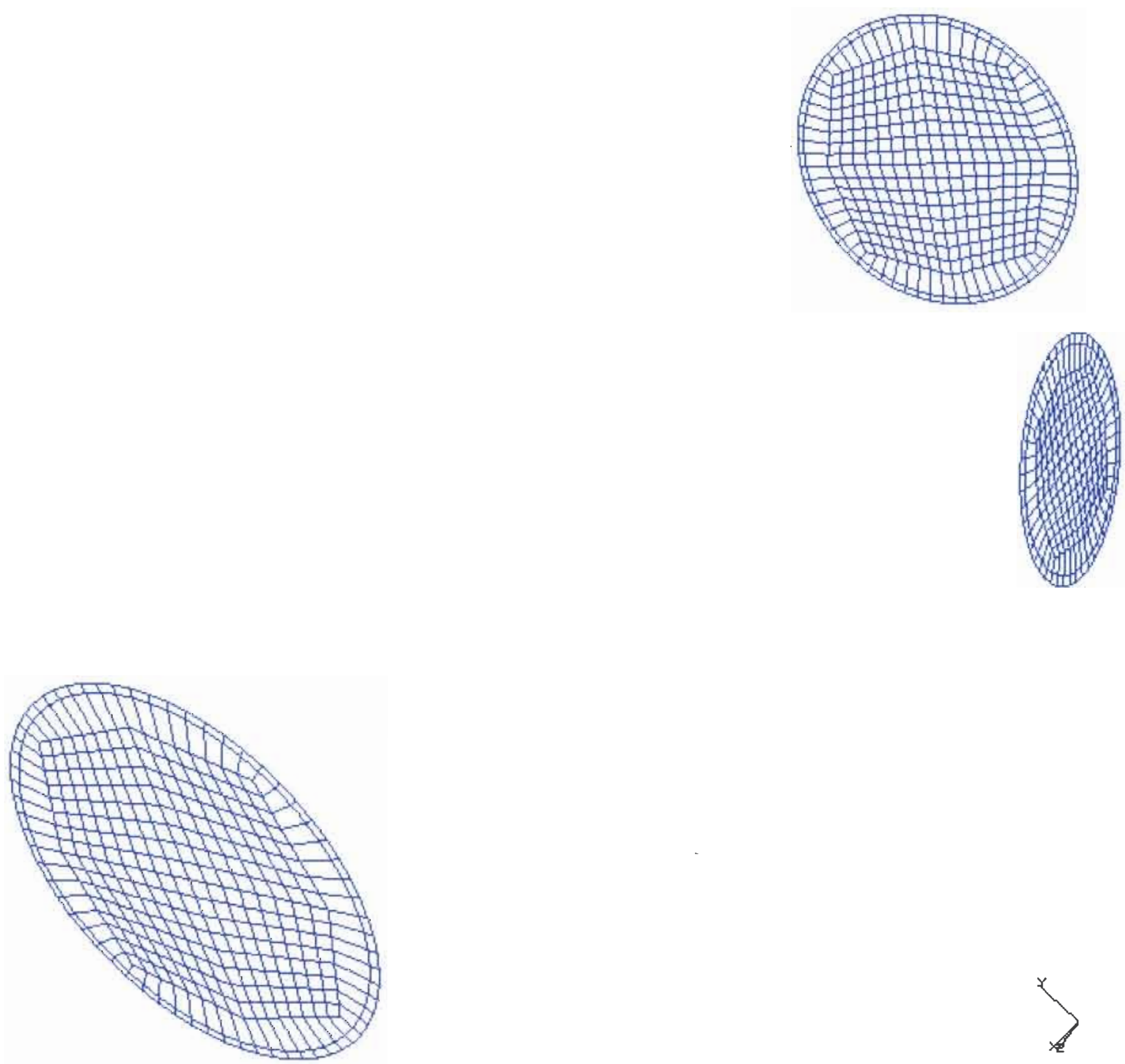

Figure F.4.1-8 – Linear quadrilateral thin shell mesh of the 0.312 inch thick end plates.

This model was defined with the same material properties as the unlisted branch in Section F.1.5. Consequently, the allowable plastic equivalent strain is 0.120 in/in. Figure F.4.1-9 shows the plastic equivalent strain at the shell midplane with averaging turned off.

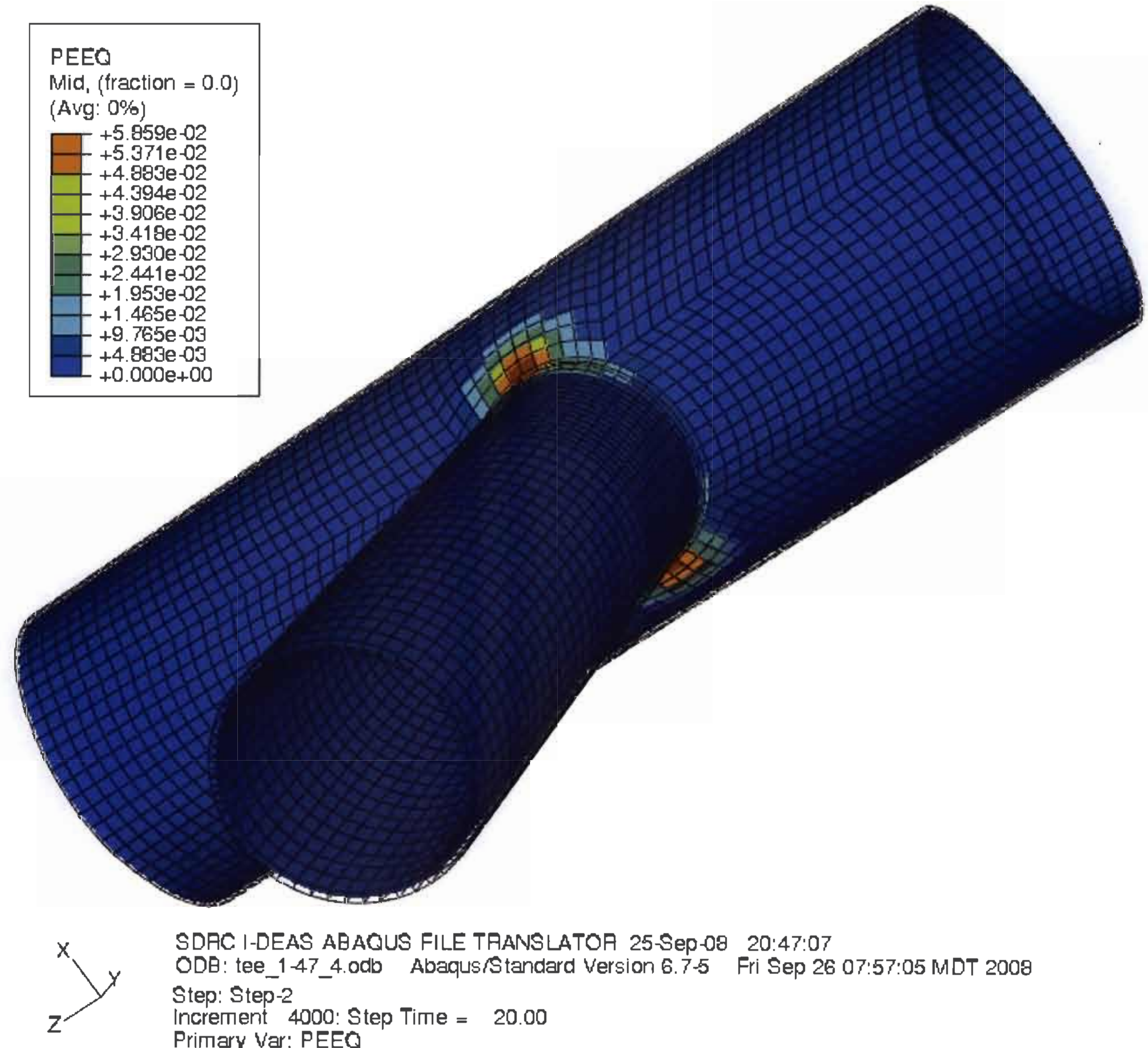

Figure F.4.1-9 – Plastic equivalent strain shown at the midplane with averaging turned off.

As shown in Figure F.4.1-9, the plastic equivalent strain is much less than the allowable 0.120 in/in. Thus, the unlisted branch component is acceptable.

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Before FE analysis was performed on model 265, scoping calculations were performed to provide flexibility adjusted section properties. These adjustments were for the first branch element considering three similar tees occurring in model 265. A check must now be performed to ensure that, at the load level of the plastic analysis, the beam element model responds similar to the shell model. Figure F.4.1-10 shows a representative beam element model from one of the three similar tees in model 265. (The beams are reoriented from model 265 to align the branch with the global axis. This is performed to simplify the test loading. The local axis of the first branch element is oriented relatively the same as in model 265.)

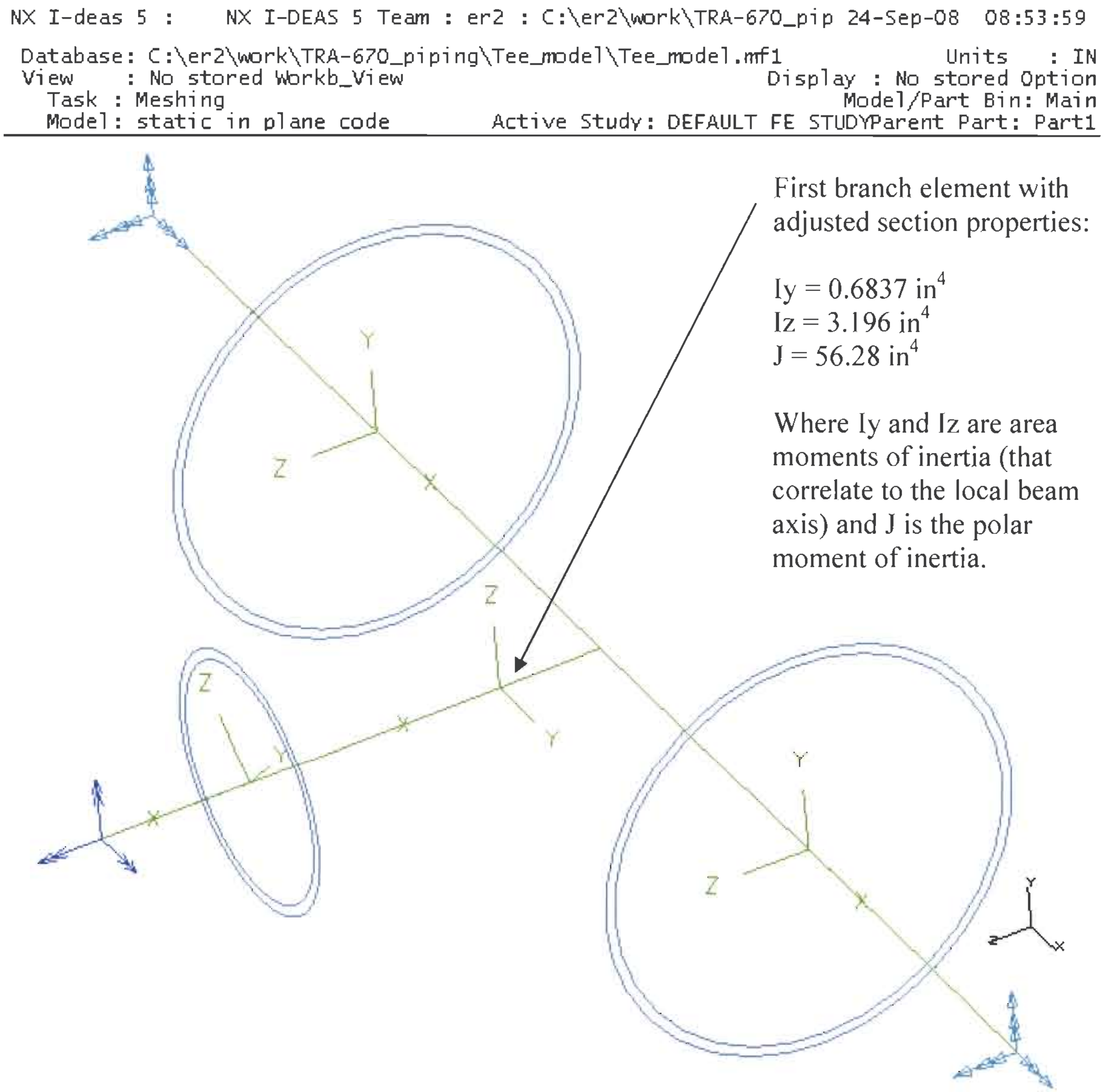

Figure F.4.1-10 – Beam model of the tee used to check flexibility.

Figure F.4.1-11 shows the reoriented shell mesh for the flexibility check. (This reoriented to correlate with the beam model).

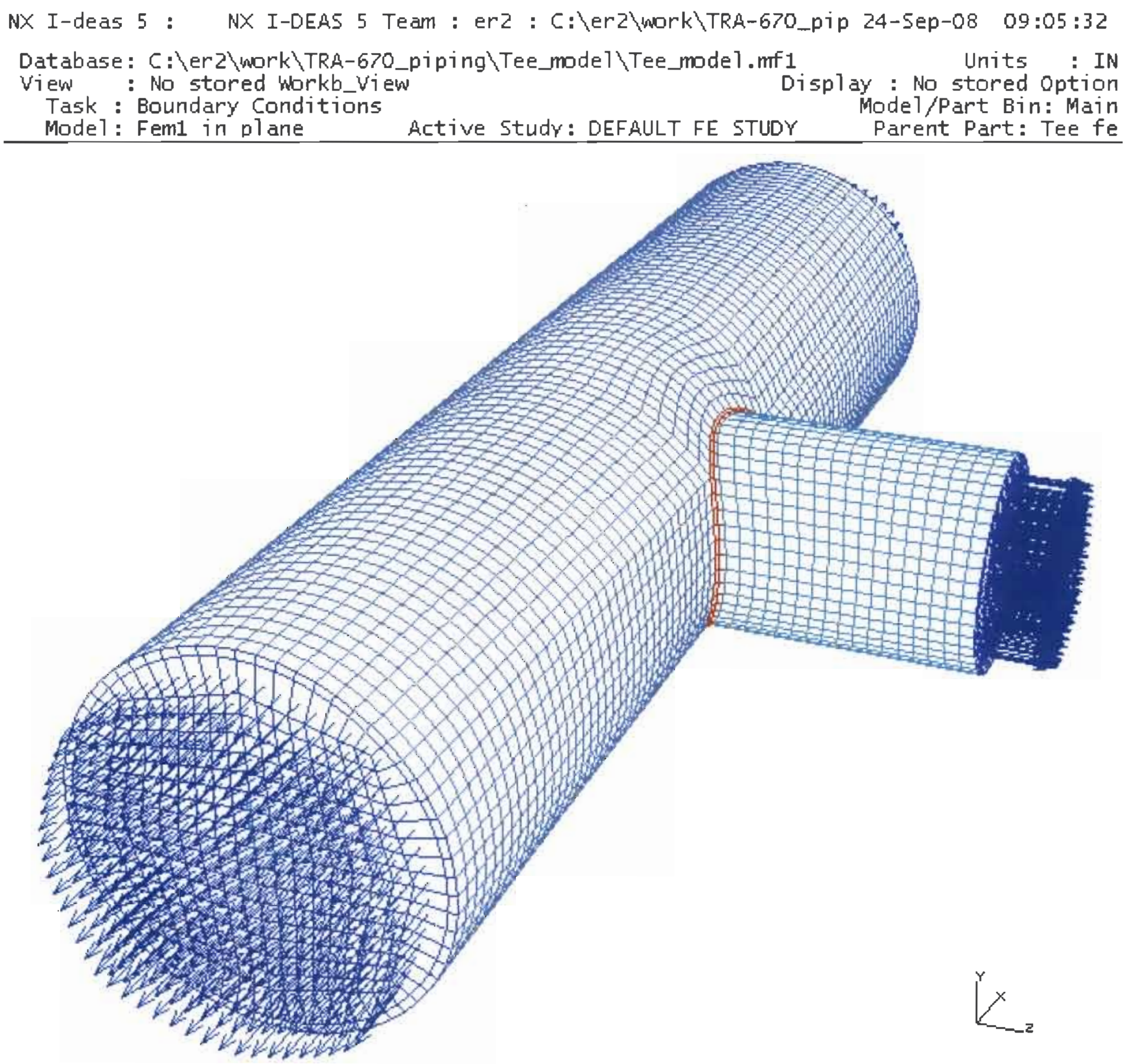

Figure F.4.1-11 – Shell model of the tee used to check flexibility.

The next step is to establish loading. From the model 265 run, 80th percentile moments are shown below. These loads include 80th percentile data from all three tees that are similar.

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Tee 1-43 (Node 238)
nd 1054

$M_{238} := \left(1.878\cdot10^4 \quad 8.475\cdot10^4 \quad 5.373\cdot10^4\right)^T \cdot in\cdot lbf$

Tee 1-43 80th percentile branch moments from Appendix C

Tee 1-46 (Node 230)
nd 1053

$M_{230} := \left(-1.573\cdot10^4 \quad -8.33\cdot10^4 \quad 2.736\cdot10^4\right)^T \cdot in\cdot lbf$

Tee 1-46 80th percentile branch moments from Appendix C

Tee 1-47 (Node 261)
nd 626

$M_{261} := \left(1.672\cdot10^5 \quad -2.468\cdot10^4 \quad 1.392\cdot10^4\right)^T \cdot in\cdot lbf$

Tee 1-46 80th percentile branch moments from Appendix C

These moments are in the global axis of the model 265 run. Consequently, they need to be transformed into the global coordinates of the meshes used to check flexibility. Figure F.4.1-12 shows the three tees as they are oriented in model 265. Using Figure F.4.1-12, measurements can be made to generate orthogonal transforms for each tee.

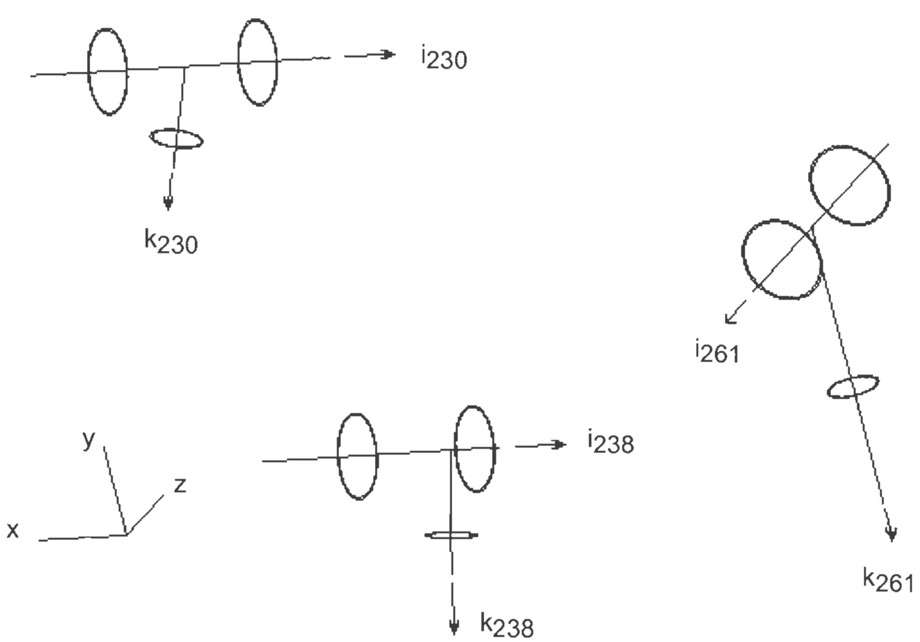

Figure F.4.1-12 – Model 265 tee orientation.

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$i'_{238} := \begin{pmatrix} -6.4375 \\ 0 \\ 0 \end{pmatrix}$ $\quad i_{238} := \frac{i'_{238}}{|i'_{238}|}$ $\quad i_{238} = \begin{pmatrix} -1 \\ 0 \\ 0 \end{pmatrix}$ Unit i-direction vector for node 238

$k'_{238} := \begin{pmatrix} 0 \\ -13.28653 \\ -7.987936 \end{pmatrix}$ $\quad k_{238} := \frac{k'_{238}}{|k'_{238}|}$ $\quad k_{238} = \begin{pmatrix} 0 \\ -0.857 \\ -0.515 \end{pmatrix}$ Unit k-direction vector for node 238

$j_{238} := k_{238} \times i_{238}$ $\quad j_{238} = \begin{pmatrix} 0 \\ 0.515 \\ -0.857 \end{pmatrix}$ Unit j-direction vector for node 238

$Q_{238} := \text{augment}(i_{238}, j_{238}, k_{238})$ Orthogonal transform for the Tee 1-43 moment vector

$$Q_{238} = \begin{pmatrix} -1 & 0 & 0 \\ 0 & 0.515 & -0.857 \\ 0 & -0.857 & -0.515 \end{pmatrix}$$

$i'_{230} := \begin{pmatrix} -20 \\ 0 \\ 0 \end{pmatrix}$ $\quad i_{230} := \frac{i'_{230}}{|i'_{230}|}$ $\quad i_{230} = \begin{pmatrix} -1 \\ 0 \\ 0 \end{pmatrix}$ Unit i-direction vector for node 230

$k'_{230} := \begin{pmatrix} 0 \\ -9.348350 \\ -9.348350 \end{pmatrix}$ $\quad k_{230} := \frac{k'_{230}}{|k'_{230}|}$ $\quad k_{230} = \begin{pmatrix} 0 \\ -0.707 \\ -0.707 \end{pmatrix}$ Unit k-direction vector for node 230

$j_{230} := k_{230} \times i_{230}$ $\quad j_{230} = \begin{pmatrix} 0 \\ 0.707 \\ -0.707 \end{pmatrix}$ Unit j-direction vector for node 230

$Q_{230} := \text{augment}(i_{230}, j_{230}, k_{230})$ Orthogonal transform for the Tee 1-46 moment vector

$$Q_{230} = \begin{pmatrix} -1 & 0 & 0 \\ 0 & 0.707 & -0.707 \\ 0 & -0.707 & -0.707 \end{pmatrix}$$

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Title: ATR Primary Coolant System Seismic Evaluation
Performer: R. E. Spears **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

$$i'_{261} := \begin{pmatrix} 0 \\ 0 \\ -18.375 \end{pmatrix} \qquad i_{261} := \frac{i'_{261}}{|i'_{261}|} \qquad i_{261} = \begin{pmatrix} 0 \\ 0 \\ -1 \end{pmatrix}$$

Unit i-direction vector for node 261

$$k'_{261} := \begin{pmatrix} 0 \\ -37.75 \\ 0 \end{pmatrix} \qquad k_{261} := \frac{k'_{261}}{|k'_{261}|} \qquad k_{261} = \begin{pmatrix} 0 \\ -1 \\ 0 \end{pmatrix}$$

Unit k-direction vector for node 261

$$j_{261} := k_{261} \times i_{261} \qquad j_{261} = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$$

Unit j-direction vector for node 261

$$Q_{261} := \text{augment}(i_{261}, j_{261}, k_{261})$$

Orthogonal transform for the Tee 1-47 moment vector

$$Q_{261} = \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & -1 \\ -1 & 0 & 0 \end{pmatrix}$$

Having the orthogonal transforms, the moments can be transformed and the maximum amplitude for each direction can be found.

$$M'_{238} := Q_{238} \cdot M_{238}$$

Transformed moment vector for Tee 1-43

$$M'_{238} = \begin{pmatrix} -1.878 \times 10^{4} \\ -2.381 \times 10^{3} \\ -1.003 \times 10^{5} \end{pmatrix} \text{in} \cdot \text{lbf}$$

$$M'_{230} := Q_{230} \cdot M_{230}$$

Transformed moment vector for Tee 1-46

$$M'_{230} = \begin{pmatrix} 1.573 \times 10^{4} \\ -7.825 \times 10^{4} \\ 3.956 \times 10^{4} \end{pmatrix} \text{in} \cdot \text{lbf}$$

$$M'_{261} := Q_{261} \cdot M_{261}$$

Transformed moment vector for Tee 1-47

$$M'_{261} = \begin{pmatrix} -2.468 \times 10^{4} \\ -1.392 \times 10^{4} \\ -1.672 \times 10^{5} \end{pmatrix} \text{in} \cdot \text{lbf}$$

$$M' := \begin{bmatrix} \max\left(\left(\left|M'238_0\right| \;\; \left|M'230_0\right| \;\; \left|M'261_0\right|\right)\right) \\ \max\left(\left(\left|M'238_1\right| \;\; \left|M'230_1\right| \;\; \left|M'261_1\right|\right)\right) \\ \max\left(\left(\left|M'238_2\right| \;\; \left|M'230_2\right| \;\; \left|M'261_2\right|\right)\right) \end{bmatrix}$$

Maximum transformed moment in each direction

$$M' = \begin{pmatrix} 2.468 \times 10^4 \\ 7.825 \times 10^4 \\ 1.672 \times 10^5 \end{pmatrix} in \cdot lbf$$

$$M'' := M' \cdot (in \cdot lbf)^{-1}$$

Moment used to scale the plots

$$M''^T = \begin{pmatrix} 2.468 \times 10^4 & 7.825 \times 10^4 & 1.672 \times 10^5 \end{pmatrix}$$

To check the flexibility, three load cases are run with the beam and shell models. Each beam model load case consists of a single moment direction applied to its end branch node (i.e. 24,680 in•lbf in the Figure F.4.1-10 global x-direction, 78,250 in•lbf in the Figure F.4.1-10 global y-direction, or 167,200 in•lbf in the Figure F.4.1-10 global z-direction). The model is fully restrained where the run pipe is cut. Each shell model is run with the same boundary conditions as its corresponding beam model. However, the shell model has an additional initial step where an internal pressure of 253 psi is applied. Figure F.4.1-13 below shows the resulting angular displacement at the end of the branch versus moment applied at the same point. The plots include the results from the shell model and the beam model. Additionally, beam results scaled plus and minus 20% are included for information. The shell model results have two steps. Displacements that occur during the first step, due to the pressure loading, are subtracted from the total curve so that only the relative displacement of caused by the moment is plotted.

The input files used for the beam models were "tee_beam_4_STp_mod_1.inp", "tee_beam_4_STp_mod_2.inp", and "tee_beam_4_STp_mod_3.inp". The input files used for the shell models were "tee_4_STp_1.inp", "tee_4_STp_2.inp", and "tee_4_STp_3.inp". In both sets of input files, the number change of 1, 2, and 3 represent the x-axis run, the y-axis run, and the z-axis run respectively.

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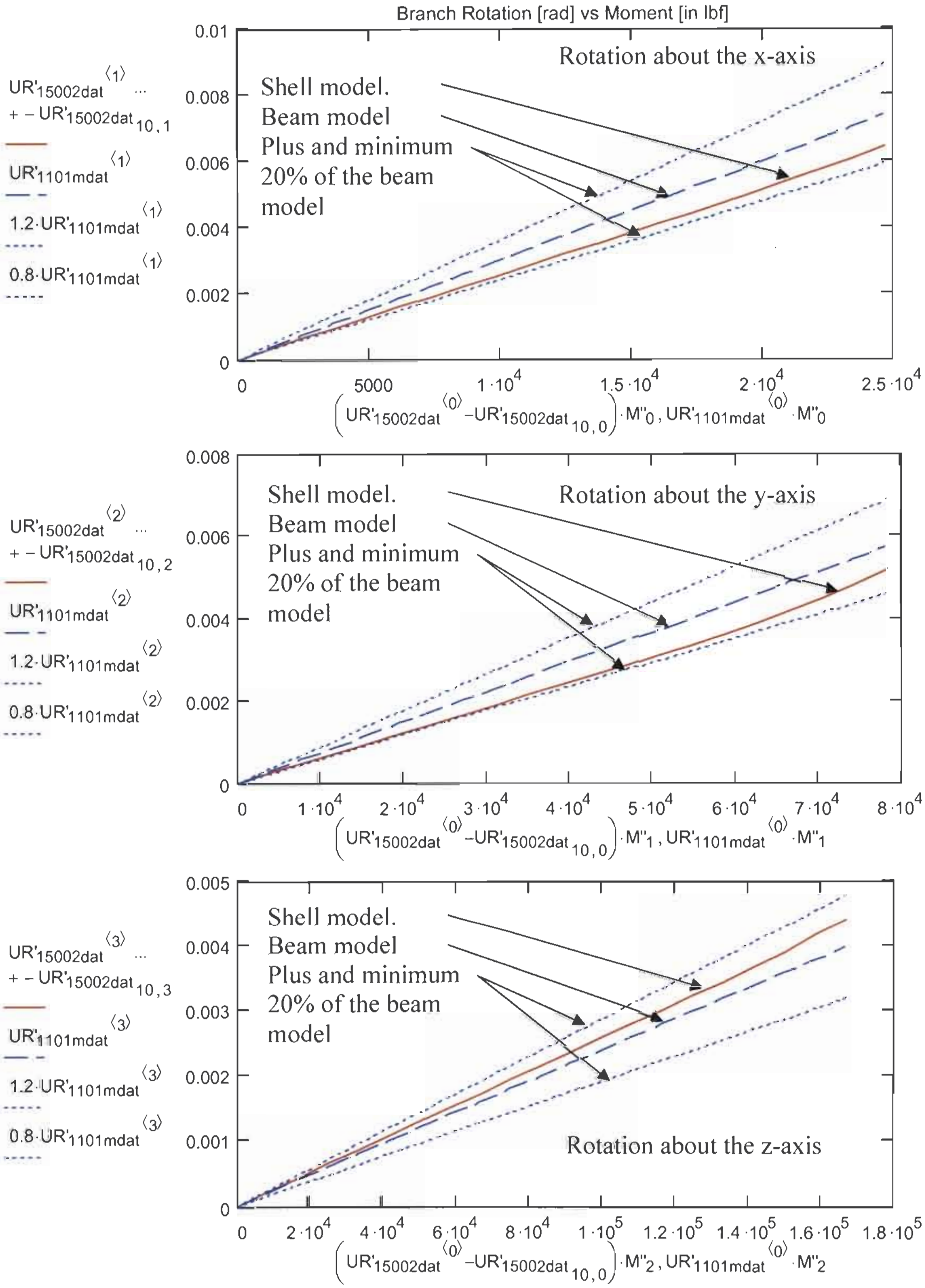

Figure F.4.1-13 – Model 265 tee branch rotation versus moment check.

Figure F.4.1-13 shows that all of the shell model plots are within the plus and minus 20% of the beam element results plots. Considering the significant nonlinearity exhibited by the tees under higher loading, the scoping analsis set the bending stiffnesses softer than the linear portion of the shell model curve. The polar moment of inertia exhibited much less nonliearity. Also, it was close to the shell model stiffness with no polar moment of inertia change, so no change was made to the polar moment of inertia. If a variation of plus or minus 20% is considered sufficiently accurate, the beam model is accurately modeling the three tees.

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F.4.2 – Flexibility Factor Determination of Tee on Line 1-19

There are several tee components that do not qualify as listed components. The purpose of this section is to check and determine (as necessary) flexibility factor for a tee on line 1-19, which is similar to other tees on lines 1-18, 1-20, and 1-21. The line 1-19 tee (hereafter referred to as T1-19) has the largest D/C ratio of the other three tees. Tees on lines 1-18, 1-20, and 1-21, shall be referred to as T1-18, T1-20, and T1-21, respectively within this report. Once the flexibility factors of T1-19 is determined, the system beam model will be updated with corresponding flexibility factors for these four tees and final solution results shall be obtained.

The four tees are located on line 1-17 (30-in x 0.438-in thick header run) and branch Southward to lines 1-18 through 1-21 (composed of 24-in x 0.375-in thick pipe) which extends to each of the four primary pump's suction entry. The four tees are reinforced with 0.375-in reinforment plates. Figure F.4.2-1 shows a pipe sketch of Model 2 and identifies the location of the four tees.

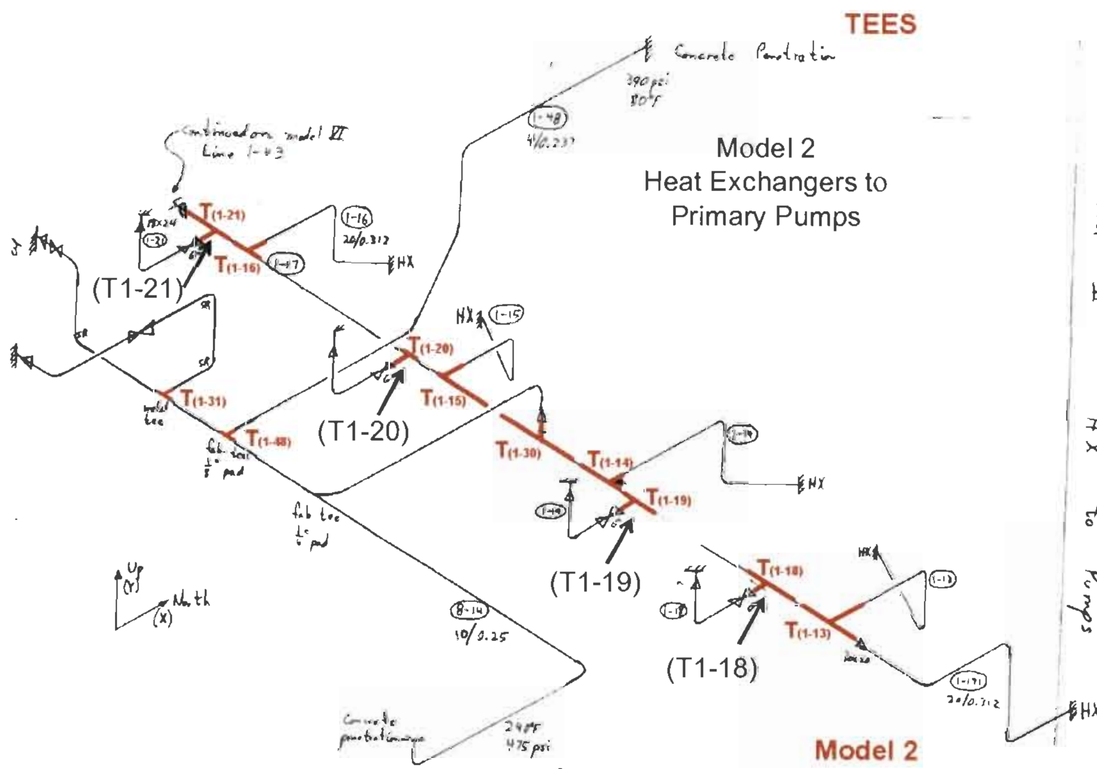

Figure F.4.2-1 – Piping Model 2, showing 30-in x 24-in reinforced tees locations.

To check the flexibility of T1-19, a shell model is created of the tee and a beam model of the tee is extracted from Model 256's system beam model. The T1-19 shell and beam models are compared to each other after three load cases are run side-by-side.

T1-19 shell model was solid-modeled and meshed within I-DEAS Master Series, Simulation, Version 12 [9]. With the meshing complete, input files were written for ABAQUS [10]. Final editing of the input files were performed in a text editor and then solution runs were performed with ABAQUS Standard, Version 6.7-5. Angular displacement results are extracted from the shell model and compared to the T1-19 beam model, to be described later.

T1-19 was meshed primarily with eight-node continuum shell elements and some rigid beam elements. The continuum shell elements support six degrees of freedom (3-translations, 3 rotations) at each node and were used to model the 30-in pipe run and 24-inch brach. The rigid beams were used as an aid in defining boundary conditions (i.e., applying loads and defining restraints) to the shell model. Figures F.4.2-2 through F.2-2-4 illustrates T1-19 as meshed with the continuum and regular quadrilateral shell elements. Table F.4.2-1 correlates element color to member name and thickness.

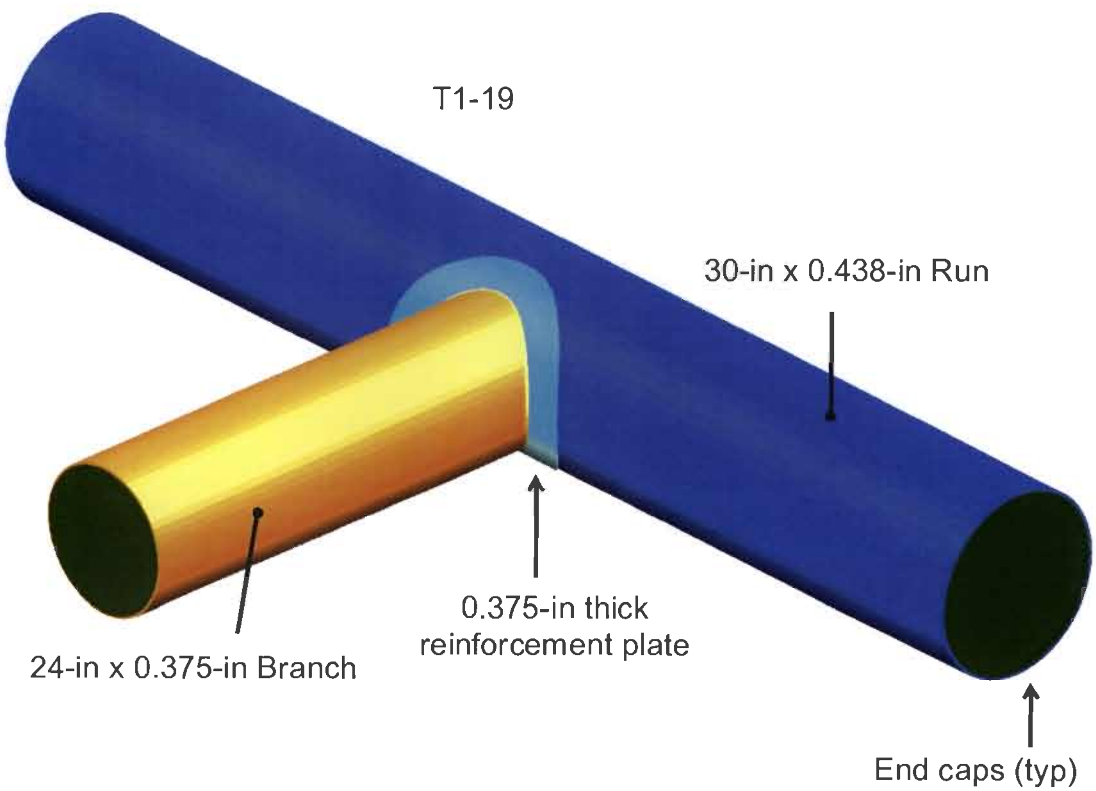

Figure F4.2-2 – T1-19 continuum and quadrilateral shell mesh.

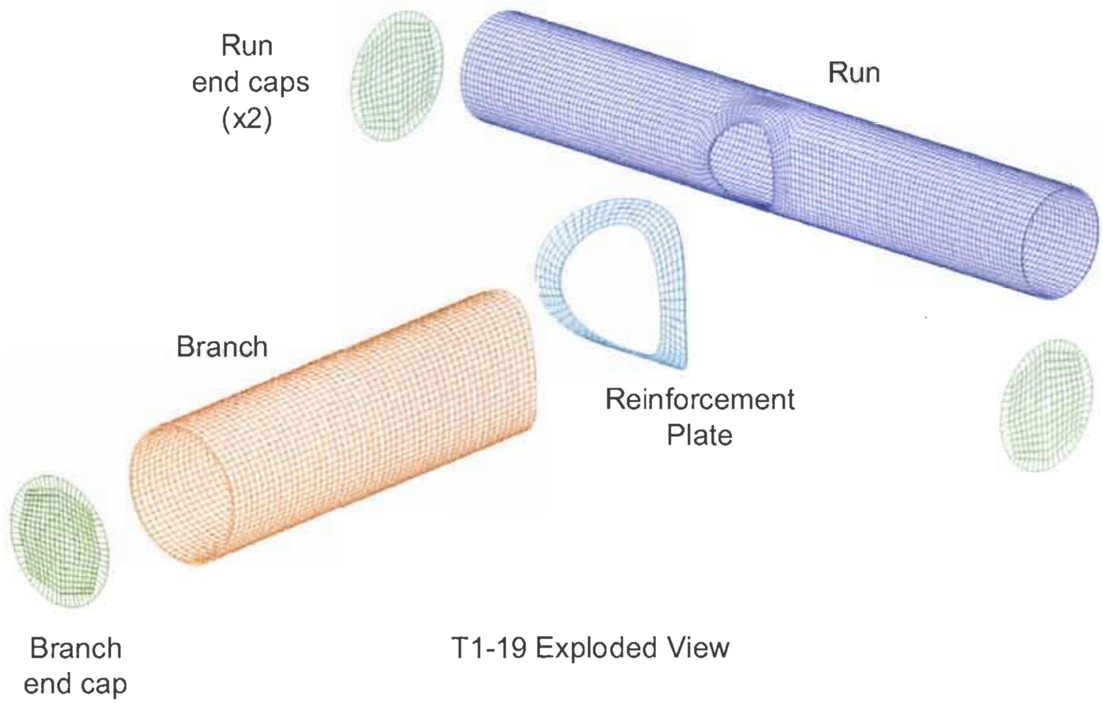

Figure F.4.2-3 – Exploded view of T1-19 is shown, identifying the components.

Figure F.4.2-4 – Rigid elements are used on T1-19 end caps to apply restraints and moments.

Table F.4.2-1 – Mesh color, thickness, and component member correlation

Member Name	Mesh Color(s)	Element Thickness
30-in Pipe Run	Blue	7/16" (0.4375-in)
24-in Pipe Branch	Orange	3/8" (0.375-in)
Reinforcement Plate	Cyan	3/8"(0.375-in)
Enc Caps	Dark Green	Match thickness of pipe
*Rigid elements	Green	N/A

*These component members were used as an aid to apply boundary conditions to T1-19.

T1-19 (as well as other three tees) are fabricated with 304 stainless steel [6] and operates at 125°F while maintaining a constant internal gauge pressure of 253-psi [11, Section 7.1]. Applicable material properties of T1-19 component is shown in Table F.4.2-2, as retrieved from Table 2 from the main report body.

Table F.4.2-2 – 304 Stainless Steel Material Properties at 125°F .

Symbol	Property Value	Property Description
μ	0.30 in/in	Poisson's Ration [1, Section NB-3683.1(b)]
E	28.0E+6	Modulus of Elasticity at 125°F Temperature [12, Table TM]
Sy	28.35 ksi	Material Yield Strength at 125°F Temperature [12, Table Y-1]
Sm	20 ksi	Maximum allowable Stress Intensity at 125°F Temperature [12, Table 2A]

The beam model of T1-19 is comprised of the same shell pipe components, as shown in Figure F.4.2-5.

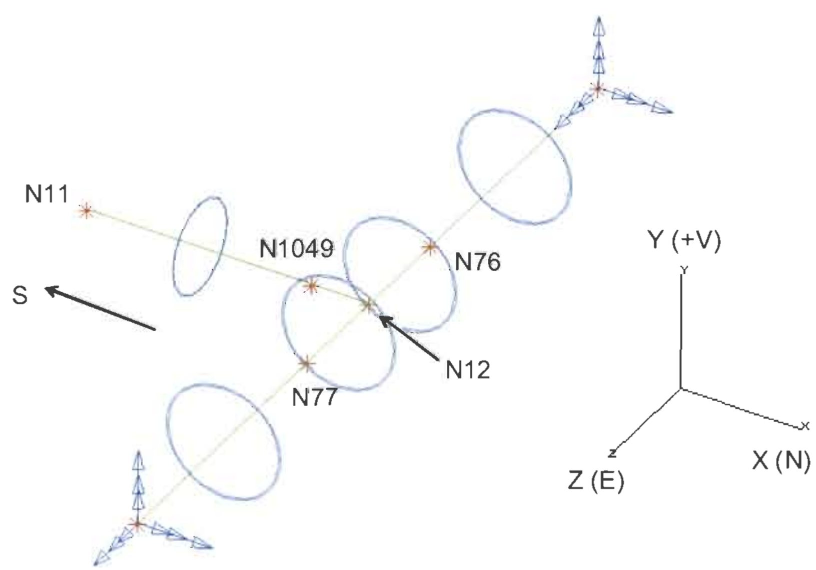

Figure 4.2-5 – Beam model of T1-19 is shown.

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Each beam model load case consists of a single moment direction applied to its end branch node (i.e. 26,970 in•lbf in global x-direction, -44,160 in•lbf in global y-direction, or -728,600 in•lbf in global z-direction). The model is fully restrained where the run pipe is cut. Each shell model is run with the same boundary conditions as its corresponding beam model. However, the shell model has an additional initial step where an internal pressure of 253 psi is applied. Figure F.4.2-6 shows common boundary conditions between the shell and beam models.

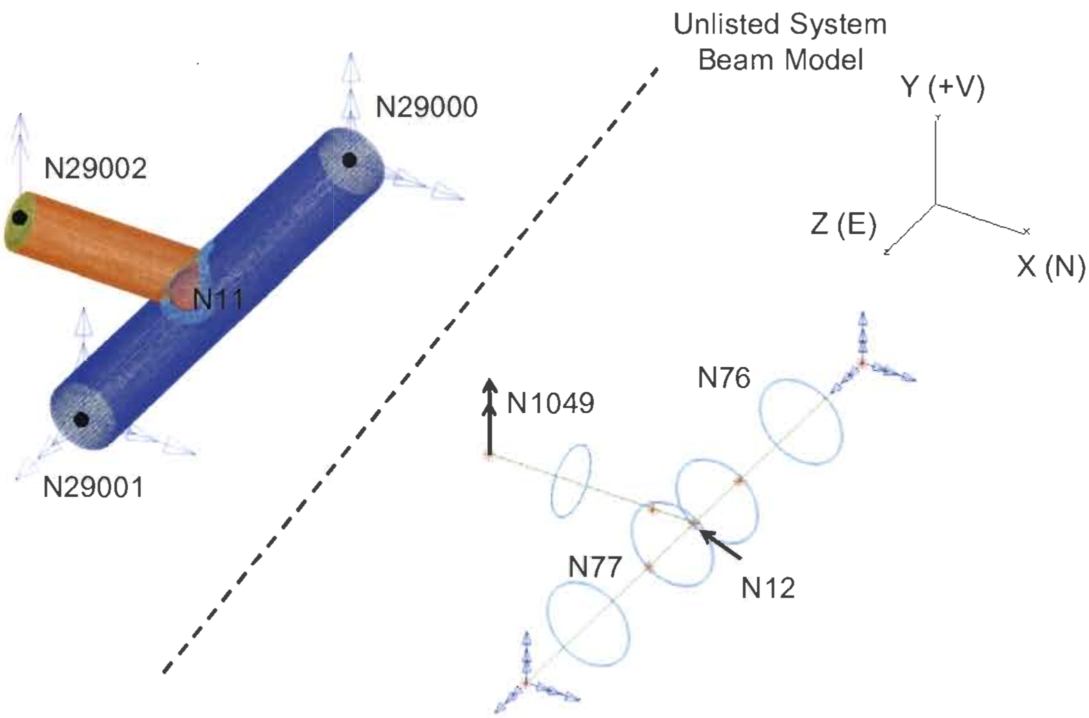

Figure F.4.2-6 - Shell and beam models of T1-19 with same boundary conditions, are shown.

Figures F.4.2-7 through F.4.2-9 show the resulting angular displacement at the end of the branch versus moment applied at the same point. The plots include the results from the shell model and the beam model. Additionally, beam results scaled plus and minus 20% are included for information. The shell model results have two steps. Displacements that occur during the first step, due to the pressure loading, are subtracted from the total curve so that only the relative displacement of caused by the moment is plotted.

The input files used for the beam models were "beam_1_tee_1.inp", "beam_1_tee_2.inp", and "beam_1_tee_3.inp". The input files used for the shell models were "shell_cont_1_tee_1.inp", "shell_cont_1_tee_2.inp", and "shell_cont_1_tee_3.inp". In both sets of input files, the number change of 1, 2, and 3 represent the x-axis run, the y-axis run, and the z-axis run respectively.

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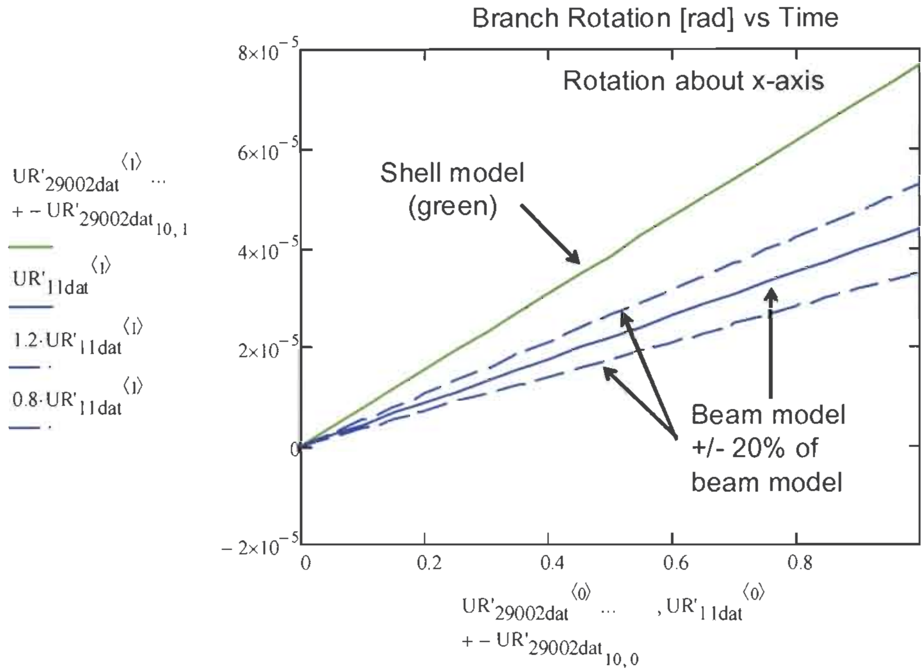

Figure F.4.2-7 - The shell model demonstrates poor correlation to the beam model, in the x-direction.

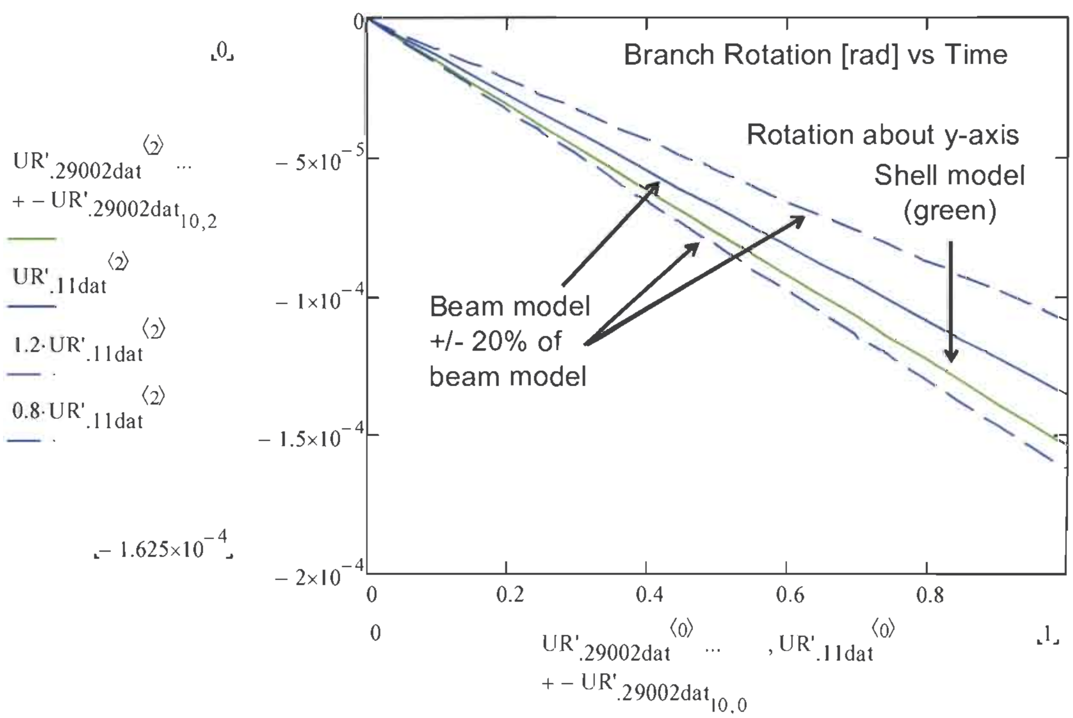

Figure F.4.2-8 - The shell model lies within the 20% beam model band, in the y-direction.

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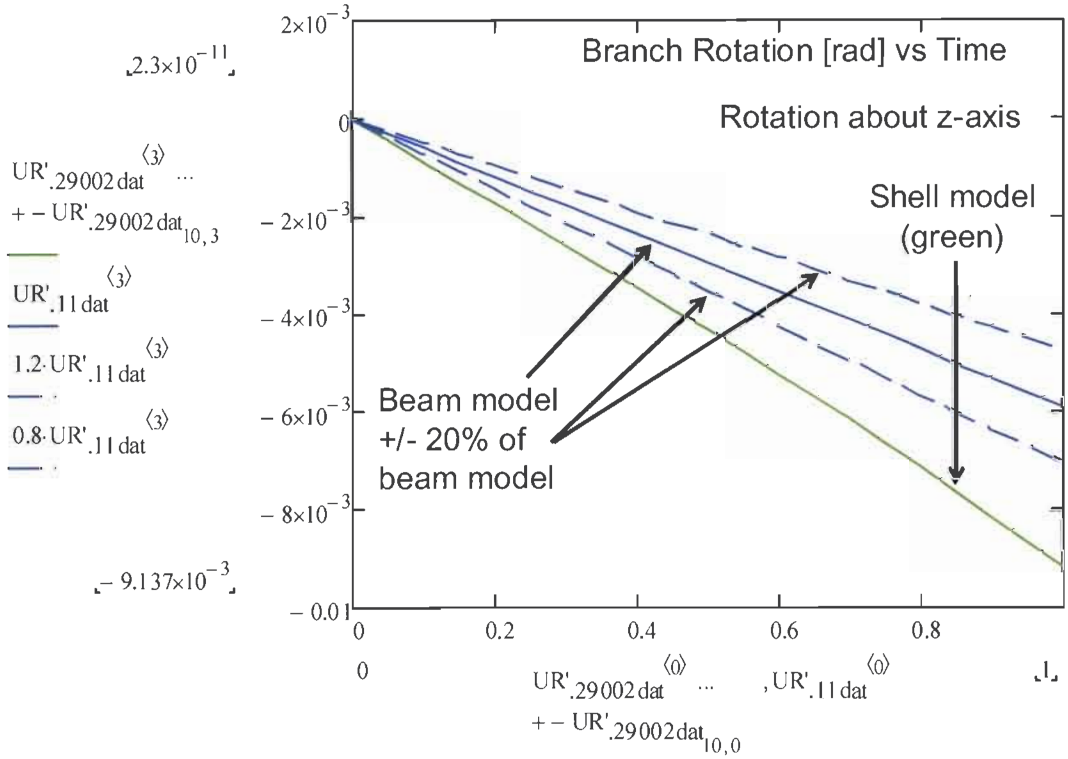

Figure F.4.2-9 Shell model displays poor correlation to the beam model, in the z-direction.

The shell and beam models demonstrate poor correlation in the x and z-directions. The shell model lies within the 20% bean model band, but better correlation could be achieved. Flexibility factors for all three directions will be determined to correlate the T1-19 shell and beam models.

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Line 1-19 Tee [30-in x 0.4375-in run (line 1-17) to 24-in x 0.375-in branch (line 1-19)]

$D_{30} := 30 \cdot in$ $t_{30} := 0.4375 in$ $d_{30} := D_{30} - 2 \cdot t_{30}$ $d_{30} = 29.125 in$

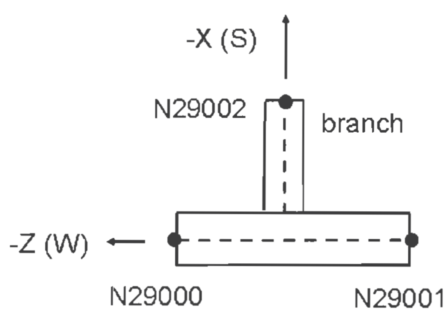
$D_{24} := 24 \cdot in$ $t_{24} := \frac{3}{8} \cdot in$ Branch diameter & thickness

$d_{24} := D_{24} - 2 \cdot t_{24}$ $d_{24} = 23.25 in$ Inner diameter of elbow

$A_{24} := \frac{\pi}{4} \cdot \left(D_{24}^2 - d_{24}^2\right)$ $A_{24} = 27.833 in^2$ Branch area

$I_{24} := \frac{\pi}{64} \cdot \left(D_{24}^4 - d_{24}^4\right)$ $I_{24} = 1.942 \times 10^3 in^4$ Branch moment of inertia

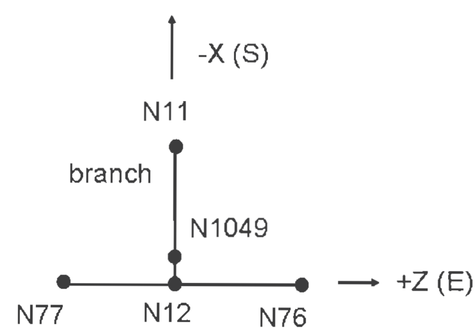
$J_{24} := \frac{\pi}{32} \cdot \left(D_{24}^4 - d_{24}^4\right)$ $J_{24} = 3.885 \times 10^3 in^4$ Branch polar moment of inertia



Shell Model
30-in x 24-in
Reinforced Tee

T1-19

FF
=
Equate



Beam Model
30-in x 24-in
Reinforced Tee

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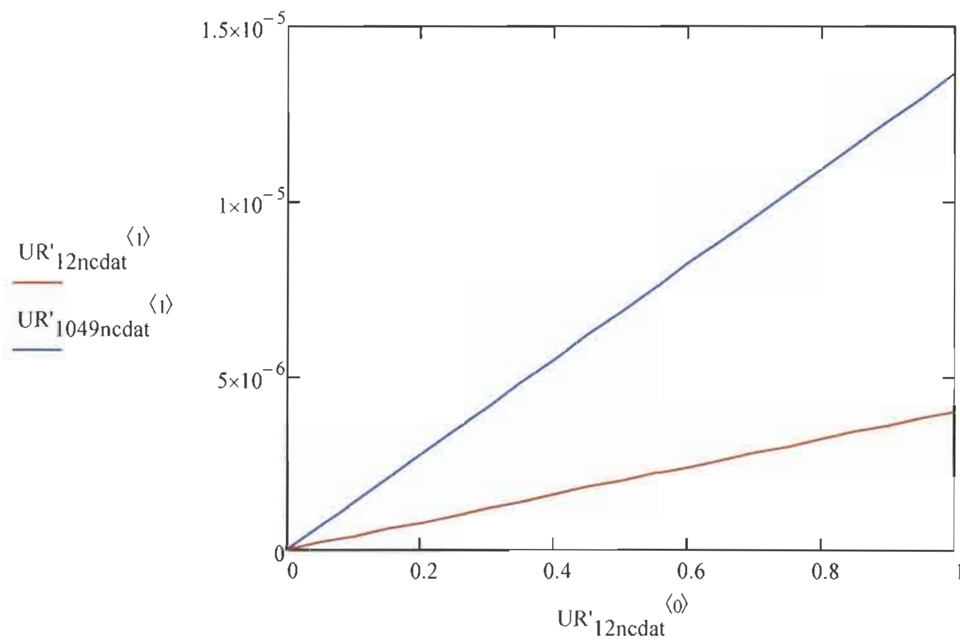
Reinforced branch (or tee) on Line 1-19 or t1-19

Global 1 (x-direction)

The beam model has two intermediate nodes (N1049 & N12) along its branch segment. Node 1049 corresonds to the run's outer diameter surface and node 12 correlates to the center intersection between the branch and run neutral axis. The shell model does not have these nodes, for it models the exterior branch/run surface of this intersection. Following are the rotations about the x-direction for these interior beam branch nodes.

$UR'_{1049ncdat} :=$ $UR'_{12ncdat} :=$

$UR'_{11ncdat} :=$ Rotations from the three branch nodes



$\theta 1\_n11b\_nc := UR'_{11ncdat_{rows(UR'_{11ncdat})-1,\,1}}$ Maximum beam rotation of branch end node (N11)

$\theta 1\_n11b\_nc = 5.171 \times 10^{-5}$

$\theta 1\_n1049b\_nc := UR'1049ncdat_{rows(UR'1049ncdat)-1,1}$

$\theta 1\_n1049b\_nc = 1.367\times 10^{-5}$

Maximum beam rotation of branch node that is located at the run's outside diameter surface.

$\theta 1\_n12b\_nc := UR'12ncdat_{rows(UR'12ncdat)-1,1}$

$\theta 1\_n12b\_nc = 3.995\times 10^{-6}$

Maximum beam rotation of branch node that lies at intersection of run and branch's neutral axis.

$\theta 1\_n29002s := UR'29002dat_{rows(UR'29002dat)-1,1}$

$\theta 1\_n29002s = 7.696\times 10^{-5}$

Maximum shell rotation of branch end node (N29002)

$\theta 1\_n11b\_nc_{ctr} := \theta 1\_n1049b\_nc - \theta 1\_n12b\_nc$

$\theta 1\_n11b\_nc_{ctr} = 9.673\times 10^{-6}$

Rotation of center tee portion of beam, between nodes 1049 and 12.

$\theta 1\_n29002s_{ctr} := \theta 1\_n29002s - (\theta 1\_n11b\_nc - \theta 1\_n11b\_nc_{ctr})$

$\theta 1\_n29002s_{ctr} = 3.492\times 10^{-5}$

Rotation of center tee portion of shell model

$k1_{t1\_19} := \dfrac{\theta 1\_n29002s_{ctr}}{\theta 1\_n11b\_nc_{ctr}}$ $k1_{t1\_19} = 3.61$ Flexibility in global 1 (x-direction)

Directions:

Global 1 (X) Local 1(X - torsion)
Global 2 (Y) Local 2 (Z - strong axis bending)
Global 3 (Z) Local 3 (Y - weak axis bending)

Local branch net effective geometric properties:

$Je = \dfrac{J}{k}$

$Jt_{t1\_19} := \dfrac{J_{24}}{k1_{t1\_19}}$ $Jt_{t1\_19} = 1.076\times 10^{3}\cdot in^{4}$

Net effective polar moment of inertia of branch (T1-19), about the x-direction.

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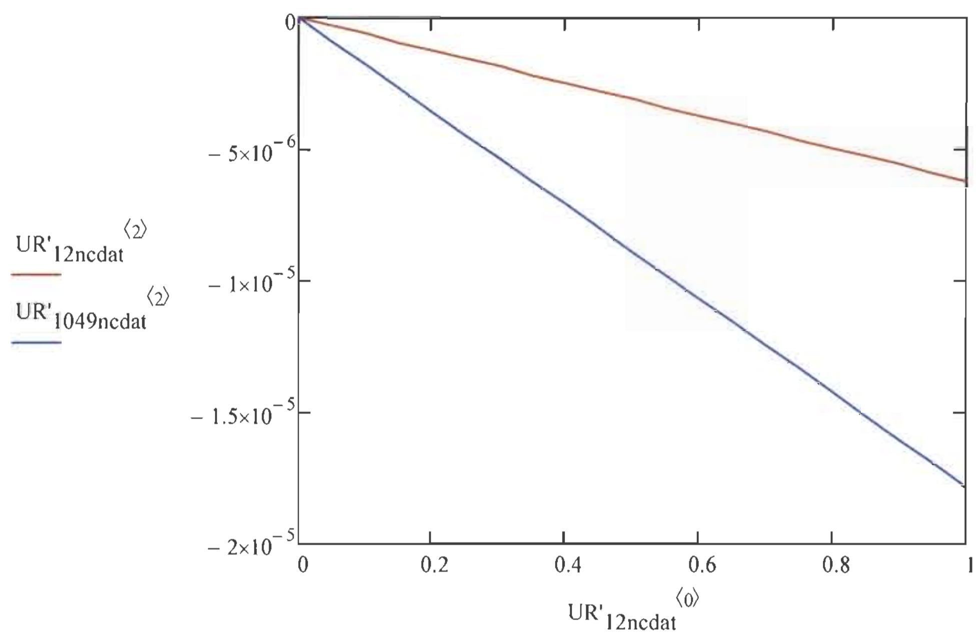
Global 2 (y-direction)



$\theta2\_n11b\_nc := UR'_{11ncdat_{rows(UR'_{11ncdat})-1,2}}$ Beam maximum branch rotation at N11

$\theta2\_n11b\_nc = -6.363\times 10^{-5}$

$\theta2\_n1049b\_nc := UR'_{1049ncdat_{rows(UR'_{1049ncdat})-1,2}}$ Beam maximum branch rotation at N1049

$\theta2\_n1049b\_nc = -1.788\times 10^{-5}$

$\theta2\_n12b\_nc := UR'_{12ncdat_{rows(UR'_{12ncdat})-1,2}}$ Beam maximum branch rotation at N12

$\theta2\_n12b\_nc = -6.244\times 10^{-6}$

$\theta2\_n29002s := UR'_{29002dat_{rows(UR'_{29002dat})-1,2}}$ Shell maximum branch rotation at end of branch

$\theta2\_n29002s = -1.532\times 10^{-4}$

$\theta2\_n11b\_nc_{ctr} := \theta2\_n1049b\_nc - \theta2\_n12b\_nc$ Rotation of center tee portion of beam, difference between N1049 and N12.

$\theta2\_n11b\_nc_{ctr} = -1.163\times 10^{-5}$

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$\theta 2\_n29002s_{ctr} := \theta 2\_n29002s - (\theta 2\_n11b\_nc - \theta 2\_n11b\_nc_{ctr})$ Rotation of center tee portion of shell model

$\theta 2\_n29002s_{ctr} = -1.012\times 10^{-4}$

$k2_{t1\_19} := \dfrac{\theta 2\_n29002s_{ctr}}{\theta 2\_n11b\_nc_{ctr}}$ $k2_{t1\_19} = 8.701$ Flexibility in global 2 (y-direction)

$I_e = \dfrac{I}{k}$ Net effective moment of inertia

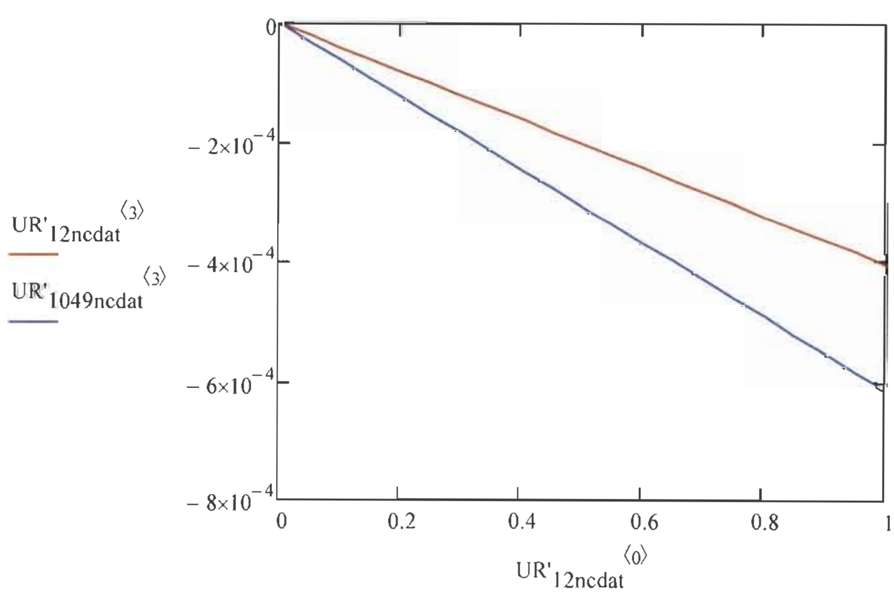
Directions:

Global 1 (X)	Local 1(X - torsion)
Global 2 (Y)	Local 2 (Z - strong axis bending)
Global 3 (Z)	Local 3 (Y - weak axis bending)

Local branch net effective geometric properties:

$Is_{t1\_19} := \dfrac{I_{24}}{k2_{t1\_19}}$ $Is_{t1\_19} = 223.234\,in^4$ Net effective moment of inertia, strong axis (Z) of branch (T1-19)

Global 3 (z-direction)



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$\theta3\_n11b\_nc := UR'11ncdat_{rows(UR'11ncdat)-1,3}$

$\theta3\_n11b\_nc = -1.452\times 10^{-3}$

$\theta3\_n1049b\_nc := UR'1049ncdat_{rows(UR'1049ncdat)-1,3}$

$\theta3\_n1049b\_nc = -6.176\times 10^{-4}$

$\theta3\_n12b\_nc := UR'12ncdat_{rows(UR'12ncdat)-1,3}$

$\theta3\_n12b\_nc = -4.055\times 10^{-4}$

$\theta3\_n29002s := UR'29002dat_{rows(UR'29002dat)-1,3}$

$\theta3\_n29002s = -9.137\times 10^{-3}$

$\theta3\_n11b\_nc_{ctr} := \theta3\_n1049b\_nc - \theta3\_n12b\_nc$ Rotation of center tee portion of beam model

$\theta3\_n11b\_nc_{ctr} = -2.12\times 10^{-4}$

$\theta3\_n29002s_{ctr} := \theta3\_n29002s - (\theta3\_n11b\_nc - \theta3\_n11b\_nc_{ctr})$ Rotation of center tee portion of shell model

$\theta3\_n29002s_{ctr} = -7.898\times 10^{-3}$

$k3_{t1\_19} := \dfrac{\theta3\_n29002s_{ctr}}{\theta3\_n11b\_nc_{ctr}}$ $k3_{t1\_19} = 37.245$ Flexibility in global 3 (z-direction)

Directions:

Global 1 (X) Local 1(X - torsion)
Global 2 (Y) Local 2 (Z - strong axis bending)
Global 3 (Z) Local 3 (Y - weak axis bending)

Local branch net effective geometric properties:

$Iw_{t1\_19} := \dfrac{I_{24}}{k3_{t1\_19}}$ $Iw_{t1\_19} = 52.149\,in^4$ Net effective moment of inertia, weak axis (Y) of branch (T1-19)

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T1-19 Summary - flexibility factors and net effective branch properties corresponding to both beam and shell models in x, y, and z-directions..

$k1_{t1\_19} = 3.61$ $k2_{t1\_19} = 8.701$ $k3_{t1\_19} = 37.245$

$Jt_{t1\_19} = 1075.95in^4$ $Is_{t1\_19} = 223.234in^4$ $Iw_{t1\_19} = 52.149in^4$

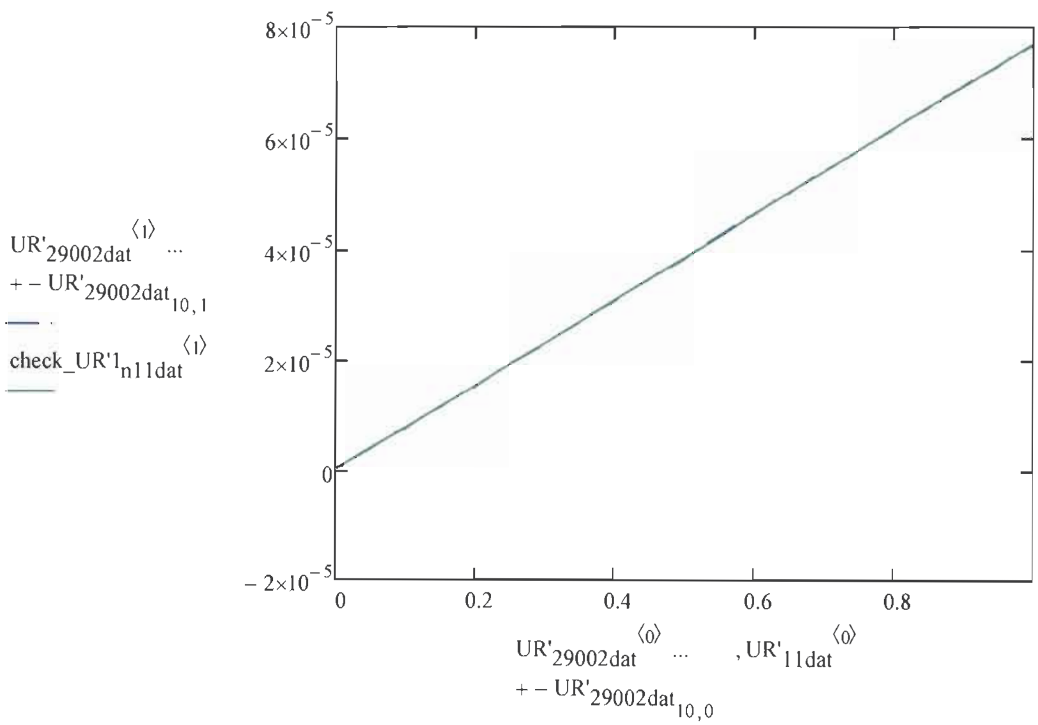
These beam section properties were defined within the beam model to check for correlation. The following diagrams determine correlation between the beam and shell models.

Check Global 1 (x-direction)

$check\_UR'1_{n11dat} :=$

$$\frac{check\_UR'1_{n11dat_{rows(check\_UR'1_{n11dat})-1,1}}}{UR'_{29002dat_{rows(UR'_{29002dat})-1,1}}} = 1$$

Shell and beam models show exact correlation, thus flexibility factor and net effective properties are correct.



Shell and beam curves overlap each other.

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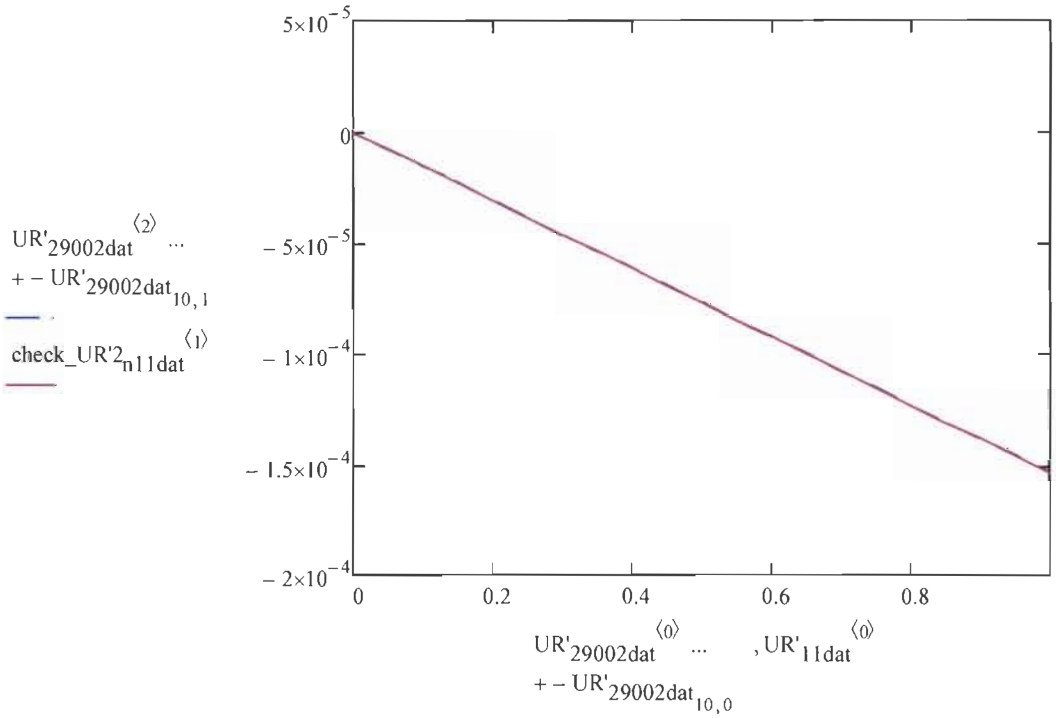
Check Global 2 (y-direction)

$check\_UR'2_{n11dat} :=$

$$\frac{check\_UR'2_{n11dat_{rows(check\_UR'2_{n11dat})-1,1}}}{UR'_{29002dat_{rows(UR'_{29002dat})-1,2}}} = 1$$

Shell and beam models show exact correlation, thus flexibility factor and net effective properties are correct.



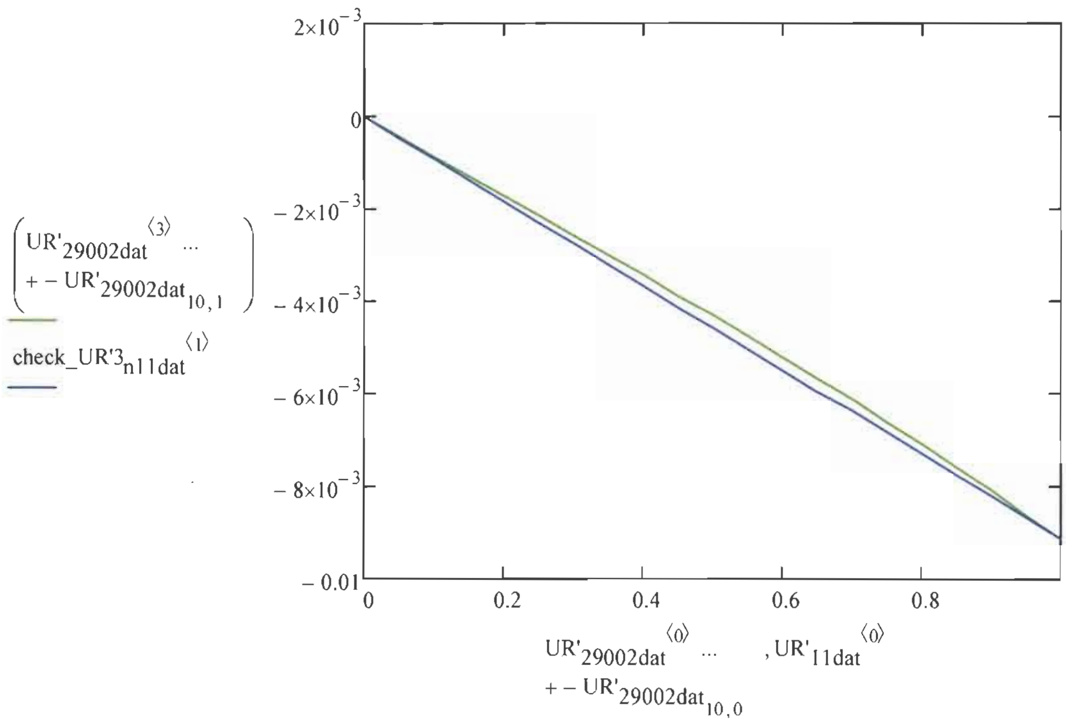
Shell and beam curves overlap each other.

Check Global 3 (z-direction)

$check\_UR'3_{n11dat} :=$

$$\frac{check\_UR'3_{n11dat_{rows(check\_UR'1_{n11dat})-1,1}}}{UR'_{29002dat_{rows(UR'_{29002dat})-1,3}}} \approx 1$$

Shell and beam models show exact correlation, thus flexibility factor and net effective properties are correct.



Shell and beam curves start and end at the same point. The shell model shows larger deformation, but shows excellent correlation with the beam model.

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F.4.3 – Flexibility Factor Determination of Tee on Line 1-11

There are several tee components that do not qualify as listed components. The purpose of this section is to check and determine (as necessary) flexibility factor for a tee on line 1-11, which is similar to other tees on lines 1-9, 1-10, and 1-12. The line 1-11 tee (hereafter referred to as T1-11) has the largest D/C ratio of the other three tees. Tees on lines 1-18, 1-20, and 1-21, shall be referred to as T1-9, T1-10, and T1-12, respectively within this report. Once the flexibility factors of T1-11 is determined, the system beam model will be updated with corresponding flexibility factors for these four tees and final solution results shall be obtained.

The four tees are located on line 1-8 (30-in x 0.438-in thick header run) and branch Northward to lines 1-9 through 1-12 (composed of 20-in x 0.312-in thick pipe) which extends to each of the four heat exchanger inlets. The four tees are reinforced with 0.375-in reinforment plates. Figure F.4.3-1 shows a pipe sketch of Model 1 and identifies the location of the four tees.

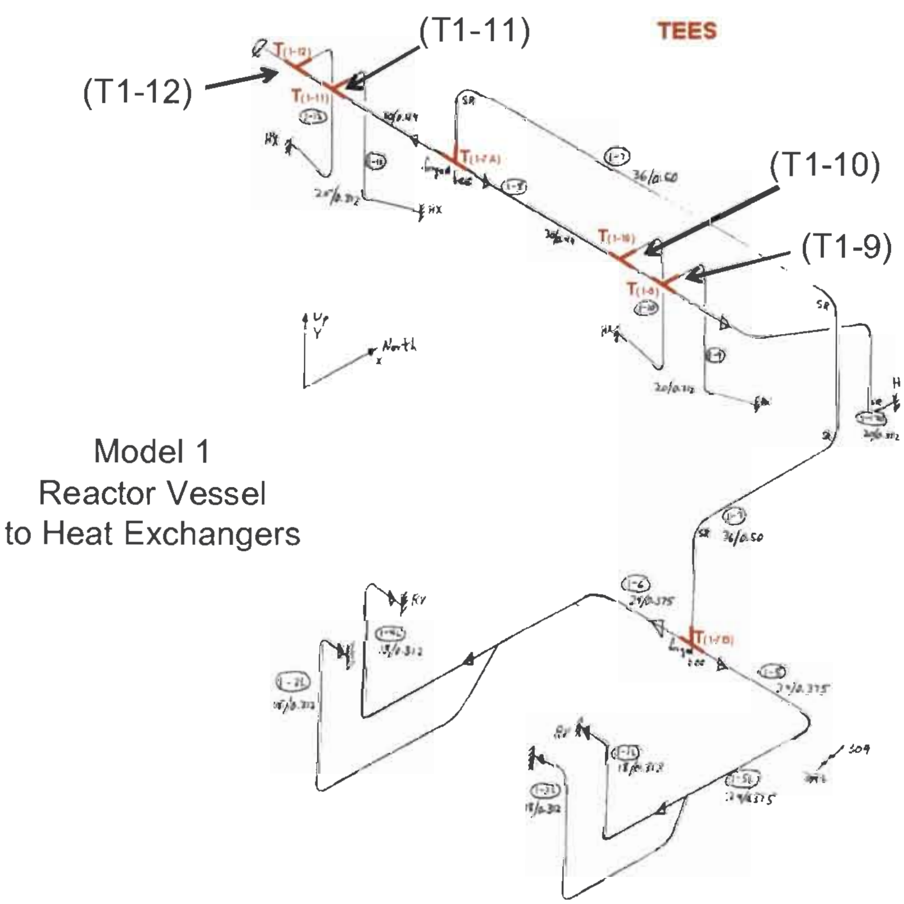

Figure F.4.3-1 – Piping Model 1, showing 30-in x 20-in reinforced tees locations.

To check the flexibility of T1-11, a shell model is created of the tee and a beam model of the tee is extracted from Model 14's system beam model. The T1-11 shell and beam models are compared to each other after three load cases are run side-by-side.

T1-11 shell model was solid-modeled and meshed within I-DEAS Master Series, Simulation, Version 12 [9]. With the meshing complete, input files were written for ABAQUS [10]. Final editing of the input files were performed in a text editor and then solution runs were performed with ABAQUS Standard, Version 6.7-5. Angular displacement results are extracted from the shell model and compared to the T1-11 beam model, to be described later.

T1-11 is nearly identical to that of T1-19 (Appendix F.4.2), excepting T1-11 branch is 20-in x 0.312-in pipe and its branch is pointing North. It too was meshed primarily with eight-node continuum shell elements and some rigid beam elements. The continuum shell elements support six degrees of freedom (3-translations, 3 rotations) at each node and were used to model the 30-in pipe run and 24-inch brach. The rigid beams were used as an aid in defining boundary conditions (i.e., applying loads and defining restraints) to the shell model. Figures F.4.2-2 illustrates T1-11 and further model details mimic that of T1-19 (Appendix F.4.2).

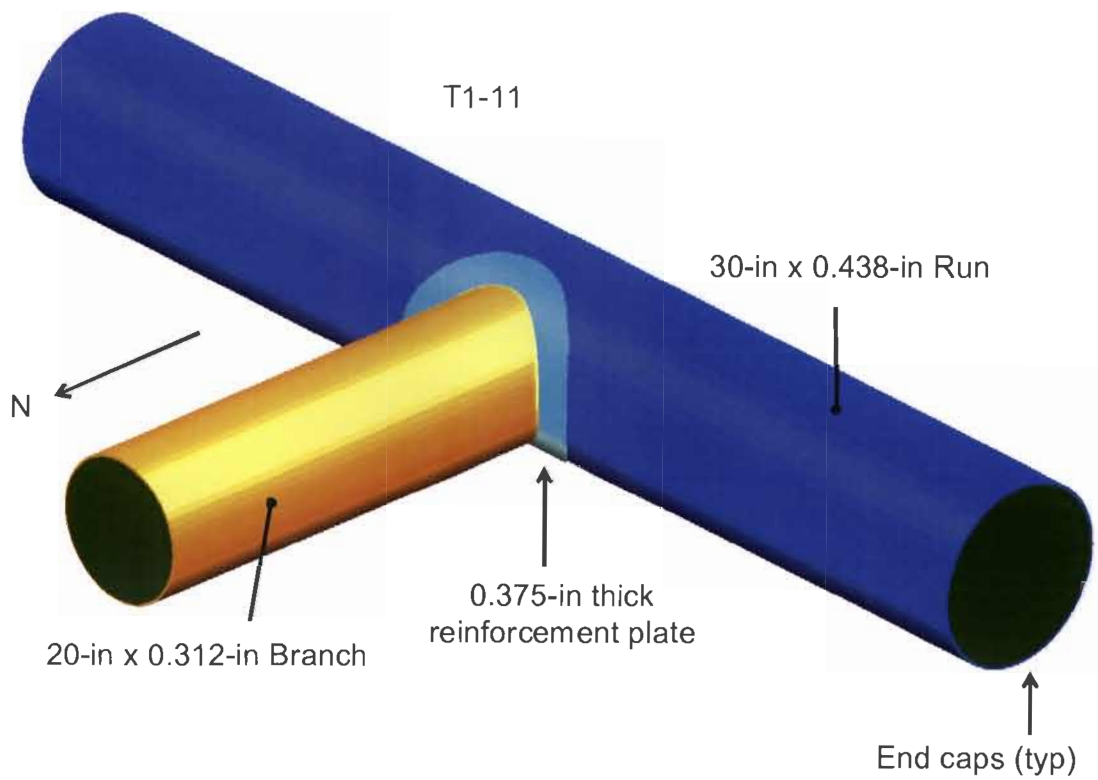

Figure F4.3-2 – T1-11 continuum and quadrilateral shell mesh.

T1-11 (as well as other three tees) are fabricated with 304 stainless steel [6] and operates at 167°F while maintaining a constant internal gauge pressure of 272-psi [11, Section 7.1]. Applicable material properties of T1-11 component is shown in Table F.4.3-1, as retrieved from Table 2 from the main report body.

Table F.4.3-1 – 304 Stainless Steel Material Properties at 167°F .

Symbol	Property Value	Property Description
μ	0.30 in/in	Poisson's Ration [1, Section NB-3683.1(b)]
E	27.7.0E+6	Modulus of Elasticity [12, Table TM]
Sy	26.12 ksi	Material Yield Strength [12, Table Y-1]
Sm	20 ksi	Maximum allowable Stress Intensity [12, Table 2A]

The beam model of T1-11 is comprised of the same shell pipe components, as shown in Figure F.4.3-3.

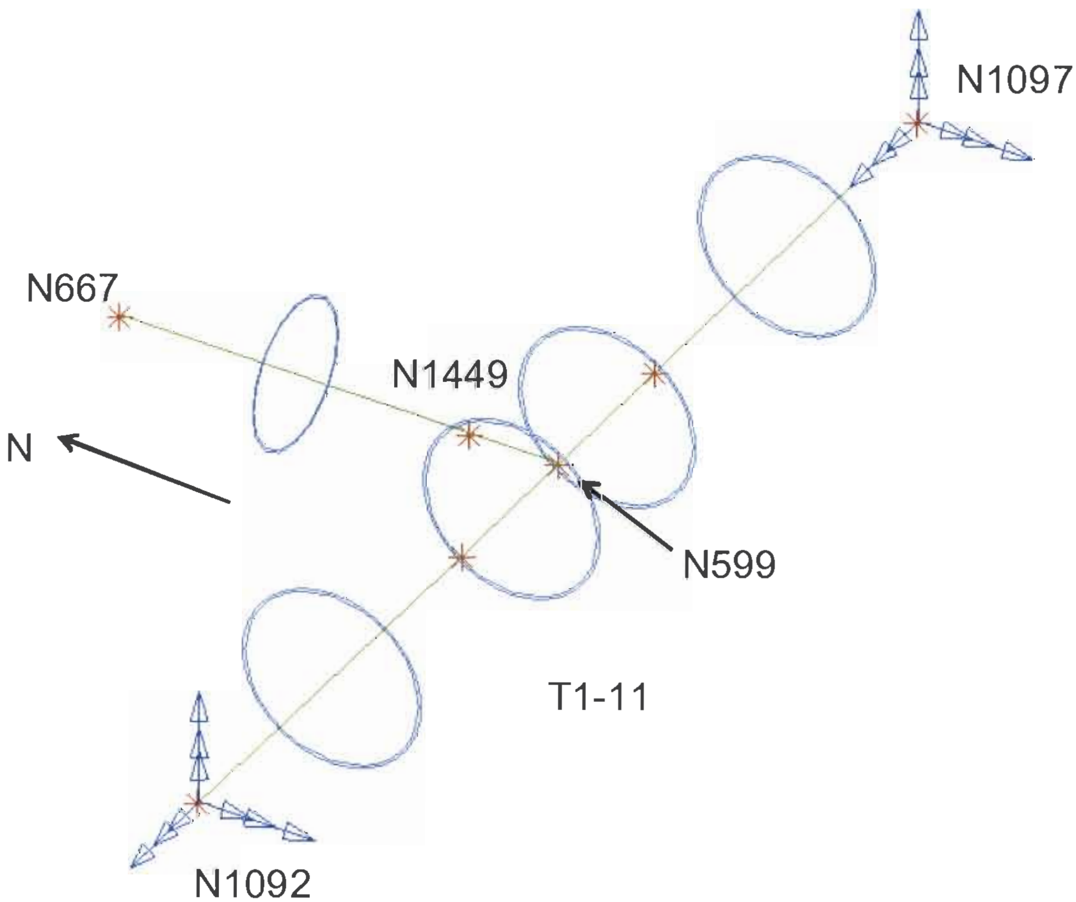

Figure 4.3-3 – Beam model of T1-11 is shown.

Each beam model load case consists of a single moment direction applied to its end branch node (i.e. 439,100 in•lbf in global x-direction, 218,100 in•lbf in global y-direction, or 164,100 in•lbf in global z-direction). The model is fully restrained where the run pipe is cut. Each shell model is run with the same boundary conditions as its corresponding beam model. However, the shell model has an additional initial step where an internal pressure of 272 psi is applied. Figure F.4.3-4 shows common boundary conditions between the shell and beam models.

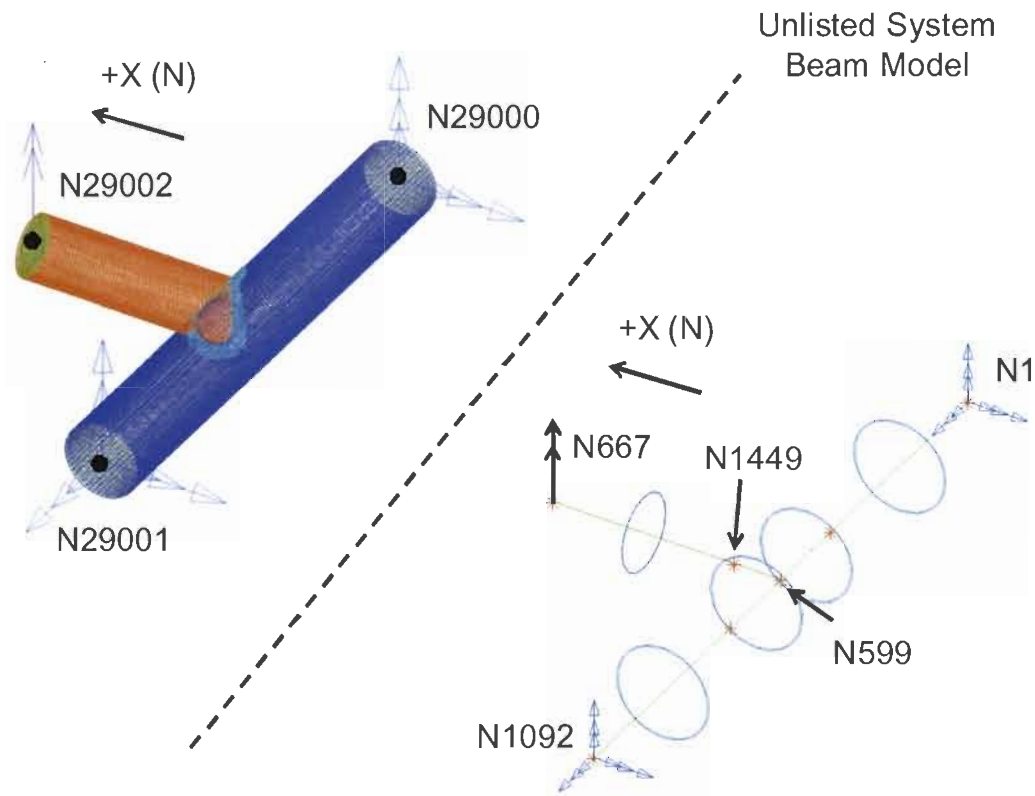

Figure F.4.3-4 - Shell and beam models of T1-11 with same boundary conditions, are shown.

Figures F.4.3-5 through F.4.3-7 show the resulting angular displacement at the end of the branch versus moment applied at the same point. The plots include the results from the shell model and the beam model. Additionally, beam results scaled plus and minus 20% are included for information. The shell model results have two steps. Displacements that occur during the first step, due to the pressure loading, are subtracted from the total curve so that only the relative displacement of caused by the moment is plotted.

The input files used for the beam models were "t1_11_beam_m1.inp", "t1_11_beam_m2.inp", and "t1_11_beam_m3.inp". The input files used for the shell models were "t1_11_shell_m1.inp", "t1_11_shell_m2.inp", and "t1_11_shell_m3.inp". In both sets of input files, the number change of 1, 2, and 3 represent the x-axis run, the y-axis run, and the z-axis run respectively.

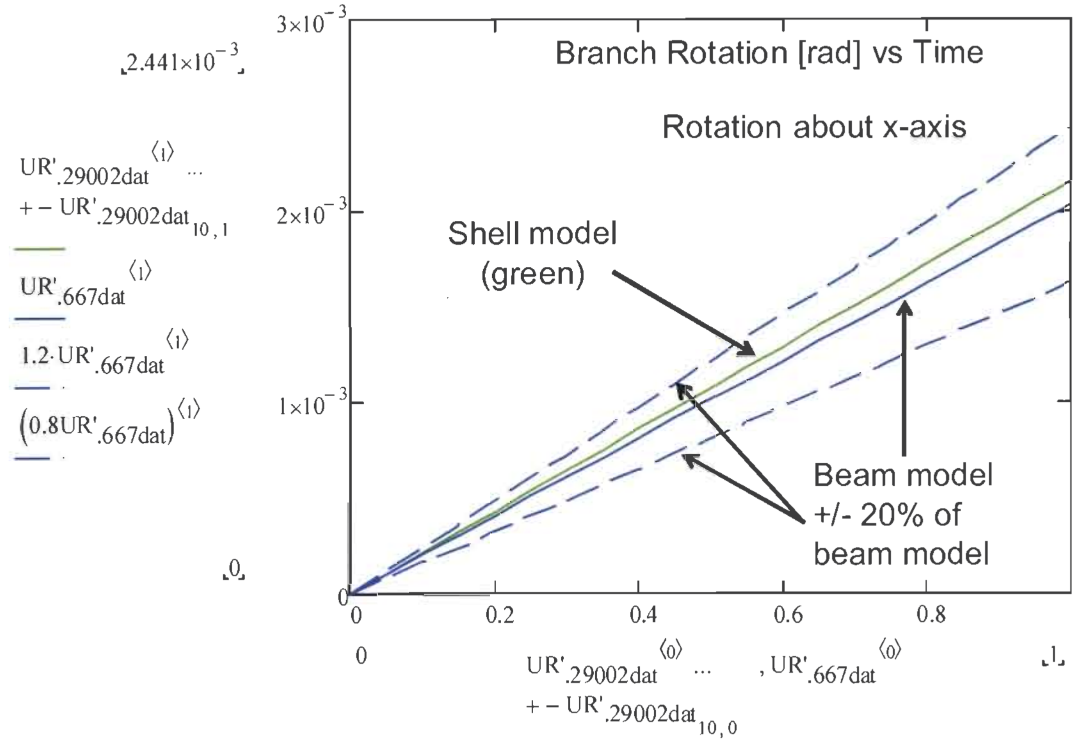

Figure F.4.2-5 - The shell model shows good correlation with the beam model, in the x-direction.

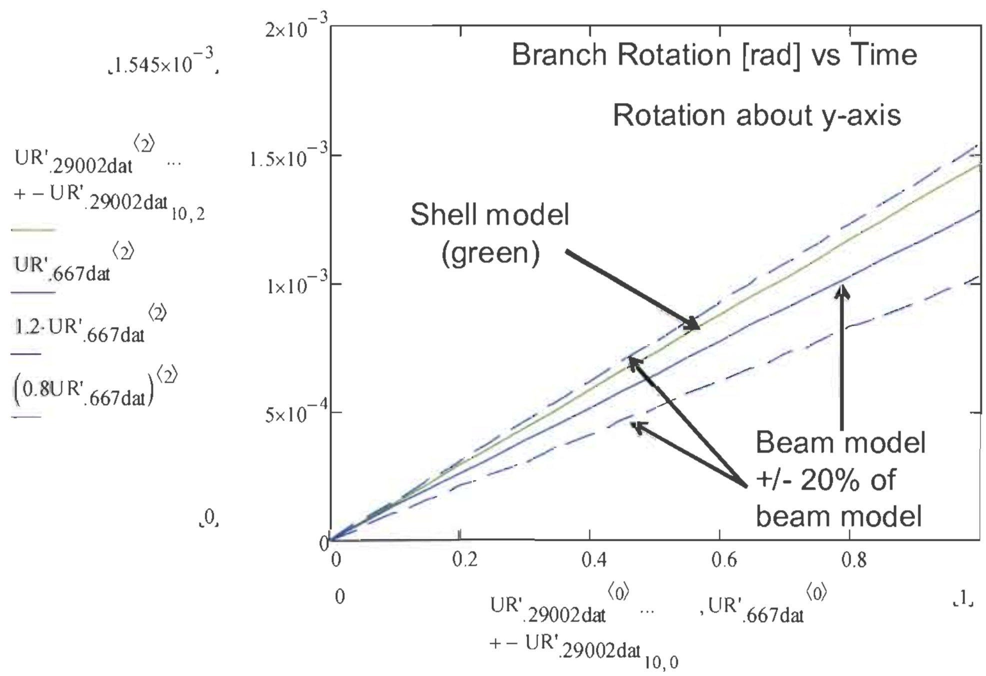

Figure F.4.2-6 - The shell model lies within the 20% beam model band, in the y-direction.

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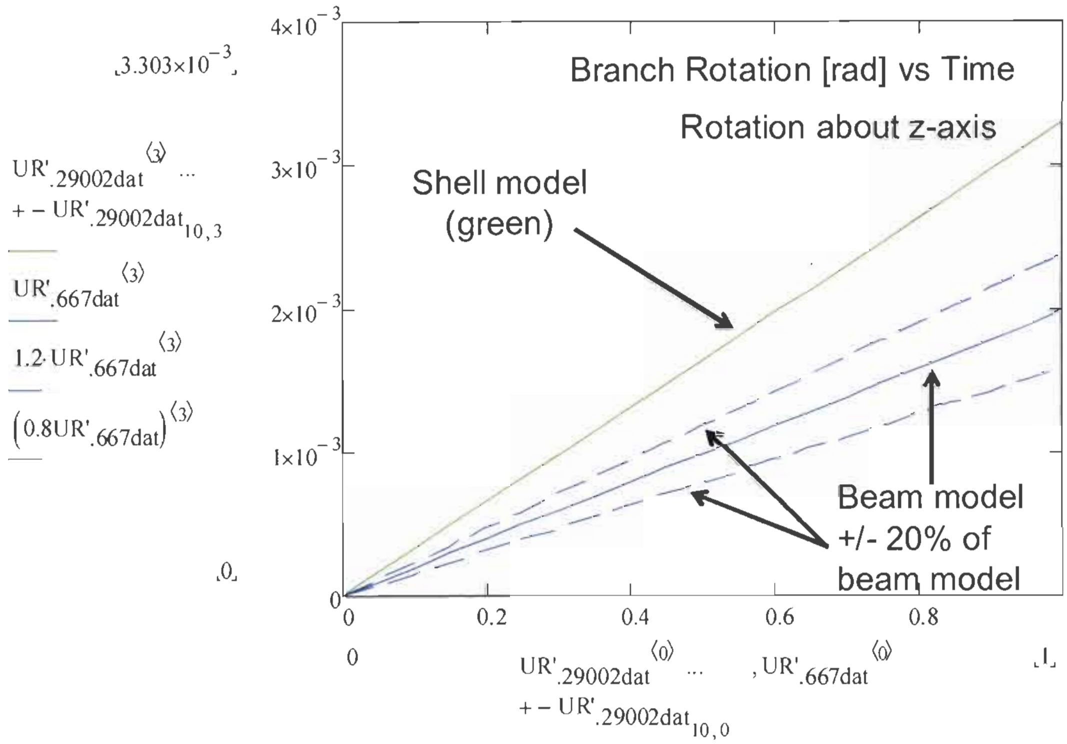


Figure F.4.2-7 Shell model displays poor correlation to the beam model, in the z-direction.

The shell and beam models demonstrate good correlation in the x and y-direction, and diverges in the z-direction. The shell model lies within the 20% bean model band for two of the directions, but better correlation could be achieved. Flexibility factors for all three directions will be determined to correlate the T1-11 shell and beam models, since T1-19 represents 3 other tees and a more accurate FF will assist with their proper load application, as well.

Line 1-11 Tee [30-in x 0.4375-in run (line 1-8) to 20-in x 0.312-in branch (line 1-11)]

$D_{30} := 30 \cdot in \quad t_{30} := 0.4375\,in \quad d_{30} := D_{30} - 2 \cdot t_{30} \quad d_{30} = 29.125\,in$

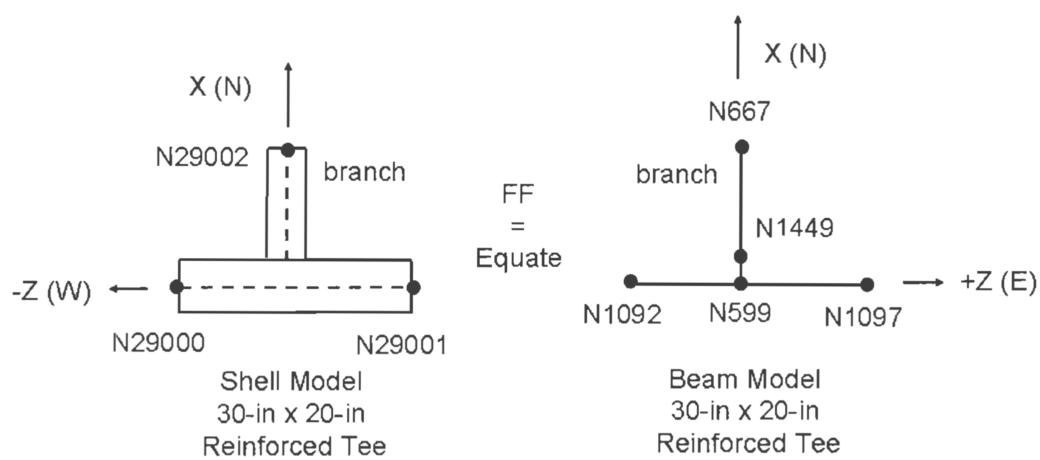
$D_{20} := 20 \cdot in \quad t_{20} := 0.312 \cdot in$ Branch diameter & thickness

$d_{20} := D_{20} - 2 \cdot t_{20} \quad d_{20} = 19.376\,in$ Inner diameter of elbow

$A_{20} := \frac{\pi}{4} \cdot \left(D_{20}^2 - d_{20}^2\right) \quad A_{20} = 19.298\,in^2$ Branch area

$I_{20} := \frac{\pi}{64} \cdot \left(D_{20}^4 - d_{20}^4\right) \quad I_{20} = 935.251\,in^4$ Branch moment of inertia

$J_{20} := \frac{\pi}{32} \cdot \left(D_{20}^4 - d_{20}^4\right) \quad J_{20} = 1.871 \times 10^3 \cdot in^4$ Branch polar moment of inertia



$Mb_{1449} := \left(4.391 \cdot 10^5 \quad 2.181 \cdot 10^5 \quad 1.641 \cdot 10^5\right)^T \quad in \cdot lbf$ Reaction moments extracted from beam model (T1-11).

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Determine net effective moment of inerias for Reinforced Tee on Line 1-11:

Global 1 (x-direction) Beam model branch rotations results are extracted from ABAQUS results and placed in a matrix for manipulation. The following matrix contains the three branch beam nodal rotations about the x-direction.

UR'_beam_ur1_ncdat :=

UR'_beam_ur1_ncdat =

Time	N559	N667	N1449
0	0	0	0
0.05	0.000003	0.000102	0.00002
0.1	0.000007	0.000203	0.00004
0.15	0.00001	0.000305	0.00006
0.2	0.000014	0.000407	0.00008
0.25	0.000017	0.000509	0.0001
0.3	0.000021	0.00061	0.00012
0.35	0.000024	0.000712	0.00014
0.4	0.000028	0.000814	0.00016
0.45	0.000031	0.000916	0.00018
0.5	0.000034	0.001017	0.0002
0.55	0.000038	0.001119	0.00022
0.6	0.000041	0.001221	0.00024
0.65	0.000045	0.001323	0.00026
0.7	0.000048	0.001424	0.00028
0.75	0.000052	0.001526	0.0003
0.8	0.000055	0.001628	0.00032
0.85	0.000059	0.001729	0.00034
0.9	0.000062	0.001831	0.00036
0.95	0.000066	0.001933	0.00038
1	0.000069	0.002035	0.0004

$UR'_{599\_ur1\_ncdat} := UR'\_beam\_ur1\_ncdat^{\langle 1 \rangle}$ $UR'_{667\_ur1\_ncdat} := UR'\_beam\_ur1\_ncdat^{\langle 2 \rangle}$

$UR'_{1449\_ur1\_ncdat} := UR'\_beam\_ur1\_ncdat^{\langle 3 \rangle}$

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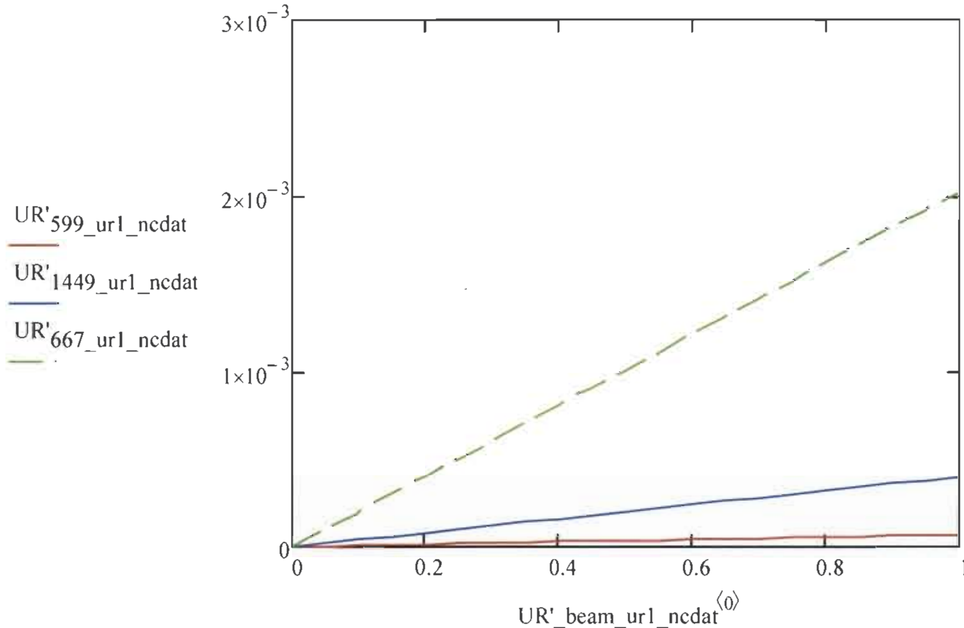

$\theta 1\_n667b\_ur1\_nc := UR'_{667\_ur1\_ncdat_{rows(UR'_{667\_ur1\_ncdat})-1}}$

$\theta 1\_n667b\_ur1\_nc = 2.035\times 10^{-3}$

Maximum branch beam end rotations

$\theta 1\_n1449b\_ur1\_nc := UR'_{1449\_ur1\_ncdat_{rows(UR'_{1449\_ur1\_ncdat})-1}}$

$\theta 1\_n1449b\_ur1\_nc = 3.995\times 10^{-4}$

Maximum branch beam rotations for N1449

$\theta 1\_n599b\_ur1\_nc := UR'_{599\_ur1\_ncdat_{rows(UR'_{599\_ur1\_ncdat})-1}}$

$\theta 1\_n599b\_ur1\_nc = 6.895\times 10^{-5}$

Maximum branch beam rotations of N599

$\theta 1\_n29002s := UR'_{29002dat_{rows(UR'_{29002dat})-1,1}}$

$\theta 1\_n29002s = 2.157\times 10^{-3}$

Maximum shell branch end rotations

$\theta 1\_n667b\_ur1\_nc_{ctr} := \theta 1\_n1449b\_ur1\_nc - \theta 1\_n599b\_ur1\_nc$

$\theta 1\_n667b\_ur1\_nc_{ctr} = 3.306\times 10^{-4}$

UR1 Rotation of center tee portion of beam

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$$\theta 1\_n29002s_{ctr} := \theta 1\_n29002s - \left(\theta 1\_n667b\_ur1\_nc - \theta 1\_n667b\_ur1\_nc_{ctr}\right)$$

$$\theta 1\_n29002s_{ctr} = 4.53 \times 10^{-4}$$

Rotation of center tee portion of shell

$$k1_{t1\_11} := \frac{\theta 1\_n29002s_{ctr}}{\theta 1\_n667b\_ur1\_nc_{ctr}} \qquad k1_{t1\_11} = 1.37$$

Flexibility in global 1 (x-direction)

$$I_e = \frac{I}{k}$$ Net effective moment of inertia

$$J_e = \frac{J}{k}$$ Net effective polar moment of inertia

Directions:

Global 1 (X) Local 1(X - torsion)
Global 2 (Y) Local 2 (Y - strong axis bending)
Global 3 (Z) Local 3 (Z - weak axis bending)

Local branch net effective geometric properties:

$$Jt_{t1\_11} := \frac{J_{20}}{k1_{t1\_11}} \qquad Jt_{t1\_11} = 1365.2\,in^4$$

Net effective polar moment of inertia, axis (X) of branch (T1-11)

Will change beam section to include net effective polar moment of inertia and check correlation accuracy about the x-direction.

$check\_UR'_{667\_m1dat} :=$

$$\frac{check\_UR'_{667\_m1dat_{rows(check\_UR'_{667\_m1dat})-1,\,1}}}{UR'_{29002dat_{rows(UR'_{29002dat})-1,\,1}}} = 1$$

Shell and beam model results correlate exactly about the x-axis.

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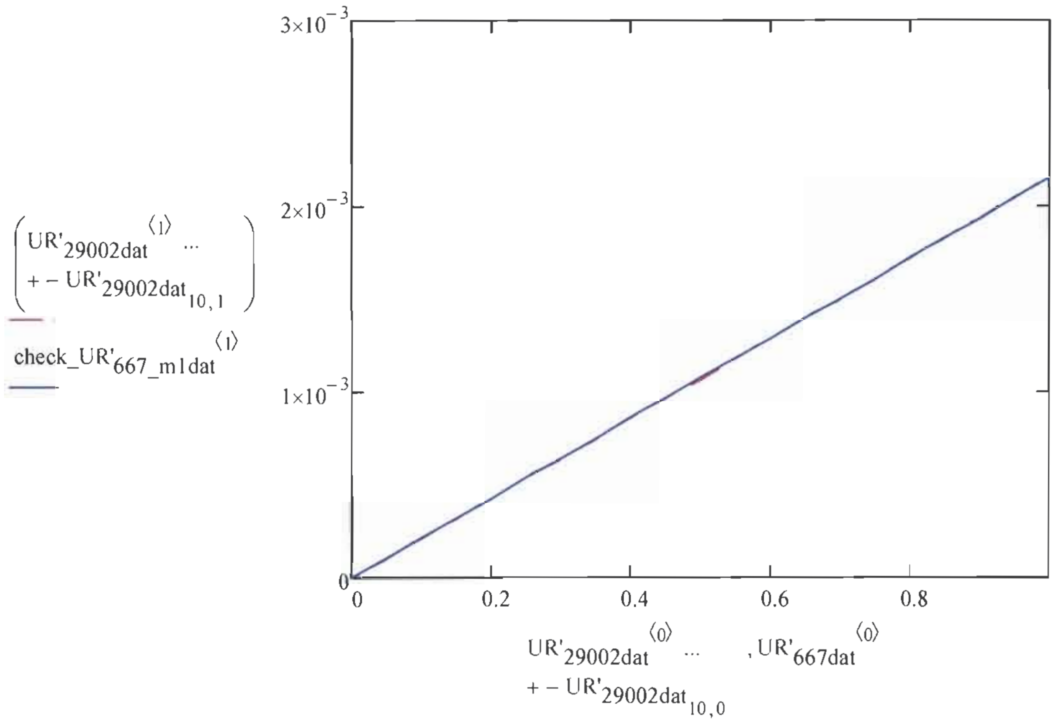

Shell and beam model curves overlap.

Flexibility of shell model (end node 29002) in Y-direction is within 20% acceptable limits of beam model (end node 667).

Determine net effective moment of inertia for Reinforced Tee on Line 1-11:

Global 2 (y-direction)

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UR'_beam_ur2_ncdat :=

	Time	N559	N667	N1449
	0	1	2	3
0	0	0	0	0
1	0.05	$1.712\cdot10^{-6}$	$3.926\cdot10^{-5}$	$8.028\cdot10^{-6}$
2	0.1	$3.425\cdot10^{-6}$	$7.853\cdot10^{-5}$	$1.606\cdot10^{-5}$
3	0.15	$5.137\cdot10^{-6}$	$1.178\cdot10^{-4}$	$2.408\cdot10^{-5}$
4	0.2	$6.849\cdot10^{-6}$	$1.571\cdot10^{-4}$	$3.211\cdot10^{-5}$
5	0.25	$8.562\cdot10^{-6}$	$1.963\cdot10^{-4}$	$4.014\cdot10^{-5}$
6	0.3	$1.027\cdot10^{-5}$	$2.356\cdot10^{-4}$	$4.817\cdot10^{-5}$
7	0.35	$1.199\cdot10^{-5}$	$2.748\cdot10^{-4}$	$5.62\cdot10^{-5}$
8	0.4	$1.37\cdot10^{-5}$	$3.141\cdot10^{-4}$	$6.422\cdot10^{-5}$
9	0.45	$1.541\cdot10^{-5}$	$3.534\cdot10^{-4}$	$7.225\cdot10^{-5}$
10	0.5	$1.712\cdot10^{-5}$	$3.926\cdot10^{-4}$	$8.028\cdot10^{-5}$
11	0.55	$1.884\cdot10^{-5}$	$4.319\cdot10^{-4}$	$8.831\cdot10^{-5}$
12	0.6	$2.055\cdot10^{-5}$	$4.712\cdot10^{-4}$	$9.634\cdot10^{-5}$
13	0.65	$2.226\cdot10^{-5}$	$5.104\cdot10^{-4}$	$1.044\cdot10^{-4}$
14	0.7	$2.397\cdot10^{-5}$	$5.497\cdot10^{-4}$	$1.124\cdot10^{-4}$
15	0.75	$2.569\cdot10^{-5}$	$5.89\cdot10^{-4}$	$1.204\cdot10^{-4}$
16	0.8	$2.74\cdot10^{-5}$	$6.282\cdot10^{-4}$	$1.284\cdot10^{-4}$
17	0.85	$2.911\cdot10^{-5}$	$6.675\cdot10^{-4}$	$1.365\cdot10^{-4}$
18	0.9	$3.082\cdot10^{-5}$	$7.068\cdot10^{-4}$	$1.445\cdot10^{-4}$
19	0.95	$3.253\cdot10^{-5}$	$7.46\cdot10^{-4}$	$1.525\cdot10^{-4}$
20	1	$3.425\cdot10^{-5}$	$7.853\cdot10^{-4}$	$1.606\cdot10^{-4}$

UR'_beam_ur2_ncdat =

$UR'_{599\_ur2\_ncdat} := UR'\_beam\_ur2\_ncdat^{\langle 1 \rangle}$ $UR'_{667\_ur2\_ncdat} := UR'\_beam\_ur2\_ncdat^{\langle 2 \rangle}$

$UR'_{1449\_ur2\_ncdat} := UR'\_beam\_ur2\_ncdat^{\langle 3 \rangle}$

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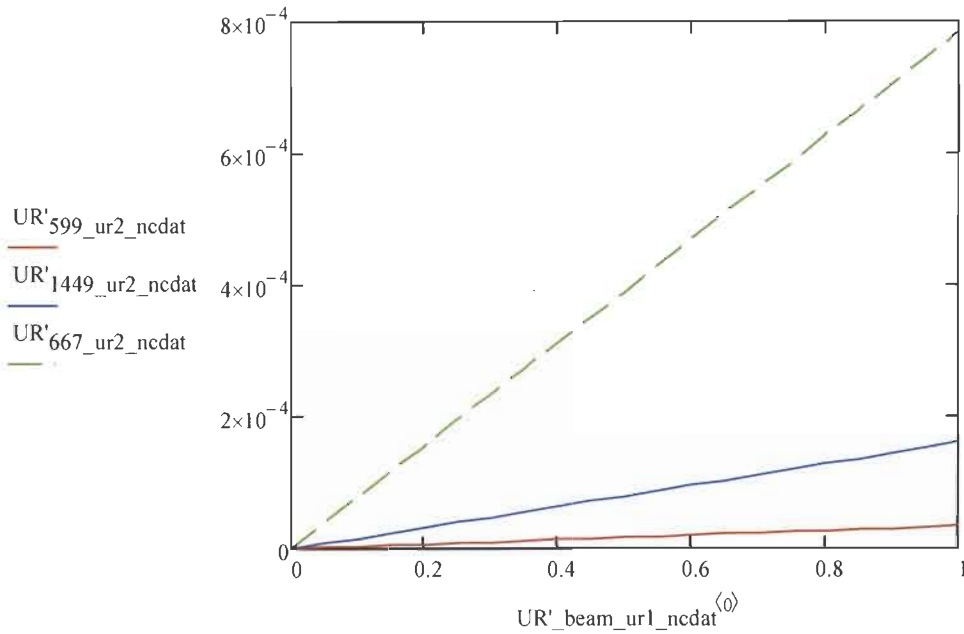

$\theta e2\_n667b\_ur2\_nc := UR'_{667\_ur2\_ncdat_{rows(UR'_{667\_ur2\_ncdat})-1}}$

$\theta e2\_n667b\_ur2\_nc = 7.853\times 10^{-4}$

Gather maximum rotations about beam branch nodes and shell model end node, then determine flexibility factor about the y-direction.

$\theta 2\_n1449b\_ur2\_nc := UR'_{1449\_ur2\_ncdat_{rows(UR'_{1449\_ur2\_ncdat})-1}}$

$\theta 2\_n1449b\_ur2\_nc = 1.606\times 10^{-4}$

$\theta 2\_n599b\_ur2\_nc := UR'_{599\_ur2\_ncdat_{rows(UR'_{599\_ur2\_ncdat})-1}}$

$\theta 2\_n599b\_ur2\_nc = 3.425\times 10^{-5}$

$\theta e2\_n29002s := UR'_{29002dat_{rows(UR'_{29002dat})-1,2}}$ $\theta e2\_n29002s = 1.468\times 10^{-3}$

$\theta 2\_n667b\_ur2\_nc_{ctr} := \theta 2\_n1449b\_ur2\_nc - \theta 2\_n599b\_ur2\_nc$

UR2 Rotation of center tee portion of beam

$\theta 2\_n667b\_ur2\_nc_{ctr} = 1.263\times 10^{-4}$

$\theta 2\_n29002s_{ctr} := \theta e2\_n29002s - (\theta e2\_n667b\_ur2\_nc - \theta 2\_n667b\_ur2\_nc_{ctr})$

Rotation of center tee portion of shell model

$\theta 2\_n29002s_{ctr} = 8.086\times 10^{-4}$

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$k2_{t1\_11} := \dfrac{\theta 2\_n29002s_{ctr}}{\theta 2\_n667b\_ur2\_nc_{ctr}}$ $k2_{t1\_11} = 6.401$ Flexibility in global 2 (Y-direction)

$I_e = \dfrac{I}{k}$ Net effective moment of inertia

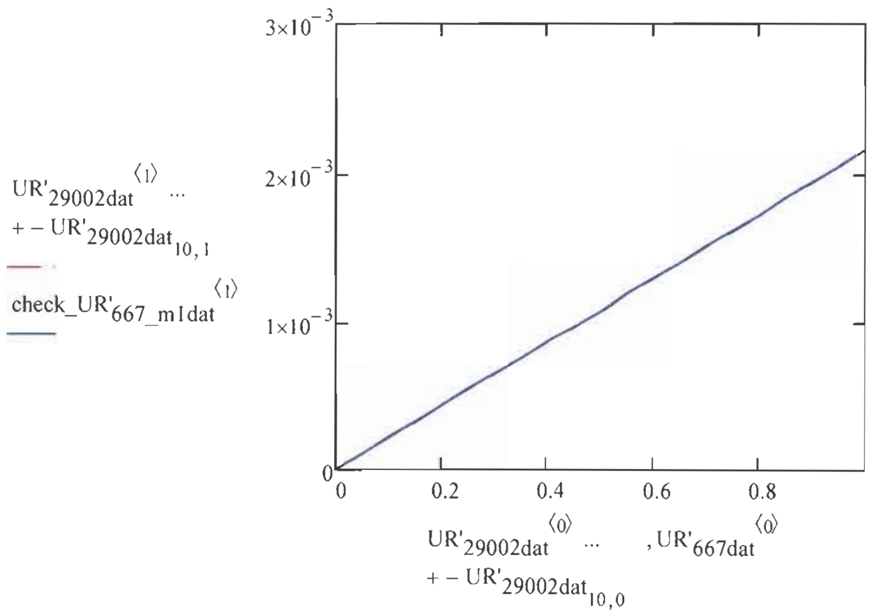
Directions:

Global 1 (X) Local 1(X - torsion)
Global 2 (Y) Local 2 (Y - strong axis bending)
Global 3 (Z) Local 3 (Z - weak axis bending)

Local branch net effective geometric properties:

$Is_{t1\_11} := \dfrac{I_{20}}{k2_{t1\_11}}$ $Is_{t1\_11} = 146.103\,in^4$ Net effective moment of inertia, strong axis (Y) of branch (T1-11)

$check\_UR'_{667\_m2dat} := \dfrac{check\_UR'_{667\_m1dat_{rows(check\_UR'_{667\_m1dat})-1,1}}}{UR'_{29002dat_{rows(UR'_{29002dat})-1,1}}} = 1$



Shell and beam models demonstrate exact correlation, for their curve overlap.

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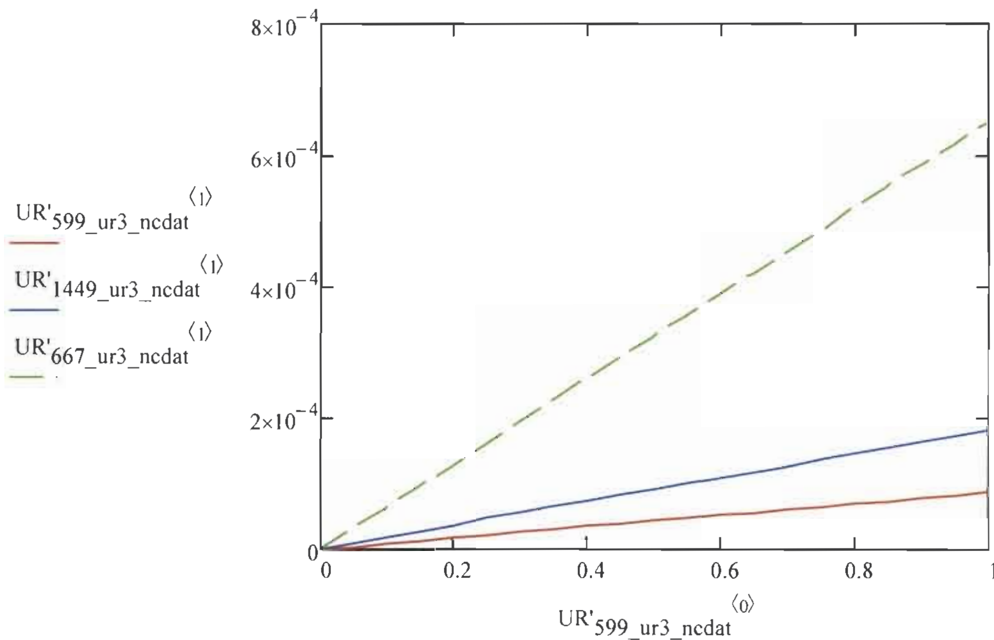
Flexibility of shell model (end node 29002) in Z-direction is out of the 20% acceptable limits of beam model (end node 667). Determine new flexibility factor about the z-axis.

Global 3 (z-direction)

$UR'_{599\_ur3\_ncdat} :=$ $UR'_{1449\_ur3\_ncdat} :=$

$UR'_{667\_ur3\_ncdat} :=$



Gather maximum rotations about beam branch nodes and shell model end node, then determine flexibility factor about the z-direction.

$\theta e3\_n667b\_ur3\_nc := UR'_{667\_ur3\_ncdat_{rows(UR'_{667\_ur3\_ncdat})-1,1}}$

$\theta e3\_n667b\_ur3\_nc = 6.527\times 10^{-4}$

$\theta 3\_n1449b\_ur3\_nc := UR'_{1449\_ur3\_ncdat_{rows(UR'_{1449\_ur3\_ncdat})-1,1}}$

$\theta 3\_n1449b\_ur3\_nc = 1.827\times 10^{-4}$

$\theta 3\_n599b\_ur3\_nc := UR'_{599\_ur3\_ncdat_{rows(UR'_{599\_ur3\_ncdat})-1,1}}$

$\theta 3\_n599b\_ur3\_nc = 8.762\times 10^{-5}$

$\theta e3\_n29002s := UR'_{29002dat_{rows(UR'_{29002dat})-1,3}}$ $\theta e3\_n29002s = 3.303\times 10^{-3}$

$\theta 3\_n667b\_ur3\_nc_{ctr} := \theta 3\_n1449b\_ur3\_nc - \theta 3\_n599b\_ur3\_nc$ UR3 Rotation of center tee portion of beam

$\theta 3\_n667b\_ur3\_nc_{ctr} = 9.504\times 10^{-5}$

$\theta 3\_n29002s_{ctr} := \theta e3\_n29002s - (\theta e3\_n667b\_ur3\_nc - \theta 3\_n667b\_ur3\_nc_{ctr})$ Rotation of center tee portion of shell model

$\theta 3\_n29002s_{ctr} = 2.745\times 10^{-3}$

$k3_{t1\_11} := \dfrac{\theta 3\_n29002s_{ctr}}{\theta 3\_n667b\_ur3\_nc_{ctr}}$ $k3_{t1\_11} = 28.885$ Flexibility in global 3 (z-direction)

Directions:

Global 1 (X)	Local 1(X - torsion)
Global 2 (Y)	Local 2 (Y - strong axis bending)
Global 3 (Z)	Local 3 (Z - weak axis bending)

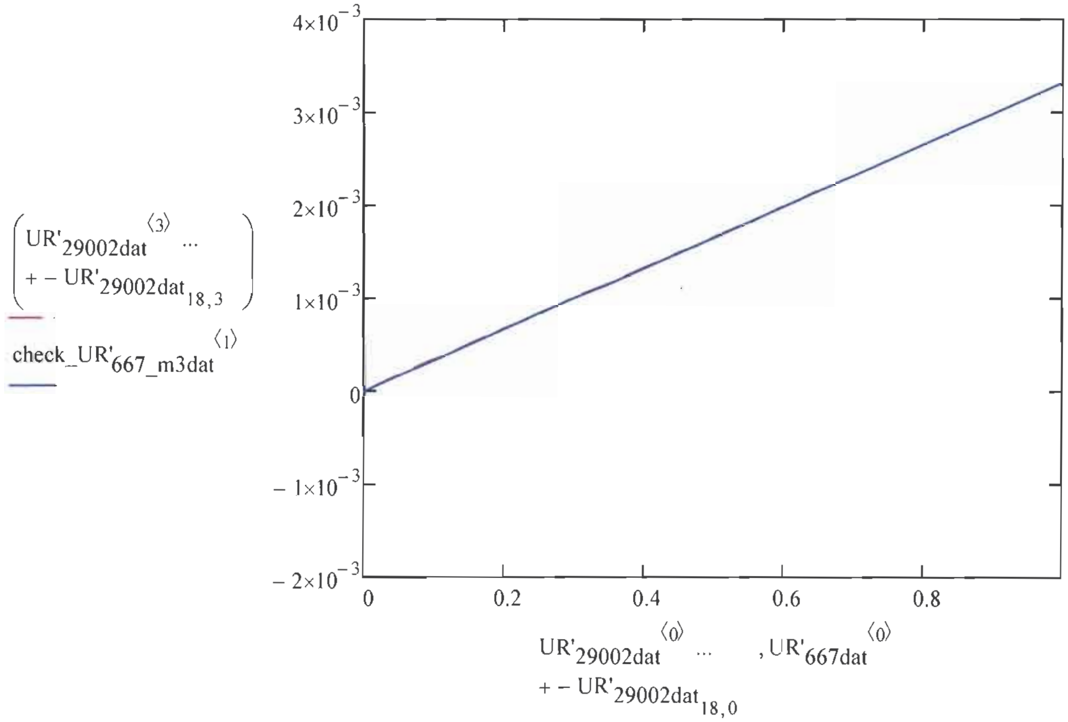
Local branch net effective geometric properties:

$Iw_{t1\_11} := \dfrac{I_{20}}{k3_{t1\_11}}$ $Iw_{t1\_11} = 32.379\,in^4$ Net effective moment of inertia, weak axis (Z) of branch (T1-11)

$check\_UR'_{667\_m3dat} :=$

$$\frac{check\_UR'_{667\_m3dat_{rows(check\_UR'_{667\_m3dat})-1,1}}}{UR'_{29002dat_{rows(UR'_{29002dat})-1,3}}} = 1$$

Shell and beam models correlate exactly about the z-direction.



Shell and beam curves overlap.

Branch Summary

Directions:

Global 1 (X)	Local 1(X - torsion)
Global 2 (Y)	Local 2 (Y - strong axis bending)
Global 3 (Z)	Local 3 (Z - weak axis bending)

Local branch net effective geometric properties:

$k1_{t1\_11} = 1.37$ $k2_{t1\_11} = 6.401$ $k3_{t1\_11} = 28.885$

$Jt_{t1\_11} = 1365.213in^4$ $Is_{t1\_11} = 146.103in^4$ $Iw_{t1\_11} = 32.379in^4$

Reininforced tee (Line 1-11) flexibility and net effective properties

Final 80th percentile solution results reflect that with the flexibility changes made to these four tees (T1—through T1-12), none of the tees have D/C values greater than unity and are therefore acceptable.

F.4.4 – Abbreviated Reprints of Tee's ABAQUS Input Files

Input file names

1. tee_beam_4_STp_mod_1.inp
2. tee_beam_4_STp_mod_2.inp
3. tee_beam_4_STp_mod_3.inp
4. tee_4_STp_1.inp
5. tee_4_STp_2.inp
6. tee_4_STp_3.inp
7. beam_1_tee_1.inp
8. beam_1_tee_2.inp
9. beam_1_tee_3.inp
10. shell_cont_1_tee_1.inp
11. shell_cont_1_tee_2.inp
12. shell_cont_1_tee_3.inp
13. check_beam_1_tee_1.inp
14. check_beam_1_tee_2.inp
15. check_beam_1_tee_3.inp
16. t1_11_beam_m1.inp
17. t1_11_beam_m2.inp
18. t1_11_beam_m3.inp
19. t1_11_shell3_tee_m1.inp
20. t1_11_shell3_tee_m2.inp
21. t1_11_shell3_tee_m3.inp
22. check_t1_11_beam_m1.inp
23. check_t1_11_beam_m2.inp
24. check_t1_11_beam_m3.inp

tee_beam_4_STp_mod_1.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Tee_model\Tee_model.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Tee_model\input\tee_beam_2_STp_code.inp
**%            EXPORTED: AT 10:30:46 ON 18-Sep-08
**%                PART: Part1
**%                 FEM: static in plane code
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
```

```
**%
**%        COORDINATE SYSTEM: PART
**%
**%            SUBSET EXPORT: OFF
**%
**%      NODE ZERO TOLERANCE: OFF
**%
**%    ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  18-Sep-08   10:30:46
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE10_75X0_25
*ELEMENT, TYPE=B31     , ELSET=PIPE6_625X0_28
*ELEMENT, TYPE=B31     , ELSET=PIPE6_625X0_28_1
**%
**% I-DEAS BEAM CROSS SECTION: PIPE10_75X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_10 ,
 ELSET=PIPE10_75X0_25,
 SECTION=PIPE
 0.53750E+01, 0.25000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_10
*ELASTIC,TYPE=ISOTROPIC
 2.73600E+07,  2.90000E-01
*DENSITY
 1.92700E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6,
 ELSET=PIPE6_625X0_28,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.70710E+00,-0.70710E+00, 0.00000E+00
*MATERIAL,NAME=SST304_6
*ELASTIC,TYPE=ISOTROPIC
 2.73600E+07,  2.90000E-01
*DENSITY
 1.12600E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
**%
**% I-DEAS BEAM CROSS SECTION: TEE_6SCL40_IY0_975_IZ3_196
**%
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:** 09/30/08	**Checker:** A. S. Siahpush	**Date:**	09/30/08

```
*BEAM GENERAL SECTION,
 ELSET=PIPE6_625X0_28_1,
 DENSITY= 0.11260E-02,
 ZERO= 0.00000E+00
 0.55814E+01, 0.68370E+00, 0.00000E+00, 0.31960E+01, 0.56284E+02, 0, 0.00000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
 0.27360E+08, 0.10605E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE10_75X0_25,
 PIPE6_625X0_28,
 PIPE6_625X0_28_1,
**%
**% ====== Z-ROTATION ======
**%
*NSET,NSET=OUT
 229,251,284
*STEP,INC=1000000,NLGEOM
*STATIC
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       229,  1, 6,      0.00000E+00
       251,  1, 6,      0.00000E+00
*CLOAD,OP=NEW
  284,    4, 2.468E+4
**   284,   5, 7.825E+4
**   284,    6, 1.672E+5
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=230, DOF=1
*END STEP
```

tee_beam_4_STp_mod_2.inp

```
**%   ==============================================================
**%
**%             NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                    FOR ABAQUS VERSION 6.x
**%
**%         MODEL FILE: C:\er2\work\TRA-670_piping\Tee_model\Tee_model.mf1
```

```
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Tee_model\input\tee_beam_2_STp_code.inp
**%            EXPORTED: AT 10:30:46 ON 18-Sep-08
**%                PART: Part1
**%                 FEM: static in plane code
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   =============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  18-Sep-08   10:30:46
**%========================================
**%          MODAL DATA
**%========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE10_75X0_25
*ELEMENT, TYPE=B31     , ELSET=PIPE6_625X0_28
*ELEMENT, TYPE=B31     , ELSET=PIPE6_625X0_28_1
**%
**% I-DEAS BEAM CROSS SECTION: PIPE10_75X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_10 ,
 ELSET=PIPE10_75X0_25,
 SECTION=PIPE
 0.53750E+01, 0.25000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_10
*ELASTIC,TYPE=ISOTROPIC
 2.73600E+07,  2.90000E-01
*DENSITY
 1.92700E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6,
 ELSET=PIPE6_625X0_28,
 SECTION=PIPE
```

```
 0.33125E+01, 0.28000E+00
 0.70710E+00,-0.70710E+00, 0.00000E+00
*MATERIAL,NAME=SST304_6
*ELASTIC,TYPE=ISOTROPIC
 2.73600E+07,  2.90000E-01
*DENSITY
 1.12600E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
**%
**% I-DEAS BEAM CROSS SECTION: TEE_6SCL40_IY0_975_IZ3_196
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE6_625X0_28_1,
 DENSITY= 0.11260E-02,
 ZERO= 0.00000E+00
 0.55814E+01, 0.68370E+00, 0.00000E+00, 0.31960E+01, 0.56284E+02, 0, 0.00000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
 0.27360E+08, 0.10605E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE10_75X0_25,
 PIPE6_625X0_28,
 PIPE6_625X0_28_1,
**%
**% ====== Z-ROTATION ======
**%
*NSET,NSET=OUT
 229,251,284
*STEP,INC=1000000,NLGEOM
*STATIC
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       229,  1, 6,      0.00000E+00
       251,  1, 6,      0.00000E+00
*CLOAD,OP=NEW
**   284,    4, 2.468E+4
   284,    5, 7.825E+4
**   284,    6, 1.672E+5
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
```

```
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=230, DOF=1
*END STEP
```

tee_beam_4_STp_mod_3.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Tee_model\Tee_model.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Tee_model\input\tee_beam_2_STp_code.inp
**%            EXPORTED: AT 10:30:46 ON 18-Sep-08
**%                PART: Part1
**%                 FEM: static in plane code
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  18-Sep-08   10:30:46
**%============================================
**%          MODAL DATA
**%============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE10_75X0_25
*ELEMENT, TYPE=B31     , ELSET=PIPE6_625X0_28
*ELEMENT, TYPE=B31     , ELSET=PIPE6_625X0_28_1
**%
**% I-DEAS BEAM CROSS SECTION: PIPE10_75X0_25
**%
*BEAM SECTION,
 MATERIAL=SST304_10 ,
 ELSET=PIPE10_75X0_25,
 SECTION=PIPE
 0.53750E+01, 0.25000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_10
*ELASTIC,TYPE=ISOTROPIC
```

```
 2.73600E+07,  2.90000E-01
*DENSITY
 1.92700E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE6_625X0_28
**%
*BEAM SECTION,
 MATERIAL=SST304_6,
 ELSET=PIPE6_625X0_28,
 SECTION=PIPE
 0.33125E+01, 0.28000E+00
 0.70710E+00,-0.70710E+00, 0.00000E+00
*MATERIAL,NAME=SST304_6
*ELASTIC,TYPE=ISOTROPIC
 2.73600E+07,  2.90000E-01
*DENSITY
 1.12600E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
**%
**% I-DEAS BEAM CROSS SECTION: TEE_6SCL40_IY0_975_IZ3_196
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE6_625X0_28_1,
 DENSITY= 0.11260E-02,
 ZERO= 0.00000E+00
 0.55814E+01, 0.68370E+00, 0.00000E+00, 0.31960E+01, 0.56284E+02, 0, 0.00000E+00
 0.10000E+01, 0.00000E+00, 0.00000E+00
 0.27360E+08, 0.10605E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE10_75X0_25,
 PIPE6_625X0_28,
 PIPE6_625X0_28_1,
**%
**% ====== Z-ROTATION ======
**%
*NSET,NSET=OUT
 229,251,284
*STEP,INC=1000000,NLGEOM
*STATIC
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       229,  1, 6,      0.00000E+00
       251,  1, 6,      0.00000E+00
*CLOAD,OP=NEW
```

```
**   284,    4, 2.468E+4
**   284,   5, 7.825E+4
   284,    6, 1.672E+5
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=230, DOF=1
*END STEP
```

tee_4_STp_1.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Tee_model\Tee_model.mf1
**%          INPUT FILE: C:\er2\work\TRA-670_piping\Tee_model\input\tee_2_STp.inp
**%            EXPORTED: AT 14:01:12 ON 17-Sep-08
**%                PART: Tee fe
**%                 FEM: Fem1 in plane
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  17-Sep-08   14:01:12
**%=========================================
**%           MODAL DATA
**%=========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL0_25
*ELEMENT, TYPE=SC8R    , ELSET=SOLID2
*SHELL SECTION,
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
 ELSET=SHELL0_25 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  2.50000E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.73600E+07,  2.90000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
*DAMPING, ALPHA=0.5236, BETA=2.653E-3
*SHELL SECTION, ELSET=SOLID2, MATERIAL=SST304
 5.0,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=CP0, GENERATE
*NSET,NSET=CP1, GENERATE
*NSET,NSET=CP2, GENERATE
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=HALF, GENERATE
*ELSET,ELSET=PIPE10, GENERATE
*ELSET,ELSET=PIPE6, GENERATE
*ELSET,ELSET=WELD, GENERATE
**%
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=BS000002, GENERATE
**%
*NSET,NSET=OUT
**%
*Surface, type=NODE, name=CP0
 CP0, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING0, REF NODE=15000, SURFACE=CP0
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP1
 CP1, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING1, REF NODE=15001, SURFACE=CP1
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP2
 CP2, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING2, REF NODE=15002, SURFACE=CP2
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
 15000, 1, 6, 0.0E-02
 15001, 1, 6, 0.0E-02
```

```
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
BS000001,     P, 2.5300E+02
BS000002,    P2, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=5782, DOF=1
*END STEP
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
 15000, 1, 6, 0.0E-02
 15001, 1, 6, 0.0E-02
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
BS000001,     P, 2.5300E+02
BS000002,    P2, 2.5300E+02
*CLOAD,OP=NEW
   15002,     4, 2.468E+4
**   15002,     5, 7.825E+4
**   15002,     6, 1.672E+5
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=5782, DOF=1
*END STEP
```

tee_4_STp_2.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:** 09/30/08	**Checker:** A. S. Siahpush	**Date:**	09/30/08

```
**%                    FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Tee_model\Tee_model.mfl
**%          INPUT FILE: C:\er2\work\TRA-670_piping\Tee_model\input\tee_2_STp.inp
**%            EXPORTED: AT 14:01:12 ON 17-Sep-08
**%                PART: Tee fe
**%                 FEM: Feml in plane
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%    ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  17-Sep-08   14:01:12
**%=========================================
**%           MODAL DATA
**%=========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL0_25
*ELEMENT, TYPE=SC8R    , ELSET=SOLID2
*SHELL SECTION,
 ELSET=SHELL0_25 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  2.50000E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.73600E+07,  2.90000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
*DAMPING, ALPHA=0.5236, BETA=2.653E-3
*SHELL SECTION, ELSET=SOLID2, MATERIAL=SST304
 5.0,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=CP0, GENERATE
*NSET,NSET=CP1, GENERATE
*NSET,NSET=CP2, GENERATE
*ELSET,ELSET=ALL, GENERATE
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
*ELSET,ELSET=HALF, GENERATE
*ELSET,ELSET=PIPE10, GENERATE
*ELSET,ELSET=PIPE6, GENERATE
*ELSET,ELSET=WELD, GENERATE
**%
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=BS000002, GENERATE
**%
*NSET,NSET=OUT
**%
*Surface, type=NODE, name=CP0
 CP0, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING0, REF NODE=15000, SURFACE=CP0
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP1
 CP1, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING1, REF NODE=15001, SURFACE=CP1
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP2
 CP2, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING2, REF NODE=15002, SURFACE=CP2
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
 15000, 1, 6, 0.0E-02
 15001, 1, 6, 0.0E-02
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
BS000001,    P, 2.5300E+02
BS000002,   P2, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=5782, DOF=1
*END STEP
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
```

```
*STATIC, STABILIZE, FACTOR=0.001
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
 15000, 1, 6, 0.0E-02
 15001, 1, 6, 0.0E-02
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
BS000001,    P, 2.5300E+02
BS000002,   P2, 2.5300E+02
*CLOAD,OP=NEW
**   15002,    4, 2.468E+4
   15002,   5, 7.825E+4
**   15002,    6, 1.672E+5
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=5782, DOF=1
*END STEP
```

tee_4_STp_3.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Tee_model\Tee_model.mf1
**%          INPUT FILE: C:\er2\work\TRA-670_piping\Tee_model\input\tee_2_STp.inp
**%            EXPORTED: AT 14:01:12 ON 17-Sep-08
**%                PART: Tee fe
**%                 FEM: Fem1 in plane
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
**%    ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  17-Sep-08   14:01:12
**%=============================================
**%          MODAL DATA
**%=============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=SHELL0_25
*ELEMENT, TYPE=SC8R    , ELSET=SOLID2
*SHELL SECTION,
 ELSET=SHELL0_25 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  2.50000E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.73600E+07,  2.90000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
*DAMPING, ALPHA=0.5236, BETA=2.653E-3
*SHELL SECTION, ELSET=SOLID2, MATERIAL=SST304
 5.0,
**%
*NSET,NSET=ALL, GENERATE
*NSET,NSET=CP0, GENERATE
*NSET,NSET=CP1, GENERATE
*NSET,NSET=CP2, GENERATE
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=HALF, GENERATE
*ELSET,ELSET=PIPE10, GENERATE
*ELSET,ELSET=PIPE6, GENERATE
*ELSET,ELSET=WELD, GENERATE
**%
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=BS000002, GENERATE
**%
*NSET,NSET=OUT
**%
*Surface, type=NODE, name=CP0
 CP0, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING0, REF NODE=15000, SURFACE=CP0
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP1
 CP1, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING1, REF NODE=15001, SURFACE=CP1
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP2
 CP2, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING2, REF NODE=15002, SURFACE=CP2
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
 15000, 1, 6, 0.0E-02
 15001, 1, 6, 0.0E-02
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
BS000001,    P, 2.5300E+02
BS000002,   P2, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=5782, DOF=1
*END STEP
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
 15000, 1, 6, 0.0E-02
 15001, 1, 6, 0.0E-02
*DLOAD,OP=NEW
 ALL, GRAV, 386.09, 0.0,-1.0, 0.0
BS000001,    P, 2.5300E+02
BS000002,   P2, 2.5300E+02
*CLOAD,OP=NEW
**   15002,    4, 2.468E+4
**   15002,    5, 7.825E+4
   15002,    6, 1.672E+5
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
```

Project:	ATR Life Time Extension Project			**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation						
Performer:	D. T. Clark	**Date:**	09/30/08	**Checker:**	A. S. Siahpush	**Date:**	09/30/08

```
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=5782, DOF=1
*END STEP
```

beam_1_tee_1.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Reinforced_Tee_model\tee_1-
19.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Reinforced_Tee_model\input\beam_1_tee.inp
**%            EXPORTED: AT 09:56:21 ON 19-Sep-08
**%                PART: beam fe
**%                 FEM: Fem1
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  19-Sep-08   09:56:21
**%============================================
**%          MODAL DATA
**%============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_438
**%
*BEAM SECTION,
 MATERIAL=SST304_B30X0438_R ,
 ELSET=PIPE,
 SECTION=PIPE
 0.15000E+02, 0.43800E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_B30X0438_R
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.25500E-03,
```

```
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304_B24X0312_BR,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.12000E+02, 0.37500E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_B24X0312_BR
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: BR_30X24_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_2,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.89153E+02, 0.00000E+00, 0.27078E+03, 0.19420E+05, 0, 0.00000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE,
 PIPE_1,
 PIPE_2,
**%
*NSET,NSET=ALL
      11,       12,       76,       77,     1049,     1051,     1052
*ELSET,ELSET=ALL
      44,       58,       59,      647,      648,      649
**%
**% ====== Z-ROTATION ======
**%
*NSET,NSET=OUT
 1052,1051,11
*STEP,INC=1000000,NLGEOM
*STATIC
 0.05,1.0,1.0E-08,0.05
```

Project:	ATR Life Time Extension Project	ECAR No.:	ECAR-194	Rev.:	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	Date: 09/30/08	Checker: A. S. Siahpush	Date:	09/30/08

```
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       1051,  1, 6,      0.00000E+00
       1052,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
**         11,     5,-4.2160E+04
**         11,     6,-7.6860E+05
         11,    4, 2.6970E+04
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=77, DOF=1
*END STEP
```

beam_1_tee_2.inp

```
**%   ============================================================
**%
**%             NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                    FOR ABAQUS VERSION 6.x
**%
**%         MODEL FILE: C:\er2\work\TRA-670_piping\Reinforced_Tee_model\tee_1-
19.mf1
**%         INPUT FILE: C:\er2\work\TRA-
670_piping\Reinforced_Tee_model\input\beam_1_tee.inp
**%           EXPORTED: AT 09:56:21 ON 19-Sep-08
**%               PART: beam fe
**%                FEM: Fem1
**%
**%             UNITS: IN-Inch (pound f)
**%                   ... LENGTH : inch
**%                   ... TIME   : sec
**%                   ... MASS   : lbf-sec**2/in
**%                   ... FORCE  : pound (lbf)
**%                   ... TEMPERATURE : deg Fahrenheit
**%
**%        COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark **Date:** 09/30/08	**Checker:**	A. S. Siahpush	**Date:**	09/30/08

```
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  19-Sep-08   09:56:21
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31      , ELSET=PIPE
*ELEMENT, TYPE=B31      , ELSET=PIPE_1
*ELEMENT, TYPE=B31      , ELSET=PIPE_2
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_438
**%
*BEAM SECTION,
 MATERIAL=SST304_B30X0438_R ,
 ELSET=PIPE,
 SECTION=PIPE
 0.15000E+02, 0.43800E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_B30X0438_R
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.25500E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304_B24X0312_BR,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.12000E+02, 0.37500E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_B24X0312_BR
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: BR_30X24_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_2,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.89153E+02, 0.00000E+00, 0.27078E+03, 0.19420E+05, 0, 0.00000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
```

```
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE,
 PIPE_1,
 PIPE_2,
**%
*NSET,NSET=ALL
      11,       12,       76,       77,     1049,     1051,     1052
*ELSET,ELSET=ALL
      44,       58,       59,      647,      648,      649
**%
**% ====== Z-ROTATION ======
**%
*NSET,NSET=OUT
 1052,1051,11
*STEP,INC=1000000,NLGEOM
*STATIC
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       1051,  1, 6,      0.00000E+00
       1052,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
         11,    5,-4.2160E+04
**         11,    6,-7.6860E+05
**         11,    4, 2.6970E+04
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=77, DOF=1
*END STEP
```

beam_1_tee_3.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
```

```
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Reinforced_Tee_model\tee_1-
19.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Reinforced_Tee_model\input\beam_1_tee.inp
**%            EXPORTED: AT 09:56:21 ON 19-Sep-08
**%                PART: beam fe
**%                 FEM: Fem1
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  19-Sep-08   09:56:21
**%========================================
**%         MODAL DATA
**%========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_438
**%
*BEAM SECTION,
 MATERIAL=SST304_B30X0438_R ,
 ELSET=PIPE,
 SECTION=PIPE
 0.15000E+02, 0.43800E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_B30X0438_R
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.25500E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_375
**%
```

```
*BEAM SECTION,
 MATERIAL=SST304_B24X0312_BR,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.12000E+02, 0.37500E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_B24X0312_BR
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: BR_30X24_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_2,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.55763E+02, 0.89153E+02, 0.00000E+00, 0.27078E+03, 0.19420E+05, 0, 0.00000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE,
 PIPE_1,
 PIPE_2,
**%
*NSET,NSET=ALL
      11,      12,      76,      77,    1049,    1051,    1052
*ELSET,ELSET=ALL
      44,      58,      59,     647,     648,     649
**%
**% ====== Z-ROTATION ======
**%
*NSET,NSET=OUT
 1052,1051,11
*STEP,INC=1000000,NLGEOM
*STATIC
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       1051,  1, 6,      0.00000E+00
       1052,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
```

```
**         11,     5,-4.2160E+04
         11,     6,-7.6860E+05
**         11,     4, 2.6970E+04
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=77, DOF=1
*END STEP
```

shell_cont_1_tee_1.inp

```
**%   ============================================================
**%
**%            NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                   FOR ABAQUS VERSION 6.x
**%
**%        MODEL FILE: C:\er2\work\TRA-670_piping\Reinforced_Tee_model\tee_1-
19.mf1
**%        INPUT FILE: C:\er2\work\TRA-
670_piping\Reinforced_Tee_model\input\shell_cont_1_tee.inp
**%          EXPORTED: AT 20:25:24 ON 19-Sep-08
**%              PART: Tee 30x24
**%               FEM: Fem1
**%
**%             UNITS: IN-Inch (pound f)
**%                   ... LENGTH : inch
**%                   ... TIME   : sec
**%                   ... MASS   : lbf-sec**2/in
**%                   ... FORCE  : pound (lbf)
**%                   ... TEMPERATURE : deg Fahrenheit
**%
**%       COORDINATE SYSTEM: PART
**%
**%           SUBSET EXPORT: OFF
**%
**%     NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  19-Sep-08   20:25:24
**%========================================
**%         MODAL DATA
**%========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_4375
```

```
*ELEMENT, TYPE=S4      , ELSET=THK_375
*ELEMENT, TYPE=SC8R, ELSET=SOLID5
*MPC
*SHELL SECTION,
 ELSET=THK_4375,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  4.37500E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
*SHELL SECTION,
 ELSET=THK_375 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  3.75000E-01,
*SHELL SECTION, ELSET=SOLID5, MATERIAL=SST304
 5.0,
**%
*ELSET, ELSET=ALLELEMENTS
 THK_4375,
 THK_375 ,
 SOLID5,
**%
*NSET,NSET=ALL, GENERATE
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=RUN, GENERATE
*ELSET,ELSET=BRANCH, GENERATE
*ELSET,ELSET=STIFFENER, GENERATE
**%
*NSET,NSET=OUT
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=BS000002, GENERATE
*ELSET, ELSET=BS000003, GENERATE
*ELSET, ELSET=BS000004, GENERATE
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      29000,  1, 6,      0.00000E+00
      29001,  1, 6,      0.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
```

```
BS000002,    P2, 2.5300E+02
BS000003,    P4, 2.5300E+02
BS000004,    P6, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=20727, DOF=1
*END STEP
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
     29000,  1, 6,      0.00000E+00
     29001,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
     29002,    4, 2.6970E+04
**      29002,    5,-4.2160E+04
**      29002,    6,-7.6860E+05
*DLOAD,OP=NEW
BS000001,     P, 2.5300E+02
BS000002,    P2, 2.5300E+02
BS000003,    P4, 2.5300E+02
BS000004,    P6, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=20727, DOF=1
*END STEP
```

shell_cont_1_tee_2.inp

```
**%    ============================================================
**%
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Reinforced_Tee_model\tee_1-
19.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Reinforced_Tee_model\input\shell_cont_1_tee.inp
**%            EXPORTED: AT 20:25:24 ON 19-Sep-08
**%                PART: Tee 30x24
**%                 FEM: Fem1
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  19-Sep-08   20:25:24
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_4375
*ELEMENT, TYPE=S4      , ELSET=THK_375
*ELEMENT, TYPE=SC8R, ELSET=SOLID5
*MPC
*SHELL SECTION,
 ELSET=THK_4375,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  4.37500E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
*SHELL SECTION,
 ELSET=THK_375 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
```

```
  3.75000E-01,
*SHELL SECTION, ELSET=SOLID5, MATERIAL=SST304
 5.0,
**%
*ELSET, ELSET=ALLELEMENTS
 THK_4375,
 THK_375 ,
 SOLID5,
**%
*NSET,NSET=ALL, GENERATE
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=RUN, GENERATE
*ELSET,ELSET=BRANCH, GENERATE
*ELSET,ELSET=STIFFENER, GENERATE
**%
*NSET,NSET=OUT
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=BS000002, GENERATE
*ELSET, ELSET=BS000003, GENERATE
*ELSET, ELSET=BS000004, GENERATE
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      29000,  1, 6,       0.00000E+00
      29001,  1, 6,       0.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
BS000001,     P, 2.5300E+02
BS000002,    P2, 2.5300E+02
BS000003,    P4, 2.5300E+02
BS000004,    P6, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=20727, DOF=1
*END STEP
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
```

```
*STATIC, STABILIZE, FACTOR=0.001
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      29000,  1, 6,      0.00000E+00
      29001,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
**      29002,    4, 2.6970E+04
      29002,    5,-4.2160E+04
**      29002,    6,-7.6860E+05
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P2, 2.5300E+02
BS000003,   P4, 2.5300E+02
BS000004,   P6, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=20727, DOF=1
*END STEP
```

shell_cont_1_tee_3.inp

```
**%   ==========================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Reinforced_Tee_model\tee_1-
19.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Reinforced_Tee_model\input\shell_cont_1_tee.inp
**%            EXPORTED: AT 20:25:24 ON 19-Sep-08
**%                PART: Tee 30x24
**%                 FEM: Fem1
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
```

```
**%            SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  19-Sep-08   20:25:24
**%============================================
**%          MODAL DATA .
**%============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_4375
*ELEMENT, TYPE=S4      , ELSET=THK_375
*ELEMENT, TYPE=SC8R, ELSET=SOLID5
*MPC
*SHELL SECTION,
 ELSET=THK_4375,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  4.37500E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 28400.0, 0.0
 97900.0, 0.276
*SHELL SECTION,
 ELSET=THK_375 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  3.75000E-01,
*SHELL SECTION, ELSET=SOLID5, MATERIAL=SST304
 5.0,
**%
*ELSET, ELSET=ALLELEMENTS
 THK_4375,
 THK_375 ,
 SOLID5,
**%
*NSET,NSET=ALL, GENERATE
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=RUN, GENERATE
*ELSET,ELSET=BRANCH, GENERATE
*ELSET,ELSET=STIFFENER, GENERATE
**%
*NSET,NSET=OUT
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=BS000002, GENERATE
*ELSET, ELSET=BS000003, GENERATE
*ELSET, ELSET=BS000004, GENERATE
```

```
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      29000,  1, 6,      0.00000E+00
      29001,  1, 6,      0.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P2, 2.5300E+02
BS000003,   P4, 2.5300E+02
BS000004,   P6, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=20727, DOF=1
*END STEP
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      29000,  1, 6,      0.00000E+00
      29001,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
**      29002,    4, 2.6970E+04
**      29002,    5,-4.2160E+04
      29002,    6,-7.6860E+05
*DLOAD,OP=NEW
BS000001,    P, 2.5300E+02
BS000002,   P2, 2.5300E+02
BS000003,   P4, 2.5300E+02
BS000004,   P6, 2.5300E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
```

```
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=20727, DOF=1
*END STEP
```

check_beam_1_tee_1.inp

```
**%   ==========================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Reinforced_Tee_model\tee_1-
19.mfl
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Reinforced_Tee_model\input\beam_1_tee.inp
**%            EXPORTED: AT 09:56:21 ON 19-Sep-08
**%                PART: beam fe
**%                 FEM: Fem1
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ==========================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  19-Sep-08   09:56:21
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31      , ELSET=PIPE
*ELEMENT, TYPE=B31      , ELSET=PIPE_1
*ELEMENT, TYPE=B31      , ELSET=PIPE_2
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_438
**%
*BEAM SECTION,
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:** 09/30/08	**Checker:** A. S. Siahpush	**Date:**	09/30/08

```
 MATERIAL=SST304_B30X0438_R ,
 ELSET=PIPE,
 SECTION=PIPE
 0.15000E+02, 0.43800E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_B30X0438_R
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.25500E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304_B24X0312_BR,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.12000E+02, 0.37500E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_B24X0312_BR
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: BR_30X24_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_2,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.27833E+02, 0.52149E+02, 0.00000E+00, 0.223234E+03, 0.1076E+04, 0, 0.00000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE,
 PIPE_1,
 PIPE_2,
**%
*NSET,NSET=ALL
     11,      12,      76,      77,    1049,    1051,    1052
```

```
*ELSET,ELSET=ALL
     44,      58,      59,     647,     648,     649
**%
**% ====== Z-ROTATION ======
**%
*NSET,NSET=OUT
 1052,1051,11
*STEP,INC=1000000,NLGEOM
*STATIC
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       1051,  1, 6,      0.00000E+00
       1052,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
**         11,     5,-4.2160E+04
**         11,     6,-7.6860E+05
         11,    4, 2.6970E+04
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=77, DOF=1
*END STEP
```

check_beam_1_tee_2.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Reinforced_Tee_model\tee_1-
19.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Reinforced_Tee_model\input\beam_1_tee.inp
**%            EXPORTED: AT 09:56:21 ON 19-Sep-08
**%                PART: beam fe
**%                 FEM: Fem1
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  19-Sep-08   09:56:21
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_438
**%
*BEAM SECTION,
 MATERIAL=SST304_B30X0438_R ,
 ELSET=PIPE,
 SECTION=PIPE
 0.15000E+02, 0.43800E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_B30X0438_R
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.25500E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304_B24X0312_BR,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.12000E+02, 0.37500E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_B24X0312_BR
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: BR_30X24_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_2,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.27833E+02, 0.52149E+02, 0.00000E+00, 0.223234E+03, 0.1076E+04, 0, 0.00000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE,
 PIPE_1,
 PIPE_2,
**%
*NSET,NSET=ALL
      11,      12,      76,      77,    1049,    1051,    1052
*ELSET,ELSET=ALL
      44,      58,      59,     647,     648,     649
**%
**% ====== Z-ROTATION ======
**%
*NSET,NSET=OUT
 1052,1051,11
*STEP,INC=1000000,NLGEOM
*STATIC
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       1051,  1, 6,      0.00000E+00
       1052,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
         11,    5,-4.2160E+04
**         11,    6,-7.6860E+05
**         11,    4, 2.6970E+04
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
```

```
*MONITOR, NODE=77, DOF=1
*END STEP
```

check_beam_1_tee_3.inp

```
**%   ===========================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Reinforced_Tee_model\tee_1-
19.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Reinforced_Tee_model\input\beam_1_tee.inp
**%            EXPORTED: AT 09:56:21 ON 19-Sep-08
**%                PART: beam fe
**%                 FEM: Fem1
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ===========================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  19-Sep-08   09:56:21
**%========================================
**%          MODAL DATA
**%========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_438
**%
*BEAM SECTION,
 MATERIAL=SST304_B30X0438_R ,
 ELSET=PIPE,
 SECTION=PIPE
 0.15000E+02, 0.43800E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_B30X0438_R
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
```

```
 2.25500E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: PIPE24_0X0_375
**%
*BEAM SECTION,
 MATERIAL=SST304_B24X0312_BR,
 ELSET=PIPE_1,
 SECTION=PIPE
 0.12000E+02, 0.37500E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_B24X0312_BR
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: BR_30X24_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_2,
 DENSITY= 0.21500E-02,
 ZERO= 0.00000E+00
 0.27833E+02, 0.52149E+02, 0.00000E+00, 0.223234E+03, 0.1076E+04, 0, 0.00000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
 0.28000E+08, 0.10769E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE,
 PIPE_1,
 PIPE_2,
**%
*NSET,NSET=ALL
      11,      12,      76,      77,    1049,    1051,    1052
*ELSET,ELSET=ALL
      44,      58,      59,     647,     648,     649
**%
**% ====== Z-ROTATION ======
**%
*NSET,NSET=OUT
 1052,1051,11
*STEP,INC=1000000,NLGEOM
*STATIC
```

```
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      1051,  1, 6,      0.00000E+00
      1052,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
**         11,    5,-4.2160E+04
         11,    6,-7.6860E+05
**         11,    4, 2.6970E+04
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=77, DOF=1
*END STEP
```

t1_11_beam_m1.inp

```
**%   ============================================================
**%
**%             NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                    FOR ABAQUS VERSION 6.x
**%
**%         MODEL FILE: C:\ugs_mdls\T1_11_9-19-2008.mf1
**%         INPUT FILE: C:\pcs\pcs2\misc_tees\t1_11_beam.inp
**%           EXPORTED: AT 12:57:22 ON 22-Sep-08
**%               PART: Part1
**%                FEM: Model_1-4
**%
**%              UNITS: IN-Inch (pound f)
**%                    ... LENGTH : inch
**%                    ... TIME   : sec
**%                    ... MASS   : lbf-sec**2/in
**%                    ... FORCE  : pound (lbf)
**%                    ... TEMPERATURE : deg Fahrenheit
**%
**%        COORDINATE SYSTEM: PART
**%
**%            SUBSET EXPORT: OFF
**%
**%      NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
SDRC I-DEAS ABAQUS FILE TRANSLATOR  22-Sep-08   12:57:22
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304_B20X0312_BR,
 ELSET=PIPE,
 SECTION=PIPE
 0.10000E+02, 0.31200E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_B20X0312_BR
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.15400E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: BR_30X20_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_1,
 DENSITY= 0.21540E-02,
 ZERO= 0.00000E+00
 0.19298E+02, 0.61867E+02, 0.00000E+00, 0.18791E+03, 0.18710E+04, 0, 0.00000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_4375
**%
*BEAM SECTION,
 MATERIAL=SST304_B30X04375_R,
 ELSET=PIPE_2,
 SECTION=PIPE
 0.15000E+02, 0.43750E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_B30X04375_R
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.25900E-03,
```

```
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE,
 PIPE_1,
 PIPE_2,
**%
*NSET,NSET=ALL
     599,      667,     1092,     1097,     1449
*NSET,NSET=ALL_NODES
     599,      667,     1092,     1097
*NSET,NSET=MODEL1
     599,      667,     1092,     1097
*NSET,NSET=LINE1-8_9_10_11_12_170
     599,      667,     1092,     1097,     1449
*ELSET,ELSET=ALL
      95,      104,      440,      869
*ELSET,ELSET=MODEL1
      95,      104,      440
*ELSET,ELSET=LINE1-8_9_10_11_12_170
      95,      104,      440,      869
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION TOTAL
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       1092,  1, 6,      0.00000E+00
       1097,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
         667,     4, 4.391E+05
**          667,     5, 2.181E+05
**          667,     6, 1.641E+05
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*END STEP
```

t1_11_beam_m2.inp

```
**%    ============================================================
**%
```

```
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\ugs_mdls\T1_11_9-19-2008.mf1
**%          INPUT FILE: C:\pcs\pcs2\misc_tees\t1_11_beam.inp
**%            EXPORTED: AT 12:57:22 ON 22-Sep-08
**%                PART: Part1
**%                 FEM: Model_1-4
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  22-Sep-08   12:57:22
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304_B20X0312_BR,
 ELSET=PIPE,
 SECTION=PIPE
 0.10000E+02, 0.31200E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_B20X0312_BR
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.15400E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: BR_30X20_BRANCH
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:**	09/30/08	**Checker:**	A. S. Siahpush	**Date:**	09/30/08

```
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_1,
 DENSITY= 0.21540E-02,
 ZERO= 0.00000E+00
 0.19298E+02, 0.61867E+02, 0.00000E+00, 0.18791E+03, 0.18710E+04, 0, 0.00000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_4375
**%
*BEAM SECTION,
 MATERIAL=SST304_B30X04375_R,
 ELSET=PIPE_2,
 SECTION=PIPE
 0.15000E+02, 0.43750E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_B30X04375_R
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.25900E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE,
 PIPE_1,
 PIPE_2,
**%
*NSET,NSET=ALL
     599,     667,    1092,    1097,    1449
*NSET,NSET=ALL_NODES
     599,     667,    1092,    1097
*NSET,NSET=MODEL1
     599,     667,    1092,    1097
*NSET,NSET=LINE1-8_9_10_11_12_170
     599,     667,    1092,    1097,    1449
*ELSET,ELSET=ALL
      95,     104,     440,     869
*ELSET,ELSET=MODEL1
      95,     104,     440
*ELSET,ELSET=LINE1-8_9_10_11_12_170
      95,     104,     440,     869
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
```

```
*STATIC
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION TOTAL
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      1092,  1, 6,      0.00000E+00
      1097,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
**         667,    4, 4.391E+05
        667,    5, 2.181E+05
**         667,    6, 1.641E+05
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*END STEP
```

t1_11_beam_m3.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\ugs_mdls\T1_11_9-19-2008.mf1
**%          INPUT FILE: C:\pcs\pcs2\misc_tees\t1_11_beam.inp
**%            EXPORTED: AT 12:57:22 ON 22-Sep-08
**%                PART: Part1
**%                 FEM: Model_1-4
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  22-Sep-08   12:57:22
**%============================================
```

```
**%          MODAL DATA
**%========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304_B20X0312_BR,
 ELSET=PIPE,
 SECTION=PIPE
 0.10000E+02, 0.31200E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_B20X0312_BR
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.15400E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: BR_30X20_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_1,
 DENSITY= 0.21540E-02,
 ZERO= 0.00000E+00
 0.19298E+02, 0.61867E+02, 0.00000E+00, 0.18791E+03, 0.18710E+04, 0, 0.00000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_4375
**%
*BEAM SECTION,
 MATERIAL=SST304_B30X04375_R,
 ELSET=PIPE_2,
 SECTION=PIPE
 0.15000E+02, 0.43750E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_B30X04375_R
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.25900E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
```

```
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE,
 PIPE_1,
 PIPE_2,
**%
*NSET,NSET=ALL
     599,      667,     1092,     1097,     1449
*NSET,NSET=ALL_NODES
     599,      667,     1092,     1097
*NSET,NSET=MODEL1
     599,      667,     1092,     1097
*NSET,NSET=LINE1-8_9_10_11_12_170
     599,      667,     1092,     1097,     1449
*ELSET,ELSET=ALL
      95,      104,      440,      869
*ELSET,ELSET=MODEL1
      95,      104,      440
*ELSET,ELSET=LINE1-8_9_10_11_12_170
      95,      104,      440,      869
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION TOTAL
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       1092,  1, 6,      0.00000E+00
       1097,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
**          667,     4, 4.391E+05
**          667,     5, 2.181E+05
        667,     6, 1.641E+05
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*END STEP
```

t1_11_shell3_tee_m1.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
```

```
**%
**%         MODEL FILE: C:\er2\work\TRA-670_piping\Reinforced_Tee_model\tee_1-
19.mf1
**%         INPUT FILE: C:\er2\work\TRA-
670_piping\Reinforced_Tee_model\input\shell_3_30x20_tee.inp
**%           EXPORTED: AT 08:16:17 ON 23-Sep-08
**%               PART: Tee 30x20
**%                FEM: Fem1
**%
**%              UNITS: IN-Inch (pound f)
**%                    ... LENGTH : inch
**%                    ... TIME   : sec
**%                    ... MASS   : lbf-sec**2/in
**%                    ... FORCE  : pound (lbf)
**%                    ... TEMPERATURE : deg Fahrenheit
**%
**%        COORDINATE SYSTEM: PART
**%
**%            SUBSET EXPORT: OFF
**%
**%      NODE ZERO TOLERANCE: OFF
**%
**%    ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  23-Sep-08   08:16:17
**%========================================
**%         MODAL DATA
**%========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_4375
*ELEMENT, TYPE=S4      , ELSET=THK_375
*ELEMENT, TYPE=SC8R, ELSET=SOLID5
*MPC
*SHELL SECTION,
 ELSET=THK_4375,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  4.37500E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 26144.6, 0.0
 95626.3, 0.276
*SHELL SECTION,
 ELSET=THK_375 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  3.75000E-01,
*SHELL SECTION, ELSET=SOLID5, MATERIAL=SST304
```

```
 5.0,
**%
*ELSET, ELSET=ALLELEMENTS
 THK_4375,
 THK_375 ,
 SOLID5,
**%
*NSET,NSET=ALL, GENERATE
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=BRANCH, GENERATE
*ELSET,ELSET=RUN, GENERATE
*ELSET,ELSET=STIFFENER, GENERATE
*ELSET,ELSET=WELD, GENERATE
**%
*NSET,NSET=OUT
*ELSET, ELSET=BS000001, GENERATE
      8330,      8569,         1
     11675,     11914,         1
     15020,     15259,         1
     18365,     18604,         1
*ELSET, ELSET=BS000002, GENERATE
      1938,      2769,         1
      6054,      7141,         1
      7157,      7159,         2
      7160,      8230,         1
      8234,      8249,         1
      8570,      9401,         1
      9418,     11594,         1
     11915,     12746,         1
     12763,     14939,         1
     15260,     16091,         1
     16108,     18284,         1
*ELSET, ELSET=BS000003, GENERATE
     11579,     11594,         1
     14924,     14939,         1
*ELSET, ELSET=BS000004, GENERATE
      8234,      8249,         1
     18269,     18284,         1
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      29000,  1, 6,      0.00000E+00
      29001,  1, 6,      0.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
BS000001,    P, 2.7200E+02
BS000002,   P2, 2.7200E+02
BS000003,   P4, 2.7200E+02
```

```
BS000004,   P6, 2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=20727, DOF=1
*END STEP
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
     29000,  1, 6,      0.00000E+00
     29001,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
     29002,    4, 4.391E+05
**      29002,    5, 2.181E+05
**      29002,    6, 1.641E+05
*DLOAD,OP=NEW
BS000001,    P, 2.7200E+02
BS000002,   P2, 2.7200E+02
BS000003,   P4, 2.7200E+02
BS000004,   P6, 2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*END STEP
```

t1_11_shell3_tee_m2.inp

```
**%   ============================================================
**%
**%            NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                   FOR ABAQUS VERSION 6.x
**%
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:**	09/30/08	**Checker:**	A. S. Siahpush	**Date:**	09/30/08

```
**%          MODEL FILE: C:\er2\work\TRA-670_piping\Reinforced_Tee_model\tee_1-
19.mf1
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Reinforced_Tee_model\input\shell_3_30x20_tee.inp
**%            EXPORTED: AT 08:16:17 ON 23-Sep-08
**%                PART: Tee 30x20
**%                 FEM: Fem1
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  23-Sep-08   08:16:17
**%========================================
**%          MODAL DATA
**%========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_4375
*ELEMENT, TYPE=S4      , ELSET=THK_375
*ELEMENT, TYPE=SC8R, ELSET=SOLID5
*MPC
*SHELL SECTION,
 ELSET=THK_4375,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  4.37500E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 26144.6, 0.0
 95626.3, 0.276
*SHELL SECTION,
 ELSET=THK_375 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  3.75000E-01,
*SHELL SECTION, ELSET=SOLID5, MATERIAL=SST304
 5.0,
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:** 09/30/08	**Checker:** A. S. Siahpush	**Date:**	09/30/08

```
**%
*ELSET, ELSET=ALLELEMENTS
 THK_4375,
 THK_375 ,
 SOLID5,
**%
*NSET,NSET=ALL, GENERATE
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=BRANCH, GENERATE
*ELSET,ELSET=RUN, GENERATE
*ELSET,ELSET=STIFFENER, GENERATE
*ELSET,ELSET=WELD, GENERATE
**%
*NSET,NSET=OUT
*ELSET, ELSET=BS000001, GENERATE
      8330,      8569,         1
     11675,     11914,         1
     15020,     15259,         1
     18365,     18604,         1
*ELSET, ELSET=BS000002, GENERATE
      1938,      2769,         1
      6054,      7141,         1
      7157,      7159,         2
      7160,      8230,         1
      8234,      8249,         1
      8570,      9401,         1
      9418,     11594,         1
     11915,     12746,         1
     12763,     14939,         1
     15260,     16091,         1
     16108,     18284,         1
*ELSET, ELSET=BS000003, GENERATE
     11579,     11594,         1
     14924,     14939,         1
*ELSET, ELSET=BS000004, GENERATE
      8234,      8249,         1
     18269,     18284,         1
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      29000,  1, 6,       0.00000E+00
      29001,  1, 6,       0.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
BS000001,    P, 2.7200E+02
BS000002,   P2, 2.7200E+02
BS000003,   P4, 2.7200E+02
BS000004,   P6, 2.7200E+02
```

```
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=20727, DOF=1
*END STEP
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      29000,  1, 6,      0.00000E+00
      29001,  1, 6,      0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
**      29002,    4, 4.391E+05
      29002,    5, 2.181E+05
**      29002,    6, 1.641E+05
*DLOAD,OP=NEW
BS000001,    P, 2.7200E+02
BS000002,   P2, 2.7200E+02
BS000003,   P4, 2.7200E+02
BS000004,   P6, 2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*END STEP
```

t1_11_shell3_tee_m3.inp

```
**%   ============================================================
**%
**%            NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                   FOR ABAQUS VERSION 6.x
**%
**%        MODEL FILE: C:\er2\work\TRA-670_piping\Reinforced_Tee_model\tee_1-
19.mf1
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
**%          INPUT FILE: C:\er2\work\TRA-
670_piping\Reinforced_Tee_model\input\shell_3_30x20_tee.inp
**%            EXPORTED: AT 08:16:17 ON 23-Sep-08
**%                PART: Tee 30x20
**%                 FEM: Fem1
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  23-Sep-08   08:16:17
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=S4      , ELSET=THK_4375
*ELEMENT, TYPE=S4      , ELSET=THK_375
*ELEMENT, TYPE=SC8R, ELSET=SOLID5
*MPC
*SHELL SECTION,
 ELSET=THK_4375,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  4.37500E-01,
*MATERIAL,NAME=SST304
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 7.25200E-04,
*PLASTIC
 26144.6, 0.0
 95626.3, 0.276
*SHELL SECTION,
 ELSET=THK_375 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=SST304
  3.75000E-01,
*SHELL SECTION, ELSET=SOLID5, MATERIAL=SST304
 5.0,
**%
*ELSET, ELSET=ALLELEMENTS
```

```
 THK_4375,
 THK_375 ,
 SOLID5,
**%
*NSET,NSET=ALL, GENERATE
*ELSET,ELSET=ALL, GENERATE
*ELSET,ELSET=BRANCH, GENERATE
*ELSET,ELSET=RUN, GENERATE
*ELSET,ELSET=STIFFENER, GENERATE
*ELSET,ELSET=WELD, GENERATE
**%
*NSET,NSET=OUT
 29000,29001,29002
*ELSET, ELSET=BS000001, GENERATE
*ELSET, ELSET=BS000002, GENERATE
*ELSET, ELSET=BS000003, GENERATE
*ELSET, ELSET=BS000004, GENERATE
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.1,1.0,1.0E-08,0.1
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      29000,  1, 6,      0.00000E+00
      29001,  1, 6,      0.00000E+00
**%  LOAD SET 1
*DLOAD,OP=NEW
BS000001,     P, 2.7200E+02
BS000002,    P2, 2.7200E+02
BS000003,    P4, 2.7200E+02
BS000004,    P6, 2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=OUT
 RF,U
*MONITOR, NODE=20727, DOF=1
*END STEP
**%
**% ====== STABILIZED STATIC G-LOAD ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC, STABILIZE, FACTOR=0.001
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION SET 1
```

```
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
      29000,  1, 6,       0.00000E+00
      29001,  1, 6,       0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
**      29002,     4, 4.391E+05
**      29002,     5, 2.181E+05
      29002,     6, 1.641E+05
*DLOAD,OP=NEW
BS000001,     P, 2.7200E+02
BS000002,    P2, 2.7200E+02
BS000003,    P4, 2.7200E+02
BS000004,    P6, 2.7200E+02
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*END STEP
```

check_t1_11_beam_m1.inp

```
**%   ============================================================
**%
**%              NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                     FOR ABAQUS VERSION 6.x
**%
**%          MODEL FILE: C:\ugs_mdls\T1_11_9-19-2008.mf1
**%          INPUT FILE: C:\pcs\pcs2\misc_tees\t1_11_beam.inp
**%            EXPORTED: AT 12:57:22 ON 22-Sep-08
**%                PART: Part1
**%                 FEM: Model_1-4
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:** 09/30/08	**Checker:** A. S. Siahpush	**Date:**	09/30/08

```
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  22-Sep-08   12:57:22
**%==========================================
**%          MODAL DATA
**%==========================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304_B20X0312_BR,
 ELSET=PIPE,
 SECTION=PIPE
 0.10000E+02, 0.31200E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_B20X0312_BR
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.15400E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
**% I-DEAS BEAM CROSS SECTION: BR_30X20_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_1,
 DENSITY= 0.21540E-02,
 ZERO= 0.00000E+00
 0.19298E+02, 0.61867E+02, 0.00000E+00, 0.18791E+03, 0.13652E+04, 0, 0.00000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_4375
**%
*BEAM SECTION,
 MATERIAL=SST304_B30X04375_R,
 ELSET=PIPE_2,
 SECTION=PIPE
 0.15000E+02, 0.43750E+00
-0.10000E+01, 0.00000E+00, 0.00000E+00
*MATERIAL,NAME=SST304_B30X04375_R
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark **Date:** 09/30/08	**Checker:**	A. S. Siahpush	**Date:**	09/30/08

```
 2.25900E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
*ELSET, ELSET=ALLELEMENTS
 PIPE,
 PIPE_1,
 PIPE_2,
**%
*NSET,NSET=ALL
     599,      667,     1092,     1097,     1449
*NSET,NSET=ALL_NODES
     599,      667,     1092,     1097
*NSET,NSET=MODEL1
     599,      667,     1092,     1097
*NSET,NSET=LINE1-8_9_10_11_12_170
     599,      667,     1092,     1097,     1449
*ELSET,ELSET=ALL
      95,      104,      440,      869
*ELSET,ELSET=MODEL1
      95,      104,      440
*ELSET,ELSET=LINE1-8_9_10_11_12_170
      95,      104,      440,      869
**%
**% ====== STEP NUMBER   1 ======
**%
*STEP,INC=1000000,NLGEOM
*STATIC
 0.05,1.0,1.0E-08,0.05
**%  BOUNDARY CONDITION TOTAL
**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       1092,  1, 6,       0.00000E+00
       1097,  1, 6,       0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
         667,     4, 4.391E+05
**          667,     5, 2.181E+05
**          667,     6, 1.641E+05
*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*END STEP
```

check_t1_11_beam_m2.inp

```
**%    ============================================================
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-194 **Rev.:** 0
Title: ATR Primary Coolant System Seismic Evaluation
Performer: D. T. Clark **Date:** 09/30/08 **Checker:** A. S. Siahpush **Date:** 09/30/08

```
**%
**%            NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%                   FOR ABAQUS VERSION 6.x
**%
**%        MODEL FILE: C:\ugs_mdls\T1_11_9-19-2008.mf1
**%        INPUT FILE: C:\pcs\pcs2\misc_tees\t1_11_beam.inp
**%          EXPORTED: AT 12:57:22 ON 22-Sep-08
**%              PART: Part1
**%               FEM: Model_1-4
**%
**%             UNITS: IN-Inch (pound f)
**%                   ... LENGTH : inch
**%                   ... TIME   : sec
**%                   ... MASS   : lbf-sec**2/in
**%                   ... FORCE  : pound (lbf)
**%                   ... TEMPERATURE : deg Fahrenheit
**%
**%       COORDINATE SYSTEM: PART
**%
**%           SUBSET EXPORT: OFF
**%
**%     NODE ZERO TOLERANCE: OFF
**%
**%   ============================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  22-Sep-08   12:57:22
**%============================================
**%          MODAL DATA
**%============================================
*NODE, NSET=ALLNODES, SYSTEM=R
*ELEMENT, TYPE=B31     , ELSET=PIPE
*ELEMENT, TYPE=B31     , ELSET=PIPE_1
*ELEMENT, TYPE=B31     , ELSET=PIPE_2
**%
**% I-DEAS BEAM CROSS SECTION: PIPE20_0X0_312
**%
*BEAM SECTION,
 MATERIAL=SST304_B20X0312_BR,
 ELSET=PIPE,
 SECTION=PIPE
 0.10000E+02, 0.31200E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
*MATERIAL,NAME=SST304_B20X0312_BR
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.15400E-03,
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
**%
```

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-194	**Rev.:**	0
Title:	ATR Primary Coolant System Seismic Evaluation				
Performer:	D. T. Clark	**Date:** 09/30/08	**Checker:** A. S. Siahpush	**Date:**	09/30/08

```
**% I-DEAS BEAM CROSS SECTION: BR_30X20_BRANCH
**%
*BEAM GENERAL SECTION,
 ELSET=PIPE_1,
 DENSITY= 0.21540E-02,
 ZERO= 0.00000E+00
 0.19298E+02, 0.61867E+02, 0.00000E+00, 0.146103E+03, 0.18710E+04, 0, 0.00000E+00
 0.00000E+00, 0.00000E+00,-0.10000E+01
 0.27700E+08, 0.10654E+08, 0.10000E-34
*CENTROID
 0.00000E+00, 0.00000E+00
*SHEAR CENTER
 0.00000E+00, 0.00000E+00
**%
**% I-DEAS BEAM CROSS SECTION: PIPE30_0X0_4375
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**%                     FOR ABAQUS VERSION 6.x
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**%          INPUT FILE: C:\pcs\pcs2\misc_tees\t1_11_beam.inp
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**%                PART: Part1
**%                 FEM: Model_1-4
**%
**%               UNITS: IN-Inch (pound f)
**%                     ... LENGTH : inch
**%                     ... TIME   : sec
**%                     ... MASS   : lbf-sec**2/in
**%                     ... FORCE  : pound (lbf)
**%                     ... TEMPERATURE : deg Fahrenheit
**%
**%         COORDINATE SYSTEM: PART
**%
**%             SUBSET EXPORT: OFF
**%
**%       NODE ZERO TOLERANCE: OFF
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 SECTION=PIPE
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 PIPE_2,
**%
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*NSET,NSET=MODEL1
     599,     667,    1092,    1097
*NSET,NSET=LINE1-8_9_10_11_12_170
     599,     667,    1092,    1097,    1449
*ELSET,ELSET=ALL
      95,     104,     440,     869
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**%  RESTRAINT SET 1
*BOUNDARY,OP=NEW
       1092,  1, 6,      0.00000E+00
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**          667,    4, 4.391E+05
**          667,    5, 2.181E+05
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*OUTPUT, FIELD ,FREQUENCY=1
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 S,PEEQ
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*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
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Appendix F.5
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Performer:	D. T. Clark	**Date:**	09/30/08	**Checker:**	A. S. Siahpush	**Date:**	09/30/08

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Revision ID: 0
Effective Date: 9/30/2008

Engineering Calculations and Analysis Report

ATR Primary Coolant System Piping Seismic Evaluation

D. T. Clark
A. L. Crawford
K. D. Ellis
R. E. Spears

Volume 1 of 5

Report Main Body, Appendix A, Appendix G

Idaho National Laboratory

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Appendix G

Independent Peer Reviewer Comments and Resolutions

Appendix G

The purpose of this Appendix is to display the Independent Peer Reviewer (R. K. Kennedy) comments on this analysis (as of Sept. 13, 2008) and provide corresponding resolutions.

The Peer Reviewer has issued documentation identifying his concerns. A copy of that communication has been generated (see following), in which resolutions and their analysis references are highlighted in yellow addressing each concern.

Peer Review Comments on
ATR Primary Coolant System Seismic Evaluation

R.P. Kennedy
September 13, 2008

1. Introduction

I have performed a review of the report entitled *ATR Primary Coolant System Seismic Evaluation.* This report details the approach and methods used to evaluate the ATR Primary Coolant System. I have carefully reviewed the main body of the report which presents an overview of the evaluation performed and results and conclusions. I have also carefully reviewed Appendix A which provides greater details on the evaluation approach, Appendix B which provides the seismic evaluation calculations for Piping Model 3, and Appendix E which provides pump anchorage evaluations, evaluation of supports with linear computed Demand/Capacity (D/C) ratios greater than 1.0, and other miscellaneous calculations. I only scanned through Appendix C (seismic evaluation calculations for Piping Model 2-6-5), and Appendix D (seismic evaluation calculation for Piping Model 1-4) because these evaluations were similar to those in Appendix B. I performed a methodology review of Appendix F which determines flexibility factors (FF) and stress indices (SI) for the pilot model unlisted branch components.

2. Summary of Review Findings

A very high quality determination of the probalistically defined seismic demand ($D_{80\%}$) and the code capacity (C) has been performed for the supports, elbows, and fabricated tees of the ATR Primary Coolant Piping.

The approach used was to perform 32 time-history evaluations using 32 sets (3 directional components each) of input time-histories representing equally likely realizations of the PC4 motions at the piping supports. These 32 sets of input time-histories account for the realistic variability of the input motion resulting from:

1. Variability of soil properties (shear wave velocity and material damping)

2. Variability of structure properties (stiffness and structural damping)

As a result of these 32 analyses, a set of 32 equally likely demand results (D) are computed for each evaluated piping component. The 32 results are ordered from highest to lowest, and the demand (D_{NEP}) at any specified non-exceedance probability (NEP) is equal to the demand (D_n) for ordered result n, where NEP is given by:

$$NEP = 100\% \, (N - n + 0.5)/N \qquad (1)$$

where N = 32. Thus, the 7th highest computed demand (n = 7) corresponds to:

$$NEP = 100\% \, (25.5/32) = 79.7\% \qquad (2)$$

or essentially 80% NEP. Similarly, the 26th highest computed demand corresponds to 20% NEP, and the median estimate (50% NEP) corresponds to midway between the 16th and 17th ordered demand result. The demand variability logarithmic standard deviation (β_{DI}) due to variability of the input motion resulting from variability of soil and structure properties can be approximated by:

$$\beta_{DI} = (D_{80\%}/D_{20\%})/1.684 \qquad (3)$$

where 1.684 is the standard normal variant between 80% NEP and 20% NEP.

Thus, the 32 demand results provide a probabilistic description of the variability in demand resulting from the variability in soil and structure properties considered in the previously performed probabilistic soil-structure-interaction analyses. Using these results, a conservatively biased demand ($D_{80\%}$) was used for comparison with the code capacity (C). I concur with the use of the 80% NEP demand ($D_{80\%}$) for computing the demand/capacity ratios (D/C).

Specific review comments are presented in following three sections. Section 3 presents my strong endorsement of specific aspects of the evaluation that I carefully reviewed. Section 4 presents my comments on technical aspects of the evaluation for which I have reservations. Section 5 presents editorial comments.

3. Strongly Endorsed Aspects of Evaluation

3.1 Selection of Building Node at Which Time-Histories are Defined

I concur with the approach used in Appendix A.2 for selecting building model nodes at which time-histories are defined for input to the piping models. I concur with the nodes selected.

3.2 Time-History Conditioning

I concur with the time-history conditioning described in Appendix Sections A.3.1 and A.3.2 which was performed to enable the provided time-histories to be used as input to the piping analyses with nonlinear supports.

3.3 Modelling of Piping Damping

I concur with the approach described in Appendix Section A.3.3 to develop Rayleigh damping constants that reasonably replicate the effect of 5% constant modal damping.

3.4 Modelling of Nonlinear Supports

I concur with the approach used in Appendix Section B.5 to develop nonlinear spring models of supports.

3.5 Development of Flexibility Factors (FF) and Stress Indices (SI) for Unlisted Branch Components

I concur with the evaluation approaches used in Appendix F to establish flexibility factors (FF) and Stress Indices (SI) for unlisted branch components.

4. Technical Concerns

I have concerns with the resolutions presented in Tables 5 through 9 for resolving and accepting components and supports with D/C ratios greater than 1.0. I also have concerns with evaluations and conclusions reached in Appendix E Sections E.7, and E.8 (called E.9 in Table of Contents). These concerns are discussed in the following subsections.

4.1 Concerns About Tables 5 Through 7 Resolutions

Tables 5 through 7 resolve a number of components with D/C ratios greater than unity by plastic analyses of several components with the higher D/C ratios. I concur that plastic analyses can be used to resolve these components. However, inelastic behavior in the component will increase the flexibility of the component and change the flexibility factor that should be used in the piping system model. For components with D/C exceeding about 1.25, I believe that a revised flexibility factor should be computed for the component as a result of the inelastic straining. This revised flexibility factor should be compared with the component flexibility factor used in the piping system model. If significantly different, the piping system model should be revised and rerun. I could not find any discussion of the increased flexibility of components with D/C greater than 1.25 and their impact on the piping system analysis.

- See:

- "ECAR-194 Main Body" (method is described in Appendix F description, p.36)
- A comparison between beam and shell models are performed and if difference is greater than 20%, flexibility factors are recomputed, applied to beam models, and new 80th percentile results are determined using the revised beam flexibility factors. Application is demonstrated in Appendix F for all unlisted components. Specific plastic analysis comparisons are listed in Appendix Sections F.1.5 (36-in x 14-in elbow/branch), F2.4.1 (16-in x 10-in elbow/branch), F.3.5 (24-in x 18-in x 45-deg. Wye), and F.4.1 (10-in x 6-in branch).
- Original Tables 5-9 (of "Conclusions and Recommendation" section) have been rearranged to identify supports and components that directly address the Peer Reviewer concerns pertaining to this matter.

4.2 Comments on Tables 8 and 9 and Appendix E.7

Tables 8 and 9, and Appendix E.7 permit D/C ratios greater than 1.0 to be resolved through the use of F_μ up to 2.0. I have several concerns with this approach.

First, the appropriate F_μ for anchorage is 1.0. An F_μ for a support should only be allowed if the strength of the anchorage is at least 125% of the yield capacity of the support so that all nonlinear behavior occurs in the support and not in the anchorage. One needs to demonstrate that the anchorage is stronger than the support before allowing F_μ greater than 1.0.

Secondly, for Limit State C, the support F_μ is limited to 1.25. This limit is imposed because larger F_μ in the supports is likely to change the Demands computed in the piping from the piping system model that did not account for this nonlinear support behavior.

For Tables 8 and 9, and Appendix E.7, I strongly recommend that the required F_μ be calculated from:

$$F_\mu = \frac{D_S}{C - D_{NS}} \tag{4}$$

where D_S is the seismic demand, D_{NS} is the non-seismic demand, and C is the capacity. Reporting this required F_μ is much more useful than reporting the D/C ratio for an assumed F_μ =2.0 as is done in Table 9 and Appendix E.7.

Based on Appendix E.7, I have computed the required F_μ for the supports shown in Table 9. Table A shows the computed F_μ.

Table A: Required F_μ

Support	D/C	F_μ
RH-23x	1.13	1.24
U-bolt	1.16	---
PS-20A	1.25	1.24
RH-19	1.76	2.02
RH-25B	1.05	1.05
AIW5	1.15	1.23

- See:

- "ECAR-194 Main Body" where Table 11 indicates the U-bolt designated support and RH-19 have moved into the strengthening category rather than acceptance via ductility. Conclusion tables will be updated with Appendix E7 results which includes information regarding Fu 1.25 factor and 125% anchorage to support capacity justification. One support that did not meet that suggested 125% anchorage to support capacity justification did not experience a loading that was greater than the anchorage capacity and therefore was deemed suitable for this analysis (Appendix E7).

I was unable to compute the required F_μ for the U-bolt because I was not able to understand the F_μ_DC calculation on Page E.7-5. For the other cases, the required F_μ is less than 1.25 except for RH-19.

I am concerned that the large required F_μ for RH-19 might result in significant changes in the piping component demands from those computed in the piping system model.

- See:

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- "ECAR-194 Main Body" where RH-19 has been moved from an acceptable state to an upgrade state.
- "App E7 Ductility Factor Calculations" where RH-19 has been removed from this appendix.

4.3 Comment on Section E.8

What is the technical basis for combining the reactions from RH21x, RH26x127, and RH26x814 by SRSS? For such a combination, one must show that these reactions are randomly phased with respect to each other. It might be better to use absolute sum and state that a D/C=1.01 is a negligible exceedance.

- See:

- "App E8 Combination of loading" which now applied the more conservative absolute sum combination method rather than an SRSS combination method.

5. Editorial Comments

5.1 Acceptance Criteria

The Acceptance Criteria statement on Page 15 is misleading since D/C ratios substantially in excess of 1.0 are being considered acceptable based on further evaluations.

- See:

- Clarification within the Acceptance Criteria has been added to allow components and supports to be accepted if D/C is in excess of 1.0, provided that their acceptance is based on plastic analysis, use of inelastic energy absorption factors of 1.25 (per limit State C), or be bounded by enveloping plastic analysis of other components. "ECAR-194, Main Body, Acceptance Criteria section, p. 15."

5.2 Figures 20 Through 27

Clarify whether these spectra are at the 80% non-exceedance probability level.

- See:

- Clarification that has been added, "ECAR-194,_Main Body, p. 25"

5.3 Figure A.2.1-14

The discussion about Point 176 versus Point 1577 immediately below Figures A.2.1-14 is opposite of what is shown in the figure.

- See:

- Discussion that has been changed to reflect proper description of points, "Appendix A, Fig A.2.1-14, p. A-25."

5.4 Page E.4-8

Embedments at welds 4, 5, and 6 have D/C ratios greater than 1.0, not just at weld 6.

- See:

- "App_E.4-8" where all embedment welds with D/C ratios greater than 1.0 are identified.