ENGINEERING CALCULATIONS AND ANALYSIS REPORT

ECAR No.: 398 ECAR Rev. No.: 0 Project File No.: 27000 Date: 9/30/2008

Title:

1. Index Codes
   Building/Type: 670 SSC ID: 670-M-2, -3, -4, -5, -85 Site Area: TRA

2. Quality Level: 1

3. Objective/Purpose
   The purpose of this analysis is to evaluate the Advanced Test Reactor primary coolant system heat exchangers with respect to the recently completed in-structure seismic motions of the site-specific probabilistic safe shutdown earthquake.

4. Conclusions/Recommendations
   The ATR primary coolant heat exchangers do not satisfy DOE-STD-1020 seismic criteria for the newly completed in-structure motions of the probabilistic SSE, and would require some physical modification before they are qualified to that upgraded seismic criteria. The limiting feature identified is anchorage of the heat exchangers to their concrete supports.

   If a strengthening design is undertaken, it is recommended that the heat exchanger pit level be used to provide as much of the lateral load path as practical, to isolate the heat exchangers from the larger motions higher in the building. Any future analysis should complete the evaluation of the heat exchanger nozzles, lugs, and supports.

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1 Review and Approval are required. See LWP-10200 for definitions and responsibilities.
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Title: ATR PCS Heat Exchanger Seismic Analysis

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Scope and Structural System or Component (SSC) Description

This analysis evaluates the Advanced Test Reactor (ATR) primary coolant system (PCS) heat exchangers under loads imposed by the recently developed in-structure seismic motions of the probabilistic soil-structure interaction analysis (PSSI) (Ref 1). The attached piping imposes significant loads on the heat exchanger nozzles, which are accounted for by including the piping in the model to a sufficient extent to properly develop the loads. The modeling and results are documented in Appendix A. The structural evaluation is documented in Appendix B.

There are five heat exchangers located in the heat exchanger pit in the primary coolant piping space of the ATR. The heat exchangers are approximately 38 feet tall and 6 feet in diameter. Details of the heat exchangers are provided in Appendix A.

Design Inputs and Sources

a) Quality Level 1 is defined per QLD RTC-000550, "Seismic Analysis of ATR Seismic Category 1 SSC"
b) ATR SC-1 structures, systems and components (SSC) are analyzed for PC-4 loading, which is the project direction of the ATR Seismic Assessment Project, per PLN-588 (Ref. 2).
c) Seismic inputs are taken from the probabilistic soil-structure interaction analysis (PSSI) (Ref 1)
d) Acceptance Criteria are per DOE-STD-1020 (Ref. 3).
e) The analysis followed the provisions of ASCE 4-98 (Ref. 4)

Results of Literature Searches and Other Background Data

The heat exchangers were evaluated in 1975 in TR-570 (Ref. 5), which applied the site independent Housner-style response spectrum in use at the time. Based upon the results of that evaluation, two lateral bracing systems were added. Near the tops of the heat exchangers, seismic support rods were installed around the shell and were tied back to the heat exchanger room north and south walls with rods anchored to plates installed in the walls with expansion bolts. The second lateral bracing system involved the installation of struts between the reinforced concrete and steel columns supporting the heat exchanger. The intent of these struts is to carry lateral loads to the heat exchanger pit walls, and thus prevent bending overload of the support pillars. The bracing design is depicted in Figure 1.

In 2005, some anomalies regarding anchor bolt installation were discovered in the seismic bracing, and a structural evaluation was undertaken to determine the acceptability of the existing design (Ref. 6). This evaluation was not done to more modern definitions of the safe shutdown earthquake (SSE), but rather used the existing loads from Ref. 5. After some correction to the anchor bolt installation (Ref. 7), the bracing was left in a condition adequate to support the loads calculated in 1975.

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A new site-specific probabilistic seismic hazard analysis was completed in the 1990's and used to define a design basis earthquake (DBE) for the ATR. The most recent update to that DBE was issued in 2002 (Ref. 8). The ATR Seismic Assessment project (Ref. 2) was undertaken to evaluate existing ATR seismic category 1 items against this newly defined SSE. The first step in that process was to complete a soil-structure interaction (SSI) analysis of the TRA-670 building (Ref. 1) which is based upon the SSE. One of the key results of the soil-structure interaction analysis is the definition of sets of seismic motions to be applied simultaneously at various building locations. These are defined in terms of 32 response motion sets, each associated with the response of the building to the same input earthquake motion applied to the SSI model with different soil parameters. The soil parameters were varied in the SSI analysis to match a probabilistic distribution of soil properties. Each of the 32 input motion sets was applied to the heat exchanger model, with the resulting demands sorted in ascending order and the seventh from the maximum taken as the demand associated with an 80% nonexceedence probability.

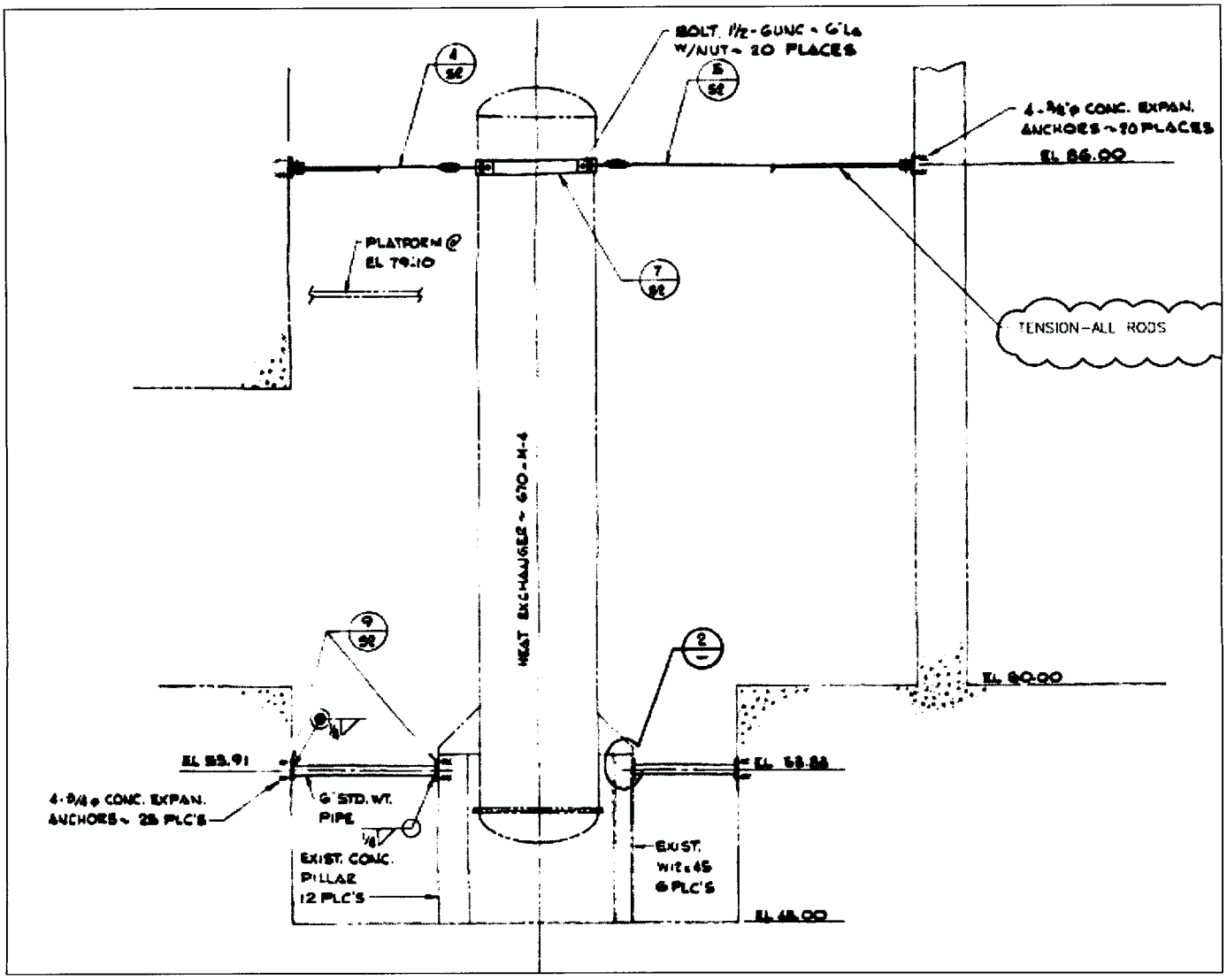

Figure 1: Heat Exchanger with Bracing

Assumptions

It is assumed that the heat exchangers and supports are accurately represented by their drawings. While an on-site walkdown was performed, it was not practical to field verify every parameter important to this analysis. This assumption is justified by the walkdown, and the long operational history of the heat exchangers where design discrepancies would likely have been noticed. Structural evaluation procedures recognize that variations of parameters as found in the field will vary from those used in the evaluations, and take this variation into account.

It is also assumed that the material condition of the heat exchangers is like-new. The shells and steel supports are painted, and are located indoors in a dry and mild environment. The heat exchangers are subject to periodic inspection and evaluation of the inspection results, which is outside the scope of this analysis.

Computer Code Validation

Two software codes were used to create and solve FE models. The IDEAS Simulation software (Ref. 9) was used to create the finite element models. An I-DEAS export feature was then used to create an ABAQUS input file. Minor text edits were made to the file to incorporate features not available in I-DEAS, with the results read into ABAQUS Standard, Version 6.7-5 (Ref. 10) for processing. ABAQUS Standard validated the input, performed the solution runs, and generated post-processing results for each model. ABAQUS Standard and Explicit, version 6.7-5 have been validated following company procedures and documented in ECAR-202 (Ref. 11).

A Precision 690 workstation, which has 4 CPUs, 8 GB RAM, and runs on dual Linux and Windows platforms, was used in the analysis. The ABAQUS Standard and Explicit, version 6.7-5 evaluation was performed on SUSE Linux 10.1.

Some response spectra were generated with ReSpect, a software program that was validated by comparison to the results of a MathCad calculation (Appendix A, Section A.3.4.1 in ECAR-194 (Ref. 15)). Additional response spectra were generated with ReSpect_var, a software program that was validated by comparison to the results of a MathCad calculation (Appendix A, Section A.3.4.2 in ECAR-194 (Ref. 15)).

Calculations were also done using Microsoft Excel software (Ref. 12) and the Mathsoft Mathcad software (Ref. 13) on a variety of platforms. This analysis software has been independently validated by visual inspection or hand calculation during the checking process.

Calculations

Analysis Overview: The analysis approach uses a probabilistic time-domain nonlinear finite element model of the heat exchangers and the major associated piping. Time history input is taken from the probabilistic soil-structure interaction analysis of TRA-670 (Ref. 1). Appropriate inputs are selected independently for model anchor points from the locations available in the SSI report. The time histories are repopulated to a 0.005 second baseline corrected to remove drift, and otherwise conditioned as detailed in Appendix A.

Rayleigh damping (mass and stiffness proportional) parameters are selected to achieve a system level response that closely matches the 5% modal damping response of a corresponding linear system. The nonlinear system model is solved through direct integration for the 32 sets of independent time histories taken from the SSI analysis. A gravity load was applied prior to application of the seismic loads, so weight was considered in conjunction with the seismic loading. 80% nonexceedance probability level results are reported for stresses in the heat exchanger shell, nozzles, and lugs, and as forces and moment reactions at the heat exchanger supports. This process and the results are documented in detail in Appendix A.

Evaluation Overview: The anchor bolt connection between the heat exchanger lug and the concrete pillar is identified as a likely governing location for the structural system. Capacities for this connection are calculated based upon ACI-318-05 (Ref. 14). The capacity is compared to the demand reported in Appendix A.

Results: The shear demand in the connection between the heat exchanger lug and the concrete pillar exceeds the capacity with a demand to capacity ratio of about 1.9. The controlling failure mode is side breakout of the concrete, which is not a ductile failure mode amenable to refined analysis approaches.

This connection is essential for the existing structural system, and the analysis concludes that some physical modification to the load path will be necessary before the heat exchangers satisfy modern seismic criteria for the probabilistic SSE. Because such a modification would affect the response of the system and the stress levels in the various components, it was not deemed necessary at this time to complete the structural evaluation on a system that would be altered.

The existing system, however, showed large loads delivered to the heat exchanger from the elevated tie bracing. The building motions at this level are much larger than the motions at the floor of the heat exchanger pit, as can be seen from comparison of response spectra in Figure 2.

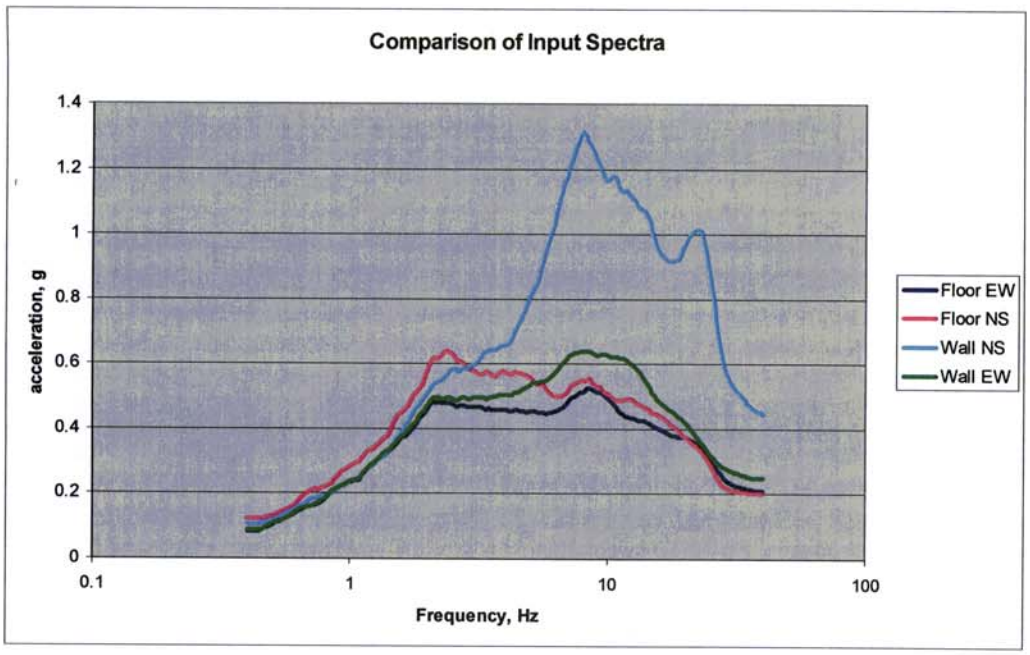

Figure 2: Comparison of Input Spectra

Recommendations

If a strengthening design is undertaken, it is recommended that the heat exchanger pit level be used to provide as much of the lateral load path as practical, to isolate the heat exchangers from the larger motions higher in the building. In particular, anchor points on the North wall of the heat exchanger cubicle should be avoided (See Figure 2 above). Any future analysis will need to include a full evaluation of the heat exchanger nozzles, lugs, and supports.

Conclusions

The ATR primary coolant heat exchangers do not satisfy DOE-STD-1020 seismic criteria for the newly completed in-structure motions of the probabilistic SSE, and would require some physical modification before they are qualified to that upgraded seismic criteria. The limiting feature identified is anchorage of the heat exchangers to their concrete supports. The capacity of top of these supports is 6 kips in the long direction (Appendix B) and the maximum demand for this situation is 11.2 kips (Appendix A).

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Appendix A

Heat Exchanger Model and Results

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A-1.0 Purpose

The purpose of this appendix is to define the modeling process and establish 80th percentile output data for the heat exchanger evaluation.

A-2.0 Results

The maximum 80th percentile tensile load in the heat exchanger seismic brace rods is 26,100 lbf (see Section A-7.1). The maximum 80th percentile compressive load in the heat exchanger seismic brace pipes is 55,300 lbf (see Section A-7.2). The maximum 80th percentile steel column loads are 71,200 lbf in compression, 4,250 lbf in the east-west direction, and 726 lbf in the north-south direction (see Section A-7.3). The maximum 80th percentile concrete column loads (see Section A-7.4) are shown in Table A-2.0-1. The realization 14 midplane Tresca stress in the primary piping nozzles and heat exchanger lugs is 31,100 psi (see Section A-7.5). This is only for information as further evaluation is needed to establish 80th percentile data

Table A-2.0-1 – Concrete column loads.

	South-side concrete columns 80th percentile summary		East- and west-side concrete columns 80th percentile summary	
	Bottom	Top	Bottom	Top
East-west shear	10,700 lbf	10,200 lbf	13,500 lbf	55,600 lbf
Vertical compression	86,200 lbf	83,300 lbf	102,000 lbf	99,100 lbf
North-south shear	5,330 lbf	35,200 lbf	11,700 lbf	11,200 lbf
East-west moment	264,000 in•lbf	402,000 in•lbf	848,000 in•lbf	64,000 in•lbf
Vertical torsion	69,800 in•lbf	69,700 in•lbf	75,200 in•lbf	75,100 in•lbf
North-south moment	774,000 in•lbf	57,800 in•lbf	572,000 in•lbf	546,000 in•lbf
Vertical tension	22,600 lbf	25,700 lbf	27,500 lbf	30,300 lbf

A-3.0 Material Properties

The material properties below represent reasonable values for analysis. They are primarily based on the material properties identified in the ATR Primary Coolant System Seismic Analysis [1].

A-3.1 Concrete Material Properties

The concrete and rebar material properties are established in part from the ATR Primary Coolant System Seismic Analysis [1]. The concrete properties are also from ACI 318-05 [2] and ASCE/SEI 43-05 [3] and the steel material properties are also established from AISC [4].)

$f'_c := 3000 \cdot psi$ Concrete compressive strength [1].

$w_c := 150 \cdot \frac{lb}{ft^3}$ Concrete density [2].

$\nu_c := 0.17$ Concrete Poisson's ratio [2].

$E_c := \left(w_c \cdot \frac{ft^3}{lb}\right)^{1.5} \cdot 33 \cdot \sqrt{f'_c \cdot psi^{-1}} \cdot psi$ Concrete modulus of elasticity [2].

$E_c = 3.321 \times 10^6 psi$

$f_y := 40 \cdot ksi$ Rebar yield strength [1].

$E_s := 29 \cdot 10^6 \cdot psi$ Rebar modulus of elasticity [4].

$w_s := 490 \cdot \frac{lb}{ft^3}$ Steel density [4].

$E_{ce} := \frac{1}{2} \cdot E_c$ Effective stiffness or reinforced concrete members (Beams-Nonprestressed, ASCE/SEI 43-05 [3]).

$E_{ce} = 1.66 \times 10^6 psi$

A-3.2 Heat Exchanger (A212) Material Properties

$E_{212} := 2.8 \cdot 10^7 \cdot psi$ Modulus of elasticity [1].

$\nu_{212} := 0.27$ Poisson's ratio [1].

$\rho_{212} := 7.31737 \cdot 10^{-4} \cdot \frac{lbf \cdot sec^2}{in^4}$ Mass density.

$\rho_{212} = 0.283 \frac{lb}{in^3}$

$\sigma_{y212} := 38 \cdot ksi$ Engineering yield stress [1].

Note: ASTM A515 [6] (which replaces ASTM A212) gives slightly lower yield value. The ATR Primary Coolant System Seismic Analysis [1] references A212B and is considered accurate.

$\sigma_{u212} := 70 \cdot ksi$ Engineering ultimate stress [1].

$\varepsilon_{y212} := \frac{\sigma_{y212}}{E_{212}}$ Engineering yield strain (0.2% offset is not considered).

$\varepsilon_{y212} = 0.001357 \frac{in}{in}$

$\varepsilon_{u212} := 0.17 \cdot \frac{in}{in}$ Minimum engineering ultimate strain based on elongation for the materials used [6].

$\sigma_{Ty212} := \sigma_{y212} \cdot (1 + \varepsilon_{y212})$ True yield stress [5, p. 51].

$\sigma_{Ty212} = 38051.6\ psi$

A-3.3 Bolt (A7) Material Properties

$E_7 := 3.0 \cdot 10^7 \cdot psi$ Modulus of elasticity [1].

$\nu_7 := 0.27$ Poisson's ratio [1].

$\rho_7 := 7.31737 \cdot 10^{-4} \cdot \frac{lbf \cdot sec^2}{in^4}$ Mass density.

$\rho_7 = 0.283 \frac{lb}{in^3}$

$\sigma_{y7} := 33 \cdot ksi$ Engineering yield stress [1].

$\sigma_{u7} := 60 \cdot ksi$ Engineering ultimate stress [1].

$\varepsilon_{y7} := \frac{\sigma_{y7}}{E_7}$ Engineering yield strain (0.2% offset is not considered).

$\varepsilon_{y7} = 0.0011 \frac{in}{in}$

$\varepsilon_{u7} := 0.21 \cdot \frac{in}{in}$ Minimum engineering ultimate strain based on elongation for the materials used [7].

$\sigma_{Ty7} := \sigma_{y7} \cdot (1 + \varepsilon_{y7})$ True yield stress [5, p. 51].

$\sigma_{Ty7} = 33036.3\ psi$

A-3.4 Pipe (A53) Material Properties

$E_{53} := 3.0 \cdot 10^7 \cdot psi$ Modulus of elasticity.

$\nu_{53} := 0.27$ Poisson's ratio.

$\rho_{53} := 7.31737 \cdot 10^{-4} \cdot \frac{lbf \cdot sec^2}{in^4}$ Mass density.

$\rho_{53} = 0.283 \frac{lb}{in^3}$

$\sigma_{y53} := 30 \cdot ksi$ Engineering yield stress [8].

$\sigma_{u53} := 48 \cdot ksi$ Engineering ultimate stress [8].

$\varepsilon_{y53} := \frac{\sigma_{y53}}{E_{53}}$ Engineering yield strain (0.2% offset is not considered).

$\varepsilon_{y53} = 0.001 \frac{in}{in}$

$\varepsilon_{u53} := 0.27 \cdot \frac{in}{in}$ Minimum engineering ultimate strain based on elongation for the materials used [8].

$\sigma_{Ty53} := \sigma_{y53} \cdot (1 + \varepsilon_{y53})$ True yield stress [5, p. 51].

$\sigma_{Ty53} = 30030\ psi$

A-3.5 Support (A36) Material Properties

$E_{36} := 3.0 \cdot 10^{7} \cdot psi$ Modulus of elasticity [1].

$\nu_{36} := 0.27$ Poisson's ratio [1].

$\rho_{36} := 7.31737 \cdot 10^{-4} \cdot \frac{lbf \cdot sec^{2}}{in^{4}}$ Mass density.

$\rho_{36} = 0.283 \frac{lb}{in^{3}}$

$\sigma_{y36} := 36 \cdot ksi$ Engineering yield stress [1].

$\sigma_{u36} := 58 \cdot ksi$ Engineering ultimate stress [1].

$\varepsilon_{y36} := \frac{\sigma_{y36}}{E_{36}}$ Engineering yield strain (0.2% offset is not considered).

$\varepsilon_{y36} = 0.0012 \frac{in}{in}$

$\varepsilon_{u36} := 0.20 \cdot \frac{in}{in}$ Minimum engineering ultimate strain based on elongation for the materials used [9].

$\sigma_{Ty36} := \sigma_{y36} \cdot (1 + \varepsilon_{y36})$ True yield stress [5, p. 51].

$\sigma_{Ty36} = 36043.2\ psi$

A-3.6 Water Material Properties

$\rho_w := 62.3 \cdot \frac{lb}{ft^3}$ Mass density [10].

$\rho_w = 0.0361 \frac{lb}{in^3}$

A-4.0 Beam and Spring Section Properties and Spring Constants

The section properties below are included for modifications due to thread area and elbow flexibility factors. The thread area calculations use equations from the Machinery's Handbook [11] and elbow flexibility factors calculations use equations from the ASME Boiler & Pressure Vessel Code [12]. The spring constants are established for elements with limited load carrying capacity and to mimic contact.

A-4.1 Bolt Thread Areas

The thread area calculations are done on a 1 inch bolt with 10 threads per inch, a 7/8 inch bolt with 18 threads per inch, and a 3/4 inch bolt with 14 threads per inch. (The threads per inch are chosen as the lowest UNS number.) The output, using equations from the Machinery's Handbook [11], is an effective diameter for the finite element beam elements.

$D_1 := 1 \cdot in$ Nominal diameter.

$n_1 := 10$ Threads per inch.

$A_{t1} := 0.7854 \cdot \left(D_1 - \frac{0.9743 \cdot in}{n_1} \right)^2 = \frac{\pi}{4} \cdot d_{e1}^2$ Tensile area [11].

$A_{t1} = 0.64\, in^2$

$d_{e1} := \sqrt{\frac{4}{\pi} \cdot A_{t1}}$ Effective diameter.

$d_{e1} = 0.903\, in$

$D_2 := \frac{7}{8} \cdot in$ Nominal diameter.

$n_2 := 18$ Threads per inch.

$$A_{t2} := 0.7854 \cdot \left(D_2 - \frac{0.9743 \cdot in}{n_2} \right)^2 = \frac{\pi}{4} \cdot d_{e2}^{\,2}$$ Tensile area [11].

$A_{t1} = 0.64\ in^2$

$$d_{e2} := \sqrt{\frac{4}{\pi} \cdot A_{t2}}$$ Effective diameter.

$d_{e2} = 0.821\ in$

$$D_3 := \frac{3}{4} \cdot in$$ Nominal diameter.

$n_3 := 14$ Threads per inch.

$$A_{t3} := 0.7854 \cdot \left(D_3 - \frac{0.9743 \cdot in}{n_3} \right)^2 = \frac{\pi}{4} \cdot d_{e3}^{\,2}$$ Tensile area [11].

$A_{t1} = 0.64\ in^2$

$$d_{e3} := \sqrt{\frac{4}{\pi} \cdot A_{t3}}$$ Effective diameter.

$d_{e3} = 0.68\ in$

A-4.2 Elbow Flexibility Factors

The ASME Boiler & Pressure Vessel Code, NB-3686.2 Curved Pipe and Welding Elbows [12] defines the flexibility factor as shown below considering that (a), (b), and (c) are met.

(a) R/r is not less than 1.7

(b) center line length Rα is greater than 2r

(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.

$$k(d_o, t, P, R) := \left| \begin{array}{l} d_i \leftarrow d_o - 2 \cdot t \\ r \leftarrow \frac{1}{4} \cdot (d_o + d_i) \\ h \leftarrow t \cdot R \cdot r^{-2} \\ X_k \leftarrow 6 \cdot \left(\frac{r}{t}\right)^{\frac{4}{3}} \cdot \left(\frac{R}{r}\right)^{\frac{1}{3}} \\ k_o \leftarrow 0 \\ k_o \leftarrow \frac{1.65}{h} \cdot \frac{1}{1 + \left(\frac{P \cdot r}{t \cdot E_s}\right) \cdot X_k} \quad \text{if } \frac{R}{r} \geq 1.7 \\ k_o \end{array} \right.$$

Flexibility factor [12].

Where:
- d_o - Outside pipe diameter.
- d_i - Inside pipe diameter.
- t - Pipe thickness.
- P - Internal pressure.
- R - Elbow radius.

The local variables r, h, and X_k are defined as shown in the code [12].

The flexibility factor is used to find the angular displacement of the elbow in the three orthogonal directions as shown below.

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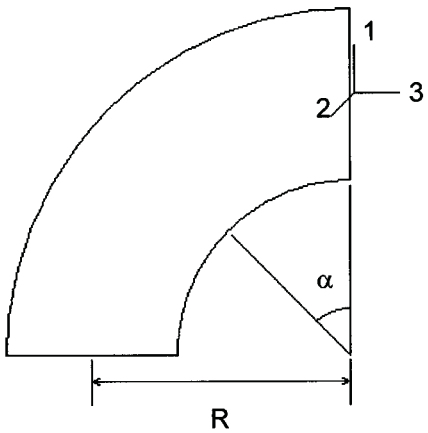

Elbow geometry

k	- Flexibility factor.
M	- Moment.
R	- Elbow radius.
E	- Modulus of elasticity.
I	- Area moment of inertia.
α	- Angle along the elbow.
θ	- Full elbow angle.
α	- Angle along the elbow.
θ	- Full elbow angle.
θ_{nom}	- Nominal angular displacement.
θ_{ab}	- Actual (code) angular displacement.

Nominal angle derivations:

$$\theta_{nom1} = \frac{R}{E \cdot I} \cdot \int_0^{\theta} M_1 \, d\alpha$$

$$\theta_{nom2} = \frac{R}{E \cdot I} \cdot \int_0^{\theta} M_2 \, d\alpha$$

$$\theta_{nom3} = \frac{R}{G \cdot J} \cdot \int_0^{\theta} M_3 \, d\alpha$$

Actual (code) angle derivations:

$$\theta_{ab1} = k \cdot \theta_{nom1} = \frac{k \cdot R}{E \cdot I} \cdot \int_0^{\theta} M_1 \, d\alpha$$

$$\theta_{ab2} = k \cdot \theta_{nom2} = \frac{k \cdot R}{E \cdot I} \cdot \int_0^{\theta} M_2 \, d\alpha$$

$$\theta_{ab3} = \theta_{nom3} = \frac{R}{G \cdot J} \cdot \int_0^{\theta} M_3 \, d\alpha$$

To address the flexibility factor in the finite element model, an effective area moment of inertia is defined as shown below: The parabolic beam elements used in the finite element model then use the effective moment of inertia for the bending directions and an unmodified polar moment of inertia for the torsion direction. The acceptability of using a parabolic beam element to produce accurate results is address in Appendix A of the ATR Primary Coolant System Seismic Evaluation [13].

$I_e = \frac{I}{k}$ Effective area moment of inertia.

Therefore:

$$\theta_{ab1} = \frac{R}{E \cdot I_e} \cdot \int_0^{\theta} M_1 \, d\alpha$$

$$\theta_{ab2} = \frac{R}{E \cdot I_e} \cdot \int_0^{\theta} M_2 \, d\alpha$$

$$\theta_{ab3} = \frac{R}{G \cdot J} \cdot \int_0^{\theta} M_3 \, d\alpha$$

Two pipe elbows are defined below including a 20 pipe with a 3/8 inch wall thickness and a 36 inch pipe with a 3/8 inch wall thickness.

A-4.2.1 Pipe (A53) 20 Inch Diameter and 3/8 Thickness

$d_{20} := 20 \cdot in$ Pipe outside diameter.

$t_{20} := 0.375 \cdot in$ Pipe thickness.

$p_{125} := 125 \cdot psi$ Internal pressure [14].

$r_{l20} := 1.5 \cdot d_{20}$ Radius for long radius elbow.

$r_{l20} = 30\,in$

$A_{20} := \frac{\pi}{4} \cdot \left[d_{20}^2 - (d_{20} - 2 \cdot t_{20})^2 \right]$ Pipe cross section area.

$A_{20} = 23.1202\,in^2$

$A_{i20} := \frac{\pi}{4} \cdot (d_{20} - 2 \cdot t_{20})^2$ Pipe internal area.

$A_{i20} = 291\,in^2$

$\rho_{sw20} := \frac{A_{20} \cdot \rho_{212} + A_{i20} \cdot \rho_w}{A_{20}}$ Mass density for the pipe with water.

$\rho_{sw20} = 1.907 \times 10^{-3} \frac{lbf \cdot sec^2}{in^4}$

$I_{20} := \frac{\pi}{64} \cdot \left[d_{20}^4 - (d_{20} - 2 \cdot t_{20})^4 \right]$ Pipe area moment of inertia.

$I_{20} = 1113.47\ in^4$

$J_{20} := \frac{\pi}{32} \cdot \left[d_{20}^4 - (d_{20} - 2 \cdot t_{20})^4 \right]$ Pipe polar moment of inertia.

$J_{20} = 2226.9\ in^4$

$k_{I20} := k(d_{20}, t_{20}, p_{125}, r_{I20})$ Flexibility factor for long radius.

$k_{I20} = 13.121$

$I_{eI20} := \frac{I_{20}}{k_{I20}}$ Effective moment of inertia for long radius.

$I_{eI20} = 84.864\ in^4$

A-4.2.2 Pipe (A53) 36 Inch Diameter and 3/8 Thickness

$d_{36} := 36 \cdot in$ Pipe outside diameter.

$t_{36} := 0.375 \cdot in$ Pipe thickness.

$p_{125} := 125 \cdot psi$ Internal pressure [14].

$r_{s36} := d_{36}$ Radius for short radius elbow.

$r_{s36} = 36\ in$

$A_{36} := \frac{\pi}{4} \cdot \left[d_{36}^{2} - (d_{36} - 2 \cdot t_{36})^{2} \right]$ Pipe cross section area.

$A_{36} = 41.9697\ in^{2}$

$A_{i36} := \frac{\pi}{4} \cdot (d_{36} - 2 \cdot t_{36})^{2}$ Pipe internal area.

$A_{i36} = 975.9\ in^{2}$

$\rho_{sw36} := \frac{A_{36} \cdot \rho_{212} + A_{i36} \cdot \rho_{w}}{A_{36}}$ Mass density for the pipe with water.

$\rho_{sw36} = 2.903 \times 10^{-3} \frac{lbf \cdot sec^{2}}{in^{4}}$

$I_{36} := \frac{\pi}{64} \cdot \left[d_{36}^{4} - (d_{36} - 2 \cdot t_{36})^{4} \right]$ Pipe area moment of inertia.

$I_{36} = 6658.92\ in^{4}$

$J_{36} := \frac{\pi}{32} \cdot \left[d_{36}^{4} - (d_{36} - 2 \cdot t_{36})^{4} \right]$ Pipe polar moment of inertia.

$J_{36} = 13317.8\ in^{4}$

$k_{s36} := k(d_{36}, t_{36}, p_{125}, r_{s36})$ Flexibility factor for short radius.

$k_{s36} = 30.603$

$I_{es36} := \frac{I_{36}}{k_{s36}}$ Effective moment of inertia for short radius.

$I_{es36} = 217.592\ in^{4}$

A-4.3 Spring Properties

Springs were used in several locations where nonlinear effects needed to be addressed. These locations included the seismic brace pipes which were credited only with compressive loads. Additionally, springs mimicking contact were put under the I-beam columns to prevent a tensile load. For the fine meshed model, further contact springs were used in the bolted connections. (Note: The modulus of

elasticity used for the spring calculations is that of the rebar steel. The difference between the modulus of elasticity of this and the correct material (A36) was not considered significant.)

A-4.3.1 Seismic Brace Pipe Springs

The seismic brace pipes are all made from 6 inch Schedule 40 pipe.

$d_{op} := 6.625 \cdot in$ — Outside diameter for 6 inch Schedule 40 pipe.

$d_{ip} := 6.065 \cdot in$ — Inside diameter for 6 inch Schedule 40 pipe.

$A_p := \frac{\pi}{4} \cdot \left(d_{op}^2 - d_{ip}^2\right)$ — Cross sectional area.

$A_p = 5.581\ in^2$

$P_p := -10^6 \cdot lbf$ — Nonlinear spring load. This is expected to be higher than any load that could occur during the dynamic analysis.

$E_s = 2.9 \times 10^7\ psi$ — Modulus of elasticity.

$L_{pn} := 5 \cdot ft + 3.5 \cdot in$ — Length of north-side seismic brace pipes.

$k_{pn} := \frac{A_p \cdot E_s}{L_{pn}}$ — North-side pipe stiffness.

$k_{pn} = 2.549 \times 10^6 \frac{lbf}{in}$

$x_{pn} := \frac{P_p}{k_{pn}}$ — North-side displacement under the n onlinear spring load.

$x_{pn} = -0.3923\ in$

$L_{ps} := 7 \cdot ft + 5 \cdot in$ — Length of south-side seismic brace pipes.

$k_{ps} := \frac{A_p \cdot E_s}{L_{ps}}$ — South-side pipe stiffness.

$k_{ps} = 1.819 \times 10^6 \frac{lbf}{in}$

$x_{ps} := \frac{P_p}{k_{ps}}$ — South-side displacement under the nonlinear spring load.

$x_{ps} = -0.5499\ in$

$L_{pw} := 2 \cdot ft + 2 \cdot in$ Length of west-end seismic brace pipe.

$k_{pw} := \frac{A_p \cdot E_s}{L_{pw}}$ West-end pipe stiffness.

$k_{pw} = 6.225 \times 10^6 \frac{lbf}{in}$

$x_{pw} := \frac{P_p}{k_{pw}}$ West-end displacement under the nonlinear spring load.

$x_{pw} = -0.1606\ in$

$L_{pe} := 1 \cdot ft + 8 \cdot in$ Length of east-end seismic brace pipe.

$k_{pe} := \frac{A_p \cdot E_s}{L_{pe}}$ East-end pipe stiffness.

$k_{pe} = 8.093 \times 10^6 \frac{lbf}{in}$

$x_{pe} := \frac{P_p}{k_{pe}}$ East-end displacement under the nonlinear spring load.

$x_{pe} = -0.1236\ in$

$L_{pm} := 4 \cdot ft + 4 \cdot in$ Length of middle seismic brace pipes.

$k_{pm} := \frac{A_p \cdot E_s}{L_{pm}}$ Middle pipe stiffness.

$k_{pm} = 3.113 \times 10^6 \frac{lbf}{in}$

$x_{pm} := \frac{P_p}{k_{pm}}$ Middle displacement under the nonlinear spring load.

$x_{pm} = -0.3213\ in$

A-4.3.2 I-beam Column Base Springs

$A_{st} := 13.2 \cdot in^2$ Cross sectional area for a 12x45 I-beam [4]

$L_{st} := 3 \cdot in$ Length for spring calculation.

This length is long enough to provide a stable run while being significantly short relative to the overall column height.

$E_s = 2.9 \times 10^7 psi$ Modulus of elasticity.

$k_{st} := \frac{A_{st} \cdot E_s}{L_{st}}$ Spring stiffness.

$k_{st} = 1.276 \times 10^8 \frac{lbf}{in}$

$P_{st} := -10^6 \cdot lbf$ Nonlinear spring load. This is expected to be higher than any load that could occur during the dynamic analysis.

$x_{st} := \frac{P_{st}}{k_{st}}$ Displacement under the nonlinear spring load.

$x_{st} = -7.837 \times 10^{-3} in$

A-4.3.3 Contact Springs

$A_s := 0.172 \cdot in^2$ Cross sectional spring area.

$L_s := .5 \cdot in$ Spring length.

This cross sectional area and length are adjusted to provide a stable run while providing significant stiffness (given how many are used).

$E_s = 2.9 \times 10^7 psi$ Modulus of elasticity.

$k_s := \frac{A_s \cdot E_s}{L_s}$ Spring stiffness.

$k_s = 9.976 \times 10^6 \frac{lbf}{in}$

$P_s := 10^6 \cdot lbf$ Nonlinear spring load. This is expected to be higher than any load that could occur during the dynamic analysis.

$x_s := \frac{P_s}{k_s}$ Displacement under the nonlinear spring load.

$x_s = 0.1\ in$

A-5.0 Finite Element Model

The finite element model consists of the heat exchangers, the heat exchanger supports, and the large primary and secondary piping near the heat exchangers. Figures A-5.1-1 – A-5.1-31 show the fine mesh and Figures A-5.2-1 – A-5.2-7 show the coarse mesh. The fine mesh is used for a single realization set of time histories. This model includes internal pressures and is intended to accurately establish stresses in the heat exchanger nozzles and lugs. The coarse mesh is run for all 32 realizations and is intended to accurately model the supports.

The restraints on the models have motion from nodal output of the Probabilistic Soil-Structure Interaction Analysis (PSSI) [15]. The output nodes from the PSSI [15] are 542, 552, 815, 1340, and 4119. Table A-5.0-1 identifies the PSSI nodes and the corresponding model restraints. The restraints, colored as identified in Table A-5.0-1, are shown in Figures A-5.1-1 - A-5.1-2. Gravitational loading is applied to all elements having mass. The loads including spring hanger loads and internal pressures are identified with the model area where they occur.

Table A-5.0-1 – PSSI nodes and the corresponding model restraints.

PSSI node	Area in the model influenced by the PSSI node	Model restraint color
542	East wall seismic brace rod attachment	Cyan
552	Primary piping and south side seismic brace rod attachment	Golden Orange
815	North wall attachment	Orange
1340	Top attachment over heat exchangers	Red
4119	Base attachment for heat exchangers and primary piping	Dark Green

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A-5.1 Fine Mesh

```
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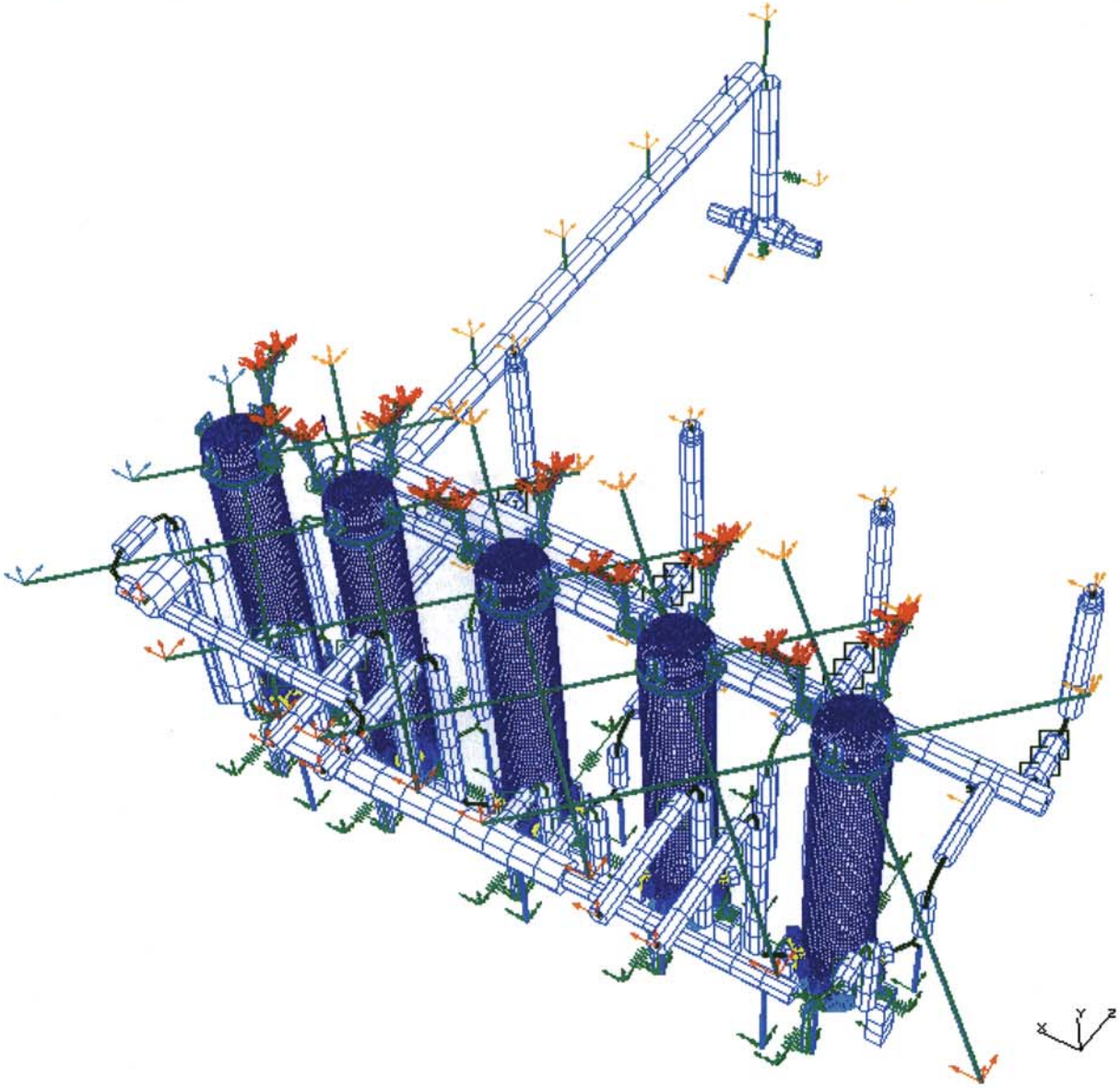

Figure A-5.1-1 – Full fine meshed model viewed from the north-west.

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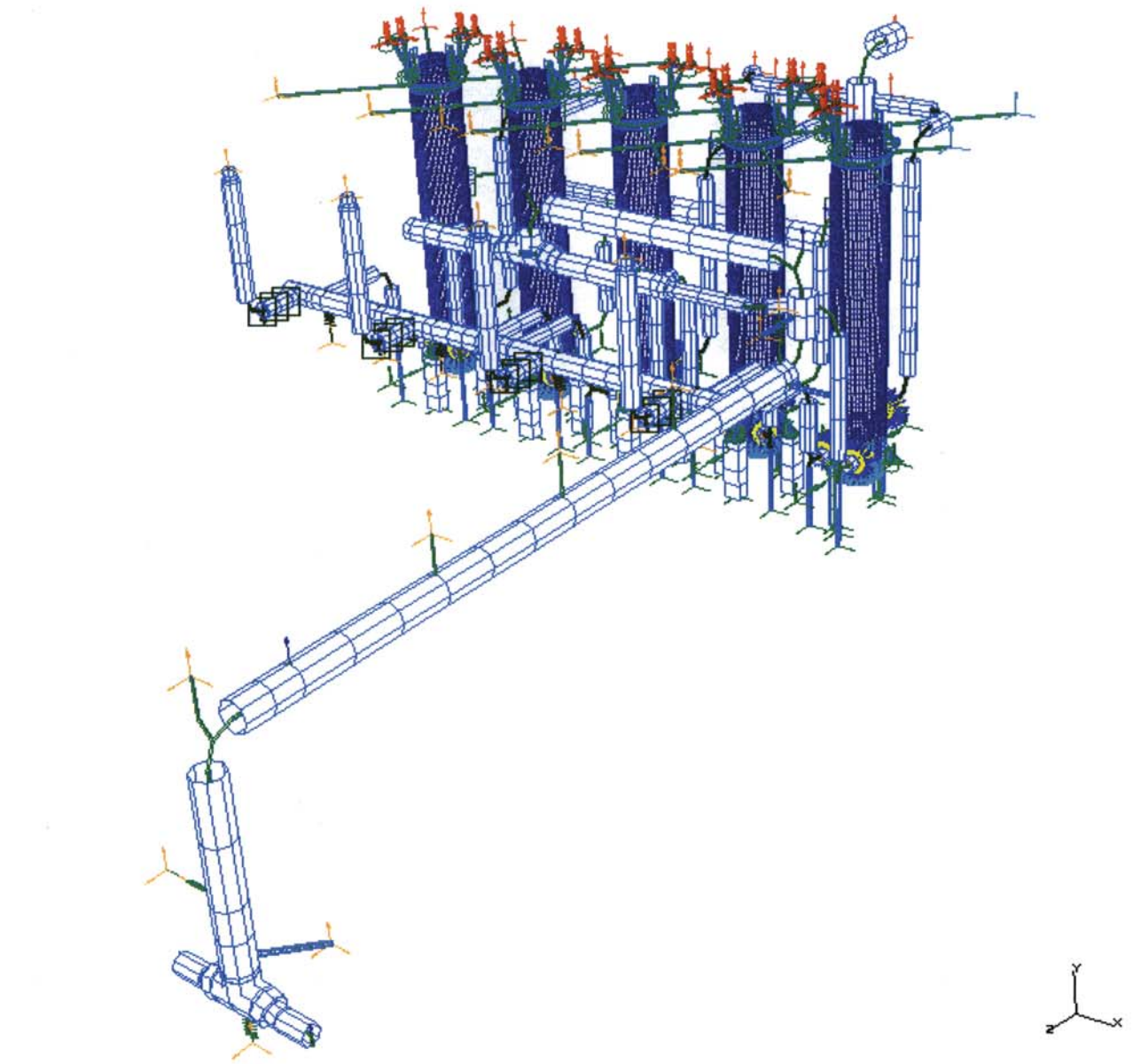

Figure A-5.1-2 – Full model viewed from the south-east.

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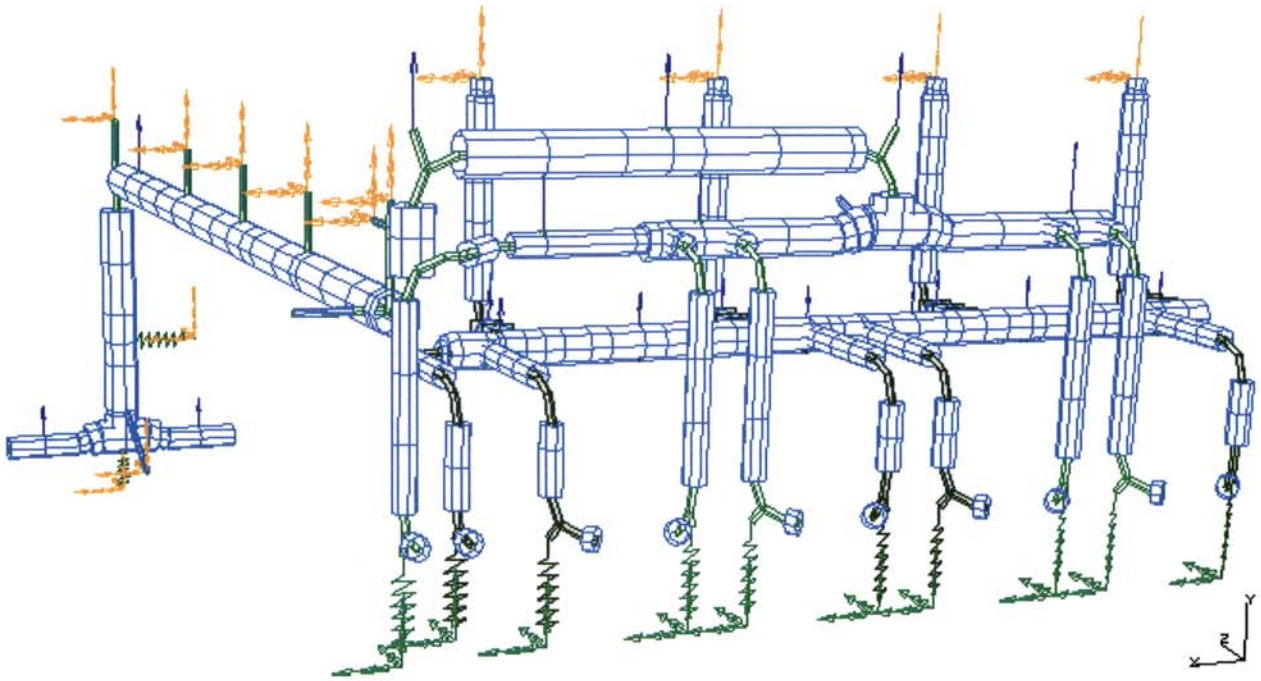

Figure A-5.1-3 – Primary piping.

The primary piping elements, loads, and restraints represent most of model 1 and model 2 in the ATR Primary Coolant System Seismic Evaluation [13]. This is used to better approximate heat exchanger nozzle loads and no stress evaluation is performed on this mesh. This model does not share nodes with the heat exchanger nozzles. It instead has a coupling defined to transfer loads from each connecting pipe element to the corresponding shells in each flange. (Note: The coupling command is not specifically addressed in the ABAQUS validation [56]. Scoping calculations were used to demonstrate that the coupling command performed as expected.) The mesh is described in detail in the ATR Primary Coolant System Seismic Evaluation [13] and no further description is given here.

```
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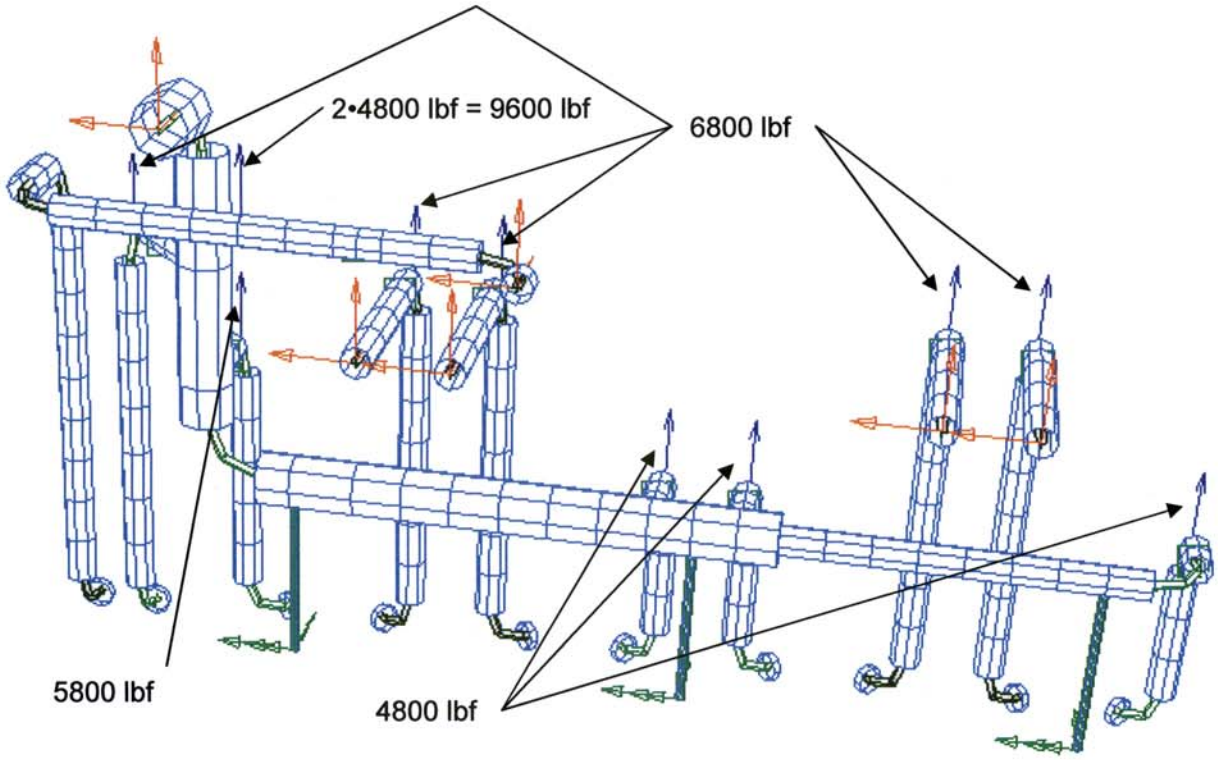

Figure A-5.1-4 – Secondary piping.

The mesh in Figure A-5.1-4 is based off of the INL drawings [16-25]. The loads are based on INL drawings [16, 17] and field observation. This portion of the model does not share nodes with the heat exchanger nozzles. It instead has a coupling defined to transfer loads from each connecting pipe element to the corresponding shells in each flange. Similar to the primary piping side, this mesh is to more accurately model the nozzle loads. No stress analysis is done on these elements.

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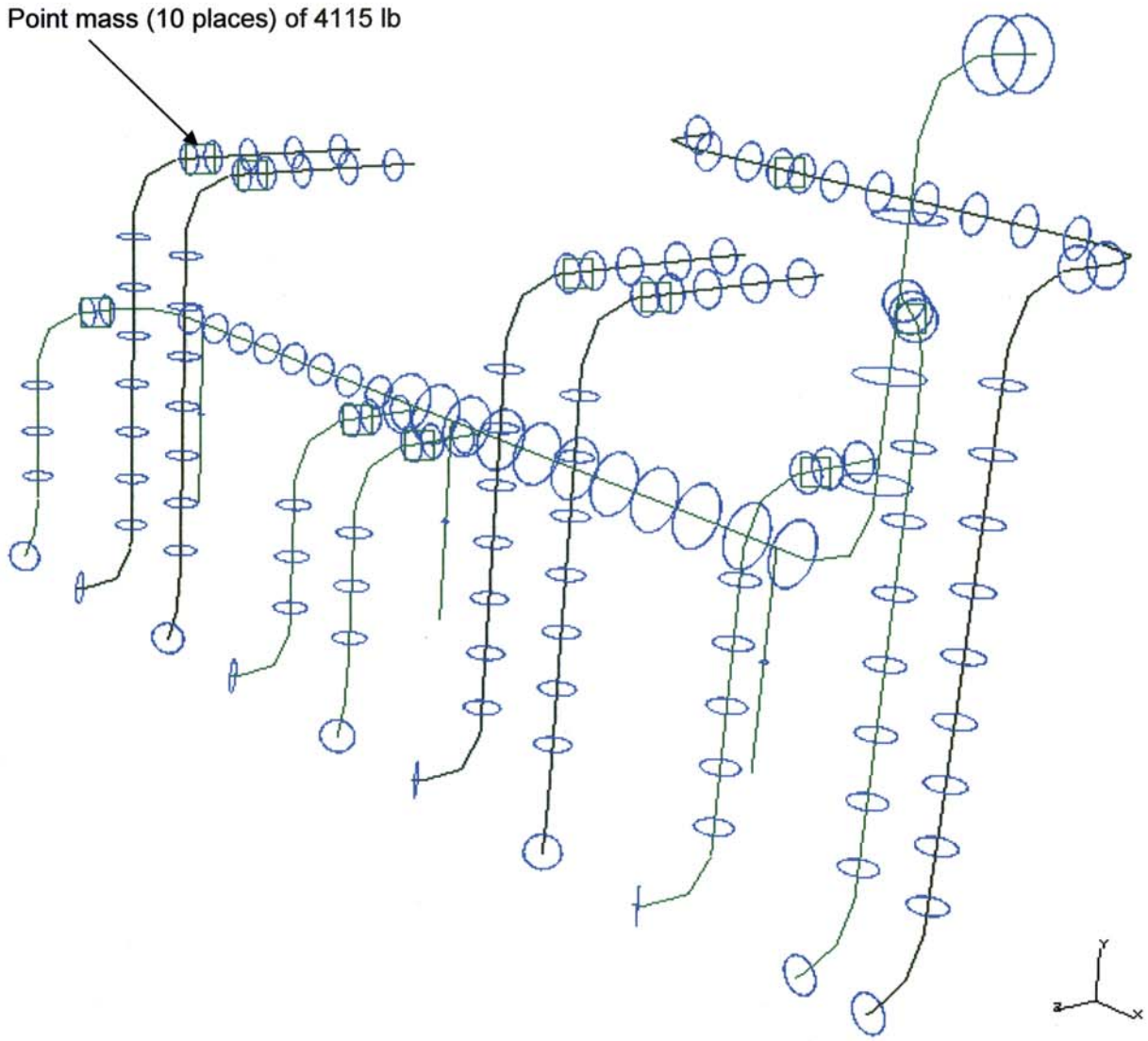

Figure A-5.1-5 – Secondary piping elements.

Figure A-5.1-5 shows all of the elements in the secondary piping. The point masses represent valve and flange combinations and are sized based on equivalent valve and flange combinations calculated for the primary piping [13].

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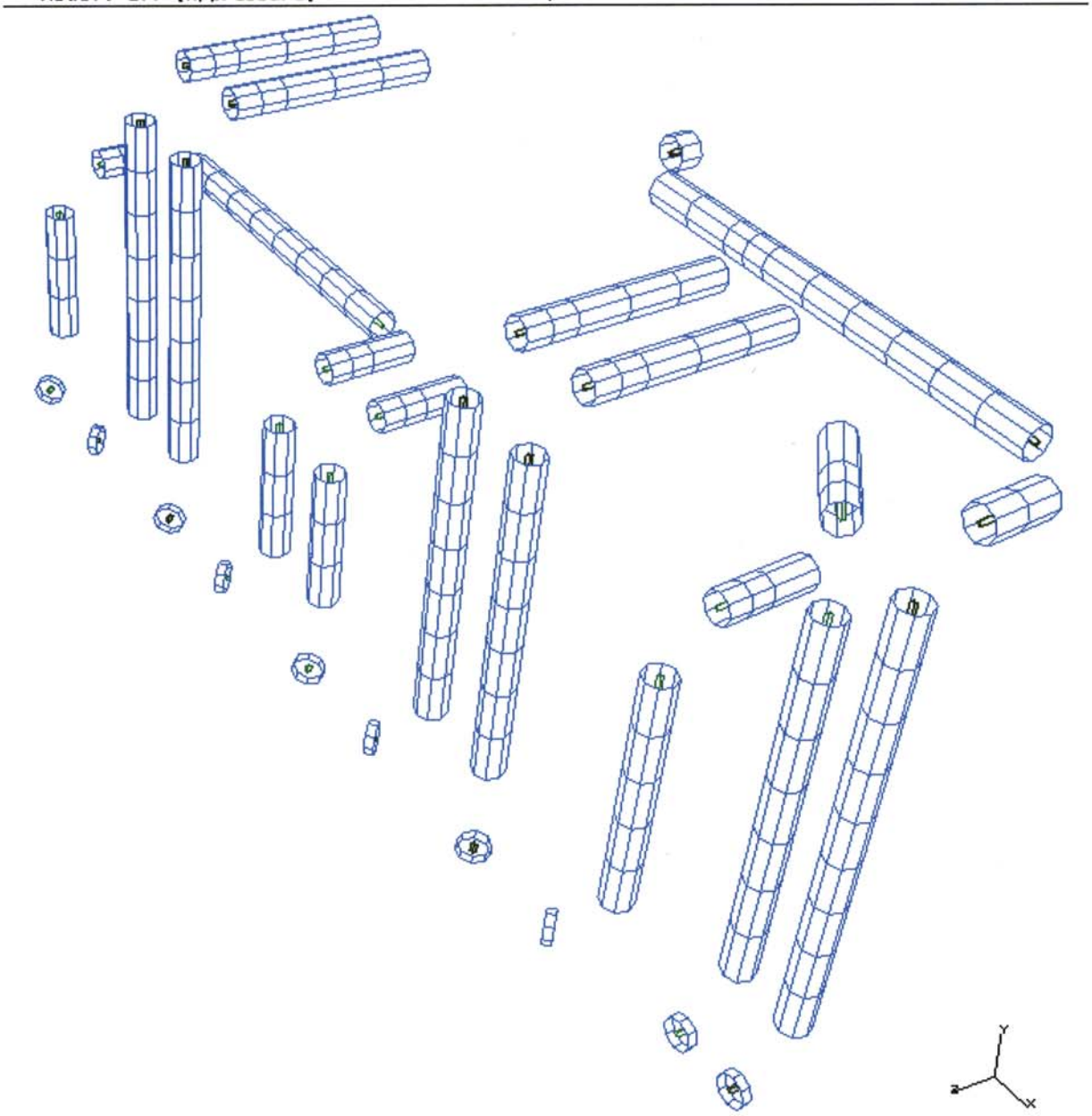

Figure A-5.1-6 – Linear beam elements representing 20" secondary piping.

Figure A-5.1-6 shows the ASTM A53 20" diameter by 3/8 inch thick secondary piping elements. The density has been adjusted to include water as calculated for the 20" elbows in Section A-4.2.1.

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Figure A-5.1-7 – Parabolic beam elements representing 20" secondary piping elbows.

Figure A-5.1-7 shows the ASTM A53 20" diameter by 3/8 inch thick secondary piping element elbows. The density and area moment of inertial has been adjusted to include water and flexibility factor as calculated for the 20" elbows in Section A-4.2.1.

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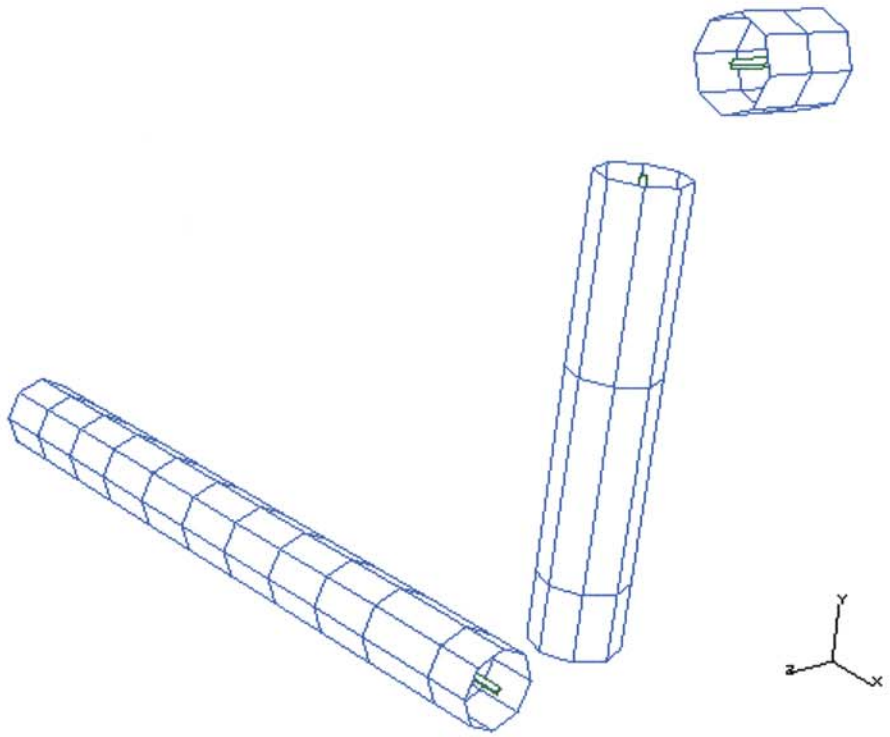

Figure A-5.1-8 – Linear beam elements representing 36" secondary piping.

Figure A-5.1-8 shows the ASTM A53 36" diameter by 3/8 inch thick secondary piping elements. The density has been adjusted to include water as calculated for the 36" elbows in Section A-4.2.2.

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```

Figure A-5.1-9 – Parabolic beam elements representing 36" secondary piping elbows.

Figure A-5.1-9 shows the ASTM A53 36" diameter by 3/8 inch thick secondary piping element elbows. The density and area moment of inertial has been adjusted to include water and flexibility factor as calculated for the 36" elbows in Section A-4.2.2.

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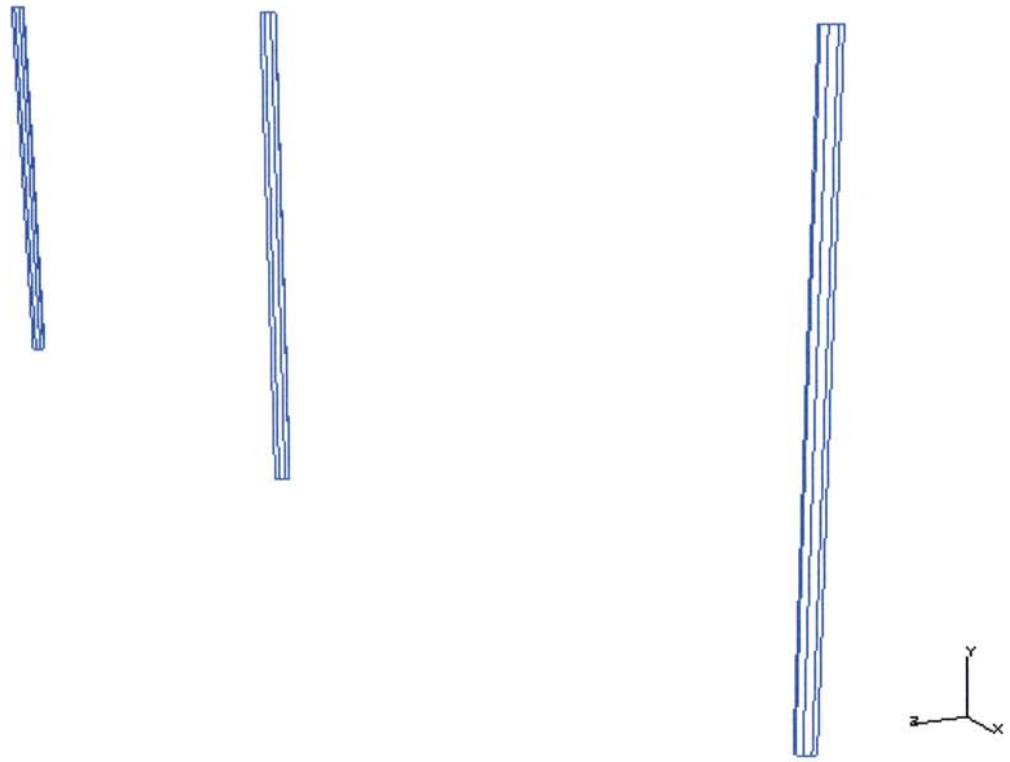

Figure A-5.1-10 – Linear beam elements representing 4" secondary piping supports.

Figure A-5.1-10 shows the ASTM A7 4" schedule 40 secondary piping element supports.

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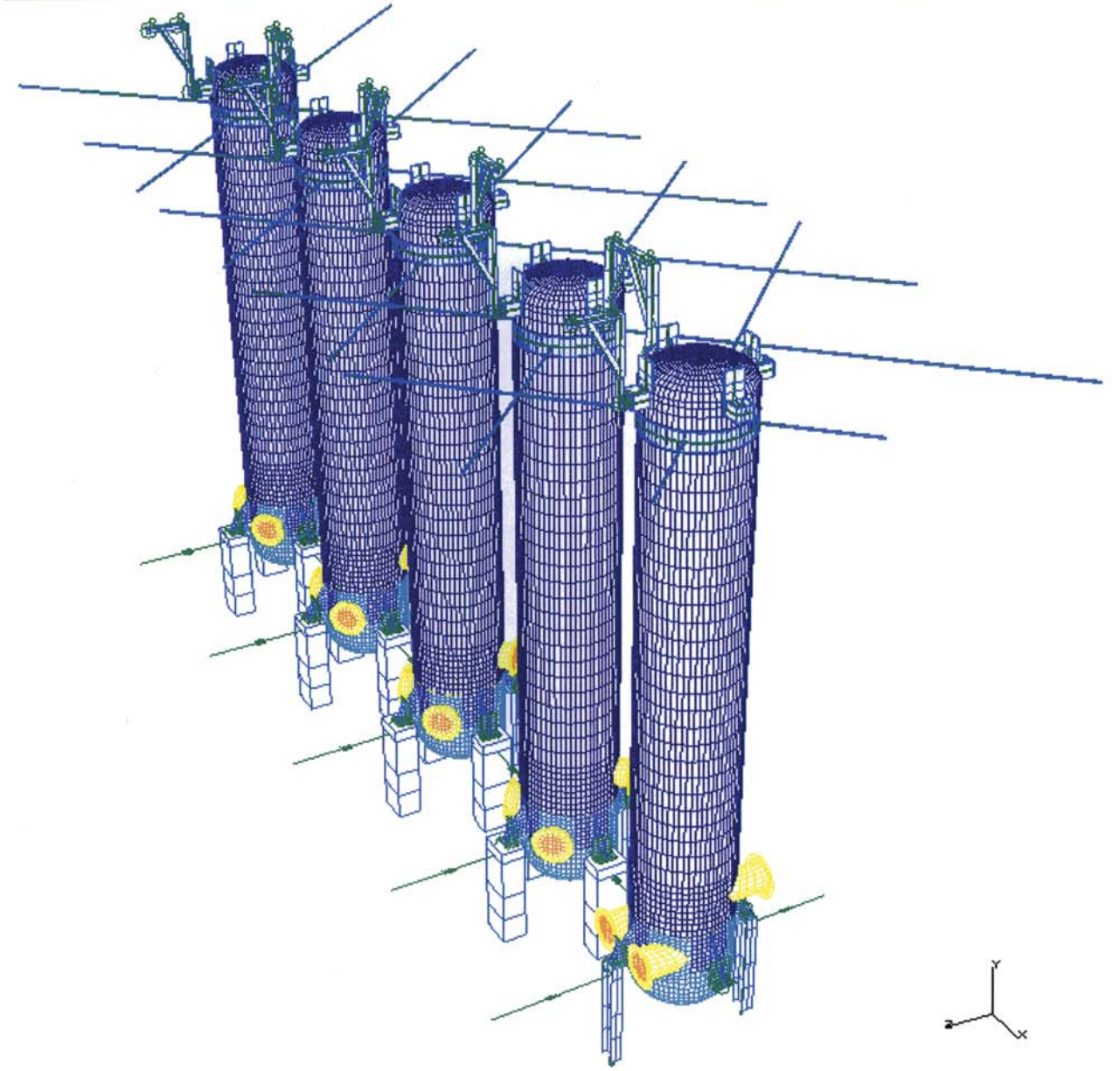

Figure A-5.1-11 – Heat exchangers and heat exchanger supports mesh.

Figure A-5.1-11 shows the heat exchangers 670 M-85, 670 M-2, 670 M-3, 670 M-4, and 670 M-5 from near right to far left respectively. The heat exchanger mesh is based off of the INL drawings [26-51]. The heat exchanger supports mesh is based off of the INL drawings [52-55].

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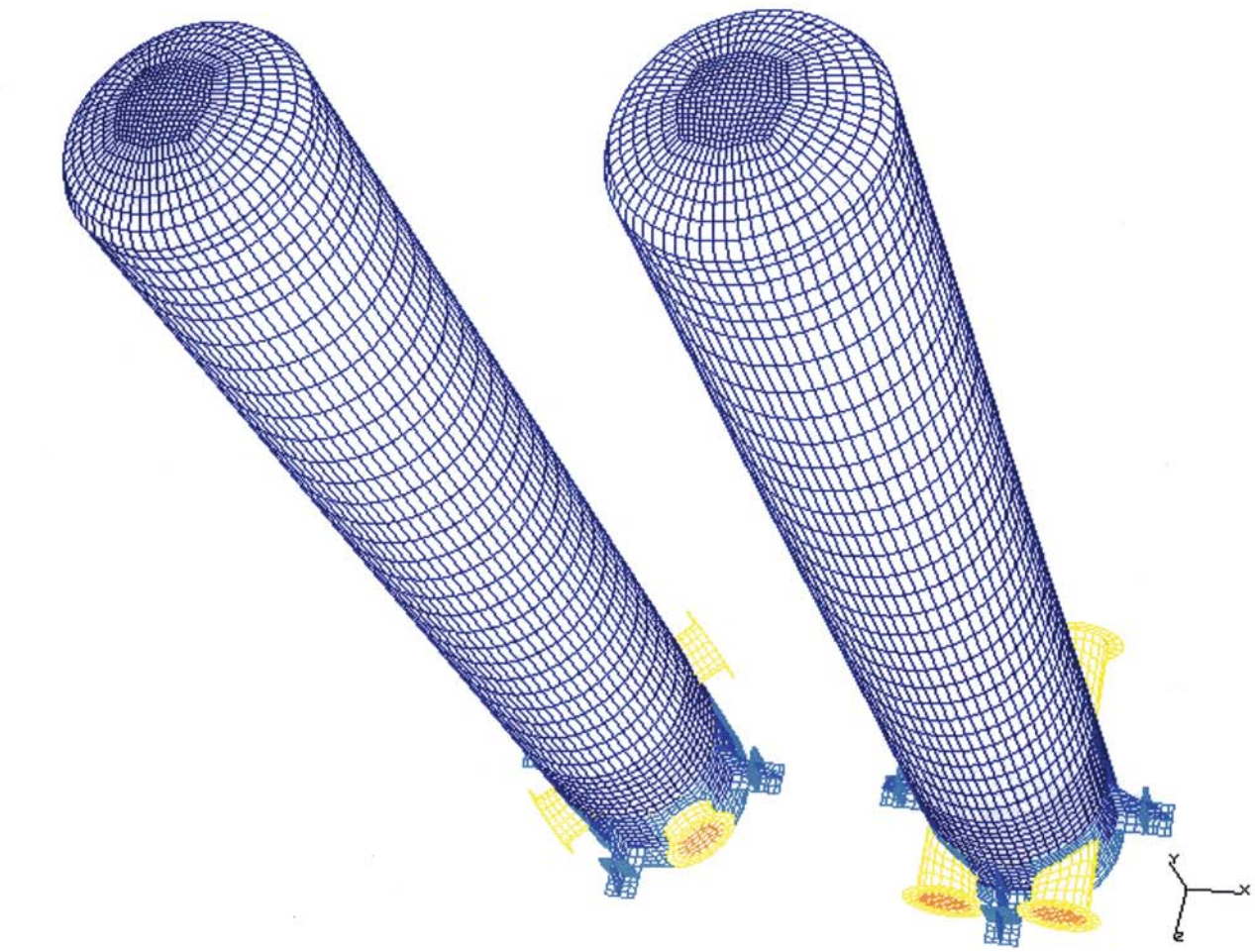

Figure A-5.1-12 – Heat exchanger shell elements.

Figure A-5.1-12 shows the heat exchangers' shell elements for heat exchangers 670 M-2 and 670 M-85 from left to right respectively. The shells in heat exchangers 670 M-3, 670 M-4, and 670 M-5 are the same as those in heat exchangers 670 M-2. Per the ATR Primary Coolant System Seismic Analysis [1], the water filled mass of each heat exchanger is 113,000 lb. To accommodate this, the outer surface shells excluding the nozzles and lugs have their density increased. This results in a total shell mass of 113,500 lb and 114,000 lb respectively.

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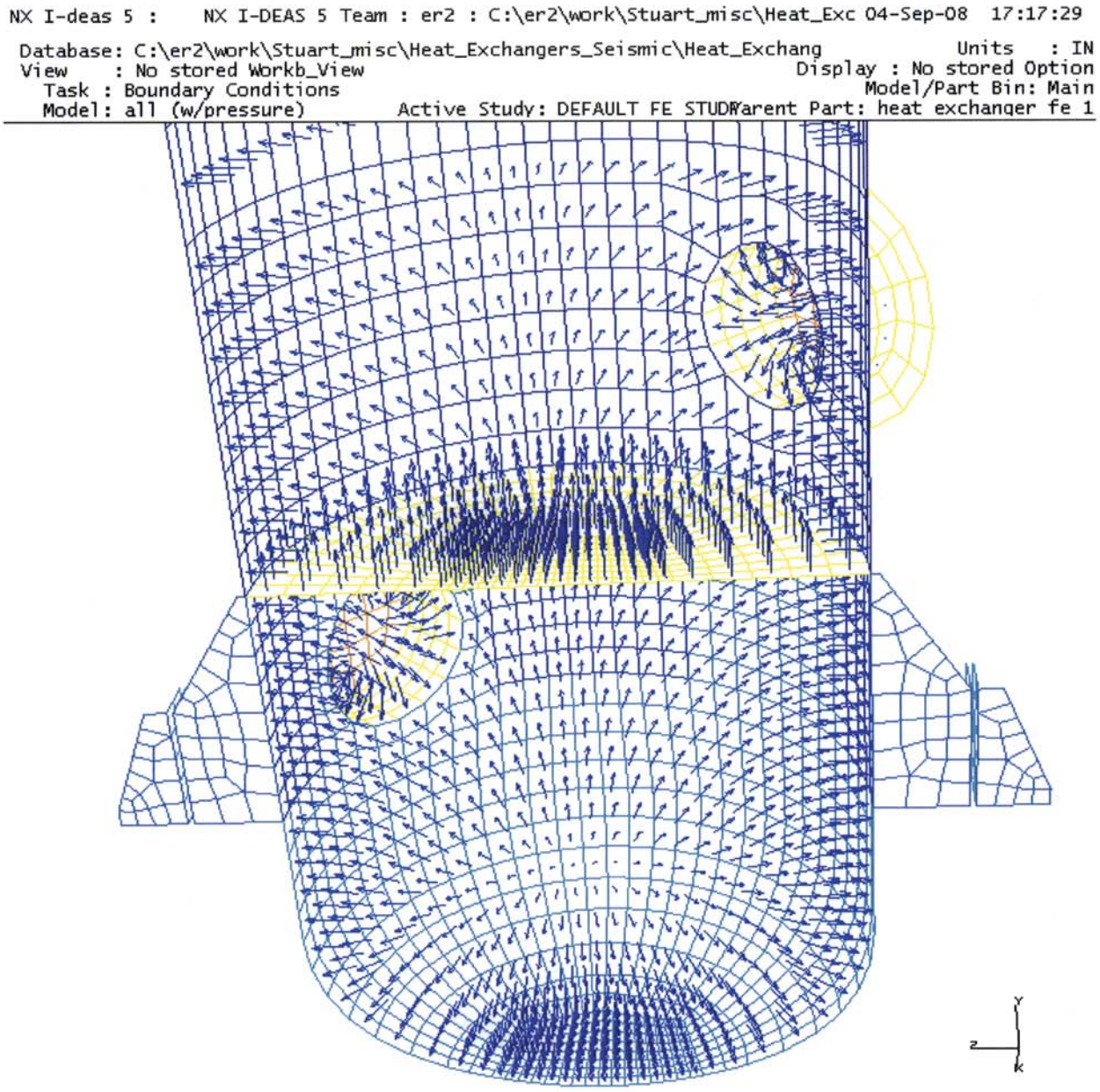

Figure A-5.1-13 – Pressure loading inside the heat exchanger shell elements.

Figure A-5.1-13 shows the heat exchanger pressure loading. The yellow elements passing through the heat exchanger approximate structural members in the heat exchanger. The thin shells elements closing off the nozzles were included to simplify the load balance. This created two separate enclosed regions. The pressure in the lower region matched that of the primary piping (272 psi [13]). The pressure in the upper region matched that of the secondary piping (125 psi [14]). The pressures on the yellow elements passing through the heat exchanger are equal to the difference of the two pressures to balance the pressure loading.

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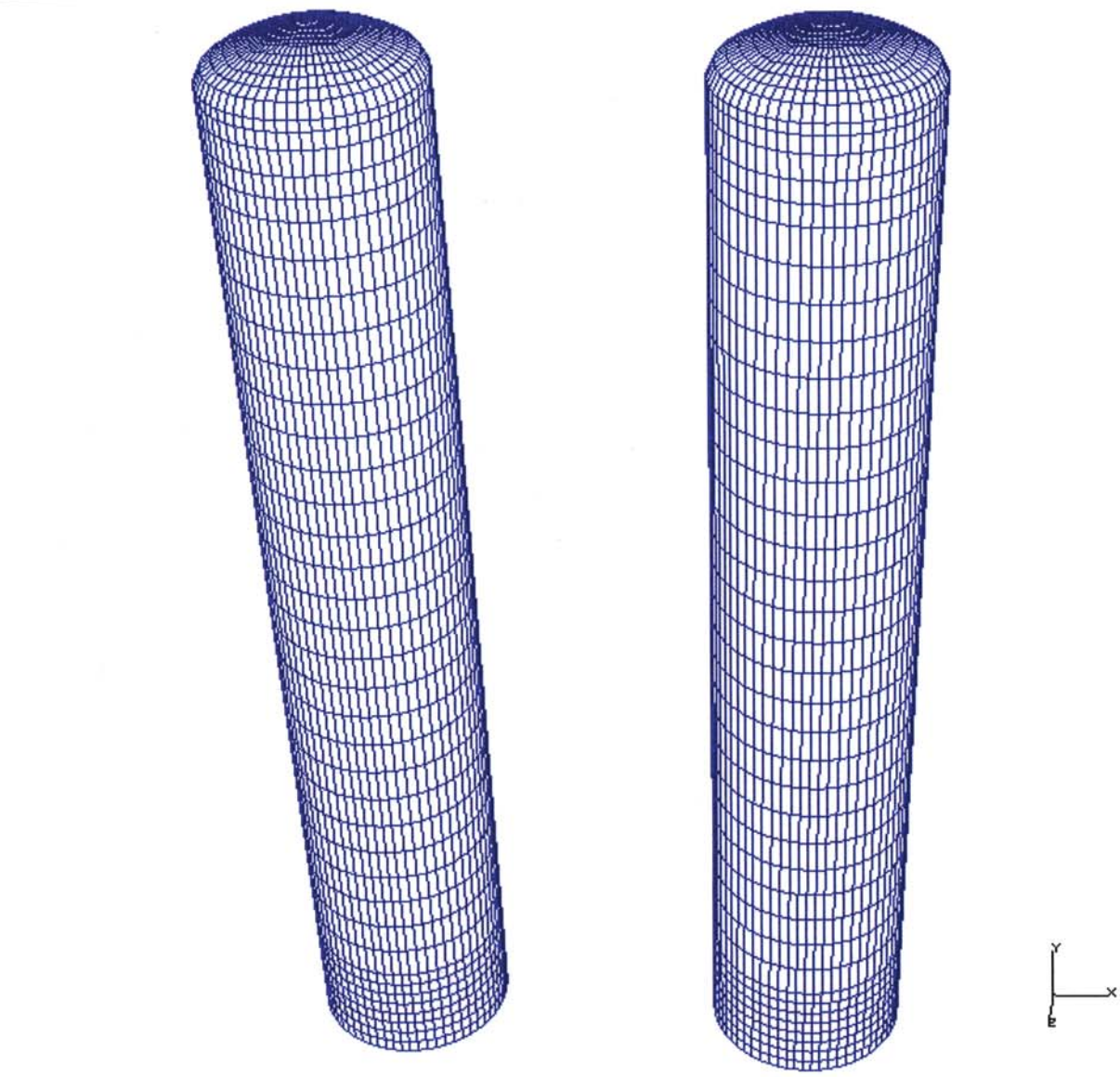

Figure A-5.1-14 – Linear quadrilateral, 5/8" thick elements in the heat exchangers.

Figure A-5.1-14 shows the ASTM A212, 5/8" thick elements in the heat exchangers.

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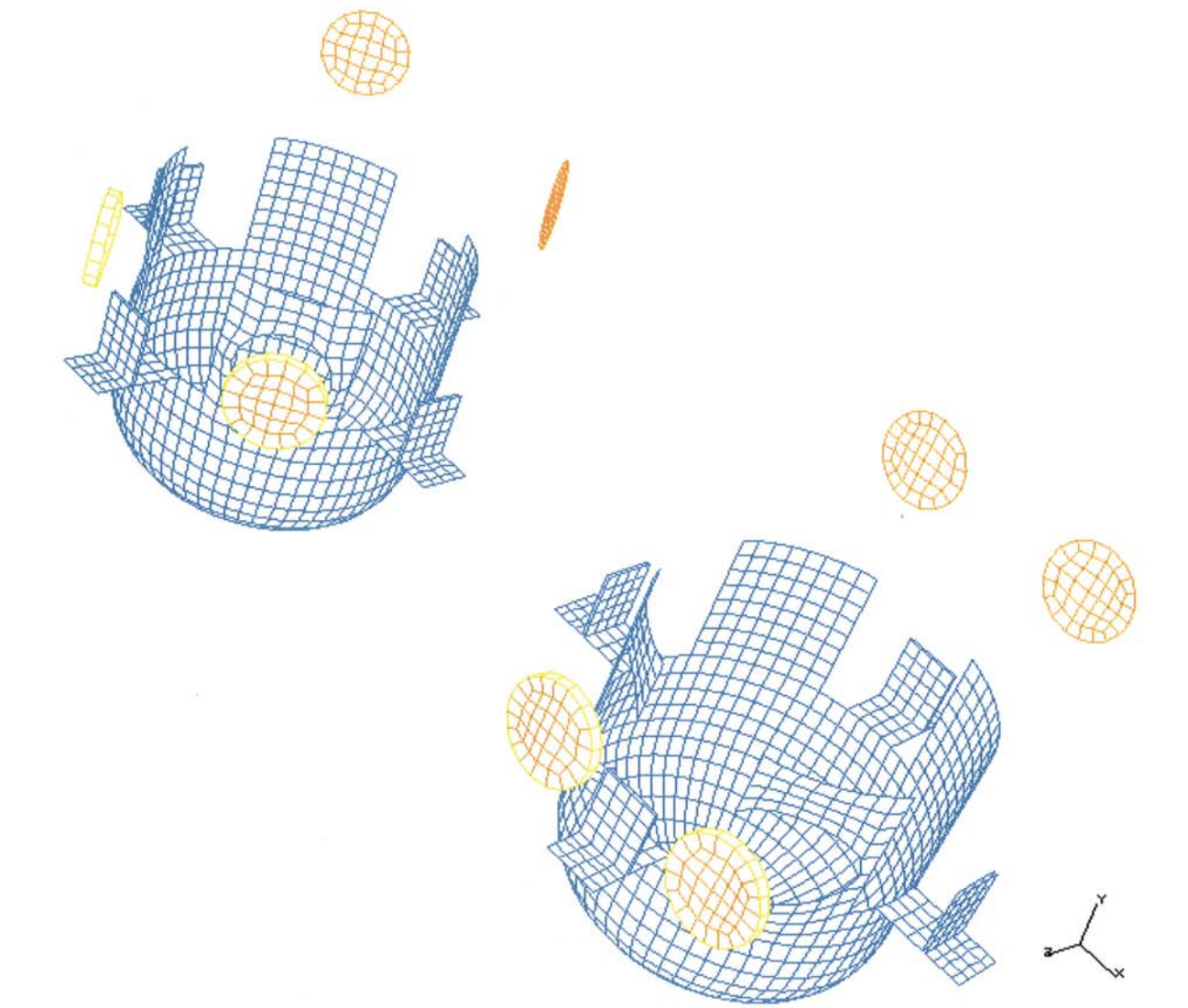

Figure A-5.1-15 – Linear quadrilateral, 1" thick elements in the heat exchangers.

Figure A-5.1-15 shows the ASTM A212, 1" thick elements in the lower part of the heat exchangers, in the lugs, and in a short portion of the primary nozzles. These elements are also used to close off all the nozzles for pressure loading as shown by the orange elements.

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Performer: R. E. Spears **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

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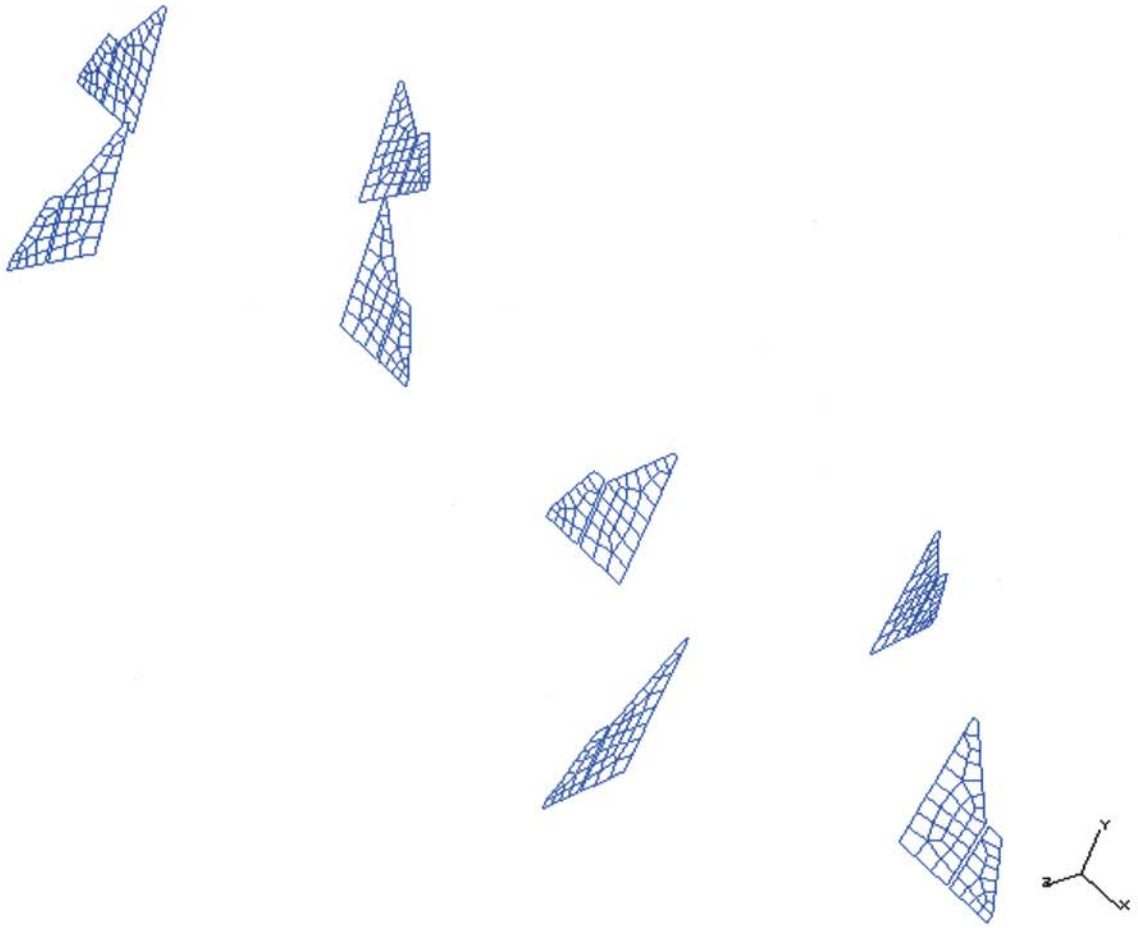

Figure A-5.1-16 – Linear quadrilateral, 3/4" thick elements in the heat exchangers.

Figure A-5.1-16 shows the ASTM A212, 3/3" thick elements in the lugs.

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Title: ATR PCS Heat Exchanger Seismic Analysis – Appendix A

Performer: R. E. Spears **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

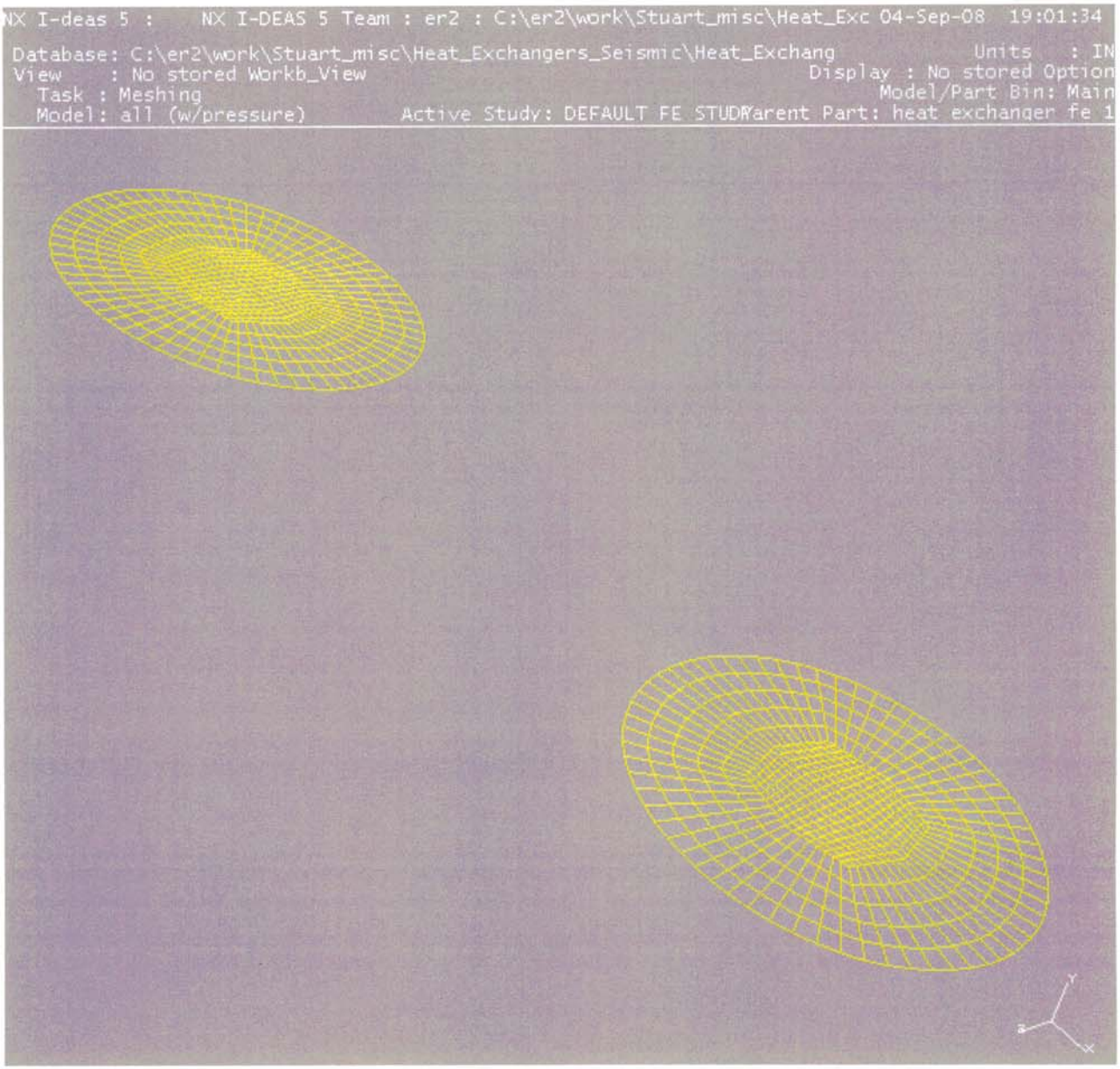

Figure A-5.1-17 – Linear quadrilateral, 7" thick elements in the heat exchangers.

Figure A-5.1-17 shows the ASTM A212, 7" thick elements that divide the primary and secondary pressures in the heat exchangers.

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Title: ATR PCS Heat Exchanger Seismic Analysis – Appendix A

Performer: R. E. Spears **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

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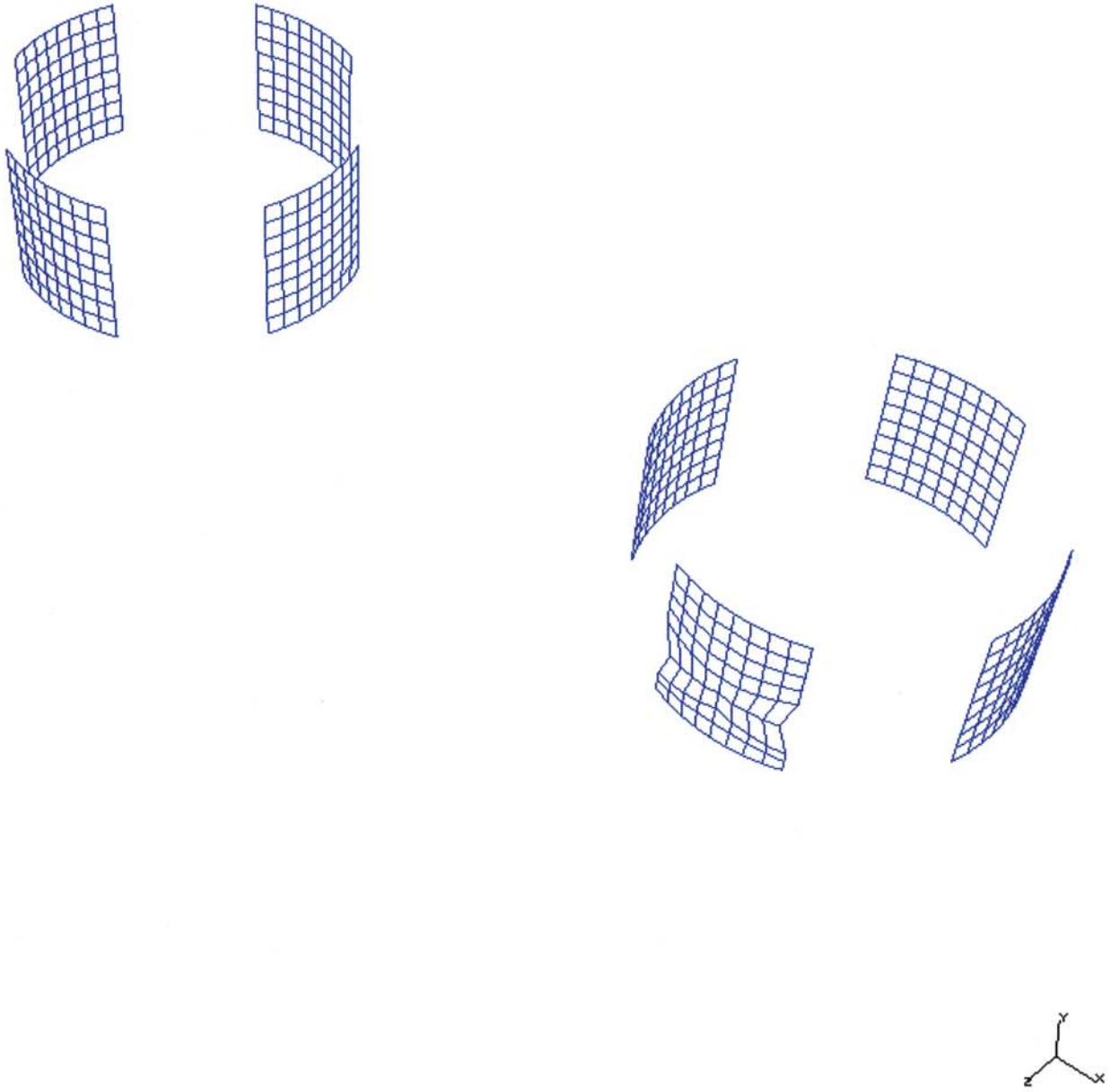

Figure A-5.1-18 – Linear quadrilateral, 1.5" thick elements in the heat exchangers.

Figure A-5.1-18 shows the ASTM A212, 1.5" thick elements in the stiffened region supporting the lugs.

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Performer: R. E. Spears **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

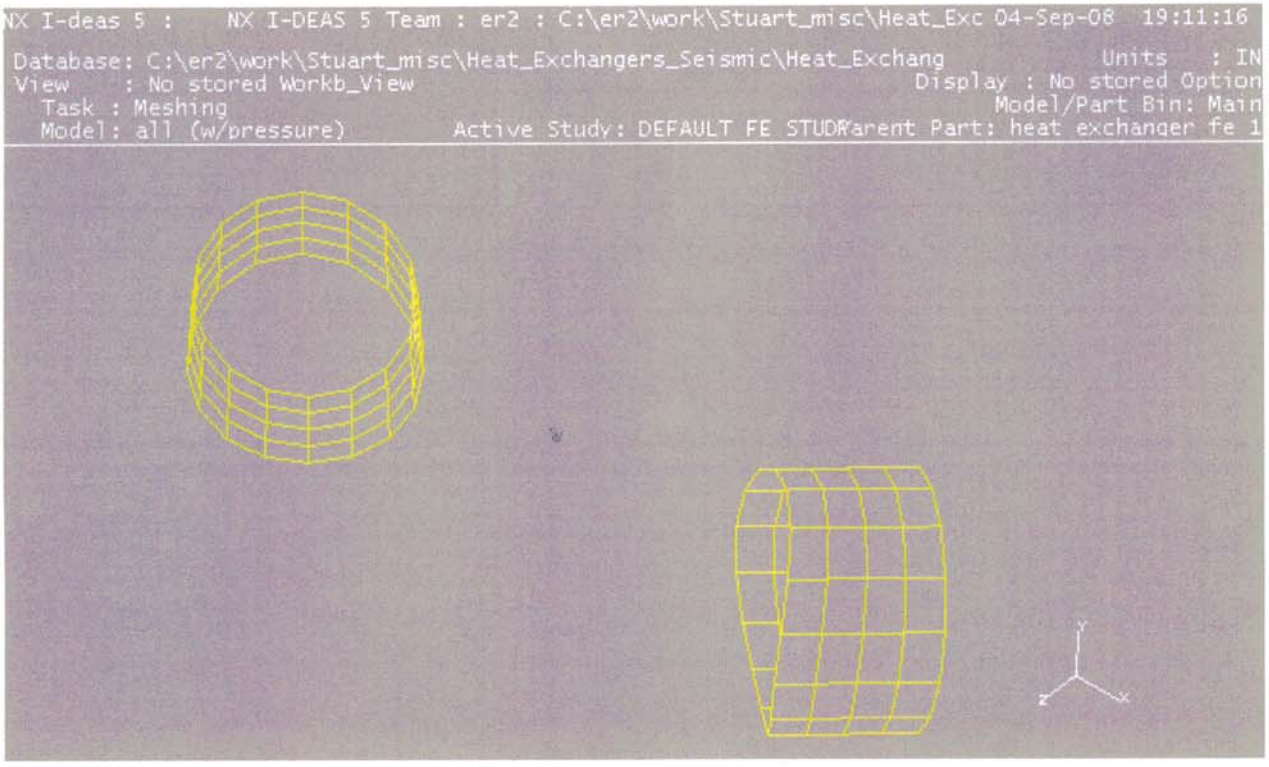

Figure A-5.1-19 – Linear quadrilateral, 3/8" thick elements in the heat exchangers.

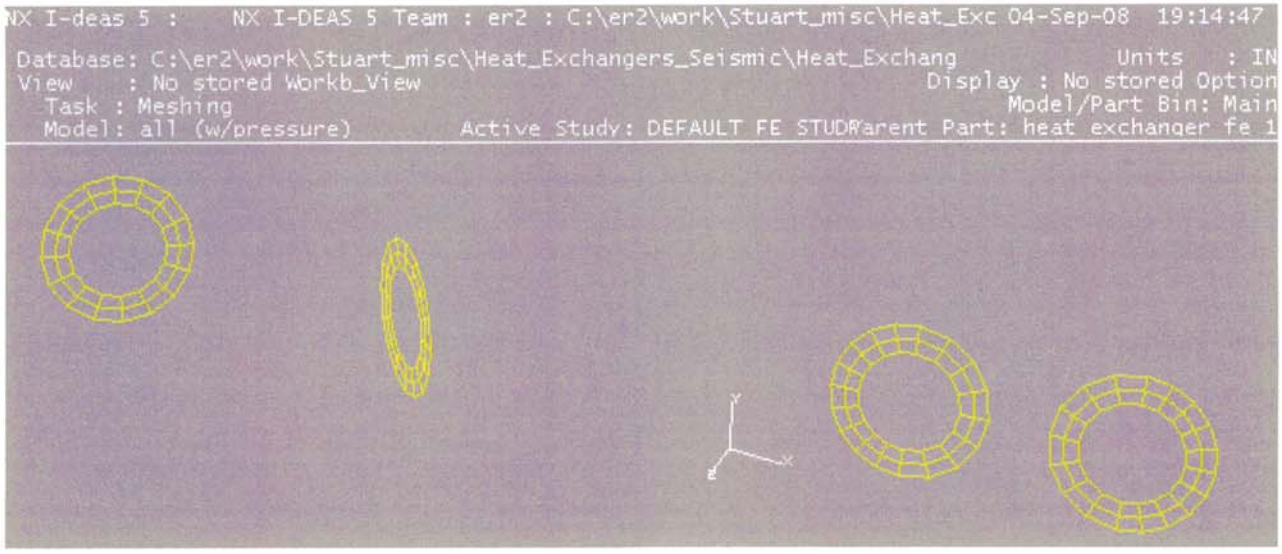

Figure A-5.1-20 – Linear quadrilateral, 11/16" thick elements in the heat exchangers.

Figure A-5.1-19 shows the ASTM A212, 5/8" thick elements in the heat exchanger 670 M-2 secondary nozzles. Figure A-5.1-20 shows the ASTM A212, 11/16" thick elements in the heat exchanger secondary nozzle flanges.

Project:	ATR Life Time Extension Project	**ECAR No.:**	ECAR-398	**Rev.:**	0
Title:	ATR PCS Heat Exchanger Seismic Analysis – Appendix A				
Performer:	R. E. Spears	**Date:** 9/30/08	**Checker:** M. J. Russell	**Date:**	9/30/08

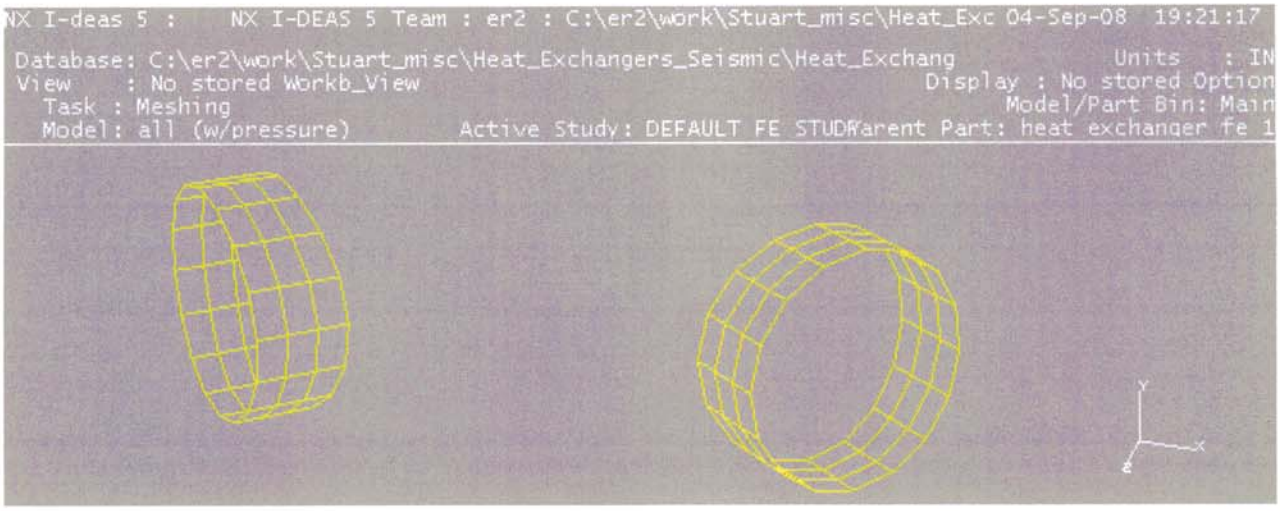

Figure A-5.1-21 – Linear quadrilateral, 2" thick elements in the heat exchangers.

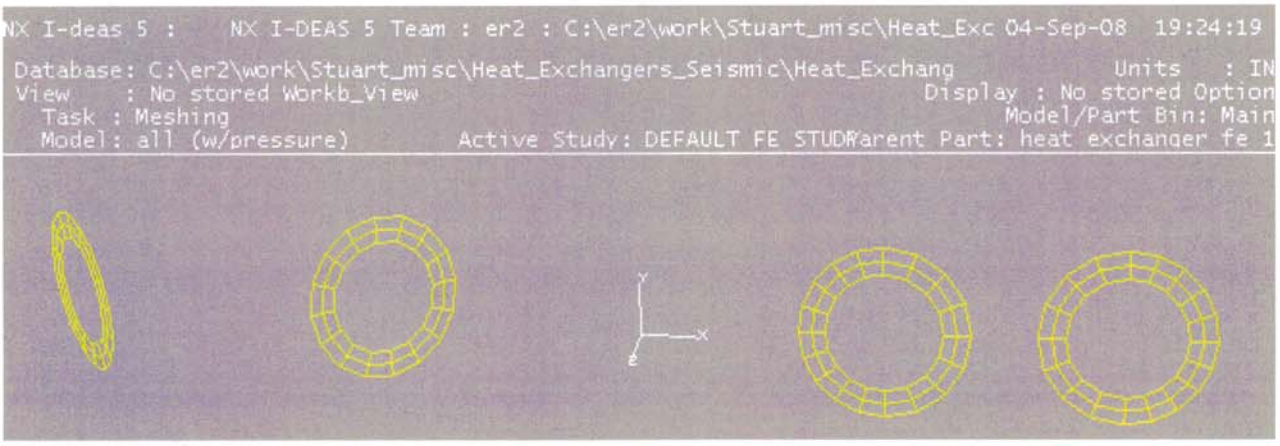

Figure A-5.1-22 – Linear quadrilateral, 2.5" thick elements in the heat exchangers.

Figure A-5.1-21 shows the ASTM A212, 2" thick elements in the heat exchanger 670 M-2 primary nozzles. Figure A-5.1-22 shows the ASTM A212, 2.5" thick elements in the heat exchanger primary nozzle flanges.

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Title: ATR PCS Heat Exchanger Seismic Analysis – Appendix A

Performer: R. E. Spears **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

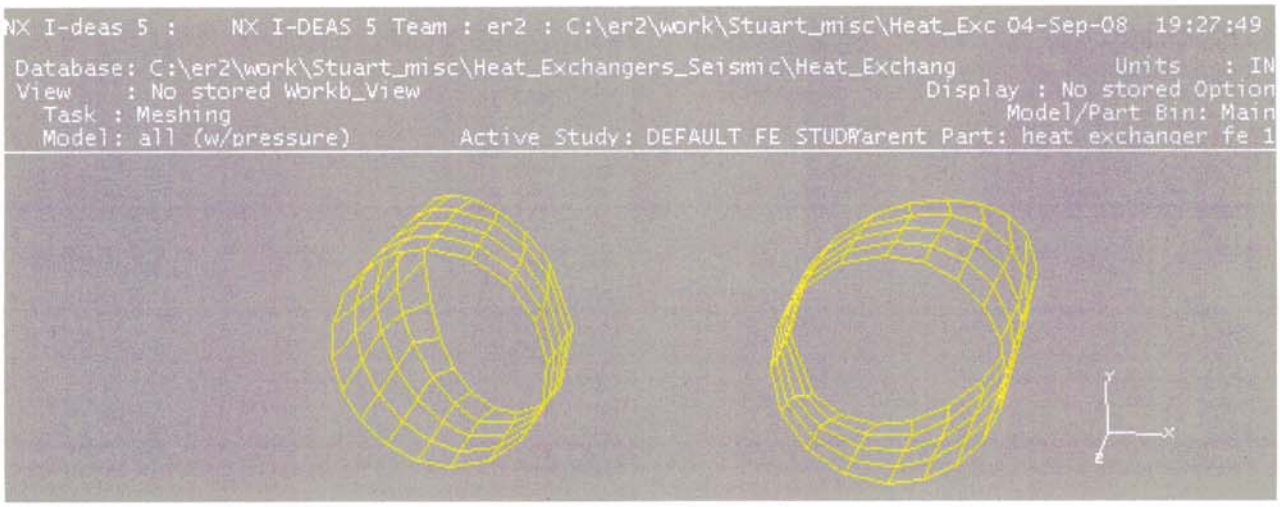

Figure A-5.1-23 – Linear quadrilateral, 2.375" thick elements in the heat exchangers.

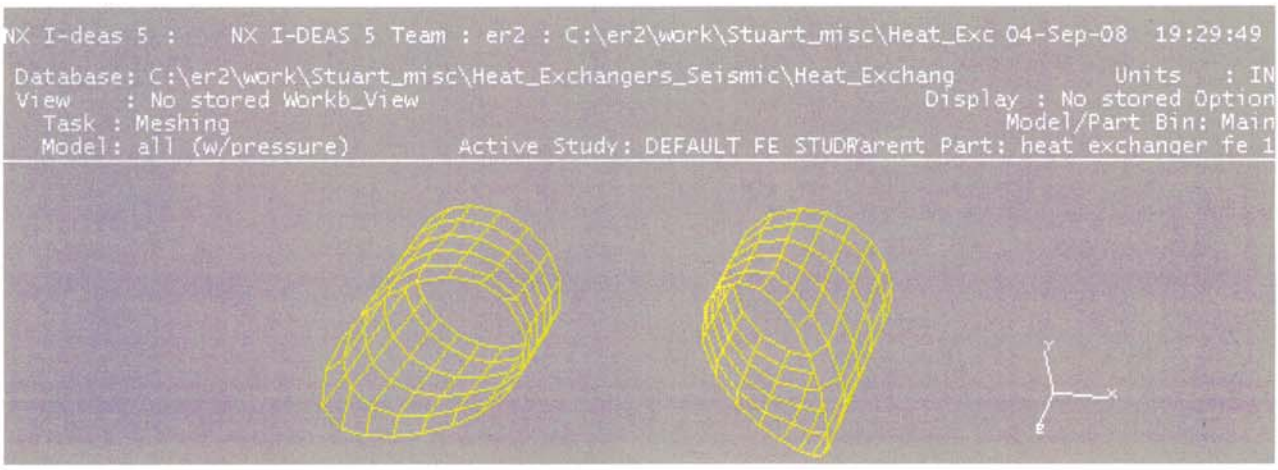

Figure A-5.1-24 – Linear quadrilateral, 0.5" thick elements in the heat exchangers.

Figure A-5.1-23 shows the ASTM A212, 2.375" thick elements in the heat exchanger 670 M-85 primary nozzles. Figure A-5.1-24 shows the ASTM A212, 0.5" thick elements in the heat exchanger 670 M-85 secondary nozzles.

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Title: ATR PCS Heat Exchanger Seismic Analysis – Appendix A

Performer: R. E. Spears **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

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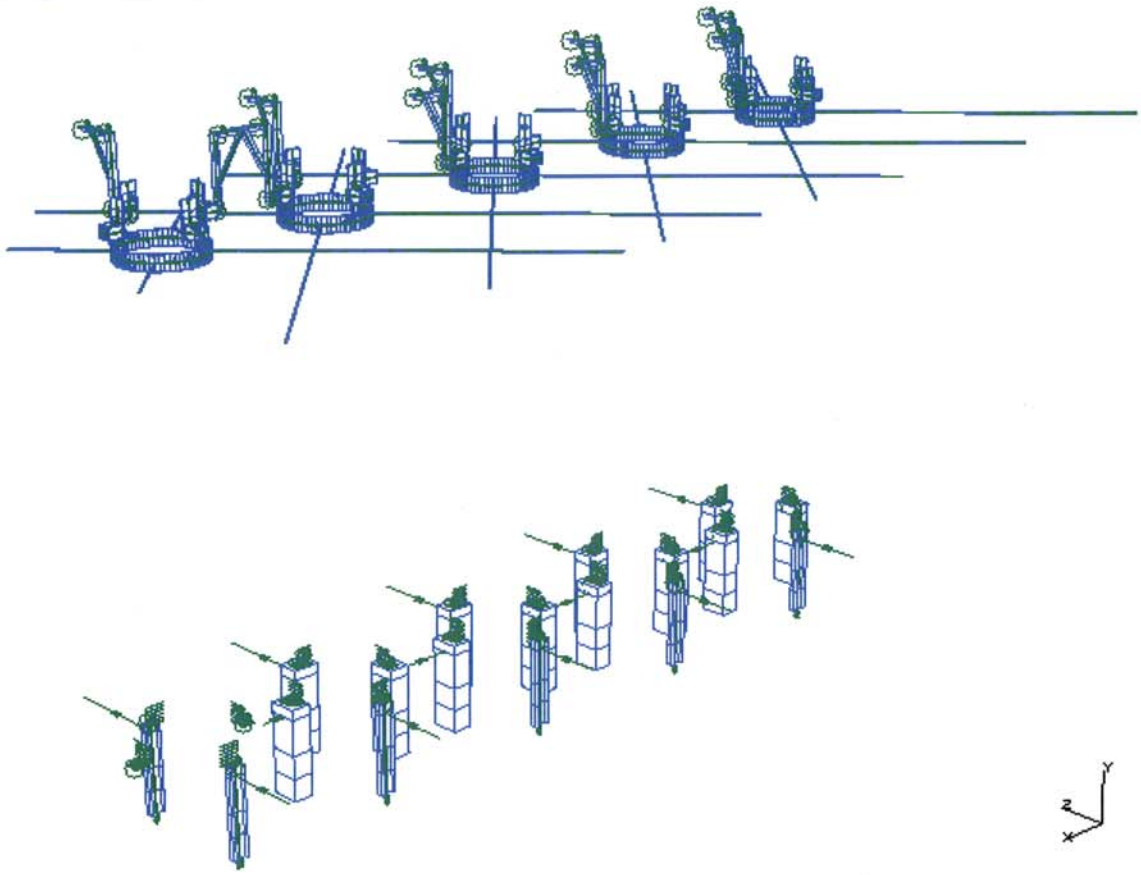

Figure A-5.1-25 – Heat exchanger support structure.

Figure A-5.1-25 shows the support structure currently attached to the heat exchangers. This was all included in the model output for scoping calculations. Modifications to the input file were then made to address three additional scenarios. First, the elements for the Oak blocks and bolts attaching the top supports and the seismic support rods were deleted so that the heat exchangers were only supported at the base. Second only the seismic supports were deleted. Third, only the elements for the Oak blocks and bolts attaching the top supports were deleted. All four models were studied and based on project management guidance; the model pursued was the one with the Oak blocks and bolts deleted. Consequently, the top supports are in the model but they do not affect the results because they impart no load to the heat exchangers.

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Performer: R. E. Spears **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

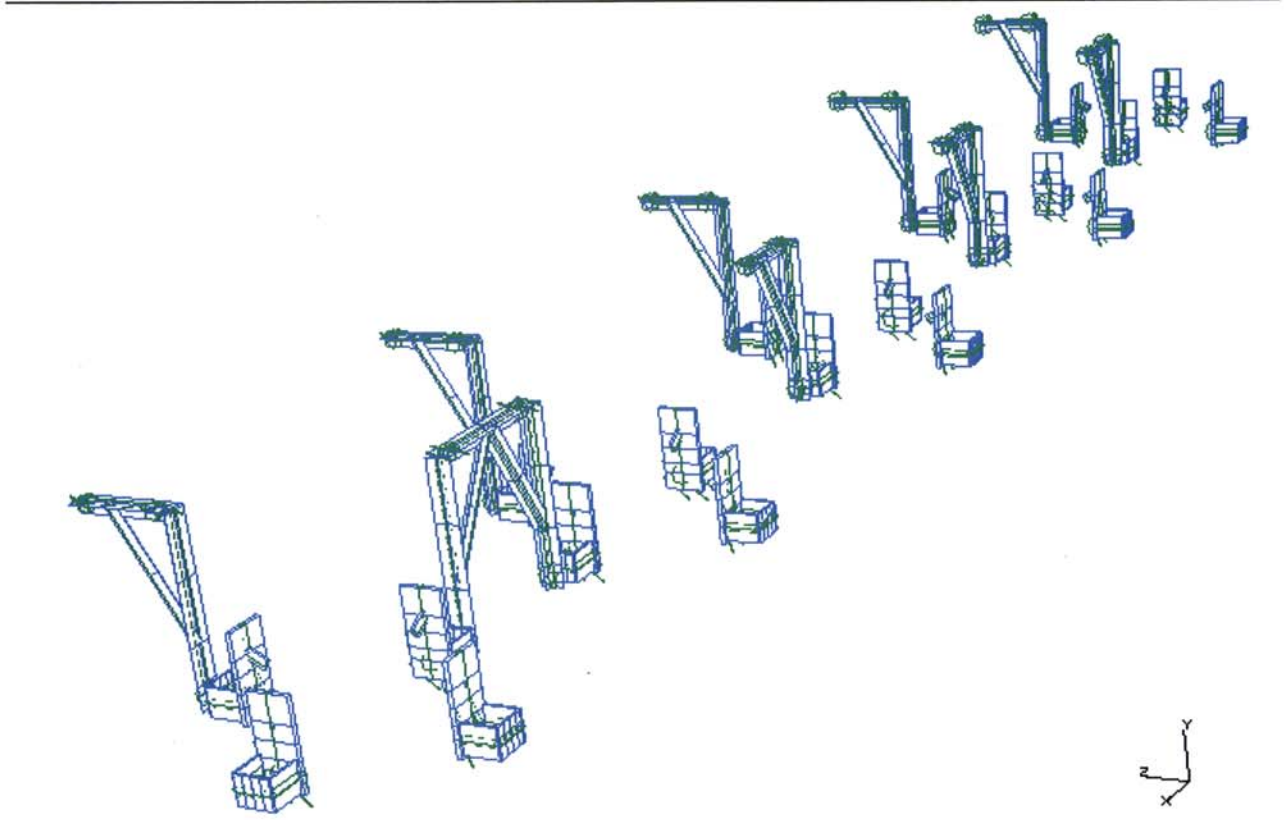

Figure A-5.1-26 – Heat exchanger top supports.

Figure A-5.1-26 shows the heat exchanger top supports as used for the dynamic analysis. The tee and angle framework is based on drawing 121123 [55]. The plate structure (modeled with linear beam elements) that is attached to the heat exchanger is based on the heat exchanger drawings [26-51]. For the dynamic analysis, there is no attachment between the vertically oriented tees and the plates as the bolts and Oak block elements in that area are removed. Consequently, the elements shown in Figure A-5.1-26 do not play a significant roll in the dynamic model.

The elements in Figure A-5.1-26 include contact springs (with the properties described in Section A-4.3.3), rigid elements (to address offsets), and linear beams. The linear beams include ASTM A212 4x15.5 tees, 4"x4"x1/4" angles, 9"x3/4" rectangular cross section, 13"x1.5" rectangular cross section, and 3.5"x1" rectangular cross section. The linear beams also include ASTM A7 7/8" bolts (with a cross sectional area as calculated in Section A-4.1). Further detailed plots are not provided due to the insignificance of these elements in the dynamic mode runs.

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Performer: R. E. Spears **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

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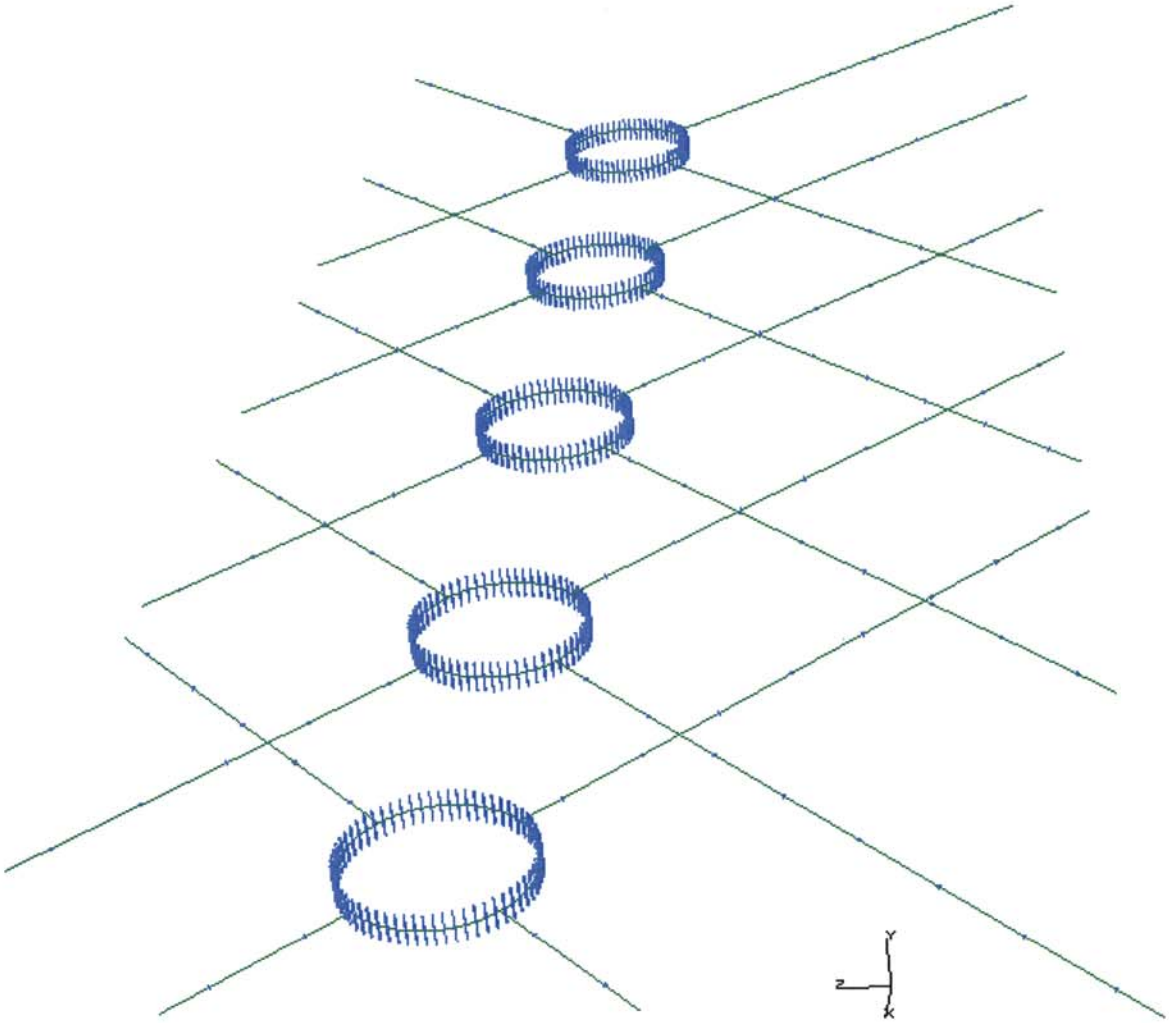

Figure A-5.1-27 – Heat exchanger seismic rod supports.

Figure A-5.1-27 shows the linear beam elements in the seismic rod supports. Each rod is only connected at its ends. Locations where rods cross do not have any interaction. The seismic support rods are ASTM A36 with a 1 3/8" diameter circular section. The bands that go around and share nodes with the heat exchanger are ASTM A36 with a 12"x3/4" rectangular cross section

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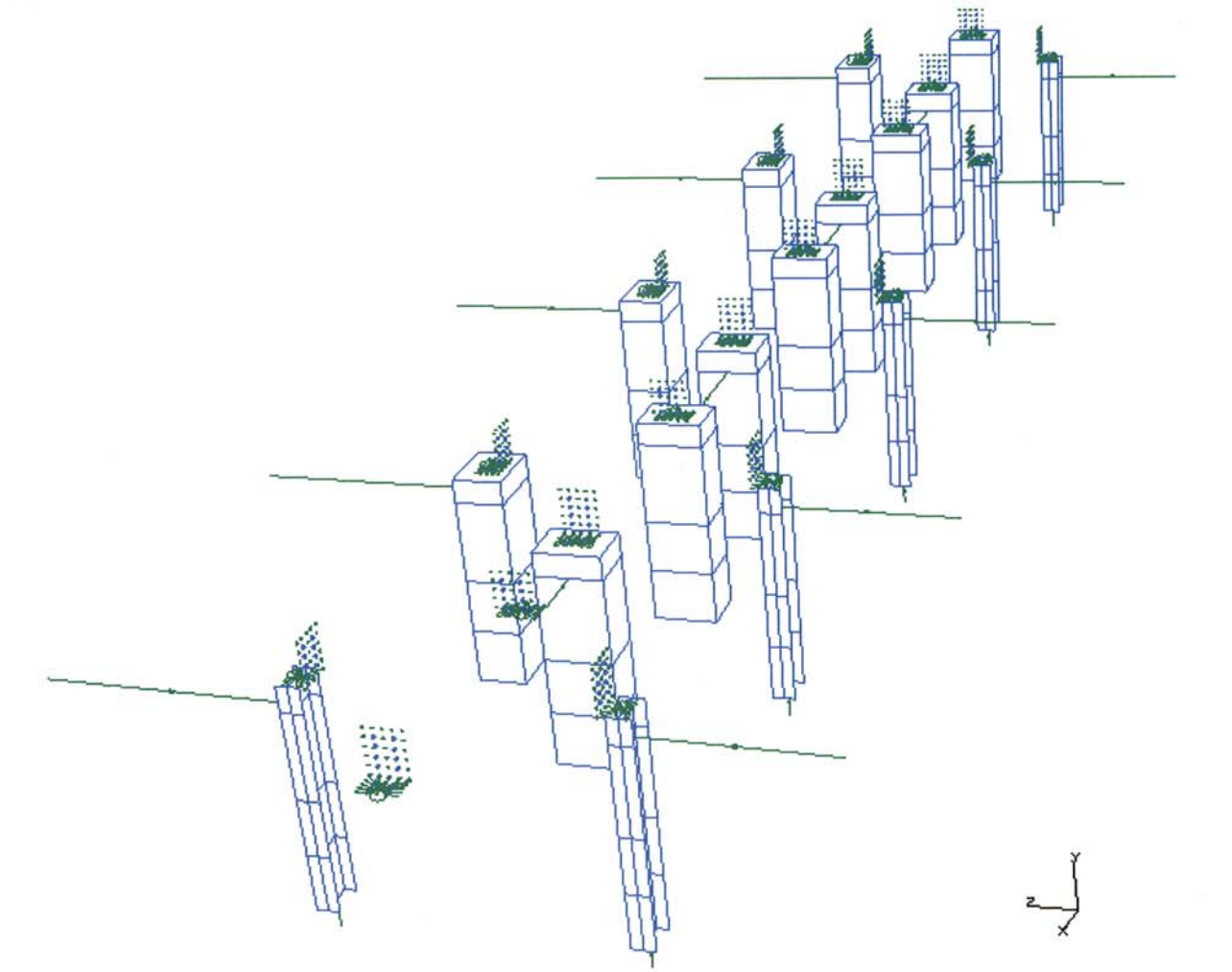

Figure A-5.1-28 – Heat exchanger base supports and non-shell elements in the heat exchanger lugs.

The heat exchanger base supports are the same for heat exchangers 670 M-2, 670 M-3, 670 M-4, and 670 M-5. Heat exchanger 670 M-85 is inset into walls on the east and west sides and has the same I-beam column on the north and south as the other heat exchangers have on their north side. Where heat exchanger 670 M-85 meets the walls, it is fixed. Likewise, the bases of the concrete columns are fixed. The steel column bases are fixed in horizontal translation and a vertical nonlinear spring (as defined in Section A-4.3.2) is put under the steel column with its base fixed. The spring offers compressive stiffness but not tensile. The expectation for the wall attachment of heat exchanger 670 M-85 is that it is similar yet more substantial than the columns. Consequently, the concrete columns are the focus for the base attachment to concrete.

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Performer: R. E. Spears **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

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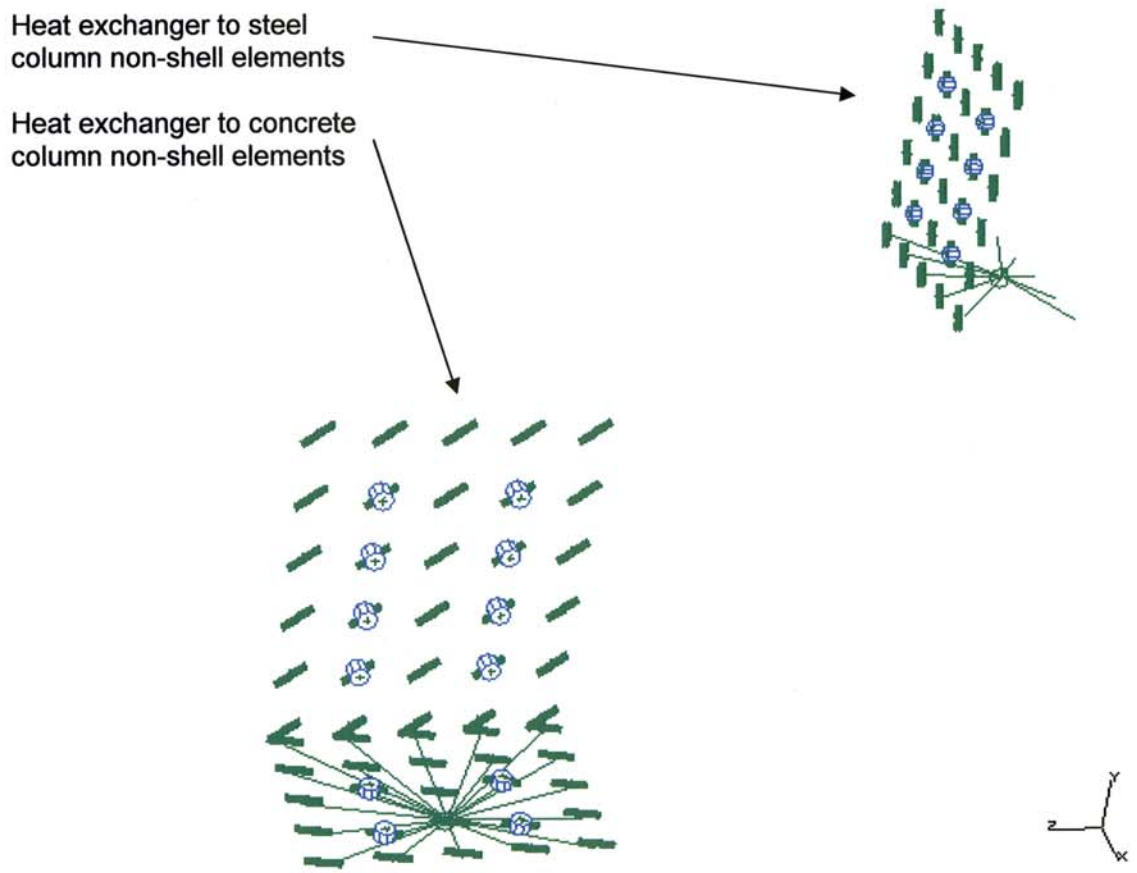

Figure A-5.1-29 – Typical non-shell elements in the heat exchanger lugs.

Figure A-5.1-29 shows the rigid elements, contact springs, and bolt beam elements in the lugs and in the lug to column attachment. For the heat exchanger to steel column non-shell elements, the rigid element attaches the top of the column to the inner and outer edges (locations where welding occurred) of the bottom of the heat exchanger lug (shell elements). The spring and beam elements in the vertical plane are in the 3/4" gap modeled between the pieces of the heat exchanger lug. (Beams and springs occurring at the same location share nodes.) The spring elements are contact springs (with the properties described in Section A-4.3.3) and they pass between all of the corresponding nodes in the lug shell elements. The 8 linear beam elements are ASTM A7 1" bolts (with a cross sectional area as calculated in Section A-4.1). For the heat exchanger to concrete column non-shell elements, the rigid element attaches the top of the concrete column (or wall location) to the bottom of the vertical contact springs (with the properties described in Section A-4.3.3) and bolt beam elements. The 4 linear beam elements are ASTM A7 1" bolts (with a cross sectional area as calculated in Section A-4.1). The spring and beam elements in this horizontal plane

are in the 1/2" gap modeled between the top of the column and the bottom of the heat exchanger lug. The spring and beam elements in the vertical plane are the same as those described for the heat exchanger to steel column.

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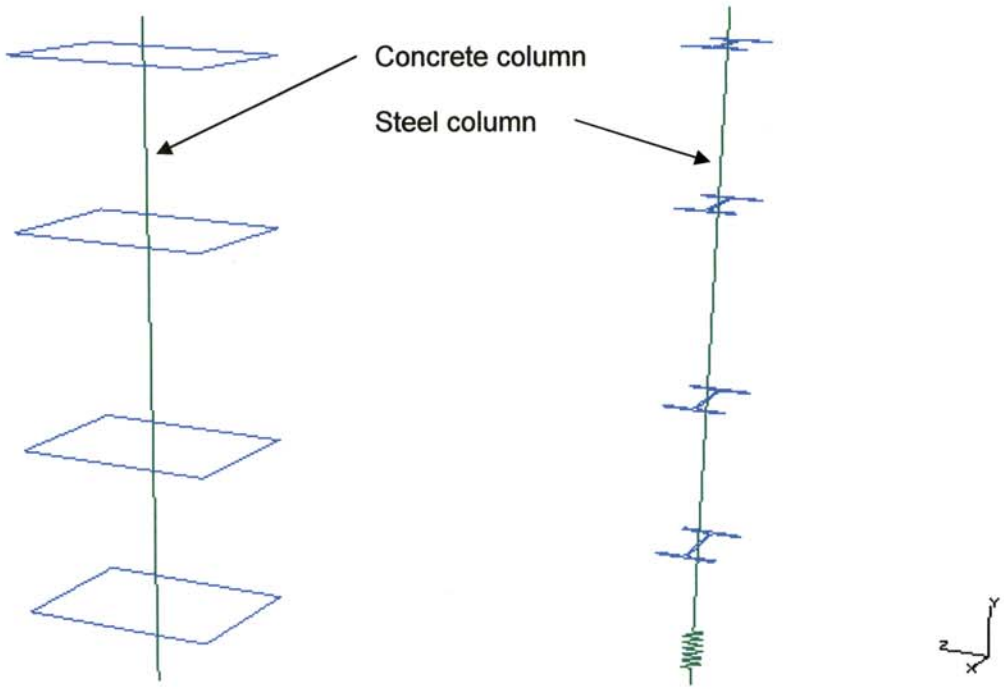

Figure A-5.1-30 – Typical concrete and steel columns.

Figure A-5.1-30 shows the concrete and steel elements. The concrete column elements are linear beam elements with cracked concrete material properties and an 18"x24" rectangular cross section. The steel column elements are linear beam elements with ASTM A36 material properties and 12"x45 I-beam section properties. The vertical spring at the base of the steel column provides compressive force but not tensile force (with the properties described in Section A-4.3.2).

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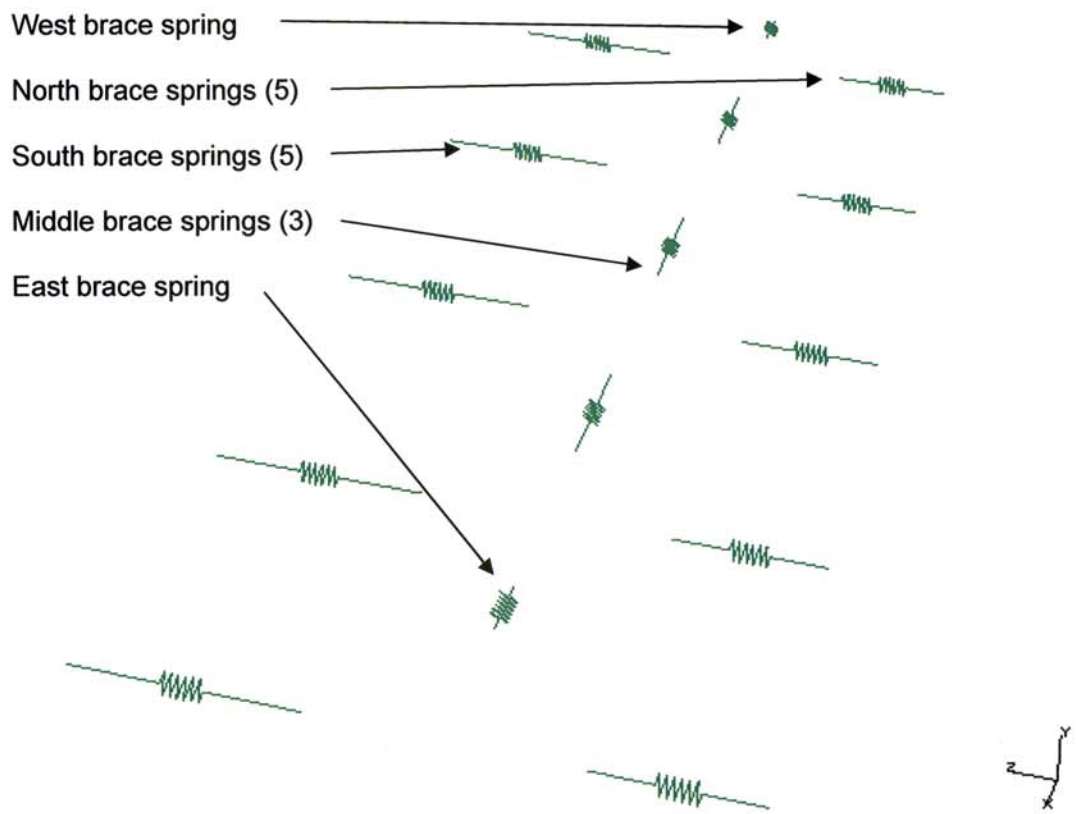

Figure A-5.1-31 – Typical concrete and steel columns.

Figure A-5.1-31 shows the brace springs (with the properties described in Section A-4.3.1). The brace springs carry compression and not tension.

A-5.2 Coarse Mesh

The coarse mesh (shown in Figures A-5.2-1 – A-5.2-7) is modeled without shell elements. The shell elements are replaced with beams and rigid elements. This is done for efficiency so that the 32 model runs can be performed in a reasonable amount of CPU time. Much of the model is the same as the fine mesh. Consequently, only the changed portions will be discussed in detail.

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Performer: R. E. Spears **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

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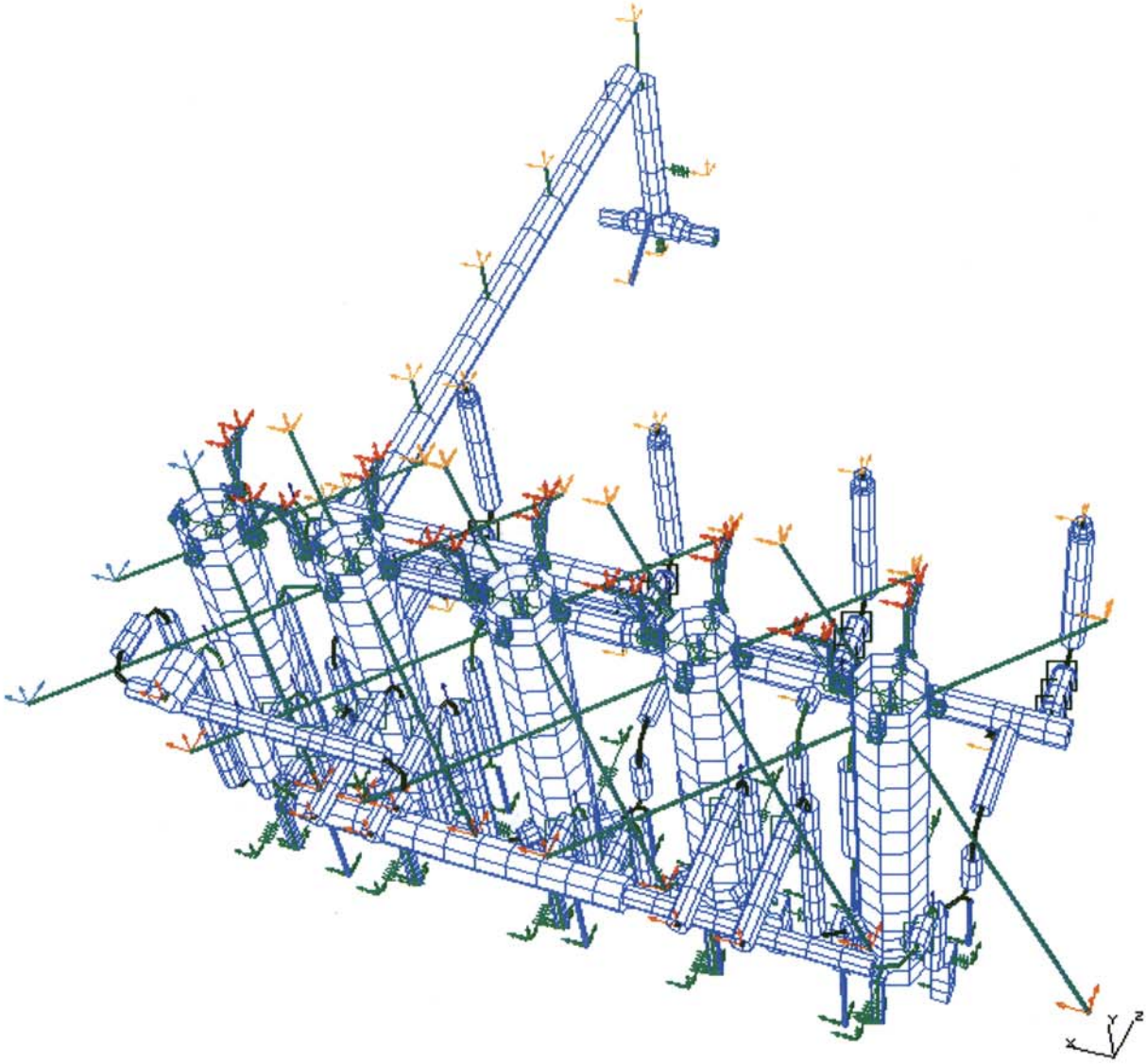

Figure A-5.2-1 – Full coarse meshed model viewed from the north-west.

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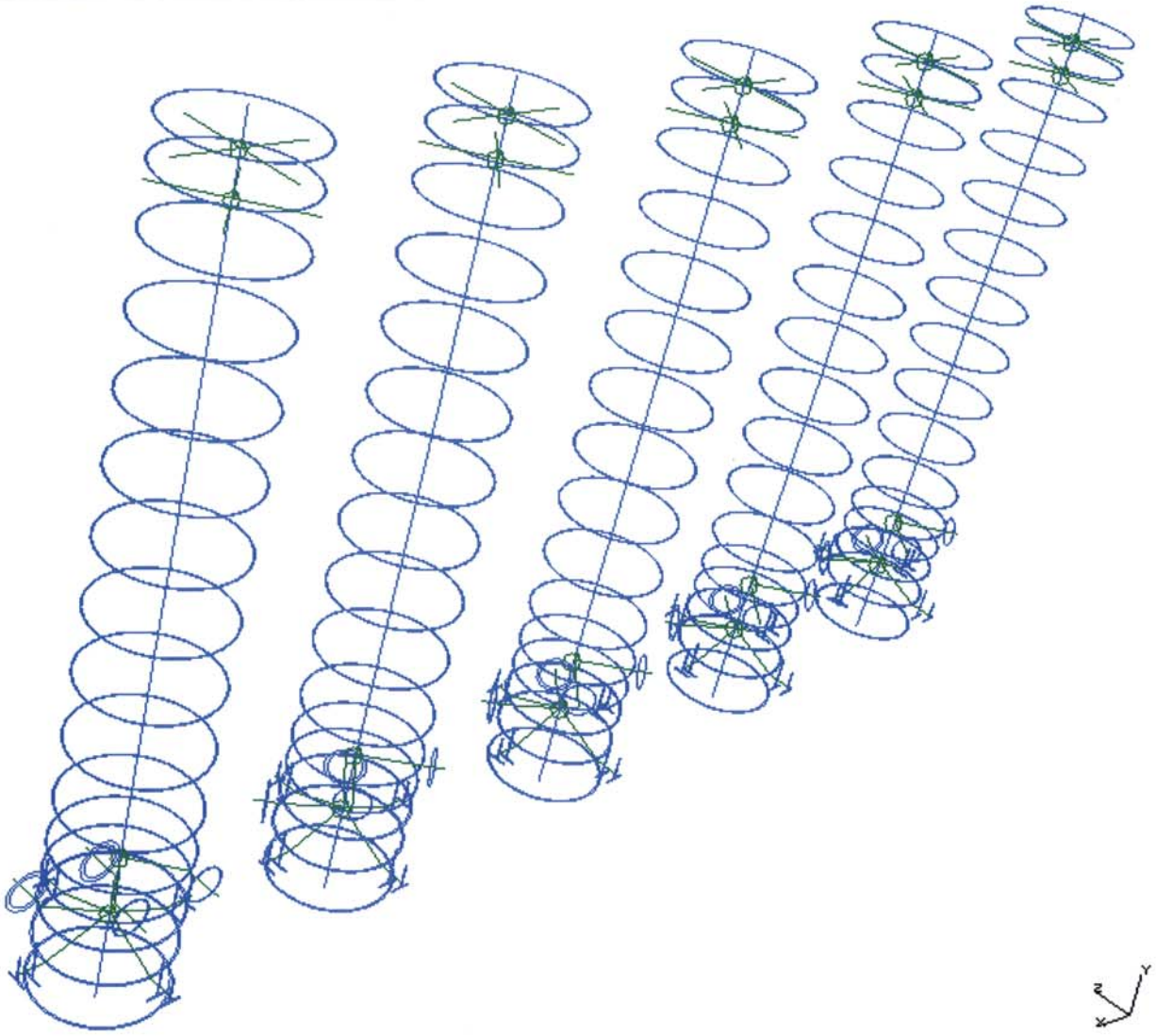

Figure A-5.2-2 – Modified portion of the coarse meshed model.

Figure A-5.3-3 shows the heat exchangers 670 M-85, 670 M-2, 670 M-3, 670 M-4, and 670 M-5 from near left to far right respectively. The heat exchanger meshes have their densities adjusted such that heat exchangers 670 M-85 weights 116,000 lbs and the others weight 115,000 lbs (with the difference due to the thicker walled and relatively longer elements for the nozzles on heat exchangers 670 M-85.

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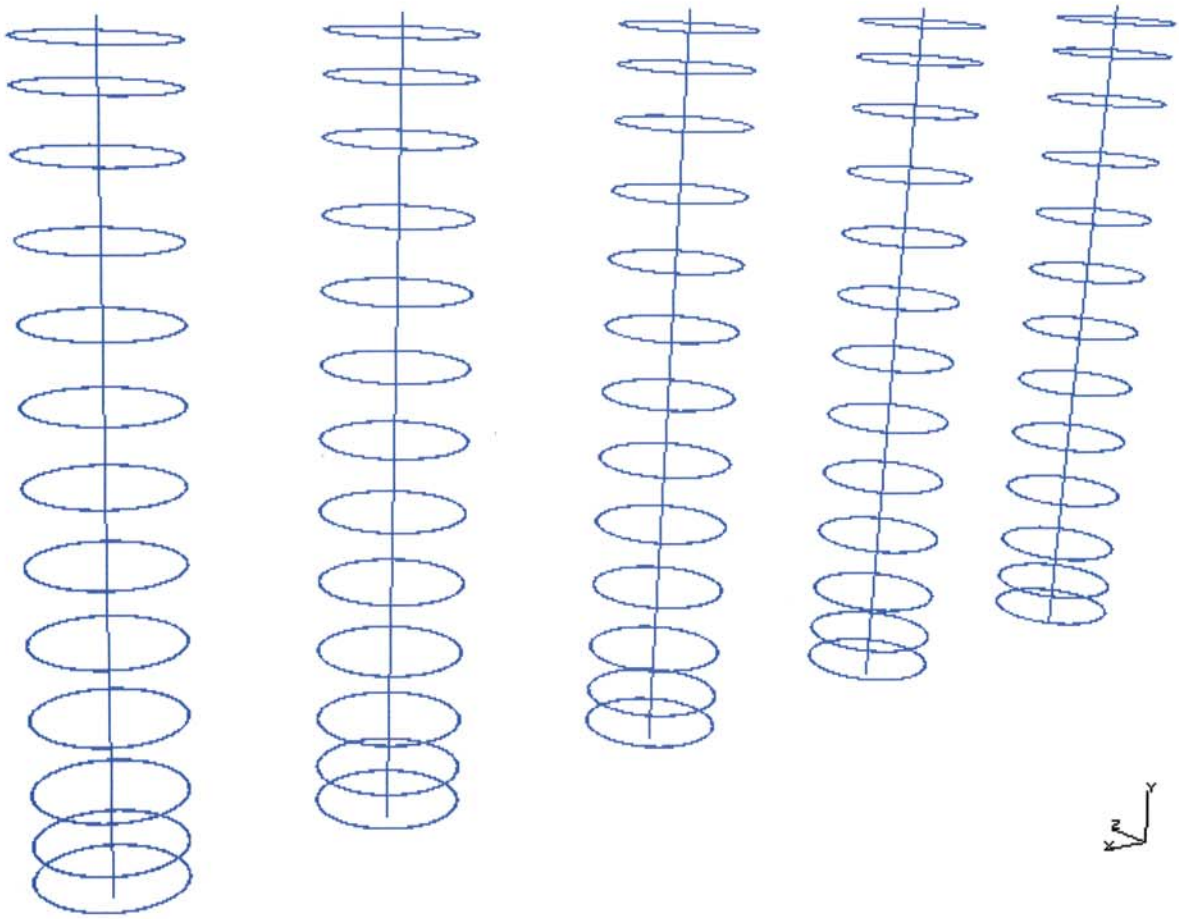

Figure A-5.2-3 – Linear beam elements representing the bulk of the heat exchangers.

Figure A-5.2-3 shows the ASTM A212 linear beam elements representing the shell of the heat exchangers. These beams have a cross section with a 69.25" outside diameter and a 68" inside diameter

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Performer: R. E. Spears **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

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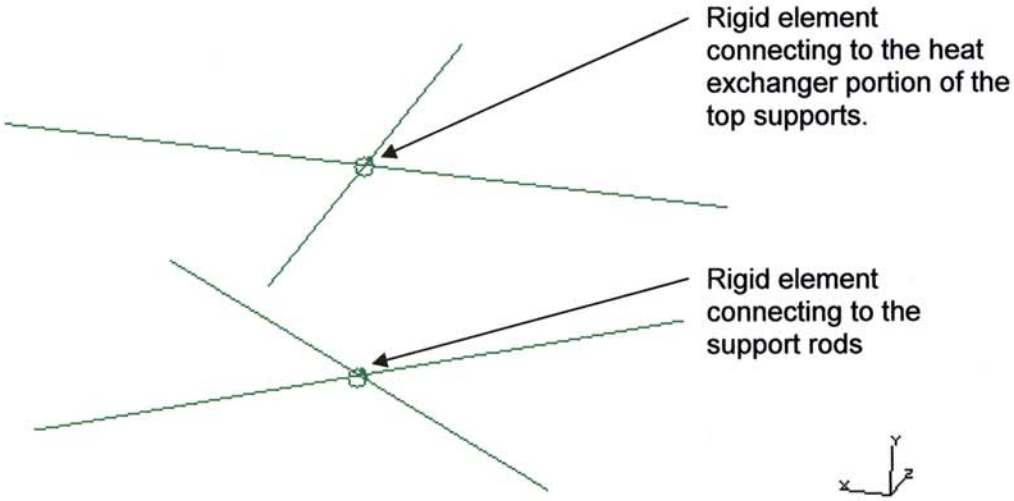

Figure A-5.2-4 – Typical top of the heat exchangers rigid elements.

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Performer: R. E. Spears **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

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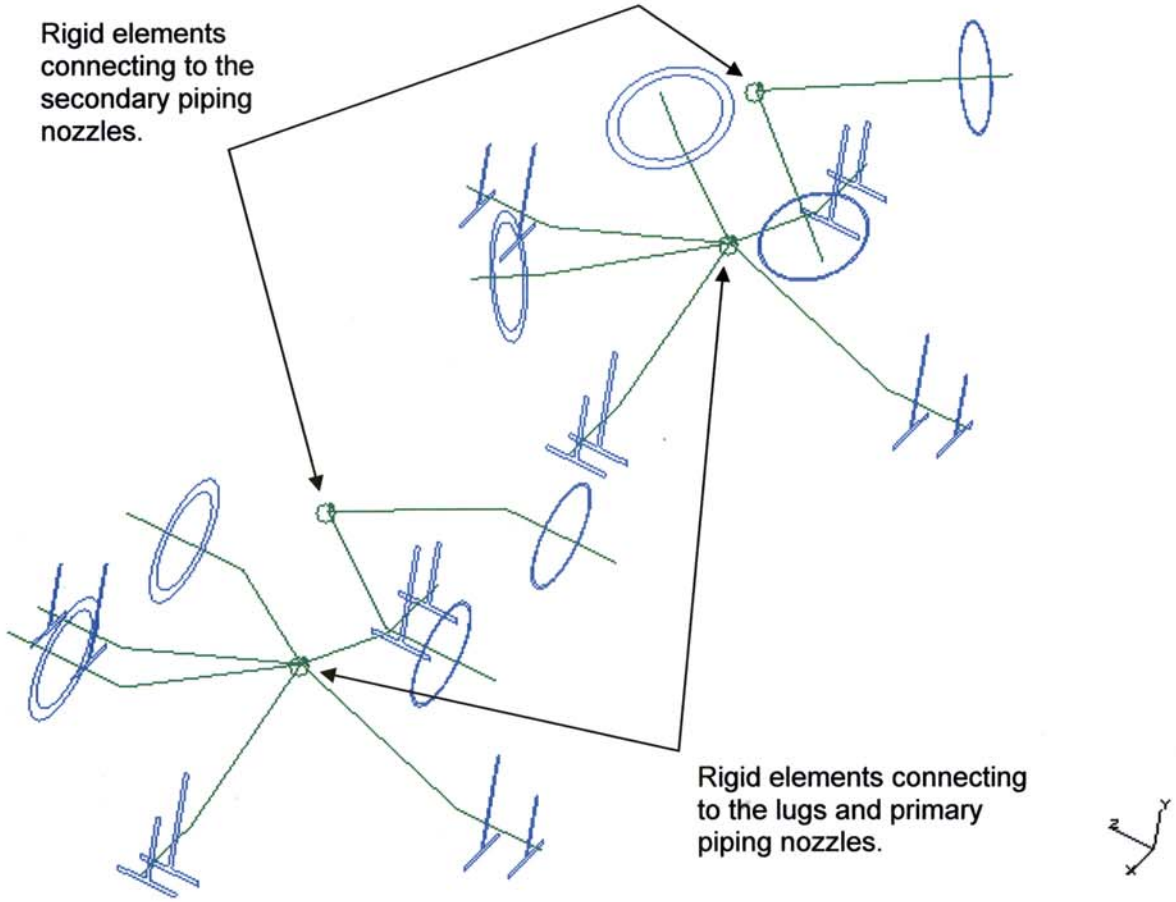

Figure A-5.2-5 – Typical lugs and nozzles.

Figure A-5.2-5 shows the typical lug and nozzle attachment for the heat exchangers. The heat exchangers shown are heat exchangers 670 M-85 and 670 M-2 from left to right respectively. The remaining heat exchangers are modeled like heat exchangers 670 M-2. The rigid element attachment occurs at a vertical level near that of the nozzles.

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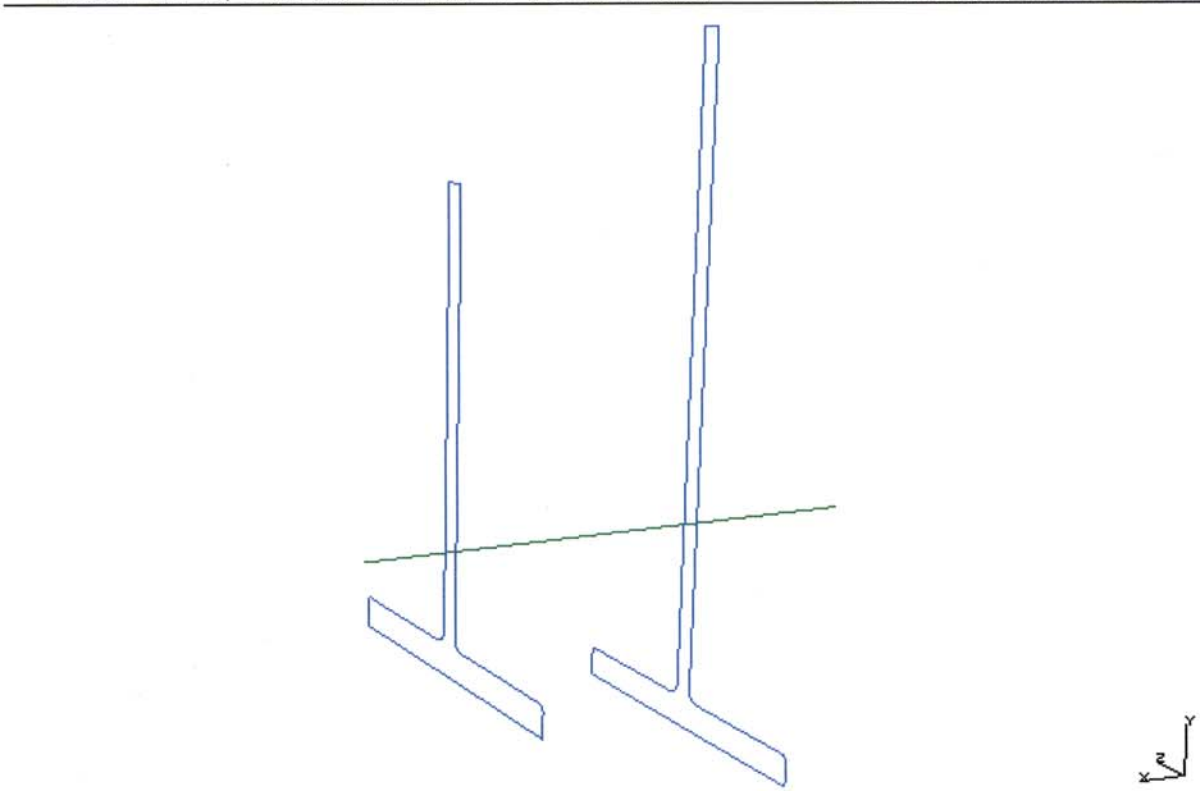

Figure A-5.2-6 – Linear beam elements representing each heat exchanger lug.

Figure A-5.2-6 shows the ASTM A212 linear beam elements representing a heat exchanger lug. These beams are tee cross sections with larger one being made up of a vertical plate that is 21.5" x 3/4" and a horizontal plate that is 12" x 1". The smaller on is made up of a vertical plate that is 14" x 3/4" and a horizontal plate that is 12" x 1". The node between the two elements is where the bolted connection occurs.

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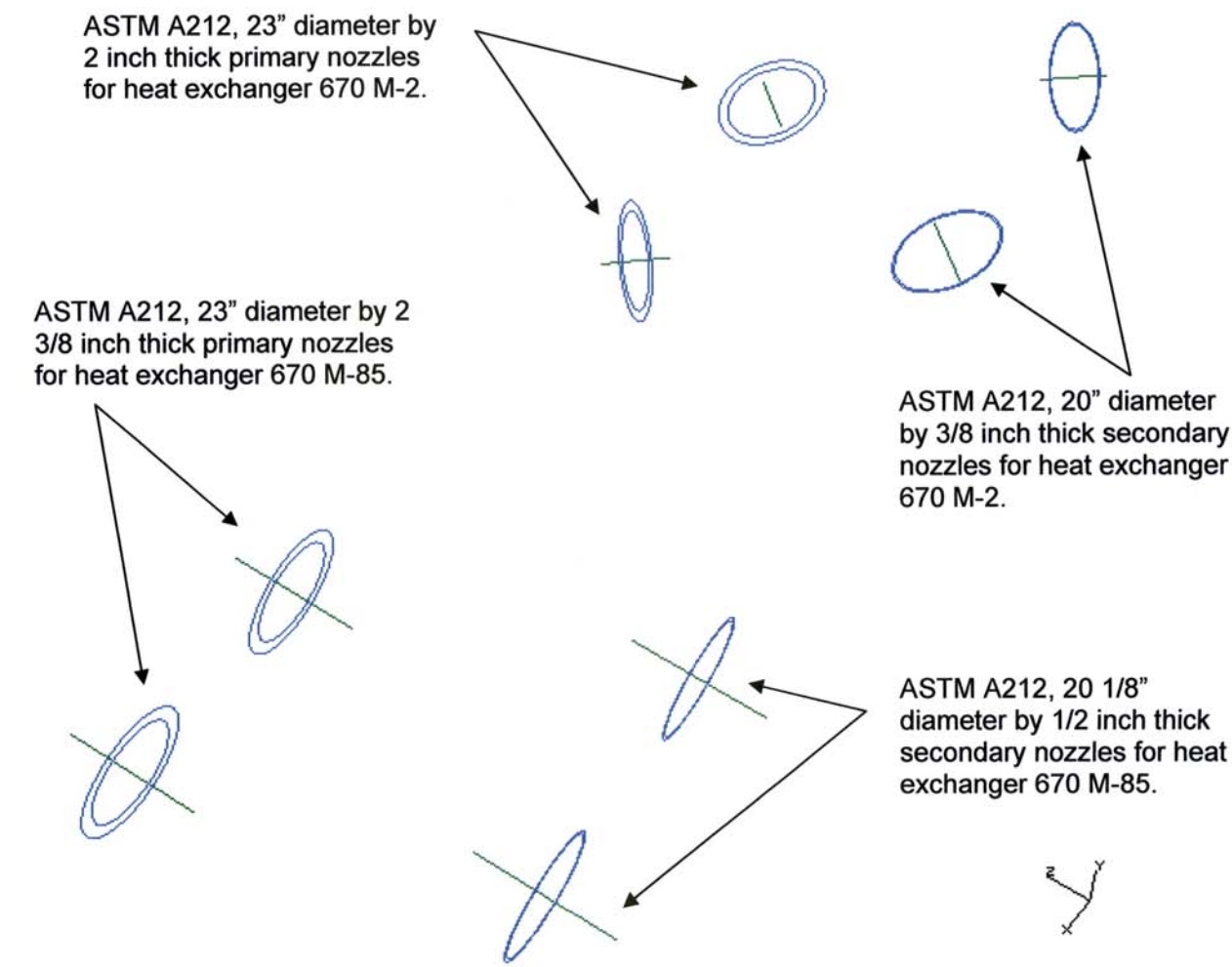

Figure A-5.2-7 – Linear beam elements representing heat exchanger nozzles.

Figure A-5.2-7 shows the ASTM A212, 5/8" thick elements in the heat exchanger 670 M-2 secondary nozzles. The remaining heat exchangers are modeled like heat exchangers 670 M-2.

A-6.0 Time Histories and Damping

The PSSI [15] provided the acceleration time histories used in this evaluation. The PSSI nodes providing input for this evaluation are 542, 552, 815, 1340, and 4119 (see Table A-5.0-1 for model restraints where these acceleration time histories are used). Additional manipulations to these acceleration time histories were performed in the ATR Primary Coolant System Seismic Evaluation [13]. These manipulations included summing the directional data (because the PSSI [15] ran three models per seismic event), adding time step points so that the time step is 0.005 seconds, and removing drift.

The ATR Primary Coolant System Seismic Evaluation [13] also addressed the time duration for model evaluation. Each time history has a duration of 40.96 seconds. Justification is provided in the ATR Primary Coolant System Seismic Evaluation [13] for using only 20 seconds for the time duration for evaluation. This is useful to reduce CPU time.

For time history analysis, a further consideration is how to address damping. A modal damping value of 5% is applicable to this evaluation, as listed in Table 3-2 of ASCE/SEI 43-05 [3]. (This is applicable because a significant portion of the model response is from the piping.) For dynamic, direct integration analysis with ABAQUS [56], modal damping is not an option. Consequently, Rayleigh damping is used. 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. To perform the analysis as a time history analysis, relevant Rayleigh damping constants must be found.

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. 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.

In the first step for calculating Rayleigh damping constants for finite element models, the 5% damping response spectra are found for the thirty-two sets of east-west, north-south, and vertical acceleration time histories. The time histories are from PSSI node 4119 which provides the base input to the heat exchangers. The response spectra analyses are performed with the ReSpect (see Appendix A.3.4 in the

ATR Primary Coolant System Seismic Evaluation [13] for validation). Each ReSpect run produces a separate report (.rpt text file) file. 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 modes of the models are needed. To accomplish this, ABAQUS modal analyses are run with the input files "HtExall10FRbb.inp" for the fine mesh (see Section A-8.1 for a reduced version of the input) and "HtExbeam10FRbb.inp" for the coarse mesh (see Section A-8.2 for a reduced version of the input). The frequency range checked for modes is from 0 Hz to 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 models and read into separate Mathcad files under the variable "dat`" in each. 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`."

For the fine mesh:

dat' =

	0	1	2	3	4	5	6	7	8
442	443	0.01	$2.98\cdot10^{-3}$	0.12	$2.44\cdot10^{3}$	$3.23\cdot10^{4}$	$2.08\cdot10^{5}$	0	49.41
443	444	0.05	0.04	0.45	$3.88\cdot10^{4}$	$1.07\cdot10^{4}$	$1.13\cdot10^{4}$	0	49.8
444	445	0.19	0.94	0.01	$2.55\cdot10^{4}$	$2.73\cdot10^{3}$	$1.07\cdot10^{5}$	0	49.91
445	0	0	0	0	0	0	0	0	0
446	0	$2.55\cdot10^{3}$	$2.41\cdot10^{3}$	$2.46\cdot10^{3}$	$3.08\cdot10^{8}$	$3.31\cdot10^{8}$	$3.95\cdot10^{8}$	0	0
447	0	$2.66\cdot10^{3}$	$2.66\cdot10^{3}$	$2.66\cdot10^{3}$	0	0	0	0	0

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

$m_{tot} := dat'_{rows(dat')-1,1}$ $\quad m_{tot} = 2655$ Total model mass.

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

$m_{eh1} := submatrix(dat', 0, rows(dat') - 4, 1, 1)$ Effective mass in the east-west direction.

$m_{eh2} := submatrix(dat', 0, rows(dat') - 4, 3, 3)$ Effective mass in the east-west direction.

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

For the coarse mesh:

dat' =

	0	1	2	3	4	5	6	7	8
369	370	0.16	0.12	0.04	423.03	2.62	$4.85\cdot10^{3}$	0	48.98
370	371	0.13	0.09	$5.86\cdot10^{-3}$	$1.77\cdot10^{4}$	$3.62\cdot10^{4}$	$1.67\cdot10^{5}$	0	49.25
371	372	0.02	1	0.11	$7.89\cdot10^{4}$	$2.27\cdot10^{4}$	$3.87\cdot10^{5}$	0	49.83
372	0	0	0	0	0	0	0	0	0
373	0	$2.48\cdot10^{3}$	$2.38\cdot10^{3}$	$2.48\cdot10^{3}$	$3.16\cdot10^{8}$	$3.34\cdot10^{8}$	$4\cdot10^{8}$	0	0
374	0	$2.67\cdot10^{3}$	$2.67\cdot10^{3}$	$2.67\cdot10^{3}$	0	0	0	0	0

The array "dat`" is then used to define the same variables. (Total model mass is shown below because it differs slightly between the two models.)

$m_{tot} := dat'_{rows(dat')-1,1}$ $\quad m_{tot} = 2667$ Total model mass.

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 effective 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.

Figures A-6.0-1 and A-6.0-2 show the effect mass and cumulative effective mass percentage versus frequency for the fine mesh and the coarse mesh.

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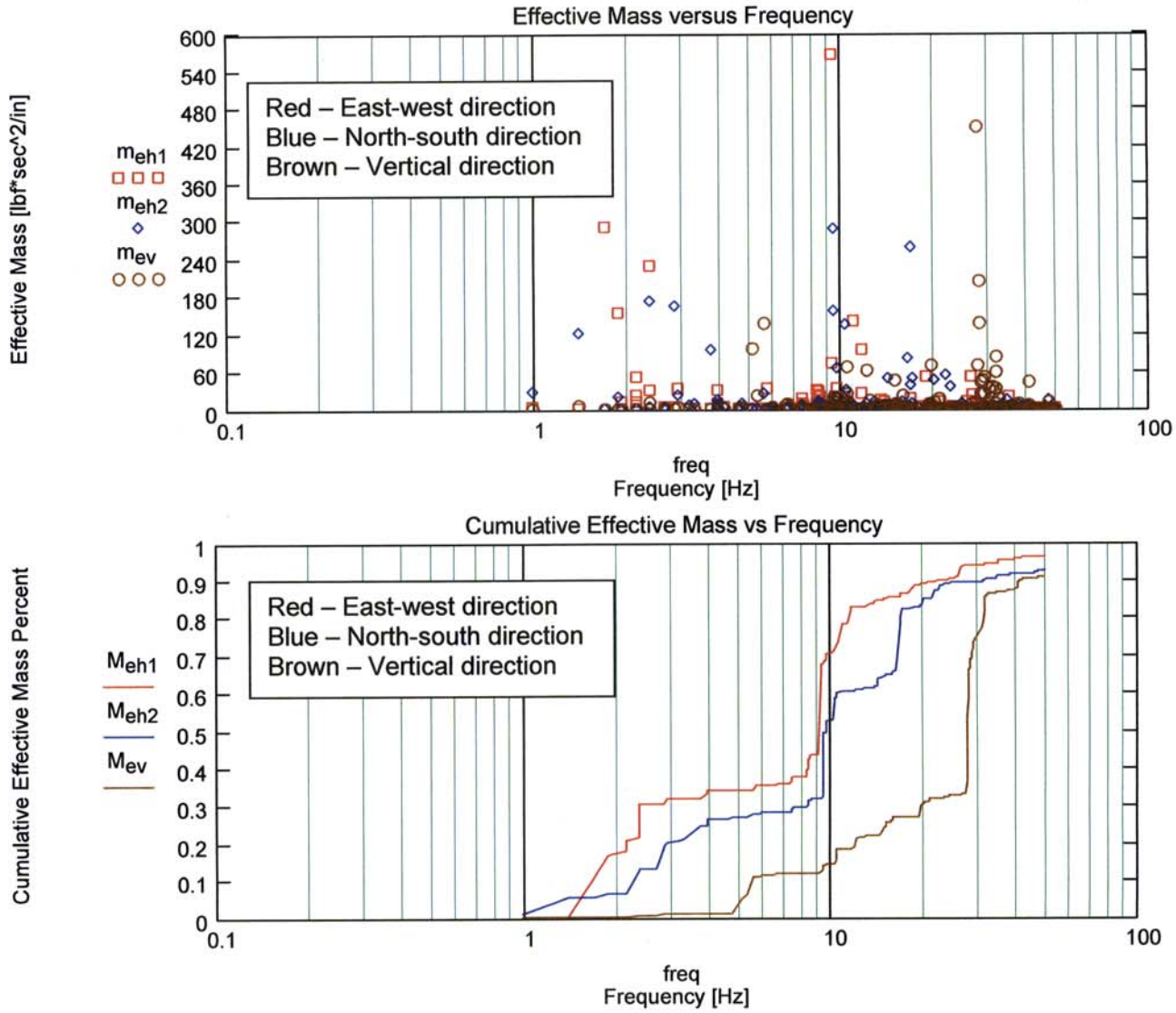

Figure A-6.0-1 – Fine mesh effective mass and cumulative effective mass percentage versus frequency.

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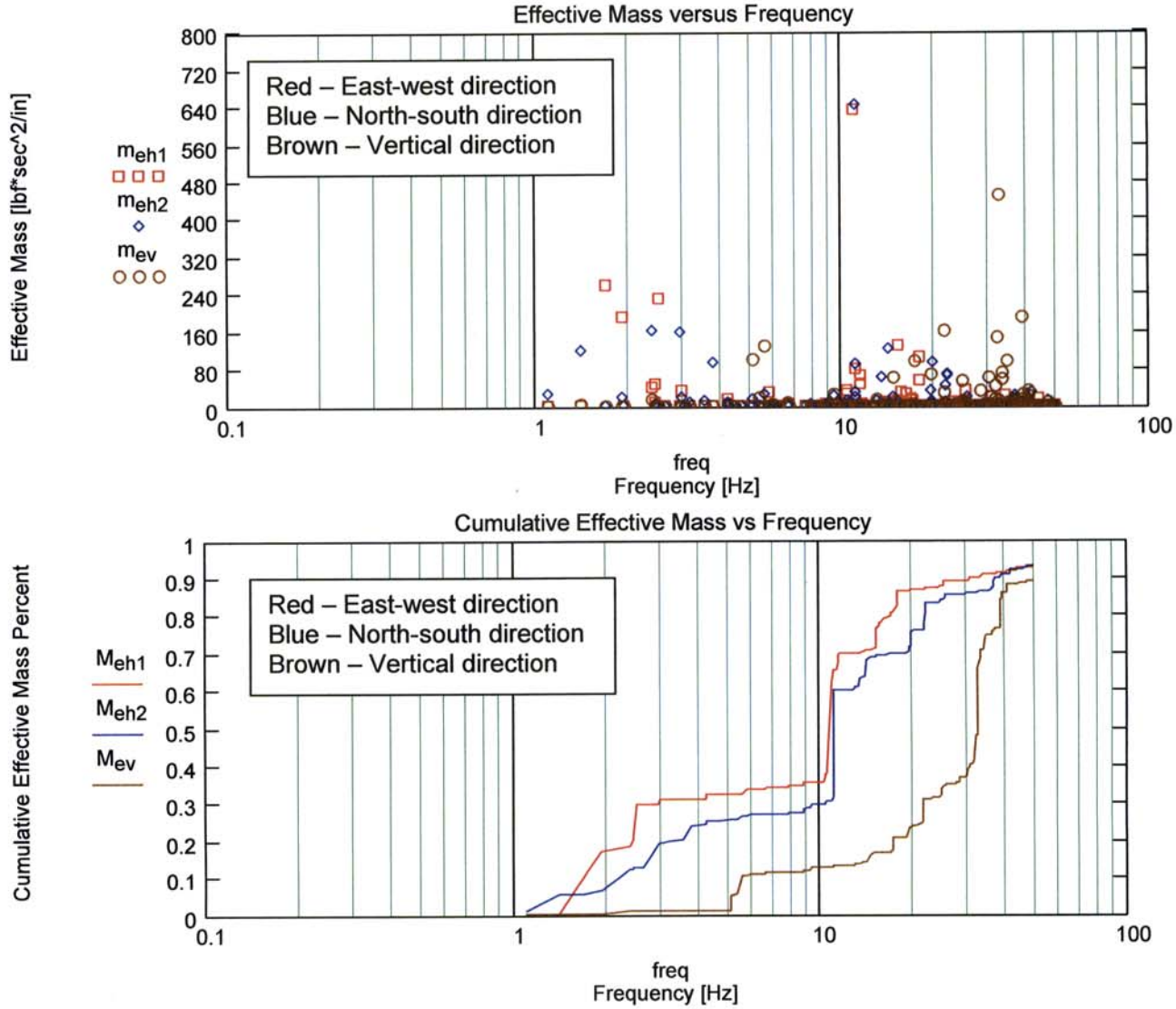

Figure A-6.0-2 – Coarse mesh effect mass and cumulative effective mass percentage versus frequency.

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.

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

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

For the fine mesh:

$P80_{H1} := P80wt(RS_05_{H1}, freq, m_{eh1})_{round(32 \cdot 80 \cdot \%)-1, 0}$ Eightieth percentile realization for east-west motion.

$P80_{H1} = 26$

$P80_{H2} := P80wt(RS_05_{H2}, freq, m_{eh2})_{round(32 \cdot 80 \cdot \%)-1, 0}$ Eightieth percentile realization for north-south motion.

$P80_{H2} = 17$

$P80_{V} := P80wt(RS_05_{V}, freq, m_{ev})_{round(32 \cdot 80 \cdot \%)-1, 0}$ Eightieth percentile realization for vertical motion.

$P80_{V} = 21$

For the coarse mesh:

$P80_{H1} := P80wt(RS_05_{H1}, freq, m_{eh1})_{round(32 \cdot 80 \cdot \%)-1, 0}$ Eightieth percentile realization for east-west motion.

$P80_{H1} = 30$

$P80_{H2} := P80wt(RS_05_{H2}, freq, m_{eh2})_{round(32 \cdot 80 \cdot \%)-1, 0}$ Eightieth percentile realization for north-south motion.

$P80_{H2} = 28$

$P80_{V} := P80wt(RS_05_{V}, freq, m_{ev})_{round(32 \cdot 80 \cdot \%)-1, 0}$ Eightieth percentile realization for vertical motion.

$P80_{V} = 21$

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.

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

$RS_{aH1} := RS_a(RS_05_{H1})$ Graphing variable for all east-west response spectra.

$RS_{aH2} := RS_a(RS_05_{H2})$ Graphing variable for all north-south response spectra

$RS_{aV} := RS_a(RS_05_V)$ Graphing variable for all vertical response spectra.

Figures A-6.0-3 and A-6.0-4 show the response spectra data for all 32 realizations as data points. They also show the response spectra realizations selected as 80th percentile for each mesh. For additional information, the 80th percentile east-west, north-south, and vertical time histories and cumulative energy ratio are shown in Figure A-6.0-5 - Figure A-6.0-8 for the fine mesh. The variables are defined as shown below using previously defined subroutines.

$\Delta t = 0.005$ Time step.

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

$dis := Int_E(vel)$ Displacement time histories 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.

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

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

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

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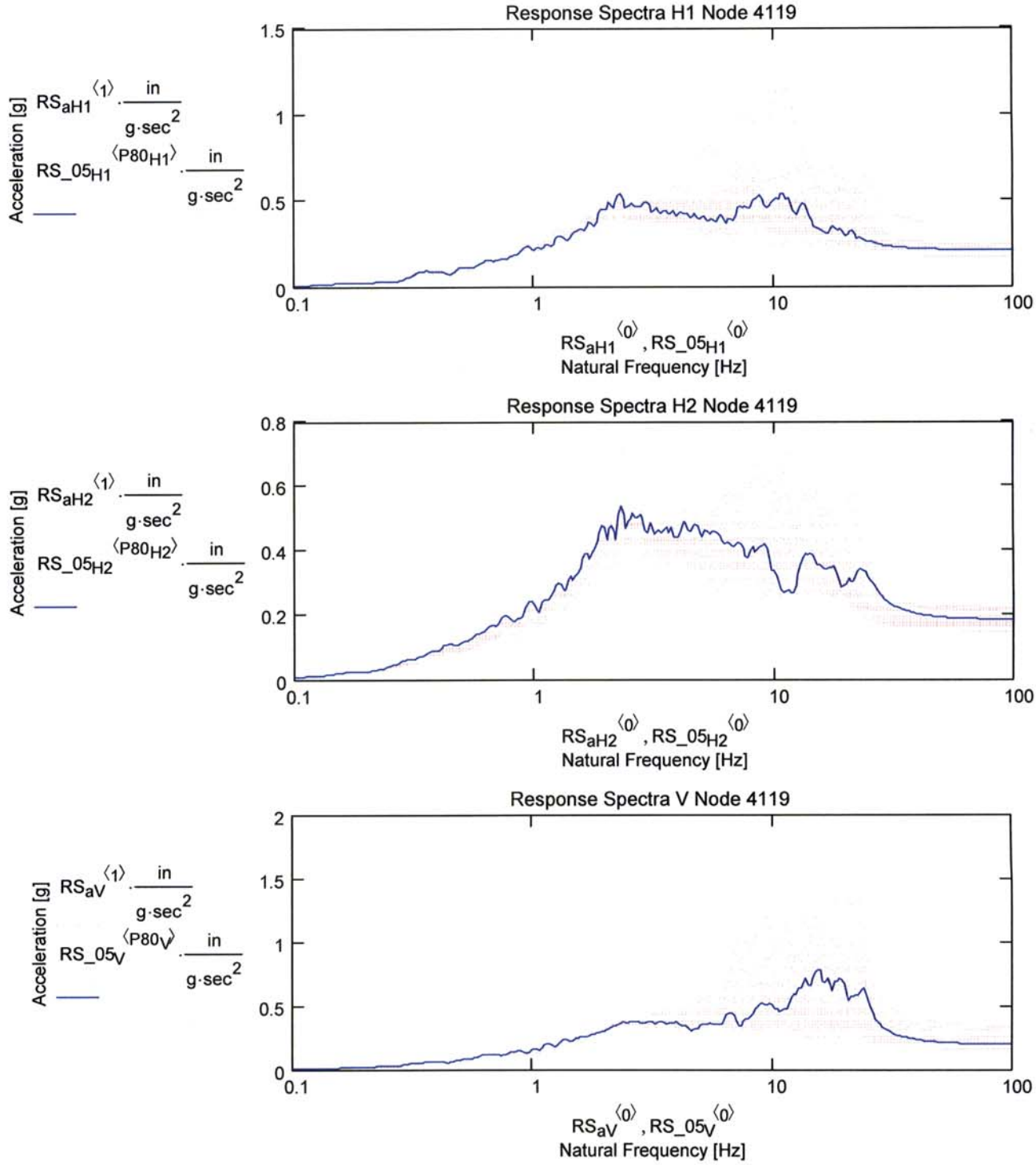

Figure A-6.0-3 – All realizations (red) and fine mesh 80th percentile (blue) 5% damping response spectra.

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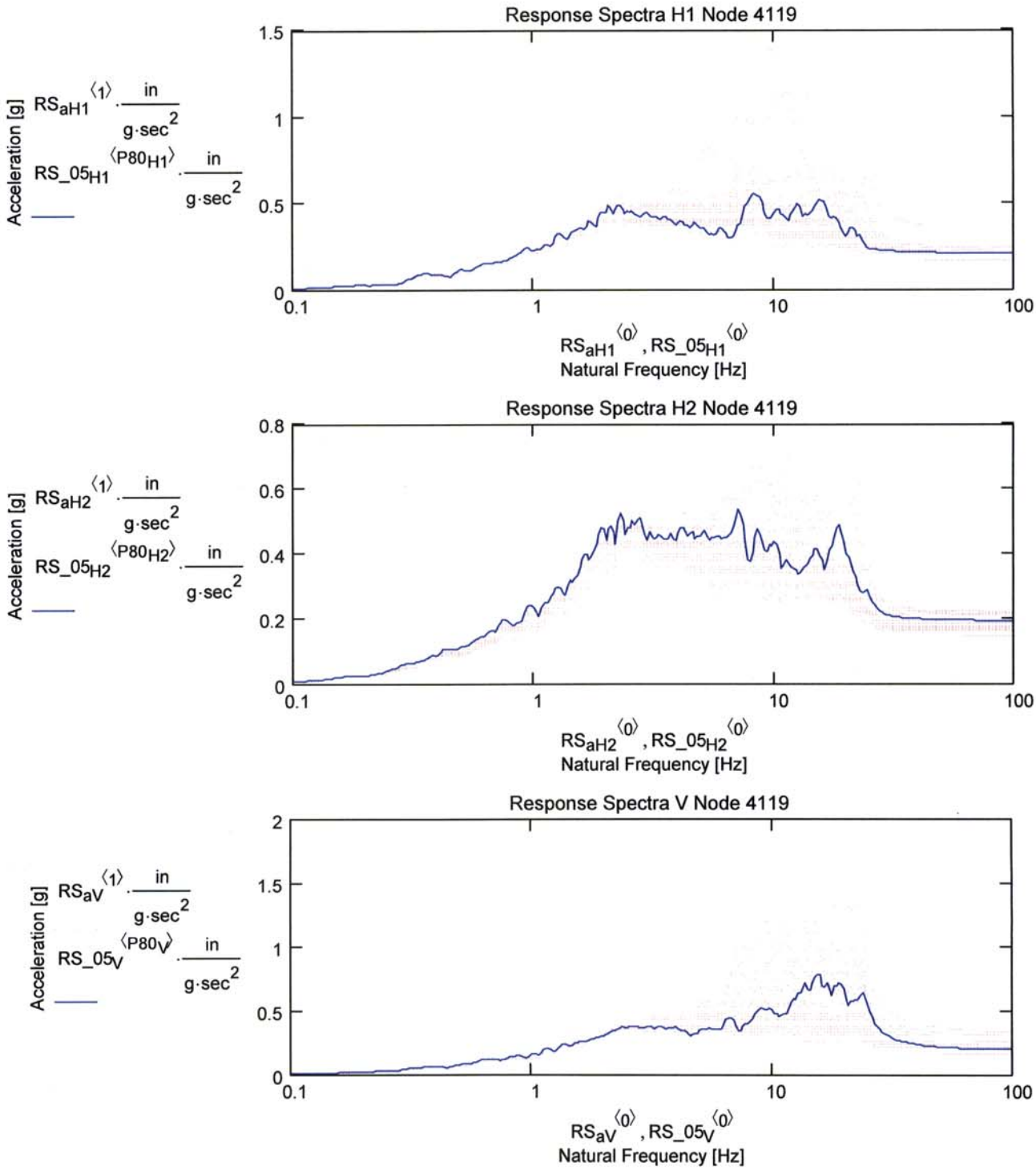

Figure A-6.0-4 – All realizations (red) and coarse mesh 80th percentile (blue) 5% damping response spectra.

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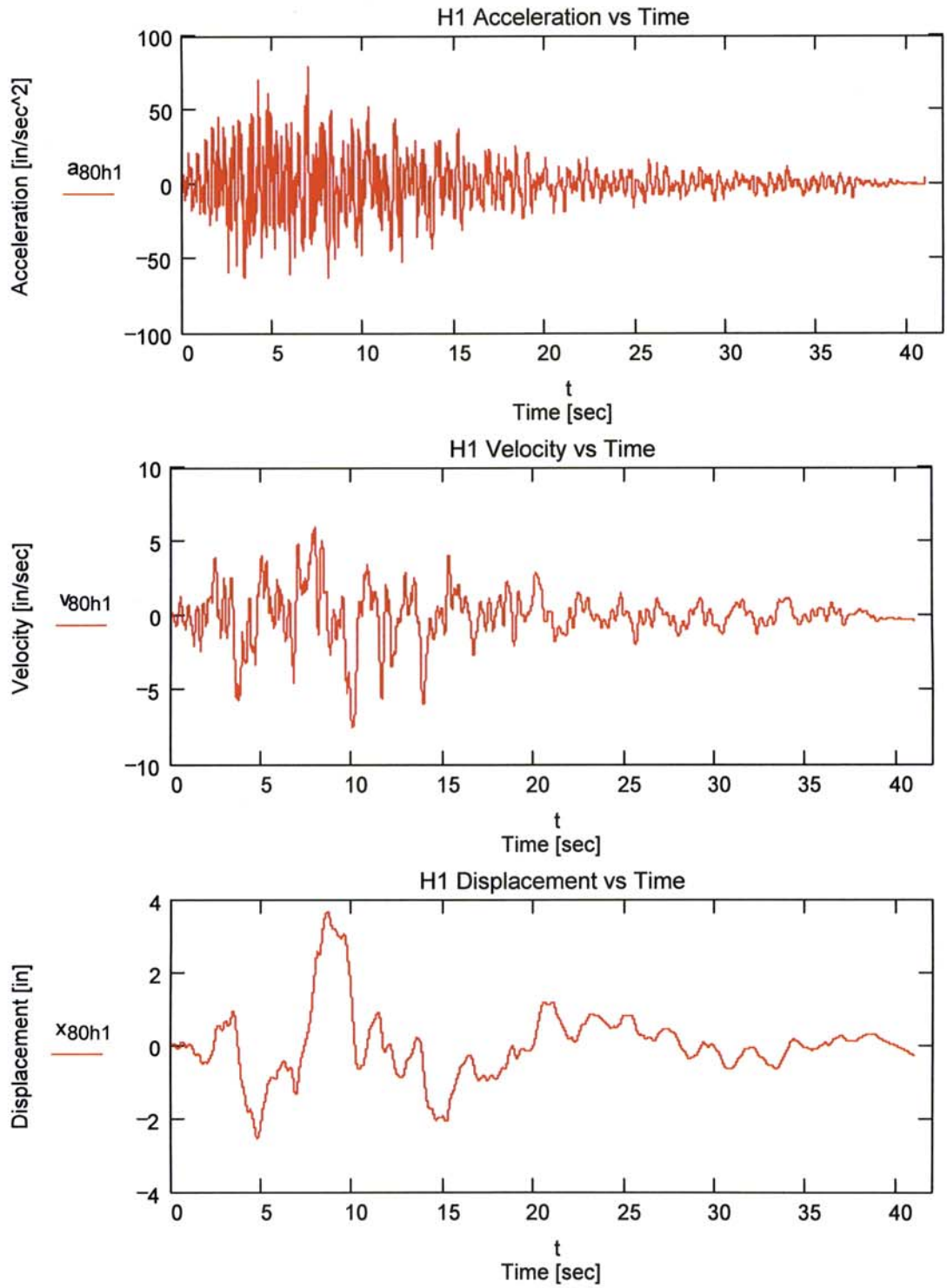

Figure A-6.0-5 – Fine mesh east-west 80th percentile time histories.

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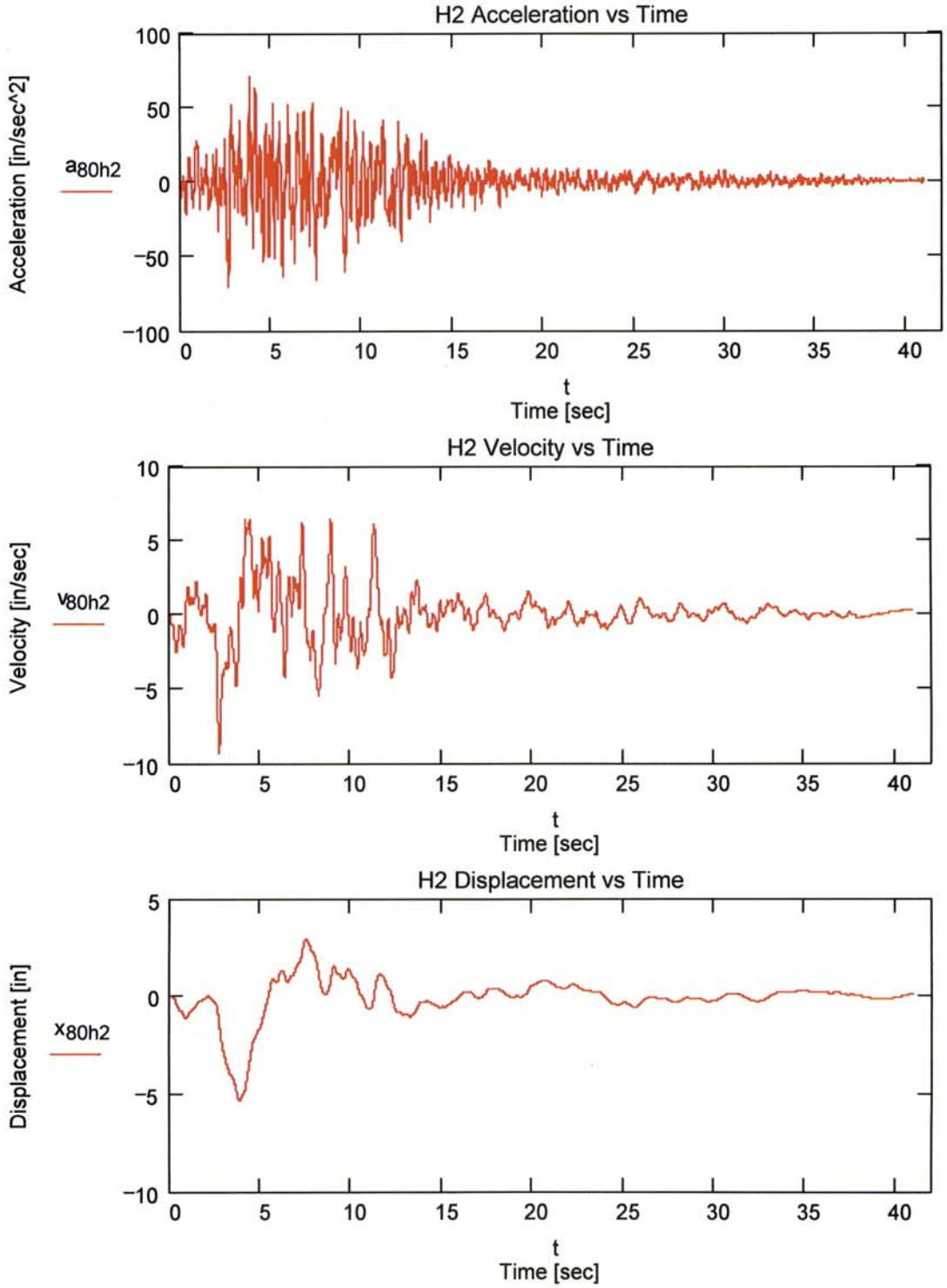

Figure A-6.0-6 – Fine mesh north-south 80th percentile time histories.

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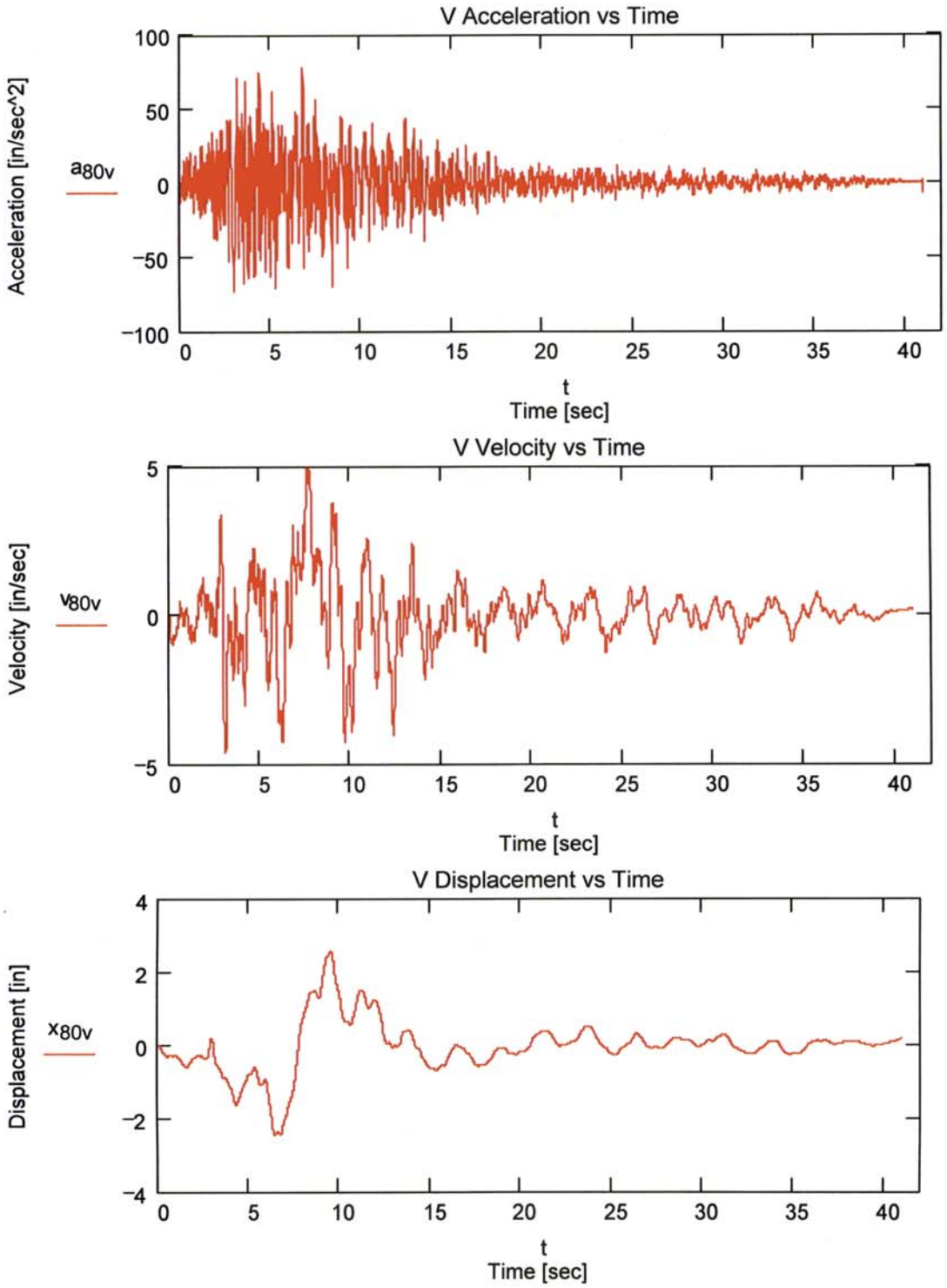

Figure A-6.0-7 – Fine mesh vertical 80th percentile time histories.

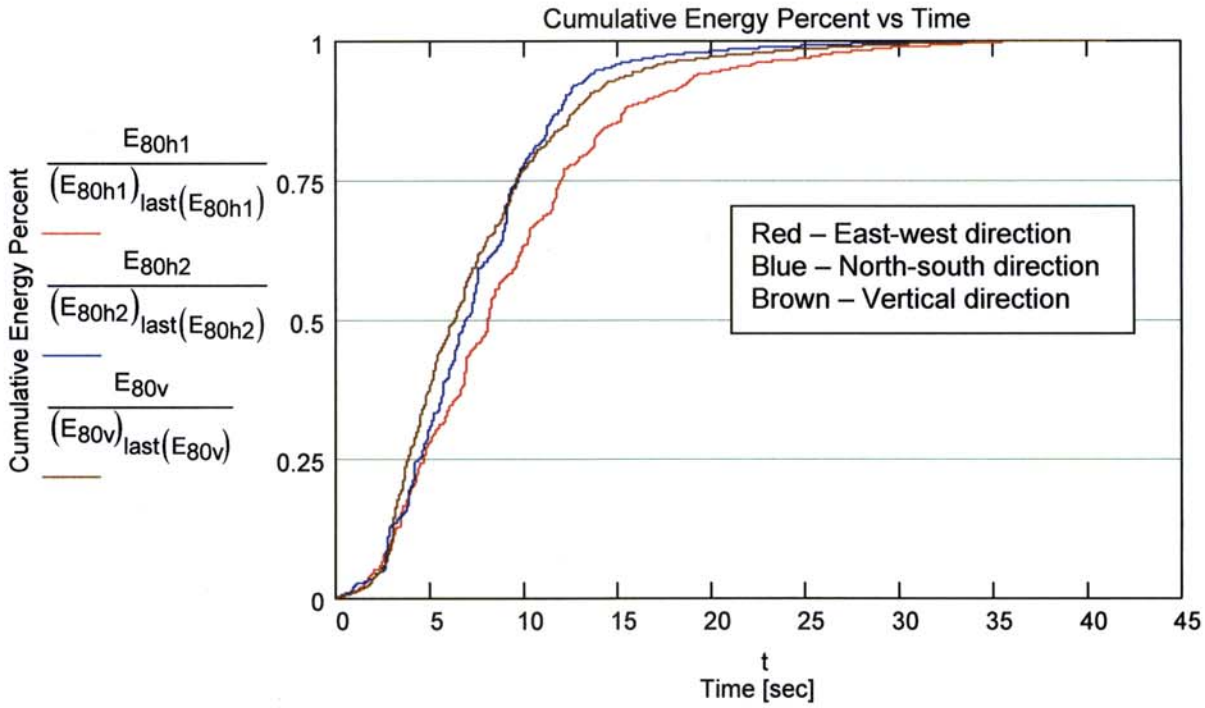

Figure A-6.0-8 – Fine mesh cumulative energy ratio versus time for 80th percentile data.

For further information, the fine mesh 80th percentile east-west, north-south, and vertical fast Fourier transform amplitudes are shown in Figure A-6.0-8 based on the variable definitions below.

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

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

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

$\Delta t = 0.005$ Time step.

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

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

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

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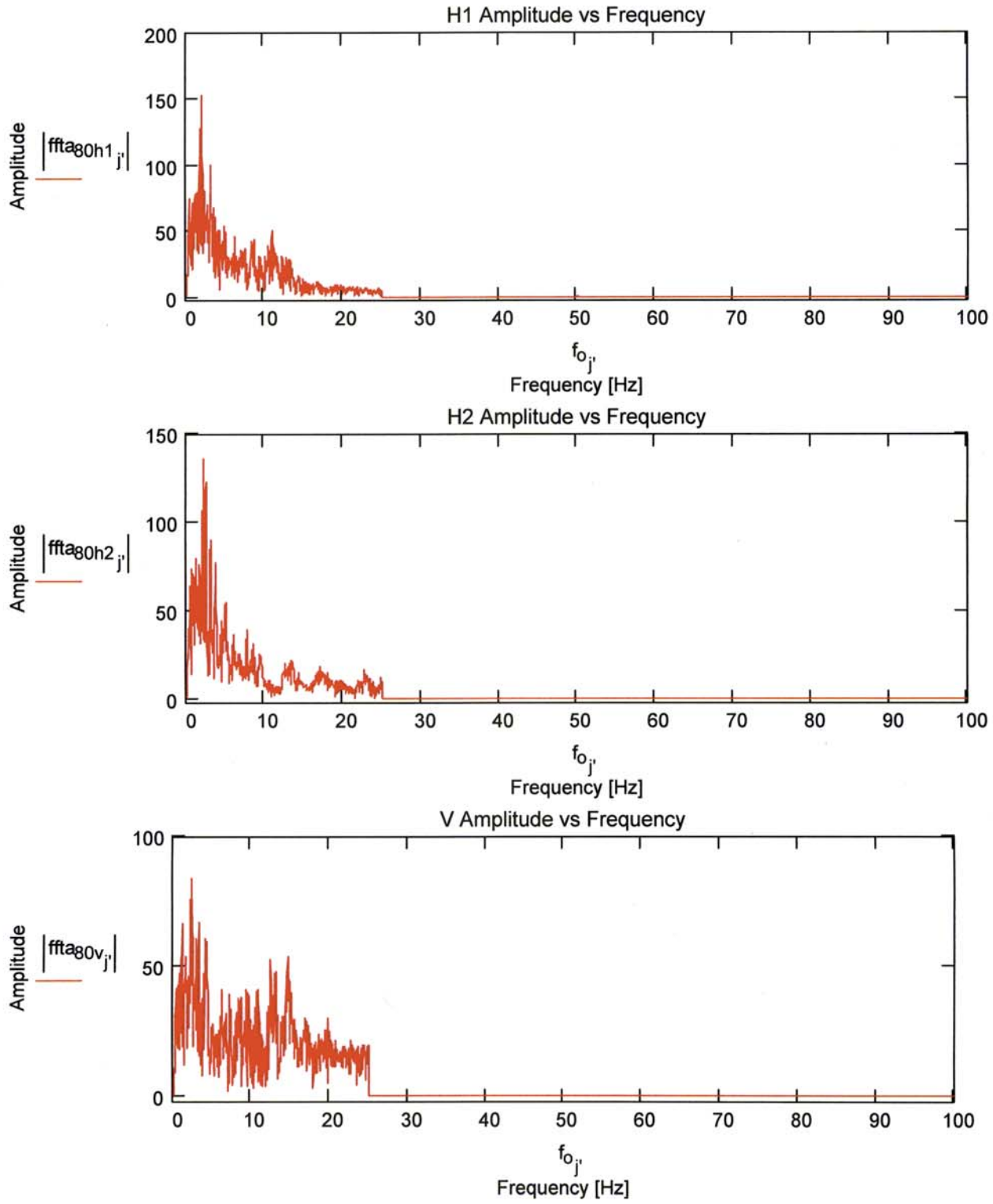

Figure A-6.0-9 – Fine mesh fast Fourier transform amplitudes for 80th percentile data.

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 Figure A-6.0-10, this occurs at 0.98 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 10.1 Hz. The derivation below shows the Rayleigh damping constants calculation and Figure A-6.0-10 shows the resulting damping curve plotted with the desired damping curve.

$\omega_0 := 2\cdot\pi\cdot 0.98$ Lower end of the natural frequency range.

$\omega_1 := 2\cdot\pi\cdot 10.1$ Upper end of the natural frequency range.

$\xi := 0.05$ Desired damping value.

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

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

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

$$\alpha\beta = \begin{pmatrix} 0.561 \\ 1.436\times 10^{-3} \end{pmatrix}$$ Constants definition.

$\alpha := \alpha\beta_0$ $\alpha = 0.5613$

$\beta := \alpha\beta_1$ $\beta = 1.436\times 10^{-3}$

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

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

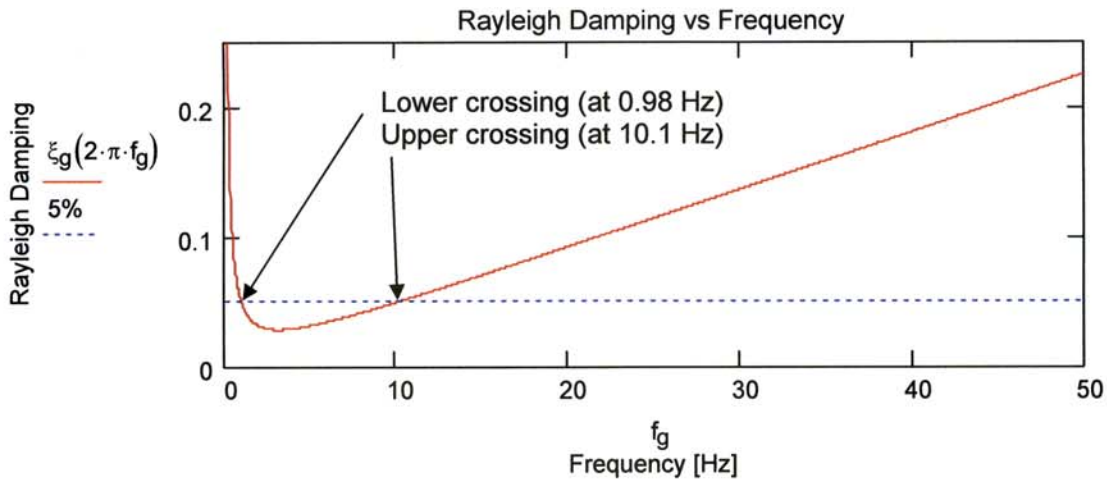

Figure A-6.0-10 – Rayleigh damping curve and desired damping curve versus frequency.

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 in the ATR Primary Coolant System Seismic Evaluation [13] 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.

Figures A-6.0-11 and A-6.0-12 show comparisons of the response spectra for 5% damping and Rayleigh damping. Figures A-6.0-13 and A-6.0-14 show the response spectra differences between Rayleigh damping and 5% damping.

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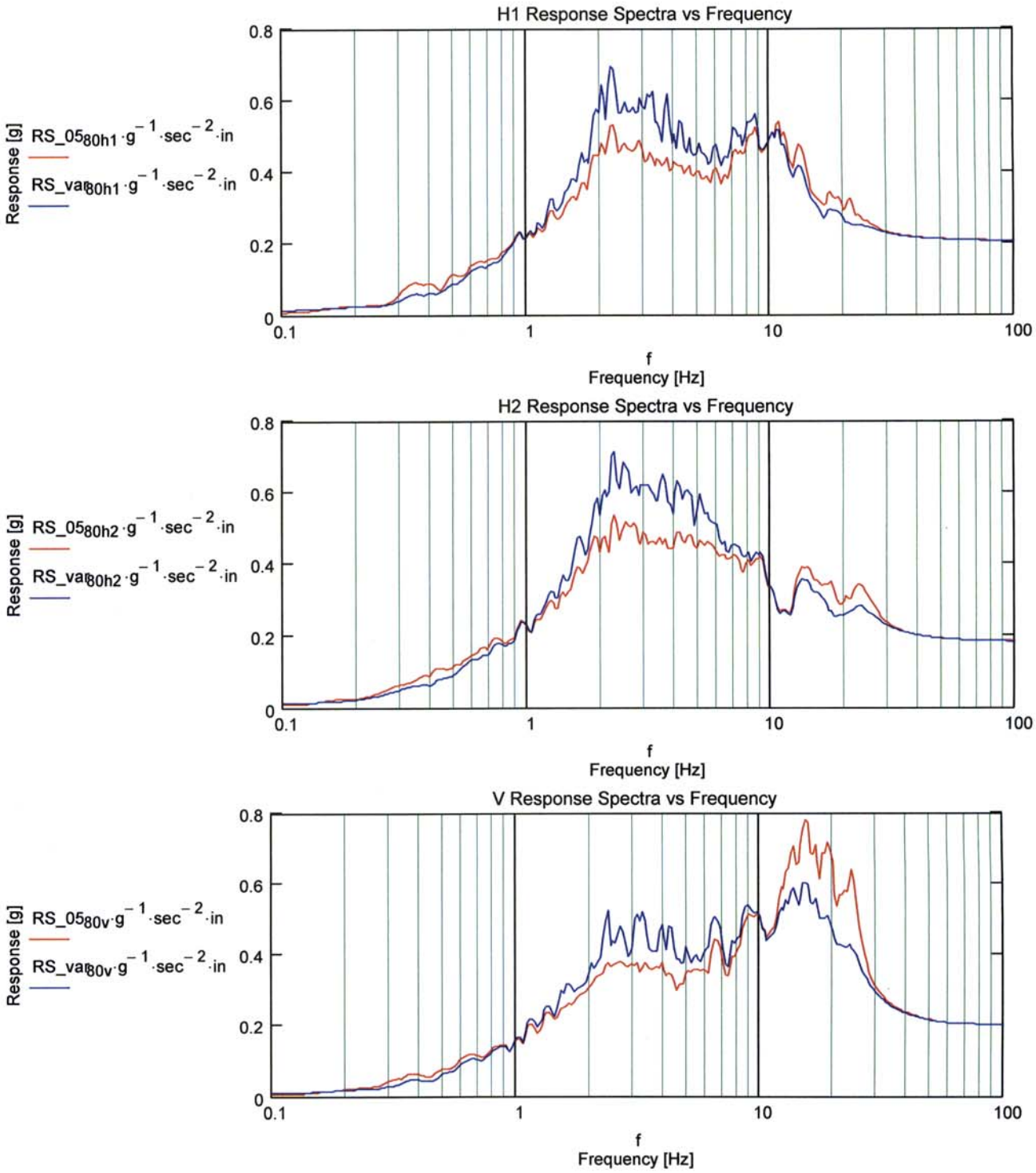

Figure A-6.0-11 – Response spectra for 5% damping (red) and fine mesh Rayleigh damping (blue).

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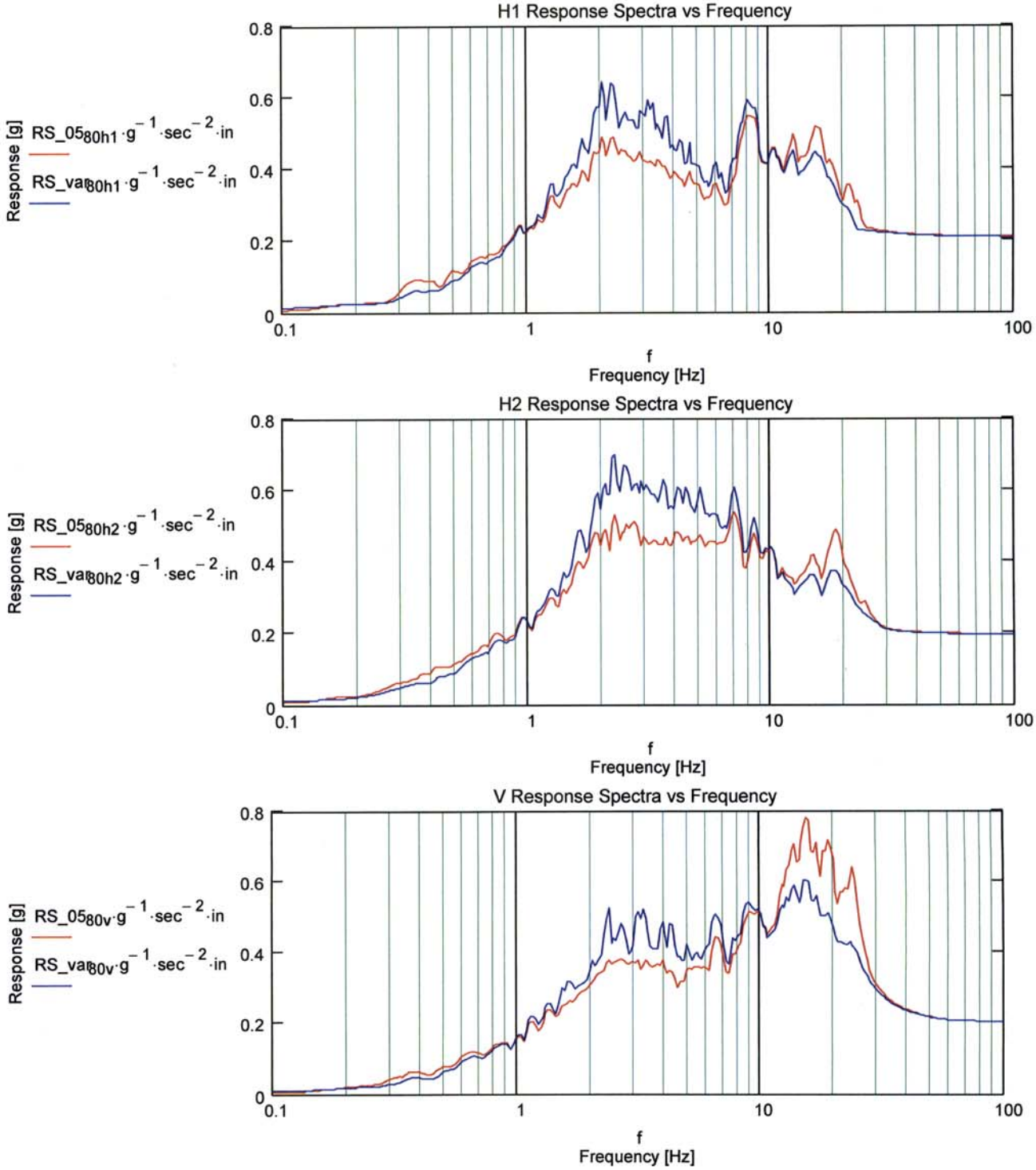

Figure A-6.0-12 – Response spectra for 5% damping (red) and coarse mesh Rayleigh damping (blue).

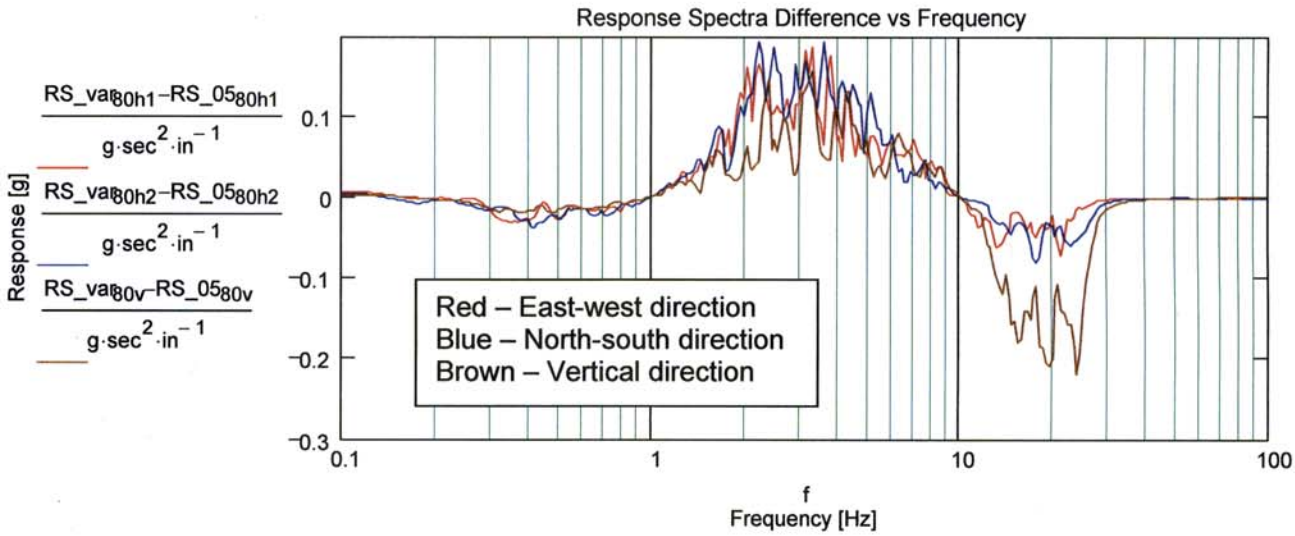

Figure A-6.0-13 – Fine mesh response spectra difference.

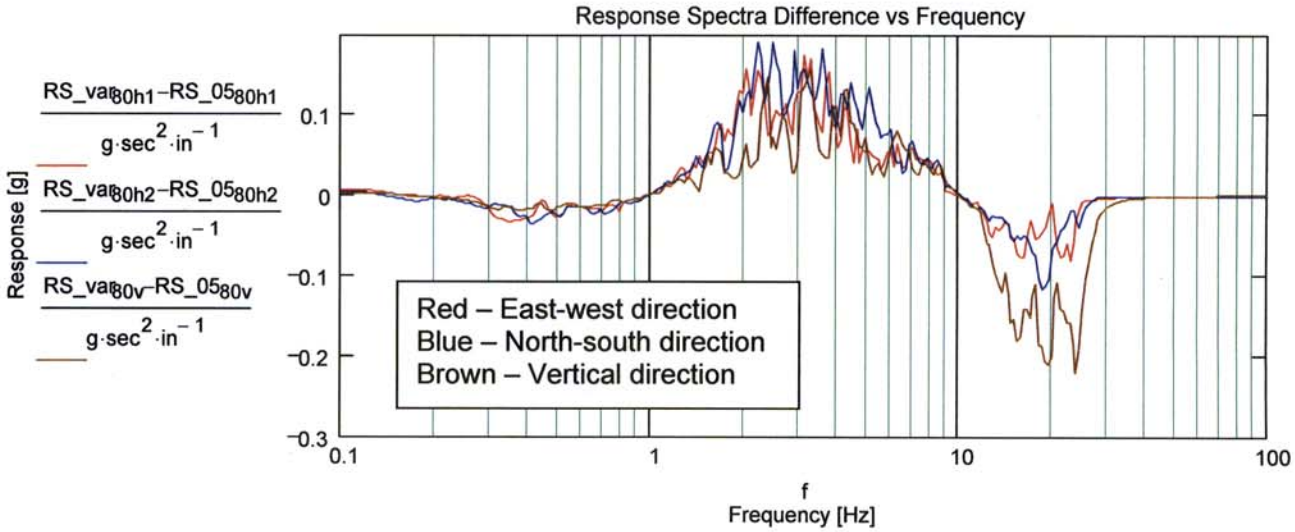

Figure A-6.0-14 – Coarse mesh response spectra difference.

The seventh step is to generate cumulative weighted response curves for the two meshes. This uses the curves generated by subtracting the 5% damping response spectra from the Rayleigh damping response spectra (shown in Figures A-6.0-15 and A-6.0-16). 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 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. The plots showing all three directions summed for each mesh are shown in Figures A-6.0-15 and A-6.0-16.

$\Delta RS_{wt_h1} := Damp_{wt}(RS_var_{80h1} - RS_05_{80h1}, f, m_{eh1}, freq)$ East-west cumulative weighted response.

$\Delta RS_{wt_h2} := Damp_{wt}(RS_var_{80h2} - RS_05_{80h2}, f, m_{eh2}, freq)$ North-southcumulative weighted response.

$\Delta RS_{wt_v} := Damp_{wt}(RS_var_{80v} - RS_05_{80v}, f, m_{ev}, freq)$ Vertical cumulative weighted response.

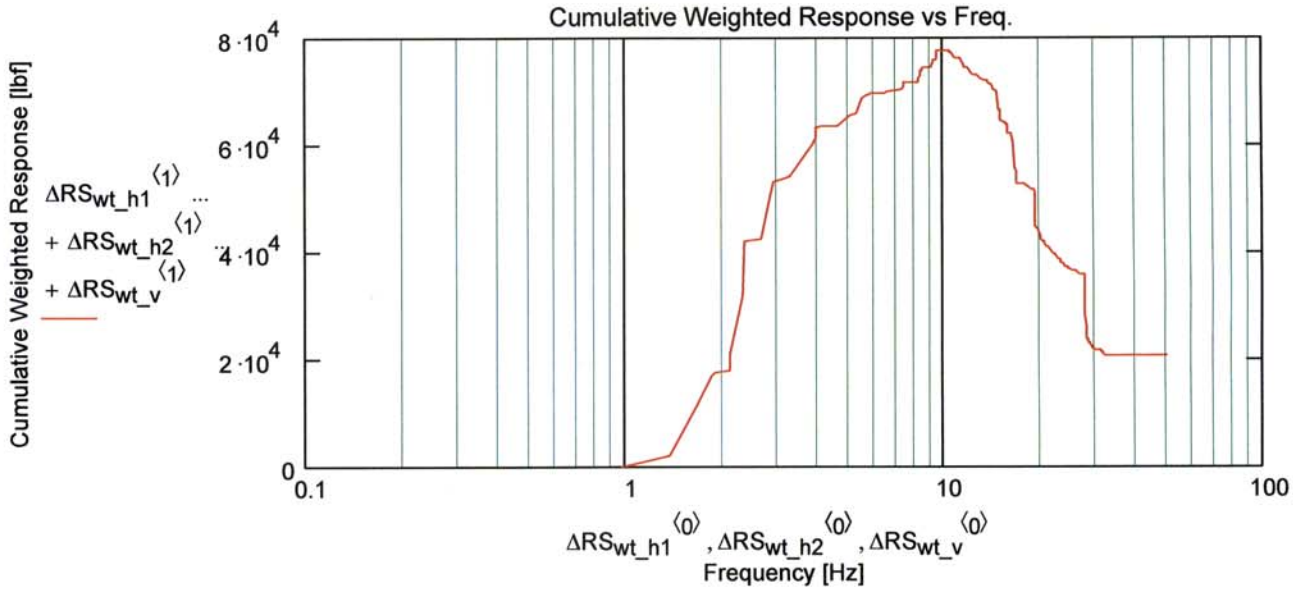

Figure A-6.0-15 – Summed cumulative weighted response for the fine mesh.

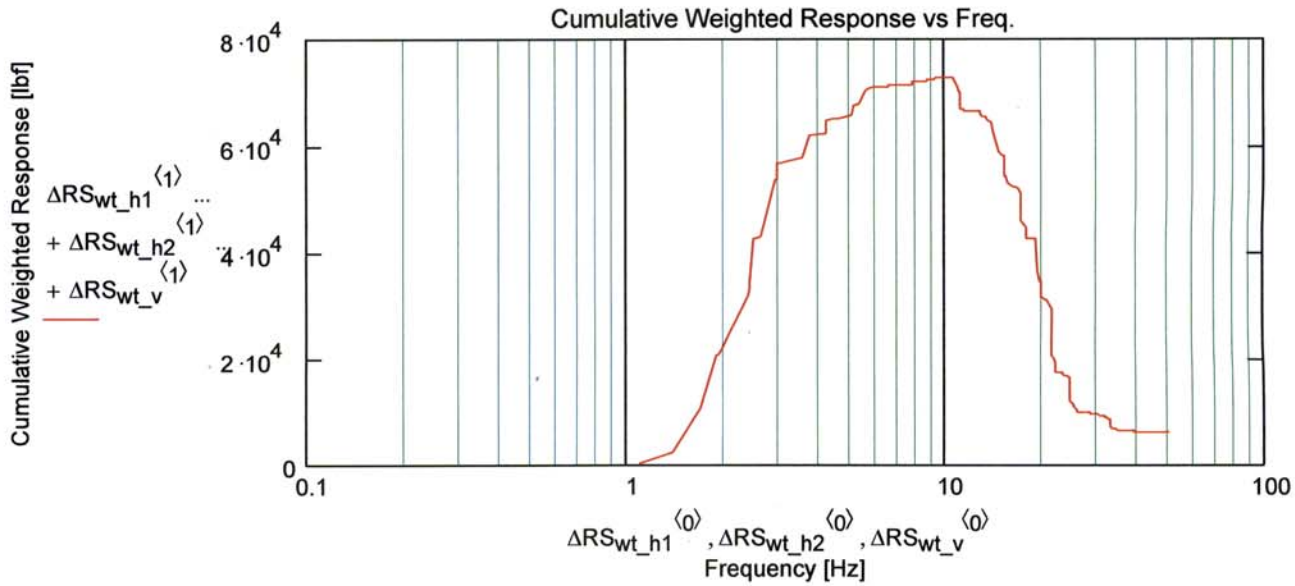

Figure A-6.0-16 – Summed cumulative weighted response for the coarse mesh.

The important feature of Figures A-6.0-15 and A-6.0-16 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-7.0 Model Runs and Calculations

Having all of the data needed for the model runs, the model runs proceeded in a series of steps. First, the fine meshed model was setup and run using realization 14 data. Only one fine mesh model was run and realization 14 was selected based on scoping calculations that indicated it could be a representative 80th percentile realization. The results showed it conservative and not conservative depending on which output was considered. Consequently, its output is scaled to address the variability. Second, a base input file was generated. Third, the Python script "HtExbeam_32inps_Linux.py" (see Section A-8.5) was run to edit the base input file into the 32 unique input files for the different realizations. Fourth, the Perl script "run_HtEx_beam10bb.pl" (see Section A-8.6) was used to run all of the input files in ABAQUS. Fifth, the Python script "HtEx_out.py" (see Section A-8.7.1) along with the ABAQUS/Viewer run file "HtEx_rpy_out.rpy" (see Section A-8.7.2) were run to generate report files for all of the realizations of the needed reaction force and nodal force data. Sixth, The Python script "rpt2prn.py" (see Section A-8.8) was used to edit the report files into print files easily read into Mathcad. Table A-7.0-1 shows the variables input into Mathcad.

Table A-7.0-1 – Variable definition.

Variable name *	Description
$RFbb_x$	Seismic brace rod translational reaction forces
$RFbr_x$	Seismic brace pipe translational reaction forces
$RFsb_x$	Steel column translational reaction forces
$RFcb_x$	Concrete column translational and rotational reaction forces
$RFft_x$	Heat exchanger lug translational and rotational nodal forces

* The subscript "*x*" in the variables is the realization number (eg. "$RFbb_1$" is for realization 1).

The Mathcad variables have their data all ordered in a similar manner. The 0 column is time, the 1 column is the translational load in the east-west direction for the first node, the 2 column is the translational load in the east-west direction for the second node… After all of the translational node loads for the east-west direction are given, the vertical and north-south translational loads are given respectively. If angular loads are given, they follow in a similar pattern.

To organize the data, the following definitions are made for RFbb(j), RFbr(j), RFsb(j), RFcb(j), and RFft(j). The variable "j" represents a column number in an input variable that is unique to a load direction and node. The definitions generate an array with the 0 column being time and the other 32 columns being load data for a given load direction and node (where the column number equals the realization number).

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$$RFbb1(j) := augment\left(RFbb_1^{\langle j\rangle}, RFbb_2^{\langle j\rangle}, RFbb_3^{\langle j\rangle}, RFbb_4^{\langle j\rangle}, RFbb_5^{\langle j\rangle}, RFbb_6^{\langle j\rangle}, RFbb_7^{\langle j\rangle}, RFbb_8^{\langle j\rangle}\right)$$
$$RFbb2(j) := augment\left(RFbb_9^{\langle j\rangle}, RFbb_{10}^{\langle j\rangle}, RFbb_{11}^{\langle j\rangle}, RFbb_{12}^{\langle j\rangle}, RFbb_{13}^{\langle j\rangle}, RFbb_{14}^{\langle j\rangle}, RFbb_{15}^{\langle j\rangle}, RFbb_{16}^{\langle j\rangle}\right)$$
$$RFbb3(j) := augment\left(RFbb_{17}^{\langle j\rangle}, RFbb_{18}^{\langle j\rangle}, RFbb_{19}^{\langle j\rangle}, RFbb_{20}^{\langle j\rangle}, RFbb_{21}^{\langle j\rangle}, RFbb_{22}^{\langle j\rangle}, RFbb_{23}^{\langle j\rangle}, RFbb_{24}^{\langle j\rangle}\right)$$
$$RFbb4(j) := augment\left(RFbb_{25}^{\langle j\rangle}, RFbb_{26}^{\langle j\rangle}, RFbb_{27}^{\langle j\rangle}, RFbb_{28}^{\langle j\rangle}, RFbb_{29}^{\langle j\rangle}, RFbb_{30}^{\langle j\rangle}, RFbb_{31}^{\langle j\rangle}, RFbb_{32}^{\langle j\rangle}\right)$$
$$RFbb(j) := augment\left(RFbb_1^{\langle 0\rangle}, RFbb1(j), RFbb2(j), RFbb3(j), RFbb4(j)\right)$$

$$RFbr1(j) := augment\left(RFbr_1^{\langle j\rangle}, RFbr_2^{\langle j\rangle}, RFbr_3^{\langle j\rangle}, RFbr_4^{\langle j\rangle}, RFbr_5^{\langle j\rangle}, RFbr_6^{\langle j\rangle}, RFbr_7^{\langle j\rangle}, RFbr_8^{\langle j\rangle}\right)$$
$$RFbr2(j) := augment\left(RFbr_9^{\langle j\rangle}, RFbr_{10}^{\langle j\rangle}, RFbr_{11}^{\langle j\rangle}, RFbr_{12}^{\langle j\rangle}, RFbr_{13}^{\langle j\rangle}, RFbr_{14}^{\langle j\rangle}, RFbr_{15}^{\langle j\rangle}, RFbr_{16}^{\langle j\rangle}\right)$$
$$RFbr3(j) := augment\left(RFbr_{17}^{\langle j\rangle}, RFbr_{18}^{\langle j\rangle}, RFbr_{19}^{\langle j\rangle}, RFbr_{20}^{\langle j\rangle}, RFbr_{21}^{\langle j\rangle}, RFbr_{22}^{\langle j\rangle}, RFbr_{23}^{\langle j\rangle}, RFbr_{24}^{\langle j\rangle}\right)$$
$$RFbr4(j) := augment\left(RFbr_{25}^{\langle j\rangle}, RFbr_{26}^{\langle j\rangle}, RFbr_{27}^{\langle j\rangle}, RFbr_{28}^{\langle j\rangle}, RFbr_{29}^{\langle j\rangle}, RFbr_{30}^{\langle j\rangle}, RFbr_{31}^{\langle j\rangle}, RFbr_{32}^{\langle j\rangle}\right)$$
$$RFbr(j) := augment\left(RFbr_1^{\langle 0\rangle}, RFbr1(j), RFbr2(j), RFbr3(j), RFbr4(j)\right)$$

$$RFsb1(j) := augment\left(RFsb_1^{\langle j\rangle}, RFsb_2^{\langle j\rangle}, RFsb_3^{\langle j\rangle}, RFsb_4^{\langle j\rangle}, RFsb_5^{\langle j\rangle}, RFsb_6^{\langle j\rangle}, RFsb_7^{\langle j\rangle}, RFsb_8^{\langle j\rangle}\right)$$
$$RFsb2(j) := augment\left(RFsb_9^{\langle j\rangle}, RFsb_{10}^{\langle j\rangle}, RFsb_{11}^{\langle j\rangle}, RFsb_{12}^{\langle j\rangle}, RFsb_{13}^{\langle j\rangle}, RFsb_{14}^{\langle j\rangle}, RFsb_{15}^{\langle j\rangle}, RFsb_{16}^{\langle j\rangle}\right)$$
$$RFsb3(j) := augment\left(RFsb_{17}^{\langle j\rangle}, RFsb_{18}^{\langle j\rangle}, RFsb_{19}^{\langle j\rangle}, RFsb_{20}^{\langle j\rangle}, RFsb_{21}^{\langle j\rangle}, RFsb_{22}^{\langle j\rangle}, RFsb_{23}^{\langle j\rangle}, RFsb_{24}^{\langle j\rangle}\right)$$
$$RFsb4(j) := augment\left(RFsb_{25}^{\langle j\rangle}, RFsb_{26}^{\langle j\rangle}, RFsb_{27}^{\langle j\rangle}, RFsb_{28}^{\langle j\rangle}, RFsb_{29}^{\langle j\rangle}, RFsb_{30}^{\langle j\rangle}, RFsb_{31}^{\langle j\rangle}, RFsb_{32}^{\langle j\rangle}\right)$$
$$RFsb(j) := augment\left(RFsb_1^{\langle 0\rangle}, RFsb1(j), RFsb2(j), RFsb3(j), RFsb4(j)\right)$$

$$RFcb1(j) := augment\left(RFcb_1^{\langle j\rangle}, RFcb_2^{\langle j\rangle}, RFcb_3^{\langle j\rangle}, RFcb_4^{\langle j\rangle}, RFcb_5^{\langle j\rangle}, RFcb_6^{\langle j\rangle}, RFcb_7^{\langle j\rangle}, RFcb_8^{\langle j\rangle}\right)$$
$$RFcb2(j) := augment\left(RFcb_9^{\langle j\rangle}, RFcb_{10}^{\langle j\rangle}, RFcb_{11}^{\langle j\rangle}, RFcb_{12}^{\langle j\rangle}, RFcb_{13}^{\langle j\rangle}, RFcb_{14}^{\langle j\rangle}, RFcb_{15}^{\langle j\rangle}, RFcb_{16}^{\langle j\rangle}\right)$$
$$RFcb3(j) := augment\left(RFcb_{17}^{\langle j\rangle}, RFcb_{18}^{\langle j\rangle}, RFcb_{19}^{\langle j\rangle}, RFcb_{20}^{\langle j\rangle}, RFcb_{21}^{\langle j\rangle}, RFcb_{22}^{\langle j\rangle}, RFcb_{23}^{\langle j\rangle}, RFcb_{24}^{\langle j\rangle}\right)$$
$$RFcb4(j) := augment\left(RFcb_{25}^{\langle j\rangle}, RFcb_{26}^{\langle j\rangle}, RFcb_{27}^{\langle j\rangle}, RFcb_{28}^{\langle j\rangle}, RFcb_{29}^{\langle j\rangle}, RFcb_{30}^{\langle j\rangle}, RFcb_{31}^{\langle j\rangle}, RFcb_{32}^{\langle j\rangle}\right)$$
$$RFcb(j) := augment\left(RFcb_1^{\langle 0\rangle}, RFcb1(j), RFcb2(j), RFcb3(j), RFcb4(j)\right)$$

$$RFft1(j) := augment\left(RFft_1^{\langle j\rangle}, RFft_2^{\langle j\rangle}, RFft_3^{\langle j\rangle}, RFft_4^{\langle j\rangle}, RFft_5^{\langle j\rangle}, RFft_6^{\langle j\rangle}, RFft_7^{\langle j\rangle}, RFft_8^{\langle j\rangle}\right)$$
$$RFft2(j) := augment\left(RFft_9^{\langle j\rangle}, RFft_{10}^{\langle j\rangle}, RFft_{11}^{\langle j\rangle}, RFft_{12}^{\langle j\rangle}, RFft_{13}^{\langle j\rangle}, RFft_{14}^{\langle j\rangle}, RFft_{15}^{\langle j\rangle}, RFft_{16}^{\langle j\rangle}\right)$$
$$RFft3(j) := augment\left(RFft_{17}^{\langle j\rangle}, RFft_{18}^{\langle j\rangle}, RFft_{19}^{\langle j\rangle}, RFft_{20}^{\langle j\rangle}, RFft_{21}^{\langle j\rangle}, RFft_{22}^{\langle j\rangle}, RFft_{23}^{\langle j\rangle}, RFft_{24}^{\langle j\rangle}\right)$$
$$RFft4(j) := augment\left(RFft_{25}^{\langle j\rangle}, RFft_{26}^{\langle j\rangle}, RFft_{27}^{\langle j\rangle}, RFft_{28}^{\langle j\rangle}, RFft_{29}^{\langle j\rangle}, RFft_{30}^{\langle j\rangle}, RFft_{31}^{\langle j\rangle}, RFft_{32}^{\langle j\rangle}\right)$$
$$RFft(j) := augment\left(RFft_1^{\langle 0\rangle}, RFft1(j), RFft2(j), RFft3(j), RFft4(j)\right)$$

A-7.1 Heat Exchanger Seismic Brace Rods 80th Percentile Loads

To evaluate the seismic brace rods, the 80th percentile tensile load must be found. To do this, the amplitudes of the translational force vectors are found at each of the seismic brace rod restraint locations. Subroutine "$RFbb_{amp}$" below is written to find these amplitudes for a given node at all time steps and realizations. For input, this subroutine accepts a column number for the first column where the given nodal output exits. It uses this to identify which node is to be evaluated. The first step in the subroutine is then to define the zero column of the temporary output variable with the time vector. Second, total number of nodes is identified knowing that only three load directions are put in the data file. Third, the reaction force arrays are defined for each direction for the given node. (They are arrays because they consist of the vector results of all 32 realizations.) Finally, the amplitude is found for each time step and realization and the final array is output.

$$
RFbb_{amp}(nd) := \left|\begin{array}{l}
out^{\langle 0 \rangle} \leftarrow RFbb_1^{\langle 0 \rangle} \\
no_{nd} \leftarrow \frac{1}{3}\cdot\left(cols(RFbb_1) - 1\right) \\
RF_1 \leftarrow RFbb(nd) \\
RF_2 \leftarrow RFbb(nd + no_{nd}) \\
RF_3 \leftarrow RFbb(nd + 2\cdot no_{nd}) \\
\text{for } j \in 1..32 \\
\quad \text{for } i \in 0..rows(RF_1) - 1 \\
\quad\quad out_{i,j} \leftarrow \left|\left(RF1_{i,j} \;\; RF2_{i,j} \;\; RF3_{i,j}\right)^T\right| \\
out
\end{array}\right.
$$

The variable "Nd_{bb}" below lists the nodes at the seismic brace rod restraint locations in the order that they are reported (with the zero term being a place holder). For example, defining "nd" as 15 in the subroutine above produces the amplitude array for node 45912 in the model.

$$Nd_{bb} := \begin{pmatrix} 0 \\ 45695 \\ 45697 \\ 45699 \\ 45701 \\ 45766 \\ 45768 \\ 45770 \\ 45772 \\ 45837 \\ 45839 \\ 45841 \\ 45843 \\ 45908 \\ 45910 \\ 45912 \\ 45914 \\ 45979 \\ 45981 \\ 45983 \\ 45985 \end{pmatrix}$$

Figure A-7.1-1 shows three of the 32 time history results produced if the definition below is made. The curves are for the 24th, 8th, and 22nd realizations respectively.

$$RFbb_{45912} := RFbb_{amp}(15)$$

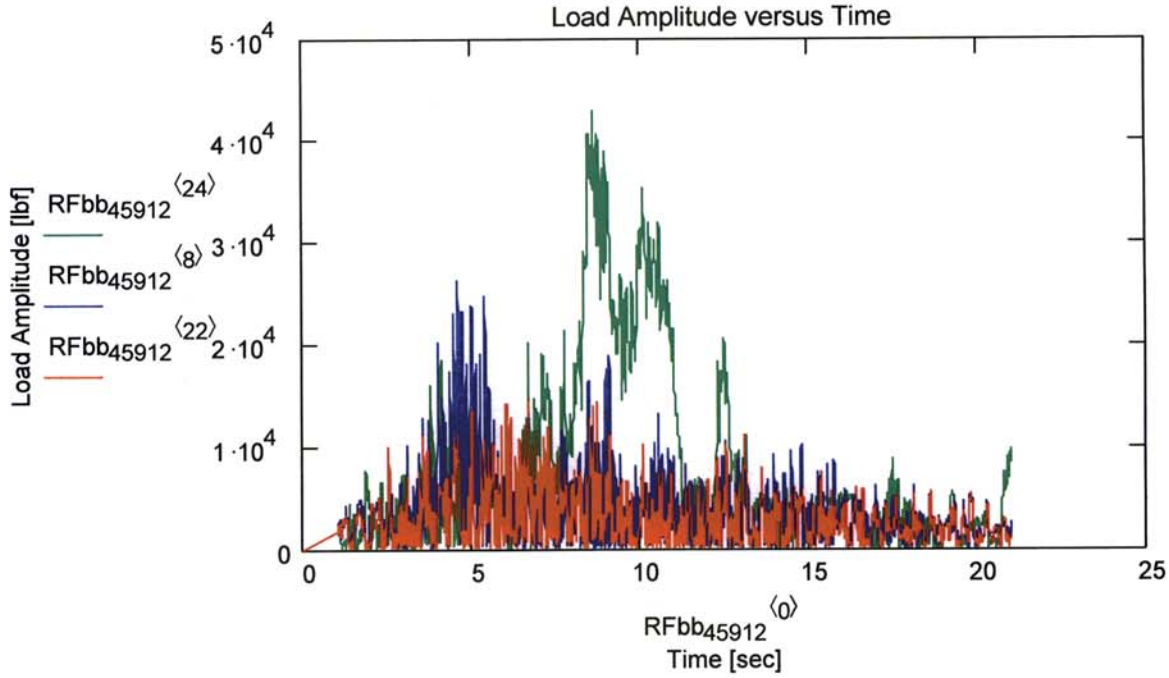

Figure A-7.1-1 – Force amplitude time histories for node 45912.

To establish the 80th percentile realization for a given node, the subroutine "$RFbb_{ord}$" is defined. For input, this subroutine accepts a column number for the first column where the given nodal output exits. The first step in the subroutine is then to run the subroutine "$FRbb_{amp}$" for the given node number. Second, an array is generated with the zero column being the maximum load for each realization and the one column being the realization number. Finally, the array is sorted base on the maximum load and output.

$$
\begin{aligned}
RFbb_{ord}(nd) := \;& RF \leftarrow RFbb_{amp}(nd) \\
& \text{for } j \in 1..32 \\
& \quad out_{j,1} \leftarrow j \\
& \quad out_{j,0} \leftarrow \max\left(RF^{\langle j \rangle}\right) \\
& csort(out, 0)
\end{aligned}
$$

Continuing the node 45912 example, the definition below can be made. Observing the definition below along with Figure A-7.1-1, realization 22 has the lowest maximum load, realization 8 has the 26th (which is the 80th percentile) lowest maximum load, and realization 24 has the highest maximum load.

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$RFbb_{ord}(15) =$

	0	1
1	$1.457 \cdot 10^4$	22
2	$1.51 \cdot 10^4$	3
3	$1.543 \cdot 10^4$	10
4	$1.617 \cdot 10^4$	19
5	$1.66 \cdot 10^4$	30
6	$1.664 \cdot 10^4$	21
7	$1.723 \cdot 10^4$	13
8	$1.737 \cdot 10^4$	1
9	$1.75 \cdot 10^4$	12
10	$1.792 \cdot 10^4$	17
11	$1.866 \cdot 10^4$	25
12	$1.927 \cdot 10^4$	32
13	$1.953 \cdot 10^4$	23
14	$1.976 \cdot 10^4$	15
15	$2.049 \cdot 10^4$	16
16	$2.06 \cdot 10^4$	28

$RFbb_{ord}(15) =$

	0	1
17	$2.066 \cdot 10^4$	7
18	$2.087 \cdot 10^4$	29
19	$2.157 \cdot 10^4$	5
20	$2.179 \cdot 10^4$	27
21	$2.258 \cdot 10^4$	14
22	$2.409 \cdot 10^4$	9
23	$2.584 \cdot 10^4$	20
24	$2.587 \cdot 10^4$	18
25	$2.602 \cdot 10^4$	11
26	$2.615 \cdot 10^4$	8
27	$2.644 \cdot 10^4$	4
28	$2.678 \cdot 10^4$	31
29	$3.135 \cdot 10^4$	2
30	$3.329 \cdot 10^4$	26
31	$3.452 \cdot 10^4$	6
32	$4.29 \cdot 10^4$	24

To find the 80th percentile load for each node and establish the maximum 80th percentile load for all of the nodes, the subroutine "$RFbb_{max80}$" is defined. The first step in the subroutine is to load the temporary "out" variable with zeros. Second, a "for" loop runs the subroutine "$RFbb_{ord}$" for each node. Within the "for" loop, a comparison of the 80th percentile values performed. For a loop cycle, if the current 80th percentile load is greater than the recorded 80th percentile load, the zero column of the "out" variable is loaded with the 80th percentile load value, the one column is loaded with the node data column value, and the two column is loaded with the realization number for the 80th percentile load.

```
RFbb_max80 := | out_{0,1} ← 0
              | for j ∈ 1 .. (1/3)·(cols(RFbb_1) − 1)
              |   | RF_ord ← RFbb_ord(j)
              |   | if out_{0,0} < RF_ord_{round(32·.8),0}
              |   |   | out_{0,0} ← RF_ord_{round(32·.8),0}
              |   |   | out_{0,1} ← j
              |   |   | out_{0,2} ← RF_ord_{round(32·.8),1}
              | out
```

Below are the subroutine "$RFbb_{max80}$" results. As shown the 80th percentile load is 26,100 lbf, and it occurs at node 45912 under the realization 8 loading.

$RFbb_{max80} = (26147 \quad 15 \quad 8)$ $\qquad Nd_{bb_{15}} = 45912$

A-7.2 Heat Exchanger Seismic Brace Pipes 80th Percentile Loads

To evaluate the seismic brace pipes, the 80th percentile compressive load must be found. This evaluation is performed with the same set of subroutines as used in section A-7.1. However, they are modified to use the correct data. These subroutines are shown below.

$$RFbr_{amp}(nd) := \left| \begin{array}{l} out^{\langle 0 \rangle} \leftarrow RFbr_1^{\langle 0 \rangle} \\ no_{nd} \leftarrow \frac{1}{3} \cdot (cols(RFbr_1) - 1) \\ RF_1 \leftarrow RFbr(nd) \\ RF_2 \leftarrow RFbr(nd + no_{nd}) \\ RF_3 \leftarrow RFbr(nd + 2 \cdot no_{nd}) \\ \text{for } j \in 1..32 \\ \quad \text{for } i \in 0..rows(RF_1) - 1 \\ \quad\quad out_{i,j} \leftarrow \left| \left(RF1_{i,j} \quad RF2_{i,j} \quad RF3_{i,j} \right)^T \right| \\ out \end{array} \right.$$

$$RFbr_{ord}(nd) := \left| \begin{array}{l} RF \leftarrow RFbr_{amp}(nd) \\ \text{for } j \in 1..32 \\ \quad \left| \begin{array}{l} out_{j,1} \leftarrow j \\ out_{j,0} \leftarrow max(RF^{\langle j \rangle}) \end{array} \right. \\ csort(out, 0) \end{array} \right.$$

```
RFbr_max80 := | out_{0,1} ← 0
              | for j ∈ 1 .. (1/3)·(cols(RFbr_1) − 1)
              |   | RF_ord ← RFbr_ord(j)
              |   | if out_{0,0} < RF_ord_{round(32·.8),0}
              |   |   | out_{0,0} ← RF_ord_{round(32·.8),0}
              |   |   | out_{0,1} ← j
              |   |   | out_{0,2} ← RF_ord_{round(32·.8),1}
              | out
```

The variable "Nd_{br}" below lists the nodes at the seismic brace rod restraint locations in the order that they are reported (with the zero term being a place holder). For example, defining "nd" as 21 in the subroutine above produces the amplitude array for node 30434 in the model.

$Nd_{br}^T =$

	0	1	2	3	4	5	6	7	8	9	10
0	0	30429	30441	24252	24264	18075	18087	8451	8518	40833	40845

$Nd_{br}^T =$

	11	12	13	14	15	16	17	18	19	20
0	30439	30443	24262	24266	18085	18089	8509	8522	40843	40846

$Nd_{br}^T =$

	21	22	23	24	25	26	27	28	29	30
0	30434	30442	8422	8516	24257	24265	18080	18088	8480	8520

Using subroutine "$RFbr_{amp}$" with "nd" defined as 23 produces the amplitude array for node 8422 in the model. Figure A-7.2-1 shows three of the 32 time history results produced if the definition below is made. The curves are for the 11th, 15th, and 29th realizations respectively.

$RFbr_{8422} := RFbr_{amp}(21)$

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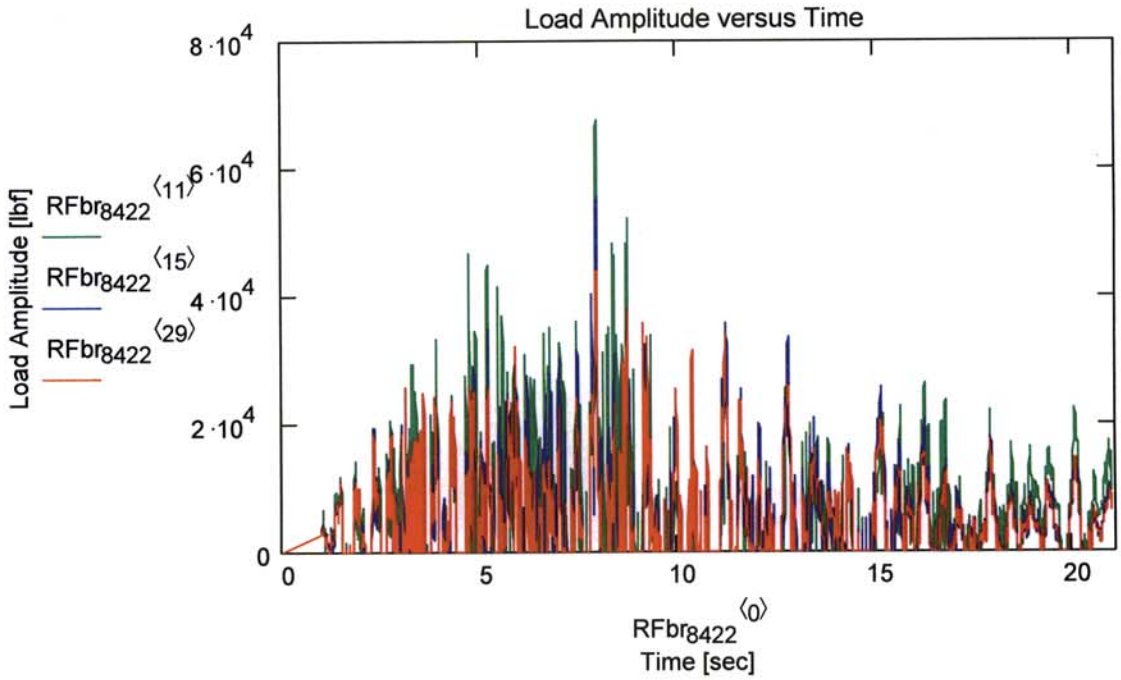

Figure A-7.2-1 – Force amplitude time histories for node 8422.

To establish the 80th percentile realization for a given node, the subroutine "$RFbr_{ord}$" is used. Continuing the node 8422 example, the definition below can be made. Observing the definition below along with Figure A-7.2-1, realization 29 has the lowest maximum load, realization 15 has the 26th (which is the 80th percentile) lowest maximum load, and realization 11 has the highest maximum load.

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$RFbr_{ord}(21) =$

	0	1
1	$4.388 \cdot 10^4$	29
2	$4.462 \cdot 10^4$	9
3	$4.496 \cdot 10^4$	1
4	$4.502 \cdot 10^4$	2
5	$4.721 \cdot 10^4$	30
6	$4.792 \cdot 10^4$	28
7	$4.857 \cdot 10^4$	16
8	$4.868 \cdot 10^4$	8
9	$4.872 \cdot 10^4$	7
10	$4.899 \cdot 10^4$	21
11	$4.917 \cdot 10^4$	12
12	$4.923 \cdot 10^4$	22
13	$4.95 \cdot 10^4$	10
14	$4.965 \cdot 10^4$	20
15	$5.066 \cdot 10^4$	14
16	$5.066 \cdot 10^4$	18

$RFbr_{ord}(21) =$

	0	1
17	$5.103 \cdot 10^4$	17
18	$5.156 \cdot 10^4$	23
19	$5.214 \cdot 10^4$	25
20	$5.242 \cdot 10^4$	32
21	$5.26 \cdot 10^4$	3
22	$5.34 \cdot 10^4$	5
23	$5.415 \cdot 10^4$	31
24	$5.426 \cdot 10^4$	27
25	$5.503 \cdot 10^4$	13
26	$5.531 \cdot 10^4$	15
27	$5.653 \cdot 10^4$	24
28	$5.753 \cdot 10^4$	26
29	$5.792 \cdot 10^4$	6
30	$5.841 \cdot 10^4$	19
31	$6.371 \cdot 10^4$	4
32	$6.73 \cdot 10^4$	11

To find the 80th percentile load for each node and establish the maximum 80th percentile load for all of the nodes, the subroutine "$RFbr_{max80}$" is defined. Below are the subroutine "$RFbr_{max80}$" results. As shown the 80th percentile load is 55,300 lbf, and it occurs at node 30434 under the realization 15 loading.

$RFbr_{max80} = (55311 \quad 21 \quad 15)$ $\qquad Nd_{br_{21}} = 30434$

A-7.3 Heat Exchanger Steel Columns 80th Percentile Loads

To evaluate the heat exchanger steel columns, the 80th percentile translational loads in all three directions at the bases must be found. This evaluation is performed with a similar set of subroutines as used in section A-7.1. A subroutine for finding amplitude is not needed as the 80th percentile for each direction is found. The subroutine "$RFsb_{ord}$" is then modified to start with defining the reaction force array and also to find the maximum absolute value with consideration of positive and negative amplitudes. The modification to "$RFsb_{max80}$" is to add an additional loop. This additional loop addresses each direction separately and puts the results of each direction on a separate row of output. These subroutines are shown below.

```
RFsb_ord(nd) := | RF ← RFsb(nd)
                | for j ∈ 1 .. 32
                |   | out_{j,1} ← j
                |   | out_{j,0} ← max((max(RF^⟨j⟩)  |min(RF^⟨j⟩)| ))
                | csort(out, 0)

RFsb_max80 := | out_{2,1} ← 0
              | no_nd ← (1/3)·(cols(RFsb_1) − 1)
              | for i ∈ 0 .. 2
              |   for j ∈ 1 .. no_nd
              |     | RF_ord ← RFsb_ord(j + i·no_nd)
              |     | if out_{i,0} < RF_ord_{round(32·.8),0}
              |     |   | out_{i,0} ← RF_ord_{round(32·.8),0}
              |     |   | out_{i,1} ← j
              |     |   | out_{i,2} ← RF_ord_{round(32·.8),1}
              | out
```

The variable "Nd_{sb}" below lists the nodes at the seismic brace rod restraint locations in the order that they are reported (with the zero term being a place holder). For example, defining "nd" as 7 in the subroutine above produces the amplitude array for node 46720 in the model.

$Nd_{sb}^{T} =$

	0	1	2	3	4	5	6	7	8	9	10	11	12
0	0	8448	18072	24249	30426	40830	44021	46720	46721	46722	46723	46724	46725

Definition of the reaction force array in the vertical direction for node 46720 is shown below. This is done considering that the node output is listed for all of the nodes in a single direction before listing the next direction and the vertical direction is the second direction output. Consequently, the "nd" must equal 7 plus the total number of nodes to get the vertical output for node 46720. Figure A-7.3-1 shows three of the 32 time history results produced if the definition below is made. The curves are for the 2nd, 23rd, and 31st realizations respectively.

$no_{sb} := \frac{1}{3} \cdot (\text{cols}(RFsb_1) - 1)$ Total number of nodes.

$no_{sb} = 12$

$RFsb_{46720} := RFsb(7 + no_{sb})$

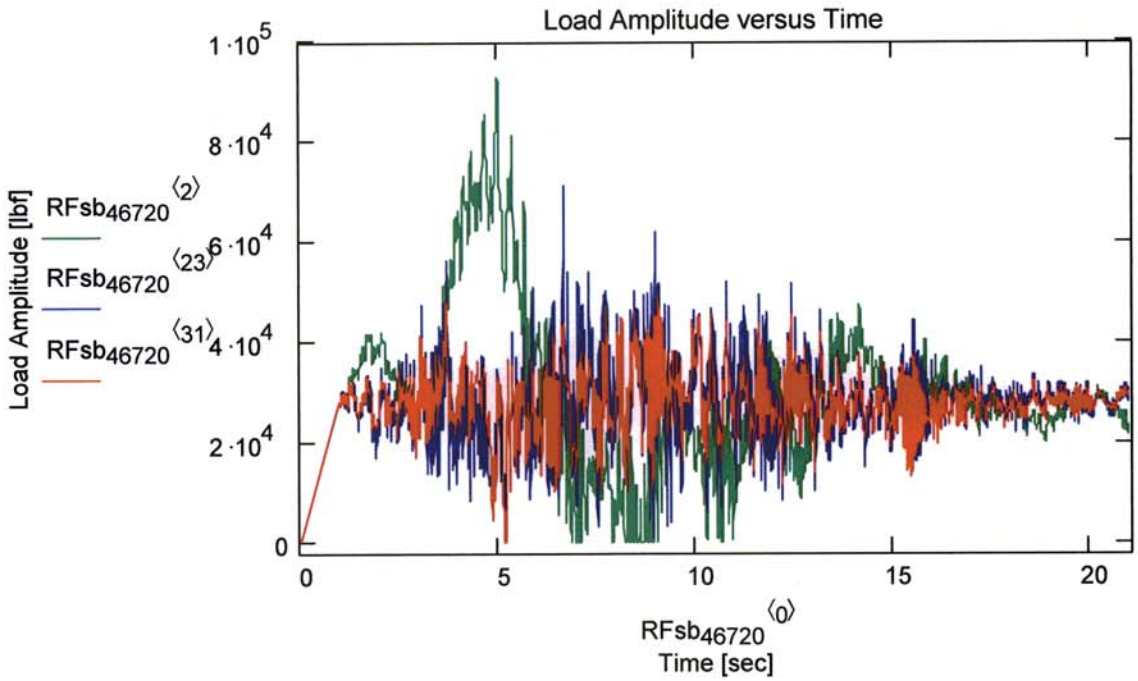

Figure A-7.3-1 – Force time histories for node 46720.

To establish the 80th percentile realization for a given node, the subroutine "$RFsb_{ord}$" is used. Continuing the vertical direction for node 46720 example, the definition below can be made. Observing the definition below along with Figure A-7.3-1, realization 31 has the lowest maximum load, realization 23 has the 26th (which is the 80th percentile) lowest maximum load, and realization 31 has the highest maximum load.

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$RFsb_{ord}(7 + no_{sb}) =$

	0	1
1	$4.912 \cdot 10^4$	31
2	$5.074 \cdot 10^4$	18
3	$5.48 \cdot 10^4$	15
4	$5.511 \cdot 10^4$	14
5	$5.571 \cdot 10^4$	21
6	$5.594 \cdot 10^4$	1
7	$5.652 \cdot 10^4$	13
8	$5.736 \cdot 10^4$	3
9	$5.798 \cdot 10^4$	19
10	$5.833 \cdot 10^4$	28
11	$5.877 \cdot 10^4$	12
12	$5.945 \cdot 10^4$	27
13	$5.968 \cdot 10^4$	32
14	$6.005 \cdot 10^4$	20
15	$6.07 \cdot 10^4$	10
16	$6.106 \cdot 10^4$	26

$RFsb_{ord}(7 + no_{sb}) =$

	0	1
17	$6.208 \cdot 10^4$	7
18	$6.227 \cdot 10^4$	11
19	$6.286 \cdot 10^4$	22
20	$6.303 \cdot 10^4$	25
21	$6.34 \cdot 10^4$	30
22	$6.419 \cdot 10^4$	29
23	$6.42 \cdot 10^4$	16
24	$6.68 \cdot 10^4$	9
25	$6.943 \cdot 10^4$	5
26	$7.124 \cdot 10^4$	23
27	$7.497 \cdot 10^4$	8
28	$7.681 \cdot 10^4$	4
29	$7.952 \cdot 10^4$	17
30	$8.214 \cdot 10^4$	6
31	$9.148 \cdot 10^4$	24
32	$9.289 \cdot 10^4$	2

To find the 80th percentile load for each node in each direction and establish the maximum 80th percentile load for all of the nodes, the subroutine "$RFsb_{max80}$" is defined. Below are the subroutine "$RFsb_{max80}$" results. As shown, the maximum 80th percentile load is 4250 lbf in the east-west direction and it occurs at node 18072 under realization 16 loading. The maximum 80th percentile load is 71,200 lbf in compression and it occurs at node 46720 under realization 23 loading. The maximum 80th percentile load is 726 lbf in the north-south direction and it occurs at node 24249 under realization 11 loading.

$$RFsb_{max80} = \begin{pmatrix} 4249 & 4 & 16 \\ 71240 & 7 & 23 \\ 726 & 4 & 11 \end{pmatrix} \qquad \begin{aligned} Nd_{sb_2} &= 18072 \\ Nd_{sb_7} &= 46720 \\ Nd_{sb_3} &= 24249 \end{aligned}$$

A-7.4 Heat Exchanger Concrete Columns 80th Percentile Loads

To evaluate the heat exchanger concrete columns, the 80th percentile translational and rotational loads in all three directions at the bases and tops must be found. The vertical direction is divided further to establish the 80th percentile compressive and tensile loads. This evaluation is performed similar to the Section A-7.3 evaluation. However, the additional details require additional changes to the approach. One significant difference is that the loads at the top of the heat exchanger concrete columns are output as element nodal forces instead of reaction forces. This produces additional unneeded nodal data. Below are the nodes corresponding to the heat exchanger elements that connect to the concrete columns (and the steel columns and the wall attachment locations).

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$Nd_{ft}^T =$

	0	1	2	3	4	5	6	7	8	9	10
0	0	37880	40826	40627	40831	40693	40836	40759	44022	8221	8449

$Nd_{ft}^T =$

	11	12	13	14	15	16	17	18	19	20
0	46	8420	8353	8507	8287	8478	17869	18073	15122	18068

$Nd_{ft}^T =$

	21	22	23	24	25	26	27	28	29	30
0	18001	18083	17935	18078	24046	24250	21299	24245	24178	24260

$Nd_{ft}^T =$

	31	32	33	34	35	36	37	38	39	40
0	24112	24255	30223	30427	27476	30422	30355	30437	30289	30432

The nodes for the heat exchanger concrete column bases are shown below.

$Nd_{cb}^T =$

	0	1	2	3	4	5	6	7	8	9	10	11	12
0	0	8419	8477	8506	18067	18077	18082	24244	24254	24259	30421	30431	30436

Definition of the reaction force array in the vertical direction for node 8419 is shown below. This is done considering that the node output is listed for all of the nodes in a single direction before listing the next direction and the vertical direction is the second direction output. Consequently, the "nd" must equal 1 plus the total number of column bottom nodes to get the vertical output for node 8419. (The definition of the total number of column top nodes is also shown below.) Figure A-7.4-1 shows five of the 32 time history results produced if the definition below is made. The curves are for the 4th, 24th, 11th, 17th, and 13th realizations respectively.

$no_{cb} := \frac{1}{6} \cdot (\mathrm{cols}(RFcb_1) - 1)$ Total number of botton nodes.

$no_{cb} = 12$

$no_{ft} := \frac{1}{6} \cdot (\mathrm{cols}(RFft_1) - 1)$ Total number of top nodes.

$no_{ft} = 40$

$RFcb_{8419} := RFcb(1 + no_{cb})$

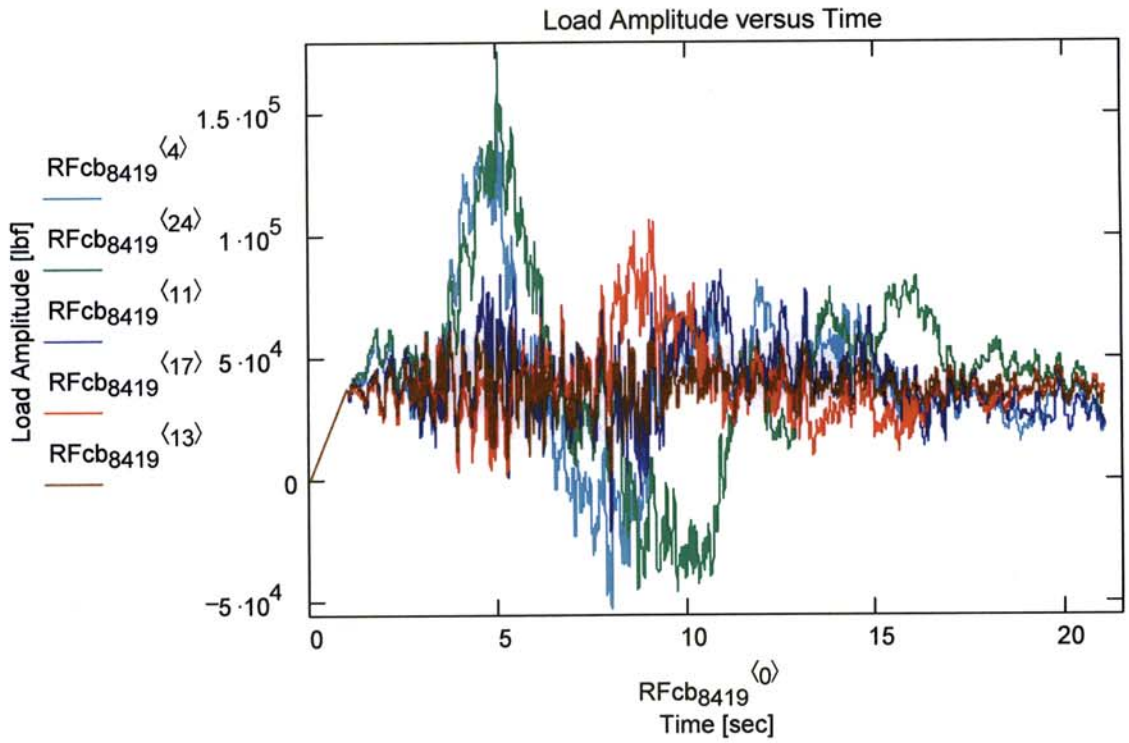

Figure A-7.4-1 – Force time histories for node 8419.

Due to the need for compressive and tensile 80th percentile loads, the ordering subroutine is defined two different ways as "RFc_{ord}" (for envelope of all loads) and "RFc_{ordv}" (for the tensile loads). The subroutine "RFc_{ord}" is defined similar to the subroutine in Section A-7.3. The subroutine "RFc_{ordv}" finds only minimums (which are appropriate for tensile loads) and then reverses the sort at the end to put the amplitude value at the highest ordered value. If a column only has compressive loads, then the zero placeholder is recorded as the minimum. This ensures that compressive load values are not mixed with tensile load values.

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$$RFc_{ord}(RF) := \left| \begin{array}{l} \text{for } j \in 1..32 \\ \quad \left| \begin{array}{l} out_{j,1} \leftarrow j \\ out_{j,0} \leftarrow \max\left(\left(\max\left(RF^{\langle j \rangle}\right) \;\; \left|\min\left(RF^{\langle j \rangle}\right)\right|\right)\right) \end{array} \right. \\ csort(out, 0) \end{array} \right.$$

$$RFc_{ordv}(RF) := \left| \begin{array}{l} \text{for } j \in 1..32 \\ \quad \left| \begin{array}{l} out_{j,1} \leftarrow j \\ out_{j,0} \leftarrow \min\left(RF^{\langle j \rangle}\right) \end{array} \right. \\ reverse(csort(out, 0)) \end{array} \right.$$

Example output for each subroutine. The first is for the compressive load in node 8419 and the second is for the tensile load in the same node. Observing the definition below along with Figure A-7.4-1, realization 13 has the lowest maximum load relative to compression, realization 17 has the lowest maximum load relative to tension, realization 11 has the 26th (which is the 80th percentile) lowest maximum load in compression and in tension, realization 24 has the highest maximum load in compression, and realization 4 has the highest maximum load for both tension.

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$RFc_{ord}(RFcb(1 + no_{cb})) =$

	0	1
1	62592	13
2	62735	9
3	63718	29
4	66326	28
5	66824	12
6	67053	32
7	67476	16
8	68615	21
9	69392	15
10	69472	19
11	69527	1
12	70079	30
13	70831	25
14	71824	27
15	71891	10
16	73072	22

$RFc_{ord}(RFcb(1 + no_{cb})) =$

	0	1
17	73145	3
18	73583	5
19	74469	8
20	75443	23
21	77892	7
22	78141	2
23	78564	18
24	80411	20
25	83777	14
26	86260	11
27	89653	31
28	95982	26
29	106921	17
30	143440	6
31	144989	4
32	175482	24

$RFc_{ordv}(RFcb(1 + no_{cb})) =$

	0	1
1	0	17
2	0	22
3	0	30
4	0	29
5	0	2
6	0	5
7	0	23
8	0	12
9	0	25
10	0	13
11	0	14
12	-341	32
13	-703	27
14	-1908	19
15	-3392	16
16	-3776	1

$RFc_{ordv}(RFcb(1 + no_{cb})) =$

	0	1
17	-3955	3
18	-5471	7
19	-6146	21
20	-7537	10
21	-7837	28
22	-8893	15
23	-13390	9
24	-19598	20
25	-20734	18
26	-21066	11
27	-24535	8
28	-29449	26
29	-30061	6
30	-39137	31
31	-46103	24
32	-52926	4

A further node variable is defined below to identify only the nodes of concern for the bottom and top of each heat exchanger concrete column.

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$$Nd_{con} = \begin{array}{c} \begin{array}{cc} \text{Bottom} & \text{Top} \end{array} \\ \begin{pmatrix} 8419 & 8420 \\ 8506 & 8507 \\ 8477 & 8478 \\ 18067 & 18068 \\ 18082 & 18083 \\ 18077 & 18078 \\ 24244 & 24245 \\ 24259 & 24260 \\ 24254 & 24255 \\ 30421 & 30422 \\ 30436 & 30437 \\ 30431 & 30432 \end{pmatrix} \end{array} \begin{array}{l} \\ \text{Heat Exchanger 670-M-2 east} \\ \text{Heat Exchanger 670-M-2 south} \\ \text{Heat Exchanger 670-M-2 west} \\ \text{Heat Exchanger 670-M-3 east} \\ \text{Heat Exchanger 670-M-3 south} \\ \text{Heat Exchanger 670-M-3 west} \\ \text{Heat Exchanger 670-M-4 east} \\ \text{Heat Exchanger 670-M-4 south} \\ \text{Heat Exchanger 670-M-4 west} \\ \text{Heat Exchanger 670-M-5 east} \\ \text{Heat Exchanger 670-M-5 south} \\ \text{Heat Exchanger 670-M-5 west} \end{array}$$

At this point, subroutine "RF_{con80}" can be defined to output 80th percentile data for each heat exchanger concrete column. Subroutine "RF_{con80}" has an input of a row number for the variable "Nd_{con}". The first step in this subroutine is to use the two node numbers in the defined row of the variable "Nd_{con}" to find the matching rows from the variables "Nd_{cb}" and "Nd_{ft}" (which in turn correlates with the reaction force array columns). The second step is to loop through each of the six degrees of freedom for the top and bottom heat exchanger column nodes. For each degree of freedom, the subroutine "RFc_{ord}" is used on the top and bottom nodes. The bottom node 80th percentile load value is defined to the zero column of the "out" variable. The bottom node 80th percentile realization value is defined to the one column of the "out" variable. The top node 80th percentile load value is defined to the two column of the "out" variable. The top node 80th percentile realization value is defined to the three column of the "out" variable. The third step is to repeat the vertical degree of freedom evaluation using the subroutine "RFc_{ordv}" (for tensile loads). The load amplitudes are the values stored to the "out" variable. Finally, the "out" variable is output.

$$
\begin{aligned}
RF_{con80}(j) := \;& p_b \leftarrow \mathrm{match}\left(Nd_{con_{j,0}}, Nd_{cb}\right)_0 \\
& p_t \leftarrow \mathrm{match}\left(Nd_{con_{j,1}}, Nd_{ft}\right)_0 \\
& \text{for } i \in 0..5 \\
& \quad RF_b \leftarrow RFc_{ord}\left(RFcb\left(p_b + i \cdot no_{cb}\right)\right) \\
& \quad RF_t \leftarrow RFc_{ord}\left(RFft\left(p_t + i \cdot no_{ft}\right)\right) \\
& \quad out_{i,0} \leftarrow RF_{b_{round(32 \cdot .8),0}} \\
& \quad out_{i,1} \leftarrow RF_{b_{round(32 \cdot .8),1}} \\
& \quad out_{i,2} \leftarrow RF_{t_{round(32 \cdot .8),0}} \\
& \quad out_{i,3} \leftarrow RF_{t_{round(32 \cdot .8),1}} \\
& RF_b \leftarrow RFc_{ordv}\left(RFcb\left(p_b + no_{cb}\right)\right) \\
& RF_t \leftarrow RFc_{ordv}\left(-RFft\left(p_t + no_{ft}\right)\right) \\
& out_{6,0} \leftarrow \left|RF_{b_{round(32 \cdot .8),0}}\right| \\
& out_{6,1} \leftarrow RF_{b_{round(32 \cdot .8),1}} \\
& out_{6,2} \leftarrow \left|RF_{t_{round(32 \cdot .8),0}}\right| \\
& out_{6,3} \leftarrow RF_{t_{round(32 \cdot .8),1}} \\
& out
\end{aligned}
$$

Below are the subroutine "RF_{con80}" results.

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Concrete column 80th percentile loads for the east column of 670-M-2.

$$RF_{con80}(0) = \begin{array}{c} \begin{array}{cccc} \text{Bottom} & & \text{Top} & \\ \text{load} & \text{real.} & \text{load} & \text{real.} \end{array} \\ \begin{pmatrix} 11087 & 27 & 50276 & 31 \\ 86260 & 11 & 83167 & 11 \\ 6684 & 9 & 6197 & 10 \\ 480361 & 9 & 34787 & 15 \\ 39951 & 20 & 39923 & 20 \\ 513222 & 27 & 386918 & 31 \\ 21066 & 11 & 23891 & 11 \end{pmatrix} \end{array} \begin{array}{l} \\ \text{East-west shear.} \\ \text{Vertical compression.} \\ \text{North-south shear.} \\ \text{East-west moment.} \\ \text{Vertical torsion.} \\ \text{North-south moment.} \\ \text{Vertical tension.} \end{array}$$

Concrete column 80th percentile loads for the south column of 670-M-2.

$$RF_{con80}(1) = \begin{array}{c} \begin{array}{cccc} \text{Bottom} & & \text{Top} & \\ \text{load} & \text{real.} & \text{load} & \text{real.} \end{array} \\ \begin{pmatrix} 10742 & 13 & 10213 & 13 \\ 86165 & 2 & 83316 & 2 \\ 4308 & 1 & 29296 & 21 \\ 203017 & 9 & 345765 & 25 \\ 41633 & 4 & 41569 & 4 \\ 773684 & 13 & 57761 & 13 \\ 15028 & 9 & 17854 & 9 \end{pmatrix} \end{array} \begin{array}{l} \\ \text{East-west shear.} \\ \text{Vertical compression.} \\ \text{North-south shear.} \\ \text{East-west moment.} \\ \text{Vertical torsion.} \\ \text{North-south moment.} \\ \text{Vertical tension.} \end{array}$$

Concrete column 80th percentile loads for the west column of 670-M-2.

$$RF_{con80}(2) = \begin{array}{c} \begin{array}{cccc} \text{Bottom} & & \text{Top} & \\ \text{load} & \text{real.} & \text{load} & \text{real.} \end{array} \\ \begin{pmatrix} 13455 & 24 & 29205 & 26 \\ 93865 & 20 & 90820 & 20 \\ 6096 & 25 & 5477 & 14 \\ 430438 & 22 & 30932 & 14 \\ 40987 & 26 & 40956 & 26 \\ 572318 & 27 & 520181 & 6 \\ 20958 & 11 & 23579 & 11 \end{pmatrix} \end{array} \begin{array}{l} \\ \text{East-west shear.} \\ \text{Vertical compression.} \\ \text{North-south shear.} \\ \text{East-west moment.} \\ \text{Vertical torsion.} \\ \text{North-south moment.} \\ \text{Vertical tension.} \end{array}$$

Concrete column 80th percentile loads for the east column of 670-M-3.

$$RF_{con80}(3) = \begin{array}{c} \begin{array}{cccc} \text{Bottom} & & \text{Top} & \\ \text{load} & \text{real.} & \text{load} & \text{real.} \end{array} \\ \begin{pmatrix} 11377 & 24 & 39845 & 23 \\ 88824 & 11 & 85765 & 11 \\ 6310 & 12 & 6206 & 28 \\ 461676 & 28 & 35119 & 28 \\ 51824 & 25 & 51791 & 25 \\ 509260 & 24 & 496124 & 23 \\ 20364 & 26 & 23334 & 26 \end{pmatrix} \end{array} \begin{array}{l} \\ \text{East-west shear.} \\ \text{Vertical compression.} \\ \text{North-south shear.} \\ \text{East-west moment.} \\ \text{Vertical torsion.} \\ \text{North-south moment.} \\ \text{Vertical tension.} \end{array}$$

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Concrete column 80th percentile loads for the south column of 670-M-3.

$$RF_{con80}(4) = \begin{array}{c} \begin{array}{cccc} \text{Bottom} & & \text{Top} & \\ \text{load} & \text{real.} & \text{load} & \text{real.} \end{array} \\ \begin{pmatrix} 7623 & 26 & 7570 & 24 \\ 85345 & 2 & 81855 & 2 \\ 4769 & 1 & 32663 & 12 \\ 239886 & 9 & 381844 & 11 \\ 55905 & 24 & 55844 & 24 \\ 559480 & 19 & 42226 & 24 \\ 18912 & 11 & 21945 & 11 \end{pmatrix} \end{array}$$

East-west shear.
Vertical compression.
North-south shear.
East-west moment.
Vertical torsion.
North-south moment.
Vertical tension.

Concrete column 80th percentile loads for the west column of 670-M-3.

$$RF_{con80}(5) = \begin{array}{c} \begin{array}{cccc} \text{Bottom} & & \text{Top} & \\ \text{load} & \text{real.} & \text{load} & \text{real.} \end{array} \\ \begin{pmatrix} 11265 & 5 & 30074 & 15 \\ 94452 & 26 & 91266 & 26 \\ 8526 & 5 & 7915 & 5 \\ 610823 & 5 & 44275 & 5 \\ 47779 & 13 & 47786 & 13 \\ 502143 & 5 & 546190 & 6 \\ 22952 & 31 & 25980 & 31 \end{pmatrix} \end{array}$$

East-west shear.
Vertical compression.
North-south shear.
East-west moment.
Vertical torsion.
North-south moment.
Vertical tension.

Concrete column 80th percentile loads for the east column of 670-M-4.

$$RF_{con80}(6) = \begin{array}{c} \begin{array}{cccc} \text{Bottom} & & \text{Top} & \\ \text{load} & \text{real.} & \text{load} & \text{real.} \end{array} \\ \begin{pmatrix} 10472 & 23 & 28951 & 2 \\ 95440 & 11 & 92126 & 11 \\ 6210 & 9 & 5755 & 9 \\ 445286 & 9 & 32091 & 15 \\ 35870 & 22 & 35892 & 22 \\ 451373 & 19 & 507145 & 31 \\ 22199 & 9 & 25071 & 9 \end{pmatrix} \end{array}$$

East-west shear.
Vertical compression.
North-south shear.
East-west moment.
Vertical torsion.
North-south moment.
Vertical tension.

Concrete column 80th percentile loads for the south column of 670-M-4.

$$RF_{con80}(7) = \begin{array}{c} \begin{array}{cccc} \text{Bottom} & & \text{Top} & \\ \text{load} & \text{real.} & \text{load} & \text{real.} \end{array} \\ \begin{pmatrix} 8630 & 26 & 8191 & 19 \\ 80683 & 4 & 77693 & 4 \\ 4898 & 14 & 34003 & 14 \\ 240431 & 22 & 399263 & 26 \\ 46423 & 14 & 46354 & 14 \\ 624449 & 19 & 46292 & 19 \\ 19512 & 9 & 22308 & 9 \end{pmatrix} \end{array}$$

East-west shear.
Vertical compression.
North-south shear.
East-west moment.
Vertical torsion.
North-south moment.
Vertical tension.

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Concrete column 80th percentile loads for the west column of 670-M-4.

$$RF_{con80}(8) = \begin{array}{c} \begin{array}{cccc} \text{Bottom} & & \text{Top} & \\ \text{load} & \text{real.} & \text{load} & \text{real.} \end{array} \\ \begin{pmatrix} 10108 & 31 & 39546 & 25 \\ 97105 & 26 & 94221 & 26 \\ 5905 & 22 & 5683 & 7 \\ 427033 & 26 & 31172 & 2 \\ 37775 & 25 & 37743 & 25 \\ 454311 & 31 & 525708 & 5 \\ 25926 & 11 & 28547 & 11 \end{pmatrix} \end{array} \begin{array}{l} \\ \text{East-west shear.} \\ \text{Vertical compression.} \\ \text{North-south shear.} \\ \text{East-west moment.} \\ \text{Vertical torsion.} \\ \text{North-south moment.} \\ \text{Vertical tension.} \end{array}$$

Concrete column 80th percentile loads for the east column of 670-M-5.

$$RF_{con80}(9) = \begin{array}{c} \begin{array}{cccc} \text{Bottom} & & \text{Top} & \\ \text{load} & \text{real.} & \text{load} & \text{real.} \end{array} \\ \begin{pmatrix} 12384 & 23 & 26578 & 27 \\ 85844 & 11 & 82955 & 11 \\ 7568 & 26 & 7483 & 11 \\ 561621 & 26 & 42243 & 11 \\ 75152 & 27 & 75141 & 27 \\ 525557 & 31 & 532877 & 23 \\ 23465 & 6 & 26500 & 6 \end{pmatrix} \end{array} \begin{array}{l} \\ \text{East-west shear.} \\ \text{Vertical compression.} \\ \text{North-south shear.} \\ \text{East-west moment.} \\ \text{Vertical torsion.} \\ \text{North-south moment.} \\ \text{Vertical tension.} \end{array}$$

Concrete column 80th percentile loads for the south column of 670-M-5.

$$RF_{con80}(10) = \begin{array}{c} \begin{array}{cccc} \text{Bottom} & & \text{Top} & \\ \text{load} & \text{real.} & \text{load} & \text{real.} \end{array} \\ \begin{pmatrix} 9270 & 24 & 8848 & 11 \\ 85044 & 7 & 81950 & 7 \\ 5325 & 25 & 35221 & 2 \\ 264027 & 25 & 402125 & 15 \\ 69762 & 30 & 69672 & 30 \\ 672023 & 24 & 50247 & 8 \\ 22577 & 19 & 25662 & 19 \end{pmatrix} \end{array} \begin{array}{l} \\ \text{East-west shear.} \\ \text{Vertical compression.} \\ \text{North-south shear.} \\ \text{East-west moment.} \\ \text{Vertical torsion.} \\ \text{North-south moment.} \\ \text{Vertical tension.} \end{array}$$

Concrete column 80th percentile loads for the west column of 670-M-5.

$$RF_{con80}(11) = \begin{array}{c} \begin{array}{cccc} \text{Bottom} & & \text{Top} & \\ \text{load} & \text{real.} & \text{load} & \text{real.} \end{array} \\ \begin{pmatrix} 9984 & 31 & 55640 & 15 \\ 102012 & 20 & 99061 & 20 \\ 11697 & 28 & 11169 & 11 \\ 848209 & 10 & 63981 & 11 \\ 59587 & 2 & 59506 & 2 \\ 467943 & 31 & 456653 & 15 \\ 27463 & 11 & 30324 & 11 \end{pmatrix} \end{array} \begin{array}{l} \\ \text{East-west shear.} \\ \text{Vertical compression.} \\ \text{North-south shear.} \\ \text{East-west moment.} \\ \text{Vertical torsion.} \\ \text{North-south moment.} \\ \text{Vertical tension.} \end{array}$$

To summarize output data, one further subroutine can be written which envelopes south-side columns and east- and west-side columns. The following definitions are first made to separate the south-side columns from the east- and west-side columns.

$$j_s := \begin{pmatrix} 1 \\ 4 \\ 7 \\ 10 \end{pmatrix}$$ Row numbers for south side columns

$$j_{ew} := \begin{pmatrix} 0 \\ 2 \\ 3 \\ 5 \\ 6 \\ 8 \\ 9 \\ 11 \end{pmatrix}$$ Row numbers for east and west side columns

The subroutine "$RF_{con80env}$" accepts one of the above two variables as input. The first step is then to loop through the nodes identified by the given variable above. If a load value in an iteration of the loop represent a maximum, then it is defined as the enveloping value. The definition of the maximum 80th percentile data is similar to that of subroutine "RF_{con80}" except the node number producing the maximum data is added to the output.

```
RF_con80env(j_cb) := | out[6,5] ← 0
                     | for j ∈ 0..last(j_cb)
                     |   for i ∈ 0..6
                     |     | RF ← RF_con80(j_cb[j])
                     |     | if out[i,0] < RF[i,0]
                     |     |   | out[i,0] ← RF[i,0]
                     |     |   | out[i,1] ← Nd_con[j,0]
                     |     |   | out[i,2] ← RF[i,1]
                     |     | if out[i,3] < RF[i,2]
                     |     |   | out[i,3] ← RF[i,2]
                     |     |   | out[i,4] ← Nd_con[j,1]
                     |     |   | out[i,5] ← RF[i,3]
                     | out
```

Below are the subroutine "$RF_{con80env}$" results.

$$RF_{con80env}(j_s) = \begin{array}{c} \begin{array}{cccccc} \text{Bottom} & & & \text{Top} & & \\ \text{load} & \text{node} & \text{real.} & \text{load} & \text{node} & \text{real.} \end{array} \\ \begin{pmatrix} 10742 & 8419 & 13 & 10213 & 8420 & 13 \\ 86165 & 8419 & 2 & 83316 & 8420 & 2 \\ 5325 & 18067 & 25 & 35221 & 18068 & 2 \\ 264027 & 18067 & 25 & 402125 & 18068 & 15 \\ 69762 & 18067 & 30 & 69672 & 18068 & 30 \\ 773684 & 8419 & 13 & 57761 & 8420 & 13 \\ 22577 & 18067 & 19 & 25662 & 18068 & 19 \end{pmatrix} \end{array}$$

Concrete column 80th percentile south column enveloping loads .

East-west shear.
Vertical compression.
North-south shear.
East-west moment.
Vertical torsion.
North-south moment.
Vertical tension.

$$RF_{con80env}(j_{ew}) = \begin{array}{c} \begin{array}{cccccc} \text{Bottom} & & & \text{Top} & & \\ \text{load} & \text{node} & \text{real.} & \text{load} & \text{node} & \text{real.} \end{array} \\ \begin{pmatrix} 13455 & 8506 & 24 & 55640 & 24260 & 15 \\ 102012 & 24259 & 20 & 99061 & 24260 & 20 \\ 11697 & 24259 & 28 & 11169 & 24260 & 11 \\ 848209 & 24259 & 10 & 63981 & 24260 & 11 \\ 75152 & 24244 & 27 & 75141 & 24245 & 27 \\ 572318 & 8506 & 27 & 546190 & 18068 & 6 \\ 27463 & 24259 & 11 & 30324 & 24260 & 11 \end{pmatrix} \end{array}$$

Concrete column 80th percentile east-west columns enveloping loads .

East-west shear.
Vertical compression.
North-south shear.
East-west moment.
Vertical torsion.
North-south moment.
Vertical tension.

A-7.5 Heat Exchanger Lug Realization 14 Shell Stresses

The shell model (Figure A-5.1-1) was run for only realization 14. This serves as an example of the stresses that could occur in the nozzles and lugs. This model included plasticity in the material properties. However, no plasticity occurred during the model run. The Tresca stress for the lugs and primary piping nozzles portion of the heat exchangers is shown in Figures A-7.5-1 – A-7.5-2.

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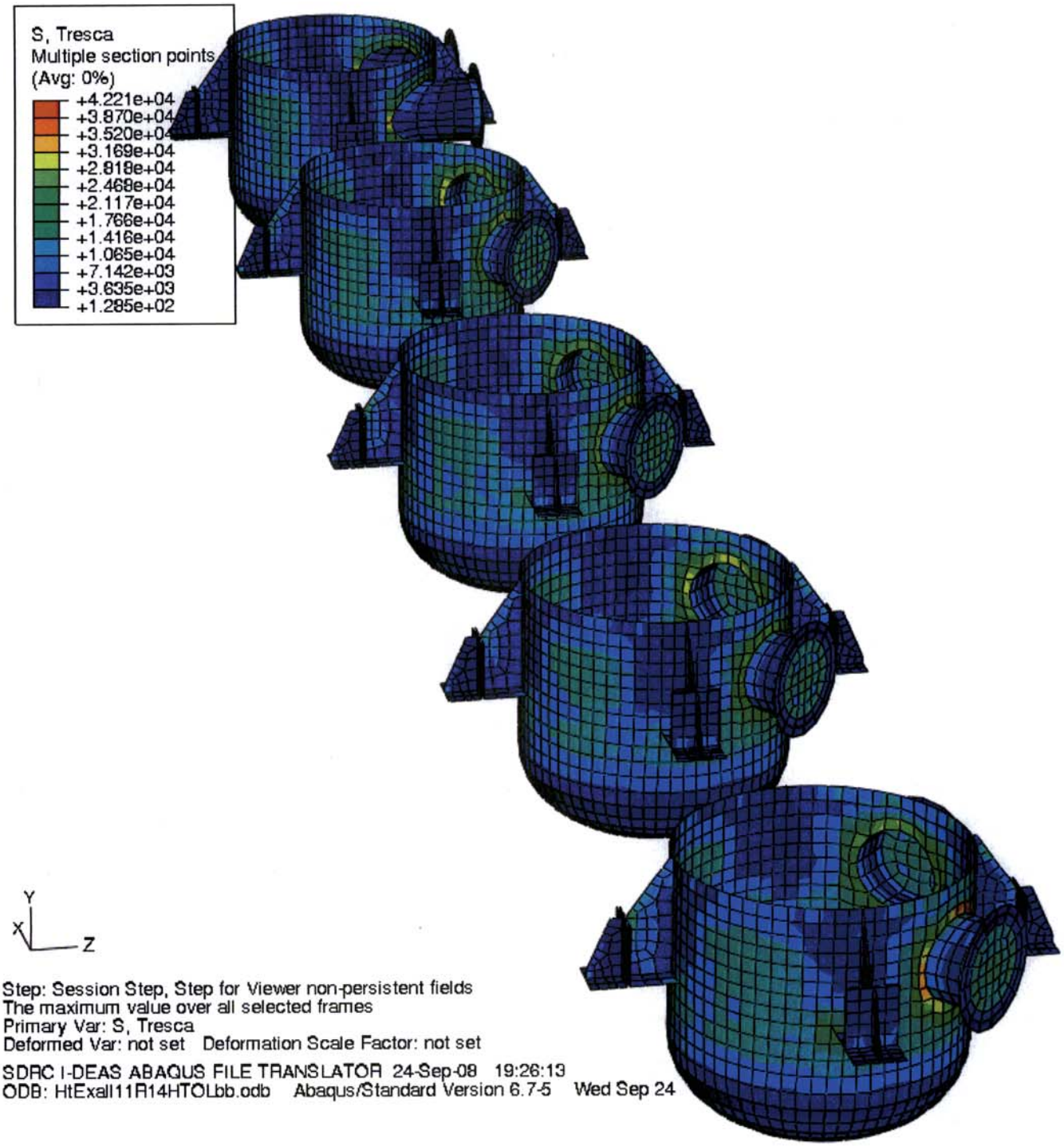

Figure A-7.5-1 – Surface Tresca stresses.

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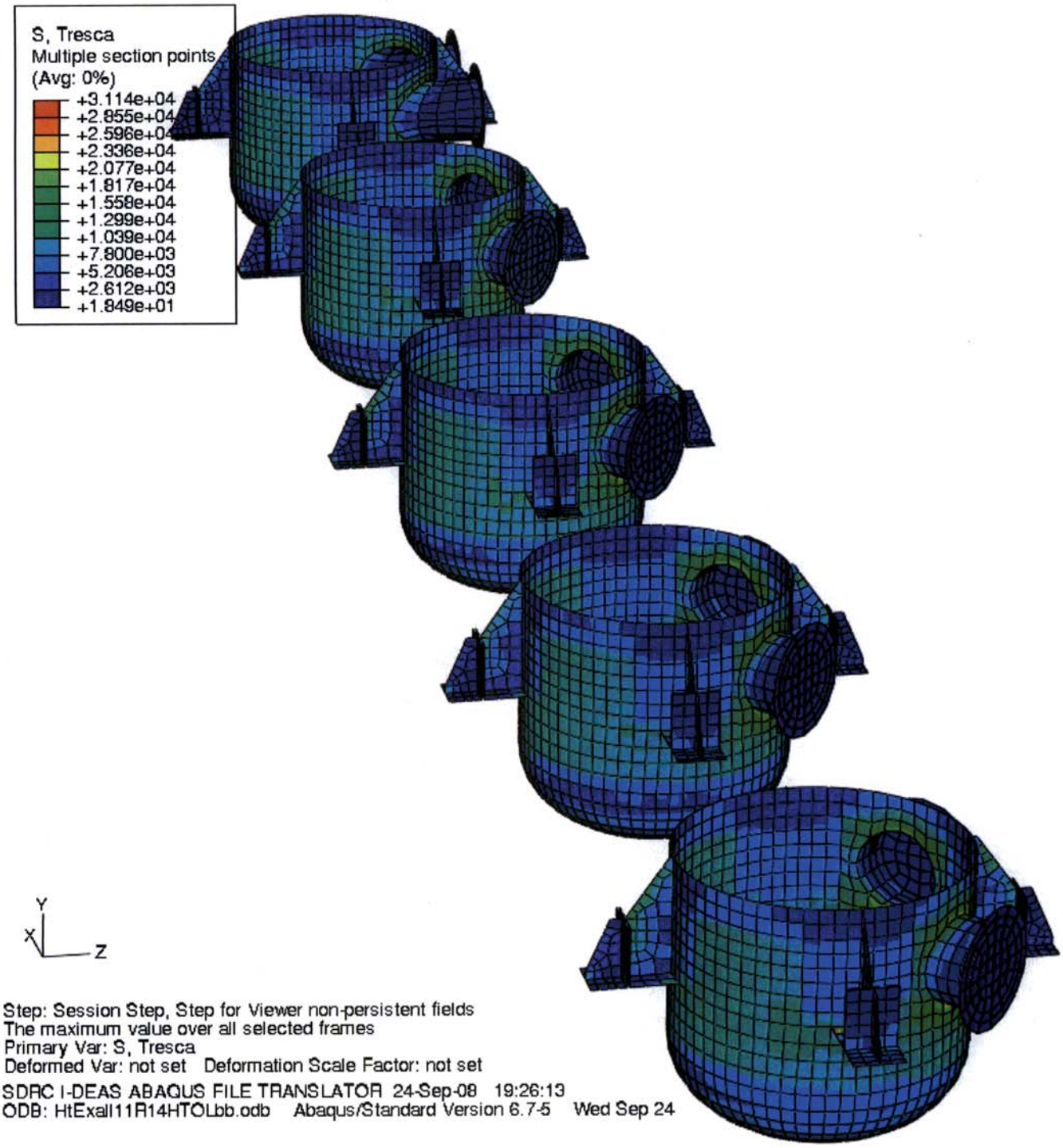

Figure A-7.5-2 – Midplane Tresca stress.

A-8.0 Abbreviated Input Files and Script Files Data

The input files below have element and node data removed to reduce the data to an amount reasonable for printing. Using this and the mesh descriptions in Section A-5.0, generation of a similar complete input file should be possible.

A-8.1 Natural Frequencies for the Fine Meshed Model

Below is a reduced version of the base model input file "HtExall11FRbb.inp." This contains header information, materials, and step information.

```
**%  ==========================================================
**%
**%          NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%               FOR ABAQUS VERSION 6.x
**%
**%       MODEL FILE: C:\er2\work\Stuart_misc\Heat_Exchangers_Seismic\Heat_Exchanger_NX5.mf1
**%       INPUT FILE: C:\er2\work\Stuart_misc\Heat_Exchangers_Seismic\input\HtExall10R14HTOLbb.inp
**%         EXPORTED: AT 19:26:13 ON 24-Sep-08
**%            PART: heat exchanger fe 1
**%             FEM: all (w/pressure)
**%
**%          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
**%=========================================
**%       MODAL DATA
**%=========================================
*MATERIAL,NAME=A212
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  2.70000E-01
*DENSITY
 7.31737E-04,
*PLASTIC
 38051.6, 0.0
*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=CONCRETE_CRACKED
*ELASTIC,TYPE=ISOTROPIC
 1.66000E+06,  1.70000E-01
```

```
*DENSITY
 2.24800E-04,
*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=A7BOLT
*ELASTIC,TYPE=ISOTROPIC
 3.00000E+07,  2.70000E-01
*DENSITY
 7.31737E-04,
*PLASTIC
 33036.3, 0.0
*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=A53_36
*ELASTIC,TYPE=ISOTROPIC
 3.00000E+07,  2.90000E-01
*DENSITY
 2.90300E-03,
*PLASTIC
 36043.2, 0.0
*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=A53_20
*ELASTIC,TYPE=ISOTROPIC
 3.00000E+07,  2.90000E-01
*DENSITY
 1.90700E-03,
*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=SST304_RED20X05
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 1.59000E-03,
*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=SST304_B30X0438_R
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
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*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=SST304_B24X0312_BR
*ELASTIC,TYPE=ISOTROPIC
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*DENSITY
 2.15000E-03,
*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*EXPANSION,TYPE=ISO
 1.00000E-35,
*CONDUCTIVITY,TYPE=ISO
 5.62022E+00,
*MATERIAL,NAME=SST304_B20X0312_R
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*DAMPING, ALPHA=0.5613, BETA=1.436E-03
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*DAMPING, ALPHA=0.5613, BETA=1.436E-03
```

```
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*DENSITY
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*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=SST304_24X0375_1
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15000E-03,
*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=SST304_20X0312_1
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
 2.15200E-03,
*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=SST304_30X0438
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
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*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=SST304_RED24X0375
*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
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*DAMPING, ALPHA=0.5613, BETA=1.436E-03
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*ELASTIC,TYPE=ISOTROPIC
 2.80000E+07,  3.00000E-01
*DENSITY
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*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=SST304_RED30X05_1
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 2.80000E+07,  3.00000E-01
*DENSITY
 2.00200E-03,
*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=SST304_24X0375
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.15200E-03,
*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=SST304_RED24X05
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.15200E-03,
*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=SST304_RED36X05
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.33900E-03,
```

```
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*MATERIAL,NAME=SST304_T3775X1375
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*DENSITY
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*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=SST304_36X05
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
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*DENSITY
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*DAMPING, ALPHA=0.5613, BETA=1.436E-03
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 2.77000E+07,  3.00000E-01
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*DAMPING, ALPHA=0.5613, BETA=1.436E-03
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*DENSITY
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*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=SST304_B30X04375_R
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.25900E-03,
*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*EXPANSION,TYPE=ISO
 1.00000E-35,
*MATERIAL,NAME=SST304_B20X0312_BR
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
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*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=SST304_B36X05_R
*ELASTIC,TYPE=ISOTROPIC
 2.77000E+07,  3.00000E-01
*DENSITY
 2.33900E-03,
*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=A36
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 3.00000E+07,  2.70000E-01
*DENSITY
 7.31737E-04,
*PLASTIC
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*DAMPING, ALPHA=0.5613, BETA=1.436E-03
```

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```
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*DENSITY
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*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=A7_STEEL
*ELASTIC,TYPE=ISOTROPIC
 3.00000E+07,  2.90000E-01
*DENSITY
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*DAMPING, ALPHA=0.5613, BETA=1.436E-03
*MATERIAL,NAME=A212_DENSE
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*DENSITY
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*PLASTIC
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*SHELL SECTION,
 ELSET=SHELL7_0,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=A212
  7.00000E+00,
*SHELL SECTION,
 ELSET=SHELL0_625,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=A212_DENSE
  6.25000E-01,
*SHELL SECTION,
 ELSET=SHELL1_5,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=A212_DENSE
  1.50000E+00,
*SHELL SECTION,
 ELSET=SHELL0_375,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=A212
  3.75000E-01,
*SHELL SECTION,
 ELSET=SHELL1_6875 ,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=A212
  1.68750E+00,
*SHELL SECTION,
 ELSET=SHELL2_0,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=A212
  2.00000E+00,
*SHELL SECTION,
 ELSET=SHELL2_5,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=A212
  2.50000E+00,
*SHELL SECTION,
 ELSET=SHELL2_375,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=A212
```

```
 2.37500E+00,
*SHELL SECTION,
 ELSET=SHELL0_5,
 SECTION INTEGRATION=SIMPSON ,
 MATERIAL=A212
 5.00000E-01,
*SPRING, ELSET=CONTACT_SPRING,NONLINEAR

 -1.0000E+6, -0.10
  0.0000E+0, 0.0000E+0
*SPRING, ELSET=ST_BEAM_SPRING,NONLINEAR

-1.0000E+6, -7.837E-3
0.0000E+0, 0.0000E+0
*SPRING, ELSET=BRACE_SPRING_N,NONLINEAR

-1.0000E+6, -0.3923
0.0000E+0, 0.0000E+0
*SPRING, ELSET=BRACE_SPRING_S,NONLINEAR

-1.0000E+6, -0.5499
0.0000E+0, 0.0000E+0
*SPRING, ELSET=BRACE_SPRING_W,NONLINEAR

-1.0000E+6, -0.1606
0.0000E+0, 0.0000E+0
*SPRING, ELSET=BRACE_SPRING_E,NONLINEAR

-1.0000E+6, -0.1236
0.0000E+0, 0.0000E+0
*SPRING, ELSET=BRACE_SPRING_M,NONLINEAR

-1.0000E+6, -0.3213
0.0000E+0, 0.0000E+0
*SPRING, ELSET=TUNNEL_RES_SPRING NEWID80, NONLINEAR

 -1.0000E+6, -0.2686968
  0.0000E+0, 0.0000E+0
  1.0000E+6, 0.6717423519
*SPRING, ELSET=PS-7 NEWID81

 1.0000E+01,
*SPRING, ELSET=RH22X_SPRING NEWID82, NONLINEAR

  0.0000E+0, 0.0000E+0
  1.0000E+6, 7.399
*SPRING, ELSET=PR6_SPRING NEWID79 NEWID85

 1E+01,
*MASS, ELSET=LMASS20VAL_FLG, ALPHA=0.5613
 1.06590E+01,
*MASS, ELSET=LMASS24LAP NEWID77 NEWID83, ALPHA=0.5613
 1.23800E+00,
*MASS, ELSET=LMASS24GT BIN1 NEWID78 NEWID84, ALPHA=0.5613
 1.73920E+01,
**%
*Surface, type=NODE, name=CP1IN
 CP1IN, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING0, REF NODE=45011, SURFACE=CP1IN
```

```
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP1OUT
 CP1OUT, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING1, REF NODE=45012, SURFACE=CP1OUT
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CS1IN
 CS1IN, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING2, REF NODE=45013, SURFACE=CS1IN
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CS1OUT
 CS1OUT, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING3, REF NODE=45014, SURFACE=CS1OUT
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP2IN
 CP2IN, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING4, REF NODE=45021, SURFACE=CP2IN
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP2OUT
 CP2OUT, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING5, REF NODE=45022, SURFACE=CP2OUT
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CS2IN
 CS2IN, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING6, REF NODE=45023, SURFACE=CS2IN
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CS2OUT
 CS2OUT, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING7, REF NODE=45024, SURFACE=CS2OUT
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP3IN
 CP3IN, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING8, REF NODE=45031, SURFACE=CP3IN
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP3OUT
 CP3OUT, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING9, REF NODE=45032, SURFACE=CP3OUT
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CS3IN
 CS3IN, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING10, REF NODE=45033, SURFACE=CS3IN
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CS3OUT
 CS3OUT, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING11, REF NODE=45034, SURFACE=CS3OUT
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP4IN
 CP4IN, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING12, REF NODE=45041, SURFACE=CP4IN
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP4OUT
 CP4OUT, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING13, REF NODE=45042, SURFACE=CP4OUT
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CS4IN
 CS4IN, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING14, REF NODE=45043, SURFACE=CS4IN
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CS4OUT
 CS4OUT, 1.0
```

```
*COUPLING, CONSTRAINT NAME=COUPLING15, REF NODE=45044, SURFACE=CS4OUT
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP5IN
 CP5IN, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING16, REF NODE=45051, SURFACE=CP5IN
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP5OUT
 CP5OUT, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING17, REF NODE=45052, SURFACE=CP5OUT
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CS5IN
 CS5IN, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING18, REF NODE=45053, SURFACE=CS5IN
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CS5OUT
 CS5OUT, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING19, REF NODE=45054, SURFACE=CS5OUT
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
**%
**% ====== STEP NUMBER   1 ======
**%
*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
BS000002,   4, 6,     0.00000E+00
 ND4119h,  1, ,     0.00000E+00
 ND4119v,  2, ,     0.00000E+00
 ND4119h,  3, ,     0.00000E+00
  ND552,   1, 3,    0.00000E+00
  ND815,   1, 3,    0.00000E+00
 ND1340,   1, 3,    0.00000E+00
  ND542,   1, 3,    0.00000E+00
**% LOAD SET 1
*CLOAD,OP=NEW
    50200,   2, 3.1000E+03
    50196,   2, 4.5000E+03
    44441,   2, 4.8000E+03
    44474,   2, 4.8000E+03
    44480,   2, 4.8000E+03
    50195,   2, 5.6000E+03
    44486,   2, 5.8000E+03
    50192,   2, 6.5000E+03
BS000003,   2, 6.8000E+03
    50415,   2, 7.2000E+03
    50414,   2, 7.8000E+03
    50416,   2, 7.8000E+03
    50417,   2, 7.8000E+03
    50398,   2, 8.1000E+03
    50409,   2, 8.4000E+03
    50395,   2, 8.7000E+03
    50400,   2, 8.9000E+03
    50403,   2, 9.0000E+03
    50187,   2, 9.2000E+03
BS000004,   2, 9.6000E+03
    50190,   2, 1.0100E+04
    50191,   2, 1.7100E+04
```

```
*DLOAD,OP=NEW
BS000005,   P,-1.2500E+02
BS000006,   P,-2.7200E+02
BS000007,   P, 1.4700E+02
 ALLBB, GRAV, 386.09, 0.0,-1.0, 0.0
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*MONITOR, NODE=10875, 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
```

A-8.2 Natural Frequencies for the Coarse Meshed Model

Below is a reduced version of the base model input file "HtExbeam11FRbb.inp." This contains header information and step information.

```
**%  ==========================================================
**%
**%          NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%               FOR ABAQUS VERSION 6.x
**%
**%       MODEL FILE: C:\er2\work\Stuart_misc\Heat_Exchangers_Seismic\Heat_Exchanger_NX5.mf1
**%       INPUT FILE: C:\er2\work\Stuart_misc\Heat_Exchangers_Seismic\input\HtExbeam11R14bb.inp
**%         EXPORTED: AT 20:36:53 ON 24-Sep-08
**%            PART: heat exchanger fe 1
**%             FEM: all w\ base and top support (beams simple)
**%
**%           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-398 **Rev.:** 0
Title: ATR PCS Heat Exchanger Seismic Analysis – Appendix A
Performer: R. E. Spears **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

```
**%
**%  ==========================================================
**%
**%
*HEADING
SDRC I-DEAS ABAQUS FILE TRANSLATOR  24-Sep-08   20:36:53
**%
**% ====== STEP NUMBER   1 ======
**%
*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
BS000002,    4, 6,     0.00000E+00
  ND4119h,   1,  ,     0.00000E+00
  ND4119v,   2,  ,     0.00000E+00
  ND4119h,   3,  ,     0.00000E+00
   ND552,    1, 3,     0.00000E+00
   ND815,    1, 3,     0.00000E+00
  ND1340,    1, 3,     0.00000E+00
   ND542,    1, 3,     0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
     50200,    2, 3.1000E+03
     50196,    2, 4.5000E+03
     44441,    2, 4.8000E+03
     44474,    2, 4.8000E+03
     44480,    2, 4.8000E+03
     50195,    2, 5.6000E+03
     44486,    2, 5.8000E+03
     50192,    2, 6.5000E+03
BS000003,    2, 6.8000E+03
     50415,    2, 7.2000E+03
     50414,    2, 7.8000E+03
     50416,    2, 7.8000E+03
     50417,    2, 7.8000E+03
     50398,    2, 8.1000E+03
     50409,    2, 8.4000E+03
     50395,    2, 8.7000E+03
     50400,    2, 8.9000E+03
     50403,    2, 9.0000E+03
     50187,    2, 9.2000E+03
BS000004,    2, 9.6000E+03
     50190,    2, 1.0100E+04
     50191,    2, 1.7100E+04
*DLOAD,OP=NEW
 ALLBB, GRAV, 386.09, 0.0,-1.0, 0.0
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*MONITOR, NODE=46150, 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
```

A-8.3 Model Run for the Fine Meshed Model

Below is a reduced version of the base model input file "HtExall11R14HTOLbb.inp." This contains header information and step information.

```
**%  ==========================================================
**%
**%          NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%               FOR ABAQUS VERSION 6.x
**%
**%       MODEL FILE: C:\er2\work\Stuart_misc\Heat_Exchangers_Seismic\Heat_Exchanger_NX5.mf1
**%       INPUT FILE: C:\er2\work\Stuart_misc\Heat_Exchangers_Seismic\input\HtExall10R14HTOLbb.inp
**%         EXPORTED: AT 19:26:13 ON 24-Sep-08
**%            PART: heat exchanger fe 1
**%             FEM: all (w/pressure)
**%
**%           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   19:26:13
**%
*AMPLITUDE, NAME=ND4119H1R14
*AMPLITUDE, NAME=ND4119H2R14
*AMPLITUDE, NAME=ND4119VR14
*AMPLITUDE, NAME=ND552H1R14
*AMPLITUDE, NAME=ND552H2R14
*AMPLITUDE, NAME=ND552VR14
*AMPLITUDE, NAME=ND815H1R14
*AMPLITUDE, NAME=ND815H2R14
```

```
*AMPLITUDE, NAME=ND815VR14
*AMPLITUDE, NAME=ND1340H1R14
*AMPLITUDE, NAME=ND1340H2R14
*AMPLITUDE, NAME=ND1340VR14
*AMPLITUDE, NAME=ND542H1R14
*AMPLITUDE, NAME=ND542H2R14
*AMPLITUDE, NAME=ND542VR14
**%
**%
*Surface, type=NODE, name=CP1IN
 CP1IN, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING0, REF NODE=45011, SURFACE=CP1IN
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP1OUT
 CP1OUT, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING1, REF NODE=45012, SURFACE=CP1OUT
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CS1IN
 CS1IN, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING2, REF NODE=45013, SURFACE=CS1IN
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CS1OUT
 CS1OUT, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING3, REF NODE=45014, SURFACE=CS1OUT
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP2IN
 CP2IN, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING4, REF NODE=45021, SURFACE=CP2IN
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP2OUT
 CP2OUT, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING5, REF NODE=45022, SURFACE=CP2OUT
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CS2IN
 CS2IN, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING6, REF NODE=45023, SURFACE=CS2IN
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CS2OUT
 CS2OUT, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING7, REF NODE=45024, SURFACE=CS2OUT
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP3IN
 CP3IN, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING8, REF NODE=45031, SURFACE=CP3IN
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP3OUT
 CP3OUT, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING9, REF NODE=45032, SURFACE=CP3OUT
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CS3IN
 CS3IN, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING10, REF NODE=45033, SURFACE=CS3IN
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CS3OUT
 CS3OUT, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING11, REF NODE=45034, SURFACE=CS3OUT
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP4IN
 CP4IN, 1.0
```

```
*COUPLING, CONSTRAINT NAME=COUPLING12, REF NODE=45041, SURFACE=CP4IN
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP4OUT
 CP4OUT, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING13, REF NODE=45042, SURFACE=CP4OUT
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CS4IN
 CS4IN, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING14, REF NODE=45043, SURFACE=CS4IN
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CS4OUT
 CS4OUT, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING15, REF NODE=45044, SURFACE=CS4OUT
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP5IN
 CP5IN, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING16, REF NODE=45051, SURFACE=CP5IN
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CP5OUT
 CP5OUT, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING17, REF NODE=45052, SURFACE=CP5OUT
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CS5IN
 CS5IN, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING18, REF NODE=45053, SURFACE=CS5IN
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
*Surface, type=NODE, name=CS5OUT
 CS5OUT, 1.0
*COUPLING, CONSTRAINT NAME=COUPLING19, REF NODE=45054, SURFACE=CS5OUT
*DISTRIBUTING, WEIGHTING METHOD=UNIFORM
**%
**% ====== STEP NUMBER   1 ======
**%
*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
BS000002,   4, 6,     0.00000E+00
 ND4119h,  1, ,     0.00000E+00
 ND4119v,  2, ,     0.00000E+00
 ND4119h,  3, ,     0.00000E+00
  ND552,   1, 3,    0.00000E+00
  ND815,   1, 3,    0.00000E+00
 ND1340,   1, 3,    0.00000E+00
  ND542,   1, 3,    0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
    50200,   2, 3.1000E+03
    50196,   2, 4.5000E+03
    44441,   2, 4.8000E+03
    44474,   2, 4.8000E+03
    44480,   2, 4.8000E+03
    50195,   2, 5.6000E+03
    44486,   2, 5.8000E+03
    50192,   2, 6.5000E+03
BS000003,   2, 6.8000E+03
    50415,   2, 7.2000E+03
```

```
    50414,   2, 7.8000E+03
    50416,   2, 7.8000E+03
    50417,   2, 7.8000E+03
    50398,   2, 8.1000E+03
    50409,   2, 8.4000E+03
    50395,   2, 8.7000E+03
    50400,   2, 8.9000E+03
    50403,   2, 9.0000E+03
    50187,   2, 9.2000E+03
BS000004,   2, 9.6000E+03
    50190,   2, 1.0100E+04
    50191,   2, 1.7100E+04
*DLOAD,OP=NEW
BS000005,   P,-1.2500E+02
BS000006,   P,-2.7200E+02
BS000007,   P, 1.4700E+02
 ALLBB, GRAV, 386.09, 0.0,-1.0, 0.0
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*MONITOR, NODE=10875, DOF=1
*END STEP
**%
**% ====== SEISMIC WITH G-LOAD ======
**%
**% Note: Damping is address in the material properties
**%
*STEP,INC=10000000,NLGEOM
*DYNAMIC, HAFTOL=1.0E+05
 0.01,20.0,1.0E-08,0.01
**% BOUNDARY CONDITION SET 1
**% RESTRAINT SET 1
**%
*BOUNDARY,OP=NEW
BS000002,   4, 6,     0.00000E+00
*BOUNDARY,AMPLITUDE=ND4119H1R14,OP=NEW,TYPE=ACCELERATION
 ND4119h, 1,,     1.00000E+00
*BOUNDARY,AMPLITUDE=ND4119VR14,OP=NEW,TYPE=ACCELERATION
 ND4119v, 2,,     1.00000E+00
*BOUNDARY,AMPLITUDE=ND4119H2R14,OP=NEW,TYPE=ACCELERATION
 ND4119h, 3,,    -1.00000E+00
*BOUNDARY,AMPLITUDE=ND552H1R14,OP=NEW,TYPE=ACCELERATION
 ND552,   1,,     1.00000E+00
*BOUNDARY,AMPLITUDE=ND552VR14,OP=NEW,TYPE=ACCELERATION
 ND552,   2,,     1.00000E+00
*BOUNDARY,AMPLITUDE=ND552H2R14,OP=NEW,TYPE=ACCELERATION
 ND552,   3,,    -1.00000E+00
*BOUNDARY,AMPLITUDE=ND815H1R14,OP=NEW,TYPE=ACCELERATION
 ND815,   1,,     1.00000E+00
*BOUNDARY,AMPLITUDE=ND815VR14,OP=NEW,TYPE=ACCELERATION
 ND815,   2,,     1.00000E+00
*BOUNDARY,AMPLITUDE=ND815H2R14,OP=NEW,TYPE=ACCELERATION
 ND815,   3,,    -1.00000E+00
*BOUNDARY,AMPLITUDE=ND1340H1R14,OP=NEW,TYPE=ACCELERATION
 ND1340,  1,,     1.00000E+00
*BOUNDARY,AMPLITUDE=ND1340VR14,OP=NEW,TYPE=ACCELERATION
```

```
 ND1340,   2,,     1.00000E+00
*BOUNDARY,AMPLITUDE=ND1340H2R14,OP=NEW,TYPE=ACCELERATION
 ND1340,   3,,    -1.00000E+00
*BOUNDARY,AMPLITUDE=ND542H1R14,OP=NEW,TYPE=ACCELERATION
 ND542,   1,,     1.00000E+00
*BOUNDARY,AMPLITUDE=ND542VR14,OP=NEW,TYPE=ACCELERATION
 ND542,   2,,     1.00000E+00
*BOUNDARY,AMPLITUDE=ND542H2R14,OP=NEW,TYPE=ACCELERATION
 ND542,   3,,    -1.00000E+00
**% LOAD SET 1
*CLOAD,OP=NEW
    50200,   2, 3.1000E+03
    50196,   2, 4.5000E+03
    44441,   2, 4.8000E+03
    44474,   2, 4.8000E+03
    44480,   2, 4.8000E+03
    50195,   2, 5.6000E+03
    44486,   2, 5.8000E+03
    50192,   2, 6.5000E+03
BS000003,   2, 6.8000E+03
    50415,   2, 7.2000E+03
    50414,   2, 7.8000E+03
    50416,   2, 7.8000E+03
    50417,   2, 7.8000E+03
    50398,   2, 8.1000E+03
    50409,   2, 8.4000E+03
    50395,   2, 8.7000E+03
    50400,   2, 8.9000E+03
    50403,   2, 9.0000E+03
    50187,   2, 9.2000E+03
BS000004,   2, 9.6000E+03
    50190,   2, 1.0100E+04
    50191,   2, 1.7100E+04
*DLOAD,OP=NEW
BS000005,   P,-1.2500E+02
BS000006,   P,-2.7200E+02
BS000007,   P, 1.4700E+02
 ALLBB, GRAV, 386.09, 0.0,-1.0, 0.0
*OUTPUT, FIELD ,FREQUENCY=8
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES, ELSET=OUTBB
 1, 3, 5
 NFORC,S,PEEQ
*OUTPUT, HISTORY, FREQUENCY=1
*ENERGY OUTPUT
 ALLSE,ALLAE,ALLKE,ETOTAL,ALLPD,ALLWK,ALLFD,ALLVD
*NODE OUTPUT,NSET=BBND
 RF,RF1,RF2,RF3
*NODE OUTPUT,NSET=CONBASE
 RF,RF1,RF2,RF3
*NODE OUTPUT,NSET=STBASE
 RF,RF1,RF2,RF3
*ELEMENT OUTPUT, ELSET=BOLTS
 NFORC1,NFORC2,NFORC3,NFORC4,NFORC5,NFORC6,
*ELEMENT OUTPUT, ELSET=SUPPIPES
 NFORC1,NFORC2,NFORC3,NFORC4,NFORC5,NFORC6,
*MONITOR, NODE=10875, DOF=1
*END STEP
```

A-8.4 Base Model for the Thirty-Two Coarse Meshed Model Runs

Below is a reduced version of the base model input file "base_HtExbeam11bb.inp." This contains header information and step information.

```
**%  ==========================================================
**%
**%          NX I-deas 5.0 ABAQUS STANDARD TRANSLATOR
**%               FOR ABAQUS VERSION 6.x
**%
**%       MODEL FILE: C:\er2\work\Stuart_misc\Heat_Exchangers_Seismic\Heat_Exchanger_NX5.mf1
**%       INPUT FILE: C:\er2\work\Stuart_misc\Heat_Exchangers_Seismic\input\HtExbeam11R14bb.inp
**%         EXPORTED: AT 20:36:53 ON 24-Sep-08
**%            PART: heat exchanger fe 1
**%             FEM: all w\ base and top support (beams simple)
**%
**%           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   20:36:53
**%
**% ====== STEP NUMBER   1 ======
**%
*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
BS000002,    4, 6,     0.00000E+00
  ND4119h,   1,  ,     0.00000E+00
  ND4119v,   2,  ,     0.00000E+00
  ND4119h,   3,  ,     0.00000E+00
   ND552,    1, 3,     0.00000E+00
   ND815,    1, 3,     0.00000E+00
  ND1340,    1, 3,     0.00000E+00
   ND542,    1, 3,     0.00000E+00
**%  LOAD SET 1
*CLOAD,OP=NEW
     50200,    2, 3.1000E+03
     50196,    2, 4.5000E+03
     44441,    2, 4.8000E+03
```

```
    44474,   2, 4.8000E+03
    44480,   2, 4.8000E+03
    50195,   2, 5.6000E+03
    44486,   2, 5.8000E+03
    50192,   2, 6.5000E+03
BS000003,   2, 6.8000E+03
    50415,   2, 7.2000E+03
    50414,   2, 7.8000E+03
    50416,   2, 7.8000E+03
    50417,   2, 7.8000E+03
    50398,   2, 8.1000E+03
    50409,   2, 8.4000E+03
    50395,   2, 8.7000E+03
    50400,   2, 8.9000E+03
    50403,   2, 9.0000E+03
    50187,   2, 9.2000E+03
BS000004,   2, 9.6000E+03
    50190,   2, 1.0100E+04
    50191,   2, 1.7100E+04
*DLOAD,OP=NEW
 ALLBB, GRAV, 386.09, 0.0,-1.0, 0.0
*OUTPUT, FIELD ,FREQUENCY=100
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*MONITOR, NODE=46150, DOF=1
*END STEP
**%
**% ====== SEISMIC WITH G-LOAD ======
**%
**% Note: Damping is address in the material properties
**%
*STEP,INC=10000000,NLGEOM
*DYNAMIC, DIRECT
 0.00125,20.0,1.0E-08,0.00125
**%  BOUNDARY CONDITION SET 1
**%  RESTRAINT SET 1
**%
*BOUNDARY,OP=NEW
BS000002,   4, 6,     0.00000E+00
*<<--BOUNDARY,AMPLITUDE=ND4119H1R<real>,OP=NEW,TYPE=ACCELERATION-->>
 ND4119H,   1,,     1.00000E+00
*<<--BOUNDARY,AMPLITUDE=ND4119VR<real>,OP=NEW,TYPE=ACCELERATION-->>
 ND4119V,   2,,     1.00000E+00
*<<--BOUNDARY,AMPLITUDE=ND4119H2R<real>,OP=NEW,TYPE=ACCELERATION-->>
 ND4119H,   3,,    -1.00000E+00
*<<--BOUNDARY,AMPLITUDE=ND552H1R<real>,OP=NEW,TYPE=ACCELERATION-->>
 ND552,   1,,     1.00000E+00
*<<--BOUNDARY,AMPLITUDE=ND552VR<real>,OP=NEW,TYPE=ACCELERATION-->>
 ND552,   2,,     1.00000E+00
*<<--BOUNDARY,AMPLITUDE=ND552H2R<real>,OP=NEW,TYPE=ACCELERATION-->>
 ND552,   3,,    -1.00000E+00
*<<--BOUNDARY,AMPLITUDE=ND815H1R<real>,OP=NEW,TYPE=ACCELERATION-->>
 ND815,   1,,     1.00000E+00
*<<--BOUNDARY,AMPLITUDE=ND815VR<real>,OP=NEW,TYPE=ACCELERATION-->>
 ND815,   2,,     1.00000E+00
*<<--BOUNDARY,AMPLITUDE=ND815H2R<real>,OP=NEW,TYPE=ACCELERATION-->>
```

```
 ND815,   3,,    -1.00000E+00
*<<--BOUNDARY,AMPLITUDE=ND1340H1R<real>,OP=NEW,TYPE=ACCELERATION-->>
 ND1340,   1,,     1.00000E+00
*<<--BOUNDARY,AMPLITUDE=ND1340VR<real>,OP=NEW,TYPE=ACCELERATION-->>
 ND1340,   2,,     1.00000E+00
*<<--BOUNDARY,AMPLITUDE=ND1340H2R<real>,OP=NEW,TYPE=ACCELERATION-->>
 ND1340,   3,,    -1.00000E+00
*<<--BOUNDARY,AMPLITUDE=ND542H1R<real>,OP=NEW,TYPE=ACCELERATION-->>
 ND542,   1,,     1.00000E+00
*<<--BOUNDARY,AMPLITUDE=ND542VR<real>,OP=NEW,TYPE=ACCELERATION-->>
 ND542,   2,,     1.00000E+00
*<<--BOUNDARY,AMPLITUDE=ND542H2R<real>,OP=NEW,TYPE=ACCELERATION-->>
 ND542,   3,,    -1.00000E+00
**% LOAD SET 1
*CLOAD,OP=NEW
    50200,   2, 3.1000E+03
    50196,   2, 4.5000E+03
    44441,   2, 4.8000E+03
    44474,   2, 4.8000E+03
    44480,   2, 4.8000E+03
    50195,   2, 5.6000E+03
    44486,   2, 5.8000E+03
    50192,   2, 6.5000E+03
BS000003,   2, 6.8000E+03
    50415,   2, 7.2000E+03
    50414,   2, 7.8000E+03
    50416,   2, 7.8000E+03
    50417,   2, 7.8000E+03
    50398,   2, 8.1000E+03
    50409,   2, 8.4000E+03
    50395,   2, 8.7000E+03
    50400,   2, 8.9000E+03
    50403,   2, 9.0000E+03
    50187,   2, 9.2000E+03
BS000004,   2, 9.6000E+03
    50190,   2, 1.0100E+04
    50191,   2, 1.7100E+04
*DLOAD,OP=NEW
 ALLBB, GRAV, 386.09, 0.0,-1.0, 0.0
*OUTPUT, FIELD ,FREQUENCY=4
*NODE OUTPUT
 U,V,A,RF
*ELEMENT OUTPUT, DIRECTIONS=YES
 1, 3, 5
 NFORC,S,PEEQ
*MONITOR, NODE=46150, DOF=1
*END STEP
```

A-8.5 Input File Generation Script

The Python script "HtExbeam_32inps_Linux.py" below modifies the base model input file "base_HtExbeam11bb.inp" (Section A-8.4) for each of the 32 time history realizations. It does this by going to the directory where the time histories (produced by the ATR Primary Coolant System Seismic Evaluation [13]) are found. It then gets the time histories for the needed PSSI [15] nodes 4119, 552, 815, 1340, and 542. These are imported for the correct realization and then the boundary conditions that use them are

edited for the same realization. The result of each cycle is a unique input file for its corresponding realization (ie. "HtEx_beam11bb_R1.inp" for realization 1, "HtEx_beam11bb_R2.inp" for realization 2, ...).

```
import time
import os

st = time.time()

Base_dir = r"/home/er2/er2/work/Stuart_misc/Heat_Exchangers_Seismic/input"          #Base Directory

#Base_dir = r"/home/crawal/PCS2/Automated_Evaluation/"          #Base Directory
mdl_dir = "HtExbeam"                                                    #Model Directory
dir_pre = 'real'                                                        #Prefix for folder representing each realization
Base_file = r"base_HtExbeam11bb.inp"                                    #Primary inp file to adapt
new_inp = 'HtEx_beam11bb_R'                                                     #Prefix for inp with time history
TH_dir = 'Substructure_time_histories/Acceleration_Time_Histories_Combined'
script_dir_1 = Base_dir+os.sep+'scripts'
script_dir_th = '/home/fserob1/ATR/PCS/PCS2/Automated_Evaluation/py_scripts/Generating_Input_Files'
TH_pre = 'hist2fitTrap_'

Cost_nodes =[4119, 552, 815, 1340, 542]

for x in xrange(1,33):
   case_dir = dir_pre+str(x)                                            #Attaching numeric value of realization to folder
   os.chdir(Base_dir+os.sep+mdl_dir+os.sep+case_dir)                    #Change the current working directory to path
                                                                         #os.sep is the seperator specific to the operating
system
   print os.getcwd()                                                    #Return a string representing the current working
directory
   outfile = open(new_inp+str(x)+'.inp','w')                            #Defines the output file to write to
   for line in open(script_dir_1+os.sep+Base_file):      #Goes through each line in primary inp file
      if line.find("<<--Replace Time History-->>") !=-1:          #Looks for line with specified statement
         th_file = open(script_dir_th+os.sep+TH_dir+os.sep+dir_pre+str(x)+os.sep+"histpoly_combined_R"+str(x)+".dat")
         th_data = th_file.readlines()
         th_file.close()
         cnt = 0
         stop_pnt = len(th_data)
         just_srt=stop_pnt-4
         lengthNodes = len(Cost_nodes)
         while cnt < stop_pnt:
            for y in xrange(0,lengthNodes):
               if cnt >= stop_pnt:
                  print cnt
                  break
               if th_data[cnt].find("*AMPLITUDE, NAME=ND"+str(Cost_nodes[y])+"H1R"+str(x)) !=-1:
                  outfile.write(th_data[cnt])
                  print th_data[cnt]
                  cnt += 1
                  while cnt < stop_pnt and th_data[cnt][0] !="*":
                     outfile.write(th_data[cnt])
                     if th_data[cnt].find('40.96,') !=-1:
                        cnt += 1
                        break
                     else:
                        cnt += 1
               if th_data[cnt].find("*AMPLITUDE, NAME=ND"+str(Cost_nodes[y])+"H2R"+str(x)) !=-1:
                  outfile.write(th_data[cnt])
                  print th_data[cnt]
                  cnt += 1
```

```
                while th_data[cnt][0] !="*":
                    outfile.write(th_data[cnt])
                    if th_data[cnt].find('40.96,') !=-1:
                        cnt += 1
                        break
                    else:
                        cnt += 1
            if th_data[cnt].find("*AMPLITUDE, NAME=ND"+str(Cost_nodes[y])+"VR"+str(x)) !=-1:
                outfile.write(th_data[cnt])
                print th_data[cnt]
                cnt += 1
                while cnt < stop_pnt or th_data[cnt][0] !="*":
                    outfile.write(th_data[cnt])
                    if th_data[cnt].find('40.96,') !=-1:
                        cnt += 1
                        break
                    else:
                        cnt += 1
        else:
            cnt += 1
                #print cnt,len(th_data)
        #for th_line in open("real_%02d.th"%x):                #Looks for Time History file labeled 'real_(realization#).th'
         #   outfile.write(th_line)                        #Writes out Time History data where line occured
    elif line.find('<<--BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[0])+'H1R<real>,OP=NEW,TYPE=ACCELERATION-->>') !=-
1:
        line_x4119 = line.replace('<<--
BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[0])+'H1R<real>,OP=NEW,TYPE=ACCELERATION--
>>','BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[0])+'H1R'+str(x)+',OP=NEW,TYPE=ACCELERATION')
        outfile.write(line_x4119)
    elif line.find('<<--BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[0])+'H2R<real>,OP=NEW,TYPE=ACCELERATION-->>') !=-
1:
        line_z4119 = line.replace('<<--
BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[0])+'H2R<real>,OP=NEW,TYPE=ACCELERATION--
>>','BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[0])+'H2R'+str(x)+',OP=NEW,TYPE=ACCELERATION')
        outfile.write(line_z4119)
    elif line.find('<<--BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[0])+'VR<real>,OP=NEW,TYPE=ACCELERATION-->>') !=-1:
        line_y4119 = line.replace('<<--
BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[0])+'VR<real>,OP=NEW,TYPE=ACCELERATION--
>>','BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[0])+'VR'+str(x)+',OP=NEW,TYPE=ACCELERATION')
        outfile.write(line_y4119)
    elif line.find('<<--BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[1])+'H1R<real>,OP=NEW,TYPE=ACCELERATION-->>') !=-
1:
        line_x552 = line.replace('<<--
BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[1])+'H1R<real>,OP=NEW,TYPE=ACCELERATION--
>>','BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[1])+'H1R'+str(x)+',OP=NEW,TYPE=ACCELERATION')
        outfile.write(line_x552)
    elif line.find('<<--BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[1])+'H2R<real>,OP=NEW,TYPE=ACCELERATION-->>') !=-
1:
        line_z552 = line.replace('<<--
BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[1])+'H2R<real>,OP=NEW,TYPE=ACCELERATION--
>>','BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[1])+'H2R'+str(x)+',OP=NEW,TYPE=ACCELERATION')
        outfile.write(line_z552)
    elif line.find('<<--BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[1])+'VR<real>,OP=NEW,TYPE=ACCELERATION-->>') !=-1:
        line_y552 = line.replace('<<--
BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[1])+'VR<real>,OP=NEW,TYPE=ACCELERATION--
>>','BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[1])+'VR'+str(x)+',OP=NEW,TYPE=ACCELERATION')
        outfile.write(line_y552)
    elif line.find('<<--BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[2])+'H1R<real>,OP=NEW,TYPE=ACCELERATION-->>') !=-
1:
```

```
        line_x815 = line.replace('<<--
BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[2])+'H1R<real>,OP=NEW,TYPE=ACCELERATION--
>>','BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[2])+'H1R'+str(x)+',OP=NEW,TYPE=ACCELERATION')
        outfile.write(line_x815)
      elif line.find('<<--BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[2])+'H2R<real>,OP=NEW,TYPE=ACCELERATION-->>') !=-
1:
        line_z815 = line.replace('<<--
BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[2])+'H2R<real>,OP=NEW,TYPE=ACCELERATION--
>>','BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[2])+'H2R'+str(x)+',OP=NEW,TYPE=ACCELERATION')
        outfile.write(line_z815)
      elif line.find('<<--BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[2])+'VR<real>,OP=NEW,TYPE=ACCELERATION-->>') !=-1:
        line_y815 = line.replace('<<--
BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[2])+'VR<real>,OP=NEW,TYPE=ACCELERATION--
>>','BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[2])+'VR'+str(x)+',OP=NEW,TYPE=ACCELERATION')
        outfile.write(line_y815)
      elif line.find('<<--BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[3])+'H1R<real>,OP=NEW,TYPE=ACCELERATION-->>') !=-
1:
        line_x1340 = line.replace('<<--
BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[3])+'H1R<real>,OP=NEW,TYPE=ACCELERATION--
>>','BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[3])+'H1R'+str(x)+',OP=NEW,TYPE=ACCELERATION')
        outfile.write(line_x1340)
      elif line.find('<<--BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[3])+'H2R<real>,OP=NEW,TYPE=ACCELERATION-->>') !=-
1:
        line_z1340 = line.replace('<<--
BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[3])+'H2R<real>,OP=NEW,TYPE=ACCELERATION--
>>','BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[3])+'H2R'+str(x)+',OP=NEW,TYPE=ACCELERATION')
        outfile.write(line_z1340)
      elif line.find('<<--BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[3])+'VR<real>,OP=NEW,TYPE=ACCELERATION-->>') !=-1:
        line_y1340 = line.replace('<<--
BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[3])+'VR<real>,OP=NEW,TYPE=ACCELERATION--
>>','BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[3])+'VR'+str(x)+',OP=NEW,TYPE=ACCELERATION')
        outfile.write(line_y1340)
      elif line.find('<<--BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[4])+'H1R<real>,OP=NEW,TYPE=ACCELERATION-->>') !=-
1:
        line_x542 = line.replace('<<--
BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[4])+'H1R<real>,OP=NEW,TYPE=ACCELERATION--
>>','BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[4])+'H1R'+str(x)+',OP=NEW,TYPE=ACCELERATION')
        outfile.write(line_x542)
      elif line.find('<<--BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[4])+'H2R<real>,OP=NEW,TYPE=ACCELERATION-->>') !=-
1:
        line_z542 = line.replace('<<--
BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[4])+'H2R<real>,OP=NEW,TYPE=ACCELERATION--
>>','BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[4])+'H2R'+str(x)+',OP=NEW,TYPE=ACCELERATION')
        outfile.write(line_z542)
      elif line.find('<<--BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[4])+'VR<real>,OP=NEW,TYPE=ACCELERATION-->>') !=-1:
        line_y542 = line.replace('<<--
BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[4])+'VR<real>,OP=NEW,TYPE=ACCELERATION--
>>','BOUNDARY,AMPLITUDE=ND'+str(Cost_nodes[4])+'VR'+str(x)+',OP=NEW,TYPE=ACCELERATION')
        outfile.write(line_y542)
      else:
        outfile.write(line)
    outfile.close()
print time.time()-st
```

A-8.6 Model Run Script

The Perl script "run_HtEx_beam11bb.pl" below is used to run all 32 ABAQUS runs in order. The use of the "Parallel::ForkManager" inside the script makes it so that the number of ABAQUS runs running simultaneously can be set. The number currently in the file is three.

```
#! /usr/bin/perl

use strict;
use warnings;
use Cwd;

use Parallel::ForkManager;
use POSIX qw(strftime);



# This subroutine returns an iterator (i.e. a code reference) that dynamically generates
# a list of strings based on a pattern.  This is useful for generating all names of
# the cluster nodes for instance ;)


# Define the needed variables
my $abq_exe = "abq675";
my $base_dir = "/home/er2/er2/work/Stuart_misc/Heat_Exchangers_Seismic/input";
my $script_dir = "$base_dir/scripts";
my $mdl_dir = "HtExbeam";
my $inp_pre = "HtEx_beam11bb_R";
my $dir_pre  = "real";

my $pm = new Parallel::ForkManager(2);
my $iter = gen_hostnames ("[1-32]");
while (my $host = $iter->()) {
        $pm->start and next;
        chdir("$base_dir/$mdl_dir/$dir_pre$host") or die "Could not find $base_dir/$mdl_dir/$dir_pre$host" ;
        print "$base_dir/$mdl_dir/$dir_pre$host; abq675 cpus=1 mp_mode=MPI double job=$inp_pre$host\n";
        `$abq_exe double int job=$inp_pre$host`;
        $pm->finish
}
$pm->wait_all_children;

sub gen_hostnames {
        my $pat = shift;
        my @tokens = split /[\[\]]/, $pat;
        for (my $i=1; $i < @tokens; $i+=2) {
                $tokens[$i] = [split (/-/, $tokens[$i])];
                unshift @{$tokens[$i]}, $tokens[$i]->[0];
        }

        # return the iterator
        my $FINISHED = 0;
        return sub {
                return if $FINISHED;
                my $finished_incrementing = 0;
                my $result = "";
                for my $token (reverse @tokens) {
                        if (ref $token eq "") { # plain string
                                $result = $token . $result;
```

```
                        } else {
                                my ($current, $start, $end) = @$token;
                                $result = $current . $result;
                                unless ($finished_incrementing) {
                                        if ($current == $end) { $token->[0] = $token->[1] }
                                        else { $token->[0]++; $finished_incrementing = 1 }
                                }
                        }
                }
                $FINISHED = 1 unless $finished_incrementing;
                return $result;
        }
}
```

A-8.7 Model Output Script

The Python script "HtEx_out.py" and ABAQUS/Viewer run file "HtEx_rpy_out.rpy" below are used to pull the needed data from the ABAQUS runs. The ABAQUS/Viewer run file contains the basic pattern for pulling data out of the ABAQUS runs. The Python script edits the ABAQUS/Viewer run file for each realization. Then is runs ABAQUS/Viewer with the edited ABAQUS/Viewer run file.

A-8.7.1 Python Script

```
import os
import time

abq_exe = r'abq675'
base_dir = r'/home/er2/er2/work/Stuart_misc/Heat_Exchangers_Seismic/input'+os.sep
script_dir = base_dir+'scripts'+os.sep
rpy_file = 'HtEx_rpy_out.rpy'
mdl_dir = "HtExbeam"
odb_pre = "HtEx_beam11bb_R"
new_rpy = 'pcs.rpy'
dir_pre = 'real'

for x in xrange(1,33):
        case_dir = dir_pre+str(x)
        os.chdir(base_dir+mdl_dir+os.sep+case_dir)

        outfile = open(new_rpy,'w')
        for line in open(script_dir+rpy_file):
                if line.find("<-ODB-Replace->") !=-1:
                        line = line.replace('<-ODB-Replace->',odb_pre+'%d.odb'%x)
                elif line.find("<-Path-Replace->") !=-1:
                        line = line.replace('<-Path-Replace->',base_dir+mdl_dir+os.sep+case_dir+os.sep+odb_pre+str(x))
                outfile.write(line)
        outfile.close()
        os.system('%s viewer -replay %s'%(abq_exe,new_rpy))
```

A-8.7.2 ABAQUS/Viewer Run File

```
# -*- coding: mbcs -*-
#
```

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```
# Abaqus/Viewer Version 6.7-5 replay file
# Internal Version: 2008_01_21-15.23.13 80075
# Run by er2 on Mon Aug 18 08:07:44 2008
#

import sys

# from driverUtils import executeOnCaeGraphicsStartup
# executeOnCaeGraphicsStartup()
#: Executing "onCaeGraphicsStartup()" in the site directory ...
from abaqus import *
from abaqusConstants import *
session.Viewport(name='Viewport: 1', origin=(0.0, 0.0), width=259.033172607422,
    height=249.742492675781)
session.viewports['Viewport: 1'].makeCurrent()
session.viewports['Viewport: 1'].maximize()
from viewerModules import *
from driverUtils import executeOnCaeStartup
executeOnCaeStartup()
o1 = session.openOdb(name='<-ODB-Replace->')
session.viewports['Viewport: 1'].setValues(displayedObject=o1)
#: Model: /home/er2/er2/work/Stuart_misc/Heat_Exchangers_Seismic/input/HtExbeam/real1/HtEx_beam11bb_R1.odb
#: Number of Assemblies:         1
#: Number of Assembly instances: 0
#: Number of Part instances:     1
#: Number of Meshes:             1
#: Number of Element Sets:       120
#: Number of Node Sets:          15
#: Number of Steps:              2
session.viewports['Viewport: 1'].odbDisplay.basicOptions.setValues(
    averageElementOutput=False)
odb = session.odbs['<-ODB-Replace->']
session.xyDataListFromField(odb=odb, outputPosition=ELEMENT_NODAL, variable=((
    'NFORC1', ELEMENT_NODAL), ('NFORC2', ELEMENT_NODAL), ('NFORC3',
    ELEMENT_NODAL), ), elementSets=('PART-1-1.SUPPIPES', ))
x0 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43807 N: 30429']
x1 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43807 N: 30441']
x2 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43808 N: 24252']
x3 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43808 N: 24264']
x4 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43809 N: 18075']
x5 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43809 N: 18087']
x6 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43810 N: 8451']
x7 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43810 N: 8518']
x8 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43811 N: 40833']
x9 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43811 N: 40845']
x10 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43812 N: 30439']
x11 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43812 N: 30443']
x12 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43813 N: 24262']
x13 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43813 N: 24266']
x14 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43814 N: 18085']
x15 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43814 N: 18089']
x16 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43815 N: 8509']
x17 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43815 N: 8522']
x18 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43816 N: 40843']
x19 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43816 N: 40846']
x20 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43817 N: 30434']
x21 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43817 N: 30442']
x22 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43818 N: 8422']
x23 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43818 N: 8516']
```

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```
x24 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43819 N: 24257']
x25 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43819 N: 24265']
x26 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43820 N: 18080']
x27 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43820 N: 18088']
x28 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43821 N: 8480']
x29 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43821 N: 8520']
x30 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43807 N: 30429']
x31 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43807 N: 30441']
x32 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43808 N: 24252']
x33 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43808 N: 24264']
x34 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43809 N: 18075']
x35 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43809 N: 18087']
x36 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43810 N: 8451']
x37 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43810 N: 8518']
x38 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43811 N: 40833']
x39 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43811 N: 40845']
x40 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43812 N: 30439']
x41 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43812 N: 30443']
x42 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43813 N: 24262']
x43 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43813 N: 24266']
x44 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43814 N: 18085']
x45 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43814 N: 18089']
x46 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43815 N: 8509']
x47 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43815 N: 8522']
x48 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43816 N: 40843']
x49 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43816 N: 40846']
x50 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43817 N: 30434']
x51 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43817 N: 30442']
x52 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43818 N: 8422']
x53 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43818 N: 8516']
x54 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43819 N: 24257']
x55 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43819 N: 24265']
x56 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43820 N: 18080']
x57 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43820 N: 18088']
x58 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43821 N: 8480']
x59 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43821 N: 8520']
x60 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43807 N: 30429']
x61 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43807 N: 30441']
x62 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43808 N: 24252']
x63 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43808 N: 24264']
x64 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43809 N: 18075']
x65 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43809 N: 18087']
x66 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43810 N: 8451']
x67 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43810 N: 8518']
x68 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43811 N: 40833']
x69 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43811 N: 40845']
x70 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43812 N: 30439']
x71 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43812 N: 30443']
x72 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43813 N: 24262']
x73 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43813 N: 24266']
x74 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43814 N: 18085']
x75 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43814 N: 18089']
x76 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43815 N: 8509']
x77 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43815 N: 8522']
x78 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43816 N: 40843']
x79 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43816 N: 40846']
x80 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43817 N: 30434']
x81 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43817 N: 30442']
x82 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43818 N: 8422']
```

```
x83 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43818 N: 8516']
x84 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43819 N: 24257']
x85 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43819 N: 24265']
x86 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43820 N: 18080']
x87 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43820 N: 18088']
x88 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43821 N: 8480']
x89 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43821 N: 8520']
session.writeXYReport(fileName='<-Path-Replace->_br.rpt',
  appendMode=OFF, xyData=(x0, x1, x2, x3, x4, x5, x6, x7, x8, x9, x10, x11,
  x12, x13, x14, x15, x16, x17, x18, x19, x20, x21, x22, x23, x24, x25, x26,
  x27, x28, x29, x30, x31, x32, x33, x34, x35, x36, x37, x38, x39, x40, x41,
  x42, x43, x44, x45, x46, x47, x48, x49, x50, x51, x52, x53, x54, x55, x56,
  x57, x58, x59, x60, x61, x62, x63, x64, x65, x66, x67, x68, x69, x70, x71,
  x72, x73, x74, x75, x76, x77, x78, x79, x80, x81, x82, x83, x84, x85, x86,
  x87, x88, x89))
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43807 N: 30429']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43807 N: 30441']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43808 N: 24252']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43808 N: 24264']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43809 N: 18075']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43809 N: 18087']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43810 N: 8451']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43810 N: 8518']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43811 N: 40833']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43811 N: 40845']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43812 N: 30439']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43812 N: 30443']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43813 N: 24262']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43813 N: 24266']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43814 N: 18085']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43814 N: 18089']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43815 N: 8509']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43815 N: 8522']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43816 N: 40843']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43816 N: 40846']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43817 N: 30434']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43817 N: 30442']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43818 N: 8422']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43818 N: 8516']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43819 N: 24257']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43819 N: 24265']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43820 N: 18080']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43820 N: 18088']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43821 N: 8480']
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43821 N: 8520']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43807 N: 30429']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43807 N: 30441']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43808 N: 24252']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43808 N: 24264']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43809 N: 18075']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43809 N: 18087']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43810 N: 8451']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43810 N: 8518']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43811 N: 40833']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43811 N: 40845']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43812 N: 30439']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43812 N: 30443']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43813 N: 24262']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43813 N: 24266']
```

```
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43814 N: 18085']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43814 N: 18089']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43815 N: 8509']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43815 N: 8522']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43816 N: 40843']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43816 N: 40846']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43817 N: 30434']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43817 N: 30442']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43818 N: 8422']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43818 N: 8516']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43819 N: 24257']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43819 N: 24265']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43820 N: 18080']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43820 N: 18088']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43821 N: 8480']
del session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43821 N: 8520']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43807 N: 30429']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43807 N: 30441']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43808 N: 24252']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43808 N: 24264']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43809 N: 18075']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43809 N: 18087']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43810 N: 8451']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43810 N: 8518']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43811 N: 40833']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43811 N: 40845']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43812 N: 30439']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43812 N: 30443']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43813 N: 24262']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43813 N: 24266']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43814 N: 18085']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43814 N: 18089']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43815 N: 8509']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43815 N: 8522']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43816 N: 40843']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43816 N: 40846']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43817 N: 30434']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43817 N: 30442']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43818 N: 8422']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43818 N: 8516']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43819 N: 24257']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43819 N: 24265']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43820 N: 18080']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43820 N: 18088']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43821 N: 8480']
del session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43821 N: 8520']
odb = session.odbs['<-ODB-Replace->']
session.xyDataListFromField(odb=odb, outputPosition=ELEMENT_NODAL, variable=((
  'NFORC1', ELEMENT_NODAL), ('NFORC2', ELEMENT_NODAL), ('NFORC3',
  ELEMENT_NODAL), ('NFORC4', ELEMENT_NODAL), ('NFORC5', ELEMENT_NODAL), (
  'NFORC6', ELEMENT_NODAL), ), elementSets=('PART-1-1.FEET', ))
x0 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43760 N: 37880']
x1 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43760 N: 40826']
x2 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43761 N: 40627']
x3 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43761 N: 40831']
x4 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43762 N: 40693']
x5 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43762 N: 40836']
x6 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43763 N: 40759']
x7 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43763 N: 44022']
```

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Performer: R. E. Spears **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

```
x8 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43764 N: 8221']
x9 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43764 N: 8449']
x10 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43765 N: 46']
x11 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43765 N: 8420']
x12 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43766 N: 8353']
x13 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43766 N: 8507']
x14 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43767 N: 8287']
x15 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43767 N: 8478']
x16 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43774 N: 17869']
x17 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43774 N: 18073']
x18 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43775 N: 15122']
x19 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43775 N: 18068']
x20 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43776 N: 18001']
x21 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43776 N: 18083']
x22 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43777 N: 17935']
x23 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43777 N: 18078']
x24 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43783 N: 24046']
x25 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43783 N: 24250']
x26 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43784 N: 21299']
x27 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43784 N: 24245']
x28 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43785 N: 24178']
x29 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43785 N: 24260']
x30 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43786 N: 24112']
x31 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43786 N: 24255']
x32 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43792 N: 30223']
x33 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43792 N: 30427']
x34 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43793 N: 27476']
x35 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43793 N: 30422']
x36 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43794 N: 30355']
x37 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43794 N: 30437']
x38 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43795 N: 30289']
x39 = session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43795 N: 30432']
x40 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43760 N: 37880']
x41 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43760 N: 40826']
x42 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43761 N: 40627']
x43 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43761 N: 40831']
x44 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43762 N: 40693']
x45 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43762 N: 40836']
x46 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43763 N: 40759']
x47 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43763 N: 44022']
x48 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43764 N: 8221']
x49 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43764 N: 8449']
x50 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43765 N: 46']
x51 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43765 N: 8420']
x52 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43766 N: 8353']
x53 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43766 N: 8507']
x54 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43767 N: 8287']
x55 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43767 N: 8478']
x56 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43774 N: 17869']
x57 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43774 N: 18073']
x58 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43775 N: 15122']
x59 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43775 N: 18068']
x60 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43776 N: 18001']
x61 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43776 N: 18083']
x62 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43777 N: 17935']
x63 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43777 N: 18078']
x64 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43783 N: 24046']
x65 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43783 N: 24250']
x66 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43784 N: 21299']
```

```
x67 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43784 N: 24245']
x68 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43785 N: 24178']
x69 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43785 N: 24260']
x70 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43786 N: 24112']
x71 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43786 N: 24255']
x72 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43792 N: 30223']
x73 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43792 N: 30427']
x74 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43793 N: 27476']
x75 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43793 N: 30422']
x76 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43794 N: 30355']
x77 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43794 N: 30437']
x78 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43795 N: 30289']
x79 = session.xyDataObjects['NFORC2: PI: PART-1-1 E: 43795 N: 30432']
x80 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43760 N: 37880']
x81 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43760 N: 40826']
x82 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43761 N: 40627']
x83 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43761 N: 40831']
x84 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43762 N: 40693']
x85 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43762 N: 40836']
x86 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43763 N: 40759']
x87 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43763 N: 44022']
x88 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43764 N: 8221']
x89 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43764 N: 8449']
x90 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43765 N: 46']
x91 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43765 N: 8420']
x92 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43766 N: 8353']
x93 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43766 N: 8507']
x94 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43767 N: 8287']
x95 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43767 N: 8478']
x96 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43774 N: 17869']
x97 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43774 N: 18073']
x98 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43775 N: 15122']
x99 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43775 N: 18068']
x100 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43776 N: 18001']
x101 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43776 N: 18083']
x102 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43777 N: 17935']
x103 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43777 N: 18078']
x104 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43783 N: 24046']
x105 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43783 N: 24250']
x106 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43784 N: 21299']
x107 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43784 N: 24245']
x108 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43785 N: 24178']
x109 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43785 N: 24260']
x110 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43786 N: 24112']
x111 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43786 N: 24255']
x112 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43792 N: 30223']
x113 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43792 N: 30427']
x114 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43793 N: 27476']
x115 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43793 N: 30422']
x116 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43794 N: 30355']
x117 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43794 N: 30437']
x118 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43795 N: 30289']
x119 = session.xyDataObjects['NFORC3: PI: PART-1-1 E: 43795 N: 30432']
x120 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43760 N: 37880']
x121 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43760 N: 40826']
x122 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43761 N: 40627']
x123 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43761 N: 40831']
x124 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43762 N: 40693']
x125 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43762 N: 40836']
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-398 **Rev.:** 0
Title: ATR PCS Heat Exchanger Seismic Analysis – Appendix A
Performer: R. E. Spears **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

```
x126 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43763 N: 40759']
x127 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43763 N: 44022']
x128 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43764 N: 8221']
x129 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43764 N: 8449']
x130 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43765 N: 46']
x131 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43765 N: 8420']
x132 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43766 N: 8353']
x133 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43766 N: 8507']
x134 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43767 N: 8287']
x135 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43767 N: 8478']
x136 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43774 N: 17869']
x137 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43774 N: 18073']
x138 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43775 N: 15122']
x139 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43775 N: 18068']
x140 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43776 N: 18001']
x141 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43776 N: 18083']
x142 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43777 N: 17935']
x143 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43777 N: 18078']
x144 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43783 N: 24046']
x145 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43783 N: 24250']
x146 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43784 N: 21299']
x147 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43784 N: 24245']
x148 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43785 N: 24178']
x149 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43785 N: 24260']
x150 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43786 N: 24112']
x151 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43786 N: 24255']
x152 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43792 N: 30223']
x153 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43792 N: 30427']
x154 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43793 N: 27476']
x155 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43793 N: 30422']
x156 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43794 N: 30355']
x157 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43794 N: 30437']
x158 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43795 N: 30289']
x159 = session.xyDataObjects['NFORC4: PI: PART-1-1 E: 43795 N: 30432']
x160 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43760 N: 37880']
x161 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43760 N: 40826']
x162 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43761 N: 40627']
x163 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43761 N: 40831']
x164 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43762 N: 40693']
x165 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43762 N: 40836']
x166 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43763 N: 40759']
x167 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43763 N: 44022']
x168 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43764 N: 8221']
x169 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43764 N: 8449']
x170 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43765 N: 46']
x171 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43765 N: 8420']
x172 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43766 N: 8353']
x173 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43766 N: 8507']
x174 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43767 N: 8287']
x175 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43767 N: 8478']
x176 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43774 N: 17869']
x177 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43774 N: 18073']
x178 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43775 N: 15122']
x179 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43775 N: 18068']
x180 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43776 N: 18001']
x181 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43776 N: 18083']
x182 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43777 N: 17935']
x183 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43777 N: 18078']
x184 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43783 N: 24046']
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-398 **Rev.:** 0
Title: ATR PCS Heat Exchanger Seismic Analysis – Appendix A
Performer: R. E. Spears **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

```
x185 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43783 N: 24250']
x186 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43784 N: 21299']
x187 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43784 N: 24245']
x188 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43785 N: 24178']
x189 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43785 N: 24260']
x190 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43786 N: 24112']
x191 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43786 N: 24255']
x192 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43792 N: 30223']
x193 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43792 N: 30427']
x194 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43793 N: 27476']
x195 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43793 N: 30422']
x196 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43794 N: 30355']
x197 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43794 N: 30437']
x198 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43795 N: 30289']
x199 = session.xyDataObjects['NFORC5: PI: PART-1-1 E: 43795 N: 30432']
x200 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43760 N: 37880']
x201 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43760 N: 40826']
x202 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43761 N: 40627']
x203 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43761 N: 40831']
x204 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43762 N: 40693']
x205 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43762 N: 40836']
x206 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43763 N: 40759']
x207 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43763 N: 44022']
x208 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43764 N: 8221']
x209 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43764 N: 8449']
x210 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43765 N: 46']
x211 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43765 N: 8420']
x212 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43766 N: 8353']
x213 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43766 N: 8507']
x214 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43767 N: 8287']
x215 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43767 N: 8478']
x216 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43774 N: 17869']
x217 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43774 N: 18073']
x218 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43775 N: 15122']
x219 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43775 N: 18068']
x220 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43776 N: 18001']
x221 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43776 N: 18083']
x222 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43777 N: 17935']
x223 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43777 N: 18078']
x224 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43783 N: 24046']
x225 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43783 N: 24250']
x226 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43784 N: 21299']
x227 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43784 N: 24245']
x228 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43785 N: 24178']
x229 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43785 N: 24260']
x230 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43786 N: 24112']
x231 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43786 N: 24255']
x232 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43792 N: 30223']
x233 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43792 N: 30427']
x234 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43793 N: 27476']
x235 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43793 N: 30422']
x236 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43794 N: 30355']
x237 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43794 N: 30437']
x238 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43795 N: 30289']
x239 = session.xyDataObjects['NFORC6: PI: PART-1-1 E: 43795 N: 30432']
session.writeXYReport(fileName='<-Path-Replace->_ft.rpt',
   xyData=(x0, x1, x2, x3, x4, x5, x6, x7, x8, x9, x10, x11, x12, x13, x14,
   x15, x16, x17, x18, x19, x20, x21, x22, x23, x24, x25, x26, x27, x28, x29,
   x30, x31, x32, x33, x34, x35, x36, x37, x38, x39, x40, x41, x42, x43, x44,
```

```
    x45, x46, x47, x48, x49, x50, x51, x52, x53, x54, x55, x56, x57, x58, x59,
    x60, x61, x62, x63, x64, x65, x66, x67, x68, x69, x70, x71, x72, x73, x74,
    x75, x76, x77, x78, x79, x80, x81, x82, x83, x84, x85, x86, x87, x88, x89,
    x90, x91, x92, x93, x94, x95, x96, x97, x98, x99, x100, x101, x102, x103,
    x104, x105, x106, x107, x108, x109, x110, x111, x112, x113, x114, x115,
    x116, x117, x118, x119, x120, x121, x122, x123, x124, x125, x126, x127,
    x128, x129, x130, x131, x132, x133, x134, x135, x136, x137, x138, x139,
    x140, x141, x142, x143, x144, x145, x146, x147, x148, x149, x150, x151,
    x152, x153, x154, x155, x156, x157, x158, x159, x160, x161, x162, x163,
    x164, x165, x166, x167, x168, x169, x170, x171, x172, x173, x174, x175,
    x176, x177, x178, x179, x180, x181, x182, x183, x184, x185, x186, x187,
    x188, x189, x190, x191, x192, x193, x194, x195, x196, x197, x198, x199,
    x200, x201, x202, x203, x204, x205, x206, x207, x208, x209, x210, x211,
    x212, x213, x214, x215, x216, x217, x218, x219, x220, x221, x222, x223,
    x224, x225, x226, x227, x228, x229, x230, x231, x232, x233, x234, x235,
    x236, x237, x238, x239))
del session.xyDataObjects['NFORC1: PI: PART-1-1 E: 43760 N: 37880']
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Project: ATR Life Time Extension Project **ECAR No.:** ECAR-398 **Rev.:** 0
Title: ATR PCS Heat Exchanger Seismic Analysis – Appendix A
Performer: R. E. Spears **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

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  nodeSets=('PART-1-1.BBND', ))
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x2 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45699']
x3 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45701']
x4 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45766']
x5 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45768']
x6 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45770']
x7 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45772']
x8 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45837']
x9 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45839']
x10 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45841']
x11 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45843']
x12 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45908']
x13 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45910']
x14 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45912']
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x26 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45770']
x27 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45772']
x28 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45837']
x29 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45839']
x30 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45841']
x31 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45843']
x32 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45908']
x33 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45910']
x34 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45912']
```

```
x35 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45914']
x36 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45979']
x37 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45981']
x38 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45983']
x39 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45985']
x40 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45695']
x41 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45697']
x42 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45699']
x43 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45701']
x44 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45766']
x45 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45768']
x46 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45770']
x47 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45772']
x48 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45837']
x49 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45839']
x50 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45841']
x51 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45843']
x52 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45908']
x53 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45910']
x54 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45912']
x55 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45914']
x56 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45979']
x57 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45981']
x58 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45983']
x59 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45985']
session.writeXYReport(fileName='<-Path-Replace->_bb.rpt',
   xyData=(x0, x1, x2, x3, x4, x5, x6, x7, x8, x9, x10, x11, x12, x13, x14,
   x15, x16, x17, x18, x19, x20, x21, x22, x23, x24, x25, x26, x27, x28, x29,
   x30, x31, x32, x33, x34, x35, x36, x37, x38, x39, x40, x41, x42, x43, x44,
   x45, x46, x47, x48, x49, x50, x51, x52, x53, x54, x55, x56, x57, x58, x59))
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45695']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45697']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45699']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45701']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45766']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45768']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45770']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45772']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45837']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45839']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45841']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45843']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45908']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45910']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45912']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45914']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45979']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45981']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45983']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 45985']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45695']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45697']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45699']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45701']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45766']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45768']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45770']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45772']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45837']
```

```
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45839']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45841']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45843']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45908']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45910']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45912']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45914']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45979']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45981']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45983']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 45985']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45695']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45697']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45699']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45701']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45766']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45768']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45770']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45772']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45837']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45839']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45841']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45843']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45908']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45910']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45912']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45914']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45979']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45981']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45983']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 45985']
odb = session.odbs['<-ODB-Replace->']
session.xyDataListFromField(odb=odb, outputPosition=NODAL, variable=(('RF',
  NODAL, ((COMPONENT, 'RF1'), (COMPONENT, 'RF2'), (COMPONENT, 'RF3'), )), (
  'RM', NODAL, ((COMPONENT, 'RM1'), (COMPONENT, 'RM2'), (COMPONENT, 'RM3'),
  )), ), nodeSets=('PART-1-1.CONBASE', ))
x0 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 8419']
x1 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 8477']
x2 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 8506']
x3 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 18067']
x4 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 18077']
x5 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 18082']
x6 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 24244']
x7 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 24254']
x8 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 24259']
x9 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 30421']
x10 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 30431']
x11 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 30436']
x12 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 8419']
x13 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 8477']
x14 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 8506']
x15 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 18067']
x16 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 18077']
x17 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 18082']
x18 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 24244']
x19 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 24254']
x20 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 24259']
x21 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 30421']
x22 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 30431']
```

```
x23 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 30436']
x24 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 8419']
x25 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 8477']
x26 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 8506']
x27 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 18067']
x28 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 18077']
x29 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 18082']
x30 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 24244']
x31 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 24254']
x32 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 24259']
x33 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 30421']
x34 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 30431']
x35 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 30436']
x36 = session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 8419']
x37 = session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 8477']
x38 = session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 8506']
x39 = session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 18067']
x40 = session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 18077']
x41 = session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 18082']
x42 = session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 24244']
x43 = session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 24254']
x44 = session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 24259']
x45 = session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 30421']
x46 = session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 30431']
x47 = session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 30436']
x48 = session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 8419']
x49 = session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 8477']
x50 = session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 8506']
x51 = session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 18067']
x52 = session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 18077']
x53 = session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 18082']
x54 = session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 24244']
x55 = session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 24254']
x56 = session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 24259']
x57 = session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 30421']
x58 = session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 30431']
x59 = session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 30436']
x60 = session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 8419']
x61 = session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 8477']
x62 = session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 8506']
x63 = session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 18067']
x64 = session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 18077']
x65 = session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 18082']
x66 = session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 24244']
x67 = session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 24254']
x68 = session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 24259']
x69 = session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 30421']
x70 = session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 30431']
x71 = session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 30436']
session.writeXYReport(fileName='<-Path-Replace->_cb.rpt',
   xyData=(x0, x1, x2, x3, x4, x5, x6, x7, x8, x9, x10, x11, x12, x13, x14,
   x15, x16, x17, x18, x19, x20, x21, x22, x23, x24, x25, x26, x27, x28, x29,
   x30, x31, x32, x33, x34, x35, x36, x37, x38, x39, x40, x41, x42, x43, x44,
   x45, x46, x47, x48, x49, x50, x51, x52, x53, x54, x55, x56, x57, x58, x59,
   x60, x61, x62, x63, x64, x65, x66, x67, x68, x69, x70, x71))
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 8419']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 8477']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 8506']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 18067']
```

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-398 **Rev.:** 0
Title: ATR PCS Heat Exchanger Seismic Analysis – Appendix A
Performer: R. E. Spears **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

```
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 18077']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 18082']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 24244']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 24254']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 24259']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 30421']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 30431']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 30436']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 8419']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 8477']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 8506']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 18067']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 18077']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 18082']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 24244']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 24254']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 24259']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 30421']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 30431']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 30436']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 8419']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 8477']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 8506']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 18067']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 18077']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 18082']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 24244']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 24254']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 24259']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 30421']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 30431']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 30436']
del session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 8419']
del session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 8477']
del session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 8506']
del session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 18067']
del session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 18077']
del session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 18082']
del session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 24244']
del session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 24254']
del session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 24259']
del session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 30421']
del session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 30431']
del session.xyDataObjects['RM:RM1 PI: PART-1-1 N: 30436']
del session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 8419']
del session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 8477']
del session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 8506']
del session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 18067']
del session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 18077']
del session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 18082']
del session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 24244']
del session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 24254']
del session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 24259']
del session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 30421']
del session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 30431']
del session.xyDataObjects['RM:RM2 PI: PART-1-1 N: 30436']
del session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 8419']
del session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 8477']
del session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 8506']
```

```
del session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 18067']
del session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 18077']
del session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 18082']
del session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 24244']
del session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 24254']
del session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 24259']
del session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 30421']
del session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 30431']
del session.xyDataObjects['RM:RM3 PI: PART-1-1 N: 30436']
odb = session.odbs['<-ODB-Replace->']
session.xyDataListFromField(odb=odb, outputPosition=NODAL, variable=(('RF',
   NODAL, ((COMPONENT, 'RF1'), (COMPONENT, 'RF2'), (COMPONENT, 'RF3'), )), ),
   nodeSets=('PART-1-1.STBASE', ))
x0 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 8448']
x1 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 18072']
x2 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 24249']
x3 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 30426']
x4 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 40830']
x5 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 44021']
x6 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 46720']
x7 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 46721']
x8 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 46722']
x9 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 46723']
x10 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 46724']
x11 = session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 46725']
x12 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 8448']
x13 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 18072']
x14 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 24249']
x15 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 30426']
x16 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 40830']
x17 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 44021']
x18 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 46720']
x19 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 46721']
x20 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 46722']
x21 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 46723']
x22 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 46724']
x23 = session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 46725']
x24 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 8448']
x25 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 18072']
x26 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 24249']
x27 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 30426']
x28 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 40830']
x29 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 44021']
x30 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 46720']
x31 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 46721']
x32 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 46722']
x33 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 46723']
x34 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 46724']
x35 = session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 46725']
session.writeXYReport(fileName='<-Path-Replace->_sb.rpt',
   xyData=(x0, x1, x2, x3, x4, x5, x6, x7, x8, x9, x10, x11, x12, x13, x14,
   x15, x16, x17, x18, x19, x20, x21, x22, x23, x24, x25, x26, x27, x28, x29,
   x30, x31, x32, x33, x34, x35))
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 8448']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 18072']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 24249']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 30426']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 40830']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 44021']
```

```
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 46720']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 46721']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 46722']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 46723']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 46724']
del session.xyDataObjects['RF:RF1 PI: PART-1-1 N: 46725']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 8448']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 18072']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 24249']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 30426']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 40830']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 44021']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 46720']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 46721']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 46722']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 46723']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 46724']
del session.xyDataObjects['RF:RF2 PI: PART-1-1 N: 46725']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 8448']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 18072']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 24249']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 30426']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 40830']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 44021']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 46720']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 46721']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 46722']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 46723']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 46724']
del session.xyDataObjects['RF:RF3 PI: PART-1-1 N: 46725']
sys.exit(0)
```

A-8.8 File Modification for Mathcad Script

The Python script "rpt2prn.py" below loads each report (.rpt) file, removes the header lines, and saves it out as a print (.prn) file. This is done to make the file easily read into Mathcad.

```
import os, string

base_dir = r'C:\er2\work\Stuart_misc\Heat_Exchangers_Seismic\output'
file_prefix = r'HtEx'
file_type = '.rpt'
output_dir = base_dir+os.sep+'prns'

os.chdir(base_dir+os.sep+'rpts')

if os.path.isdir(output_dir) == False:
   os.mkdir(output_dir)

for file in os.listdir('./'):
   if file.find(file_prefix) !=-1 and file.find(file_type) !=-1:
      tmp_file = open(file)
      tmp_data=tmp_file.readlines()[4:]
      tmp_file.close()
      print file
```

```
outfile = open(output_dir+os.sep+os.path.splitext(file)[0]+'.prn','w')
for line in tmp_data:
   outfile.write(line)

outfile.close()
```

A-9.0 References

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18. INL Drawing Number 120935, "MISCELLANEOUS SYSTEMS PIPE HANGERS & DETIALS SHEET #2," Revision 7.

19. INL Drawing Number 127070, "PIPING SPOOL-SECONDARY COOLING WATER SH 2 OF 2," Revision 1.

20. INL Drawing Number 127071, "PIPING SPOOL-SECONDARY COOLING WATER," Revision 1.

21. INL Drawing Number 127072, "PIPING SPOOL-SECONDARY COOLING WATER," Revision 1.

22. INL Drawing Number 127073, "PIPING SPOOL-SECONDARY COOLING WATER," Revision 1.

23. INL Drawing Number 127074, "PIPING SPOOL-SECONDARY COOLING WATER PIPING SPOOL-SECONDARY COOLING WATER SH 1 OF 2," Revision 1.

24. INL Drawing Number 127075, "PIPING SPOOL-SECONDARY COOLING WATER SH 2 OF 2," Revision 1.

25. INL Drawing Number 127076, "PIPING SPOOL-SECONDARY COOLING WATER SH 2 OF 2," Revision 1.

26. INL Drawing Number 124669, "PRIMARY HEAT EXCHANGER," Revision 5.

27. INL Drawing Number 124670, "PRIMARY HEAT EXCHANGER TUBE SHEET DRILLING TEMPLATE," Revision 1.

28. INL Drawing Number 124671, "PRIMARY HEAT EXCHANGER U TUBE BUNDLE ASSEMBLY," Revision 2.

29. INL Drawing Number 124672, "PRIMARY HEAT EXCHANGER CHANNEL COVER," Revision 3.

30. INL Drawing Number 124673, "PRIMARY HEAT EXCHANGER TUBE SHEET AND CHANNEL DETAILS," Revision 3.

31. INL Drawing Number 124674, "PRIMARY HEAT EXCHANGER SHELL DETAILS," Revision 1.

32. INL Drawing Number 124675, "PRIMARY HEAT EXCHANGER SUPPORT BARS FOR U BENDS," Revision 0.

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36. INL Drawing Number 124714, "SHELL BARREL PRIMARY HEAT EXCHANGER," Revision 0.

37. INL Drawing Number 124715, "SHELL BARREL PRIMARY HEAT EXCHANGER," Revision 0.

38. INL Drawing Number 124716, "U-TUBE BUNDLE ASSEMBLY PRIMARY HEAT EXCHANGER," Revision 0.

39. INL Drawing Number 124717, "U-TUBE BUNDLE ASSEMBLY PRIMARY HEAT EXCHANGER," Revision 0.

40. INL Drawing Number 124718, "SHELL ATR PRIMARY HEAT EXCHANGER," Revision 0.

41. INL Drawing Number 124719, "SHELL ATR PRIMARY HEAT EXCHANGER," Revision 0.

42. INL Drawing Number 124720, "CHANNEL COVER ASS Y PRIMARY HEAT EXCHANGER," Revision 0.

43. INL Drawing Number 124721, "PRIMARY HEAT EXCHANGER OUTLINE,670-M-2," Revision 0.

44. INL Drawing Number 124722, "PRIMARY HEAT EXCHANGER OUTLINE,670-M-3," Revision 0.

45. INL Drawing Number 124726, "TUBE SHEET ATR PRIMARY HEAT EXCHANGER," Revision 0.

46. INL Drawing Number 124727, "BAFFLES ATR PRIMARY HEAT EXCHANGER," Revision 0.

47. INL Drawing Number 124728, "BAFFLES ATR PRIMARY HEAT EXCHANGER," Revision 0.

48. INL Drawing Number 124729, "PRIMARY HEAT EXCHANGER GENERAL ASSEMBLY," Revision 0.

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55. INL Drawing Number 121123, "REACTOR BUILDING HEAT EXCHANGER PLATFORMS & MISCELLANEOUS STEEL," Revision 4.

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Appendix B

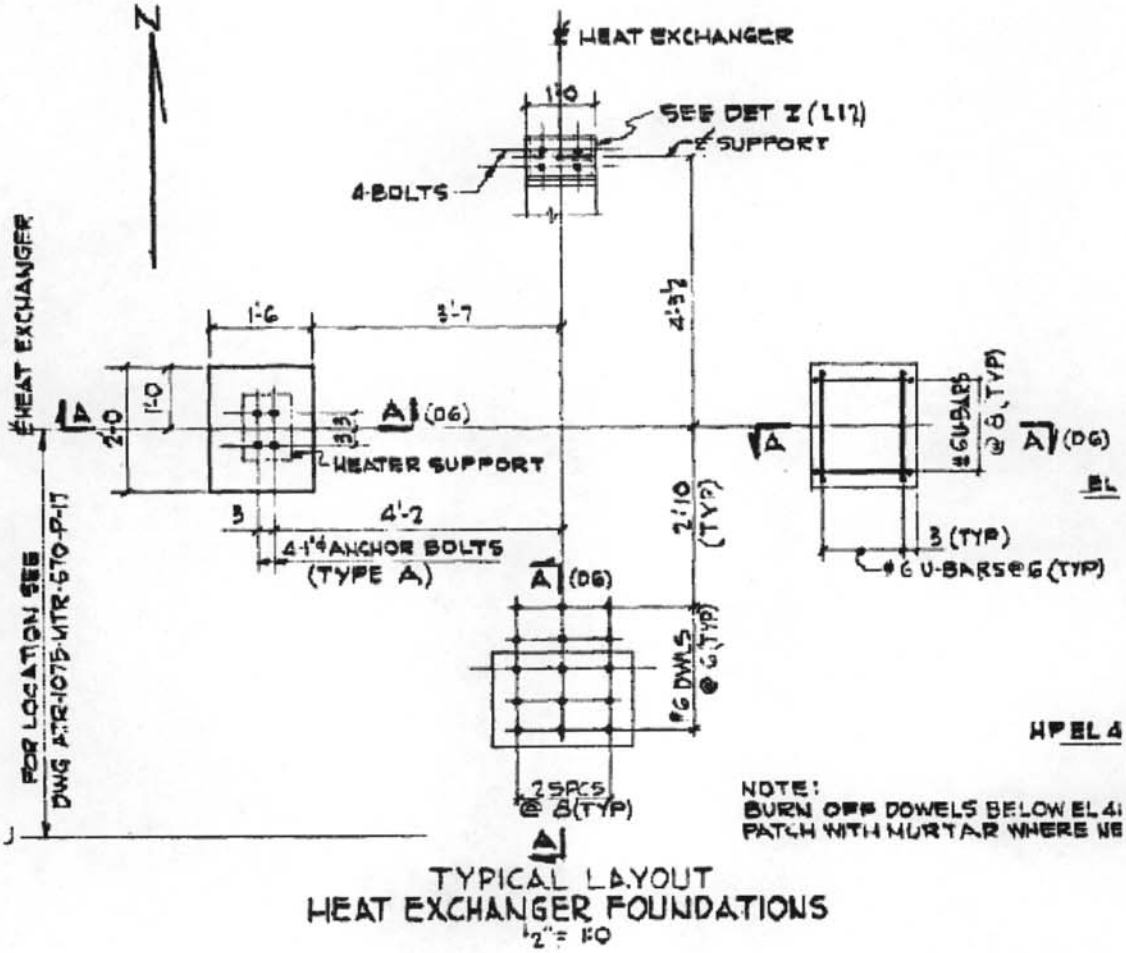
Heat Exchanger Anchorage Evaluation

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-398 **Rev.:** 0

Title: ATR PCS Heat Exchanger Seismic Analysis – Appendix B

Performer: B. G. Harris **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

The purpose of the following calculations is to evaluate the allowable capacities of the anchorage to the short columns supporting the Heat Exchanger (see dwg. 121084 (S-65)).



TYPICAL LAYOUT
HEAT EXCHANGER FOUNDATIONS
½" = 1'-0

Excerpt from drawing 121084 showing plan view of the heat exchanger supports

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-398 **Rev.:** 0

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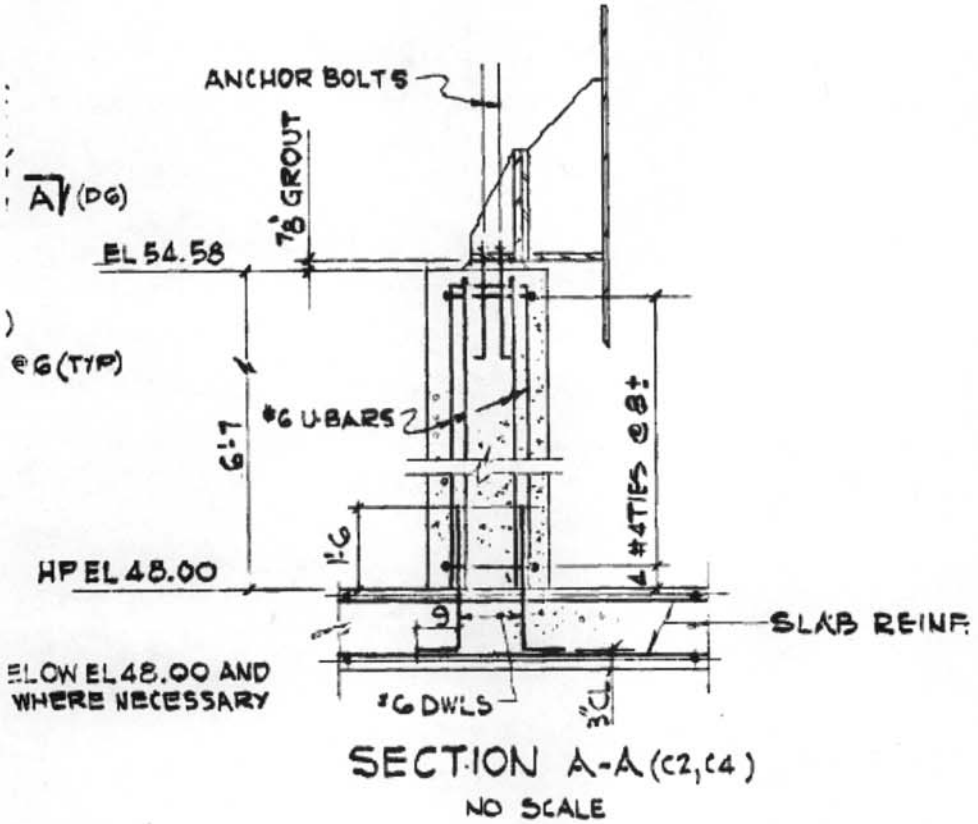
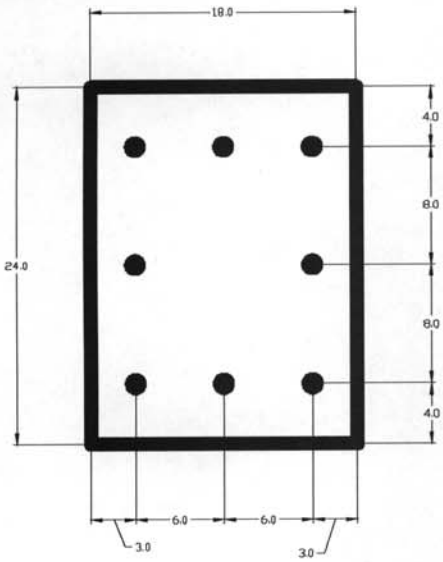
Performer: B. G. Harris **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08



Excerpt from drawing 121084 showing an elevation of a typical heat exchanger support column

Column cross section:

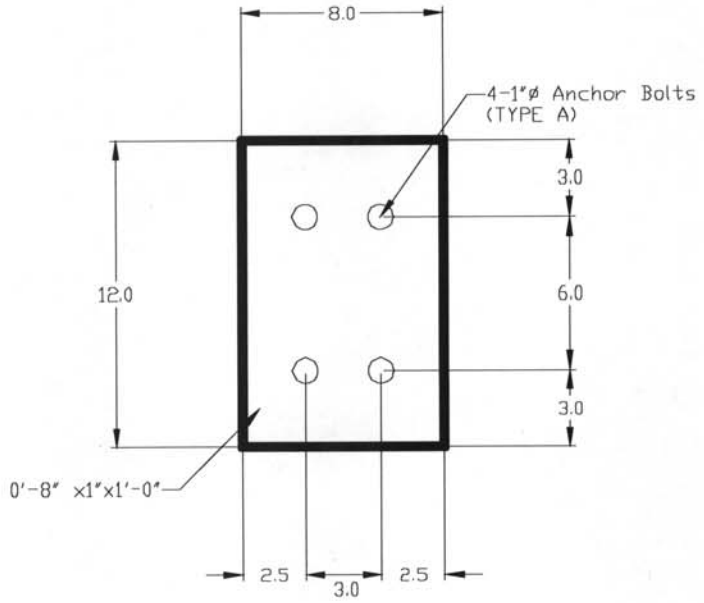


Project: ATR Life Time Extension Project **ECAR No.:** ECAR-398 **Rev.:** 0

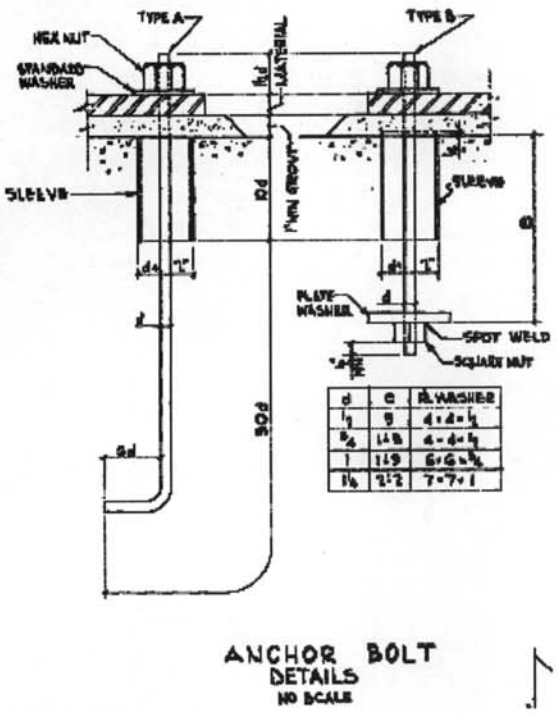
Title: ATR PCS Heat Exchanger Seismic Analysis – Appendix B

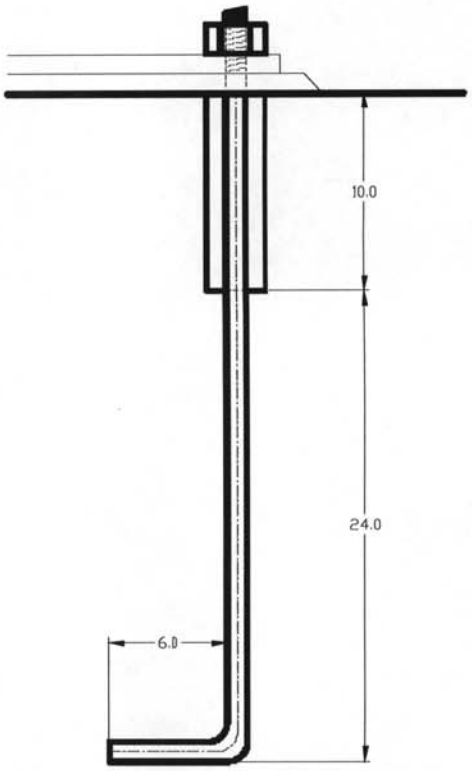
Performer: B. G. Harris **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

Baseplate:



Base plate dimensions:





Anchor dimensions

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-398 **Rev.:** 0
Title: ATR PCS Heat Exchanger Seismic Analysis – Appendix B
Performer: B. G. Harris **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

ACI 349-06, Appendix B, does not address "J" or "L" bolts. It only addresses headed or nutted anchor bolts. ACI 318-05 Appendix D does include "J" or "L" bolts. Therefore, the following calculations are based on ACI 318-05, Appendix D. Note that -02 variables were used throughout, with a correlation as specified Unless otherwise noted, dimensions are from the design drawings [2]

$f_{y_bolt} := 33ksi$ Yield strength of ASTM A-7 bolting [1]l

$f_{u_bolt} := 60ksi$ Tensile strength of ASTM A-7 bolting [1]

$n_{bolt} := 4$ Number of anchor bolts

$d_{bolt} := 1in$ Diameter of anchor bolts

$A_{bolt} := \frac{\pi \cdot d_{bolt}^2}{4}$ $A_{bolt} = 0.785 \cdot in^2$ Area of a single anchor bolt

$c_1 := 7.5in$ $s_1 := 3in$ Edge distance and hole spacing

$c_2 := 9in$ $s_2 := 6in$ Edge distance and hole spacing

$c_{max} := max(c_1, c_2)$ $c_{max} = 9 \cdot in$ $s_{max} := max(s_1, s_2)$ $s_{max} = 6 \cdot in$

$c_{min} := min(c_1, c_2)$ $c_{min} = 7.5 \cdot in$

$f'_c := 3 \cdot ksi$ Strength of concrete [2]

$b := 18in$ Width of short side

$h := 24in$ Width of long side

D.5.1 - Steel strength of anchor in tension

$\phi := 0.75$ Based on ductile steel (D.4.4)

$A_{se} := 0.606in^2$ Net tensile area (see AISC 13th Table 7-18)

$f_{ut} := min(f_{u_bolt}, 1.9 \cdot f_{y_bolt}, 125ksi)$ $f_{ut} = 60000psi$ (D.5.1.2)

$\phi N_s := \phi \cdot n_{bolt} \cdot A_{se} \cdot f_{ut}$ $\phi N_s = 109.08kip$ Steel strength of 4 anchors in tension (Eqn. D-3)

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D.5.2 - Concrete breakout strength of anchor in tension

$\phi := 0.70$ — Assume condition B (D.4.4)

$h_{ef} := \max\left[\left(\frac{s_{max}}{3}\right), \frac{c_{max}}{1.5}\right]$ $\quad h_{ef} = 6 \cdot in$ — Effective anchor embedment depth (D.5.2.3)

$A_{no} := 9 \cdot h_{ef}^2$ $\quad A_{no} = 324 \cdot in^2$ — Projected concrete failure of one anchor when not limited by edge distance or spacing Eqn D-6

$1.5 \cdot h_{ef} = 9 \cdot in$ — Therefore, A_h will be limited by the area of the column.

$A_n := b \cdot h$ $\quad A_n = 432 \cdot in^2$ — Projected concrete failure of a group of anchors

$k := 24$ — Factor for cast-in anchors (D.5.5.2)

$N_b := k \cdot \sqrt{\frac{f'_c}{psi}} \cdot psi \cdot \left(\frac{h_{ef}}{in}\right)^{1.5} \cdot in^2$ $\quad N_b = 19.32 kip$ — Basic concrete breakout strength in tension (Eqn. D-7)

$\psi_1 := 1.0$ — Modification factor for eccentrically loaded anchor group assuming no eccentricity (Eqn. D-9 - Same as ? $_{ec,N}$)

$\psi_2 := 0.7 + 0.3 \frac{c_{min}}{1.5 \cdot h_{ef}}$ $\quad \psi_2 = 0.95$ — Modification factor for edge effects (Eqn. D-11 - Same as ? $_{ed,N}$)

$\psi_3 := 1.0$ — Modification factor assuming cracked concrete (D.5.2.6 - Same as ? $_{c,N}$)

$\psi_4 := 1.0$ — Modification factor for post-installed anchors (D.5.2.7 - Same as ? $_{cp,N}$)

$N_{cbg} := \frac{A_n}{A_{no}} \psi_1 \cdot \psi_2 \cdot \psi_3 \cdot \psi_4 \cdot N_b$ $\quad N_{cbg} = 24.472 kip$ — Nominal concrete breakout strength in tension of a group of anchors Eqn D-5

$\phi N_{cbg} := \phi \cdot N_{cbg}$ $\quad \phi N_{cbg} = 17.13 kip$ — Concrete breakout strength in tension

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D.5.3 - Pullout strength of anchor in tension

$\phi := 0.70$ — Assume condition B (D.4.4)

$e_h := 4.5 \cdot d_{bolt}$ $\quad e_h = 4.5 \cdot in$ — e_h cannot exceed $4.5d_o$ (D.5.3.5)

$N_p := 0.9 \cdot f'_c \cdot e_h \cdot d_{bolt}$ $\quad N_p = 12.15 kip$ — Pullout strength in tension of a single anchor in cracked concrete

$\psi_3 := 1.0$ — Modification factor assuming cracked concrete (D.5.2.6, per D.5.3. - Same as ? $_{c,N}$)

$N_{pn} := \psi_3 \cdot N_p$ $\quad N_{pn} = 12.15 kip$ — Nominal pullout strength in tension of a single anchor

$\phi N_{pn} := \phi \cdot n_{bolt} \cdot N_{pn}$ $\quad \phi N_{pn} = 34.02 kip$ — Pullout strength of group of 4 L-bolts in tension

D.5.4 Concrete side-face blow out strength of a headed anchor in tension

Note: since L-bolts are used side face blowout failure is not applicable, Per ACI 318-05 D.5.4 requirements are applicable to headed anchors.

D.6.1 - Steel strength of anchor in shear

$\phi := 0.65$ Based on ductile steel (D.4.4)

$V_s := n_{bolt} \cdot 0.6 A_{se} \cdot f_{u_bolt} \cdot 0.8 \quad V_s = 69.811 kip$ Nominal strength in shear of a group of anchors as governed by the steel strength (D.6.1.2 & D.6.1.3)

$\phi V_s := \phi \cdot V_s \quad \phi V_s = 45.377 kip$ Anchor group shear strength

D.6.2 - Concrete breakout strength of anchor in shear

$\phi := 0.70$ Assume condition B (D.4.4)

Calculate Shear Capacity in Direction Parallel to Long Side of Column

$c_{1y} := 9in \quad c_{2y} := 7.5in \quad s_{1y} := 3in \quad s_{2y} := 6in \quad c_{ymin} := \max(c_{1y}, c_{2y}) \quad c_{ymin} = 9 \cdot in$

$A_{voy} := 4.5 \cdot c_{ymin}^2 \quad A_{voy} = 364.5 in^2$

$A_{vy} := \min(3 \cdot c_{1y} + s_{1y}, 18in) \cdot 1.5 \cdot c_{1y} \quad A_{vy} = 243 \cdot in^2$

$\psi_5 := 1$ Modification factor for eccentrically loaded anchor group assuming no eccentricity (Eqn. D-26 - Same as ?$_{ec,V}$)

$\frac{c_{2y}}{c_{1y}} = 0.833$

$\psi_6 := 0.7 + 0.3 \cdot \frac{c_{2y}}{1.5 \cdot c_{1y}} \quad \psi_6 = 0.867$ Modification factor for edge effect (Eqn. D-28 - Same as ?$_{ed,V}$)

$\psi_7 := 1.0$ Modification factor assuming cracked concrete (D.6.2.7 - Same as ?$_{c,V}$)

$l := h_{ef} \quad l = 6 \cdot in$ Bearing area of anchor bolts are not known since they are in sleeves. Assume the annulus in the sleeves is grouted. (D.6.2.2)

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$$V_{by} := 7\cdot\left(\frac{\frac{l}{in}}{\frac{d_{bolt}}{in}}\right)^{0.2}\cdot\sqrt{\frac{d_{bolt}}{in}}\cdot\sqrt{\frac{f'_c}{psi}}\cdot\left(\frac{c_{1y}}{in}\right)^{1.5}\cdot lbf \qquad V_{by} = 14.813\,kip$$

Eqn. D-24

$$V_{cbgy} := \frac{A_{vy}}{A_{voy}}\cdot\psi_5\cdot\psi_6\cdot\psi_7\cdot V_{by} \qquad V_{cbgy} = 8.559\,kip$$

Nominal concrete breakout strength in shear of a group of anchors (Eqn. D-22)

$$\phi V_{cbgy} := \phi\cdot V_{cbgy} \qquad \phi V_{cbgy} = 5.991\cdot kip$$

Concrete breakout shear strength in direction parallel to long side

Calculate Shear Capacity in Direction Parallel to Short Side of Column

$c_{1x} := 7.5in$ $\quad c_{2x} := 9in$ $\quad s_{1x} := 6in$ $\quad s_{2x} := 3in$ $\quad c_{xmin} := \min(c_{1x}, c_{2x})$ $\quad c_{xmin} = 7.5\cdot in$

$A_{vox} := 4.5\cdot c_{xmin}^2 \qquad A_{vox} = 253.125\,in^2$

$A_{vx} := \min(3\cdot c_{1x} + s_{1x}, 24in)\cdot 1.5\cdot c_{1x} \qquad A_{vx} = 270\cdot in^2$

$\psi_5 := 1$

Modification factor for eccentrically loaded anchor group assuming no eccentricity (Eqn. D-26 - Same as ? $_{ec,V}$)

$$\frac{c_{2x}}{c_{1x}} = 1.2$$

$$\psi_6 := 0.7 + 0.3\cdot\frac{c_{2x}}{1.5\cdot c_{1x}} \qquad \psi_6 = 0.94$$

Modification factor for edge effect (Eqn. D-28 - Same as ?$_{ed,V}$)

$\psi_7 := 1.0$

Modification factor assuming cracked concrete (D.6.2.7 - Same as ? $_{c,V}$)

$l := h_{ef} \qquad l = 6\cdot in$

Bearing area of anchor bolts are not known since they are in sleeves. Assume the annulus in the sleeves is grouted. (D.6.2.2)

$$V_{bx} := 7\cdot\left(\frac{\frac{l}{in}}{\frac{d_{bolt}}{in}}\right)^{0.2}\cdot\sqrt{\frac{d_{bolt}}{in}}\cdot\sqrt{\frac{f'_c}{psi}}\cdot\left(\frac{c_{1x}}{in}\right)^{1.5}\cdot lbf \qquad V_{bx} = 11.269\,kip$$

Eqn. D-24

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$A_{vx} = 270 \cdot in^2$

$A_{vox} = 253.1 \cdot in^2$

$A_{vx} < 2 \cdot A_{vox} = 1$ OK D.6.2.1

$V_{cbgx} := \frac{A_{vx}}{A_{vox}} \cdot \psi_5 \cdot \psi_6 \cdot \psi_7 \cdot V_{bx}$ $V_{cbgx} = 11.299 kip$ Nominal concrete breakout strength in shear of a group of anchors (Eqn. D-22)

$\phi V_{cbgx} := \phi \cdot V_{cbgx}$ $\phi V_{cbgx} = 7.909 kip$ Concrete breakout shear strength in direction parallel to short side

Capacity Summary:

Tension in concrete anchors:

$\phi N_s = 109.08 kip$ Steel strength of 4 anchors in tension

$\phi N_{cbg} = 17.13 kip$ <--- Controls tension Concrete breakout strength of 4 anchors in tension

$\phi N_{pn} = 34.02 kip$ Pullout strength of 4L-bolts in tension

Shear in concrete anchors:

$\phi V_s = 45.377 kip$ Group of 4 anchor shear strength

$\phi V_{cbgx} = 7.909 kip$ Group of 4 concrete breakout strength in shear

$\phi V_{cbgy} = 5.991 \cdot kip$ <--- Controls shear Group of 4 concrete breakout shear strength in direction parallel to long side

Demand Summary:

The maximum shear demand on the anchorage occurs in the east-west direction, and is reported in Appendix A to be 55 kip. This is obviously in excess of the shear capacity by itself. There is no need to evaluate tension/shear interaction or other loads. Recommend design modification be considered

Project: ATR Life Time Extension Project **ECAR No.:** ECAR-398 **Rev.:** 0
Title: ATR PCS Heat Exchanger Seismic Analysis – Appendix B
Performer: B. G. Harris **Date:** 9/30/08 **Checker:** M. J. Russell **Date:** 9/30/08

References

1. ASTM A-7, "Standard Specifiction for Steel for Bridges and Buildings," ASTM International, 1966.
2. Drawing 121084, "REACTOR BUILDING EQUIPMENT FOUNDATIONS CONCRETE & REINFORCING," Revision 3, March 1965.