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.

5. Review (R) and Approval (A) and Acceptance (Ac)[1]:

		Typed Name/Organization	Signature/Date[2]
Performer/Author		R. E. Spears	Robert E. Spears 9-30-08
Performer/Author		B. G. Harris	B.G. Harris for SR Jensen 9/30/08
Technical Checker	R	M. J. Russell	Pages checked: All Body, App B Mark Russell 9/30/08
Independent Peer Reviewer[3]	R	S. D. Snow	SD Snow 9/30/08
Performer's Manager	A	C. C. O'Brien	[illegible] 9/30/08
Requester	Ac	S. R. Jensen	SR Jensen 9/30/08
Nuclear Safety[3]	Ac	J.C. Chapman /G125	JC Chapman 30 Sep 2008
Technical Checker	R	P.J Matonis	Pages checked: App B Peter J Matonis 30 SEP 08
DOC Control		Laura Smith	Laura Smith 12/2/08

1 Review and Approval are required. See LWP-10200 for definitions and responsibilities.
2 An Electronic Change Request (ECR) indicating final review and concurrence by the listed individuals can be used in lieu of signatures.
3 If Required, per LWP-10200.

6. Additional Distribution: (Name and Mail Stop)	Document Control:

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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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Title: ATR PCS Heat Exchanger Seismic Analysis

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.

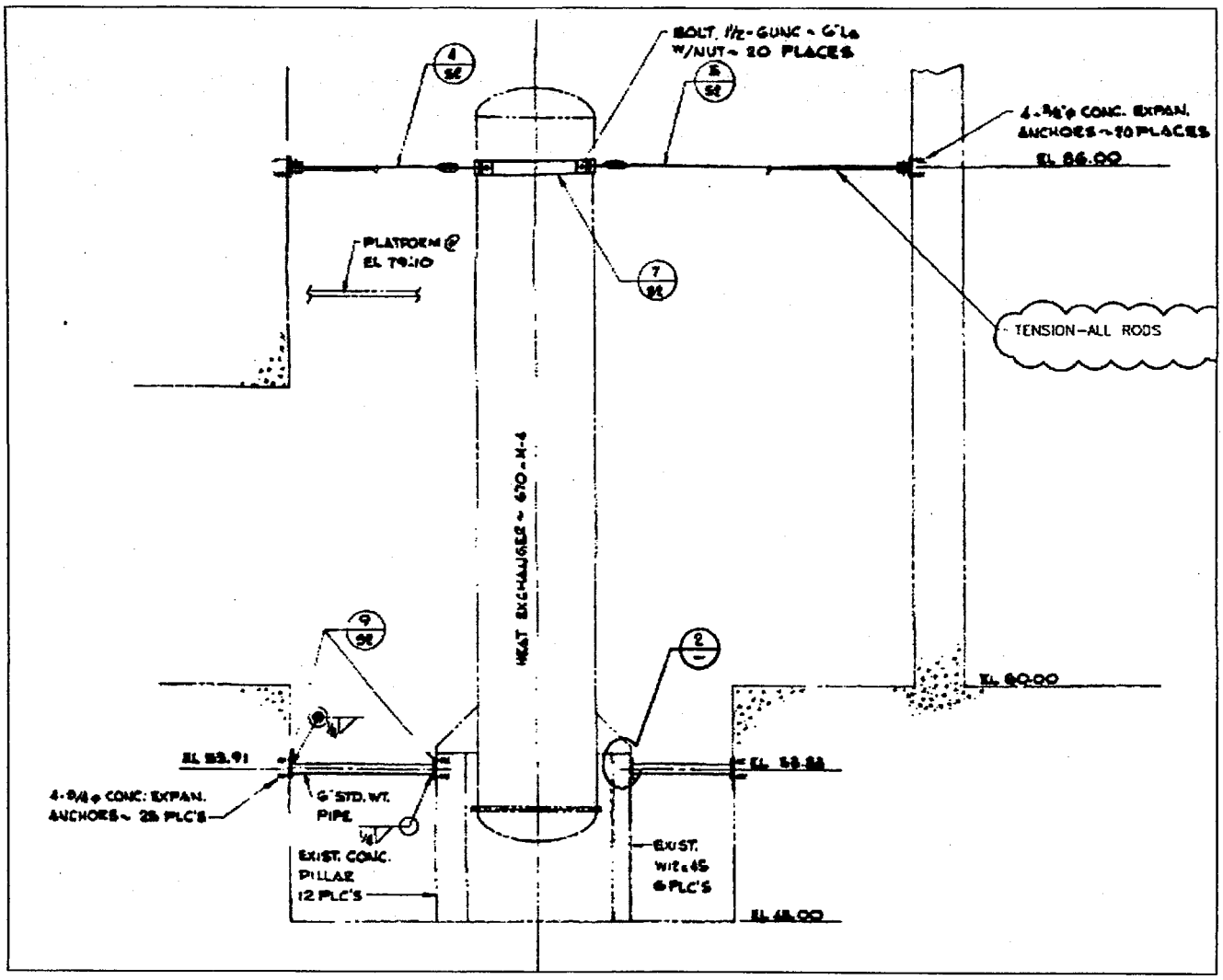

Figure 1: Heat Exchanger with Bracing

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.

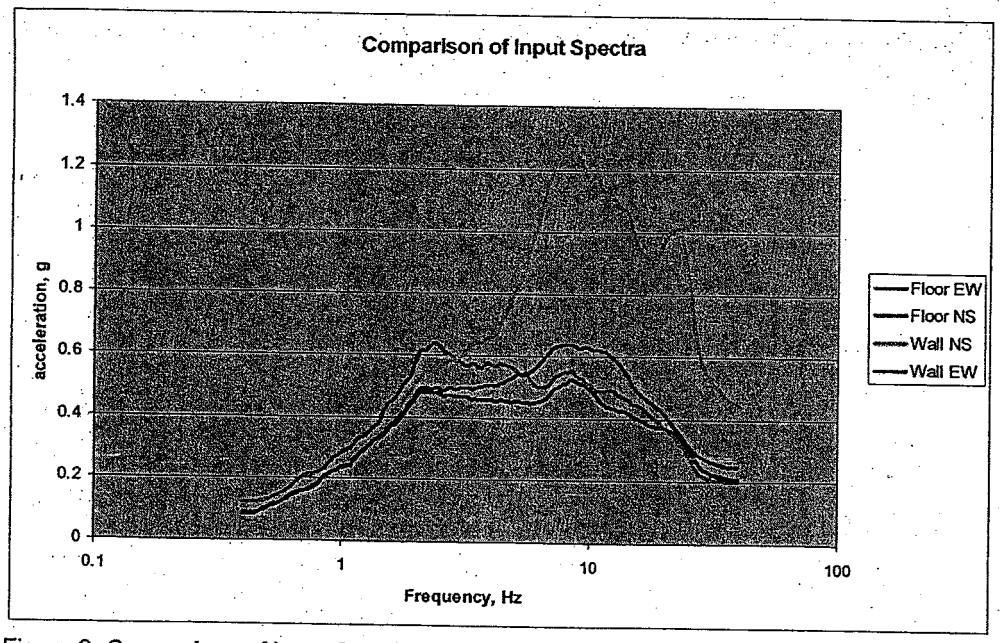

Figure 2: Comparison of Input Spectra

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).

References

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