ENCLOSURE 5

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PCCS Condenser Seismic Analysis

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NORTH ANNA 3 PCCS CONDENSER SEISMIC ANALYSIS

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1. INTRODUCTION

1.1 Purpose

The structural adequacy of the ESBWR Passive Containment Cooling System (PCCS) Condenser is evaluated for DCD plant conditions in Reference 1. Question 03.07.02-21 of Request for Additional Information 123 (Reference 2) identifies North Anna 3 (NA3) site-specific exceedances in the Safe Shutdown Earthquake (SSE) response spectra at the location of the PCCS Condensers and requests an assessment of the structural design of the PCCS Condensers using site-specific, seismic demands.

The dynamic analysis discussed in Appendix B of Reference 1 ("PCCS Structural Analysis with Detonation Loading") was repeated with the NA3 acceleration response spectra. All finite element models, analysis methods and assumptions from the seismic analysis in Reference 1 were retained with the exception that the support saddle thickness was revised (see Section 2.1). A stress evaluation was then performed using this dynamic analysis and the results were combined with the detonation stresses calculated for the standard plant in Reference 1. The response spectra analysis (RSA), stress evaluation and combination of dynamic and detonation stresses are documented in Reference 3.

The purpose of this report is to summarize the results of the Reference 3 calculation, which demonstrates the adequacy of the PCCS Condenser design for the NA3 seismic demands.

1.2 Scope

This report contains a summary of the results of the NA3 seismic adequacy evaluation (Reference 3) of the PCCS Condenser as well as a comparison of the NA3 response spectra to the ESBWR DCD spectra. The results include NA3 component stresses which are compared to the DCD values and the design limits. In addition, the reaction loads at the bolting locations are provided with comparison to the DCD values. These loads are to be used for the bolt selection and embedment design at a later time.

2. PCCS CONDENSER ADEQUACY EVALUATION

The structural integrity of the ESBWR PCCS Condenser is evaluated for DCD plant conditions in Appendix B and Appendix C of Reference 1. To ensure the structural adequacy of the PCCS Condenser for the seismic demands of NA3, the seismic analysis documented in Appendix B of Reference 1 is repeated using the NA3 site specific SSE acceleration response spectra. The stresses from the site-specific seismic loads are combined with the existing stresses from the non-seismic loads to confirm the adequacy of the PCCS Condenser. The site-specific RSA, stress evaluation and combination of dynamic and detonation stresses are documented in Reference 3.

A brief summary of the structural assessment is provided in Section 2.1. This section, which is a repeat of the methodology information provided in the ESBWR DCD PCCS Condenser seismic evaluation, is provided to facilitate understanding of the current, site-specific evaluation. The site-specific seismic response spectra are discussed in Section 2.2. The results of the assessment including stress results and anchorage loadings are provided in Section 2.3.

2.1 Analysis Summary

The following is a brief description of the site-specific seismic evaluation of the PCCS Condenser. See Reference 1 for a complete discussion of the methodology used in the evaluation especially for detonation loads which are taken directly from the Reference 1 results.

Overview

The PCCS Condensers are two module drum-and-tube type heat exchangers using horizontal upper and lower drums connected with multiple vertical tubes (see Figure 1). Two identical modules are coupled to form one PCCS heat exchanger unit. The PCCS Condenser assembly forms an integral part of the containment boundary and is submerged in the water of an Isolation Condenser/Passive Containment Cooling System (IC/PCCS) pool sub compartment. The PCCS Condenser is anchored to the Reactor Concrete Containment Vessel (RCCV) Top Slab.

Design Code

The PCCS Condenser is an integral part of the containment drywell pressure boundary and is designed to ASME Boiler and Pressure Vessel (BP&V) Code, Section III, Division 1, Subsection NE as a Class MC component. Stress in the supports of the PCCS Condenser shall not exceed the allowable stress levels given in the ASME BP&V Code Section III, Division 1 Subsection NF.

Loads and Combinations

The load combinations affected by the change in seismic demand are shown in this section; all other load combination results are unaffected.

Level C-1: $$D + P_a + T_a + SSE + SRVD + LOCA \qquad (1)$$
Level C-2: $$D + DET + T_a + SSE \qquad (2)$$

The dead weight (D) is evaluated as a static load under the effect of gravity. The SSE, Safety Relief Valve Discharge (SRV), and Loss-of-Coolant Accident (LOCA) are all building vibration loads. The thermal loads (T_a) are evaluated by finite element analysis at the design accident temperature of 171°C. The detonation stresses were calculated by applying an equivalent static detonation peak pressure in Appendix B of Reference 1 and a traveling pressure wave in Appendix C of Reference 1.

The building vibration loads are combined by Square Root of Sum of Squares (SRSS) methodology which are then combined using absolute summation with the other loads in Eq. (1). For the Eq. (2) combination, the DET and SSE loads are combined by absolute summation when DET stresses are calculated using a static equivalent evaluation (Appendix B of Reference 1) and by SRSS when DET stresses are calculated as part of a dynamic analysis (Appendix C of Reference 1). The combined DET and SSE loads are then combined by absolute summation with the remaining Eq. (2) loads.

Analysis Procedure

The analysis of the PCCS Condenser for seismic stresses is performed in a RSA in ANSYS v14.0. The detailed finite element model used for the RSA consists of shell and beam elements with the internal and external water included. The model is the same one used in the Reference 1 analysis with the exception that the Support Saddle thickness has been increased from 10 mm to 34 mm. This is discussed in Section C.1.6.6 of Reference 1 which justifies the use of the stress results calculated before the thickness change. The analysis is performed using the first 10 modes of the model up to 45.3 Hz. This cutoff frequency is considered acceptable as it captures the main bending modes of the structure and above it are a large number of local tube bending modes with negligible effective masses and, therefore, low contribution in the solution response. The site-specific spectra used in this evaluation are discussed in Section 2.2. Consistent with NRC Regulatory Guide 1.92 Revision 1, the modal responses for a given dynamic load in each direction are combined using the grouping method and the resulting spatial components are combined by SRSS. The effects of missing mass in the response spectra analysis are accounted for using pseudo-static evaluation consistent with Appendix A of Reg. Guide 1.92.

The results of the RSA are used to determine the membrane and the local membrane plus bending stresses for the SSE terms in the Level C-1 and Level C-2 load combinations.

2.2 Seismic Demand

The NA3 site-specific response spectra used for analysis of the PCCS Condenser are envelopes of the in-structure response generated at the following nodes (Reference 4).

X-Direction (North-South): Node 108 and 208

Y-Direction (East-West): Node 108 and 208

Z-Direction (Vertical): Node 108, 208, 9081, 9082, 9085, and 9086

Node 108 and 208 are at the elevation of the bottom of the IC/PCCS pools with node 108 on the Reactor Building and node 208 on the RCCV. The additional nodes in the vertical direction are slab oscillators that capture vertical floor flexibility effects. All spectra for the PCCS Condenser are taken at 3% damping consistent with Reference 1.

The NA3 response spectra for the PCCS Condenser are compared to the corresponding standard plant spectra in Figure 2, Figure 3 and Figure 4 for the North-South, East-West and Vertical direction, respectively.

2.3 Results

The key findings from this reanalysis are documented in Table 1 through Table 4 with comparisons to the corresponding results found in Appendix B and Appendix C of Reference 1. For most components of the NA3 PCCS Condenser stresses are similar or see slight decreases. This is reasonable as the spectral exceedances are relatively minor in the horizontal direction and the structure is relatively rigid. Further, the largest spectral increases in the vertical direction (see Figure 4) occur from approximately 20-40 Hz, but the structure has no modes with frequencies in this range, so only the smaller magnitude exceedance at 45.3 Hz is relevant. Given that the horizontal response of the structure dominates, the exceedances in the vertical response spectra have only a modest effect on the resulting combined stresses.

Table 1 provides a comparison of the Service Level C-1 stresses on the components of the PCCS Condenser. These values are compared with the Reference 1 results and the design limits. All component stresses remain below their allowable value with stress margins[1] of at least 37% and typically closer to 90%. The Service Level C-1 combination does not contain detonation loads which tend to result in the largest loads.

Table 2 summarizes the critical stress results obtained from the Service Level C-2 analysis of the PCCS Condenser using a static application of the detonation

[1] Margin = (1- Calculated / Allowable) * 100

load discussed in Appendix B of Reference 1. These values are compared with the Reference 1 results and design limits. Again, all of the component stresses remain below their allowable values with the minimum margin on the lower header cover of 0.4% with nearly all of this stress being attributed to detonation.

Table 3 summarizes the critical stress results for the Service Level C-2 analysis of the PCCS Condenser resulting from the application of the detonation wave described in Appendix C of Reference 1. These values are compared with the Reference 1 results and design limits. Table 3 does not contain updated results for those components that will experience a reduction in stress resulting from SSE as the existing stresses remain bounding. All component stresses remain below their allowable value with the minimum margin on the support saddle of 13.4%.

Table 4 summarizes the enveloping maximum reactions on the top slab penetration and support base plate anchor bolts. All loads remain below their Reference 1 value with the exception of the tension on the support saddle bolts. Consistent with Reference 1, the bolts and their corresponding embedment have not been designed and so no allowable loads exist. The support saddle bolts and embedment will be designed to withstand this increase in the NA3 tension load.

Table 1: Stress Summary Comparison of the PCCS Condenser and Supports (Service Level C-1)

Component	Stress Category	Allowable Stress (MPa)	NEDE-33572P Rev. 3 Values (Table B-2b) Calculated Stress (MPa)	NEDE-33572P Rev. 3 Values (Table B-2b) Stress Margin (%)[1]	NA3 Specific Values Calculated Stress (MPa)	NA3 Specific Values Stress Margin (%)[1]
Upper Header	P_m	291.4[2]	52.8	81.9%	30.8	89.4%
	P_L+P_b	381.7[2]	64.8	83.0%	54.7	85.7%
Lower Header (Ligaments)	P_m	291.4	16.4	94.4%	11.4	96.1%
	P_L+P_b	437.1	18.5	95.8%	18.2	95.8%
Lower Header (drain nozzle)	P_m	291.4	16.4	94.4%	11.4	96.1%
	P_L+P_b	421.3	18.5	95.6%	18.2	95.7%
Tubes	P_m	291.4	7.4	97.5%	14.9	94.9%
	P_L+P_b	381.7	42.1	89.0%	41.1	89.2%
Feed Line	P_m	137.9	100.9	26.8%	59.9	56.6%
	P_L+P_b	180.7	139.9	22.6%	112.4	37.8%
Steam Line	P_m	137.9	43.1	68.7%	47.7	65.4%
	P_L+P_b	180.7	45.7	74.7%	61.1	66.2%
Steam Distributor	P_m	137.9	47.1	65.8%	25.6	81.4%
	P_L+P_b	180.7	66.5	63.2%	55.6	69.3%
Condensate Line Head Fitting	P_m	241.6	65.5	72.9%	20.6	91.5%
	P_L+P_b	362	65.9	81.8%	57.7	84.1%
Condensate Line Sleeve	P_m	241.6	65.5	72.9%	20.6	91.5%
	P_L+P_b	330.7	65.9	80.1%	57.7	82.6%
Condensate Line Flange	P_m	241.6	65.5	72.9%	20.6	91.5%
	P_L+P_b	316.4	65.9	79.2%	57.7	81.8%
Upper Header Cover	P_m	201.3	58.1	71.1%	58.4	71.0%
	P_L+P_b	381.7	58.4	84.7%	58.4	84.7%
Lower Header Cover	P_m	201.3	4.4	97.8%	4.9	97.6%
	P_L+P_b	381.7	4.5	98.8%	4.9	98.7%
Upper Header Bolt	Average Stress	220.2	25.7	88.3%	25.7	88.3%
Lower Header Bolt	Average Stress	424.6	8.3	98.0%	8.3	98.0%
Support Saddle	P_m	274.5	53.3	80.6%	47.2	82.8%
	P_L+P_b	411.7	53.4	87.0%	82.2	80.0%
	Shear	164.7	11.1	93.3%	9.7	94.1%
Steel Frame Support Structure	Tension	131	41.5	68.3%	34.8	73.4%
	Shear	87.3	9.5	89.1%	12.8	85.3%
	Compression	83.6	41.5	50.4%	34.8	58.4%
	Bending	144.1	44.5	69.1%	33.0	77.1%

(1) Margin = (1- Calculated / Allowable) * 100
(2) Table B-2b of NEDE-33572P Rev. 3 provides different allowable stresses for the Upper Header for Service Level C-1 and C-2. The Upper Header material was changed to XM-19 (see Section 2.3 of NEDE-33572P) but the allowable stresses for Service Level C-1 were not updated. The lower allowable values listed in NEDE-33572P for Service Level C-1 are conservative but inconsistent. Allowable values for the Upper Header made of XM-19 are provided in this report.

Table 2: Stress Summary Comparison of the PCCS Condenser and Supports (Service Level C-2)

Component	Stress Category	Allowable Stress (MPa)	NEDE-33572P Rev. 3 Values (Table B-2b) Calculated Stress (MPa)	NEDE-33572P Rev. 3 Values (Table B-2b) Stress Margin (%)(1)	NA3 Specific Values Calculated Stress (MPa)	NA3 Specific Values Stress Margin (%)(1)
Upper Header	P_m	291.4	41.6	85.7%	19.6	93.3%
	P_L+P_b	381.7	53.5	86.0%	43.4	88.6%
Lower Header (Ligaments)	P_m	291.4	271.9	6.7%	266.9	8.4%
	P_L+P_b	437.1	326.0	25.4%	325.7	25.5%
Lower Header (drain nozzle)	P_m	291.4	202.9	30.4%	197.9	32.1%
	P_L+P_b	421.3	383.0	9.1%	382.7	9.2%
Tubes	P_m	291.4	274.8	5.7%	282.3	3.1%
	P_L+P_b	381.7	344.3	9.8%	343.3	10.1%
Feed Line	P_m	137.9	90.8	34.2%	49.8	63.9%
	P_L+P_b	180.7	130.0	28.1%	102.5	43.3%
Steam Line	P_m	137.9	32.1	76.7%	36.7	73.4%
	P_L+P_b	180.7	34.7	80.8%	50.1	72.3%
Steam Distributor	P_m	137.9	34.5	75.0%	13.0	90.6%
	P_L+P_b	180.7	53.8	70.2%	42.9	76.3%
Condensate Line Head Fitting	P_m	241.6	125.0	48.3%	80.1	66.8%
	P_L+P_b	362.0	184.0	49.2%	175.8	51.4%
Condensate Line Sleeve	P_m	241.6	124.0	48.7%	79.1	67.3%
	P_L+P_b	330.7	171.0	48.3%	162.8	50.8%
Condensate Line Flange	P_m	241.6	136.7	43.4%	91.8	62.0%
	P_L+P_b	316.4	53.2	83.2%	45.0	85.8%
Upper Header Cover	P_m	201.3	2.8	98.6%	3.1	98.5%
	P_L+P_b	381.7	3.1	99.2%	3.1	99.2%
Lower Header Cover	P_m	201.3	200.1	0.6%	200.6	0.4%
	P_L+P_b	381.7	200.2	47.6%	200.6	47.5%
Upper Header Bolt	Average Stress	220.2	0.1	100.0%	0.1	100.0%
Lower Header Bolt	Average Stress	424.6	375.7	11.5%	375.7	11.5%
Support Saddle	P_m	274.5	53.1	80.7%	47.0	82.9%
	P_L+P_b	411.7	53.2	87.1%	82.0	80.1%
	Shear	164.7	11.0	93.3%	9.6	94.2%
Steel Frame Support Structure	Tension	131.0	82.8	36.8%	69.6	46.9%
	Shear	87.3	18.8	78.5%	25.6	70.7%
	Compression	83.6	82.8	1.0%	69.6	16.7%
	Bending	144.1	88.8	38.4%	66.0	54.2%

(1) Margin = (1- Calculated / Allowable) * 100

Table 3: Stress Summary Comparison for Selected PCCS Components Due to Detonation Wave in Lower Header

			NEDE-33572P Rev. 3 Values (Table C-6)			NA3 Site Specific Values	
Section	Stress Category	Allowable Stress for Service Level C-2 (MPa)	Calculated Stress Under Detonation Load (MPa)	Calculated Stress for Service Level C-2 Load Combination (MPa)	Margin %(1)	Calculated Stress for Service Level C-2 Load Combination NA3 (MPa)	Margin %(1)
Condensate Line Head Fitting	P_m	291.4	99.7	125.5	56.9%	Note (2)	Note (2)
	Deleted						
Condensate Line Sleeve	P_m	291.4	188.9	209.1	28.2%	Note (2)	Note (2)
	Deleted						
Support Saddle	P_m	274.5	76.3	93.0	66.1%	Note (2)	Note (2)
	P_L+P_b	411.7	323.6	327.9	20.4%	356.7	13.4%
	Shear	164.7	15.5	19.1	88.4%	Note (2)	Note (2)
Tube End	P_m	291.4	75.2	96.1	67.0%	102.7	64.8%
	P_L+P_b	381.7	198.5	237.0	37.9%	Note (2)	Note (2)

(1) Margin = (1- Calculated / Allowable) * 100

(2) Site specific stress is bounded by the NEDE-33572P Rev. 3 value.

Table 4: PCCS Condenser Top Slab Penetration Steam Line Anchor Bolt Dynamic Reactions (per bolt) Comparison[1]

		NEDE-33572P, Rev. 3 Values		NA3 Site Specific Values	
Component Anchor Load	Service Level	Tension (kN)	Shear (kN)	Tension (kN)	Shear (kN)
Steam Line Reaction per bolt	C-1	11[2]	0.9[2]	9.0	0.65
	C-2	22[2]	1.8[2]	18	1.3
Condensate Line Reaction per bolt	C-1	40[2]	16[2]	35	7.4
	C-2	352[3]	143[3]	352	142
Steel Frame Support Structure Reaction per bolt	C-1	194[4]	81[4]	165	50
	C-2	386[4]	192[4]	330	100
Support Saddle Reaction per bolt	C-1	26[4]	5.0[4]	41	4.4
	C-2[1]	295[3]	48[3]	297	48

(1) As anchorages have not been specified, margins and allowable values are not included.

(2) Reference 1, Table B-3a

(3) Calculated from Table C-7 of Reference 1 because Reference 1 only provides the maximum reaction loads at the base of the Support Saddles. The full calculation can be found in Reference 3.

(4) Reference 1, Table B-4a

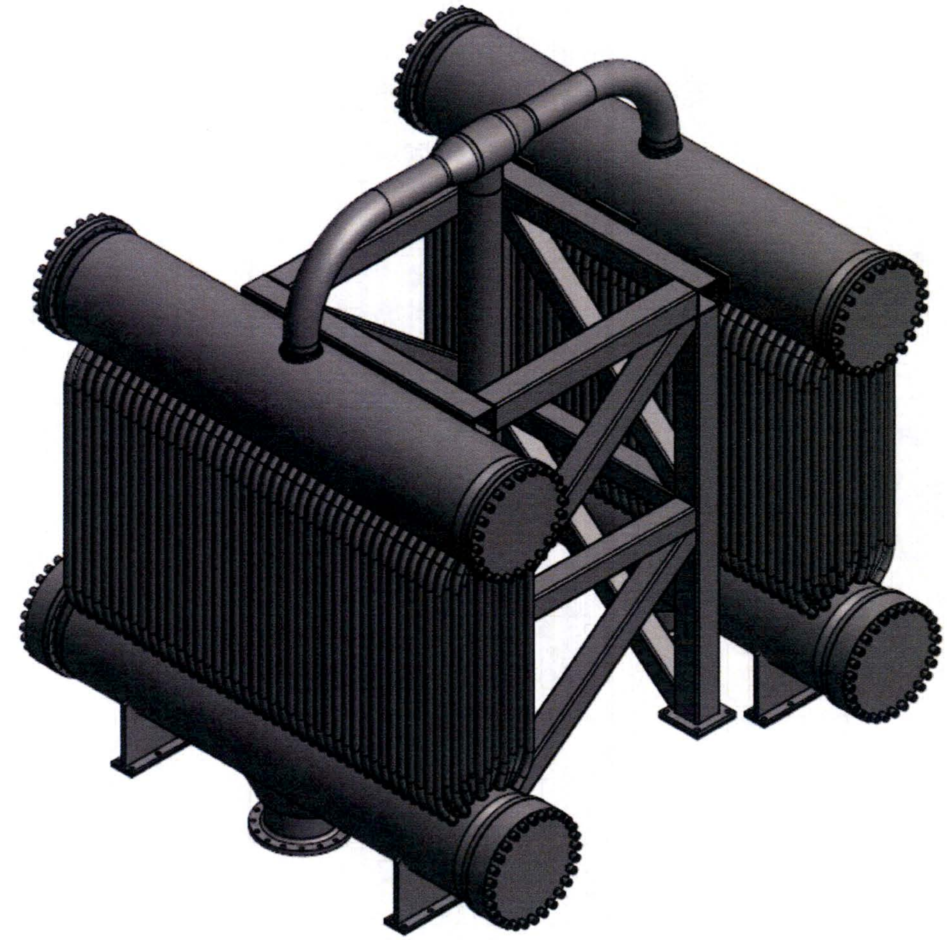

Figure 1: PCCS Condenser Isometric View

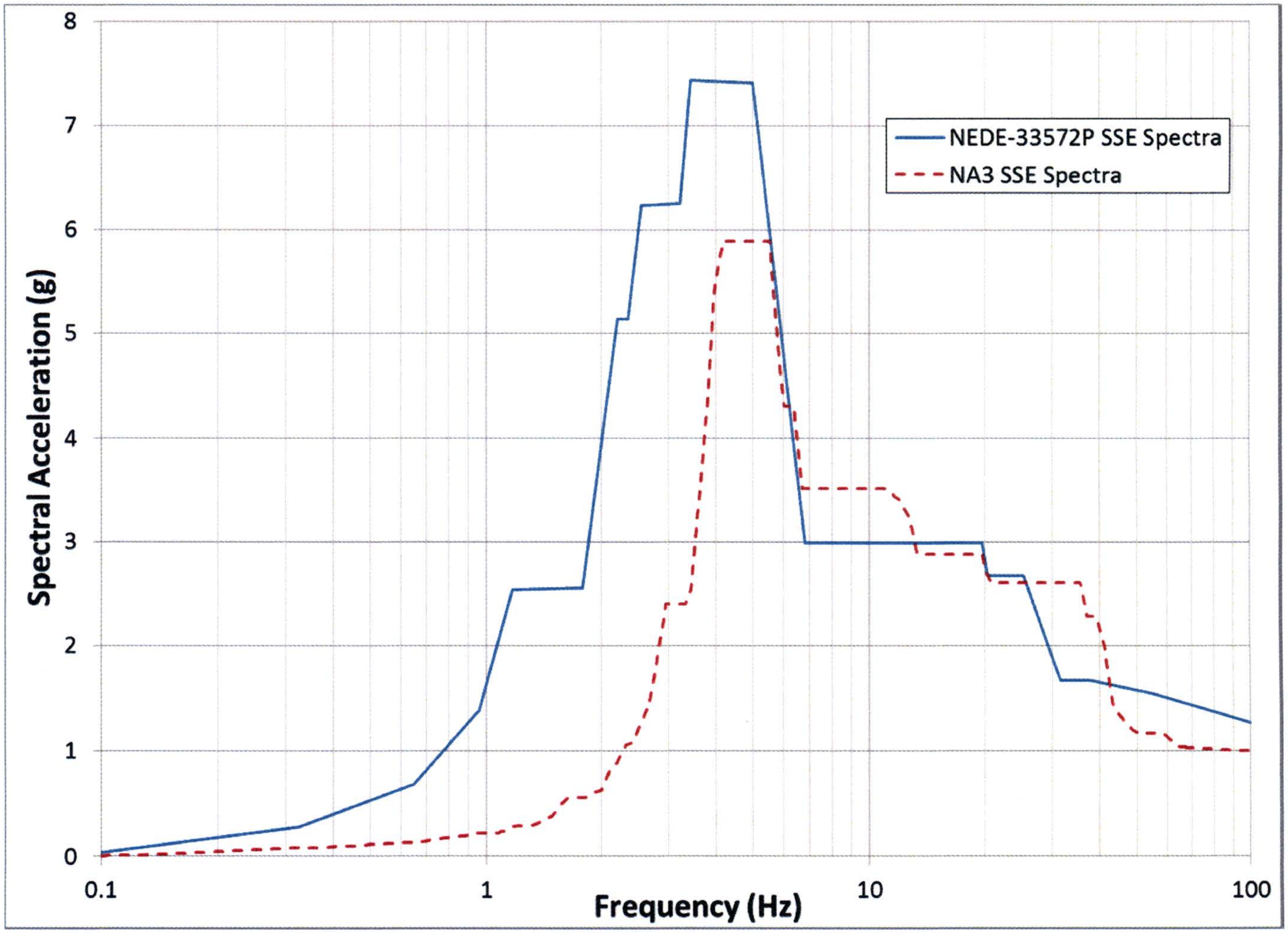

Figure2: North-South SSE Acceleration Response Spectra Comparison (3% Damping)

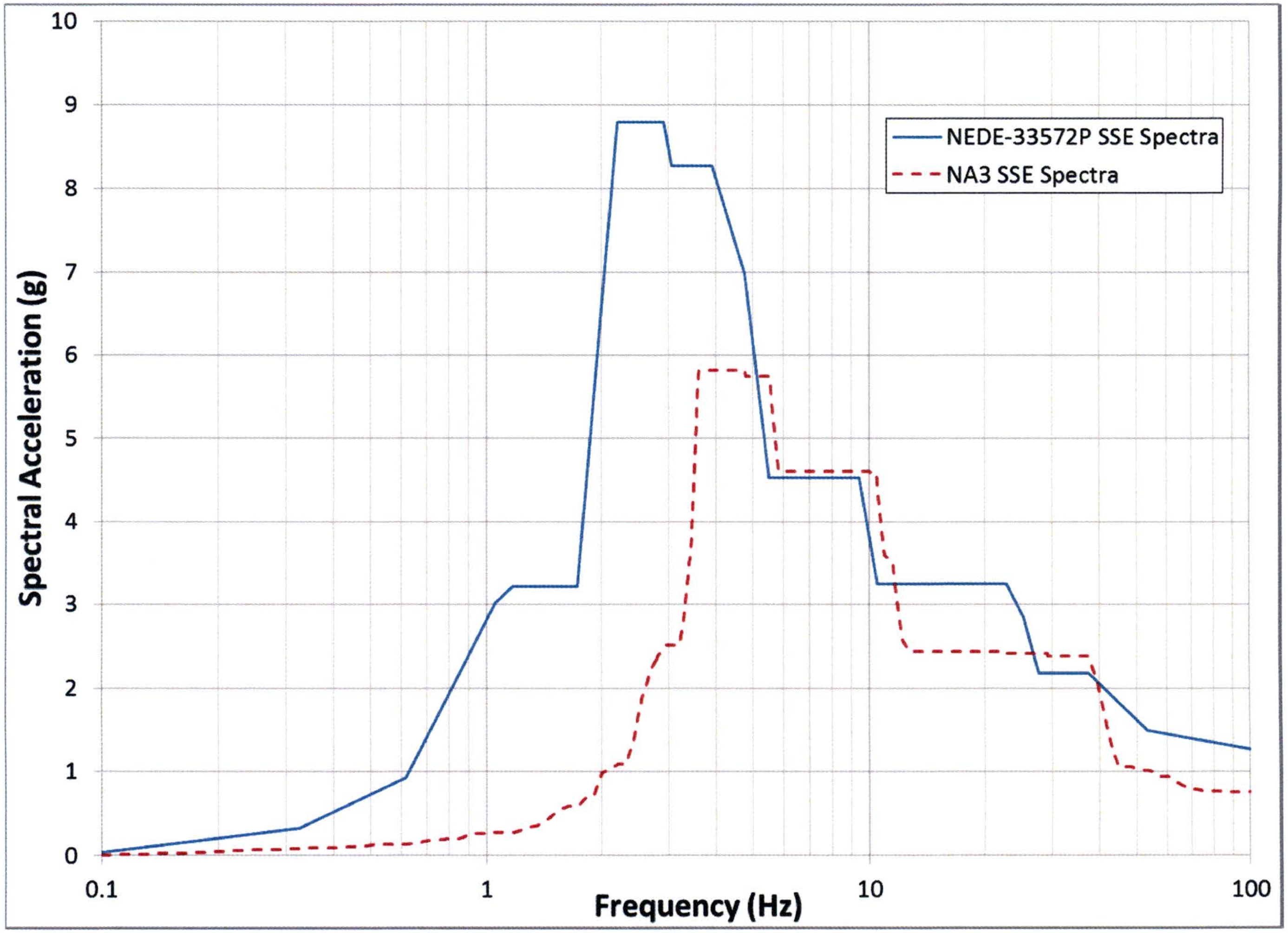

Figure 3: East-West Acceleration Response Spectra Comparison (3% Damping)

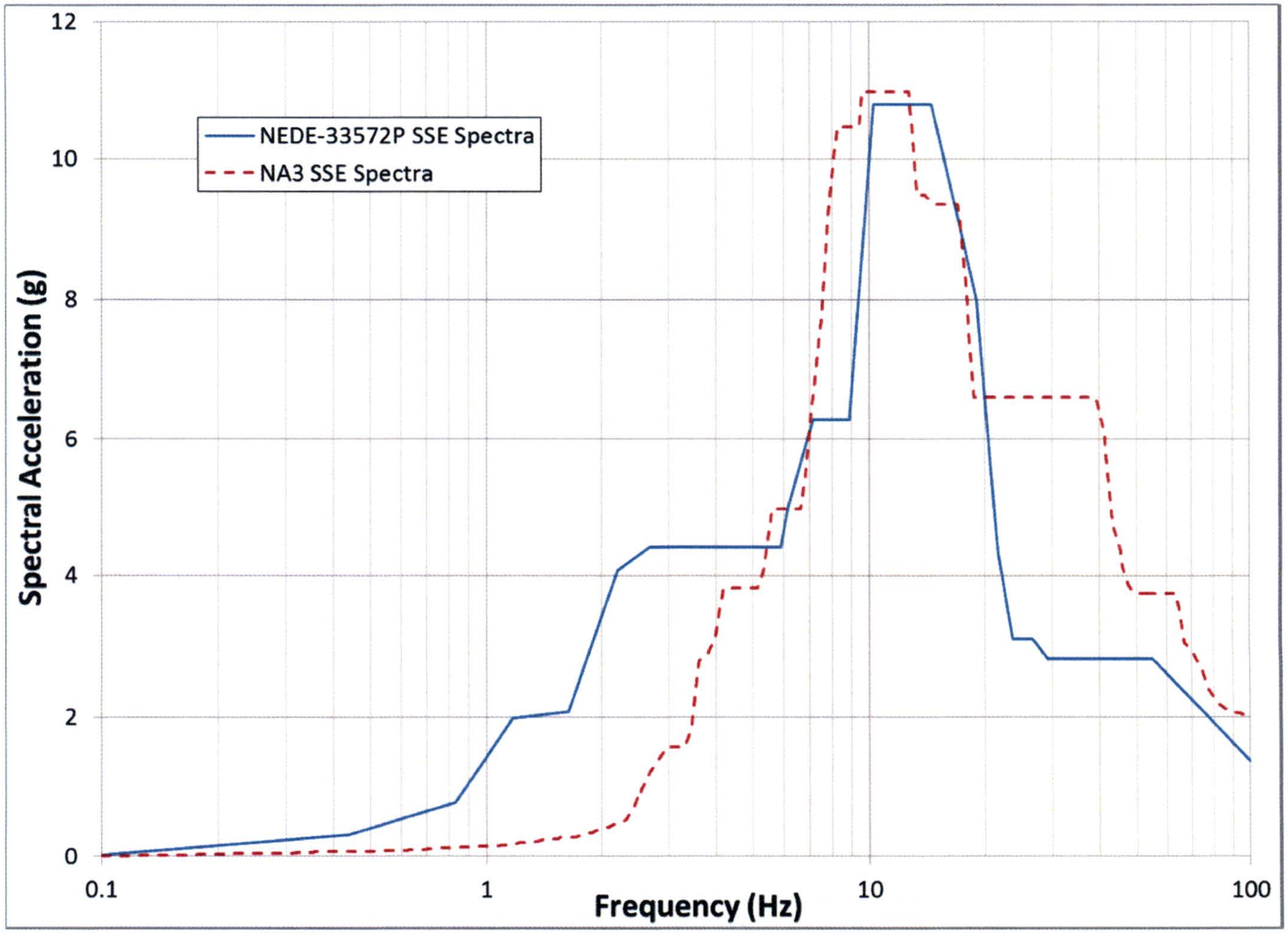

Figure 4: Vertical Acceleration Response Spectra Comparison (3% Damping)

3. CONCLUSION

The PCCS Condenser was re-evaluated using NA3 site specific acceleration response spectra. The re-evaluation showed that the PCCS Condenser design remains adequate for the NA3 seismic demands.

All stresses remain below their allowable values. The increase in the NA3 support saddle embedment tension load will be accommodated during the final embedment design.

Although the NA3 site specific PCCS Condenser seismic analysis concludes that the response spectra of the ESBWR standard plant is not bounded across all frequencies, these changes do not invalidate the seismic qualification of the standard ESBWR PCCS Condenser as described in Reference 1.

4. REFERENCES

1) NEDE-33572P Rev. 3, "ESBWR ICS and PCCS Condenser Combustible Gas Mitigation and Structural Evaluation", September 2010.

2) North Anna 3, Docket Number 52-017, Request for Additional Information 123, July 2014.

3) DBR-0010229 Rev. 2, "ESBWR Design Basis for PCCS Condenser RAI Response," April 2016.

4) SER-DMN-019 Rev. 1, "RB/FB Seismic Analyses Bounding Results and In-Structure Response Spectra," April 2015.