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NORTH ANNA 3 FUEL RACK SEISMIC ANALYSIS

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1. INTRODUCTION

1.1 Purpose

The structural integrity of the ESBWR fuel racks are evaluated for DCD plant conditions in Reference 1. Question 03.07.02-20 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 locations of the fuel racks and requests an assessment of the structural design of these racks using site-specific SSE seismic demands.

The ESBWR design utilizes three fuel rack designs: spent fuel pool fuel storage racks (FSR), buffer pool deep pit FSR, and buffer pool new FSR. Assessments have been performed for each of these fuel rack designs using the guidance provided in Appendix D of NRC Standard Review Plan (SRP) Section 3.8.4 ("Guidance on Spent Fuel Pool Racks"). The purpose of this report is to summarize the structural assessments of all three FSR designs. Additionally, for those components of the individual fuel racks that are overstressed resulting from increased seismic demand, a description of the design changes are provided.

1.2 Scope

This document only provides a summary of the maximum enveloping results from the site-specific assessments of the FSR as well as comparisons of the site-specific seismic demand to the ESBWR DCD seismic demand. The full analyses of the FSR can be found in Reference 3, Reference 4 and Reference 5 for the spent fuel pool FSR, buffer pool deep pit FSR, and the buffer pool new FSR, respectively.

The structural evaluation of the fuel assemblies enclosed in the FSR is not within the scope of this document. The fuel assemblies are qualified for the NA3 site-specific seismic demand in Reference 6.

The structural evaluations of the pool liners and anchorage embedment designs are outside of the scope of this report. However, the loads on the pool liner are provided for free stranding racks (spent fuel pool FSR) and the anchor embedment loads are provided for anchored racks (buffer pool deep pit FSR and buffer pool new FSR).



The load drop impact analysis and thermal hydraulic analysis contained in Section 4.0 and 5.0 of Reference 1 are not considered as these evaluations are unaffected by seismic demands.

Section 2.0 of this report contains a summary of the results of the NA3 SSE site-specific seismic evaluation of the spent fuel pool FSR.

Section 3.0 contains a summary of the results of the NA3 SSE site-specific seismic evaluation of the buffer pool deep pit FSR. The design changes of these racks and the justification for the adequacy of these changes for the ESBWR DCD seismic demands are contained in Section 3.4.

Section 4.0 contains a summary of the results of the NA3 SSE site-specific seismic evaluation of the buffer pool new FSR. The design changes of these racks and the justification for the adequacy of these changes for the ESBWR DCD seismic demands are contained in Section 4.4.



2. SPENT FUEL RACKS IN THE SPENT FUEL POOL

The structural adequacy of the FSR in the spent fuel pool to the ESBWR DCD seismic demands was demonstrated in Section 1.0 of Reference 1. To ensure the structural adequacy of the FSR in the spent fuel pool for the seismic demands of NA3, the analysis documented in Section 1.0 of Reference 1 was repeated using the NA3 site-specific SSE acceleration response spectra. This analysis is contained in Reference 3.

A brief summary of the structural assessment is provided in Section 2.1. The information contained in Section 2.1 is a repeat of information provided in the ESBWR DCD spent fuel pool FSR report (Section 1.0 of Reference 1) as an aide for understanding the current, site-specific evaluation of these racks. The site-specific seismic demand for these racks is discussed in Section 2.2. The maximum enveloping results of the assessment including stress results, displacements, and loads on the fuel pool liner are provided in Section 2.3.

2.1 Analysis Summary

The spent fuel pool FSR are qualified using guidance from Appendix D of SRP Chapter 3.8.4. The following is a brief description of the site-specific seismic evaluation of the spent fuel pool FSR. See Reference 3 for the assessment in its entirety.

Overview

The spent fuel racks in the spent fuel pool are designed to support and protect the spent fuel assemblies. They are made of stainless steel and borated stainless steel plates, forming 15x12 (or 14x12) cells to house the spent fuel assemblies. The spent fuel pool racks are supported on four bottom-corner cylindrical feet, each of which rests on a bearing pad shared by the feet of adjacent racks. The spent fuel pool racks are free to slide and are only supported by their own weight and friction between the bearing pads and the pool liner. Upper link crossarms connect adjacent racks at the upper corners.



To analyze these racks both a RSA and transient analysis are performed to ensure the structural adequacy of the individual components responsible for maintaining the adequacy of the spent fuel pool FSR.

Design Code

The spent fuel pool FSR are designed to the stress limits of ASME Boiler and Pressure Vessel (B&PV) Code, Section III, Division 1, Subsection NF requirements for Class 3 component supports (Reference 7).

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. The load combination for the response spectrum analysis (RSA) is provided in Eq. (1) and Eq. (2) for the transient analysis.

$$\begin{array}{ll} \text{Level D:} & D + SSE + SRVD + LOCA + T_a \text{ (RSA)} \quad (1) \\ \text{Level D:} & D + SSE + T_a \text{ (transient dynamic analysis)} \quad (2)^1 \end{array}$$

The dead weight (D) is evaluated as a static load under the effect of gravity. The SSE, Safety Relief Valve Discharge (SRVD), and Loss-of-Coolant Accident (LOCA) are all dynamic loads acting at the base of the rack. There are no thermal (T_a) loads on the structure because sufficient clearance is provided for thermal expansion; however, the thermal displacement is considered in determining the potential impact with the pool wall.

Analysis Procedure

The analysis of the racks is divided into two calculation stages which both utilize the finite element program ANSYS 10.0. A RSA is used to calculate global loads

¹ Only the SSE effects are evaluated in the transient analysis. There is no licensing basis for combining LOCA and SSE loads in Appendix D of SRP 3.8.4.



on the structure and a non-linear transient analysis is used to determine the impact loads between structures as well as the maximum displacements.

Analysis Procedure (RSA)

A detailed finite element model of a single spent fuel pool rack is developed using shell and lumped mass elements. The structural response to the dead load is determined by static analysis. The dynamic loads are determined by RSA using the first 100 modes up to 185.4 Hz. The site-specific response spectra are discussed in Section 2.2. Consistent with NRC Regulatory Guide 1.92, 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 Square Root of the Sum of Squares (SRSS). The effects of missing mass in the RSA 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 overall stresses at the critical locations of the rack's components. These are combined, as appropriate, with the impact stresses resulting from the transient analysis.

Analysis Procedure (Transient Analysis)

Synthesized site-specific acceleration time histories are converted to displacements by double integration and used as base input motion to a global model containing 20 simplified FSR models each composed of beam and lumped mass elements. The global model simulates contact, hydrodynamic coupling and link conditions between the individual freestanding racks. This time history analysis was performed for 16 seconds using 0.005 second intervals. Rayleigh proportional damping is used which provides effective damping below 4% of critical damping across the 2 Hz to 53 Hz frequency band which was deemed the most significant. The displacement time-histories for each direction are applied simultaneously at the nodes representing the pool floor and walls.

The time history analysis is performed for six scenario-cases which vary the fuel assembly fill levels and bearing pad friction for individual racks. This analysis is used to generate relative displacements, reactions, and transmission forces



which are bounded across the scenario cases. From the six scenario-cases the enveloping forces, moments and displacements are extracted.

The spent fuel pool rack local stresses are then calculated based on the maximum impact forces evaluated in the transient analysis. The maximum impact forces are applied at the top of the rack and at the rack base plate in both tension and compression resulting in four impact load cases. The maximum stresses across the four impact load cases are used in the final stress evaluation.

The impact stresses are combined with the overall stresses generated in the RSA to generate the limiting stresses that are then evaluated using ASME Code Section III, Division 1, Subsection NF acceptance criteria.

2.2 Seismic Demand

The NA3 site-specific response spectra for the ESBWR fuel racks are provided in a site-specific design specification data sheet for the fuel racks (Reference 8). The NA3 response spectra for the spent fuel pool racks documented in Reference 8 are taken from the Node 2 results of the Shimizu bounding in-structure RSA (Reference 9). Node 2 represents the base slab which the spent fuel pool rests on. All spectra for the fuel racks are taken at 4% damping consistent with Reg. Guide 1.61 for welded steel structures for SSE analysis.

The NA3 spent fuel pool FSR response spectra are shown with comparisons to the DCD response spectra in Figure 1, Figure 2, and Figure 3 for the plant North-South, East-West and Vertical direction, respectively². The DCD response spectra retrieved from Section 1.0 of Reference 1.

The analysis of the spent fuel racks requires synthesized acceleration time histories in addition to the response spectra. The time history is used in a non-linear transient analysis to determine the dynamic behavior of the freestanding spent fuel pool FSR (see Section 2.1 for further discussion). The synthesized

² The response spectra are provided from 10 Hz to 200 Hz as the fundamental frequency of the spent fuel pool storage rack is 13.8 Hz and the highest eigenvalue included in the RSA is 185.4 Hz.



acceleration time histories for the spent fuel pool FSR are documented in Reference 10. The verification process of Reference 10 demonstrated that the response spectra generated in each of the 3 orthogonal directions envelops the design spectra.

The NA3 synthesized acceleration time histories are shown in Figure 4, Figure 5, and Figure 6 for the plant North-South, East-West, and Vertical direction, respectively.

2.3 Results

The key findings from this reanalysis are documented in Table 1, Table 2, and Table 3 with comparisons to the corresponding results from the DCD. In general large reductions in displacements, forces, and stresses are seen as a result of using the NA3 site-specific SSE demands. This decrease is a result of the decrease in the horizontal spectra across all frequencies. The horizontal modes tend to dominate the component stresses for structures that are relatively rigid in the vertical direction such as the FSR. The effects of increased seismic demand in vertical direction for the spent fuel pool FSR is offset by the reduction in the horizontal direction.

Table 1 summarizes the enveloping maximum displacements and forces for the FSR obtained from the SSE time history analysis. The large decrease in displacement between the FSR foot and the pool floor confirms that there is no risk of the spent fuel pool FSR impacting the fuel pool wall. However, for reference, this is confirmed by adding the thermal displacement to the maximum SSE displacement here:

The maximum displacement due to a seismic event is 2.7 mm in the North-South direction and 3.4 mm in the East-West direction (see Table 1). When combined with the thermal displacements resulting from a pool temperature of 121.1°C the maximum total displacements are:

North-South Total Displacement = 7.7 mm < 92 mm (North-South wall min distance)



East-West Total Displacement = 6.1 mm < 60 mm (East-West walls min distance)

As these displacements are less than the minimum horizontal distance to the pool walls, the FSR will not impact the walls.

Table 2 summarizes the critical stress results obtained from the analysis of the FSR and the comparison with the allowable values in accordance with the design code (Reference 7). All component stresses remain below their code allowable values and below the DCD results. The components of the spent fuel pool are structurally acceptable relative to the NA3 seismic demand.

Table 3 summarizes the enveloping maximum reactions on the bearing pad in the pool floor liner. All pool liner loads remain below their DCD results. There is no concern that there is an increase in the loads on the pool liner resulting from the site-specific NA3 seismic demand.


Table 1: Maximum Displacements and Forces Summary

Displacement/Force	NEDO-33373 Rev. 5 Values (Table 1-2)		NA3 Specific Values	
	Horizontal	Vertical	Horizontal	Vertical
Relative displacement between FSR foot and pool floor (mm)	39.5 (N-S direction) 36.1 (E-W direction)	26.0	2.5 (N-S direction) 3.2 (E-W direction)	1.6
Force by FSR foot between bearing pad and pool floor (kN)	Shear 1344	Compression 1843	Shear 736	Compression 1164
Relative horizontal displacement between FSR top and pool wall (mm)	39.5 (N-S direction) 48.9 (E-W direction)	-	2.7 (N-S direction) 3.4 (E-W direction)	-
Force between two FSRs at the lower link device (kN)	1306	-	728	-
Force between two FSRs at the upper link device (kN)	1227	-	433	-
Relative displacement between fuel and FSR (mm)	10 (at top)	3.7	10 (at top)	1.9
Force between fuel (all assemblies and FSR (kN)	1017 (at top) 814 (at bottom)	1708	331 (at top) 243 (at bottom)	1481
Global bending moment on the FSR base plate (kN*m)	1645 (E-W axis) 2176 (N-S axis)	-	1027 (N-S axis) 1434 (E-W axis)	-

**Table 2: Fuel Storage Rack Main Stresses Summary Comparison**

Steel Plates	Stress Limit (MPa)	NEDO-33373 Rev. 5 Values (Table 1-3)		NA3 Specific Values	
		Stress (MPa)	Ratio	Stress (MPa)	Ratio
10 mm thick Enveloping Plate	292.8	226	0.77	103	0.35
10 mm thick Enveloping Plate Welds	198.6	163	0.82	107	0.54
7 mm Thick Upper Level Plates	292.8	227	0.78	92	0.31
7 mm thick Upper Level Plate Welds	198.6	91	0.46	63	0.32
Fuel Support Base Plate	292.8	274	0.94	176	0.60
20 mm thick Base Plate Stiffener Plates	292.8	208	0.71	166	0.57
20 mm thick Base Plate Stiffener Plate Welds	198.6	136	0.68	99	0.50
Foot Cylindrical Nut	292.8	253	0.86	160	0.55
Foot Cylindrical Nut Welds	198.6	141	0.71	101	0.51
Nut Thread	198.6	107	0.54	68	0.34
Lower Links (Bearing Pad)	419.9	363	0.86	202	0.48
Upper Links (Assembly Crossarm)	1049.7	927	0.88	327	0.31

Table 3: Pool Liner Maximum Reactions

	NEDO-33373 Rev. 5 Values (Table 1-3a)	NA3 Specific Values
Shear (kN)	1398	866
Compression (kN)	1843	1782

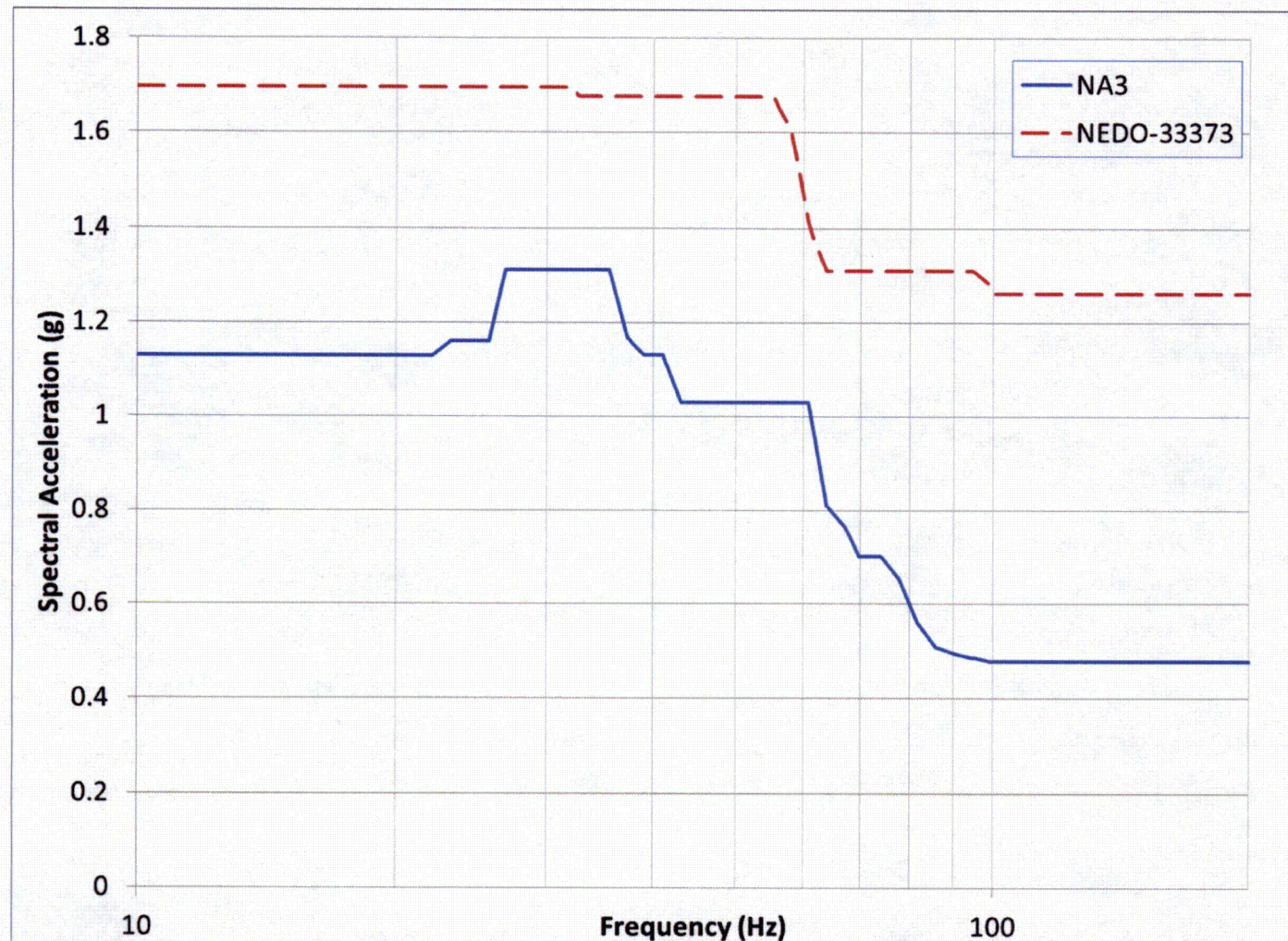


Figure 1: North-South Spent Fuel Pool FSR SSE Spectra Comparison (4% Damping)

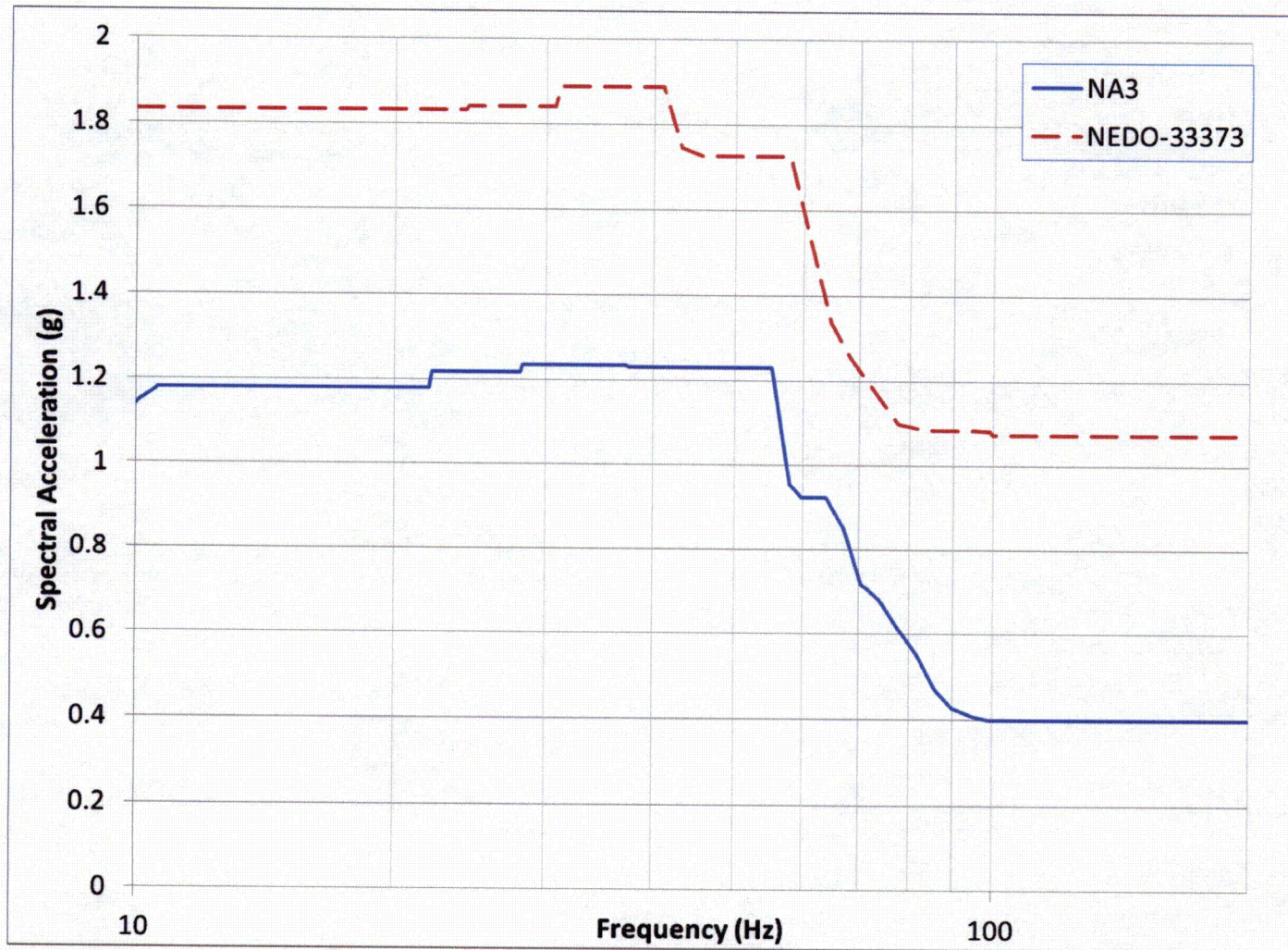


Figure 2: East West Spent Fuel Pool FSR SSE Spectra Comparison (4% Damping)

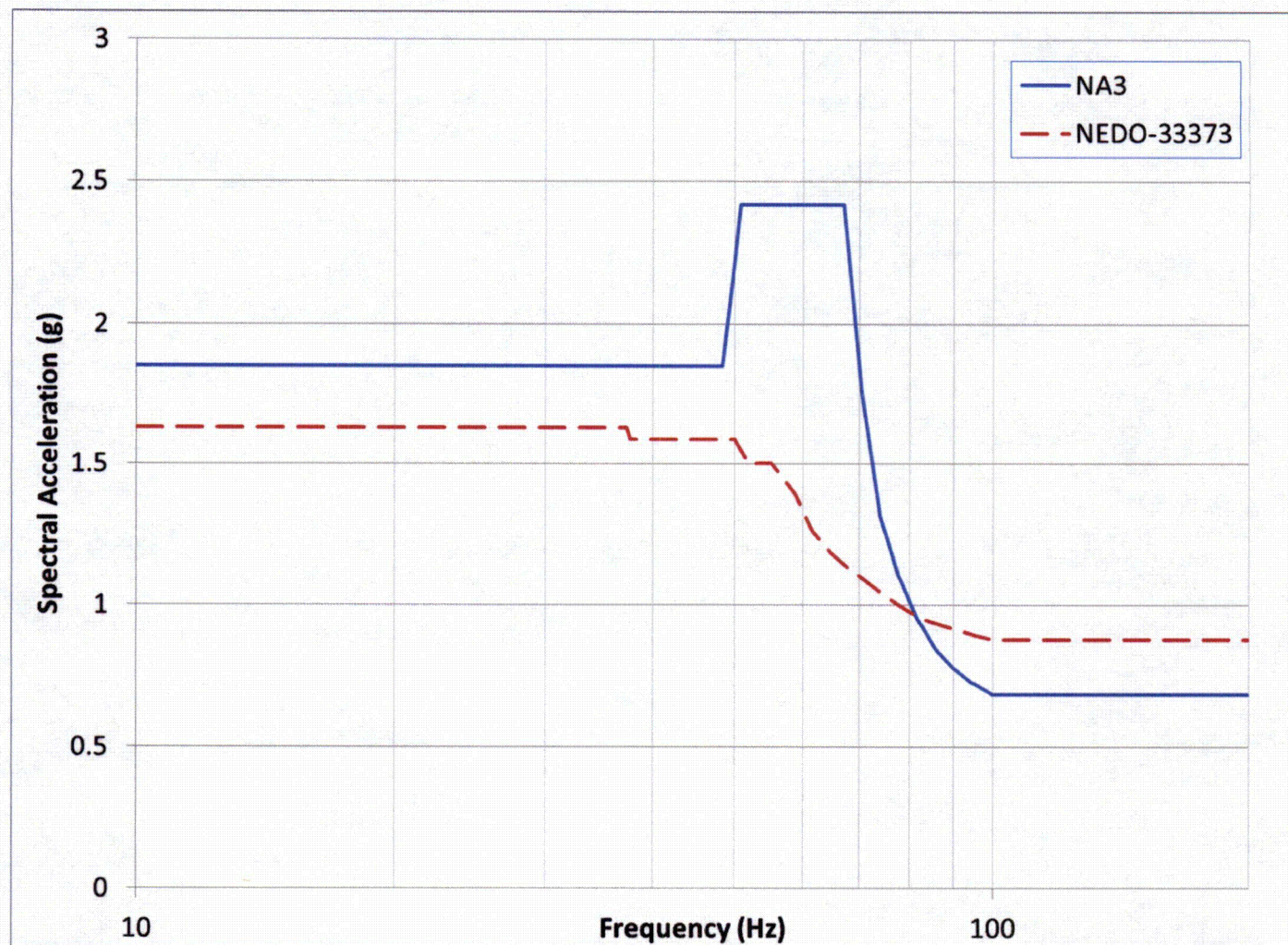


Figure 3: Vertical Spent Fuel Pool FSR SSE Spectra Comparison (4% Damping)

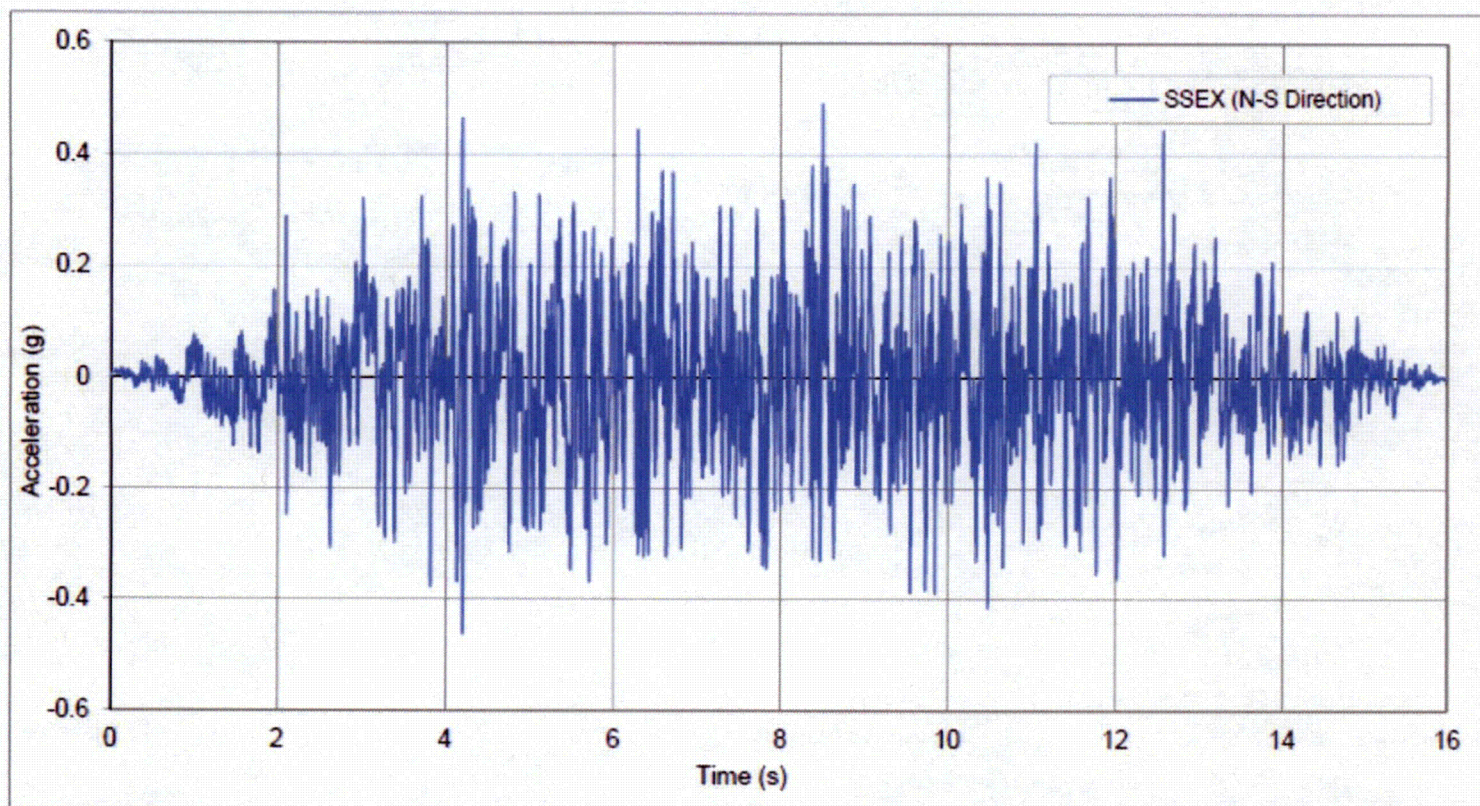


Figure 4: North-South Spent Fuel Pool FSR SSE Acceleration Time History

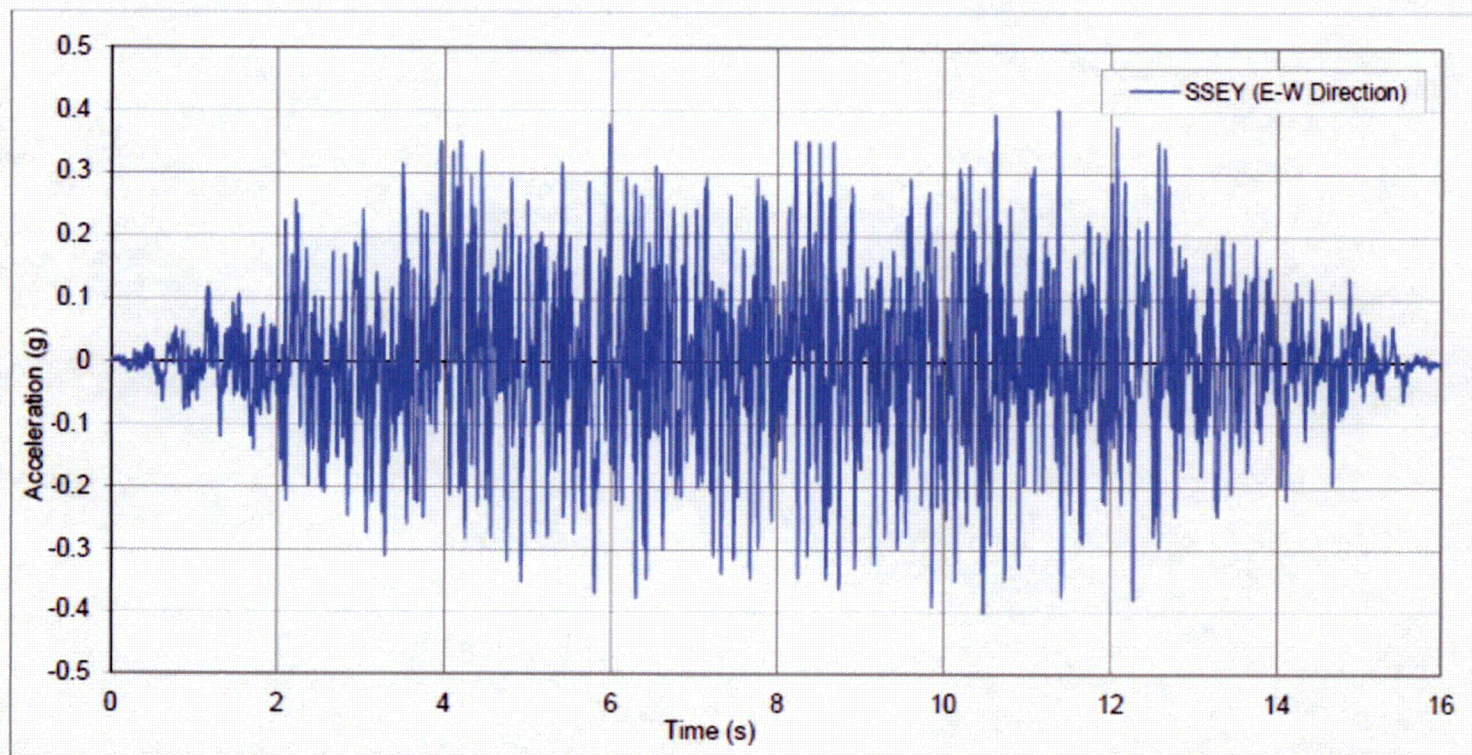


Figure 5: East-West Spent Fuel Pool FSR SSE Acceleration Time History

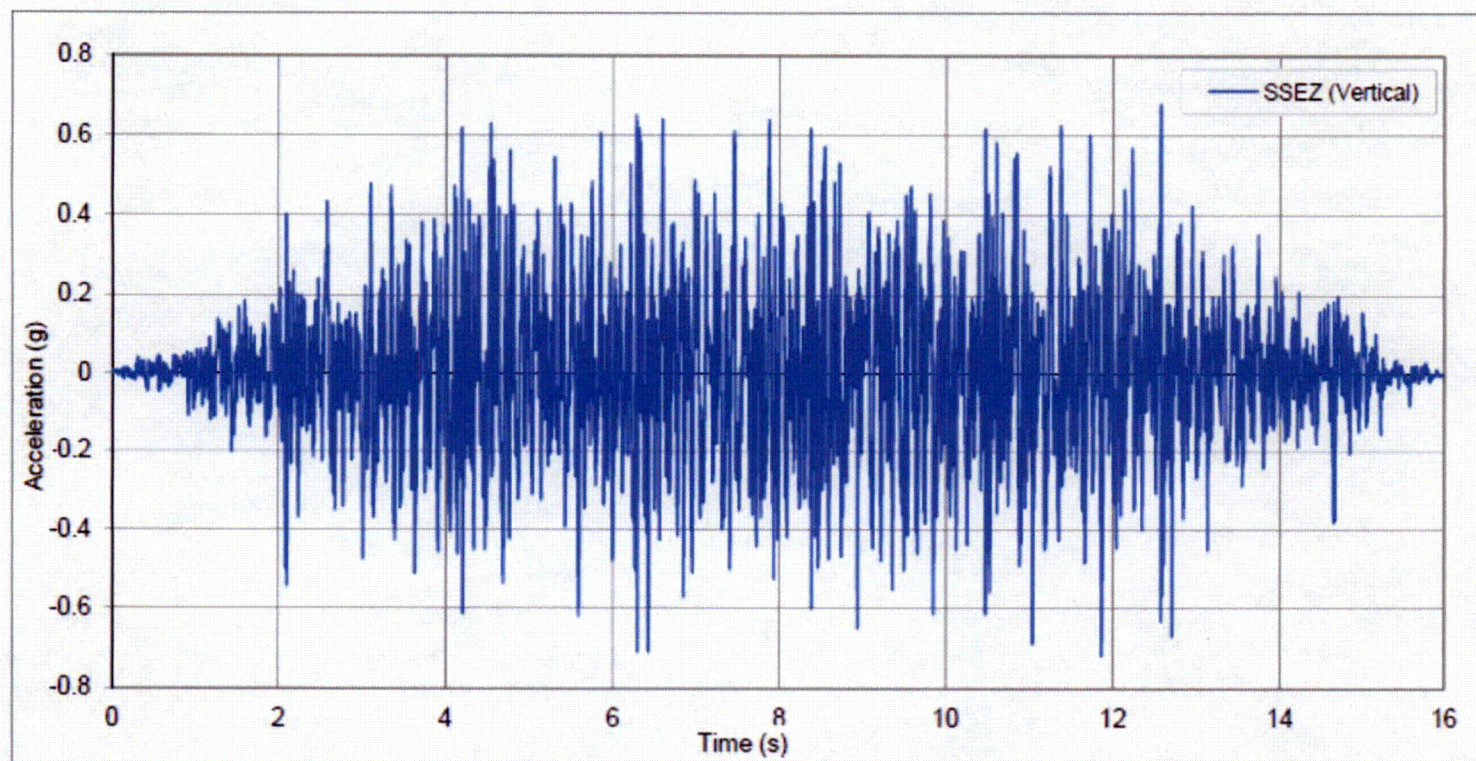


Figure 6: Vertical Spent Fuel Pool FSR SSE Acceleration Time History



3. SPENT FUEL RACKS IN THE BUFFER POOL DEEP PIT

The structural adequacy of the FSR in the buffer pool deep pit to the ESBWR DCD seismic demands was demonstrated in Section 2.0 of Reference 1. To ensure the structural adequacy of the FSR in the buffer pool deep pit for the seismic demands of NA3, the analysis documented in Section 2.0 of Reference 1 was repeated using the NA3 site-specific SSE acceleration response spectra. This analysis is contained in Reference 4.

A brief summary of the structural assessment is provided in Section 3.1. The information contained in Section 3.1 is a repeat of information provided in the ESBWR DCD buffer pool deep pit FSR report (Section 2.0 of Reference 1) as an aide in understanding the current, site-specific evaluation of these racks. The site-specific seismic demand for these racks is discussed in Section 3.2. The maximum enveloping results of the assessment including stress results, displacements and anchorage embedment loads are provided in Section 3.3. Finally, the design changes to these racks to prevent overstressed components resulting from site-specific seismic demands are provided in Section 3.4.

3.1 Analysis Summary

The buffer pool deep pit FSR are qualified using guidance from Appendix D of SRP Chapter 3.8.4. The following is a brief description of the site-specific seismic evaluation of the buffer pool deep pit FSR. See Reference 4 for the assessment in its entirety.

Overview

The spent fuel racks in the buffer pool deep pit are designed to support and protect the spent fuel assemblies. They are made of stainless steel and borated stainless steel plates, forming 11x7 cells to house the spent fuel assemblies. The buffer pool deep pit FSR are anchored to the pool floor at the four bottom corner locations.

To analyze these racks both a RSA and transient analysis are performed to ensure the structural adequacy of the individual components responsible for maintaining the adequacy of the buffer pool deep pit FSR.

Design Code

The buffer pool deep pit FSR are designed to the stress limits of ASME B&PV Code, Section III, Division 1, Subsection NF requirements for Class 3 component supports (Reference 7).

Loads and Combinations

The only load combinations affected by the change in seismic demand is shown in Eq. (3) all other load combination results are unaffected by SSE loads.

$$\text{Level D:} \qquad D + SSE + SRVD + LOCA + T_a \qquad (3)$$

The dead weight (D) is evaluated as a static load under the effect of gravity. The SSE, Safety Relief Valve Discharge (SRVD), and Loss-of-Coolant Accident (LOCA) are all dynamic loads acting at the base of the rack. There are no thermal (T_a) loads on the structure because sufficient clearance is provided for thermal expansion; however, the thermal displacement is considered in determining the potential impact with the pool wall.

Analysis Procedure

The analysis of the racks is divided in to two calculation stages which both utilize the finite element program ANSYS 10.0. The structural adequacy of the buffer pool deep pit FSR to the static and vibration loads is evaluated by RSA. Additionally, the potential for the fuel rack to impact during an SSE and the local stress qualification of the fuel base plate for this impact is evaluated in a non-linear transient analysis.

Analysis Procedure (RSA)

A detailed finite element model of a single buffer pool deep pit FSR is developed using shell and lumped mass elements. The deadweight loads are resolved by static analysis. The dynamic loads are resolved by RSA using first 100 modes up to 263.8 Hz. The site-specific response spectra are discussed in Section 3.2.



Consistent with NRC Regulatory Guide 1.92, 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 Square root of the Sum of Squares (SRSS). The effects of missing mass in the RSA 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 stresses in the buffer pool deep pit FSR components and the embedment loads to be used in the design of the embedment. In addition, the maximum displacements are combined with thermal displacements to ensure that the buffer pool deep pit wall is not impacted.

Analysis Procedure (Transient Analysis – Fuel Impact)

Synthesized site-specific acceleration time histories are converted to displacements by double integration and used as base input motion for simplified models representing the structural characteristics of the buffer pool deep pit FSR in the East-West and North-South direction. Each simplified model is composed of 2-D elastic beam elements representing the enveloping plate of the FSR and the fuel elements. The masses of the structures are lumped and hydrodynamic coupling is simulated between the pool wall and the FSR, the fuel and the FSR and between adjacent fuel racks. The fuel's lowest node is coupled to the FSR in the horizontal direction and a contact element is used in the vertical direction which allows the fuel to uplift and then impact the FSR. The fuel's uppermost node has horizontal contact elements to evaluate lateral impacts of the fuel with the FSR. This time history analysis was performed for 16 seconds using 0.005 second intervals.

Maximum impact forces are obtained from the transient analysis. These forces include the horizontal forces at the top and bottom of the fuel and vertical force at the bottom of the fuel. The stresses produced at top of the fuel rack are negligible as the force at the top of the FSR is small (137 N). The stresses produced by the fuel forces on the base plate are analyzed by applying the impact loads (Vertical – 40,520 N, Horizontal 1,026 N) as nodal loads in three directions (max horizontal load applied in both horizontal directions) to the detailed model of the buffer pool deep pit FSR. Due to the large vertical forces, a



plastic stress-strain material curve is used and the stress is shown to be below the allowable value from Appendix F of the ASME Code.

3.2 Seismic Demand

The NA3 site-specific response spectra for the ESBWR fuel racks are provided in a site-specific design specification data sheet for the fuel racks (Reference 8). The NA3 response spectra for the spent fuel racks in the buffer pool deep pit documented in Reference 8 are the enveloped spectra from Node 106, 206, and 107 of the Shimizu bounding in structure RSA (Reference 9). Node 106 and 206 are located at the elevation of the base of the buffer pool deep pit with node 106 on the Reactor Building (RB) and 206 on the Reinforced Concrete Containment Vessel (RCCV). Node 107 is located on the deep pit wall on the RB at an elevation at which the input motion at this location would be coupled to the FSR through the water in the pool and so its spectrum is conservatively included. All spectra for the fuel racks are taken at 4% damping consistent with Reg. Guide 1.61 for welded steel structures for SSE analysis.

The NA3 deep pit fuel FSR response spectra are shown with comparison to the equivalent DCD response spectra in Figure 7, Figure 8, and Figure 9 for the plant North-South, East-West and Vertical direction, respectively³. The DCD response spectra were retrieved from Section 2.0 of Reference 1.

The analysis of the spent fuel racks requires a synthesized acceleration time history in addition to the response spectra. The time history is used in a non-linear transient analysis to determine the effect of fuel impact during SSE. The time histories for this evaluation are shown in Figure 14 and Figure 15 for the horizontal and vertical direction, respectively. These time histories are discussed in Section 4.2 and were generated from the response spectra for the new FSR in the buffer pool. The new FSR are located just above the buffer pool deep pit FSR and it is conservative to use the time history from the higher elevation.

³ The response spectra are provided from 10 Hz to 300 Hz as the fundamental frequency of the deep pit fuel racks is 13.6 Hz and the highest eigenvalue of the FSR calculated was 263.8 Hz.



3.3 Results

The key findings from this reanalysis are documented in Table 4, Table 5, and Table 6 with comparisons to the corresponding results from the DCD. In general, there are increases in the stress and displacement results of roughly 15%-20%. The site-specific increases in the horizontal response spectra at low frequencies results in greater excitation of the low frequency structural modes that dominate the response of the FSR.

Due to the increase in the site-specific stresses on the FSR in the buffer pool resulted in overstressing the design of the anchor bolts and the 6 mm corner welds of the FSR. This is discussed in Section 3.4.

Table 4 summarizes the enveloping maximum horizontal displacement for the FSR obtained from the dynamic reanalysis. The maximum displacement has increased 1.1 mm from the DCD results. Given that the new maximum displacement is now 6.6 mm and the minimum distance to the nearest FSR or pool wall is 100 mm, there is not concern over an impact with a wall or an adjacent FSR.

Table 5 summarizes the critical stress results obtained from the analysis of the FSR and the comparison with the allowable values in accordance with the design code (Reference 7). All component stresses are below their code allowable values when the changes identified in Section 3.4 are incorporated.

Finally, Table 6 summarizes the enveloping maximum reactions on the bearing pad in the pool floor liner. The anchor embedment loads increased from the DCD results. However, embedment design is outside the scope of this analysis and will be addressed later in the design process.

3.4 Design Changes

The site-specific evaluation of the FSR in the deep pit of the buffer pool resulted in the overstressing of the existing M48 anchor bolts and the corner fillet welds attaching the 10 mm thick enveloping plate to the base stiffener plate.



To accommodate the increase anchor loadings, the anchor bolts were switched from M48 to M52 bolts. The change in the size of anchor bolts does not affect the existing structural analysis as the bolt loadings are equivalent to the loading of the fixed nodes at the base of the FSR and thus, this design change has no effect on the structural qualification of the remaining FSR components.

The increase in the bending stresses at the weld from the 10 mm thick enveloping plate to the base stiffener plates resulted in the increase of the fillet weld size from 6 mm to 8 mm at the corner locations. The change in this weld size does not affect the existing structural analysis as the weld size is not explicitly modeled. Instead, the stress is evaluated as the peak stress at the base of the enveloping plate corner multiplied by the ratio of the enveloping plate area to the weld area. See Figure 10 to review the location of the weld size changes.

The change in the anchor bolt and weld size do not invalidate the existing DCD structural adequacy evaluation (Reference 1) because the increase in size of both design changes result in lower stresses in these components and negligible change in stress in the other buffer pool deep pit FSR components.

**Table 4: Maximum Buffer Pool FSR Displacements***

	NEDO-33373 Rev. 5 Values (Section 2.5.1)	NA3 Specific Values
Maximum Displacement (mm)	5.7	6.6

* Minimum distance between nearest FSR or pool wall is 100 mm

Table 5: Fuel Storage Racks Main Analysis Results

		NEDO-33373 Rev. 5 Values (Table 2-2)		NA3 Specific Values	
Steel Plates	Stress Limit (MPa)	Stress (MPa)	Ratio	Stress (MPa)	Ratio
10 mm thick enveloping plate	292.8	131	0.45	153.7	0.52
10 mm thick enveloping plate welds ⁽¹⁾	198.6	185.5	0.93	176.1 ⁽¹⁾	0.90 ⁽¹⁾
7 mm thick upper level plates	292.8	55.8	0.19	62.8	0.21
20 mm thick base plate	292.8	101	0.34	118	0.40
20 mm thick base plate stiffener plates	292.8	142	0.48	166	0.57
20 mm thick base plate stiffener plate welds	198.6	155.1	0.78	177	0.89
60 mm thick bolted support plates	292.8	174	0.59	200.1	0.68
Anchor Bolts ⁽²⁾	1 ⁽³⁾	0.87 ⁽³⁾	0.87 ⁽³⁾	0.79 ^{(2),(3)}	0.79 ^{(2),(3)}

- (1) Component design has changed from Reference 1. The fillet size for the 10 mm thick enveloping plates has been updated from 6 mm to 8 mm due to a critical stress ratio of 1.06 for this component using the original weld design. See Section 3.1 for a discussion of this change.
- (2) Component design has changed from Reference 1. M48x2 Anchor Bolts were changed to M52x2 Anchor Bolts due to a critical stress ratio of 1.12 using the original bolts. See Section 3.1 for a discussion of this change.
- (3) This is a stress ratio, not a stress value.

**Table 6: Anchor Bolt Embedment Loads⁽¹⁾**

	NEDO-33373 Rev. 5 Values (Table 2-13)	NA3 Specific Values
Level A Conditions Shear (N)	27665	27665
Level A Conditions Tensile (N)	54220 ⁽²⁾	54220 ⁽²⁾
Level D Conditions Shear (N)	396554	435233
Level D Conditions Tensile (N)	718507	841770

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

(2) Bolts do not withstand compression load in normal conditions

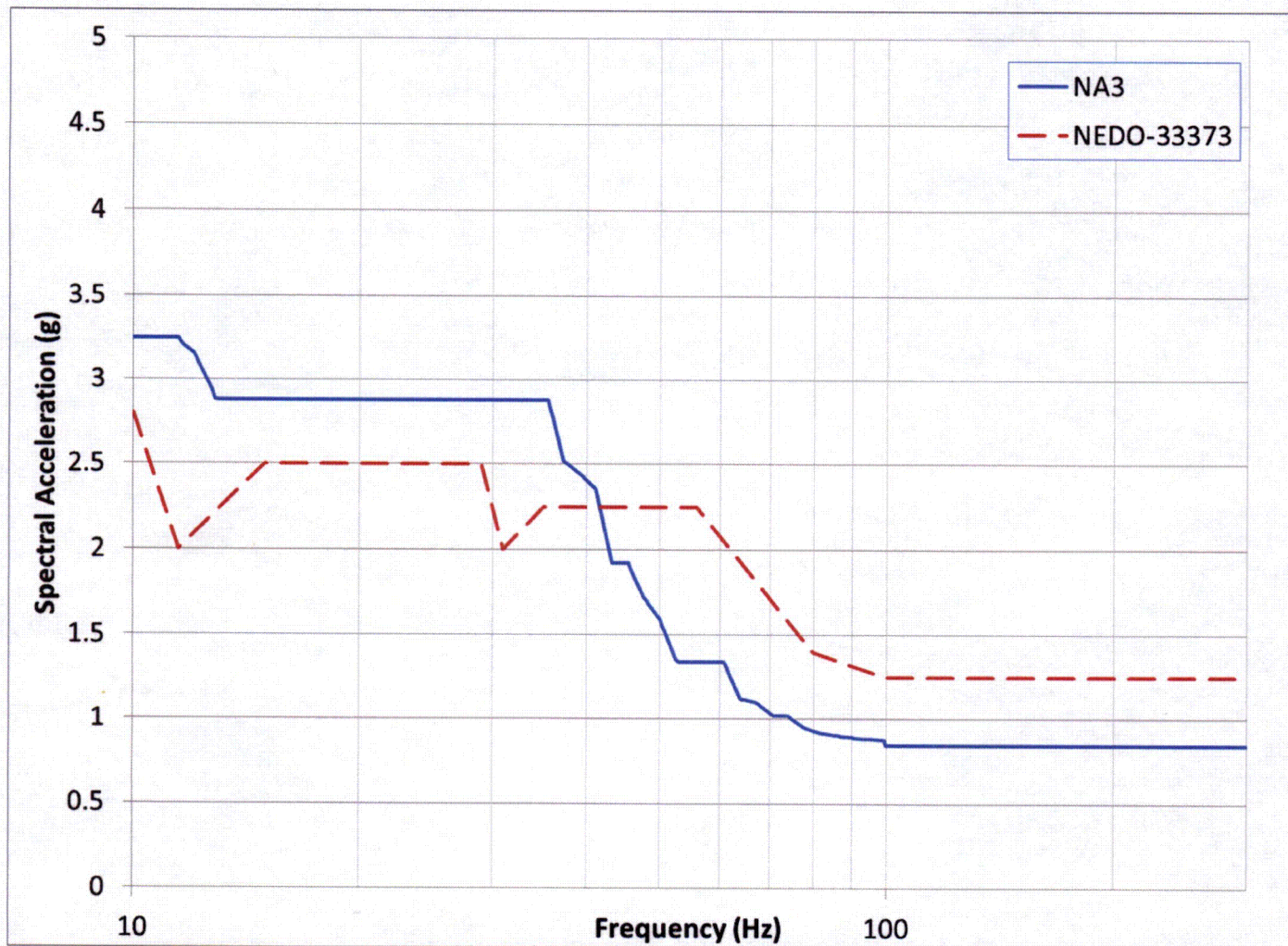


Figure 7: North-South Buffer Pool FSR SSE Spectra Comparison (4% Damping)

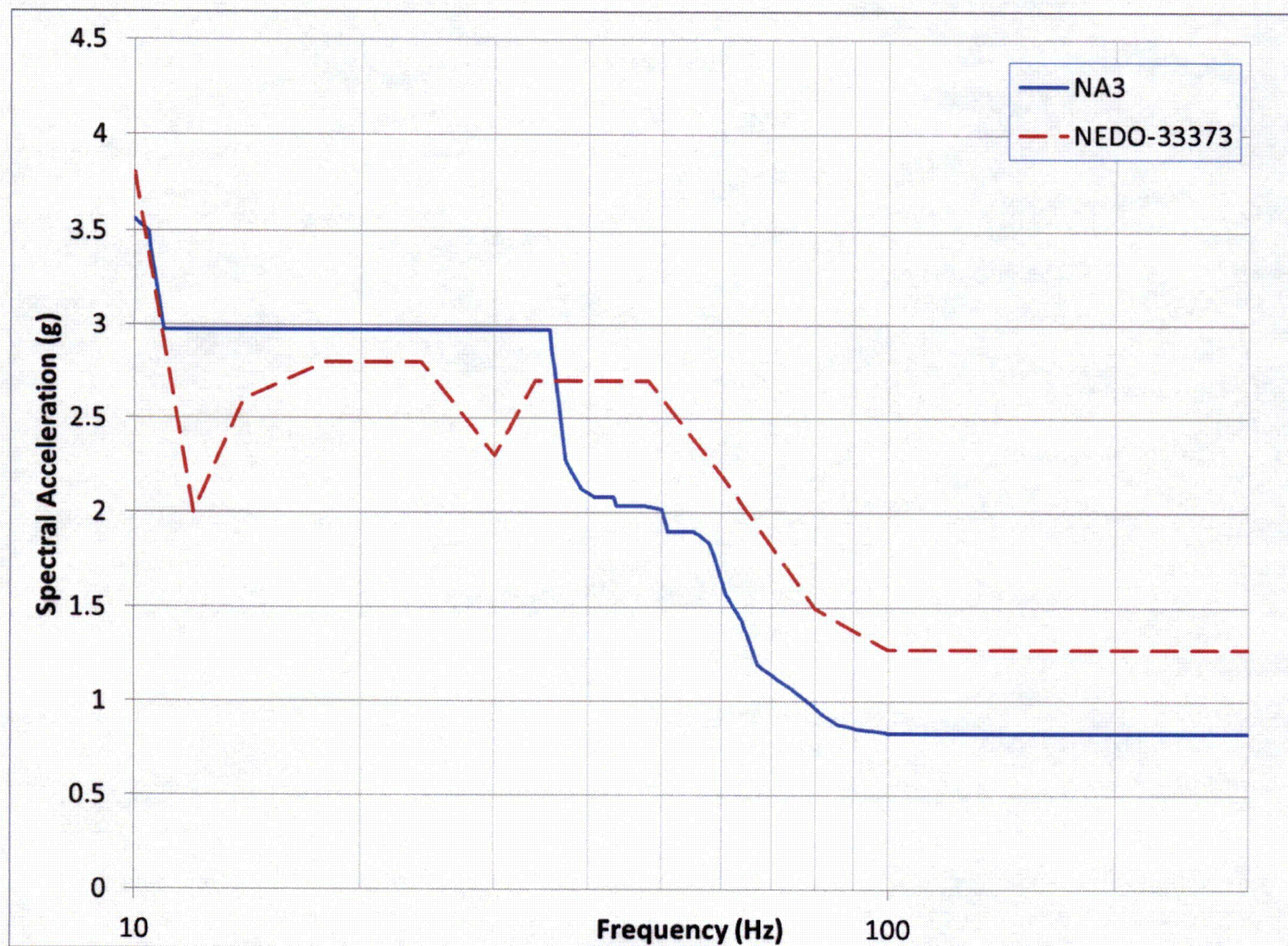


Figure 8: East West Buffer Pool FSR SSE Spectra Comparison (4% Damping)

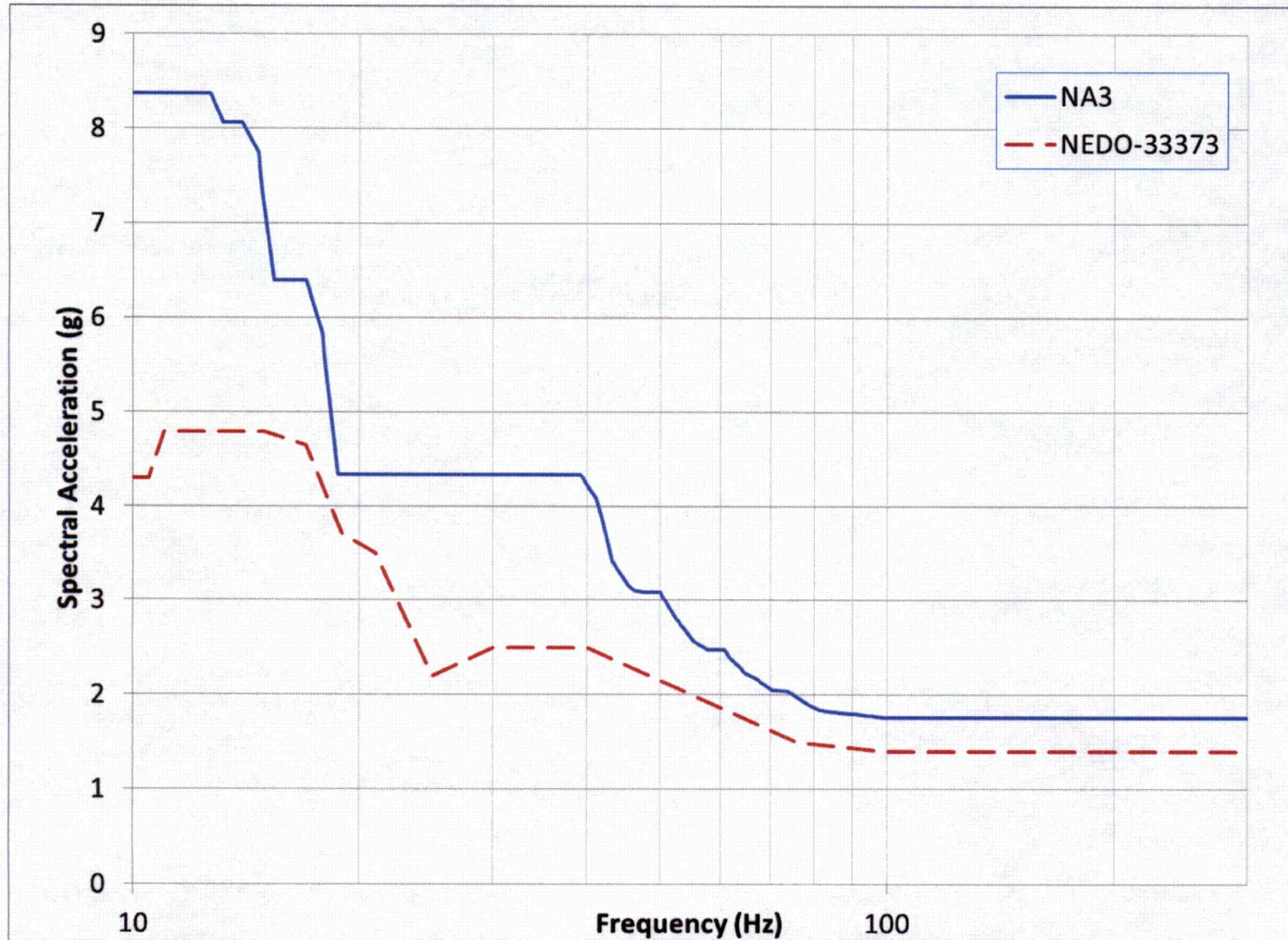


Figure 9: Vertical Buffer Pool FSR SSE Spectra Comparison (4% Damping)

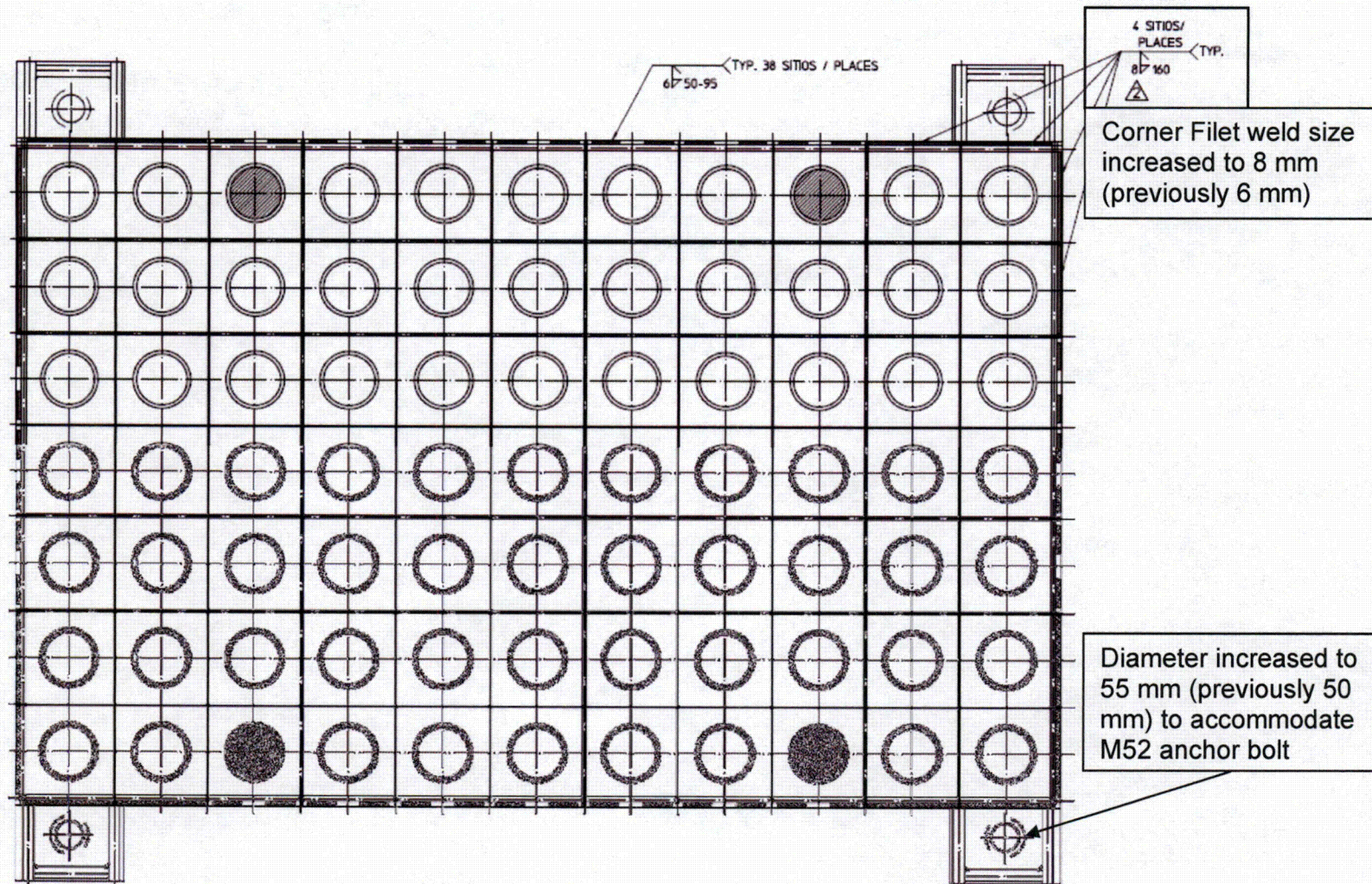


Figure 10: Spent Fuel Racks in the Buffer Pool Design Changes



4. NEW FUEL RACKS IN THE BUFFER POOL

The structural adequacy of the buffer pool new FSR to the ESBWR DCD seismic demands was demonstrated in Section 3.0 of Reference 1. To ensure the structural adequacy of the buffer pool new FSR for the seismic demands of NA3, the analysis documented in Section 3.0 of Reference 1 was repeated using the NA3 site-specific SSE acceleration response spectra. This analysis is contained in Reference 5.

A brief summary of the structural assessment is provided in Section 4.1. The information contained in Section 4.1 is a repeat of information provided in the ESBWR DCD buffer pool new FSR report (Section 3.0 of Reference 1) as an aide in understanding the current, site-specific evaluation of these racks. The site-specific seismic demand for these racks is discussed in Section 4.2. The maximum enveloping results of the assessment including stress results, displacements, and anchorage embedment loads are provided in Section 4.3. Finally, the design changes to these racks to prevent overstressed components resulting from site-specific seismic demands are provided in Section 4.4.

4.1 Analysis Summary

The buffer pool new FSR are qualified using guidance from Appendix D of SRP Chapter 3.8.4. The following is a brief description of the site-specific seismic evaluation of the buffer pool new FSR. See Reference 5 for the assessment in its entirety.

Overview

The new fuel storage racks in the reactor building buffer pool are designed to support and protect new fuel assemblies. They are made of stainless steel plates, forming 7x2 cells each cell housing a new fuel assembly. Two new FSR are joined and installed together forming a 14x2 configuration. The new FSR are anchored to floor of the buffer pool at several locations along their length.

To analyze these racks both a RSA and transient analysis are performed to ensure the structural adequacy of the individual components responsible for maintaining the adequacy of the buffer pool new FSR.

Design Code

The buffer pool new FSR are designed to the stress limits of ASME B&PV Code, Section III, Division 1, Subsection NF requirements for Class 3 component supports (Reference 7).

Loads and Combinations

The only load combination affected by the change in seismic demand is shown in Eq. (4) all other load combination results are unaffected by SSE loads.

$$\text{Level D:} \quad D + SSE + SRVD + LOCA + T_a \quad (4)$$

The dead weight (D) is evaluated as a static load under the effect of gravity. The SSE, Safety Relief Valve Discharge (SRVD), and Loss-of-Coolant Accident (LOCA) are all dynamic loads acting at the base of the rack. There are no thermal (T_a) loads on the structure because sufficient clearance is provided for thermal expansion; however, the thermal displacement is considered in determining the potential impact with the pool wall.

Analysis Procedure

The analysis of the NFSR is divided in to two calculation stages which both utilize the finite element program ANSYS 10.0. The structural adequacy of the buffer pool deep pit FSR to the static and vibration loads is evaluated by RSA. Additionally, the potential for the fuel rack to impact during an SSE and the local stress qualification of the fuel base plate for this impact is evaluated in a non-linear transient analysis.

Analysis Procedure (RSA)

A detailed finite element model of joined buffer pool new FSR set (14x2 cells) is developed using shell and lumped mass elements. The deadweight loads are resolved by static analysis. The dynamic loads are resolved by RSA using the first 150 modes up to 81.63 Hz. The site-specific response spectra are



discussed in Section 4.2. 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 RSA are accounted for using pseudo-static evaluation consistent with Appendix A of Reg. Guide 1.92.

The results of the RSA analysis are used to determine the stresses in the buffer pool new FSR components and the embedment loads to be used in the design of the embedment. In addition, the maximum displacements are combined with thermal displacements to ensure that the buffer pool deep pit wall is not impacted.

Analysis Procedure (Transient Analysis – Fuel Impact)

Synthesized site-specific acceleration time histories are converted to displacements by double integration and used as base input motion for simplified models representing the structural characteristics of the buffer pool new FSR in the East-West and North-South direction. Each simplified model is composed of 2-D elastic beam elements representing the enveloping plate of the FSR and the fuel elements. The masses of the structures are lumped and hydrodynamic coupling is simulated between the fuel and the FSR. The fuel's lowest node is coupled to the FSR in the horizontal direction and a contact element is used in the vertical direction which allows the fuel to uplift and then impact the FSR. The fuel's uppermost node has horizontal contact elements to evaluate lateral impacts of the fuel with the FSR. This time history analysis was performed for 16 seconds using 0.005 second intervals.

Maximum impact forces are obtained from the transient analysis. These forces include the horizontal forces at the top and bottom of the fuel and the vertical impact force at the bottom of the fuel. The stresses produced at top of the fuel rack are negligible as the force at the top of the FSR is small (692 N). The stresses produced by the fuel forces on the base plate are analyzed by applying the fuel's lower loads (Vertical – 60,714 N, Horizontal 2,221 N) as nodal loads in three directions (maximum horizontal applied in both horizontal directions) to the detailed model of the deep pit FSR used for the RSA. Due to the large vertical



forces, a plastic stress-strain material curve is used and the stress is shown to be below the allowable value from Appendix F of the ASME Code.

4.2 Seismic Demand

The NA3 site-specific response spectra for the ESBWR fuel racks are provided in a site-specific design specification data sheet for the fuel racks (Reference 8). The NA3 response spectra for the buffer pool new FSR documented in Reference 8 are the enveloped spectra from the following nodes from the Shimizu bounding in-structure RSA (Reference 9).

X-Direction: Node 108 and 208

Y-Direction: Node 108 and 208

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

Node 108 and 208 are at the elevation of the bottom of the buffer pool with node 108 on the Reactor Building and node 208 on the RCCV. The additional nodes in the vertical direction are vertical slab oscillators that represent additional motion resulting from floor flexibility. All spectra for the fuel racks are taken at 4% damping consistent with Reg. Guide 1.61 for welded steel structures for SSE analysis.

The NA3 buffer pool new FSR response spectra are shown with comparison to the equivalent DCD response spectra in Figure 11, Figure 12 and Figure, 13 for the plant North-South, East-West and Vertical direction respectively⁴. All DCD responses were retrieved from Section 3.0 of Reference 1.

The analysis of the new FSR requires a synthesized acceleration time histories in addition to the response spectra. The time history is used in a non-linear transient analysis to determine the fuel impact forces occurring after fuel uplift

⁴ The response spectra are provided from 1 to 100 Hz as the fundamental frequency of the buffer pool new FSR is 7.2 Hz and the highest eigenvalue of the FSR calculated was 81.6 Hz.



has occurred during an SSE event. The synthesized acceleration time histories for the buffer pool new FSR are documented in Reference 11. Reference 11 demonstrated that the response spectra generated in each direction envelops the design spectra.

The NA3 synthesized acceleration time histories are shown in Figure 14 and Figure 15 for the horizontal and vertical direction, respectively.

4.3 Results

The key findings from this reanalysis are documented in Table 7, Table 8, and Table 9 with comparisons to the corresponding results from the DCD. There is slight increase in the stresses and displacements of some, but not all, of the components. This is primarily due to the horizontal site-specific spectra exceedances at the natural frequency of the structure (7.2 Hz).

The increase in the site-specific stress on the buffer pool new FSR resulted in the overstressing of the anchor bolts. The increase in the diameter of these bolts is discussed in Section 4.4.

Table 7 summarizes the enveloping maximum horizontal displacement for the new FSR obtained from the dynamic reanalysis. The maximum horizontal displacement has increased 3 mm from the DCD results; however, the site-specific maximum displacement (24 mm) is still well below the minimum distance to the nearest rack or wall (100 mm). There is no concern about the new FSR impacting either adjacent racks or the pool wall.

Table 8 summarizes the enveloping critical stress results obtained from the analysis of the new FSR and the comparison with the allowable values in accordance with the design code. All component stresses remain below their code allowable values when the design change identified in Section 4.4 has been incorporated.

Table 9 summarizes the enveloping maximum reactions on the bearing pad in the pool floor liner. The Level D anchor embedment shear load has decreased from the DCD results while the tensile load has increased. The increased loads



on the embedment will be accounted for in the future work of designing the buffer pool new FSR bolt embedment.

4.4 Design Changes

The site-specific evaluation of the NFSR in the buffer pool resulted in the overstressing of the existing M24 anchor bolts.

To accommodate the increase anchor loadings, the anchor bolts were switched from M24 to M27 bolts. The existing design of the rack had enough room to accommodate this increase in the bolt size and so no changes were made to the rack itself. The change in the size of anchor bolts does not affect the existing structural analysis as the bolt loadings are equivalent to the loading of the fixed nodes at the base of the FSR and thus, this design change has no effect on the structural qualification of the remaining components.

The change in the anchor bolt size does not invalidate the existing DCD structural adequacy evaluation (Reference 1) because the increase in size would result in lower stresses in the bolts with negligible change in the buffer pool new FSR component stresses.

**Table 7: Maximum Buffer Pool NFSR Displacements***

	NEDO-33373 Rev. 5 Values (Section 3.5.1)	NA3 Specific Values
Maximum Displacement (mm)	21.0	23.96

* Minimum distance between FSR and pool wall is 100 mm

Table 8: NFSR Main Analysis Results

		NEDO-33373 Rev. 5 Values (Table 3-2)		NA3 Specific Values	
Steel Plates	Stress Limit (MPa)	Stress (MPa)	Ratio	Stress (MPa)	Ratio
8 mm thick channel plate	292.8	267	0.91	197	0.67
Channel to support-base welds	198.6	182	0.92	185.3	0.93
12 mm thick door plates	195.2	123	0.63	145	0.74
Assembly grid plate	195.2	52.5	0.27	43.9	0.23
Axis and hinge	195.2	130	0.67	152.8	0.78
15 mm thick support-base stiffeners	195.2	138	0.71	155	0.79
15 mm thick folded base plate	292.8	266	0.91	247	0.84
30 mm thick bolted support plates	292.8	124	0.42	144	0.49
Anchor Bolts ⁽¹⁾	1 ⁽²⁾	0.91 ⁽²⁾	0.91 ⁽²⁾	0.62 ^{(1),(2)}	0.62 ^{(1),(2)}

(1) Component design has changed from Reference 1. M24x2 Anchor Bolts were changed to M27x2 Anchor Bolts due to a critical stress ratio of 1.03 using the original bolts. See Section 4.1 for a discussion of this change.

(2) This is a stress ratio, not a stress value.

**Table 9: Anchor Bolt Embedment Loads⁽¹⁾**

	NEDO-33373 Rev. 5 Values (Table 3-15)	NA3 Specific Values
Level A Conditions Shear (N)	5390	5390
Level A Conditions Tensile (N)	2239 ⁽²⁾	2239 ⁽²⁾
Level D Conditions Shear (N)	93701	77771
Level D Conditions Tensile (N)	218410	254340

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

(2) Bolts do not withstand compression load in normal conditions

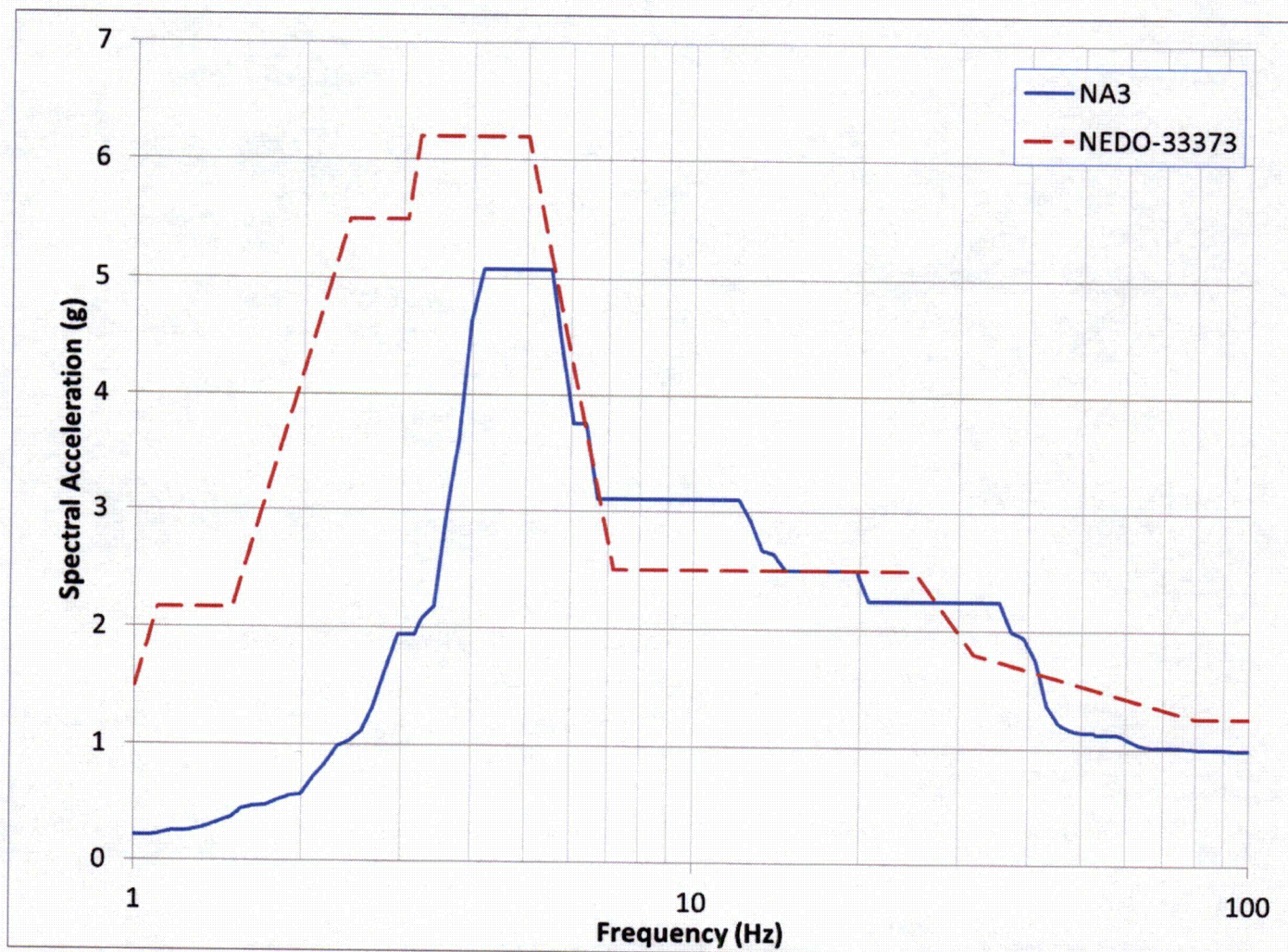


Figure 11: North-South Buffer Pool New Fuel Rack SSE Spectra Comparison (4% Damping)

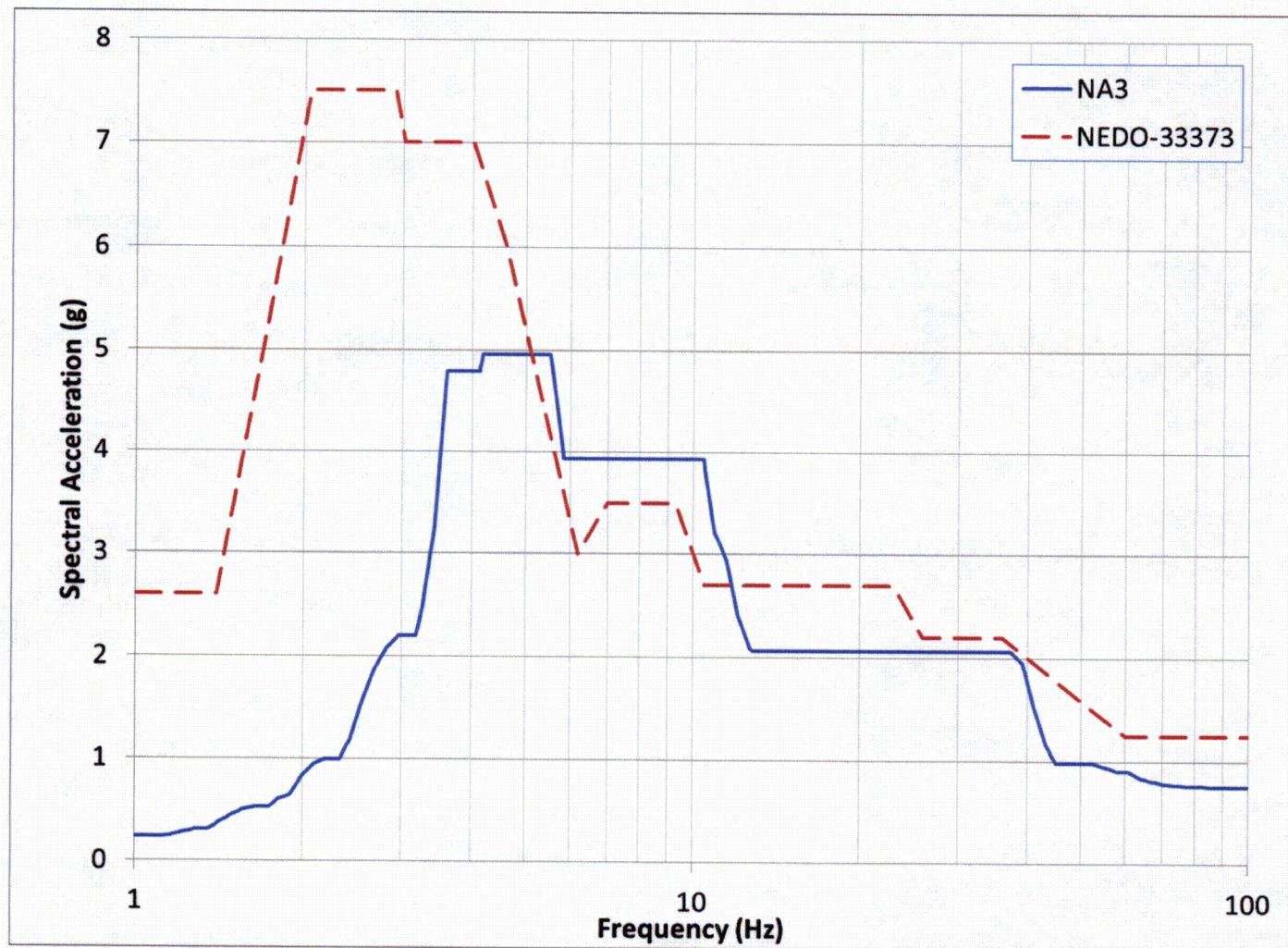


Figure 12: East-West Buffer Pool New Fuel Rack SSE Spectra Comparison (4% Damping)

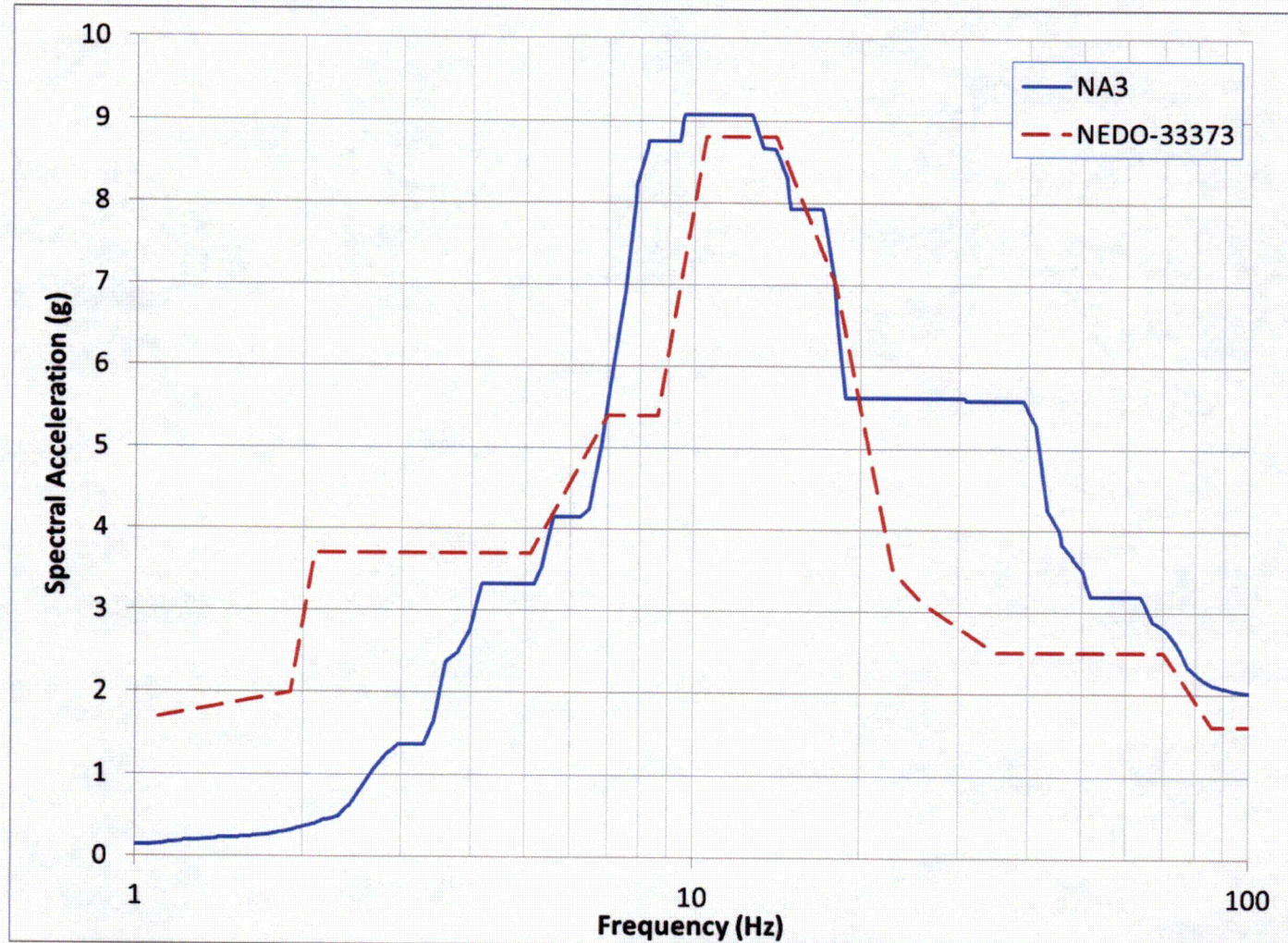


Figure 13: Vertical Buffer Pool New Fuel Rack SSE Spectra Comparison (4% Damping)

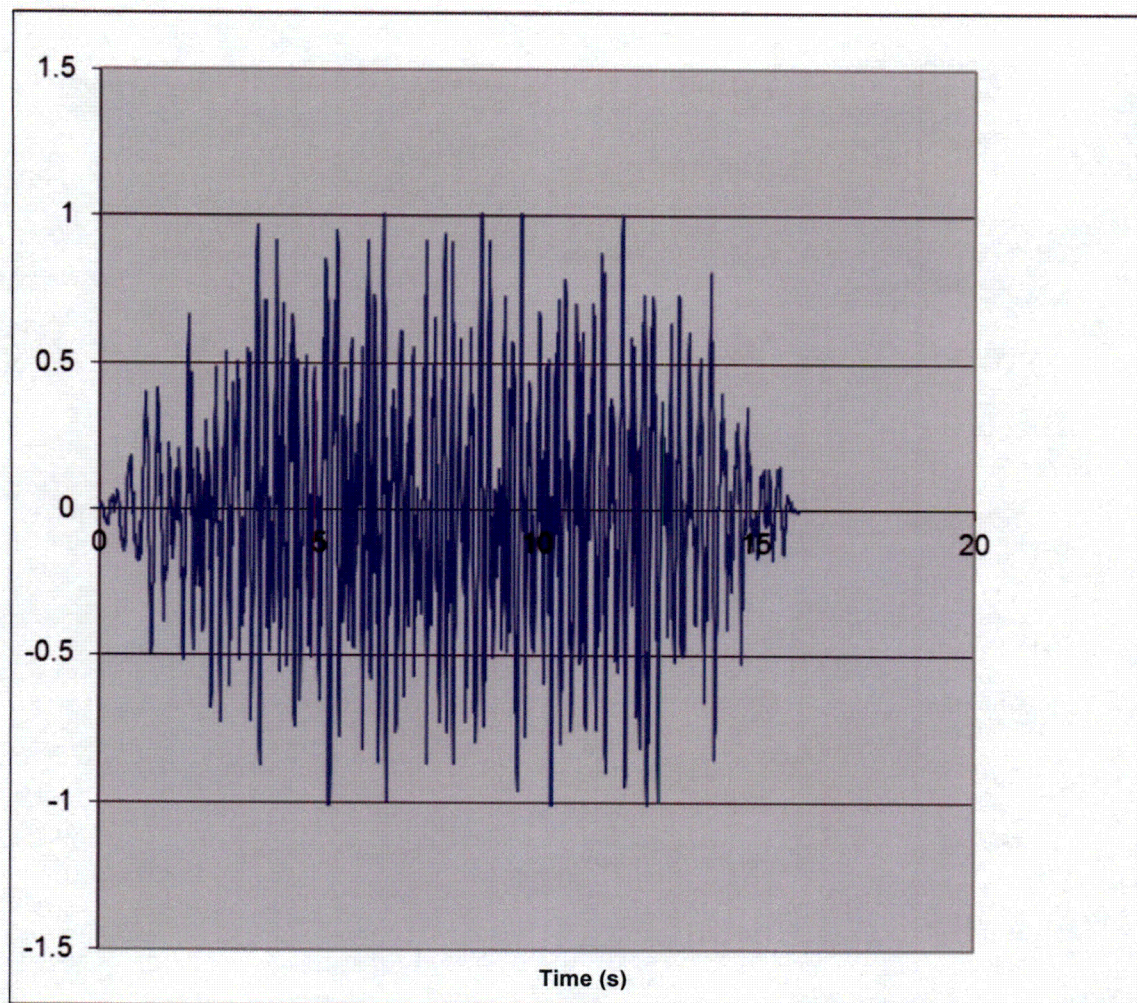


Figure 14: Horizontal Buffer Pool FSR SSE Acceleration Time History (Units: g)

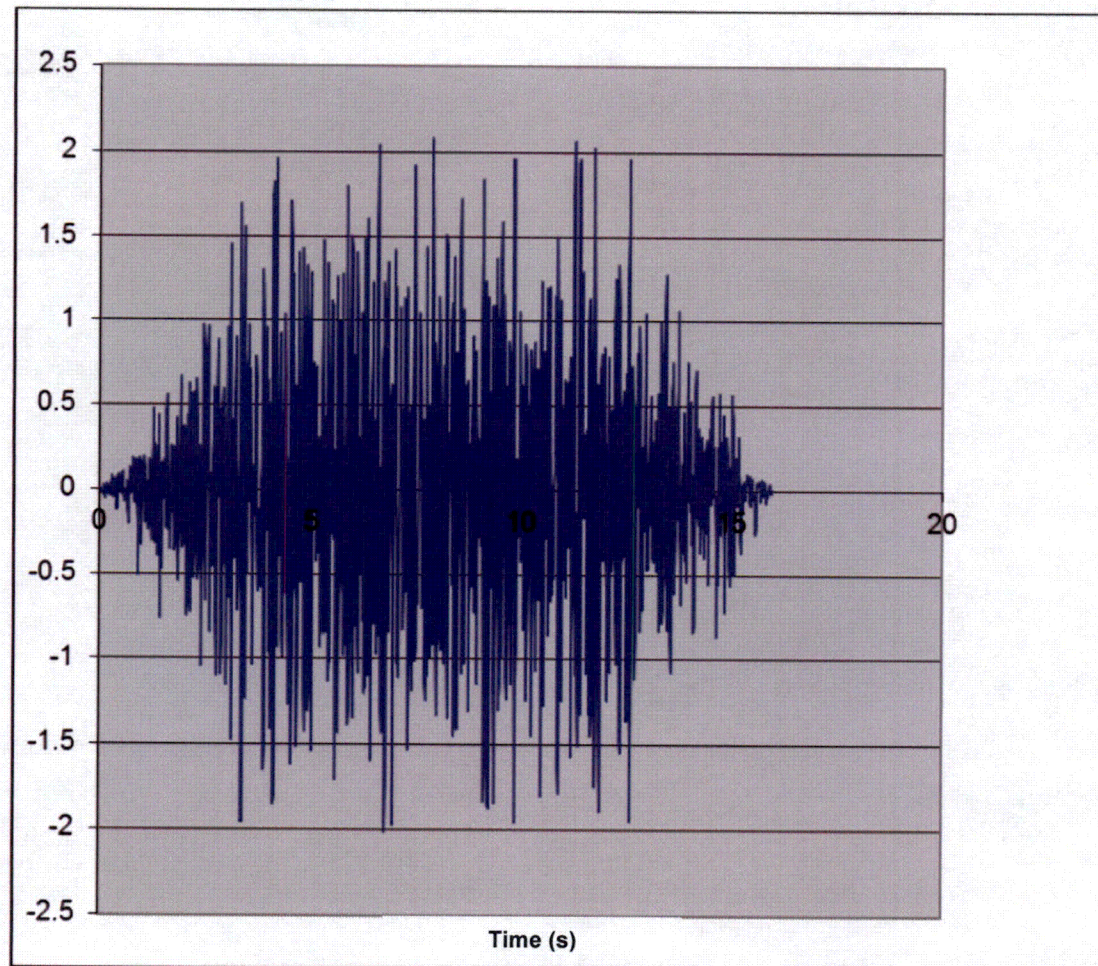


Figure 15: Vertical Buffer Pool FSR SSE Acceleration Time History (Units: g)

**5. CONCLUSION**

Using methodologies identical to those used in the ESBWR Licensing Topical Report (Reference 1), the fuel storage rack designs were re-evaluated using NA3 site-specific acceleration response spectra.

The re-evaluation showed:

1. The spent fuel storage racks in the spent fuel pool had decreases in maximum displacements, stresses and pool reaction loads, demonstrating the adequacy of the design of these racks for NA3 seismic demands.
2. The spent fuel storage racks in the buffer pool deep pit required increases to the size of the anchor bolts and the welds from the enveloping plate to the base plates due to NA3 seismic demands. The NA3 embedment loads increased which will be accommodated during final embedment design.
3. The new fuel storage racks in the buffer pool required an increase to the size of the anchor bolts due to NA3 seismic demands. The NA3 embedment loads increased which will be accommodated during final embedment design.

Although the NA3 site-specific fuel rack seismic analysis concludes that the response spectra of the ESBWR DCD is not bounded across all frequencies and requires design changes for NA3, these changes do not invalidate the seismic qualification of the standard ESBWR plant design as described in Reference 1 because they result in lower component stresses.

**6. REFERENCES**

- 1) NEDO-33373 Rev. 5, "Dynamic, Load-Drop and Thermal-Hydraulic Analyses for ESBWR Fuel Racks", September 2010.
- 2) North Anna 3, Docket Number 52-017, Request for Additional Information 123, July 2014.
- 3) Document # 092-322-F-M-00001 Rev. 1 "Design Report of the Spent Fuel Storage Racks in the Fuel Building for North Anna 3," June 2015.
- 4) Document # 092-322-F-M-00003 Rev. 1 "Design Report of the Spent Fuel Storage Racks in the Reactor Building for North Anna 3," June 2015.
- 5) Document # 092-322-F-M-00002 Rev. 2 "Design Report of the New Fuel Storage Racks in the Reactor Building for North Anna 3," June 2015.
- 6) GEH Document # 003N0526 Rev. 0, "North Anna 3 Seismic Qualification of Spent Fuel in the Spent Fuel Racks," October 2015.
- 7) ASME Boiler and Pressure Vessel Code, Section III Rules for Construction of Nuclear Facility Components, Division 1, Subsection NF, Supports, 2001 Edition with Add. 2003.
- 8) GEH Document # 26A7032AA, "Fuel Storage Rack Design Specification Data Sheet," April 2015.
- 9) Document # SER-DMN-019 Rev. 0, "RB/FB Seismic Analyses Bounding Results and In-Structure Response Spectra," April 2015.
- 10) Document # 5926ATN02 Rev. 3, "ESBWR Fuel Building Pool Bottom Synthesized SSE Acceleration Time Histories," October 2015.
- 11) Document # 5926ATN04 Rev. 2, "ESBWR Reactor Pool Bottom (elevation +27 m) Synthesized SSE Acceleration Time Histories," October 2015.

Serial No. NA3-16-001
Docket No. 52-017

ENCLOSURE 5

GEH Technical Report

002N8530 Revision 2

PCCS Condenser Seismic Analysis

002N8530 Revision 2

NORTH ANNA 3 PCCS CONDENSER SEISMIC ANALYSIS

Changes from Revision 1 to Revision 2

Rev. 2 addresses changes discussed with the NRC in seismic Audit 1, Action Item 0910GEN02. The major changes are summarized below:

1. Section 1.0 ("Introduction") has been split into Section 1.1 ("Purpose") and Section 1.2 ("Scope"). 2nd and 3rd Paragraphs of Section 1.1 now provide more background detail regarding the report.
2. Section 2.0 ("PCCS Condenser Adequacy Evaluation") now has new subsections 2.1 ("Analysis Summary"), 2.2 ("Seismic Demand"), and 2.3 ("Results"):
 - a. Section 2.1 provides information about the following: description of the PCCS Condenser, analysis methods, design code, load combinations, analysis procedure for response spectrum analysis (RSA) and transient analysis, stress calculation discussion, and stress limits.
 - b. Section 2.2 provides an overview of how the site-specific response spectra were generated.
 - c. Section 2.3 provides the analysis summary results. The results discussion in Section 2.0 of the Rev. 1 has been expanded with further discussion in Section 2.3 of Rev. 2.
 - d. Figure 1 was added to provide an isometric view of the PCCS Condenser for clarity.



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**002N8530
Revision 2
Class I
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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 purpose of this report is to summarize the results of this 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 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.

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.

$$\text{Level C-1:} \quad D + P_a + T_a + SSE + SRVD + LOCA \quad (1)$$

$$\text{Level C-2:} \quad D + DET + T_a + SSE \quad (2)$$

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 by a response spectrum analysis (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 Shimizu in-structure response generated at the following nodes (Reference 3).

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 fuel racks 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 have been 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 spectra differences 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 margins¹ 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.

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



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 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)		NA3 Specific Values	
			Calculated Stress (MPa)	Stress Margin (%) ⁽¹⁾	Calculated Stress (MPa)	Stress Margin (%) ⁽¹⁾
Upper Header	P _m	291.4	52.8	81.9%	30.8	89.4%
	P _L +P _b	381.7	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

**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)		NA3 Specific Values	
			Calculated Stress (MPa)	Stress Margin (%) ⁽¹⁾	Calculated Stress (MPa)	Stress Margin (%) ⁽¹⁾
Upper Header	P _m	291.4	41.6	85.7%	19.6	93.3%
	P _L +P _b	291.7	53.5	81.7%	43.4	85.1%
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	221.2	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**

Section	Stress Category	Allowable Stress for Service Level C-2 (MPa)	NEDE-33572P Rev. 3 Values (Table C-6)			NA3 Site Specific Values	
			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⁾

Component Anchor Load	Service Level	NEDE-33572P, Rev. 3 Values		NA3 Site Specific Values	
		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	350 ⁽³⁾	142 ⁽³⁾	344	134
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⁾	216 ⁽³⁾	48 ⁽³⁾	231	47

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

(2) Reference 1, Table B-3a

(3) Calculated from Reference 1, Table C-7

(4) Reference 1, Table B-4a

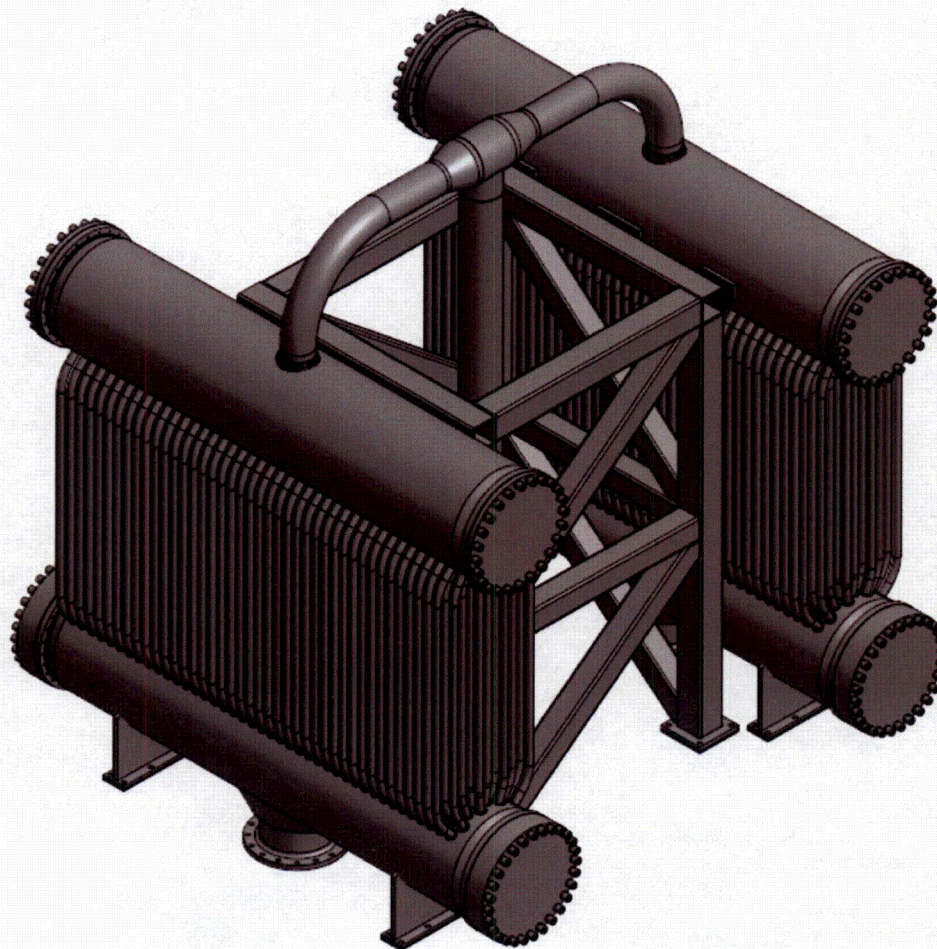


Figure 1: PCCS Condenser Isometric View

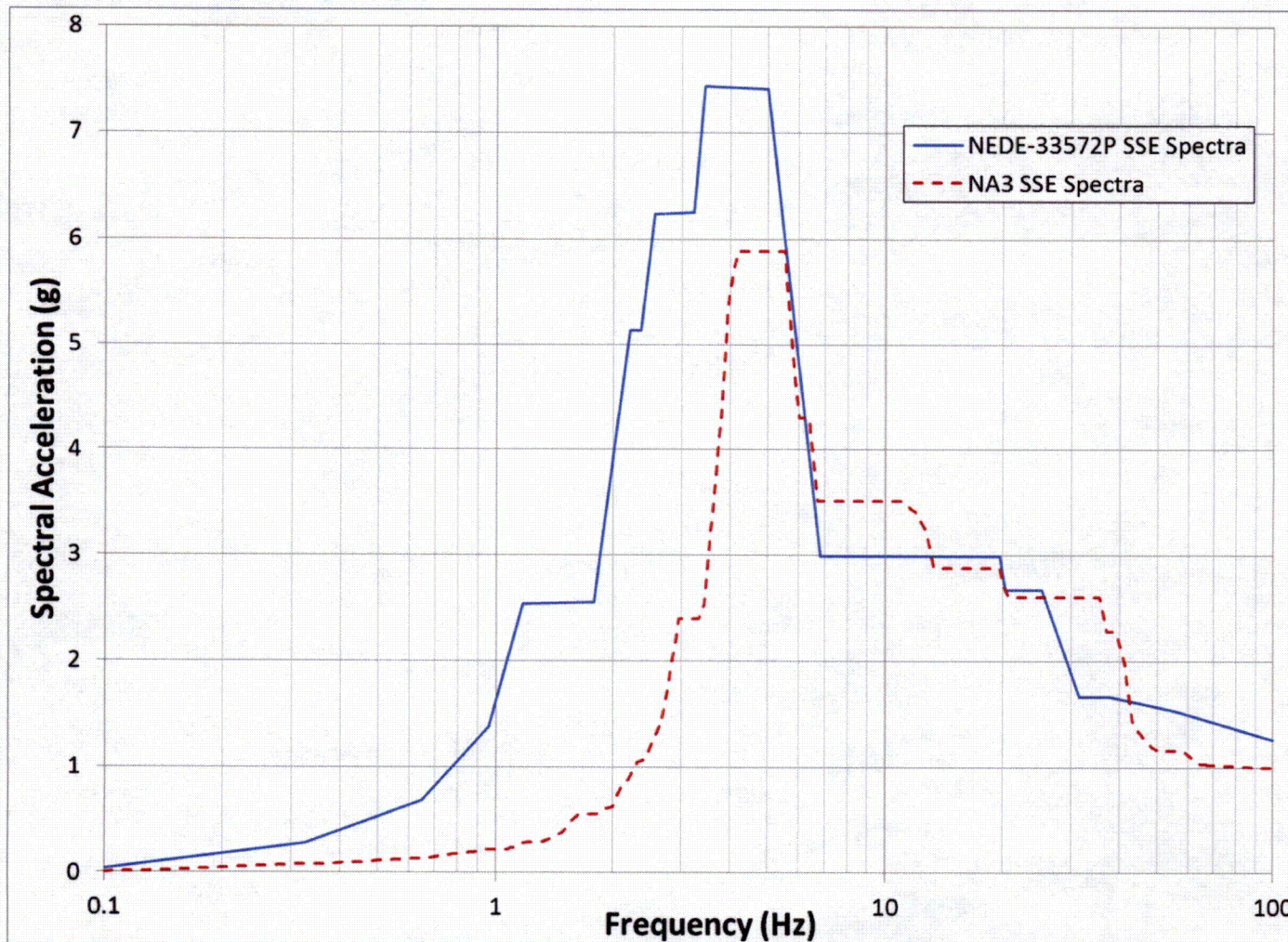


Figure2: North-South SSE Acceleration Response Spectra Comparison (3% Damping)

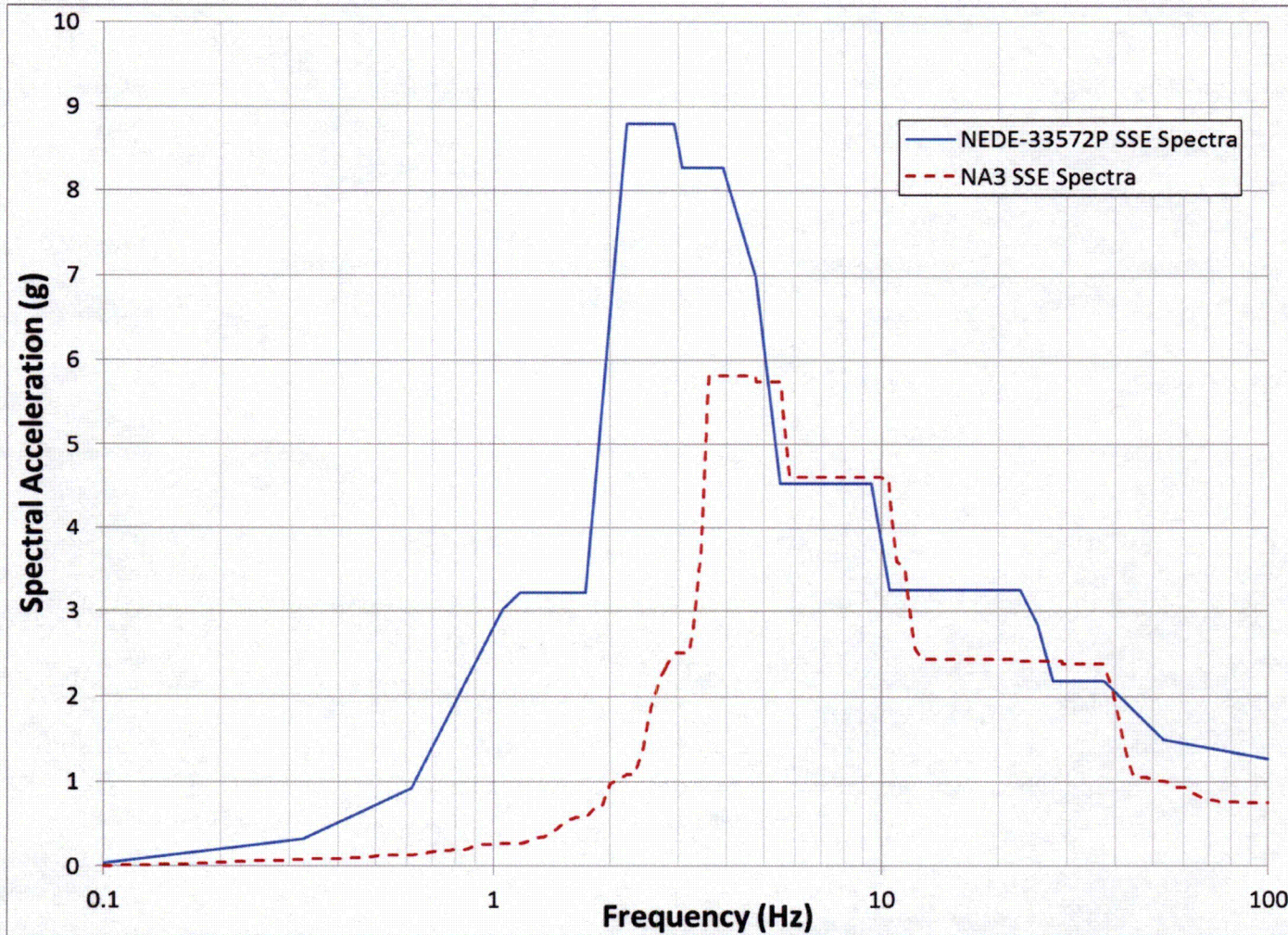


Figure 3: East-West Acceleration Response Spectra Comparison (3% Damping)

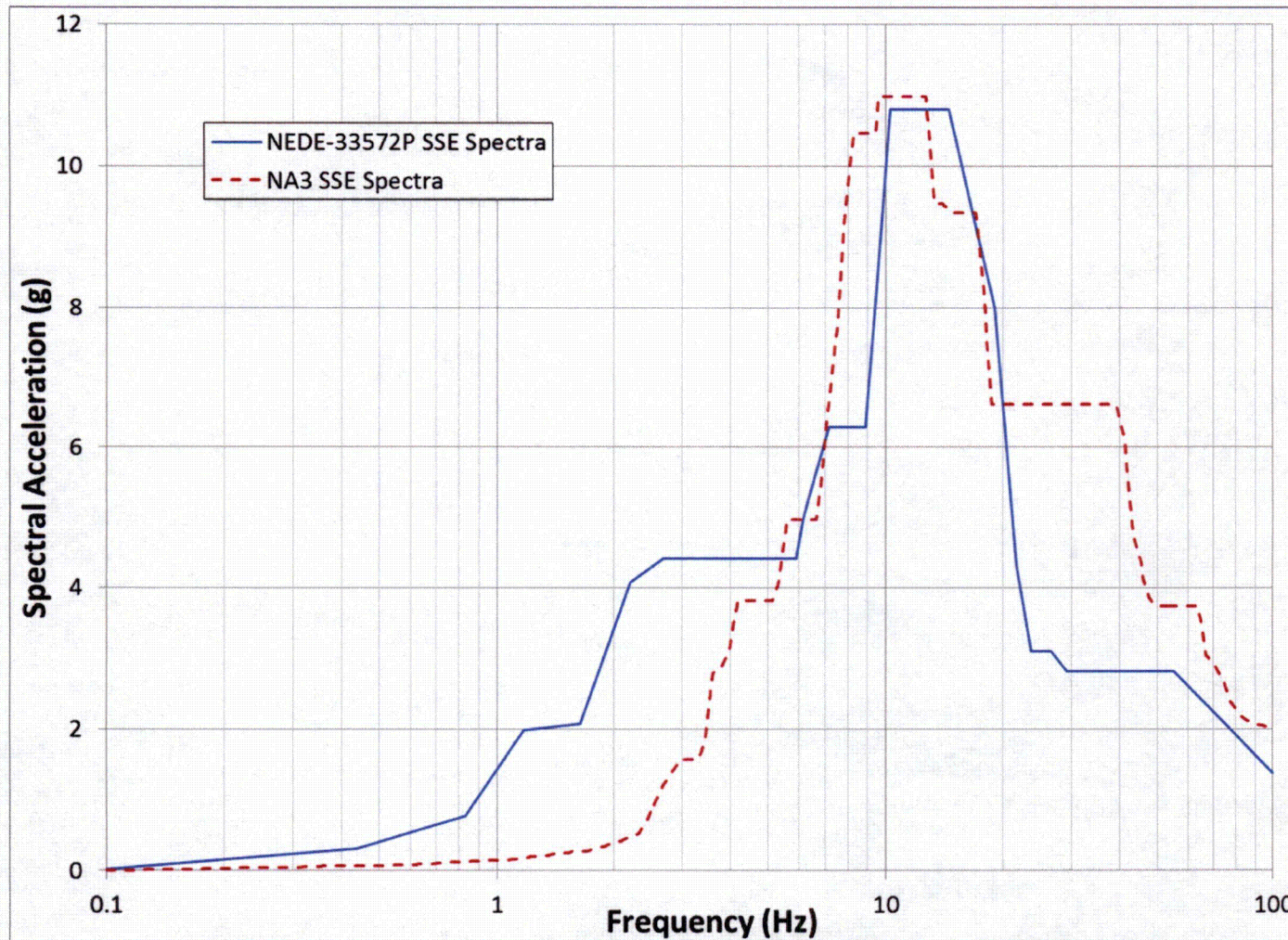


Figure 4: Vertical Acceleration Response Spectra Comparison (3% Damping)



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