Westinghouse

Westinghouse Electric Company
Nuclear Power Plants
P.O. Box 355
Pittsburgh, Pennsylvania 15230-0355
USA

U.S. Nuclear Regulatory Commission
ATTENTION: Document Control Desk
Washington, D.C. 20555

Direct tel: 412-374-6206
Direct fax: 412-374-5005
e-mail: sisk1rb@westinghouse.com

Your ref: Docket Number 52-006
Our ref: DCP/NRC2276

October 16, 2008

Subject: AP1000 DCD Impact Document Submittal of APP-GW-GLR-115 (TR 115), Revision 1

Westinghouse is submitting Revision 1 of APP-GW-GLR-115, "Effect of High Frequency Seismic Content on SSCs," Technical Report 115 (TR-115). The primary purpose of Technical Report 115 is to provide an evaluation of the effects of high frequency seismic input on the AP1000 design. The purpose of this revision to TR-115 is to incorporate Request for Additional Information (RAI) responses as agreed upon in multiple interactions between Westinghouse and the NRC staff. This report is submitted in support of the AP1000 Design Certification Amendment Application (Docket No. 52-006). The information provided in this report is generic and is expected to apply to all Combined Operating License (COL) applicants referencing the AP1000 Design Certification and the AP1000 Design Certification Amendment Application.

Pursuant to 10 CFR 50.30(b), APP-GW-GLR-115, Revision 1, "Effect of High Frequency Seismic Content on SSCs," is submitted as Enclosure 1. Revision 0 of this report was submitted under letter DCP/NRC2028 dated October 19, 2007.

It is expected that when the NRC review of Technical Report Number 115 is complete, Technical Report 115 will be considered approved generically for COL applicants referencing the AP1000 Design Certification and the AP1000 Design Certification Amendment Application.

Questions or requests for additional information related to the content and preparation of this report should be directed to Westinghouse. Please send copies of such questions or requests to the prospective applicants for combined licenses referencing the AP1000 Design Certification. A representative for each applicant is included on the cc: list of this letter.

Very truly yours,

D. A. Lindgren / FOR

Robert Sisk, Manager
Licensing and Customer Interface
Regulatory Affairs and Standardization

D063
NRR

00515psa.doc

/Enclosure

1. APP-GW-GLR-115, Revision 1, "Effect of High Frequency Seismic Content on SSCs"

cc:	D. Jaffe	-	U.S. NRC	1E
	E. McKenna	-	U.S. NRC	1E
	B. Gleaves	-	U.S. NRC	1E
	P. Ray	-	TVA	1E
	P. Hastings	-	Duke Power	1E
	R. Kitchen	-	Progress Energy	1E
	A. Monroe	-	SCANA	1E
	J. Wilkinson	-	Florida Power & Light	1E
	C. Pierce	-	Southern Company	1E
	E. Schmiech	-	Westinghouse	1E
	G. Zinke	-	NuStart/Entergy	1E
	R. Grumbir	-	NuStart	1E
	B. LaPay	-	Westinghouse	1E

ENCLOSURE 1

APP-GW-GLR-115

Revision 1

"Effect of High Frequency Seismic Content on SSCs"

AP1000 DOCUMENT COVER SHEET

TDC:_______ Permanent File:_______

AP1000 DOCUMENT NO.	REVISION	PAGE	ASSIGNED TO	OPEN ITEMS (Y/N)
APP-GW-GLR-115	1	1 of 111	W-SISK	N

DOCUMENT STATUS: ☐ PRE ☐ CFC ☐ CAE ☒ DES PAG 10/6/08

ALTERNATE DOCUMENT NUMBER: TR 115 WORK BREAKDOWN #: GW

ORIGINATING ORGANIZATION: Westinghouse Electric Company

TITLE: **Effect of High Frequency Seismic Content on SSCs**

ATTACHMENTS: N/A	DCP #/REV. INCORPORATED IN THIS DOCUMENT REVISION: N/A
CALCULATION/ANALYSIS REFERENCE: N/A	

ELECTRONIC FILENAME	ELECTRONIC FILE FORMAT	ELECTRONIC FILE DESCRIPTION
APP-GW-GLR-115 R1.doc	MS Word	This report.

LEGAL REVIEW T. J. White	SIGNATURE / DATE (If processing electronic approval select option) T. J. White 10.6-08
PATENT REVIEW M. M. Corletti	SIGNATURE / DATE M. M. Corletti 10/6/08

ORIGINATOR(S) W. S. LaPay	SIGNATURE / DATE (If processing electronic approval select option) W. S. LaPay 10/03/2008	
REVIEWER(S) J. Parello	SIGNATURE / DATE James Parello 10/6/2008	
V. P. Prabhu	SIGNATURE / DATE PJ Kotowski FOR V. P. PRABHU 10/6/2008	
M. A. Ahmed	Mostafa A. Ahmed 10/6/08 (For Section 6.4)	
P. A. Guzmán	SIGNATURE / DATE Priscilla A. Guzmán 10/6/08	
VERIFIER(S) K. L. Coogler	SIGNATURE / DATE K L C 10/3/2008	Verification Method: Independent Review

Plant Applicability: ☒ All AP1000 plants except: No Exceptions
☐ Only the following plants:

APPLICABILITY REVIEWER** J. A. Speer	SIGNATURE / DATE [signature] 10/6/08
RESPONSIBLE MANAGER* L. J. Tunon-Sanjur	SIGNATURE / DATE L. Tunon-Sanjur 10/6/08

* Approval of the responsible manager signifies that the document and all required reviews are complete, the appropriate proprietary class has been assigned, electronic file has been provided to the EDMS, and the document is released for use.

Westinghouse Non-Proprietary Class 3

APP-GW-GLR-115
Revision 1

October 2008

AP1000 Standard Combined License Technical Report

Effect of High Frequency Seismic Content on SSCs

Revision 1

Westinghouse Electric Company LLC
Nuclear Power Plants
Post Office Box 355
Pittsburgh, PA 15230-0355

AP1000 RECORD OF CHANGES

Rev	Date	Revision Description
0	10/07	Original Issue
1	See EDMS	See Revision 1 Road Map that follows

Road Map of Changes from Rev. 0 to Rev. 1 for TR115 (APP-GW-GLR-115)

Item	Rev. 0 Section Number	Change in Rev. 1	Reason for Change
1	Introduction	1st, 5th, and last paragraphs modified; Tables 1.0-1 and 1.0-2 replaced	RAI-SRP3.7.1-SEB1-02
2	5.1 Adequacy of CSDRS and HRHF Response Spectra	Entire section modified; Table 5.1-1 through 5.1-3 inserted; Figures 5.1-1 to 5.1-3 inserted.	RAI-SRP3.7.1-SEB1-06
3	5.1 Adequacy of CSDRS and HRHF Response Spectra	Last paragraph modified; Figures 5.1-7 and 5.1-8 inserted.	RAI-SRP3.7.1-SEB1-08 Rev. 1
4	5.2 Comparison of CSDRS and HRHF Response Spectra	First paragraph modified; Figure 5.2-1 through 5.2-6 replaced.	RAI-SRP3.7.1-SEB1-10 Rev. 1
3	Table 6.1-1	Table replaced	RAI-SRP3.7.1-SEB1-14
4	Table 6.1-2	Table replaced	RAI-SRP3.7.1-SEB1-14
5	Table 6.1-3	Table replaced	RAI-SRP3.7.1-SEB1-14
6	Table 6.1-4	Table replaced	RAI-SRP3.7.1-SEB1-14
7	Table 6.1-5	Table replaced	RAI-SRP3.7.1-SEB1-14
8	Table 6.1-6	Table replaced	RAI-SRP3.7.1-SEB1-14
9	6.3 Piping Systems	1st sentence of 1st paragraph, "seismic response spectra" is replaced with "GMRS"	RAI-SRP3.12-EMB-03 Rev. 1
10	6.3 Piping Systems	2nd sentence of 1st paragraph, "seismic" replaced with "GMRS", AP1000 inserted before "CSDRS", "basis" removed	RAI-SRP3.12-EMB-03 Rev. 1

Item	Rev. 0 Section Number	Change in Rev. 1	Reason for Change
11	6.3 Piping Systems	2nd paragraph, 1st bullet, "floor response spectra" replaced with "GMRS" and "design spectra" replaced with "CSDRS"	RAI-SRP3.12-EMB-03 Rev. 1
12	6.3.1 Package Consideration	Last sentence of first paragraph replaced	RAI-SRP3.12-EMB-03 Rev. 1
13	6.3.1.1 Layout	"Packages without valves or concentrated..." added to end of paragraph	RAI-SRP3.12-EMB-03 Rev. 1
14	6.3.1.2 Review of Spectra	1st paragraph, "AP1000 CSDRS seismic..." removed, "in structure design" replaced with "the AP1000 CSDRS", last sentence replaced with "The elevations with..."	RAI-SRP3.12-EMB-03 Rev. 1
15	6.3.1.2 Review of Spectra	3rd paragraph replaced with "Packages below elevation..."	RAI-SRP3.12-EMB-03 Rev. 1
16	6.3.1.3 Modal Analysis	"system" removed from 1st paragraph, "Likewise" replaced with "Inversely" in 2nd paragraph	RAI-SRP3.12-EMB-03 Rev. 1
17	Table 6.3.1-1: Reviewed Lines	Reasons replaced for Direct Vessel Injection Line A, Direct Vessel Injection Line B, CMT 2B Supply Line, ADS 4th Stage East, Normal RHR Suction Line, Spent Resin from Cont. Pen., From SCV Pen. To CVS-12A0007, Hydrogen Supply from CVS-12A0022, Main Steam Line B, and From Cont. Pen. To past Valve V024	RAI-SRP3.12-EMB-03 Rev. 1
18	6.3.2.1 Automatic Depressurization System 4th Stage West and Passive RHR Supply (APP-PXS-PLA-030)	1st paragraph, Figures 6.3.2.1-1, 6.3.2.1-2, and 6.3.2.1-3, and last sentence of 2nd paragraph replaced.	RAI-SRP3.12-EMB-03 Rev. 1
19	6.3.2.2 Normal RHR Heat Exchanger Inlet and Outlet (APP-	1st and 2nd paragraphs replaced with "Figures 6.3.2.2-1 to 6.3.2.2-3 are plots of local..."; Figures 6.3.2.2-1, 6.3.2.2-2, and 6.3.2.2-3 replaced; last sentence of last	RAI-SRP3.12-EMB-03 Rev. 1

Item	Rev. 0 Section Number	Change in Rev. 1	Reason for Change
	RNS-PLA-170)	paragraph replaced.	
20	6.3.2.3 Analysis Method	Section replaced.	RAI-SRP3.12-EMB-03 Rev. 1
21	6.3.3 Results	Section removed.	RAI-SRP3.12-EMB-03 Rev. 1
22	6.3.3.1 Automatic Depressurization System Stage 4 West (APP-PXS-PLA-030)	1st paragraph modified, 2nd paragraph removed, 3rd and 4th paragraphs modified. Tables 6.3.3.1-1 and 6.3.3.1-2 replaced, new table inserted for 6.3.3.1-3, Tables 6.3.3.1-4, 6.3.3.1-5, 6.3.3.1-6, 6.3.3.1-7, and 6.3.3.1-8 replaced. Results summary at end of section replaced.	RAI-SRP3.12-EMB-03 Rev. 1
23	6.3.3.2 Normal RHR Heat Exchanger Inlet and Outlet between P19 and P20 (APP-RNS-PLA-170)	1st paragraph modified, 2nd paragraph removed, 3rd and 4th paragraphs modified. Tables 6.3.3.2-1 and 6.3.3.2-2 replaced, new table inserted for 6.3.3.2-3, Tables 6.3.3.2-4, 6.3.3.2-5, 6.3.3.2-6, 6.3.3.2-7, and 6.3.3.2-8 replaced. Results summary at end of section replaced.	RAI-SRP3.12-EMB-03 Rev. 1
24	6.3.4 Summary and Conclusions	Section replaced.	RAI-SRP3.12-EMB-03 Rev. 1

Table of Contents

List of Tables

List of Figures

1.0 Introduction

The purpose of this report is two fold: (1) to confirm that high frequency seismic input evaluated is not damaging to equipment and structures qualified by analysis for the AP1000 Certified Seismic Design Response Spectra (CSDRS); and (2) to demonstrate that normal design practices result in an AP1000 design that is safer and more conservative than that which would result if designed for the high frequency input evaluated.

The seismic analysis and design of the AP1000 plant is based on the Certified Seismic Design Response Spectra (CSDRS) shown in Figures 1.0-1 and 1.0-2. These spectra are based on Regulatory Guide 1.60 with an increase in the 25 hertz region. The CSDRS has its dominant energy content in the frequency range of 2 to10 Hz. For new sites, the Ground Motion Response Spectra (GMRS) is obtained from site-specific probabilistic hazard-based ground motion. Many of the GMRS of the Central and Eastern United States (CEUS) rock sites show higher amplitude at higher frequency than the CSDRS. These seismic response spectra, however, are associated with significantly less displacement and lower response spectra values in the low frequency (less than 10 Hz) range, and therefore are expected to be less damaging for plant structures and housed equipment than events with input motions having spectra similar to the Reg. Guide 1.60-based design spectra. The EPRI report *Program on Technology Innovation: The Effects of High-Frequency Ground Motion on Structures, Components, and Equipment in Nuclear Power Plants* (Reference 1.0-1) summarizes a significant amount of empirical and theoretical evidence, as well as regulatory precedents, which support the conclusion that such High Frequency (HF) motions are non-damaging to virtually all types of nuclear plant structures, systems, and components (SSCs).

Furthermore, it is the belief of much of the engineering community that high frequency vibration will be filtered out due to numerous nonlinear features in the plant design. It is also believed that the analytical high frequency seismic requirements inside the buildings are mainly theoretical rather than real. This is because many nonlinear details exist in equipment mounting configurations and piping support design details that are very difficult and impractical to simulate in finite element models.

Westinghouse agrees with the industry position that HF motions are non-damaging and thus offers in this report an evaluation of the AP1000 nuclear island for high frequency input based on the analysis of a representative sample of structures, components, supports, and piping to further demonstrate that the high frequency seismic response is non-damaging. The evaluation includes building structures, reactor pressure vessel internals, primary component supports, primary loop nozzles, piping, and electro-mechanical equipment.

A Hard Rock High Frequency (HRHF) spectrum has been developed that envelopes three hard rock sites for which Combined License applications using the AP1000 as the vendor design are being prepared. Figures 1.0-1 and 1.0-2 compare the HRHF at foundation level against the AP1000 CSDRS for both the horizontal and vertical directions for 5% damping. The HRHF exceeds the CSDRS for frequencies above about 15 Hz. Evaluations in this report are for Ground Motion Response Spectra (GMRS) with high frequency input.

This report describes the methodology and criteria used in the evaluation to confirm that high frequency input is not damaging to equipment and structures qualified by analysis for the AP1000 CSDRS. This report also demonstrates that the AP1000 envelopes any requirements that HF would impose. Thus, HF does not need to be considered explicitly in the design. It provides supplemental criteria for selection and testing of equipment whose function might be sensitive to high frequency. The HRHF GMRS provide an alternate set of spectra for evaluation of site specific GMRS. A site is acceptable if its site specific GMRS falls within the AP1000 HRHF GMRS. Therefore, a site is not considered acceptable without additional analyses if it does not fall within Figures 1.0-1 and 1.0-2. This report provides a summary of the analysis and applicable test results

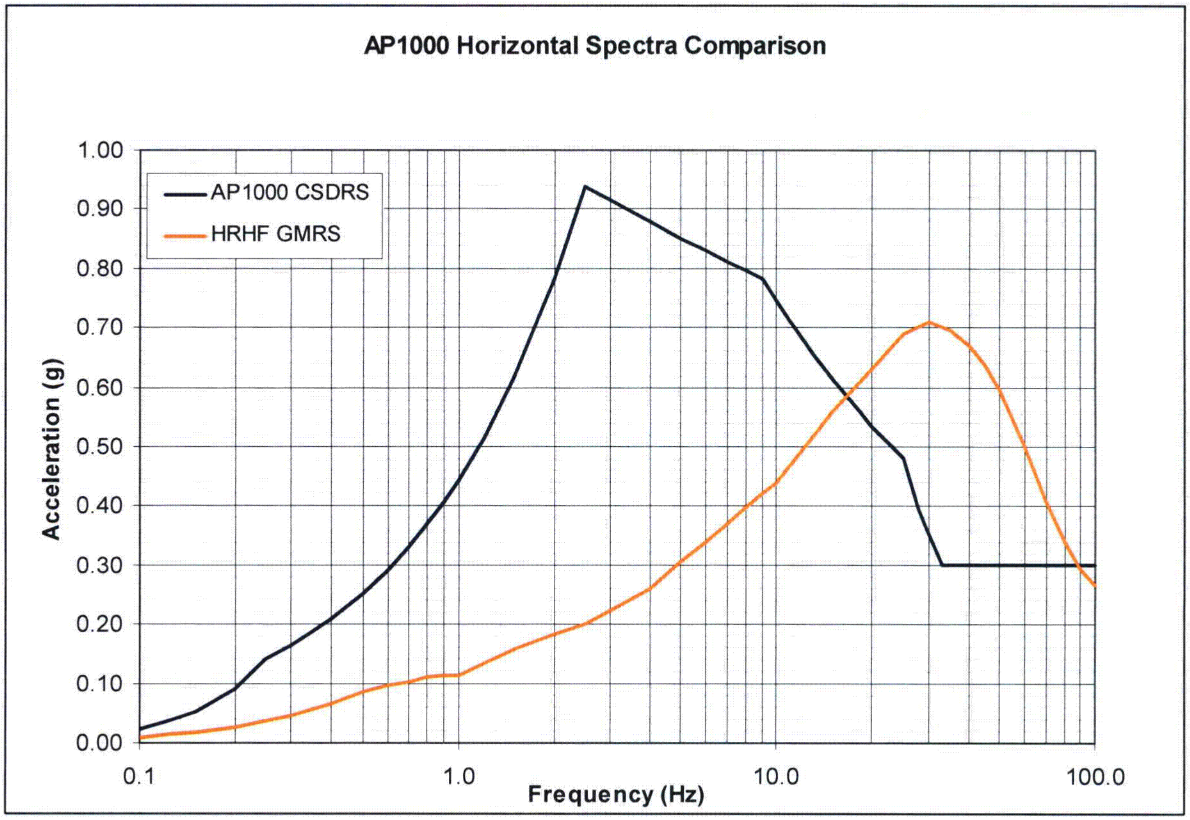


Figure 1.0-1: Comparison of the HRHF horizontal input spectra to the CSDRS

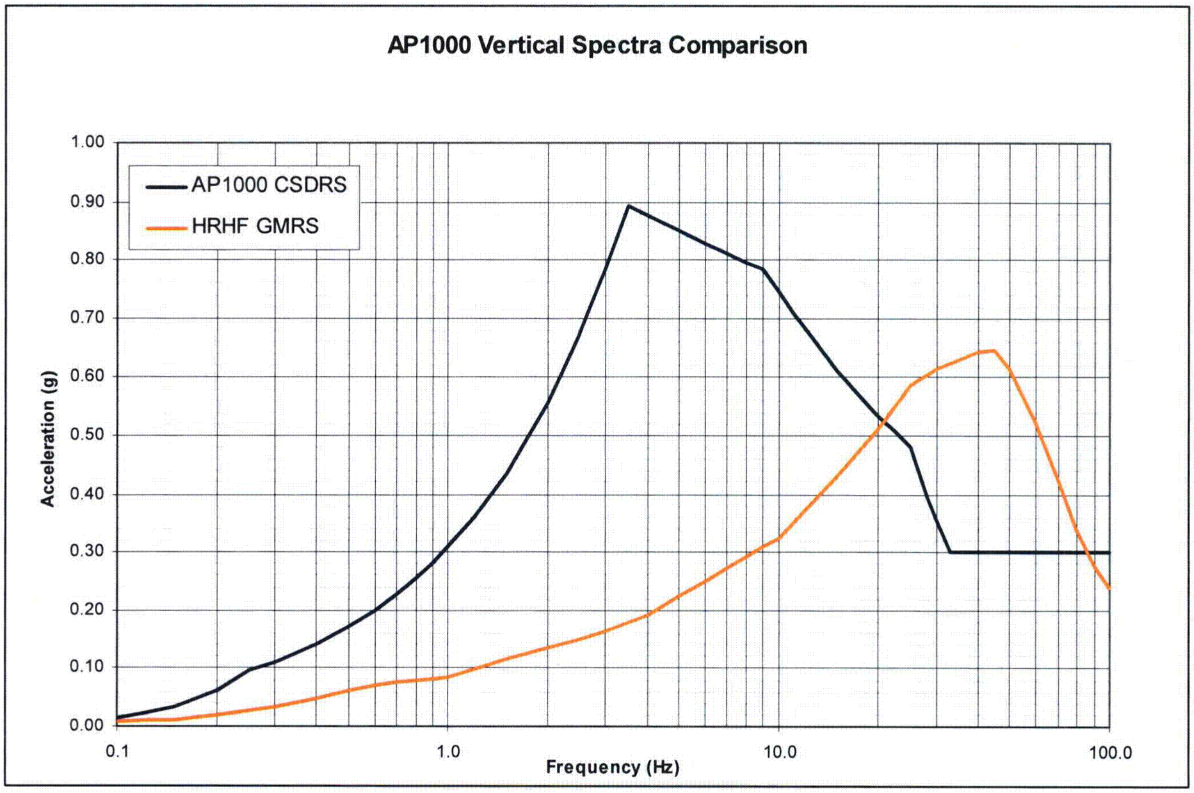


Figure 1.0-2: Comparison of the HRHF vertical input spectra to the CSDRS

2.0 High Frequency Seismic Input

Presented in Figures 1.0-1 and 1.0-2 is a comparison of the horizontal and vertical HRHF and the AP1000 CSDRS. The HRHF presented is calculated at foundation level (39.5' below grade) at the upper most competent material and treated as an outcrop for calculation purposes.

For each direction, the HRHF exceeds the design spectra in higher frequencies (greater than 15 Hz horizontal and 20 Hz vertical).

3.0 Evaluation Methodology

Demonstration that the AP1000 nuclear power plant design is not controlled by the high frequency seismic response does not require analysis of the total plant. The evaluations are made of representative systems, structures, and components that have been selected by screening as potentially sensitive to high frequency input in locations where there were exceedances in the high frequency region. Acceptability of this sample is considered sufficient to demonstrate that the AP1000 design is controlled by the CSDRS.

The high frequency seismic analyses used the soil structure interaction code ACS SASSI (Reference 3.0-1). The results presented in this report are based on the stochastic (multiple, statistical analyses) seismic incoherent soil structure interaction (SSI) analysis approach referred herein as the Simulation approach. The ACS SASSI incoherent SSI analysis includes the following computational steps:

a. Compute the free-field coherency matrix at interaction nodes

b. Perform spectral factorization of the coherency matrix (also checking its accuracy)

c. Use linear superposition of scaled spatial modes at each selected frequency (zero phases for Algebraic Sum (AS), and a set of simulated random phases for Simulation)

d. Compute Transfer Functions (TF), including interpolation error smoothing to avoid spurious peaks (smoothing parameter was selected as SP=50 after a parametric SSI study)

e. Adjust TF phases to avoid canceling wave phase effects (default option)

f. Perform convolution of complex TF with input control motion Fast Fourier Transform (FFT)

g. Compute acceleration time histories at selected structural nodes by inverse FFT

h. Compute ISRS (In-Structure Response Spectra) from acceleration time histories at selected structural nodes

i. If Simulation is used, the mean SSI response is computed by statistical averaging of the individual SSI responses computed for the simulated random phase samples

The evaluations performed assess the ability of the system, structure, or component to maintain its safety function.

Supplementary analyses could have been performed as needed to show that high frequency floor response spectra exceedances are not damaging. These analyses include: gap nonlinearities and material inelastic behavior. These supplementary analyses were not necessary for the analyses reported herein. Tests on equipment are specified as needed where function cannot be demonstrated by analysis, or analysis is not appropriate.

4.0 General Selection Screening Criteria

The following general screening criteria are used to identify representative AP1000 SSCs for samples to be evaluated to demonstrate acceptability of the AP1000 nuclear power plant for the high frequency motion.

- Select systems, structures, and components based on their importance to safety. This includes the review of component safety function for the Safe Shutdown

Earthquake (SSE) event and its potential failure modes due to an SSE. Those components whose failure modes do not impact the ability to achieve safe shutdown are excluded.

- Select systems, structures, and components that are located in areas of the plant that are susceptible to large high frequency seismic inputs.

- Select systems, structures, and components that have significant modal response within the region of high frequency amplification. Significance is defined by such items as: modal mass, participation factor, stress and/or deflection.

- Select systems, structures, and components that have significant total stress as compared to allowable, when considering load combinations that include seismic.

5.0 Comparison of HRHF Floor Response Spectra

5.1 Adequacy of CSDRS and HRHF Response Spectra

The adequacy of the NI20 model is demonstrated by:

1. Mesh size is adequate to transmit the high frequency through the finite elements
2. Close comparison to NI10 results

The NI20 (~20' finite element mesh size) model is used to develop the HRHF response spectra using the finite element program SASSI. For a concrete of 4000 psi with a poisson's ratio (υ) of approximately 0.17, the shear modulus of elasticity (G) is 221,846 ksf.

$$G = \frac{57400\sqrt{fc'}}{2(1+\nu)}$$ Where *fc'* is Concrete stress in psi

The shear wave velocity (V_s) is 6900 ft/sec for the concrete density of 0.15 ksf.

$$V_s = \sqrt{\frac{G}{\rho}}$$ ρ is mass density

For a maximum analysis frequency (f_{max}) of 50 Hz which must transmit through the finite elements, the shortest wavelength (λ) is 138 ft.

$$\lambda = \frac{V_s}{f_{\max}}$$

Approximately 7 (6.9) nodes per wavelength are available for a mesh size of 20', and this is adequate to transmit the high frequency through the finite elements in the NI20 model. A portion of the NI20 model has an element mesh size of ~ 10' for the Containment and Internal Structure (CIS).

In addition to the above, a modal response comparison is made between the NI10 and NI20 models to demonstrate the adequacy of the NI20 model to predict high frequency response up to 50 hertz.

Table RAI-SRP3.7.1-SEB1-06-1 shows the comparison of the frequency for each model at certain modes. Due to the increased refinement of the NI10 model, the NI20 reaches higher frequencies at lower modes. This is also shown in Tables RAI-SRP3.7.1-SEB1-06-2 and RAI-SRP3.7.1-SEB1-06-3. Tables RAI-SRP3.7.1-SEB1-06-2 and RAI-SRP3.7.1-SEB1-06-3 show the highest numbered mode found in each 10 Hz frequency range and also shows how many modes are in each of the aforementioned ranges.

Figures RAI-SRP3.7.1-SEB1-06-1 to RAI-SRP3.7.1-SEB1-06-3 show a summation of the of the effective mass verses frequency for the X, Y and Z directions. The effective masses associated with the NI20 and NI10 models compare closely over the frequency range of 1 to 80 Hz.

From this comparison it can be concluded that the modal response of the NI20 model is very similar to the NI10 model, and therefore, is adequate to predict the high frequency response up to 50 hertz. A comparison between the fine mesh (NI10) model used for design and the NI20 model shows the adequacy of the NI20 model to represent building responses. This comparison is shown in Figures 5.1-1 to 5.1-8 (5% damping). The response spectra from the two models compare closely, with the response spectra from the NI20 being slightly more conservative in most cases. Figures 5.1-1 to 5.1-3 compare results from the ANSYS. Figures 5.1-7 and 5.1-8 compare results from ANSYS and SASSI.

Table 5.1-1: Mode Number vs. Frequency

Mode	Ni20	Ni10
50	9.29	8.29
100	14.05	12.47
150	16.81	14.83
200	20.27	16.73
250	22.61	18.69
300	24.82	21.00
350	26.97	22.37
400	28.72	23.48
450	30.59	24.49
500	32.39	25.37
550	34.23	26.13
600	35.84	26.71
650	37.52	27.48
700	39.38	28.59
750	41.15	29.87
800	42.81	30.96
850	44.34	32.19
900	45.85	33.48
950	47.41	34.48
1000	48.86	35.44
1050	50.10	36.18
1100	51.72	36.99
1150	53.10	37.78
1200	54.55	38.37
2000	N/A	58.8127

Table 5.1-2: Modes Per Range (NI10)

NI10		
Frequency Range	**Max Mode in**	**Modes Per Range**
0-10	69	69
10-20	277	208
20-30	755	478
30-40	1303	548
40-55	1848	545

Table 5.1-3: Modes Per Range (NI20)

NI20		
Frequency Range	**Max Mode in**	**Modes Per Range**
0-10	58	58
10-20	193	135
20-30	434	241
30-40	716	282
40-55	1200	484

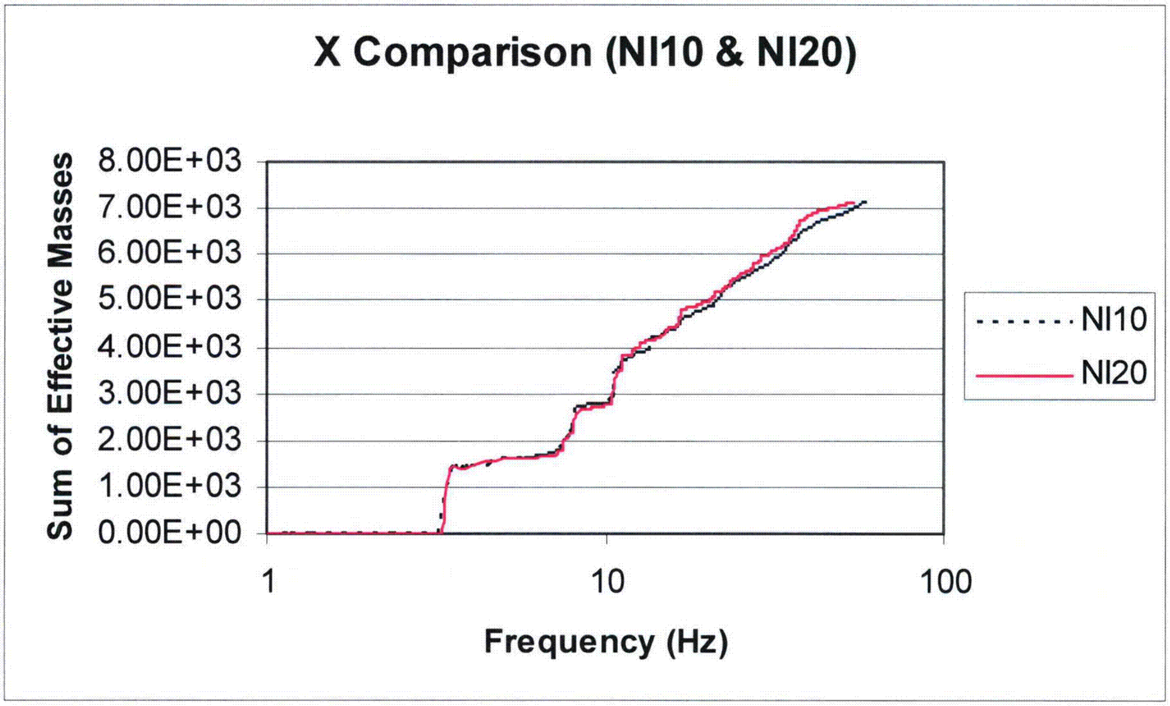


Figure 5.1-1: X-Direction Comparison

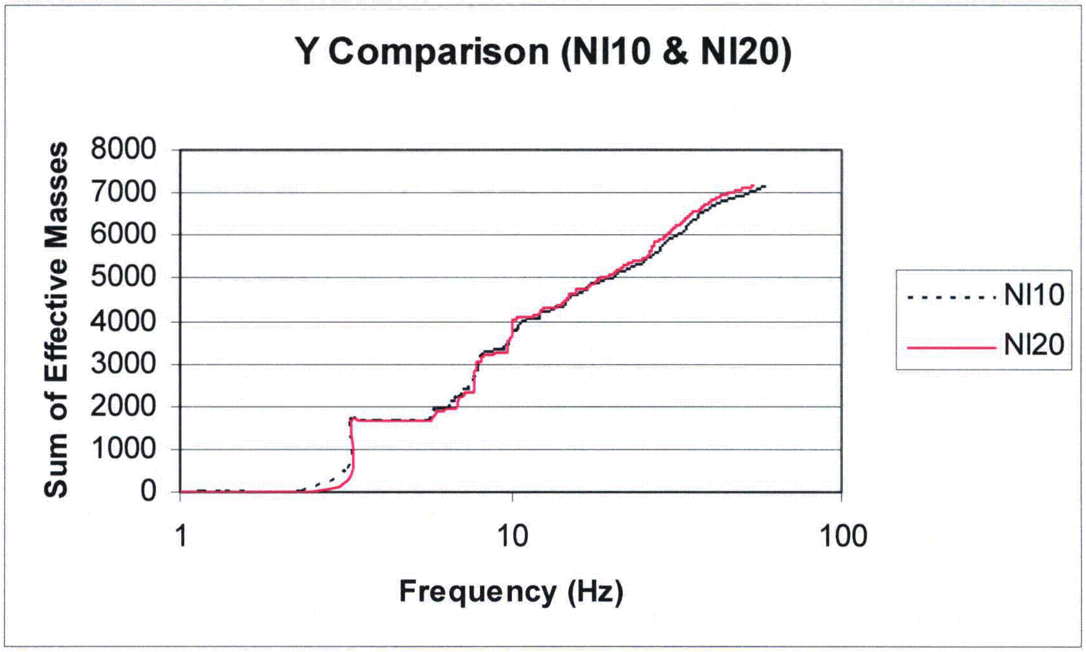


Figure 5.1-2: Y-Direction Comparison

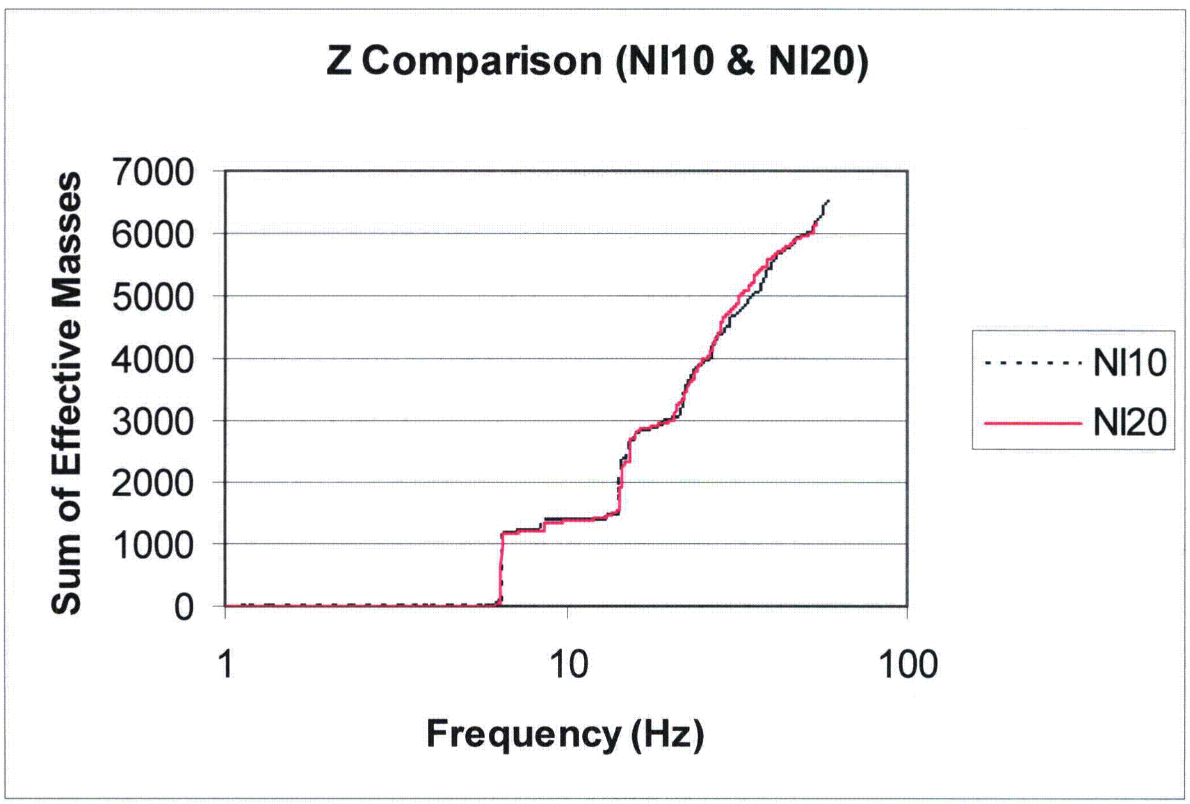


Figure 5.1-3: Z-Direction Comparison

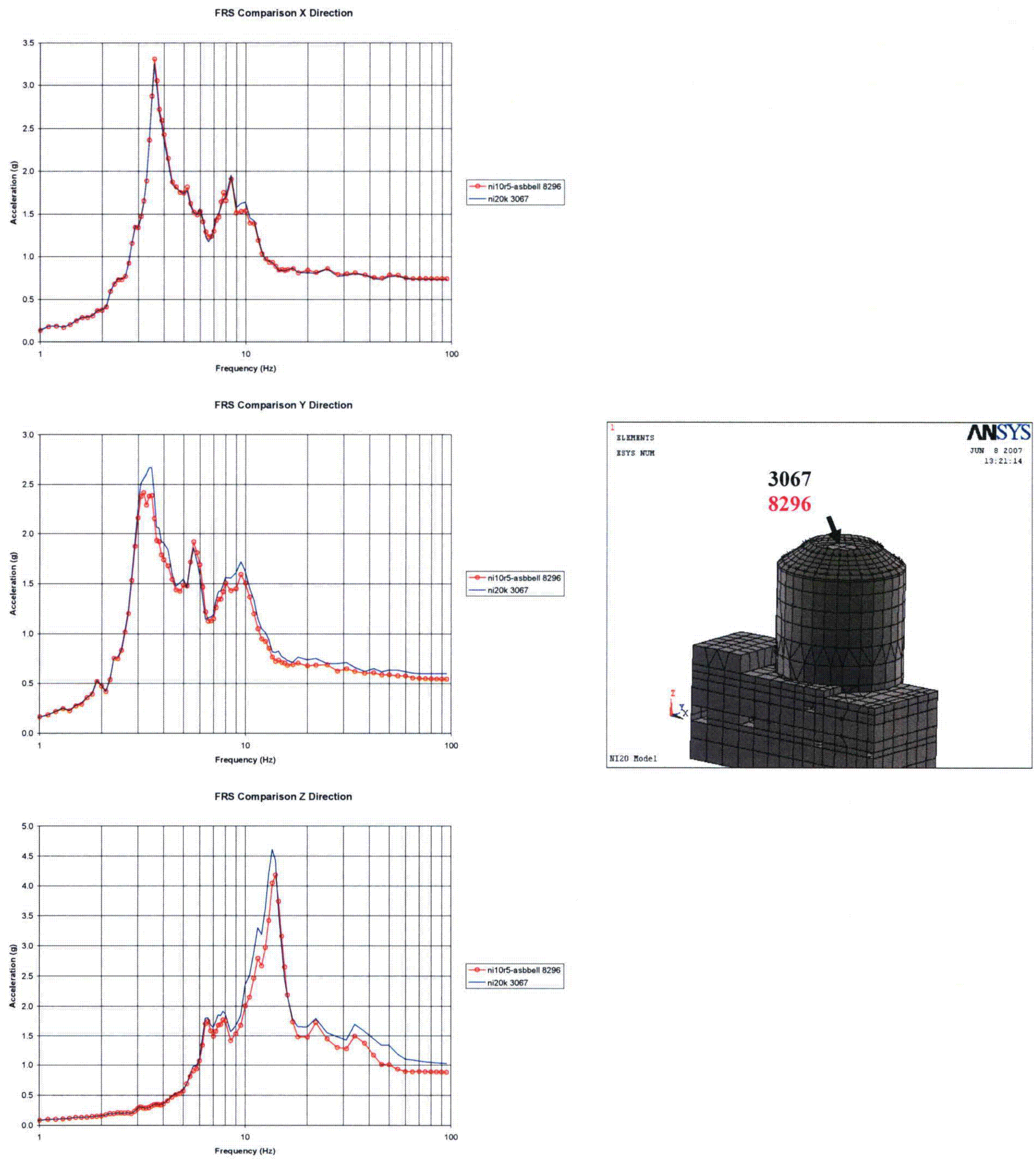


Figure 5.1-4: Comparison of NI20 and NI10 Seismic Response Spectra on roof of Shield Building

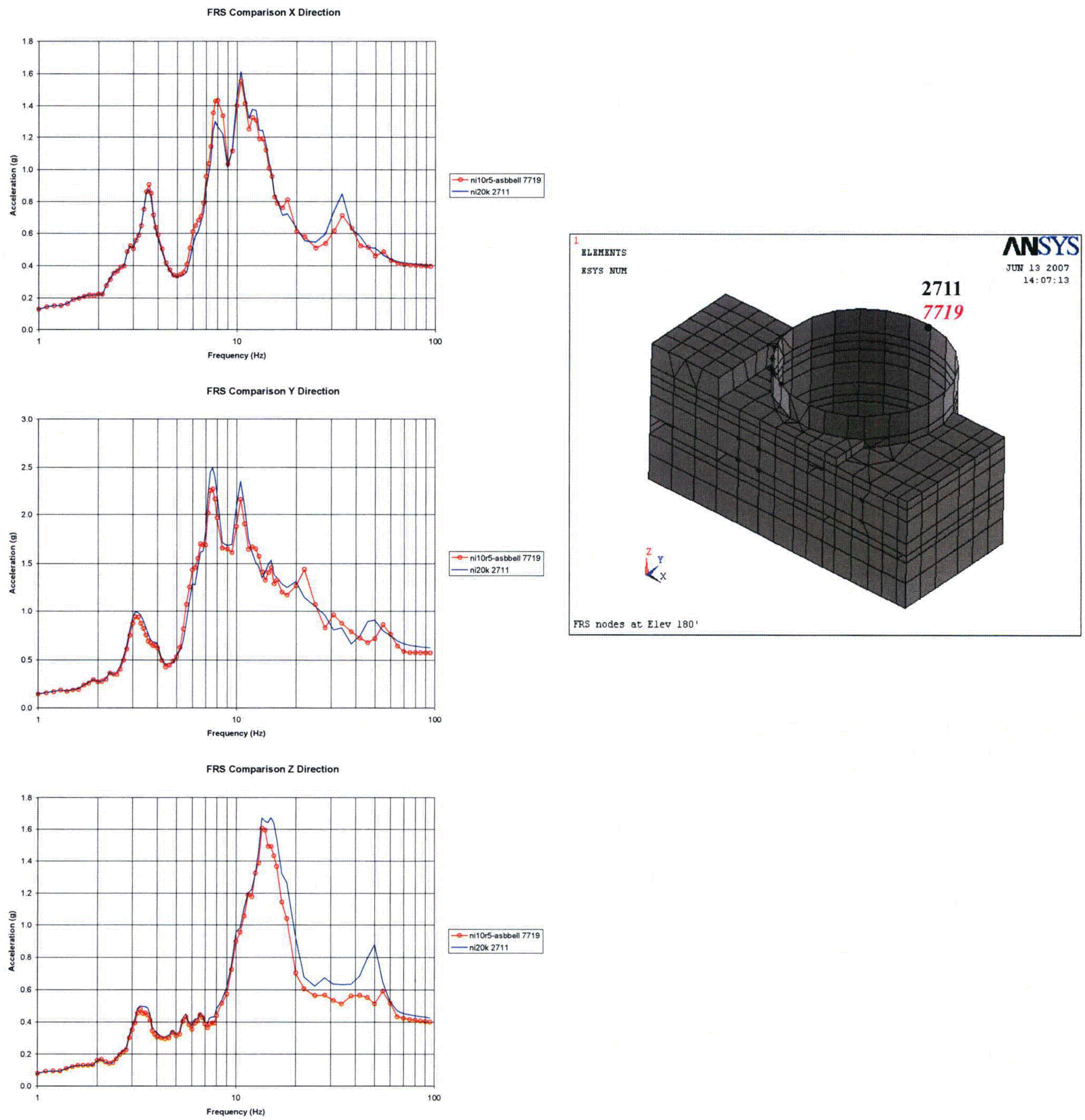


Figure 5.1-5: Comparison of NI20 and NI10 Seismic Response Spectra for West Side of Shield Building

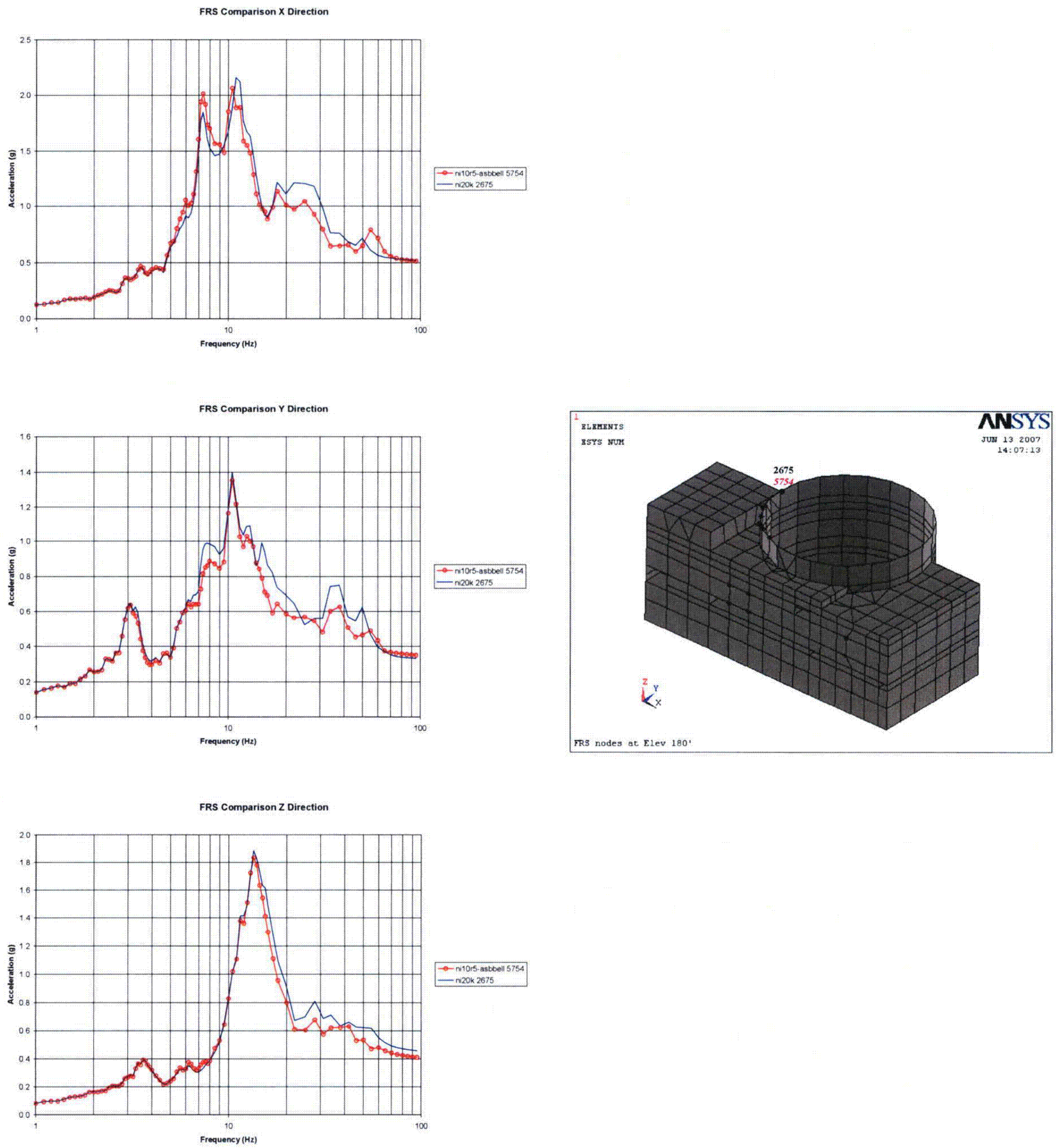


Figure 5.1-6: Comparison of NI20 and NI10 Seismic Response Spectra of South Side of Shield Building

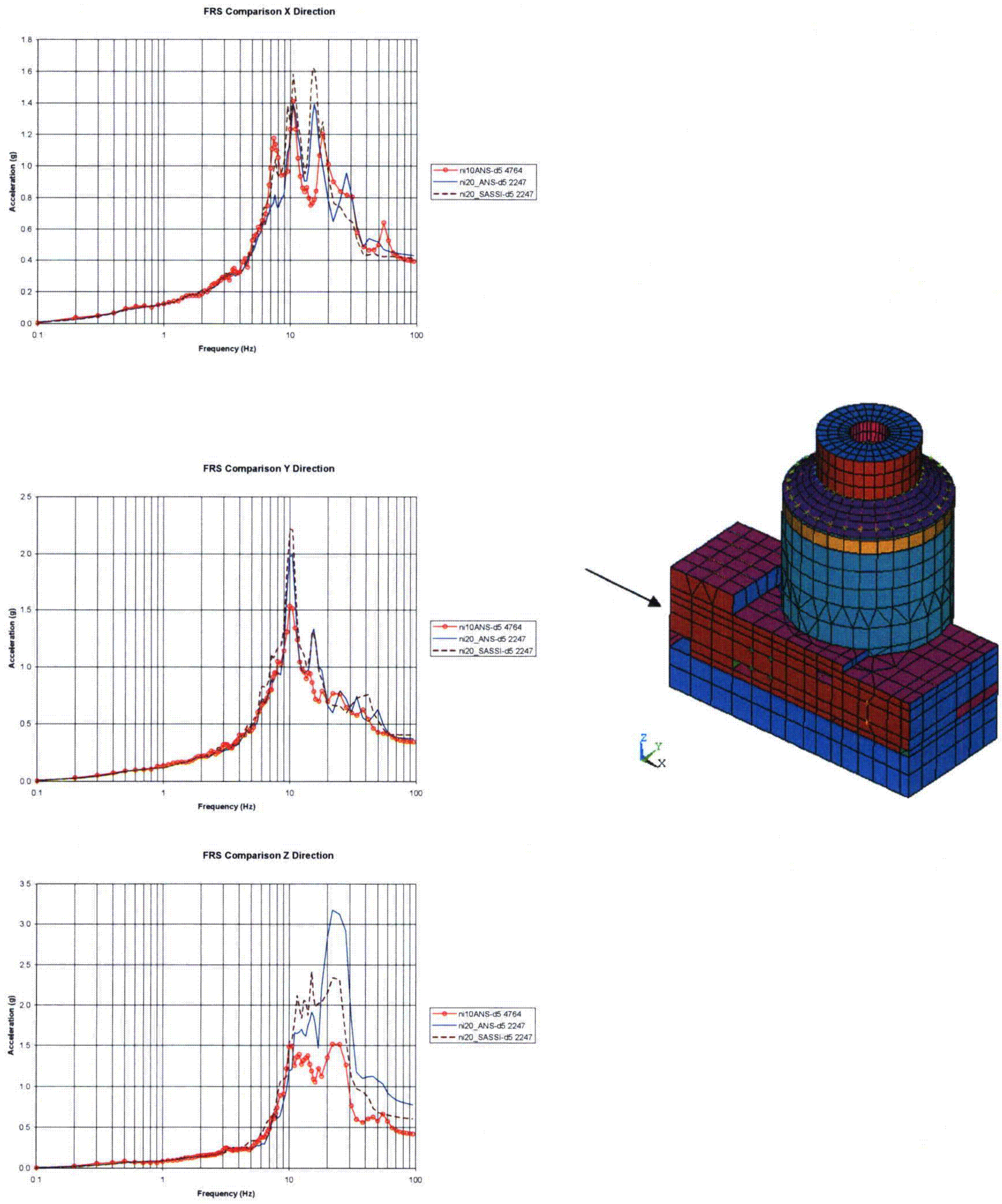


Figure 5.1-7: Comparison of NI20 and NI10 Seismic Response Spectra at Southeast Corner of Auxiliary Building at Elevation 135'

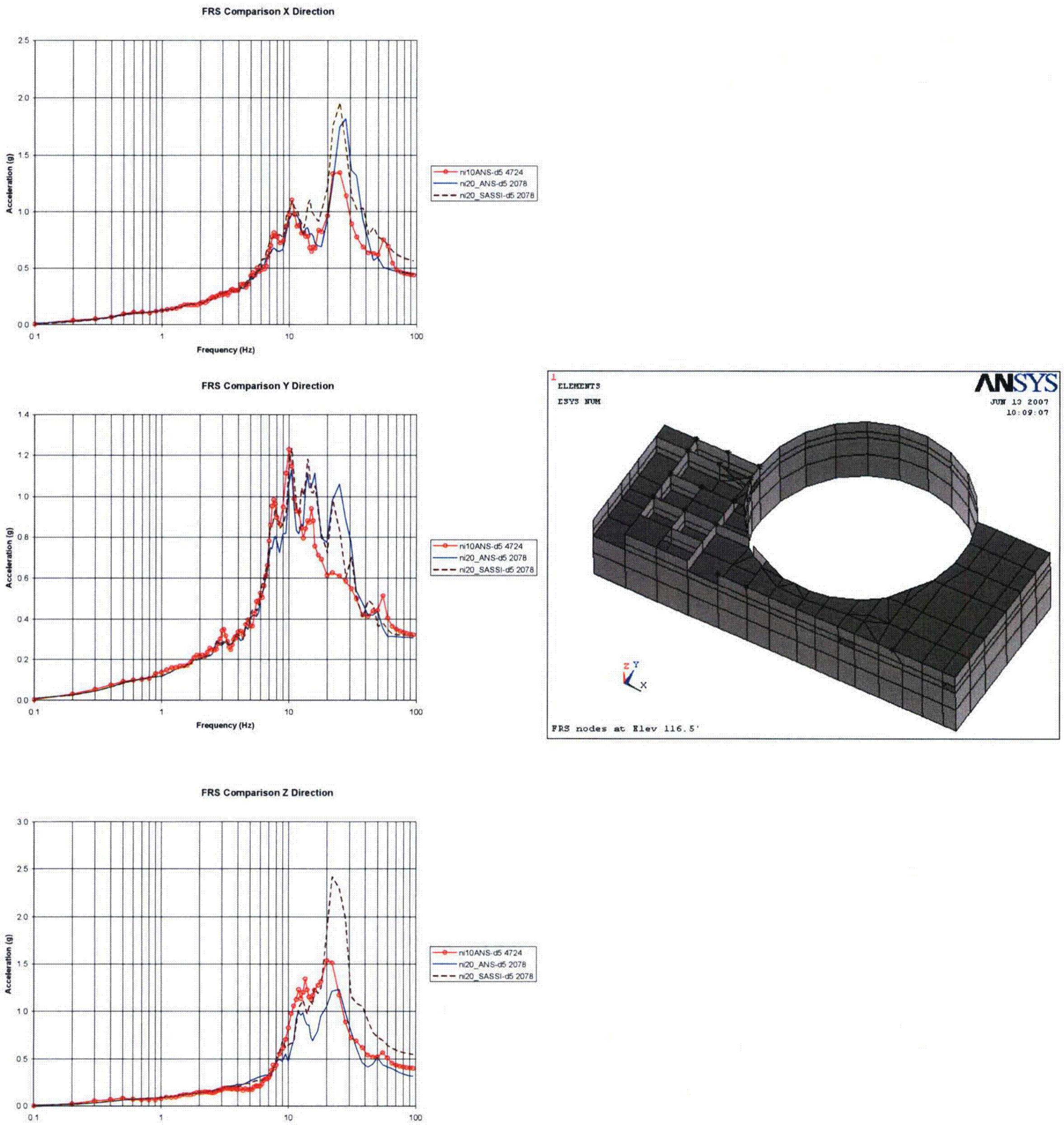


Figure 5.1-8: Comparison of NI20 and NI10 Seismic Response Spectra at Northeast Corner of Auxiliary Building at Elevation 116.5'

5.2 Comparison of CSDRS and HRHF Response Spectra

To show the significance of the HRHF response spectra, the CSDRS and HRHF seismic responses are compared. Figures 5.2-1 through 5.2-6 (5% damping) compare the response spectra with coherent and incoherent considerations at a number of locations in the nuclear island. There are some exceedances, mostly above the 15 Hz region. These curves are typical of the plant comparative responses found throughout the plant.

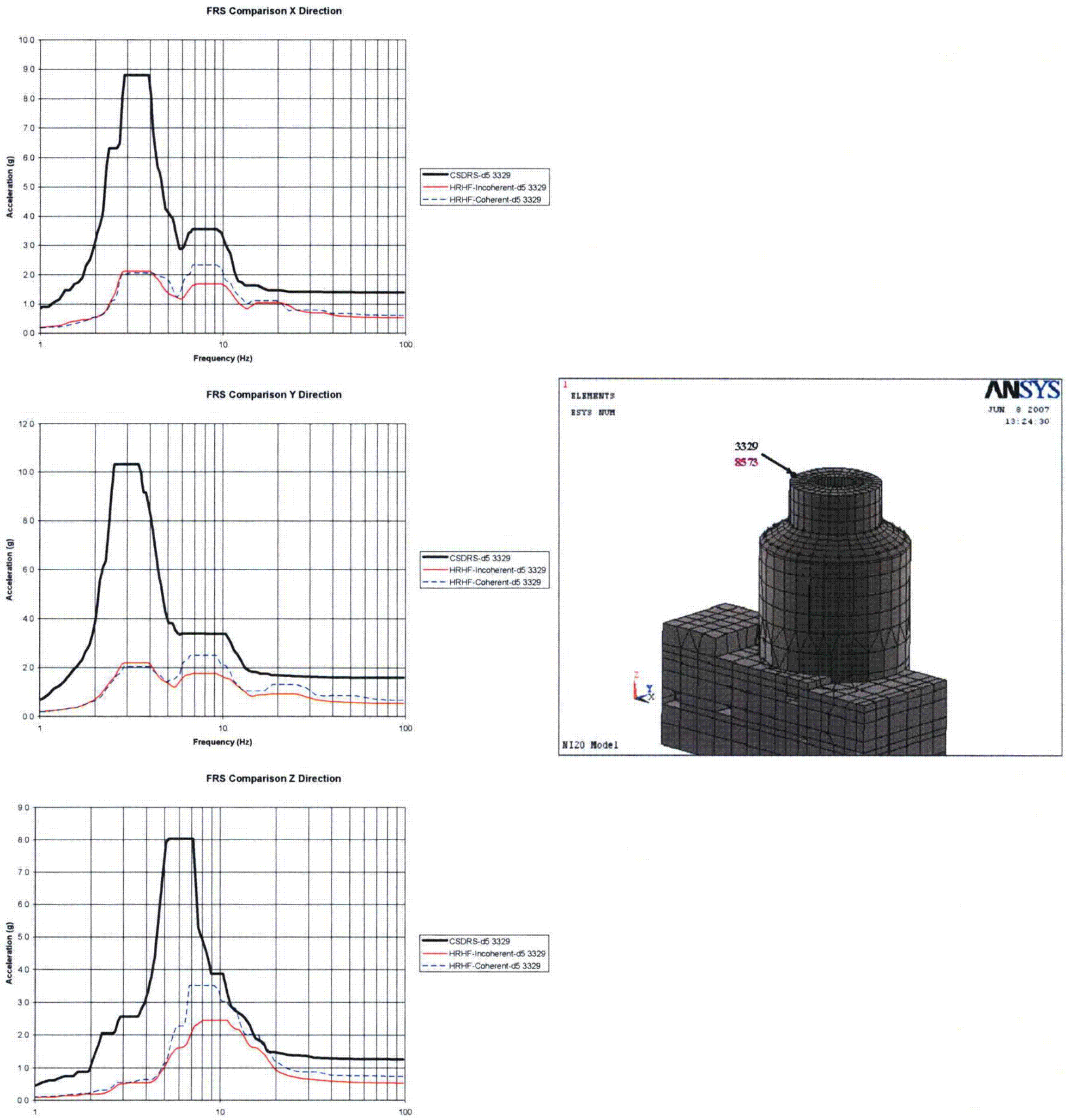


Figure 5.2-1: ASB at Elevation 327.4'

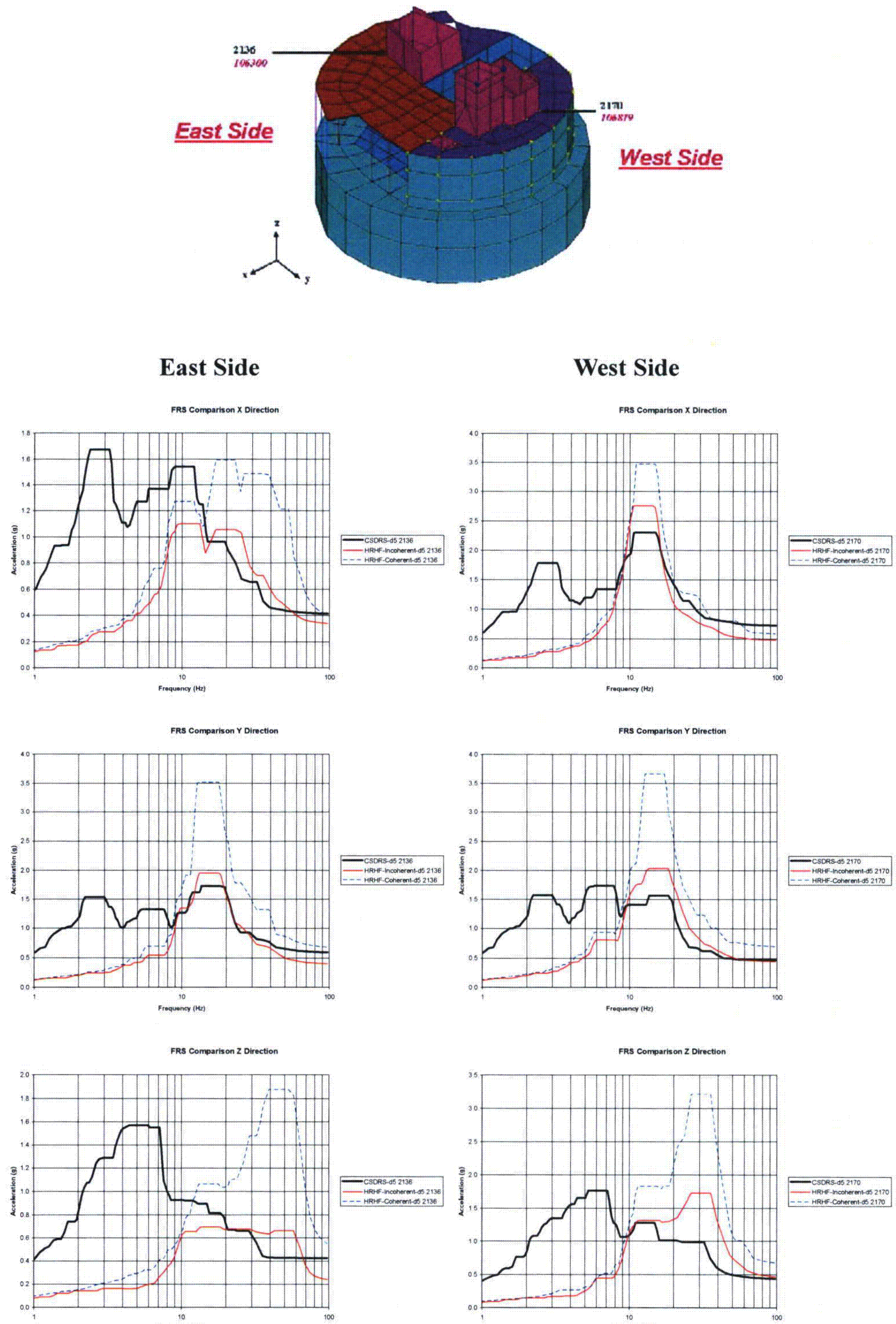


Figure 5.2-2: Containment Operating Floor (Elevation 134.25')

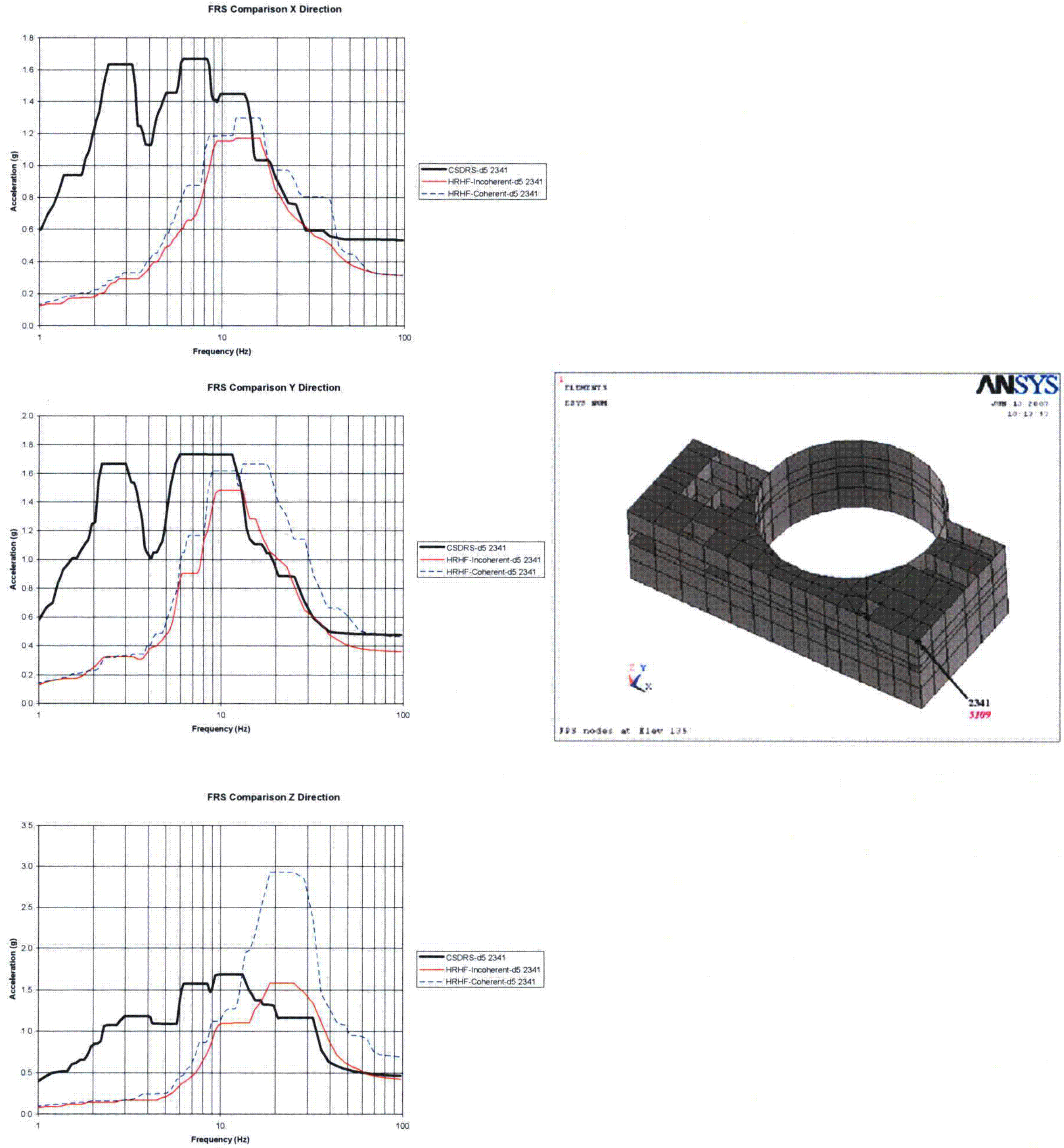


Figure 5.2-3: ASB at Northeast Corner (Elevation 134.5')

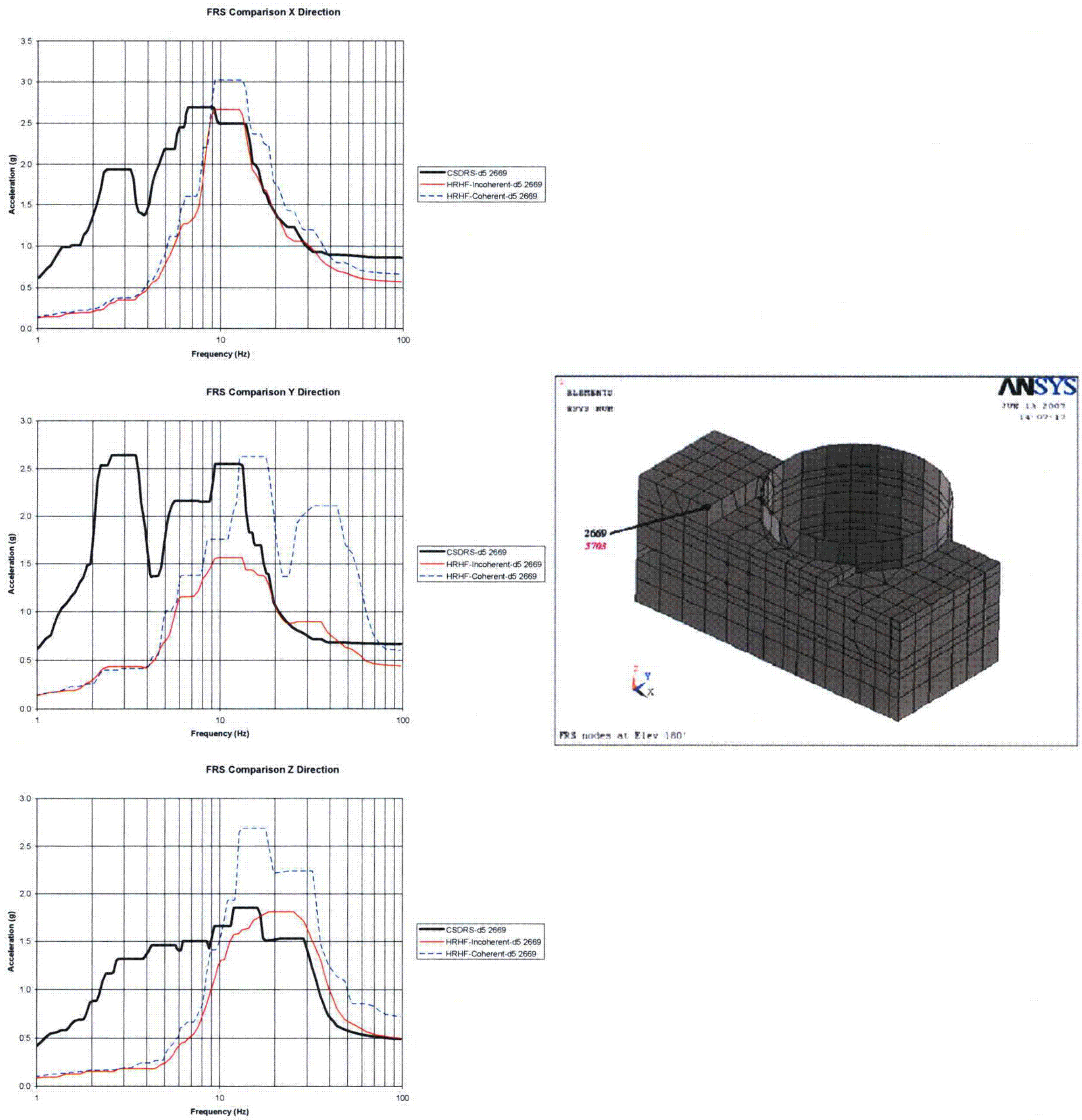
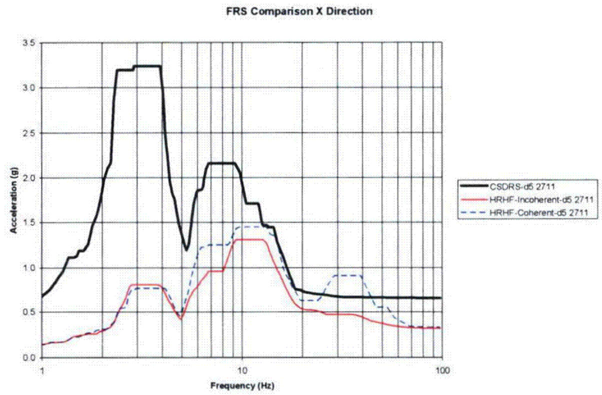
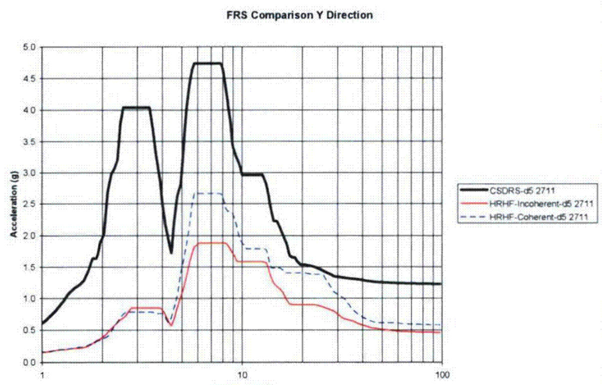
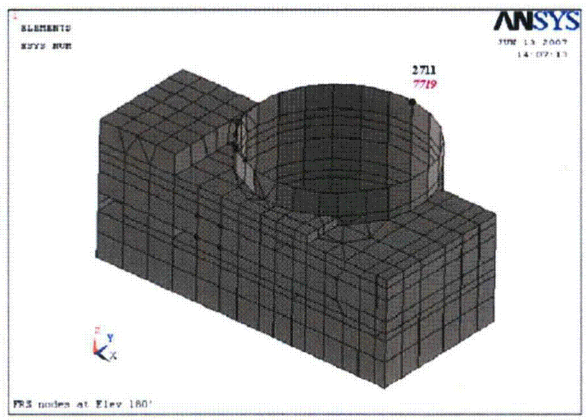


Figure 5.2-4: ASB at Fuel Building Roof (Elevation 179.56')







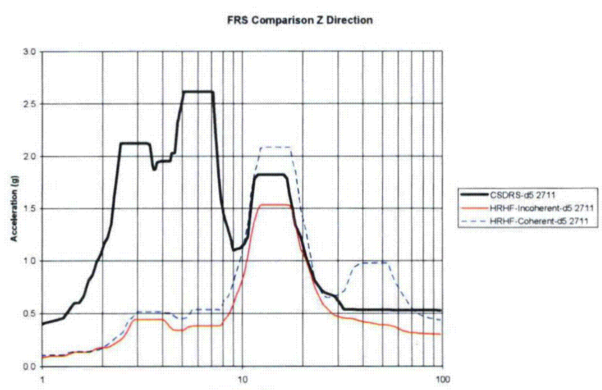


Figure 5.2-5: FRS Nodes – Elevation 180'

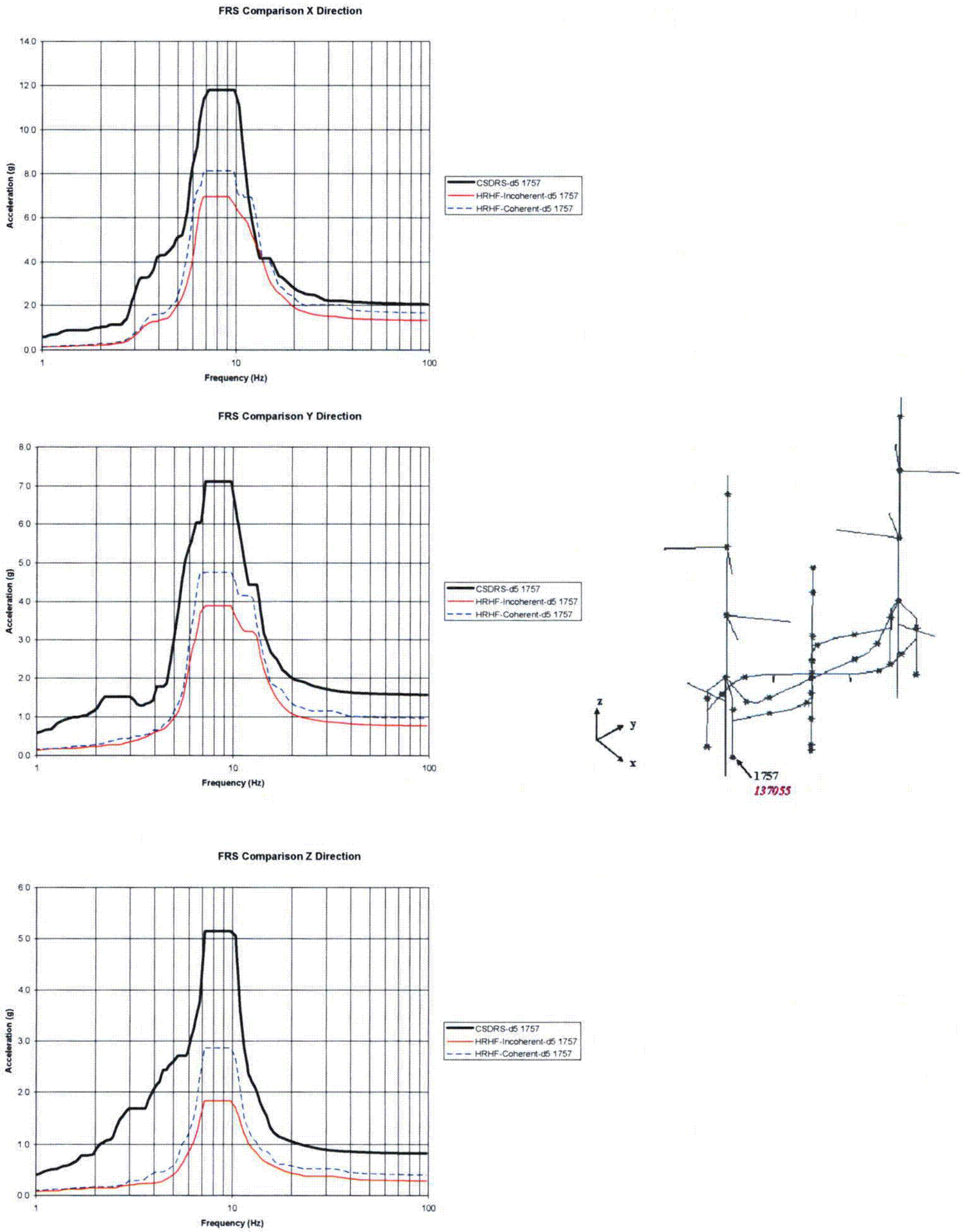


Figure 5.2-6: Reactor Coolant Pump

6.0 Evaluation

Identified in this section are the portions of structures, components, and systems that are evaluated for high frequency seismic response. Based on the screening criteria applicable to the SSCS, the sample to be evaluated consists of the following:

- Building Structures
  - Auxiliary Building
  - Shield Building
  - Containment Internal Structures (CIS)
- Primary Equipment
  - Reactor Internals
  - Primary Component Supports
  - Reactor Coolant Loop Primary Equipment Nozzles
- Piping Systems – at least two piping analysis packages that might be susceptible to high frequency
- Electro-Mechanical Equipment – Equipment that is potentially sensitive to high frequency input (see Table 6.4.6-1)

These structures, components, and systems are discussed in more detail in the sections that follow.

6.1 Building Structures

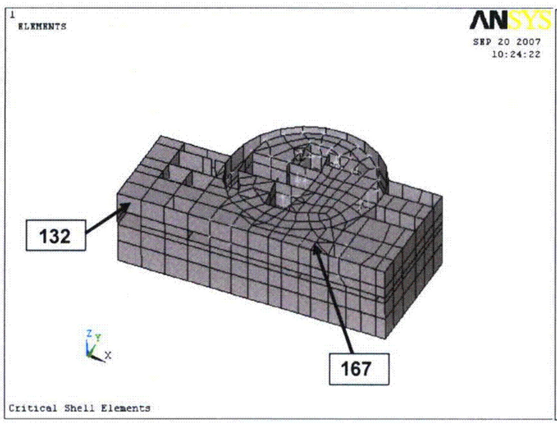
Maintaining the NI buildings' structural integrity is important to the safety of the plant. Representative portions of the buildings that were evaluated for the effect of high frequency input are selected based on the areas that can experience high seismic shear and moment loads due to the seismic event.

Three locations in the Auxiliary Building were selected for comparison and shown in Figure 6.1-1. These locations represent the bottom of a wall where the shear would be large (element 1342), a wall in the vicinity of a floor that is influenced by high frequency response (element 167), and a corner intersection of walls (element 132).

Eight locations were evaluated on the Shield Building and are shown in Figures 6.1.-2 and 6.1-3. There are four at elevation 107' and four at elevation 211'. These locations are located on the east, west, north, and south sides.

Three areas within Containment Internal Structures were compared and shown in Figures 6.1-4 through 6.1-6. The southwest wall of the refueling canal (Figure 6.1-4) was evaluated since it is a representative wall on the refueling canal. The west wall of the steam generator (Figure 6.1-5) was evaluated because it receives contributions from both the steam generator lateral support and the refueling canal. The CA02 wall (Figure 6.1-6) was evaluated since it is a representative wall associated with the IRWST.

The evaluation consisted of a comparison of the loads from high frequency input to those obtained from the AP1000 design spectra, shown in Figures 1.0-1 and 1.0-2, for the representative building structures. The NI building structures are considered qualified for the high frequency input if the seismic loads from the CSDRS envelope those from the high frequency input. Tables 6.1-1 through 6.1-6 compare the member forces (TX, TY and TXY) for elements shown in Figures 6.1-1 through 6.1-6. The element solutions for the upper portion southwest steam generator wall are grouped and the maximum member forces are reported in Table 6.1-5. The comparisons show that seismic loads from CSDRS enveloped those from the high frequency input.



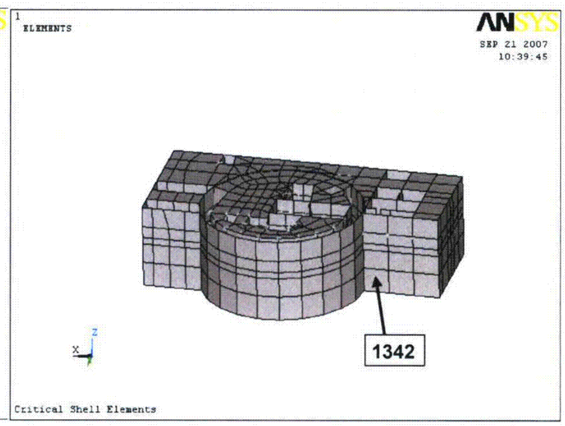


Figure 6.1-1: Auxiliary Building Critical Shell Elements

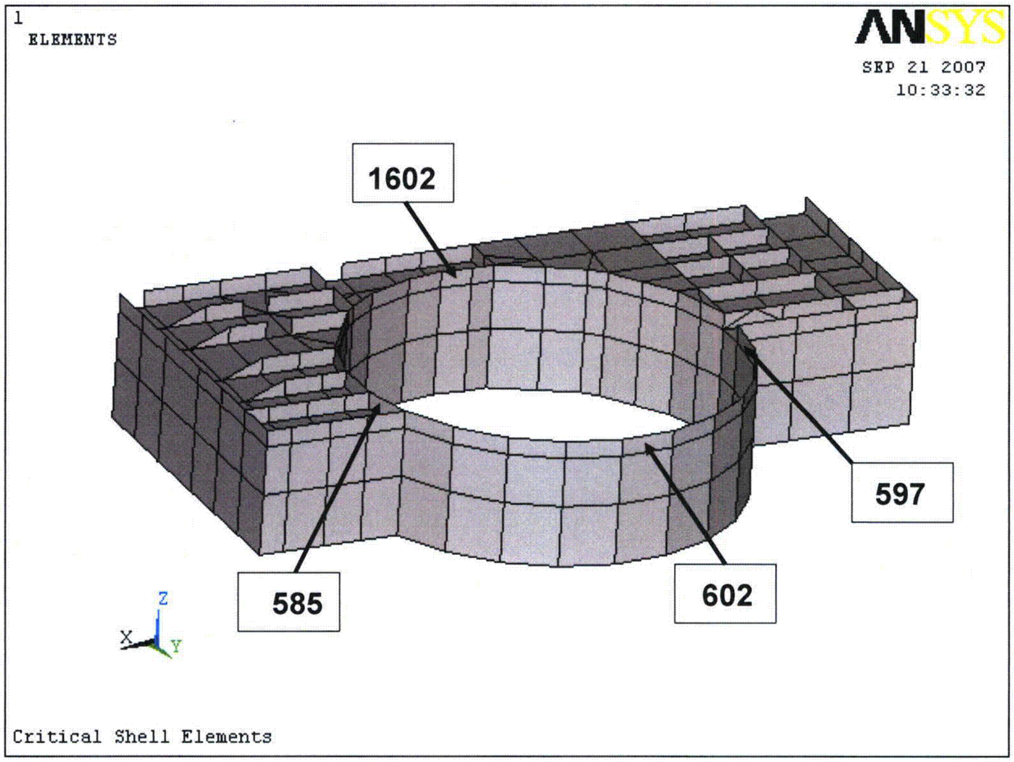


Figure 6.1-2: Shield Building Critical Shell Elements

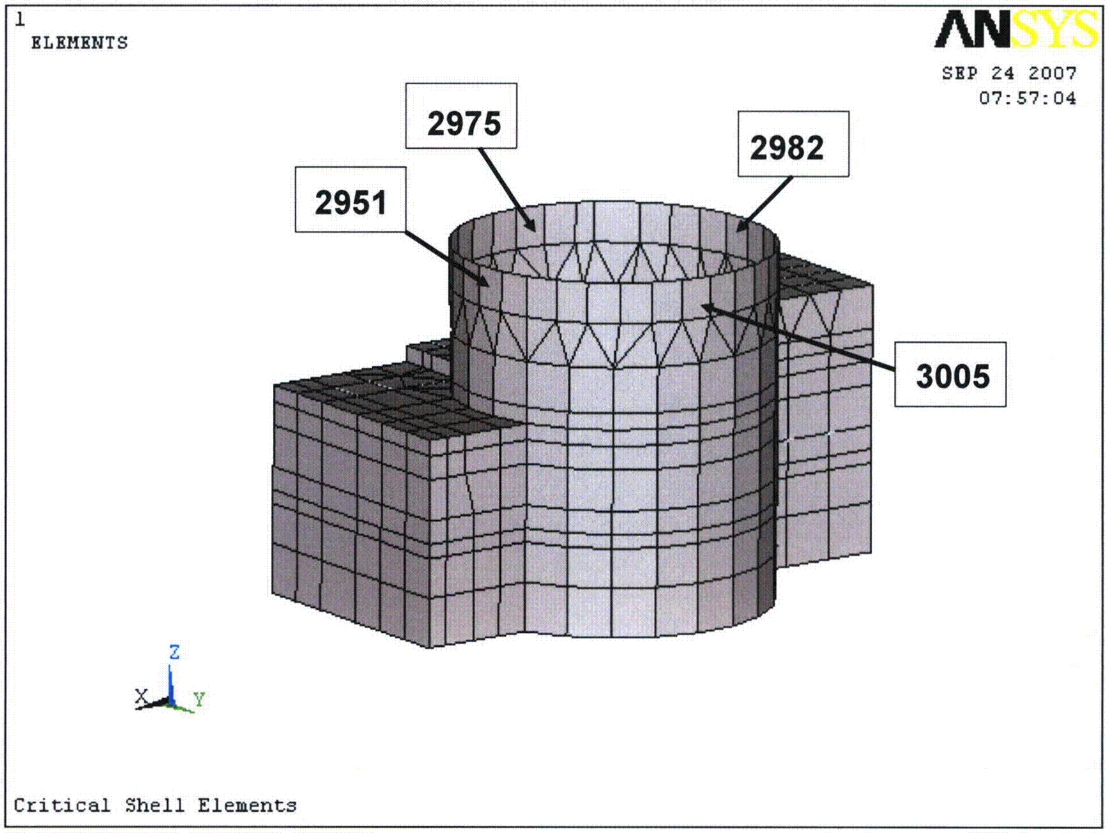


Figure 6.1-3: Shield Building Critical Shell Elements

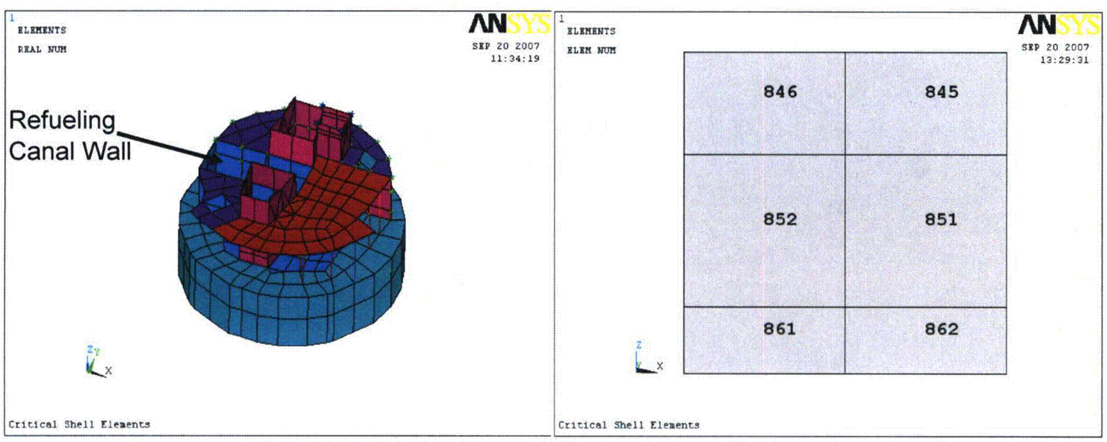


Figure 6.1-4: Refueling Wall Shell Elements

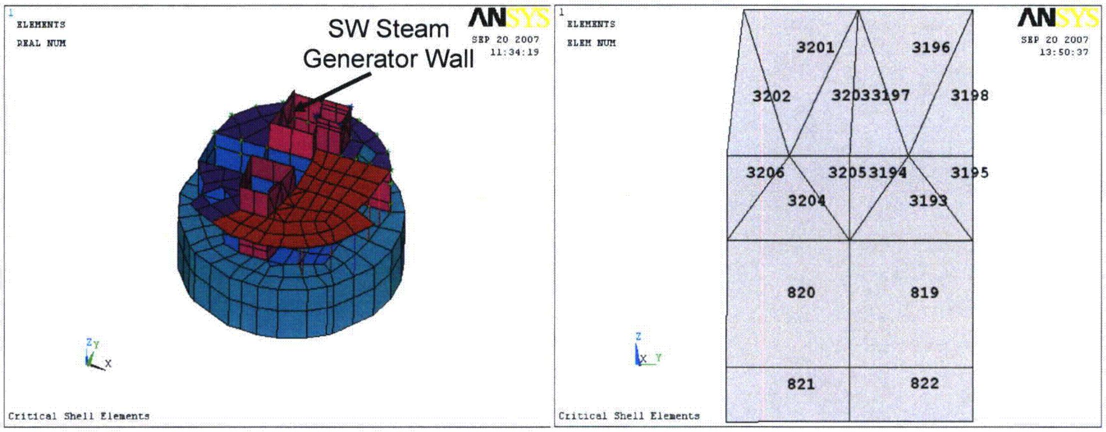


Figure 6.1-5: SW Steam Generator Wall Shell Elements

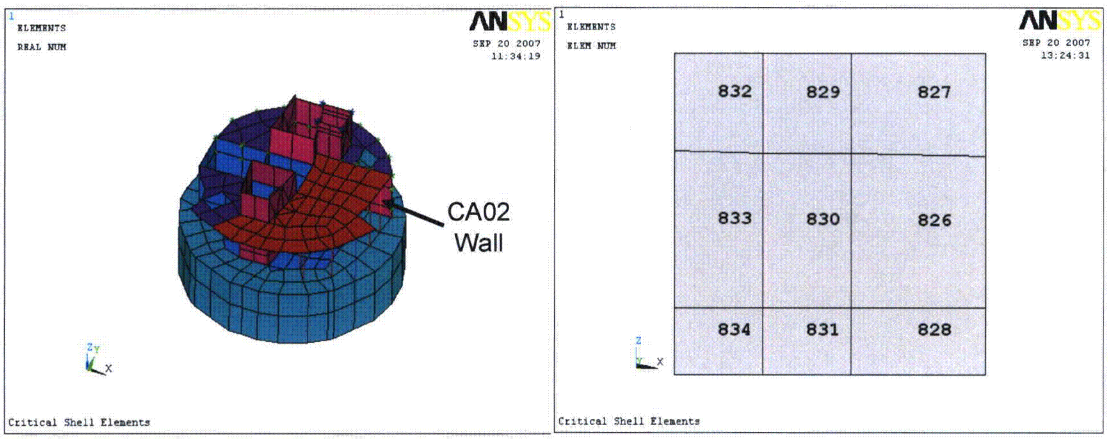


Figure 6.1-6: CA02 Wall Shell Elements

Table 6.1-1: Auxiliary Building Time History Member Force Comparison

	HRHF (kips/ft)			CSDRS (kips/ft)		
Element #	TX	TY	TXY	TX	TY	TXY
132	9.2	16.5	10.3	18.8	35.8	26.7
167	2.4	40.1	34.9	4.0	151.4	136.6
1342	27.0	50.2	32.0	68.5	149.6	59.9

Table 6.1-2: Shield Building Time History Member Force Comparison

	HRHF (kips/ft)			CSDRS (kips/ft)		
Element #	TX	TY	TXY	TX	TY	TXY
585	8.2	53.2	46.1	20.9	163.2	136.0
597	23.7	69.8	49.4	63.2	254.1	131.1
602	18.5	120.4	59.1	62.9	448.6	221.3
1602	13.1	75.6	23.0	43.8	281.0	53.2

Table 6.1-3: Shield Building Time History Member Force Comparison

	HRHF (kips/ft)			CSDRS (kips/ft)		
Element #	TX	TY	TXY	TX	TY	TXY
2951	14.9	49.9	43.8	36.8	196.8	150.2
2975	13.2	45.9	49.2	38.4	157.3	157.4
2982	18.4	55.8	45.3	70.5	222.3	157.4
3005	14.6	49.9	33.4	65.5	164.2	115.6

Table 6.1-4: Refueling Wall Time History Member Force Comparison

	HRHF (kips/ft)			CSDRS (kips/ft)		
Element #	TX	TY	TXY	TX	TY	TXY
845	4.5	7.5	19.4	13.4	24.1	44.2
846	4.2	4.9	14.4	17.3	16.1	31.1
851	7.7	10.2	23.6	14.8	23.4	47.0
852	4.1	14.4	20.4	14.7	25.3	38.8
861	11.5	27.8	26.5	28.0	48.6	46.0
862	10.9	12.7	24.2	25.5	33.1	61.1

Table 6.1-5: SW Steam Generator Wall Time History Member Force Comparison

	HRHF (kips/ft)			CSDRS (kips/ft)		
Element #	**TX**	**TY**	**TXY**	**TX**	**TY**	**TXY**
819	3.9	30.8	18.8	15.2	52.9	30.1
820	6.0	9.8	25.0	14.5	12.0	40.3
821	12.0	11.2	17.1	31.1	29.7	40.4
822	15.2	50.0	22.8	34.9	83.9	38.0
3193-3195	14.9	27.3	13.9	34.2	49.2	32.9
3196-3198	7.3	14.5	16.7	83.4	48.5	37.4
3201-3203	11.4	23.7	16.1	58.3	45.8	32.2
3204-3206	21.7	19.7	15.0	32.8	33.8	44.7

Table 6.1-6: CA02 Wall Building Time History Member Force Comparison

	HRHF (kips/ft)			CSDRS (kips/ft)		
Element #	**TX**	**TY**	**TXY**	**TX**	**TY**	**TXY**
826	4.9	24.1	14.6	32.5	49.4	22.9
827	3.1	7.4	8.4	32.0	17.8	22.4
828	10.8	45.8	23.4	29.5	58.9	33.7
829	6.4	6.3	17.3	20.4	17.1	28.2
830	8.4	18.0	23.2	38.0	39.9	38.4
831	10.0	19.1	24.2	24.3	35.2	50.7
832	10.2	16.8	24.4	28.5	19.6	37.6
833	8.4	13.6	25.2	30.7	21.6	41.6
834	9.5	14.1	25.9	16.8	21.4	60.7

The load comparison for building structures shows that seismic loads resulting from the CSDRS input motion are greater than loads obtained from HRHF input motion.

6.2 Primary Coolant Loop

A failure within the reactor coolant loop could challenge the integrity of the reactor coolant pressure boundary. Therefore, it was chosen for evaluation. The components evaluated are as follows:

- Reactor internals
- Primary Component Supports and Nozzles

6.2.1 Reactor Internals

The reactor internals were selected because they are important to safety and their analysis is representative of major primary components. The building structure below the reactor vessel supports is fairly stiff and there may be amplification at the supports of the reactor pressure vessel. Furthermore, reactor vessel internals have relatively complex structural systems including gap nonlinearities and sliding elements. Also, they may be sensitive to high frequency input as summarized below:

- Vertical and horizontal modes of the upper internals and the reactor vessel modes are in the relatively high frequency range.
- Additional high frequencies are associated with nonlinear impact.

The evaluation consisted of a comparison of the loads from the HRHF input to those obtained from the time history associated with the hard rock case input.

The reactor internals system model was utilized using the HRHF spectra time history and the resulting system loads were compared to the loads generated from the same reactor internals system model using time history associated with the CSDRS hard rock case.

An ANSYS model is shown in Figures 6.2.1-1 and 6.2.1-2. Figure 6.2.1-1 presents the entire system model including the reactor coolant loops. Figure 6.2.1-2 highlights the model of the core barrel, reactor vessel, and the major components within the reactor internals.

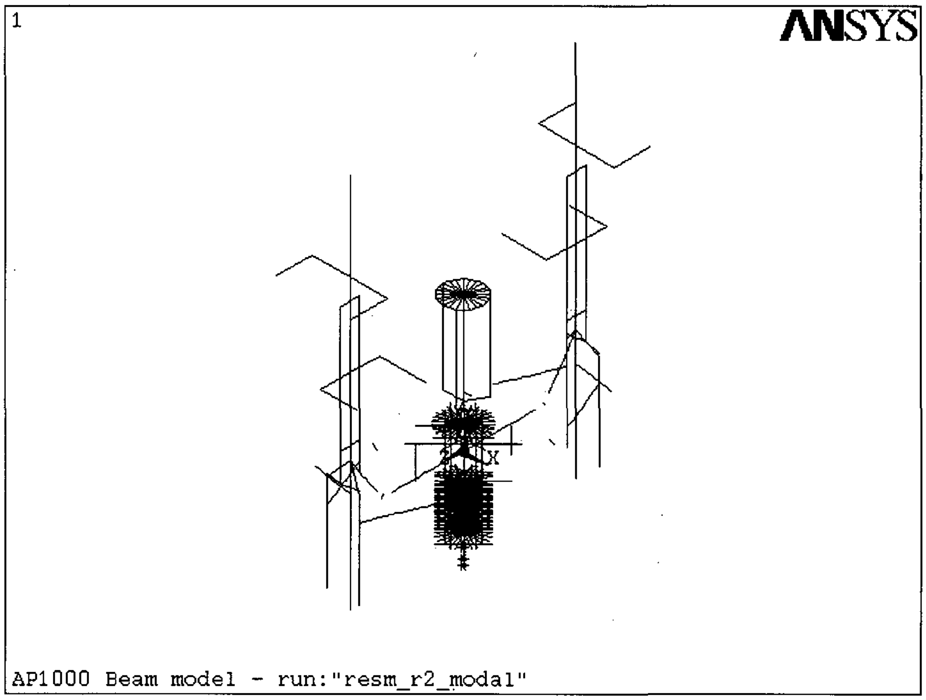


Figure 6.2.1-1: View of Entire System Model including RCL Super Elements

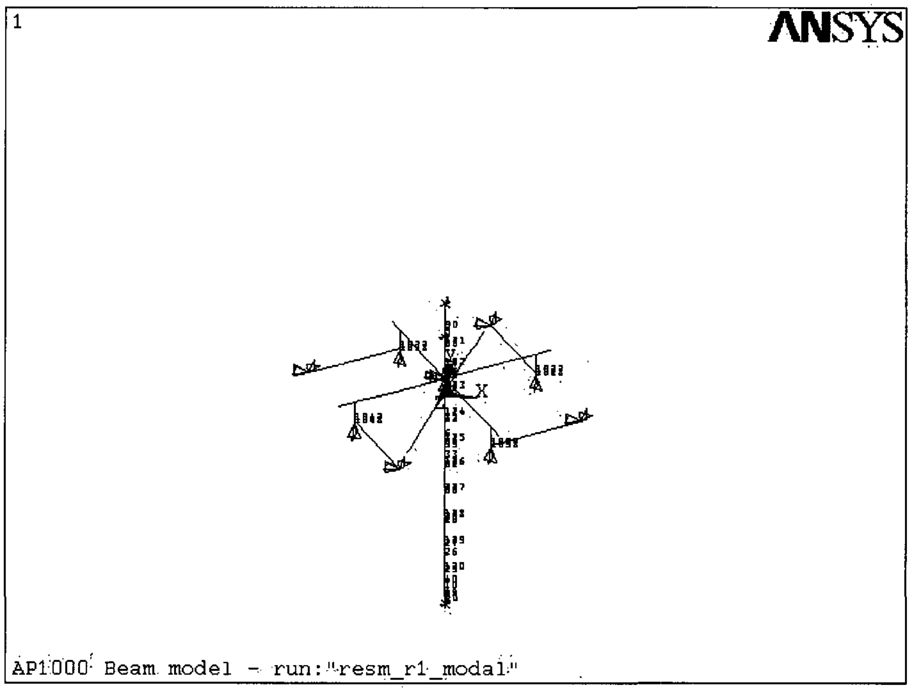


Figure 6.2.1-2: View of Model of Core Barrel, RPV, Inlet Nozzles, Outlet Nozzles, and Supports

The reactor equipment system model load generation analysis considered time history input at the vessel support elevation. Broadening was considered by frequency variation.

A comparison of the resulting interface loads for components such as the outlet nozzle, lower radial support, upper core plate pins, and the shroud pins; indicated a load reduction of approximately 81% to 29% for the HRHF time history compared to the previous interface loads generated from the CSDRS hard rock time history analysis.

Besides the comparison of the interface loads above, equipment loads in a select list of major internals components were reviewed. The significant loads on the reactor internals, such as the transverse loads from use of HRHF excitation, were less than those of the CSDRS (hard rock only) excitation. There were some occurrences where seismic loads, due to the HRHF, were slightly increased from the CSDRS excitation, but these seismic loads are small and not sufficient to cause unacceptable stresses in the stress analysis because the LOCA loads dominate. This comparison is for hard rock. It is expected that evaluations of the CSDRS 'all-soil' case will bound the results of the HRHF as well as the hard soil CRDRS cases. The 'all-soil' case includes the soft-soil, soft to medium, upper bound soft to medium, soft rock, firm rock, and hard rock cases. The 'all soil' case is higher than the hard rock case. The HRHF loads will not govern the design.

6.2.2 Primary Component Supports and Nozzles

Maintaining the integrity of the reactor vessel and steam generator supports is important to preserving the primary component safety function. The reactor vessel and steam generator supports are representative of supports on components and see high loads. The reactor coolant loop stick model is part of the nuclear island (NI20) model, with the primary support locations as shown in Figure 6.2.2-1. Included in Table 6.2.2-1 is a description of the support acronyms. A comparison of support loads on the reactor pressure vessel supports (both tangential and vertical) is provided in Table 6.2.2-2. A comparison of steam generator support loads (axial force in the supporting direction only) is provided in Table 6.2.2-3. The support loads for the CSDRS case are bounding at all locations.

The reactor coolant loop nozzles at the cold and hot leg interfaces of the reactor pressure vessel, reactor coolant pumps, and steam generators are important to include in the evaluation since these are critical areas of components. The evaluation of the primary component supports and reactor coolant loop nozzles consisted of a comparison of the loads from the HRHF input to those obtained from the CSDRS input. These items are considered acceptable for the HRHF input if the seismic loads from the CSDRS enveloped those from the high frequency input.

The reactor coolant nozzles are identified in Figures 6.2.2-2 and 6.2.2-3. Included in Table 6.2.2-4 is a description of the nozzle acronyms. A comparison of nozzle loads (SRSS of the bending moments applied for the two non-axial directions) is provided in Table 6.2.2-5. The nozzle loads for the CSDRS case are bounding at all locations.

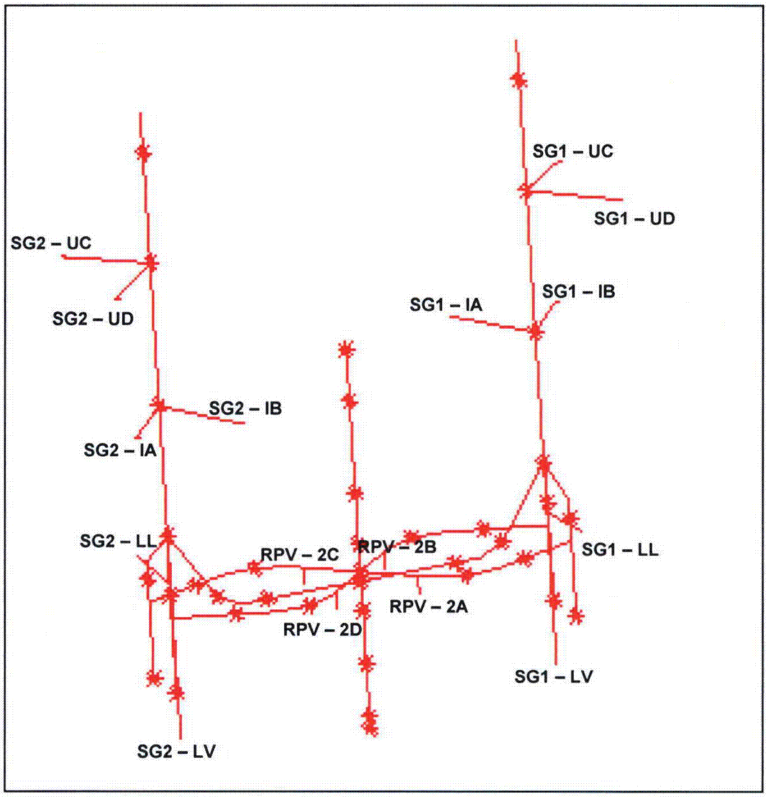


Figure 6.2.2-1: Reactor Coolant Loop Component Supports

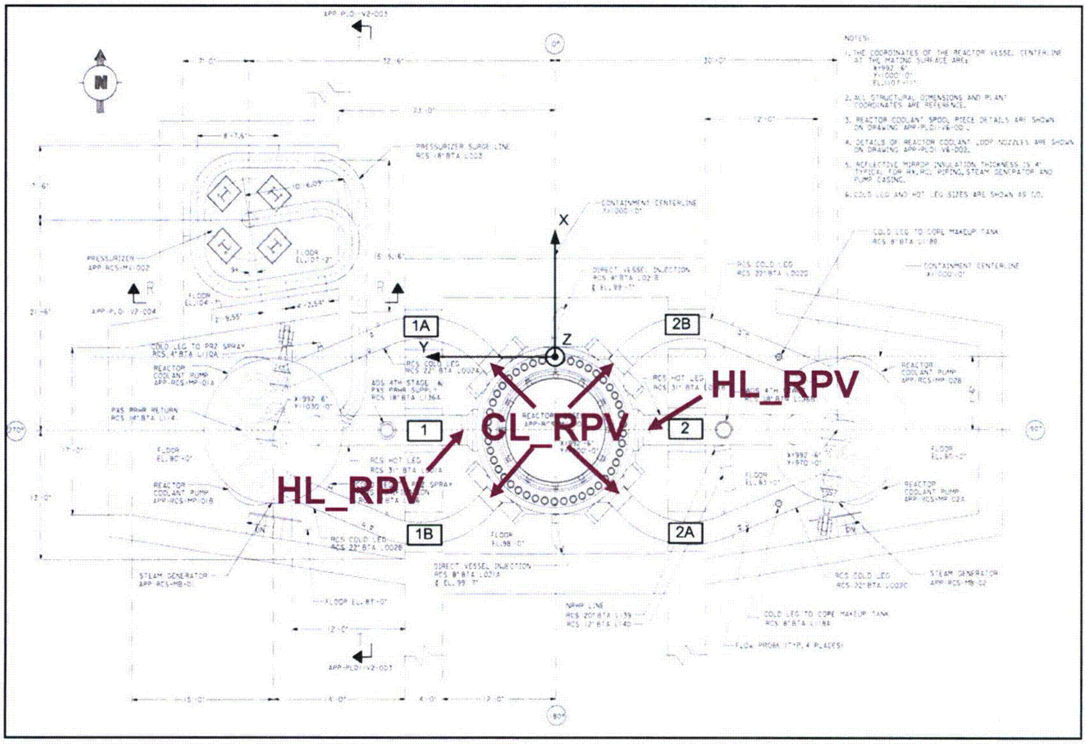


Figure 6.2.2-2: Reactor Coolant Loop Primary Equipment Nozzles

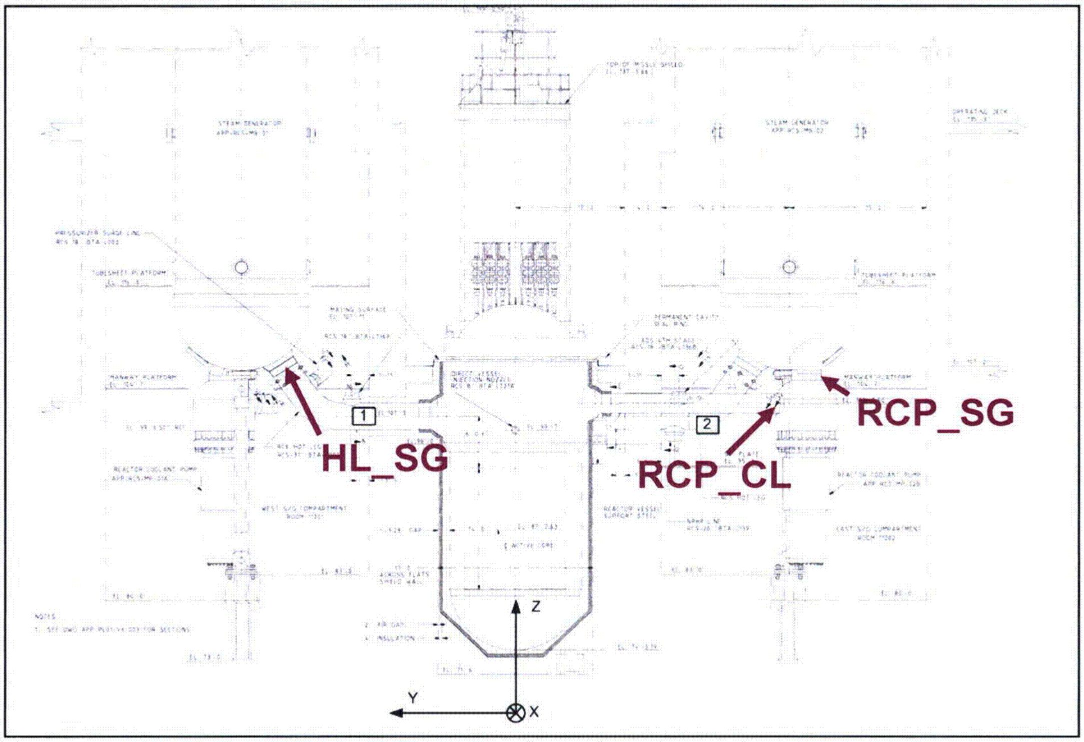


Figure 6.2.2-3: Reactor Coolant Loop Primary Equipment Nozzles

Table 6.2.2-1: Description of Reactor Coolant Loop Supports

Acronym	Support	Description
RPV - 2A	Cold Leg (L002A)	Reactor Pressure Vessel Supports, Connected at Cold Leg Indicated
RPV - 2B	Cold Leg (L002B)	
RPV - 2C	Cold Leg (L002C)	
RPV - 2D	Cold Leg (L002D)	
SG1-LV	SG1 Vertical Support	West Steam Generator Vertical Support Beam
SG1-LL	SG1 Lower Lateral	West Steam Generator Lower Lateral Support
SG1-IA	Int. Lateral 2A	West Steam Generator Intermediate Lateral Supports - Y Direction
SG1-IB	Int. Lateral 2B	
SG1-UC	Upper Lateral 3C	West Steam Generator Upper Lateral Supports - X Direction
SG1-UD	Upper Lateral 3D	
SG2-LV	SG2 Vertical Support	East Steam Generator Vertical Support Beam
SG2-LL	SG2 Lower Lateral	East Steam Generator Lower Lateral Support
SG2-IA	Int. Lateral 2A	East Steam Generator Intermediate Lateral Supports - Y Direction
SG2-IB	Int. Lateral 2B	
SG2-UC	Upper Lateral 3C	East Steam Generator Upper Lateral Supports - X Direction
SG2-UD	Upper Lateral 3D	

Table 6.2.2-2: Reactor Pressure Vessel Support Comparison

RPV Support Forces	HRHF Time History Forces (kips)	CSDRS Seismic Forces (kips)
Tangential	642	1447
Vertical	603	992

Table 6.2.2-3: Steam Generator Support Comparison

RCL Support Forces	HRHF Time History Forces (kips)	CSDRS Time History Forces (kips)
Vertical	753	1716
Lower Lateral	486	1060
Intermediate Lateral	341	1134
Upper Lateral	427	913

Table 6.2.2-4: Description of Reactor Coolant Loop Nozzle Acronyms

Acronym	Component 1	Component 2
RCP_SG	Reactor Coolant Pump	Steam Generator
RCP_CL	Reactor Coolant Pump	Cold Leg
CL_RPV	Cold Leg	Reactor Pressure Vessel
HL_RPV	Hot Leg	Reactor Pressure Vessel
HL_SG	Hot Leg	Steam Generator

Table 6.2.2-5: Reactor Coolant Loop Primary Equipment Nozzle Load Comparison

RCL Nozzle	HRHF Time History	CSDRS Time History
	Bending Moment (kip-ft)	
RCP_SG	2603	4157
RCP_CL	272	560
CL_RPV	372	706
HL_RPV	712	1684
HL_SG	893	2035

6.3 Piping Systems

To determine the effect of HRHF GMRS on piping, a comparison of stress analyses was made using the PIPESTRESS computer program. The study compared results for HRHF GMRS input against the AP1000 CSDRS input. Since piping lines and piping supports are designed throughout the plant using specific guidelines, the stress analysis of a sample of lines is representative of all lines in the plant.

Susceptibility to excitation caused by high frequency input requires a number of factors:

- The local HRHF GMRS need to have exceedances relative to AP1000 in the high frequency range.
- The system must have modes or natural frequencies in the high frequency range.
- The system layout must include valves or other concentrated masses that would require closely spaced supports and therefore, cause high local natural frequencies. This generally yields significant cumulative mass in the high frequency range.

6.3.1 Package Consideration

Packages taken into consideration were those with already completed AP1000 analyses, as outlined in Table 6.3.1-1. Several steps were taken to filter these packages to find the package most susceptible to high frequency excitation. First, a layout of piping lines was inspected to determine if valves or other concentrated masses existed. To further narrow the most eligible packages: 1.) input seismic response spectra was reviewed for elevations with exceedances, and 2.) modal mass was reviewed for high frequency participation.

To determine if the initial list of analysis packages was or was not a narrow representation, isometric drawings from the remaining unanalyzed piping analysis packages were reviewed. Piping layout was examined for vertical runs and valves with closely spaced supports. The packages with these vertical runs and valves were then further examined, along with the corresponding local high frequency seismic response spectra. This examination produced no further candidates for analysis.

6.3.1.1 Layout

Layout was examined to determine whether the analyzed piping package could be susceptible to high frequency excitation. The existence of valves usually results in closely spaced supports. Though the mass of such a valve would reduce the natural frequency, the nearby supports could drive that frequency upward. Packages without valves or concentrated masses were not included in the sample because the majority of the modal mass has lower frequency participation.

6.3.1.2 Review of Spectra

The HRHF GMRS was reviewed for exceedances of the AP1000 CSDRS in the high frequency region. The elevations with exceedances of seismic response spectra in high frequency were examined to either highlight or dismiss packages.

The Passive Core Cooling System (PCS) piping packages are located above the Steel Containment Vessel in the Shield Building. This area does not have exceedances in high frequency seismic response spectra, so the PCS packages (APP-PCS-PLA-050, 060, 070, 100, 200, 210, 220, 230, 240, 250, 270, 290, 300, 310, 410, 420, and 430) were eliminated from consideration.

Packages below elevation 100 ft are not considered since exceedances in both the Containment and Auxiliary buildings are small at this elevation. More significant exceedances occur at the 135 ft elevation and above. Therefore, packages closer to the 135 ft elevation are given more consideration than packages closer to the 100 ft elevation.

6.3.1.3 Modal Analysis

Packages with layouts susceptible to high frequency excitation and exceedances in local seismic spectra had modal extraction run in PIPESTRESS to determine the mass participation factors of the systems. Large equipment, such as heat exchangers and pumps, were decoupled for this analysis to reveal the characteristics of only the piping. The mass participation factors were then calculated and plotted as a cumulative mass participation against frequency. The cumulative mass represents the accumulated percentage mass of the system excited as the modes are included. Packages determined to be of further interest have significant mass participation among all directions in the high frequency range.

These plots of system behavior were compared against the corresponding plots of local input seismic response spectra. Packages with high frequency behavior shown in the cumulative mass curves but without high frequency input were eliminated. Inversely, packages with high frequency seismic input spectra but without high frequency behavior were eliminated. Only packages with high frequency modal mass participation and corresponding exceedances of seismic response spectra in high frequency were considered.

Table 6.3.1-1 lists the reasons for susceptibility of the analysis packages to high frequency excitation. The table also shows the two packages determined to be most susceptible to high frequency seismic input spectra, and therefore representative of the entire plant; Automatic Depressurization Stage 4 West (APP-PXS-PLA-030) inside containment and Normal RHR Heat Exchanger Inlet and Outlet between containment penetrations (APP-RNS-PLA-170) outside containment.

Table 6.3.1-1: Reviewed Lines

Analysis Package Description	Package Designator	Candidate	Reason
Direct Vessel Injection Line A	APP-PXS-PLA-010	No	Due to the low elevation of APP-PXS-PLA-010, exceedances in high frequency are small.
Direct Vessel Injection Line B	APP-PXS-PLA-020	No	Due to the low elevation of APP-PXS-PLA-020, exceedances in high frequency are small.
ADS 4th Stage West and PRHR Supply	APP-PXS-PLA-030	Yes	See section 6.3.2.1
Passive RHR Return Line	APP-PXS-PLA-040	No	Due to the low elevation of APP-PXS-PLA-040, this location does not have exceedances of seismic response spectra in high frequency.
CMT 2A Supply Line	APP-PXS-PLA-050	No	The increases in modal mass and exceedances of high frequency spectra are not aligned at the same frequencies for APP-PXS-PLA-050.
CMT 2B Supply Line	APP-PXS-PLA-060	No	The increases in modal mass and exceedances of high frequency spectra are not aligned at the same frequencies for APP-PXS-PLA-060.
PSADS System (Lower Tier/Upper Tier)	APP-RCS-PLA-010	No	APP-RCS-PLA-010 does not contain significant X and Y modal mass participation in the high frequency region. Modal mass participation in the Z direction is similar to that of the chosen packages.
ADS 4th Stage East	APP-RCS-PLA-030	No	APP-PXS-PLA-030 was considered over APP-RCS-PLA-030 for its greater complexity and higher elevation.
Pressurizer Surge Line	APP-RCS-PLA-040	No	APP-RCS-PLA-040 contains no valves.
Reactor Coolant Loop Piping	APP-RCS-PLA-050	No	This analysis is reviewed in section 6.2 of this report.
Normal RHR Suction Line	APP-RNS-PLA-010	No	APP-RNS-PLA-010 lies in lower elevations of Containment, where the spectra contains small exceedances in high frequency.
Spent Resin from Cont. Pen.	APP-CVS-PLA-520	No	APP-CVS-PLA-520 lies in lower elevations of the Auxiliary Building, where the spectra contains small exceedances in high frequency.
From SCV Pen. to CVS-12A0007	APP-CVS-PLA-530	No	APP-CVS-PLA-530 lies in lower elevations of the Auxiliary Building, where the spectra contains small exceedances in high frequency.
Hydrogen Supply from CVS-12A0022	APP-CVS-PLA-700	No	APP-CVS-PLA-700 lies in lower elevations of the Auxiliary Building, where the spectra contains small exceedances in high frequency.
HX Inlet and Outlet between P19 & P20	APP-RNS-PLA-170	Yes	See section 6.3.2.2
Main Steam Line A	APP-SGS-PLA-030	No	The valves of APP-SGS-PLA-030/040 reside outside containment in lower elevations of the Auxiliary Building, where the spectra contains small exceedances in high frequency.
Main Steam Line B	APP-SGS-PLA-040	No	
Blowdown Line B from Cont. Pen. to TB	APP-SGS-PLA-090	No	APP-SGS-PLA-090/100 does not contain any valves.
Blowdown Line A from Cont. Pen. to TB	APP-SGS-PLA-100	No	
From SCV Pen. to VFS-12A2004	APP-VFS-PLA-010	No	The increases in modal mass and exceedances in high frequency spectra are not aligned at the same frequencies for APP-VFS-PLA-010/030.
From Cont. Pen. to past Valve V010	APP-VFS-PLA-030	No	
From Cont. Pen. to past Valve V024	APP-WLS-PLA-520	No	The valves of APP-WLS-PLA-520 reside outside containment in lower elevations of the Auxiliary Building, where the spectra contains small exceedances in high frequency.
Supply to Distribution Bucket (Embed)	APP-PCS-PLA-050	No	The PCS system is located at the top of the Shield Building. The spectra at these elevations do not contain exceedances in high frequency.
Recirculation Line inside PCS Tank	APP-PCS-PLA-060	No	
Recirculation Line inside PCS Tank	APP-PCS-PLA-070	No	
PCS Room 12306 (Auxiliary Building)	APP-PCS-PLA-100	No	

Overflow inside PCS Tank	APP-PCS-PLA-200	No	
Vent Line inside PCS Tank	APP-PCS-PLA-210	No	
Room 12701 PCS Tank Vent	APP-PCS-PLA-220	No	
Vent Line inside PCS Tank	APP-PCS-PLA-230	No	
Room 12701 PCS Tank Vent	APP-PCS-PLA-240	No	
Discharge Line inside PCS Tank	APP-PCS-PLA-250	No	
Discharge Line inside PCS Tank	APP-PCS-PLA-270	No	
Discharge Line inside PCS Tank	APP-PCS-PLA-290	No	
Instrumentation Line	APP-PCS-PLA-300	No	
Instrumentation Line	APP-PCS-PLA-310	No	
Overflow Line from PCS Tank	APP-PCS-PLA-410	No	
Supply to Distribution Bucket	APP-PCS-PLA-420	No	
Auxiliary Supply to Distribution Bucket	APP-PCS-PLA-430	No	
From RNS-12A2037 to Spent Fuel Pool	APP-RNS-PLA-100	No	The modal mass and high frequency spectra are not aligned at the same frequencies for APP-RNS-PLA-100.

The two packages determined to be most susceptible to high frequency excitation are Automatic Depressurization System 4th West (APP-PXS-PLA-030) inside containment and Normal RHR Heat Exchanger Inlet and Outlet between containment penetrations (APP-RNS-PLA-170) outside containment. These two packages have layout sensitive to high frequency excitation and local seismic response spectra with exceedances in high frequency.

6.3.2 Analysis of Selected Candidates

6.3.2.1 Automatic Depressurization System 4th Stage West and Passive RHR Supply (APP-PXS-PLA-030)

Figures 6.3.2.1-1 through 6.3.2.1-3 are the plots of the AP1000 CSDRS with 5% damping and HRHF GMRS with 5% damping and incoherence. The response spectra for both AP1000 CSDRS and HRHF GMRS are representative of the containment building up to elevation 135'.

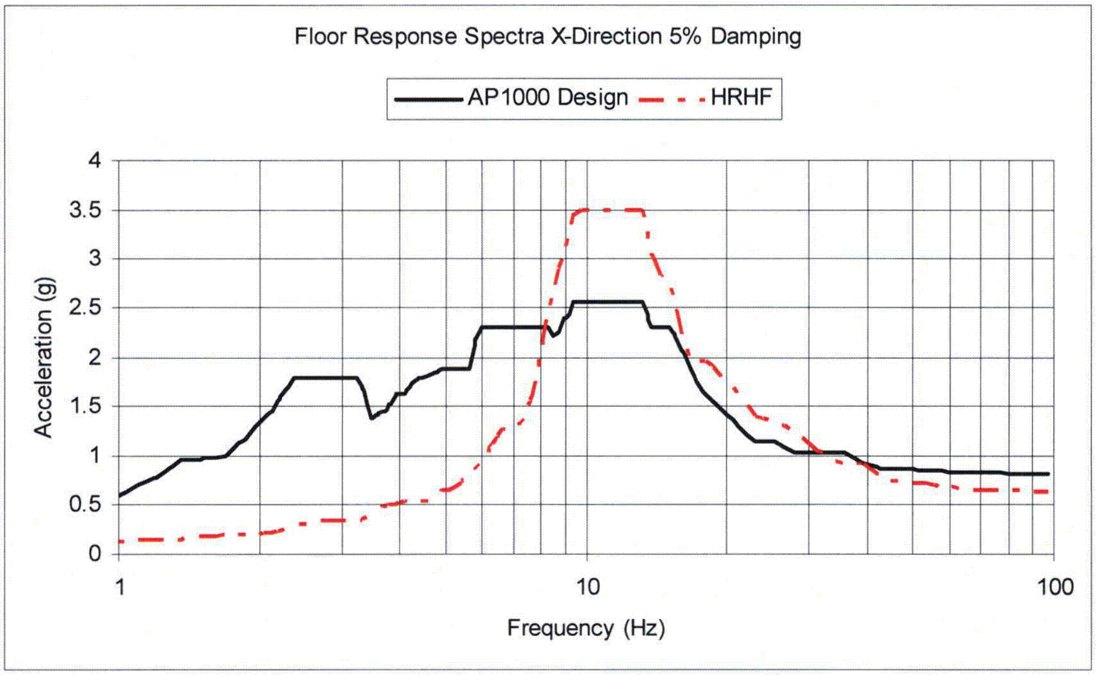


Figure 6.3.2.1-1: APP-PXS-PLA-030 Floor Response Spectra X-Direction

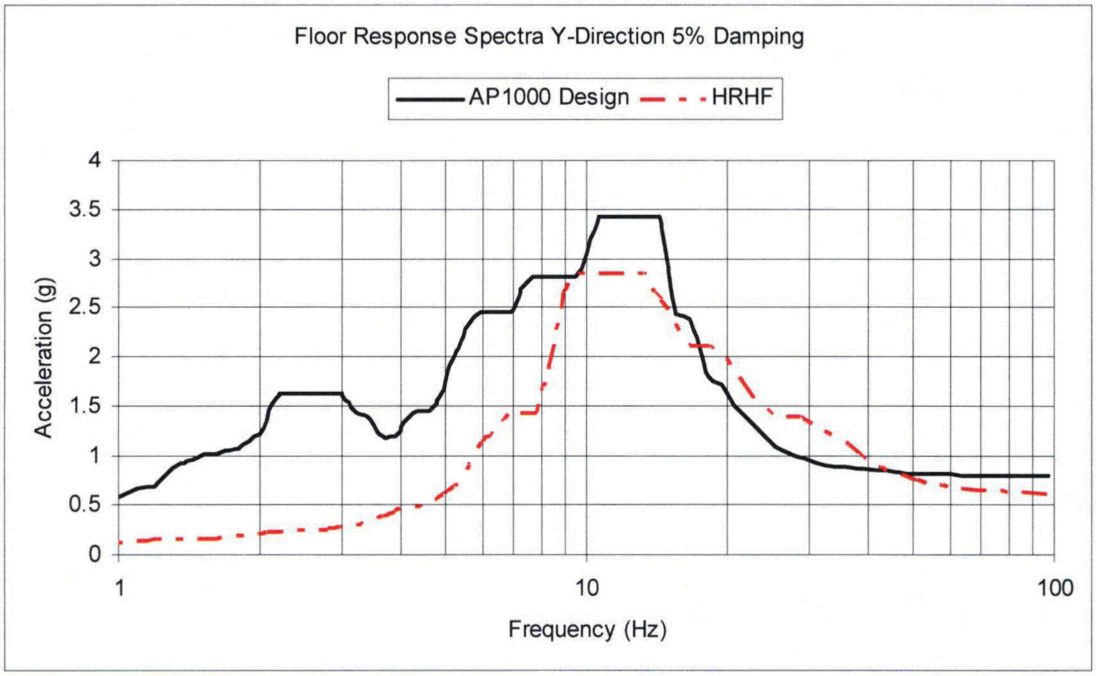


Figure 6.3.2.1-2: APP-PXS-PLA-030 Floor Response Spectra Y-Direction

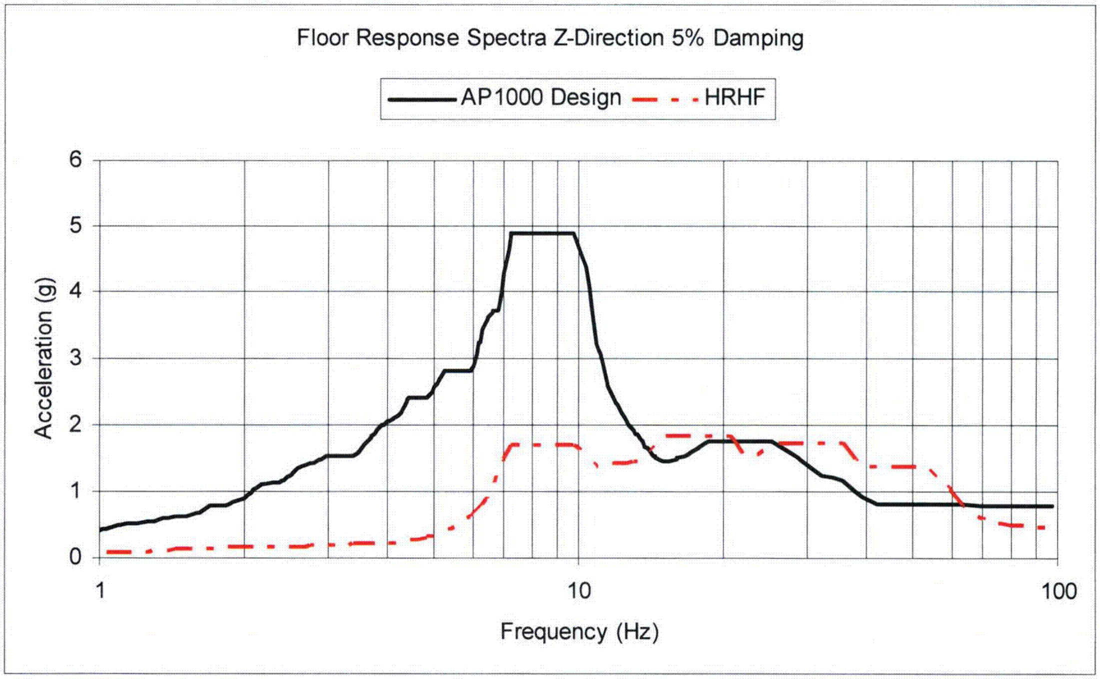


Figure 6.3.2.1-3: APP-PXS-PLA-030 Floor Response Spectra Z-Direction

The layout of APP-PXS-PLA-030 is potentially sensitive to high frequency response; the package spans a very small distance, yet has sixteen supports and anchors. The package also has five large valves, three of which are greater than 10,000 lbs. Figure 6.3.2.1-4 shows the cumulative mass of the analysis package; approximately forty, twenty, and fifty mass percent of the package (in the X, Y, and Z directions, respectively) is active in frequencies of HRHF exceedance.

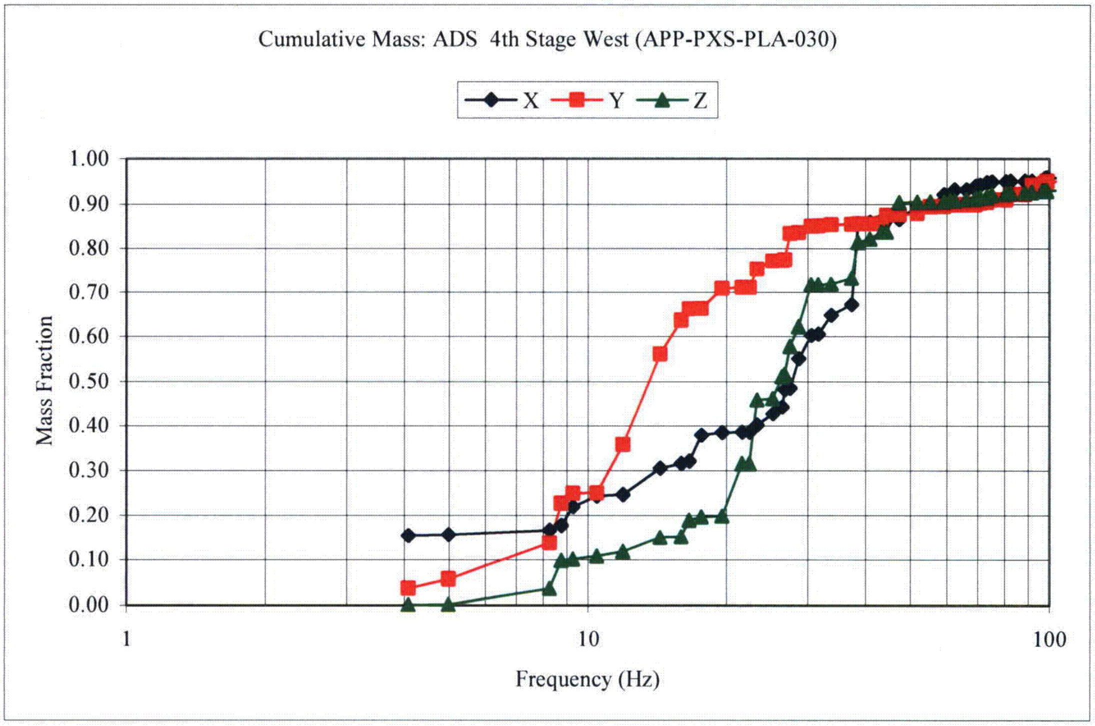


Figure 6.3.2.1-4: APP-PXS-PLA-030 Cumulative Mass: ADS 4th Stage West

Due to exceedances of high frequency seismic response spectra and its high frequency sensitive layout, APP-PXS-PLA-030 is representative of a piping package most susceptible to excitation caused by high frequency input inside containment.

6.3.2.2 Normal RHR Heat Exchanger Inlet and Outlet (APP-RNS-PLA-170)

Figures 6.3.2.2-1 to 6.3.2.2-3 are plots of local 4% damping and HRHF seismic response spectra with 4% damping and incoherence. The response spectra for both AP1000 CSDRS and HRHF GMRS are representative of the auxiliary building up to elevation 135'.

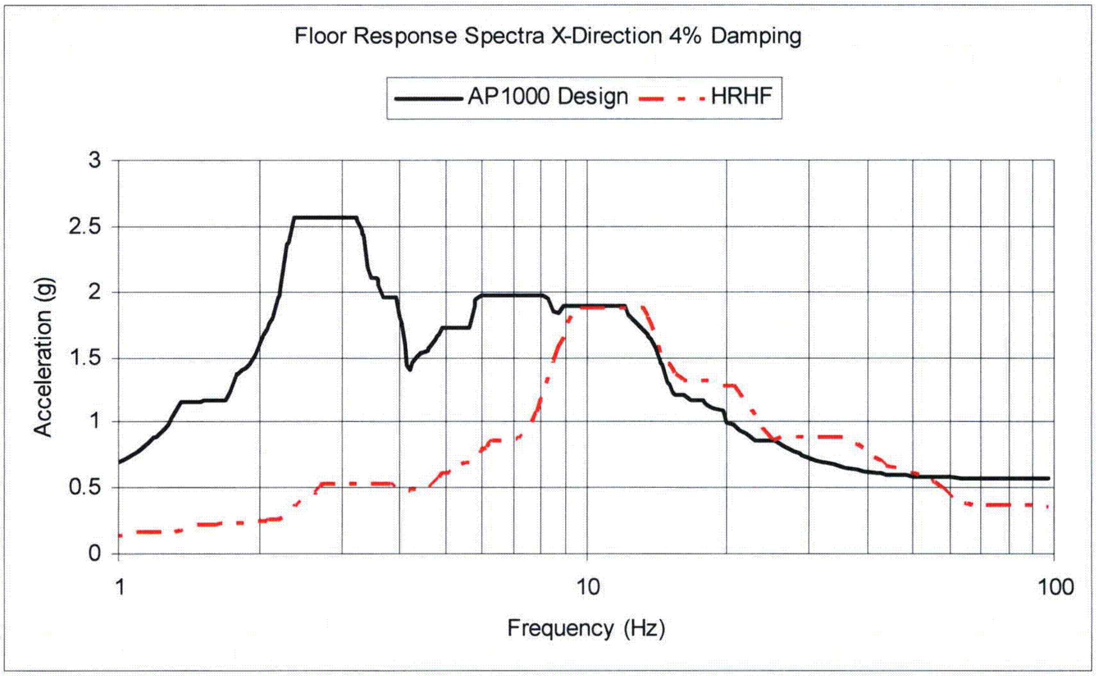


Figure 6.3.2.2-1: APP-RNS-PLA-170 Floor Response Spectra X-Direction

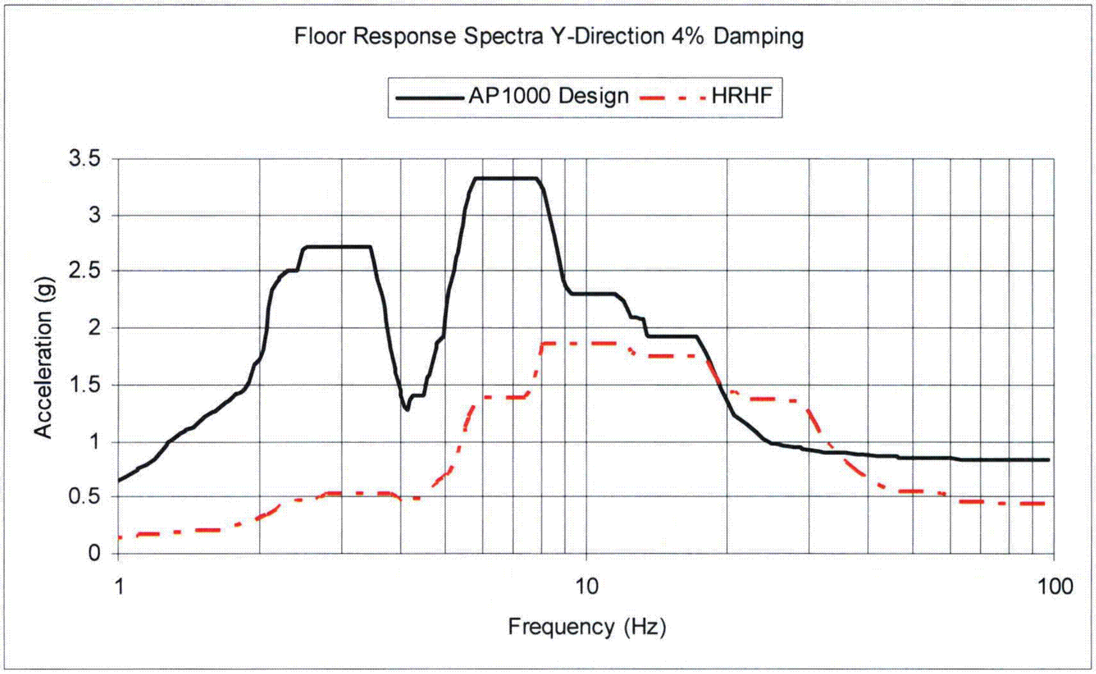


Figure 6.3.2.2-2: APP-RNS-PLA-170 Floor Response Spectra Y-Direction

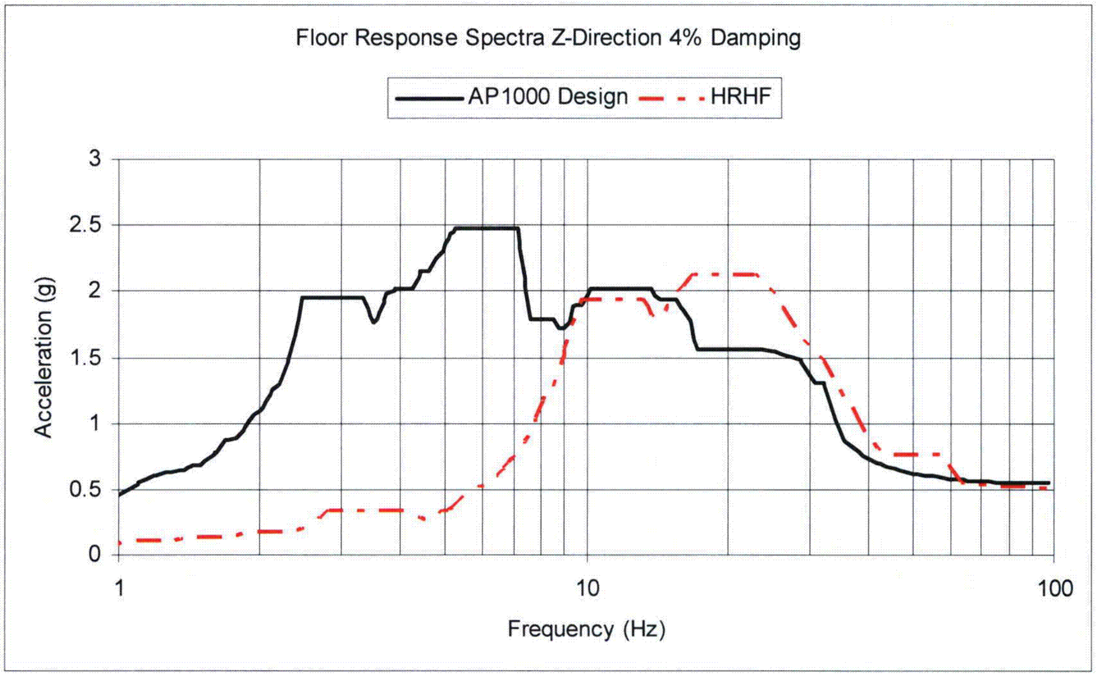


Figure 6.3.2.2-3: APP-RNS-PLA-170 Floor Response Spectra Z-Direction

APP-RNS-PLA-170 is a system with many vertical runs. The package has fourteen valves; as well as eighty-three supports and anchors. The complexity of the package represents a wide number of piping layout configurations, which should encompass the layouts throughout the plant. Figure 6.3.2.2-4 shows the cumulative mass of the analysis package; approximately forty, thirty, and fifty mass percent of the package (in the X, Y, and Z directions, respectively) is active in frequencies of HRHF exceedance.

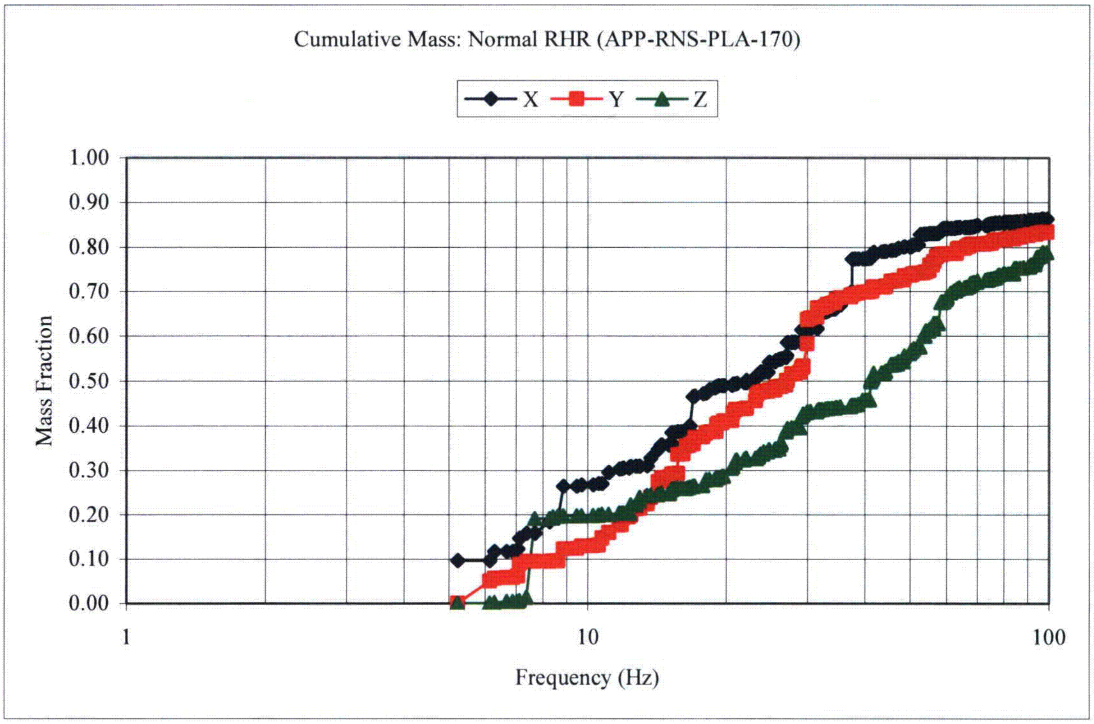


Figure 6.3.2.2-4: APP-RNS-PLA-170 Cumulative Mass: Normal RHR

Due to its location near exceedances of seismic response spectra in high frequency, APP-RNS-PLA-170 is representative of a piping package that is susceptible to excitation caused by high frequency input outside containment.

6.3.2.3 Analysis Method

The analysis method for both the AP1000 CSDRS and HRHF GMRS analyses, shown below, are consistent with normal design practices.

Both the AP1000 CSDRS and HRHF GMRS have been enveloped across entire building elevations. This is not only a conservative approach, but this also eliminates concerns of building location as the spectra is representative of an entire elevation.

Identical PIPESTRESS models were run for the two selected analysis packages, with the exception of the input seismic response spectra. The base case used AP1000 CSDRS with 15% peak broadened and enveloped response spectra. Input for the high frequency comes from the HRHF GMRS with 15% peak broadened and enveloped response spectra with incoherence.

The cutoff frequency for the AP1000 CSDRS base case was 33 Hz. The cutoff frequency for the HRHF GMRS case was the ZPA frequency. Both the AP1000 CSDRS and HRHF GMRS analyses used uniform support motion methodology (USM), which allows the same damping values of 4% and 5% to be used.

The seismic analyses were combined with deadweight and pressure analyses to show that the HRHF results do not exceed the limits of ASME Section III Equation 9F.

6.3.3 Results

6.3.3.1 Automatic Depressurization System Stage 4 West (APP-PXS-PLA-030)

Comparisons of the AP1000 CSDRS and HRHF GMRS analyses are listed in Tables 6.3.3.1-1 to 6.3.3.1-8.

Table 6.3.3.1-1 shows the ten highest stressed points of the AP1000 CSDRS analysis. Table 6.3.3.1-2 shows the ten highest stressed points of the HRHF analysis. Table 6.3.3.1-3 shows the ten highest stress increases of the HRHF GMRS analysis from the AP1000 CSDRS analysis.

Table 6.3.3.1-4 compares the valve end stress ratios. Table 6.3.3.1-5 compares stress ratios of tee connections. Tables 6.3.3.1- 6 and 7 compare support and anchor loads, respectively. Support loads are listed for individual restraint directions. Table 6.3.3.1-8 compares the equipment nozzle stress ratios.

Table 6.3.3.1-1: Ten Highest AP1000 Design Stress Points for APP-PXS-PLA-030

Node #	Equation 9F Stress Ratio		
	AP1000 CSDRS	HRHF	% Change
1276	0.610	0.484	-20.66%
1275	0.558	0.433	-22.40%
1261	0.557	0.483	-13.29%
1045	0.533	0.453	-15.01%
1005	0.531	0.447	-15.82%
1345	0.500	0.409	-18.20%
Z002	0.498	0.423	-15.06%
Z013	0.494	0.398	-19.43%
1331	0.489	0.410	-16.16%
1040	0.469	0.399	-14.93%

Table 6.3.3.1-2: Ten Highest High Frequency Stress Points for APP-PXS-PLA-030

Node #	Equation 9F Stress Ratio		
	AP1000 CSDRS	HRHF	% Change
1276	0.610	0.484	-20.66%
1261	0.557	0.483	-13.29%
1045	0.533	0.453	-15.01%
1005	0.531	0.447	-15.82%

1275	0.558	0.433	-22.40%
Z002	0.498	0.423	-15.06%
1331	0.489	0.410	-16.16%
1345	0.500	0.409	-18.20%
Z012	0.469	0.406	-13.43%
1040	0.469	0.399	-14.93%

Table 6.3.3.1-3: Ten Highest Stress Increases from AP1000 CSDRS to HRHF GMRS for APP-PXS-PLA-030

Node #	Equation 9F Stress Ratio		
	AP1000 CSDRS	HRHF	% Change
1420	0.142	0.142	0.00%
1421	0.140	0.140	0.00%
1425	0.139	0.139	0.00%
1160	0.034	0.034	0.00%
1345	0.146	0.145	-0.68%
1055	0.037	0.036	-2.70%
1155	0.036	0.035	-2.78%
1060	0.035	0.034	-2.86%
1110	0.318	0.302	-5.03%
1111	0.335	0.318	-5.07%

Table 6.3.3.1-4: Valve End Stresses for APP-PXS-PLA-030

Label	Equation 9F Stress Ratio		
	AP1000 CSDRS	HRHF	% Change
V004A	0.035	0.034	-2.86%
V004C	0.034	0.034	0.00%
V014A	0.325	0.298	-8.31%
V014A	0.350	0.317	-9.43%
V014C	0.321	0.304	-5.30%
V014C	0.293	0.266	-9.22%
V101	0.397	0.331	-16.62%
V101	0.455	0.382	-16.04%

Table 6.3.3.1-5: Tee Connection Stresses for APP-PXS-PLA-030

Type	Equation 9F Stress Ratio		
	AP1000 CSDRS	HRHF	% Change
WELDING TEE	0.621	0.539	-13.20%
WELDING TEE	0.442	0.385	-12.90%
WELDING TEE	0.470	0.388	-17.45%

Table 6.3.3.1-6: Seismic Support Loads for APP-PXS-PLA-030

Type	Force - X (lb)			Force - Y (lb)			Force - Z (lb)			Resultant Force (lb)		
	AP1000 CSDRS	HRHF	% Change	AP1000 CSDRS	HRHF	% Change	AP1000 CSDRS	HRHF	% Change	AP1000 CSDRS	HRHF	% Change
RIG SUPORT							-56952	-55629	-2.32%	-56952	-55629	-2.32%
RIG SUPORT	-35327	-35216	-0.31%				-20397	-20332	-0.32%	-40792	-40664	-0.31%
RIG SUPORT	-30307	-29233	-3.54%	-17497	-16877	-3.54%	-20205	-19488	-3.55%	-40410	-38977	-3.55%
SNUBBER				-46119	-38248	-17.07%				-46119	-38248	-17.07%
RIG SUPORT	-47176	-44831	-4.97%				-27238	-25884	-4.97%	-54474	-51766	-4.97%
RIG SUPORT	-44054	-40976	-6.99%	-16020	-14900	-6.99%	-27060	-25169	-6.99%	-54127	-50344	-6.99%
RIG SUPORT				-47750	-41295	-13.52%	-47750	-41295	-13.52%	-67529	-58401	-13.52%
RIG SUPORT				-68771	-56763	-17.46%				-68771	-56763	-17.46%
RIG SUPORT				-38839	-31784	-18.16%				-38839	-31784	-18.16%
RIG SUPORT							-31622	-25324	-19.92%	-31622	-25324	-19.92%
RIG SUPORT	-41722	-33079	-20.72%							-41722	-33079	-20.72%
RIG SUPORT	-5911	-5240	-11.35%				-15737	-13951	-11.35%	-16810	-14902	-11.35%
RIG SUPORT							-63958	-53087	-17.00%	-63958	-53087	-17.00%
RIG SUPORT				-63216	-48648	-23.04%				-63216	-48648	-23.04%

Table 6.3.3.1-7: Seismic Anchor Loads for APP-PXS-PLA-030

Point	Force - X (lb)			Force - Y (lb)			Force - Z (lb)			Resultant Force (lb)		
Label	AP1000 CSDRS	HRHF	% Change	AP1000 CSDRS	HRHF	% Change	AP1000 CSDRS	HRHF	% Change	AP1000 CSDRS	HRHF	% Change
West Hot Leg	-29681	-25436	-14.30%	-14853	-10785	-27.39%	-18466	-16241	-12.05%	37981	32048	-15.62%
PRHR HX	-21320	-14836	-30.41%	-22864	-12991	-43.18%	-26831	-20206	-24.69%	41197	28234	-31.47%
Point	Moment - X (ft-lb)			Moment - Y (ft-lb)			Moment - Z (ft-lb)			Resultant Moment (ft-lb)		
Label	AP1000 CSDRS	HRHF	% Change	AP1000 CSDRS	HRHF	% Change	AP1000 CSDRS	HRHF	% Change	AP1000 CSDRS	HRHF	% Change
West Hot Leg	-61630	-50094	-18.72%	-97519	-81270	-16.66%	-103248	-69578	-32.61%	154817	118133	-23.70%
PRHR HX	-62587	-36544	-41.61%	-133172	-67113	-49.60%	-42188	-23996	-43.12%	153074	80097	-47.67%

Table 6.3.3.1-8: Equipment Nozzle Stresses for APP-PXS-PLA-030

Label	Equation 9F Stress Ratio		
	AP1000 CSDRS	HRHF	% Change
West Hot Leg	0.324	0.303	-6.48%
PRHR HX	0.324	0.226	-30.25%

Results Summary for APP-PXS-PLA-030

- Equation 9F stress ratios are all less than 1.0. No point of the HRHF GMRS analysis fails qualification.
- No points show an increase in stress ratio.
- Valve nozzles stress ratios show no increase.
- Tee connection stress ratios show no increase.
- Resultant support loads show no increase.
- Resultant anchor loads show no increase.
- Piping stress ratios at equipment show no increase.

6.3.3.2 Normal RHR Heat Exchanger Inlet and Outlet between P19 and P20 (APP-RNS-PLA-170)

Comparisons of the AP1000 CSDRS and HRHF GMRS analyses are listed in Tables 6.3.3.2-1 to 6.3.3.2-8.

Table 6.3.3.2-1 shows the ten highest stressed of the AP1000 CSDRS analysis. Table 6.3.3.2-2 shows the ten highest stressed points of the HRHF GMRS analysis. Table 6.3.3.2-3 shows the ten highest stress increases of the HRHF GMRS analysis from the AP1000 CSDRS analysis.

Table 6.3.3.2-4 compares the valve end stress ratios. Table 6.3.3.2-5 compares stress ratios of tee connections. Tables 6.3.3.2-6 and 6.3.3.2-7 compare support and anchor loads, respectively. Support loads are listed for individual restraint directions. Table 6.3.3.2-8 compares the equipment nozzle stress ratios.

Table 6.3.3.2-1: Ten Highest AP1000 Design Stress Points for APP-RNS-PLA-170

Node #	Equation 9F Stress Ratio		
	AP1000 CSDRS	HRHF	% Change
4645	0.840	0.475	-43.45%
Z057	0.811	0.439	-45.87%
Z058	0.789	0.417	-47.15%
4650	0.724	0.381	-47.38%
4581	0.716	0.499	-30.31%
5140	0.713	0.456	-36.04%
Z056	0.706	0.394	-44.19%
4630	0.680	0.377	-44.56%

4582	0.679	0.47	-30.78%
4645	0.670	0.379	-43.43%

Table 6.3.3.2-2: Ten Highest High Frequency Stress Points for APP-RNS-PLA-170

Node #	Equation 9F Stress Ratio		
	AP1000 CSDRS	HRHF	% Change
1525	0.607	0.600	-1.15%
2520	0.581	0.587	**1.03%**
5105	0.667	0.540	-19.04%
2600	0.664	0.517	-22.14%
5370	0.577	0.511	-11.44%
4581	0.716	0.499	-30.31%
3570	0.510	0.495	-2.94%
3560	0.492	0.479	-2.64%
4645	0.840	0.475	-43.45%
4582	0.679	0.470	-30.78%

Table 6.3.3.2-3: Ten Highest Stress Increases from AP1000 CSDRS to HRHF GMRS for APP-RNS-PLA-170

Node #	Equation 9F Stress Ratio		
	AP1000 CSDRS	HRHF	% Change
2750	0.386	0.454	**17.62%**
2760	0.165	0.194	**17.58%**
2720	0.138	0.162	**17.39%**
2710	0.076	0.087	**14.47%**
2740	0.243	0.277	**13.99%**
Z032	0.052	0.057	**9.62%**
4080	0.052	0.057	**9.62%**
1660	0.084	0.092	**9.52%**
Z033	0.054	0.059	**9.26%**
4090	0.092	0.100	**8.70%**

Table 6.3.3.2-4: Valve End Stresses for APP-RNS-PLA-170

Label	Equation 9F Stress Ratio		
	AP1000 CSDRS	HRHF	% Change
V005A	0.197	0.131	-33.50%
V005A	0.317	0.205	-35.33%
V005B	0.178	0.132	-25.84%
V005B	0.268	0.197	-26.49%
V006A	0.134	0.131	-2.24%
V006A	0.106	0.098	-7.55%
V006B	0.129	0.13	**0.78%**
V006B	0.108	0.113	**4.63%**
V007A	0.147	0.148	**0.68%**
V007A	0.094	0.092	-2.13%

V007B	0.2	0.197	-1.50%
V007B	0.122	0.125	**2.46%**
V008A	0.373	0.263	-29.49%
V008A	0.359	0.25	-30.36%
V008B	0.241	0.239	-0.83%
V008B	0.286	0.285	-0.35%
V011	0.375	0.344	-8.27%
V011	0.159	0.125	-21.38%
V022	0.249	0.195	-21.69%
V022	0.257	0.212	-17.51%
V053	0.226	0.179	-20.80%
V053	0.184	0.116	-36.96%
V055	0.135	0.134	-0.74%
V055	0.277	0.253	-8.66%
V056	0.096	0.09	-6.25%
V056	0.132	0.13	-1.52%
V057A	0.421	0.401	-4.75%
V057A	0.492	0.479	-2.64%
V057B	0.346	0.309	-10.69%
V057B	0.395	0.369	-6.58%

Table 6.3.3.2-5: Tee Connection Stresses for APP-RNS-PLA-170

Type	Equation 9F Stress Ratio		
	AP1000 CSDRS	HRHF	% Change
WELDING TEE	0.511	0.439	-14.09%
WELDING TEE	0.466	0.464	-0.43%
WELDING TEE	0.776	0.730	-5.93%
WELDING TEE	0.597	0.558	-6.53%
WELDING TEE	0.702	0.719	**2.42%**
WELDING TEE	0.800	0.651	-18.63%
WELDING TEE	0.495	0.320	-35.35%
WELDING TEE	0.594	0.605	**1.85%**
BRANCH CONN	0.827	0.663	-19.83%
BRANCH CONN	0.579	0.408	-29.53%
WELDING TEE	0.797	0.578	-27.48%
WELDING TEE	0.801	0.574	-28.34%
WELDING TEE	0.814	0.645	-20.76%

Table 6.3.3.2-6: Seismic Support Loads for APP-RNS-PLA-170

Label	Force – X (lb)			Force – Y (lb)			Force - Z (lb)			Resultant Force (lb)		
	AP1000 CSDRS	HRHF	% Change	AP1000 CSDRS	HRHF	% Change	AP1000 CSDRS	HRHF	% Change	AP1000 CSDRS	HRHF	% Change
RIG SUPORT							5001	4817	-3.68%	5001	4817	-3.68%
RIG SUPORT	-6639	-4819	-27.41%							-6639	-4819	-27.41%
RIG SUPORT							7447	5351	-28.15%	7447	5351	-28.15%
RIG SUPORT				-7336	-6684	-8.89%				-7336	-6684	-8.89%
RIG SUPORT							1879	1703	-9.37%	1879	1703	-9.37%
RIG SUPORT				1767	1561	-11.66%				1767	1561	-11.66%
RIG SUPORT							2689	2057	-23.50%	2689	2057	-23.50%
RIG SUPORT	4144	3731	-9.97%							4144	3731	-9.97%
RIG SUPORT				-4114	-4083	-0.75%				-4114	-4083	-0.75%
RIG SUPORT							5369	4861	-9.46%	5369	4861	-9.46%
RIG SUPORT				2105	2150	**2.14%**				2105	2150	**2.14%**
RIG SUPORT	-7046	-6835	-2.99%							-7046	-6835	-2.99%
RIG SUPORT				1423	1439	**1.12%**				1423	1439	**1.12%**
RIG SUPORT							3207	2858	-10.88%	3207	2858	-10.88%
RIG SUPORT				-2158	-2124	-1.58%				-2158	-2124	-1.58%
RIG SUPORT							4209	3402	-19.17%	4209	3402	-19.17%
RIG SUPORT	-1182	-1121	-5.16%							-1182	-1121	-5.16%
RIG SUPORT				917	915	-0.22%				917	915	-0.22%
RIG SUPORT				2006	2081	**3.74%**				2006	2081	**3.74%**
RIG SUPORT	-6194	-5810	-6.20%							-6194	-5810	-6.20%
RIG SUPORT				1098	1222	**11.29%**				1098	1222	**11.29%**
RIG SUPORT							3762	3858	**2.55%**	3762	3858	**2.55%**
RIG SUPORT				-3026	-3047	**0.69%**				-3026	-3047	**0.69%**
RIG SUPORT							3648	3477	-4.69%	3648	3477	-4.69%
RIG SUPORT							2934	2572	-12.34%	2934	2572	-12.34%
RIG SUPORT	2658	2770	**4.21%**							2658	2770	**4.21%**
RIG SUPORT				3485	3008	-13.69%				3485	3008	-13.69%
RIG SUPORT				-2148	-1963	-8.61%				-2148	-1963	-8.61%
RIG SUPORT	-1156	-1167	**0.95%**							-1156	-1167	**0.95%**
RIG SUPORT				1059	1146	**8.22%**				1059	1146	**8.22%**
RIG SUPORT	-4308	-3560	-17.36%							-4308	-3560	-17.36%
RIG SUPORT							4992	4756	-4.73%	4992	4756	-4.73%
RIG SUPORT	-190	-215	**13.16%**							-190	-215	**13.16%**
RIG SUPORT				-224	-223	-0.45%				-224	-223	-0.45%
RIG SUPORT							2485	1964	-20.97%	2485	1964	-20.97%
RIG SUPORT				2465	1218	-50.59%				2465	1218	-50.59%
RIG SUPORT							1808	1431	-20.85%	1808	1431	-20.85%

RIG SUPORT							663	620	-6.49%	663	620	-6.49%
RIG SUPORT	1369	1399	**2.19%**							1369	1400	**2.26%**
RIG SUPORT				1506	1216	-19.26%				1506	1217	-19.19%
RIG SUPORT	-588	-534	-9.18%							-588	-532	-9.52%
RIG SUPORT				-1728	-1748	**1.16%**				-1728	-1747	**1.10%**
RIG SUPORT							4726	4867	**2.98%**	4726	4866	**2.96%**
RIG SUPORT				-863	-652	-24.45%				-863	-642	-25.61%
RIG SUPORT	795	820	**3.14%**							795	821	**3.27%**
RIG SUPORT							-2326	-2484	**6.79%**	-2326	-2481	**6.66%**
RIG SUPORT							2385	2602	**9.10%**	2385	2604	**9.18%**
RIG SUPORT				1133	1265	**11.65%**				1133	1265	**11.65%**
RIG SUPORT				1042	937	-10.08%				1042	964	-7.49%
RIG SUPORT	1051	1094	**4.09%**							1051	1100	**4.66%**
RIG SUPORT				-1343	-1355	**0.89%**				-1343	-1357	**1.04%**
RIG SUPORT							5918	6169	**4.24%**	5918	6177	**4.38%**
RIG SUPORT	-587	-531	-9.54%	1017	919	-9.64%				1174	1073	-8.60%
RIG SUPORT	-1043	-974	-6.62%	-602	-562	-6.64%				-1204	-1126	-6.48%
RIG SUPORT							-3225	-3442	**6.73%**	-3225	-3462	**7.35%**
RIG SUPORT							2068	1851	-10.49%	-2068	-1867	-9.72%
RIG SUPORT							1496	1363	-8.89%	-1496	-1366	-8.69%
RIG SUPORT	1410	1346	-4.54%							1410	1356	-3.83%
RIG SUPORT				-1598	-1614	**1.00%**				-1598	-1614	**1.00%**
RIG SUPORT				728	704	-3.30%				728	704	-3.30%
RIG SUPORT							2109	2044	-3.08%	2109	2081	-1.33%
RIG SUPORT				-608	-976	**60.53%**				-608	-985	**62.01%**
RIG SUPORT							1984	1723	-13.16%	1984	1776	-10.48%
RIG SUPORT	-4043	-3193	-21.02%							-4043	-3325	-17.76%
RIG SUPORT				2143	1199	-44.05%				2143	1381	-35.56%
RIG SUPORT							624	538	-13.78%	624	567	-9.13%

Table 6.3.3.2-7: Seismic Anchor Loads for APP-RNS-PLA-170

Label	Force - X (lb)			Force - Y (lb)			Force - Z (lb)			Resultant Force (lb)		
	AP1000 CSDRS	HRHF	% Change	AP1000 CSDRS	HRHF	% Change	AP1000 CSDRS	HRHF	% Change	AP1000 CSDRS	HRHF	% Change
Penetration P20	1813	1618	-10.76%	-1360	-1118	-17.79%	3607	3230	-10.45%	4259	3781	-11.22%
ANCHOR	1075	669	-37.77%	896	748	-16.52%	3258	2506	-23.08%	3546	2699	-23.89%
ANCHOR	1470	649	-55.85%	-1548	-709	-54.20%	651	555	-14.75%	2232	1111	-50.22%
ANCHOR	636	362	-43.08%	825	438	-46.91%	1079	805	-25.39%	1500	986	-34.27%
Penetration P19	11097	10056	-9.38%	-7929	-5286	-33.33%	5081	5403	**6.34%**	14554	12580	-13.56%

ANCHOR	-4020	-3548	-11.74%	-1532	-1601	**4.50%**	3722	3288	-11.66%	5688	5095	-10.43%
ANCHOR	-3208	-3367	**4.96%**	2431	2250	-7.45%	4053	3933	-2.96%	5713	5645	-1.19%
ANCHOR	3780	2938	-22.28%	4787	4311	-9.94%	6332	4819	-23.89%	8792	7102	-19.22%

Label	Moment - X (ft-lb)			Moment - Y (ft-lb)			Moment - Z (ft-lb)			Resultant Moment (ft-lb)		
	AP1000 CSDRS	HRHF	% Change	AP1000 CSDRS	HRHF	% Change	AP1000 CSDRS	HRHF	% Change	AP1000 CSDRS	HRHF	% Change
Penetration P20	-3541	-3102	-12.40%	13752	12441	-9.53%	5702	5687	-0.26%	15303	14026	-8.34%
ANCHOR	5593	3902	-30.23%	-8566	-4437	-48.20%	1747	987	-43.50%	10379	5990	-42.29%
ANCHOR	-298	-255	-14.43%	280	237	-15.36%	-301	-131	-56.48%	507	372	-26.63%
ANCHOR	-450	-458	**1.78%**	621	585	-5.80%	-217	-173	-20.28%	797	763	-4.27%
Penetration P19	-21916	-23723	**8.25%**	11168	12148	**8.78%**	69914	54200	-22.48%	74115	60399	-18.51%
ANCHOR	-4880	-4185	-14.24%	-18235	-16218	-11.06%	-8176	-8115	-0.75%	20571	18612	-9.52%
ANCHOR	-9923	-9625	-3.00%	-6067	-6336	**4.43%**	2865	3211	**12.08%**	11979	11962	-0.14%
ANCHOR	-13095	-11856	-9.46%	-11543	-10006	-13.32%	12149	11017	-9.32%	21268	19028	-10.53%

Table 6.3.3.2-8: Equipment Nozzle Stresses for APP-RNS-PLA-170

Label	Equation 9F Stress Ratio		
	AP1000 CSDRS	HRHF	% Change
HX ME01A Inlet	0.174	0.163	-6.32%
HX ME01A Outlet	0.119	0.119	0.00%
HX ME01B Inlet	0.167	0.174	**4.19%**
HX ME01B Outlet	0.165	0.194	**17.58%**
Pump MP01A Inlet	0.257	0.169	-34.24%
Pump MP01A Outlet	0.042	0.043	**2.38%**
Pump MP01B Inlet	0.248	0.174	-29.84%
Pump MP01B Outlet	0.061	0.06	-1.64%

Results Summary for APP-RNS-PLA-170

- Equation 9F stress ratios are all less than 1.0. No point of the HRHF GMRS analysis fails qualification.
- The ten highest stressed points for both the AP1000 CSDRS and HRHF GMRS analyses show decreases in stress ratio at all but one point, which is a 1% increase.
- Less than 15% of all points show an increase in stress ratio. These increases occur at points with low stress ratios (< 0.5). The greatest increase is approximately 18%.
- Valve nozzles stress ratio increases are within 5%.
- Tee connection stress ratio increases are within 2%.
- The greatest resultant support load increases occur at supports with low loads (< 2000 lbs). All other resultant support loads show increases less than 10%.
- Resultant anchor loads show no increase.
- Piping stress ratios at equipment show small to moderate increases, but at stress ratios less than 0.2.

6.3.4 Summary and Conclusions

PIPESTRESS seismic analyses of the two packages were performed with both AP1000 CSDRS and HRHF GMRS input. The AP1000 CSDRS analysis was performed with 15% peak broadened and enveloped response spectra. The HRHF GMRS analysis was performed with 15% peak broadened and enveloped response spectra with incoherence.

The majority of all points showed a decrease or no change in stress ratio. For the points that did show stress ratio increases, the stress ratios were already low and remained low (< 0.5). The largest increase was approximately 18%, but this still resulted in a low stress ratio of 0.454.

The few resultant support and anchor loads increases were at points with low loads (< 2000 lbs). At other points with higher loads, increases were within 10%.

These small increases could be reduced or eliminated with more complex analysis techniques. These techniques would further show that HRHF has minimal impact on piping stresses. These techniques include:

- Use of multiple input response spectra. Multiple input response spectra reduces the spectra exciting the lower points dues to attachments at higher elevations.
- Use of more selective input response spectra. The spectra shown here, envelope entire floors: a practice used for the AP1000 design basis analysis. A more localized selection of nodes would lower the input HRHF GMRS to a more appropriate level.
- Use of a time history analysis. A time history analysis would further reduce results by eliminating the conservatism of a response spectrum analysis.
- Use of non-linear analysis. A non-linear analysis would allow for more accurate modeling of gapped supports. The gap of installed supports are not reflected in a PIPESTRESS analysis. By modeling support gaps, the response of higher modes may be eliminated because supports are not engaged due to the low displacements (< 1/16 of an inch) of high frequency inputs.

6.4 Safety-Related Electrical Equipment

6.4.1 Introduction

This section presents the results of a technical study performed to confirm that seismic qualification to the AP1000 Certified Seismic Response Spectra (CSDRS) envelops the seismic qualification to the hard rock high frequency (HRHF) seismic inputs for most applications.

The study also includes review of existing seismic test data of typical equipment supplied to nuclear power plants. The review concludes that low frequency seismic tests envelop high frequency input up to 2.0 g spectral acceleration (at 5% critical damping) and no additional seismic testing is required when the HRHF seismic inputs are below this level.

Susceptibility to excitation caused by high frequency input requires the following factors to be present:

- The local HRHF floor response spectra need to exceed the AP1000 CSDRS in the high frequency range.
- The safety-related equipment must have modes or natural frequencies in the high frequency range.
- The safety-related components must have potential failure modes involving change of state, chatter, signal change/drift, and/or connection problems.

It is expected that equipment with modes in the range of the high frequency response excitation will experience higher loads and amplifications than equipment with modes outside this range. To support this expectation and determine the effect of high frequency seismic motion on the AP1000 safety-related electrical equipment, a review of the equipment configuration, location, stress analysis methodology, and equipment qualification testing procedure was conducted. This review led to a selection of safety-related electrical equipment that is most susceptible to high frequency motion.

The conclusion of the study presented in this section is that the qualification methodology (analytical evaluations and testing procedures) currently employed generally leads to a more conservative design than that which would result from the HRHF spectra. This study also provides a process to determine and address equipment which may have sensitivity to the HRHF excitation.

6.4.2 Evaluation Process

The intent of the evaluation is to provide evidence that seismic qualification (testing and analysis) of safety-related equipment to the CSDRS produces seismic loads and accelerations that envelop the loads and accelerations generated by the high frequency seismic inputs. This is achieved by completion of the following steps:

a. Comparative Analyses

Analysis is performed on finite element models of typical safety-related equipment structures to show that low frequency seismic input produces loads and accelerations that envelop most of the seismic loads and accelerations generated by the high frequency seismic input. The comparative seismic analyses are performed on finite element models associated with typical equipment used to house safety-related electrical equipment. The comparative seismic analyses (time history and response spectra) are performed for both low frequency AP1000 CSDRS and HRHF seismic inputs generated for the AP1000 Auxiliary and Shield Building Main Control Room (MCR) floor at an elevation of 116.5 ft. The analytical study compares results for AP1000 CSDRS low frequency seismic input against the AP1000 HRHF seismic input. The comparative seismic analyses are made using the ANSYS (Version 10) computer program.
The evaluation includes:

i. Selection of equipment samples and models
ii. Comparison of the evaluation of analytical models to high and low frequency seismic inputs
iii. Evaluation of the results

b. Review of Existing Test Data

Existing test data for multi-frequency (random) multi-axis seismic test programs are reviewed to determine if high frequency excitation was exhibited in the frequency range of 25 to 50 Hz. Test data for seismic test programs for safety-related electrical cabinets and electrical cabinets which were tested for compliance with the Uniform Building Code (UBC) were reviewed. Selection of test programs for this study was based on the following:

- Test program not fragility test program

- Equipment was required to maintain functional operability and structural integrity
- Seismic random test motion in each of the three orthogonal input axes was generated in compliance with IEEE Std 344-1987.

The evaluation includes:

i. Selection of existing seismic test programs
ii. Review of seismic test data
iii. Results and conclusions

c. Development of the Screening Process to Determine Sensitive Equipment

The end result of the evaluation is the development of a process to be followed for screening sensitive equipment. The evaluation includes:

i. Determination of structural response to high frequency
ii. Identification of sensitive equipment and components
iii. Establish criteria for screening equipment that may require incremental testing

6.4.3 Comparative Analyses

The purpose of the study is to gain intelligence and evaluate the effects of high frequency seismic input on typical safety-related equipment. These analyses are used to determine if qualification based upon low frequency seismic input generated in accordance with the CSDRS envelops the qualification at sites with the HRHF high frequency input.

6.4.3.1 Seismic Inputs

The evaluation of the finite element models compares the seismic loads, stresses, displacements, and In-Equipment Response Spectra (IERS) produced by high frequency seismic input with those produced by low frequency seismic input. The high and low frequency response spectra and time histories provided for this study are based on the AP1000 Main Control Room (MCR) floor seismic requirements at an elevation of 116.5 ft. The high frequency response spectra and time histories are based on HRHF levels. Figure 6.4.3.1-1 shows the locations of the nodes from the finite element model of the AP1000 Auxiliary and Shield Building used to generate both the high and low frequency response spectra and time histories.

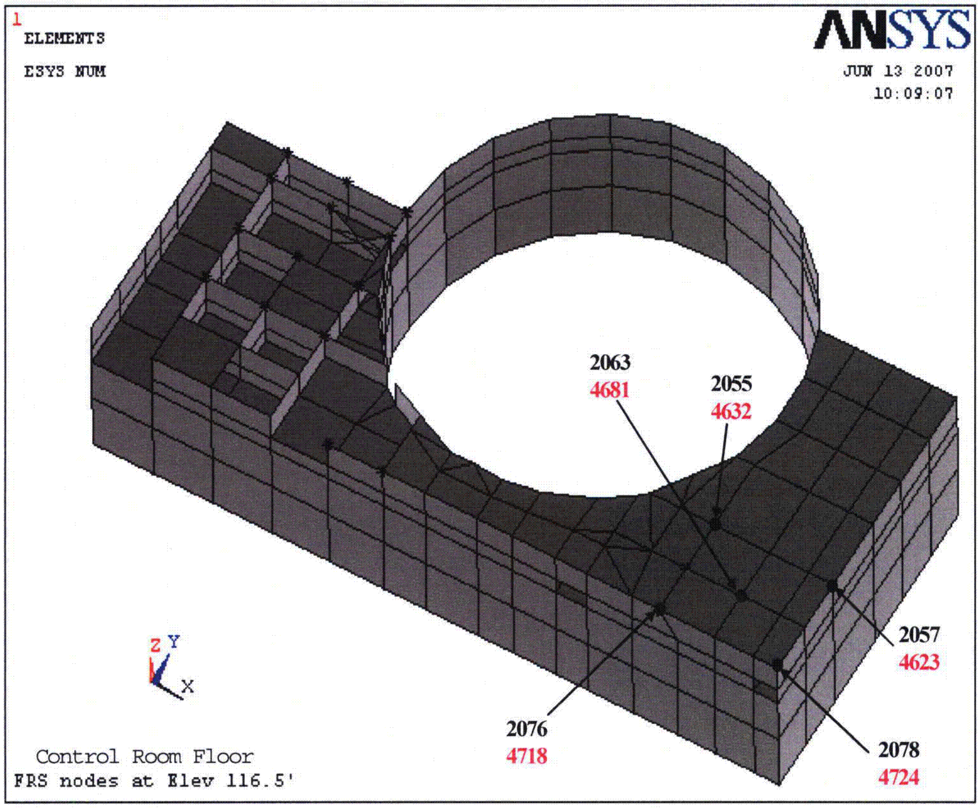


Figure 6.4.3.1-1: AP1000 Auxiliary and Shield Building Finite Element Model

6.4.3.2 Finite Element Model Samples

Equipment finite element models typical of safety-related equipment for nuclear power plant applications were used as representative samples for the comparative evaluation.

Five finite element cabinet and console models developed for seismic qualification of safety-related equipment in nuclear power plants were selected for this study. These models were chosen to provide a wide range of dynamic responses and dominant natural frequencies and include:

- Main Control Room (MCR) SafetyA01-A05 Console Line-up (Figure 6.4.3.2-1)
- Auxiliary Protection Cabinet (APC) (Figure 6.4.3.2-2)
- MCR Large Display (B13-B16) Panel Line-up (Figure 6.4.3.2-3)
- Process Instrumentation (PI) 4 Cabinet Suite (Figure 6.4.3.2-4)
- Remote Operator Shutdown Panel (ROP) Console (Figure 6.4.3.2-5)

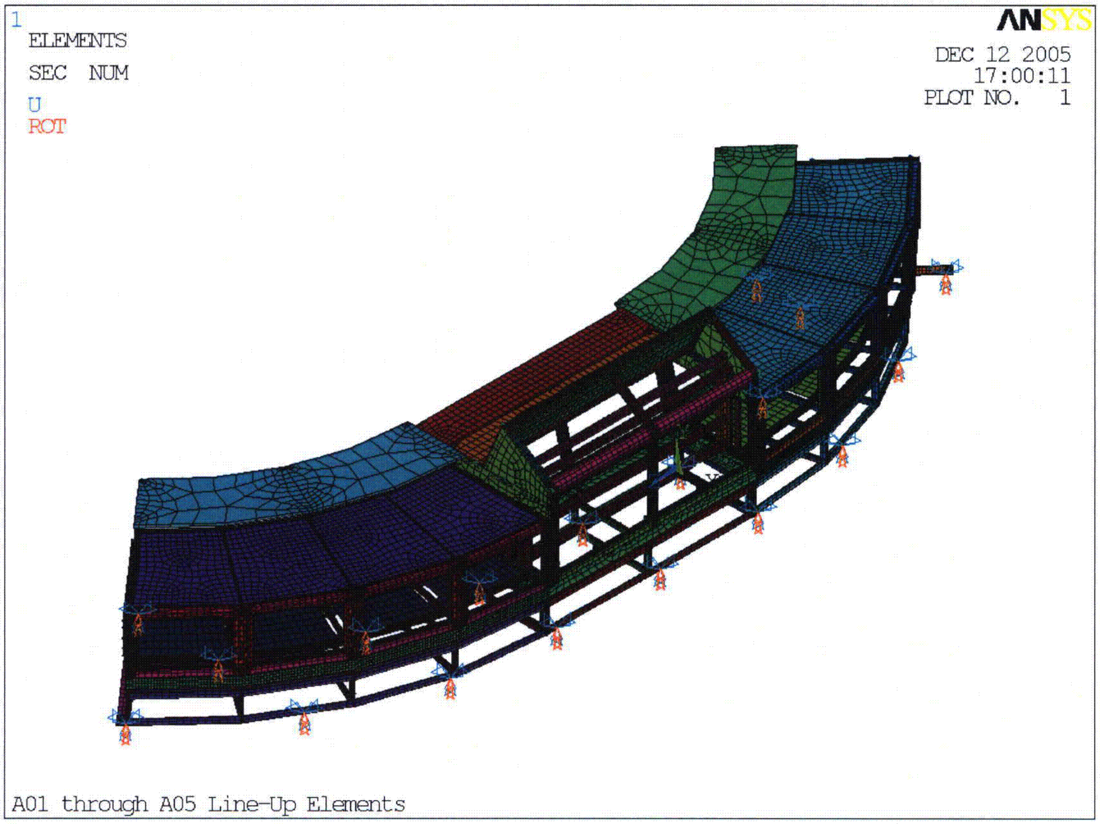


Figure 6.4.3.2-1: MCR (A01-A05) Safety Console Line-up Finite Element Model

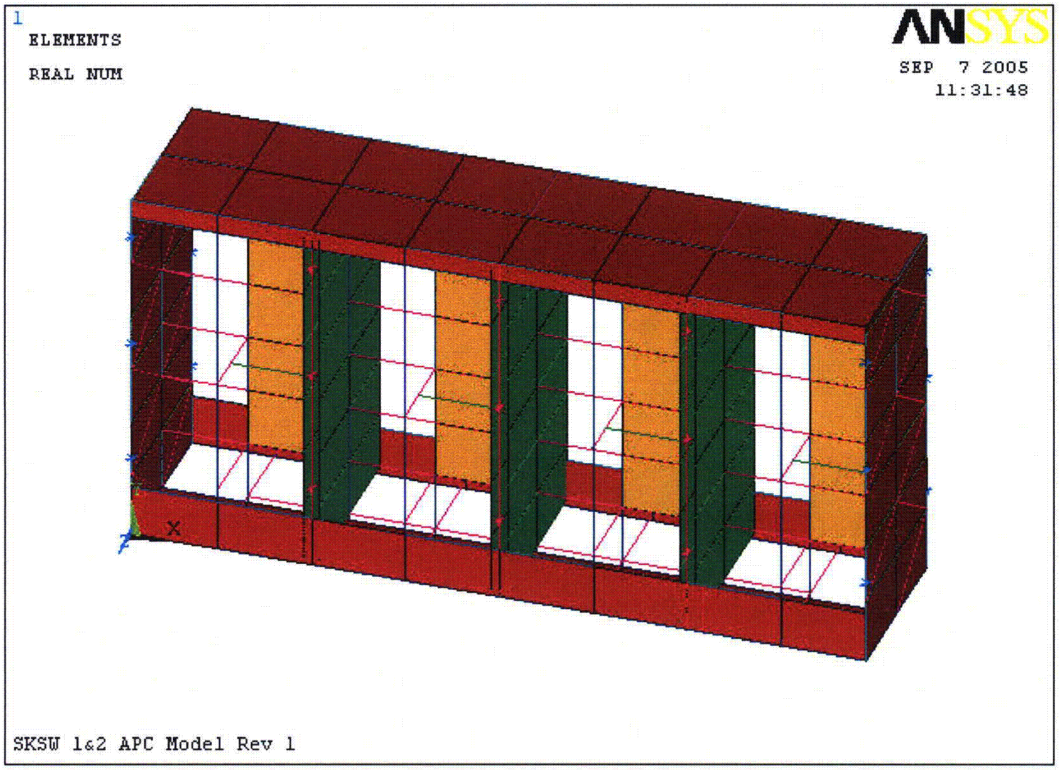


Figure 6.4.3.2-2: Finite Element Model of Auxiliary Protection Cabinet (APC)

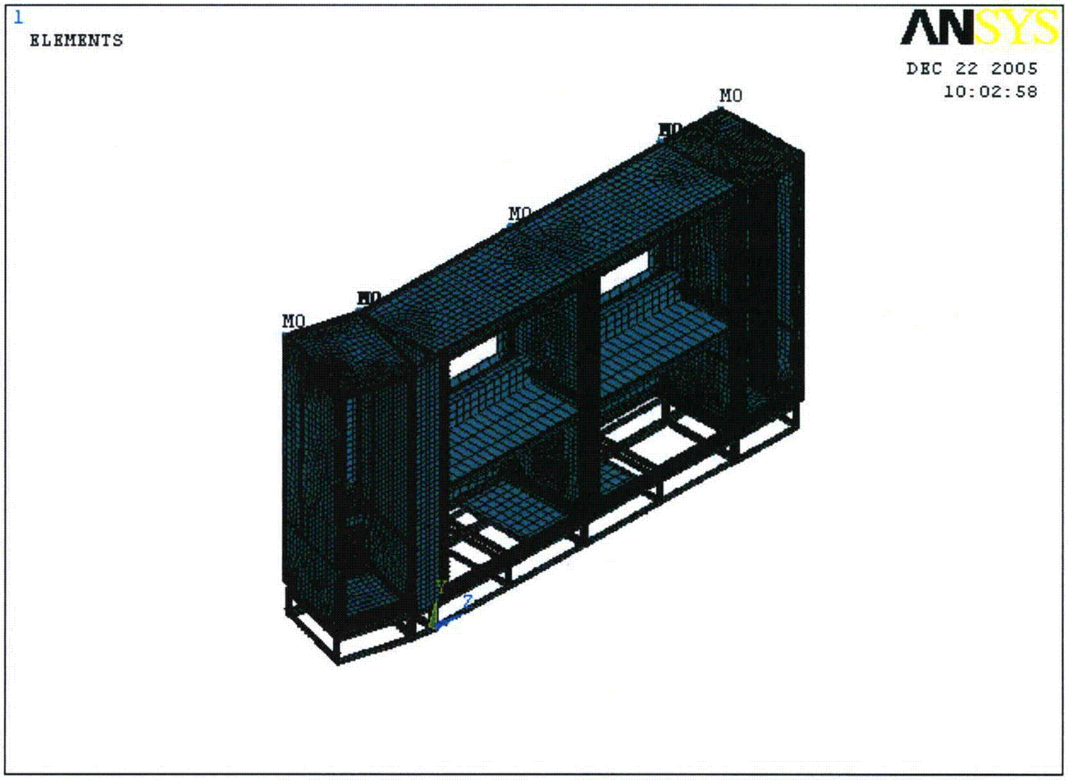


Figure 6.4.3.2-3: MCR Large Display (B13-B16) Panel Line-up Finite Element Model

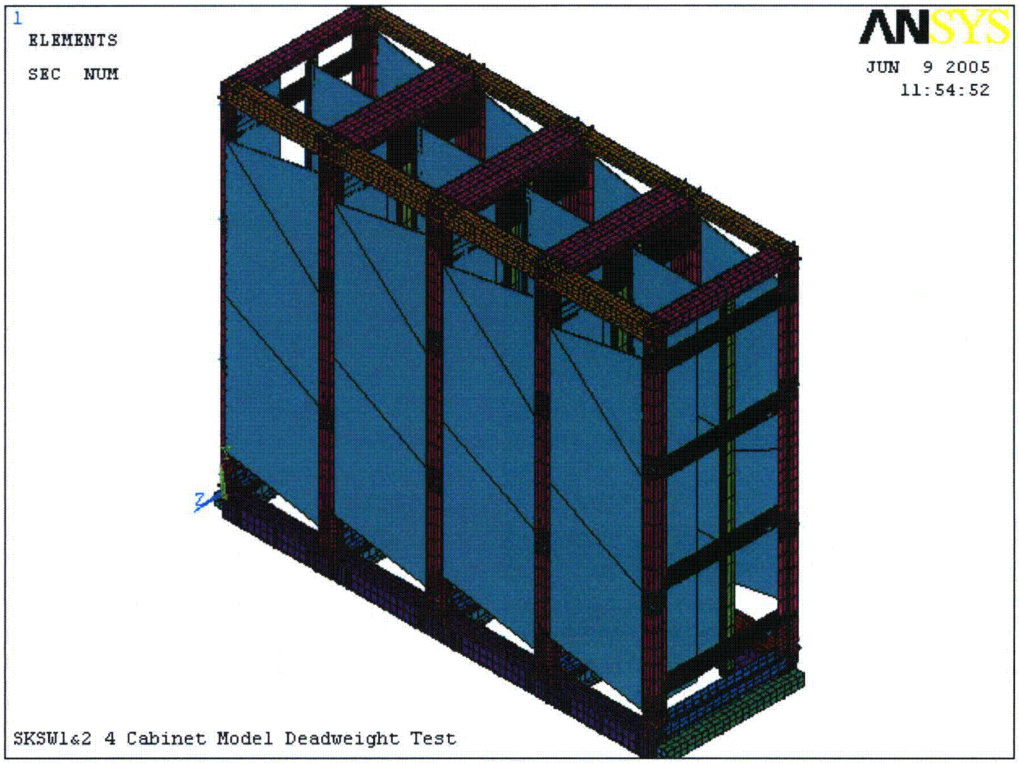


Figure 6.4.3.2-4: Process Instrumentation (PI) 4 Cabinet Suite Finite Element Model

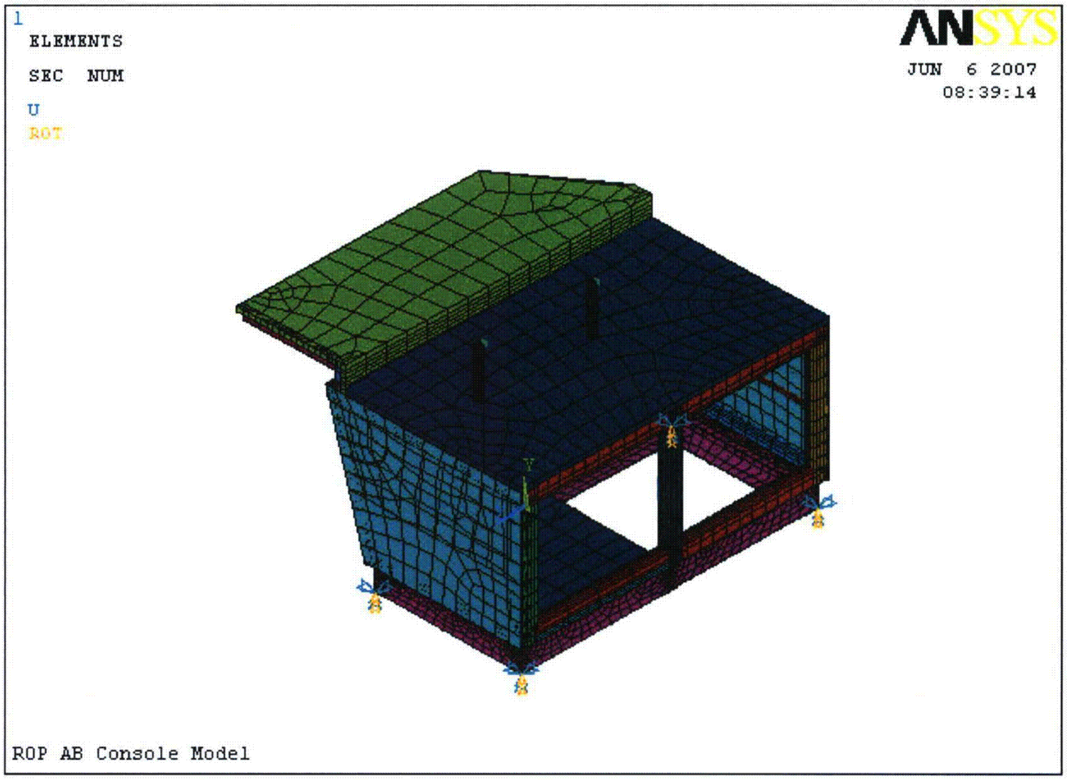


Figure 6.4.3.2-5: Remote Operator Shutdown Panel (ROP) Console Finite Element Model

6.4.3.3 Seismic Analysis of Models

6.4.3.3.1 General

The five models are analyzed using low frequency seismic input based on CSDRS and high frequency inputs based on HRHF seismic requirements. The initial analyses demonstrate that the B13-B16 Panel Line-up and the ROP Console have low frequency results that envelop the high frequency results. This is expected as the B13-B16 Panel Line-up has natural frequencies in the 8 to 9 Hz range and the ROP Console is rigid (first natural frequency in excess of 50 Hz). This supports the initial expectation that equipment without modes in the high frequency range (25 to 50 Hz) is not sensitive to the HRHF excitation.

The following sections provide results for the three remaining models (A01-A05, APC, and PI models-Figures 6.4.3.2-1, 6.4.3.2-2 and 6.4.3.2-4, respectively) which were chosen for the high frequency seismic analysis. The response spectra and time history analyses are performed using ANSYS, Version 10.0. The details of the analyses and a comparison of the results from the high frequency versus the low frequency input for each of the three models are discussed in the following sections. The analyses demonstrate that the high frequency results are enveloped by the results of the low frequency seismic input, except when the high frequency input coincides with the predominate natural frequencies of the cabinet.

6.4.3.3.2 Analysis Method and Floor Seismic Requirements

The intent of the study is to generate analytical data to aid in understanding how finite element models respond to low and high frequency inputs and how the dominant natural frequencies of the models affect the results. The evaluation is performed using the steps listed below:

- Determine seismic inputs (low and high frequency)
- Perform response spectra analyses to generate loads and stresses in the structural members and mounting configurations due to both low and high frequency inputs
- Perform time history analysis to generate in-equipment response spectra (IERS) at the components' mounting due to both low and high frequency inputs
- Compare results from high frequency seismic input with results from low frequency input and confirm that low frequency results envelop high frequency seismic input results.

Figures 6.4.3.3.2-1 through 6.4.3.3.2-3 show the high and low frequency response spectra considered in this study.

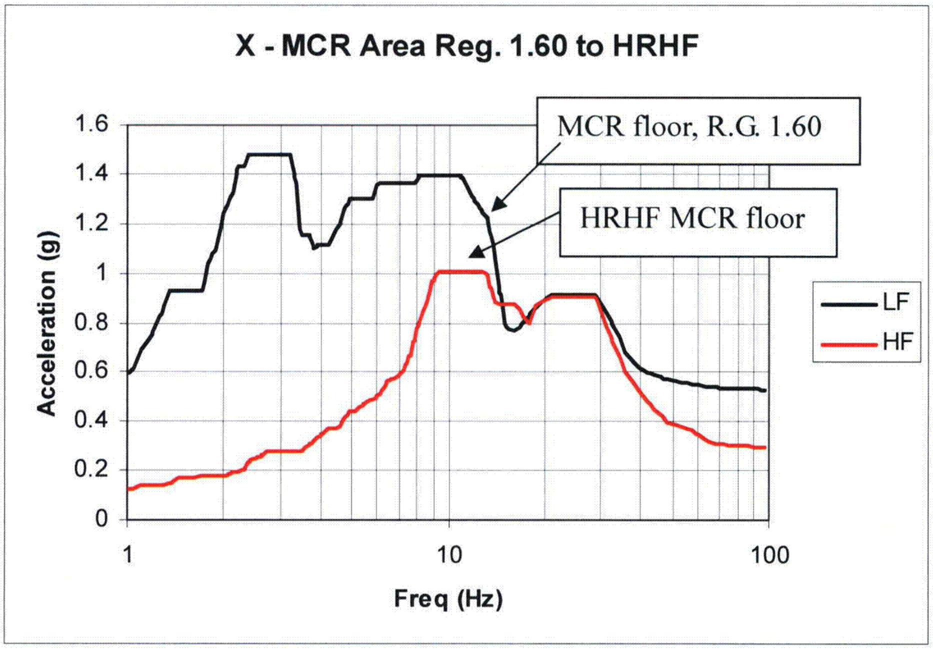


Figure 6.4.3.3.2-1: High/Low Frequency Response Spectra X-Direction (Horizontal) High Frequency Response Spectra Shown in Red (5% Critical Damping)

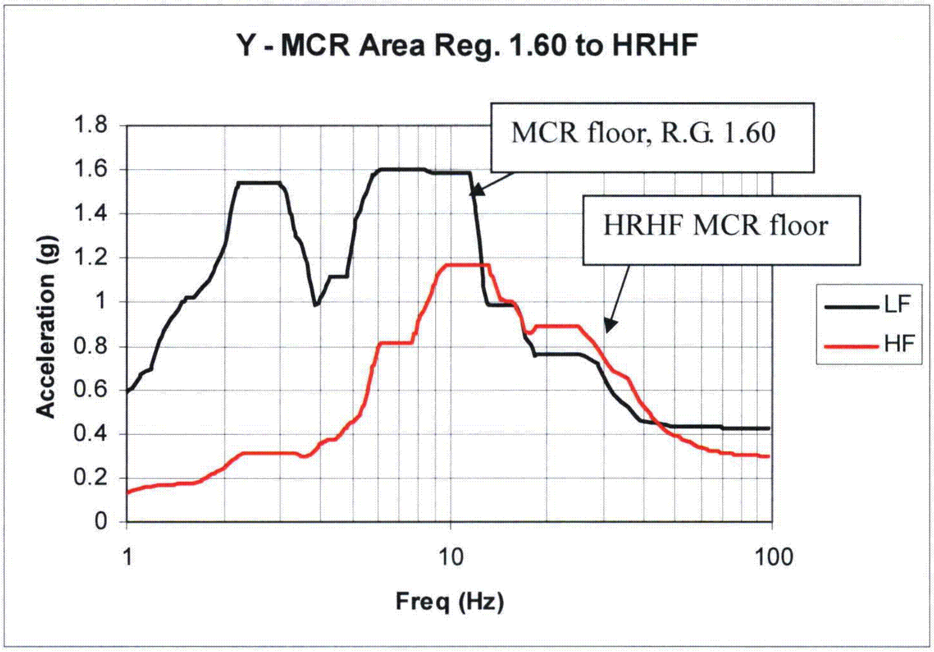


Figure 6.4.3.3.2-2: High/Low Frequency Response Spectra Y-Direction (Horizontal)
High Frequency Response Spectra Shown in Red
(5% Critical Damping)

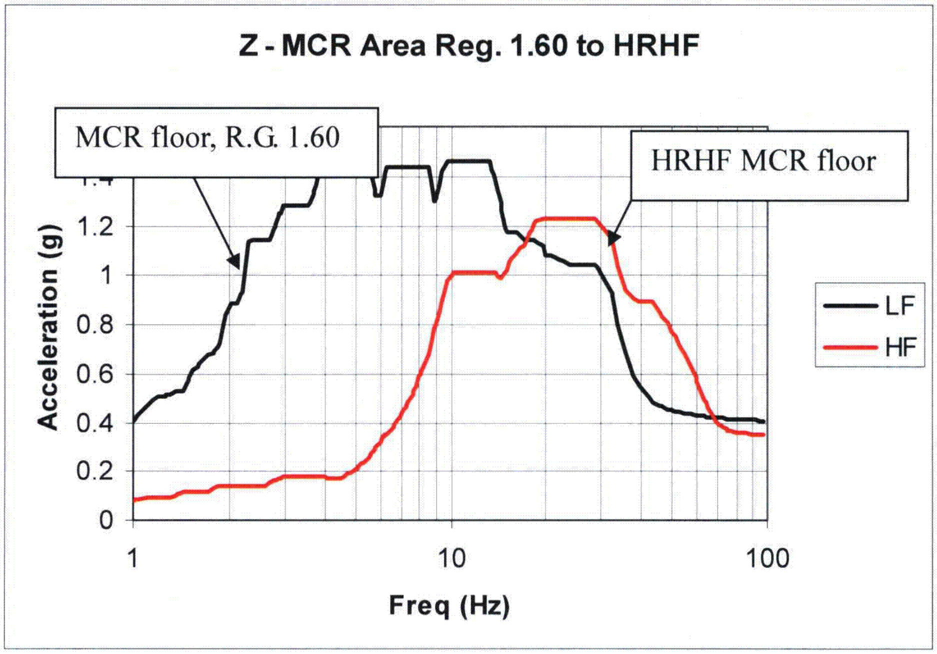


Figure 6.4.3.3.2-3: High/Low Frequency Response Spectra Z-Direction (Vertical)
High Frequency Response Spectra Shown in Red
(5% Critical Damping)

6.4.3.3.3 Analysis of A01-A05 Console Line-up Model

Figure 6.4.3.2-1 shows the finite element plot of the A01-A05 console line-up model. The natural frequencies of the model are:

X-direction (Front-Back):	11.4 Hz
Y-direction (Side-Side):	18.0 Hz
Z-direction (Vertical):	26.8 Hz

The response spectrum analysis determines the model displacements, loads and stresses resulting from the input response spectra. Tables 6.4.3.3.3-1 and 6.4.3.3.3-2 compare the results of the response spectrum analysis using high frequency input with the results using low frequency input for the maximum console displacement and mounting bolt loads. These results are representative of the seismic response of the console. The results of the evaluation demonstrate that low frequency seismic input resultant loads and stresses envelop the results of the high frequency seismic input.

The time history analysis determine that the In-Equipment Response Spectra (IERS) at the top corners of the model desktop and the base node where the input time histories are applied to the model. Figures 6.4.3.3.3-1 through 6.4.3.3.3-3 show the comparison of the IERS developed using high frequency input with the IERS developed using low frequency input.

The IERS produced by high frequency input are generally enveloped by or equivalent to the IERS produced by low frequency seismic input except for the vertical direction (Figure 6.4.3.3.3-3). Figure 6.4.3.3.3-3 reveals that the vertical IERS peak at the model vertical natural frequency of 26.8 Hz. This supports the conclusion that low frequency seismic IERS predictably envelop those generated by the high frequency input when the dominant natural frequencies of the equipment do not coincide with the HRHF floor peak accelerations. For this particular instance, the Test Response Spectra (TRS) for the A01-A05 component testing is also shown in Figures 6.4.3.3.3-1 through 6.4.3.3.3-3 and envelops the HRHF IERS.

Table 6.4.3.3.3-1: Comparison of A01-A05 Maximum Console Displacements

Spectra	Description	UX Max (Console Front-to-Back)		UY Max (Console Side-to-Side)	UZ Max (Console Vertical)	Max. HF/LF Ratio
Low Frequency	**Node:**	**12334**	**12358**	**20132**	**10150**	**0.96**
	Value (mm):	**4.45**	**4.40**	**1.12**	**5.54**	
High Frequency	**Node:**	**12334**	**12358**	**20132**	**10150**	
	Value (mm):	**3.66**	**3.67**	**1.05**	**5.31**	

Table 6.4.3.3.3-2: Comparison of A01-A05 Maximum Console Mounting Bolt Loads

Spectra	Maximum Tension	Maximum Shear	SRSS (N)	Ratio (HF/LF)
Low	**4760.4**	**5599.2**	**7349.3**	**0.82**
High	**3957.0**	**4592.3**	**6061.9**	

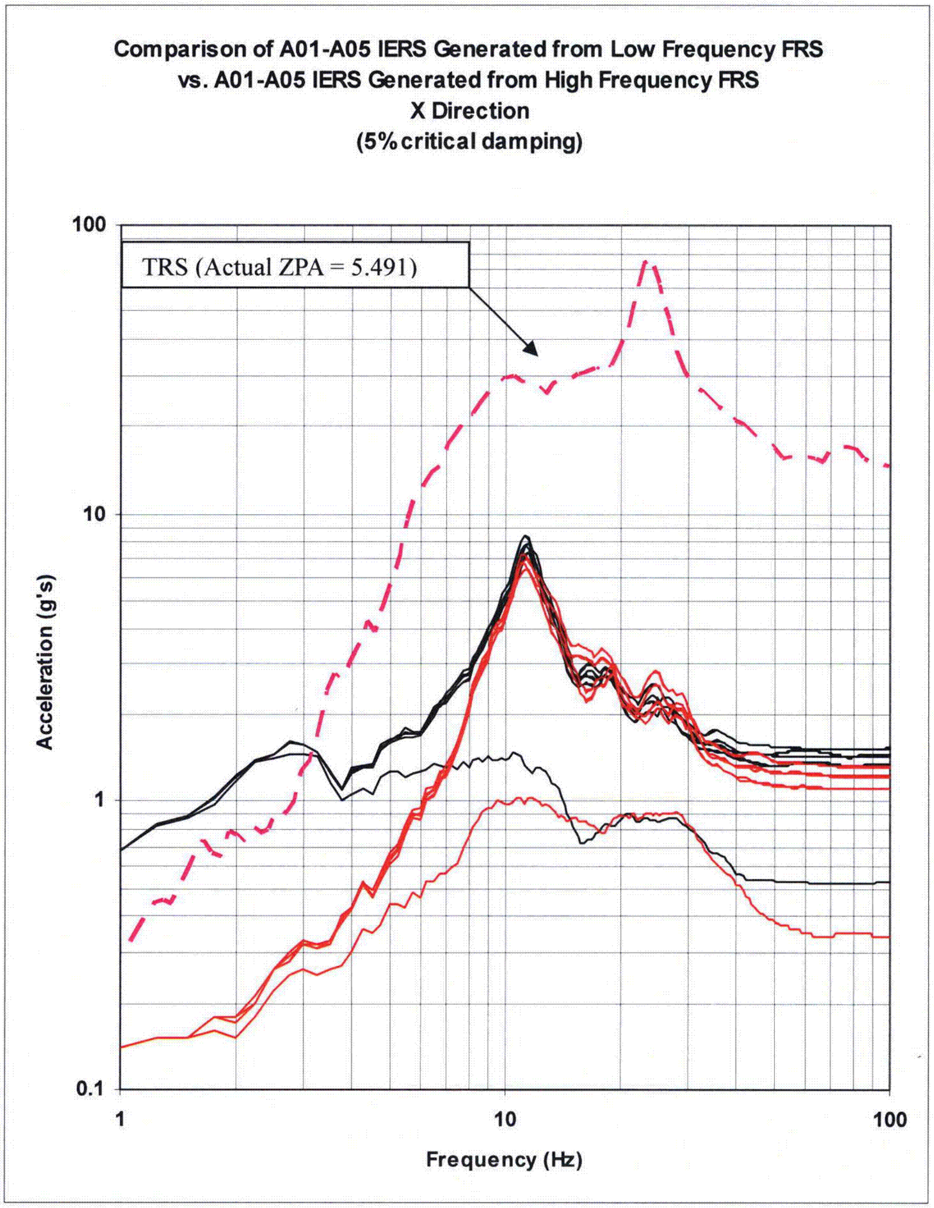


Figure 6.4.3.3.3-1: Comparison of A01-A05 Console Model IERS, X-Direction (Front-Back) High Frequency IERS Shown in Red, Low Frequency IERS shown in Black, Tested Spectra is Shown in Dashed Pink (5% Critical Damping)

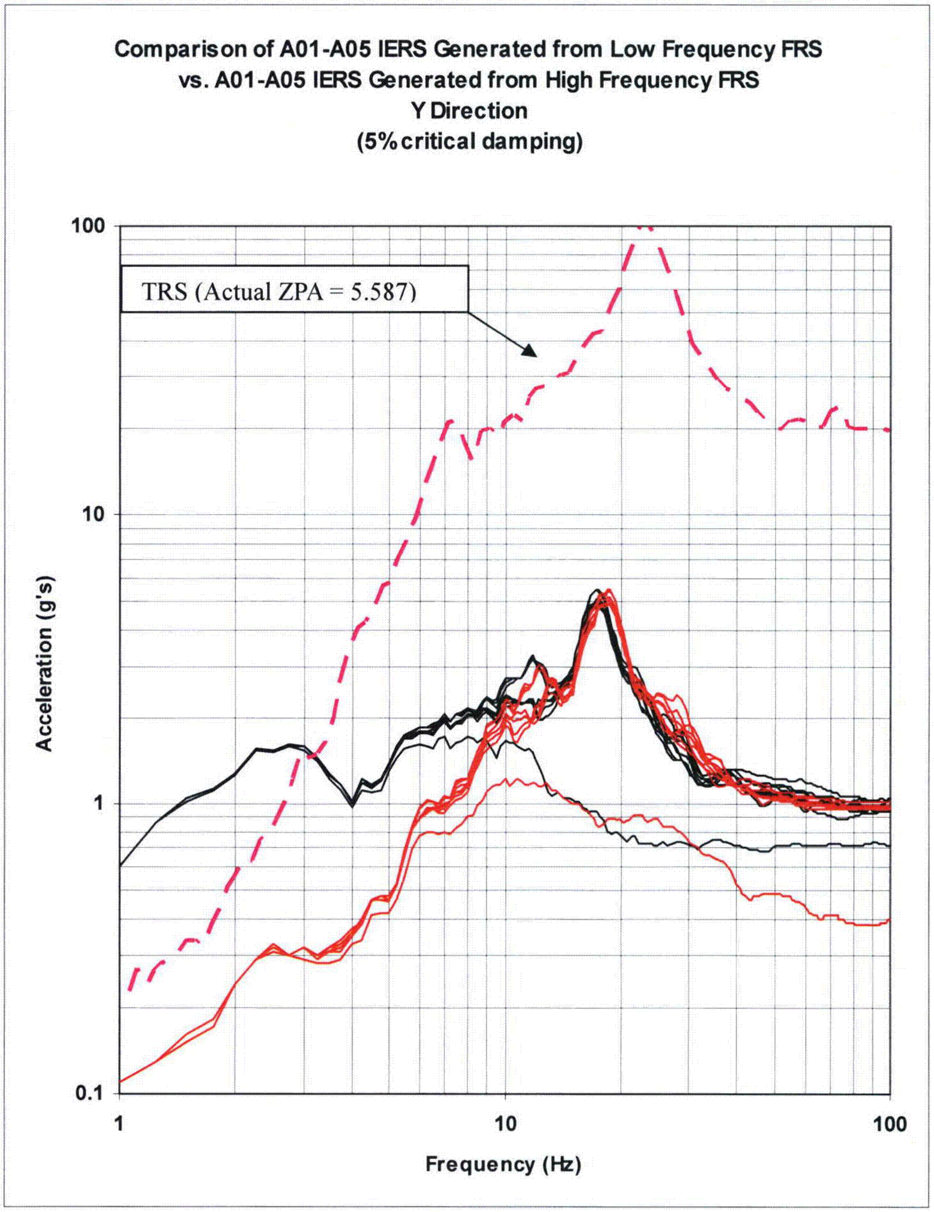


Figure 6.4.3.3.3-2: Comparison of A01-A05 Console Model IERS, Y-Direction (Side-Side) High Frequency IERS Shown in Red, Low Frequency IERS shown in Black, Tested Spectra is Shown in Dashed Pink (5% Critical Damping)

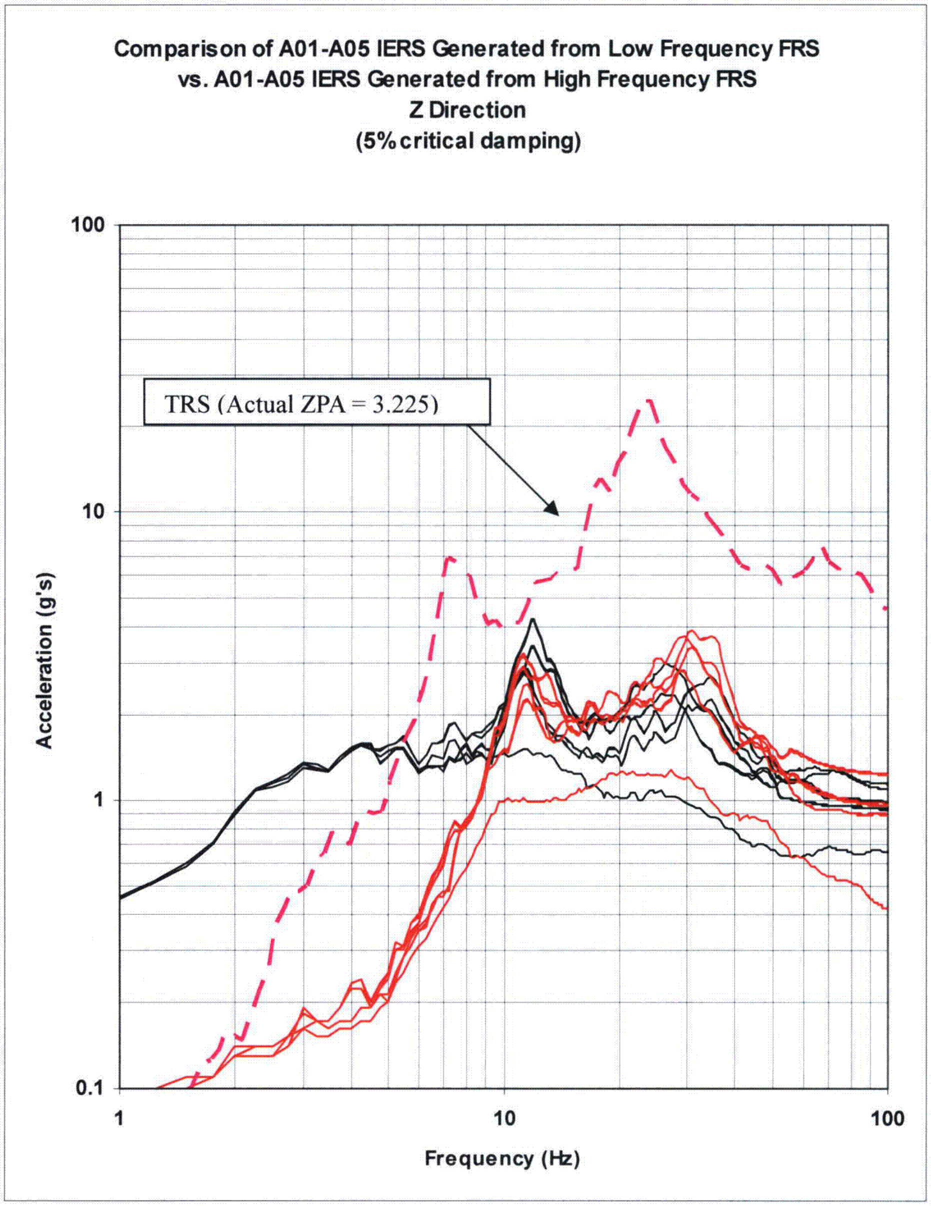


Figure 6.4.3.3.3-3: Comparison of A01-A05 Console Model IERS, Z-Direction (Vertical) High Frequency IERS Shown in Red, Low Frequency IERS shown in Black, Tested Spectra is Shown in Dashed Pink (5% Critical Damping)

6.4.3.3.4 Analysis of APC Finite Element Model

Figure 6.4.3.2-2 shows the APC finite element model. The natural frequencies are computed as:

X-direction (Side-Side):	18.7 Hz
Y-direction (Front-Back):	28.0 Hz
Z-direction (Vertical):	>33 Hz

The response spectrum analysis determines the model displacements, loads, and stresses resulting from the input response spectra. Tables 6.4.3.3.4-1 and 6.4.3.3.4-2 compare the results of the response spectrum analysis using high frequency input with the results using low frequency input for the APC model.

Table 6.4.3.3.4-1 shows that the maximum displacement of the structure increased from 0.013 inch (low frequency seismic input) to 0.014 inch (high frequency seismic input) with a maximum ratio of 1.09. This increase, while expected as the front-back mode at 28.0 Hz lies within the HF range, is very small. It is also noted that this particular cabinet is very stiff and has extremely small displacements that are not of a concern. Also, Table 6.4.3.3.4-2 shows that the mounting bolt loads from the low frequency input envelop those of the high frequency input.

The time history analysis determined the IERS at various points within the model and the base node where the input time histories are applied to the model. Figures 6.4.3.3.4-1 through 6.4.3.3.4-3 show the comparison that the IERS developed using high frequency input with the IERS developed using low frequency input for the APC model. Consistent with expectations, the HRHF IERS are higher than the low frequency IERS at the cabinet resonances in the high frequency range.

The study of the APC model results in the conclusion that when safety-related equipment has dominant natural frequencies in the HRHF exceedance range, additional evaluation is required to verify acceptability.

Table 6.4.3.3.4-1: Comparison of APC Maximum Cabinet Displacements

Spectra	Description	UX Max (Cabinet Side-to-Side)	UY Max (Cabinet Front-to-Back)	UZ Max (Cabinet Vertical)	Max. HF/LF Ratio
Low Frequency	**Node:**	**64**	**80**	**229**	**1.09**
	Value (inches):	**0.040**	**0.013**	**0.009**	
High Frequency	**Node:**	**64**	**80**	**229**	
	Value (inches):	**0.035**	**0.014**	**0.009**	

Table 6.4.3.3.4-2: Comparison of APC Maximum Cabinet Mounting Bolt Loads

Spectra	Maximum Tension	Maximum Shear (lb)	SRSS (lb)	Ratio (HF/LF)
Low Frequency	**2113.5**	**932.1**	**2309.9**	**0.94**
High Frequency	**1983.0**	**861.3**	**2162.0**	

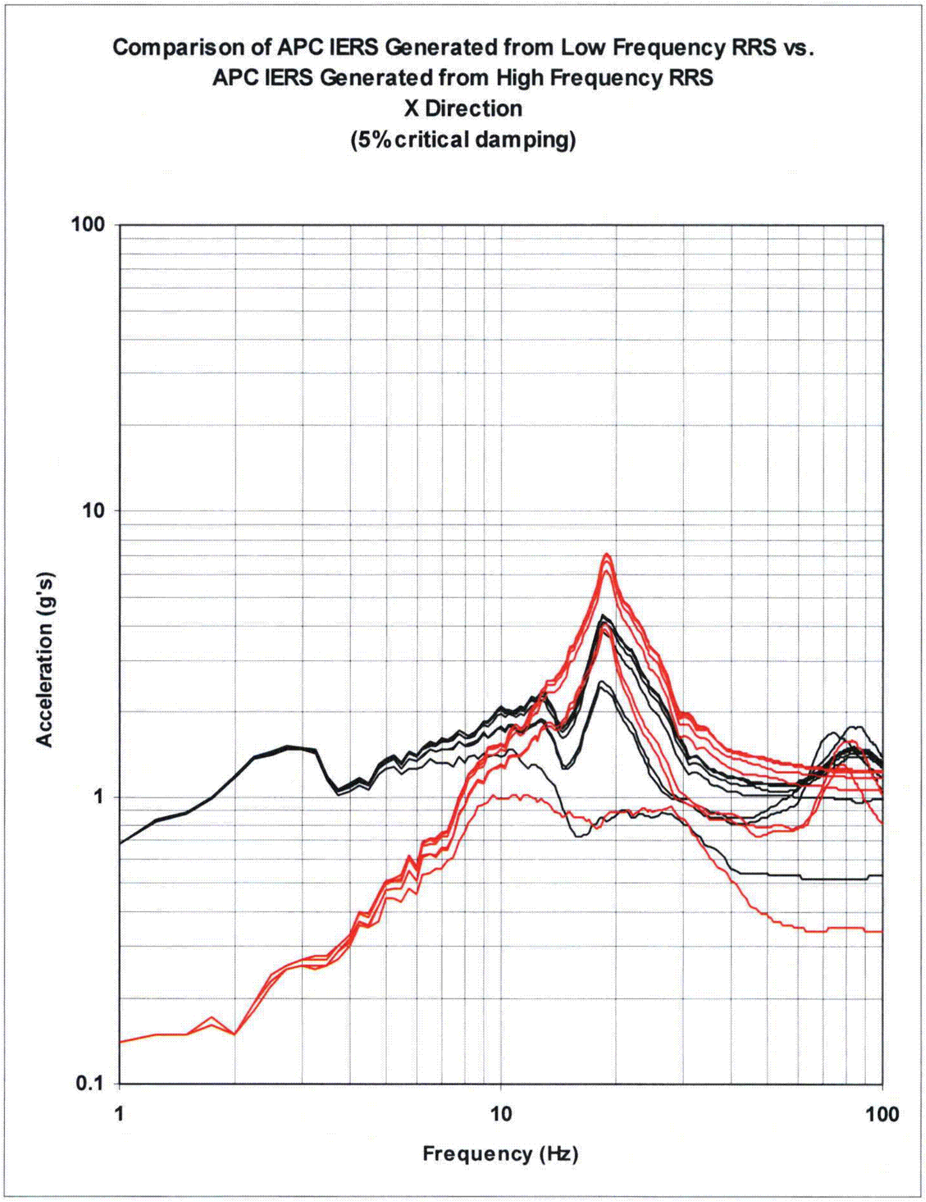


Figure 6.4.3.3.4-1: Comparison of APC Model IERS, X-Direction (Side-Side) High Frequency IERS Shown in Red, Low Frequency IERS shown in Black (5% Critical Damping)

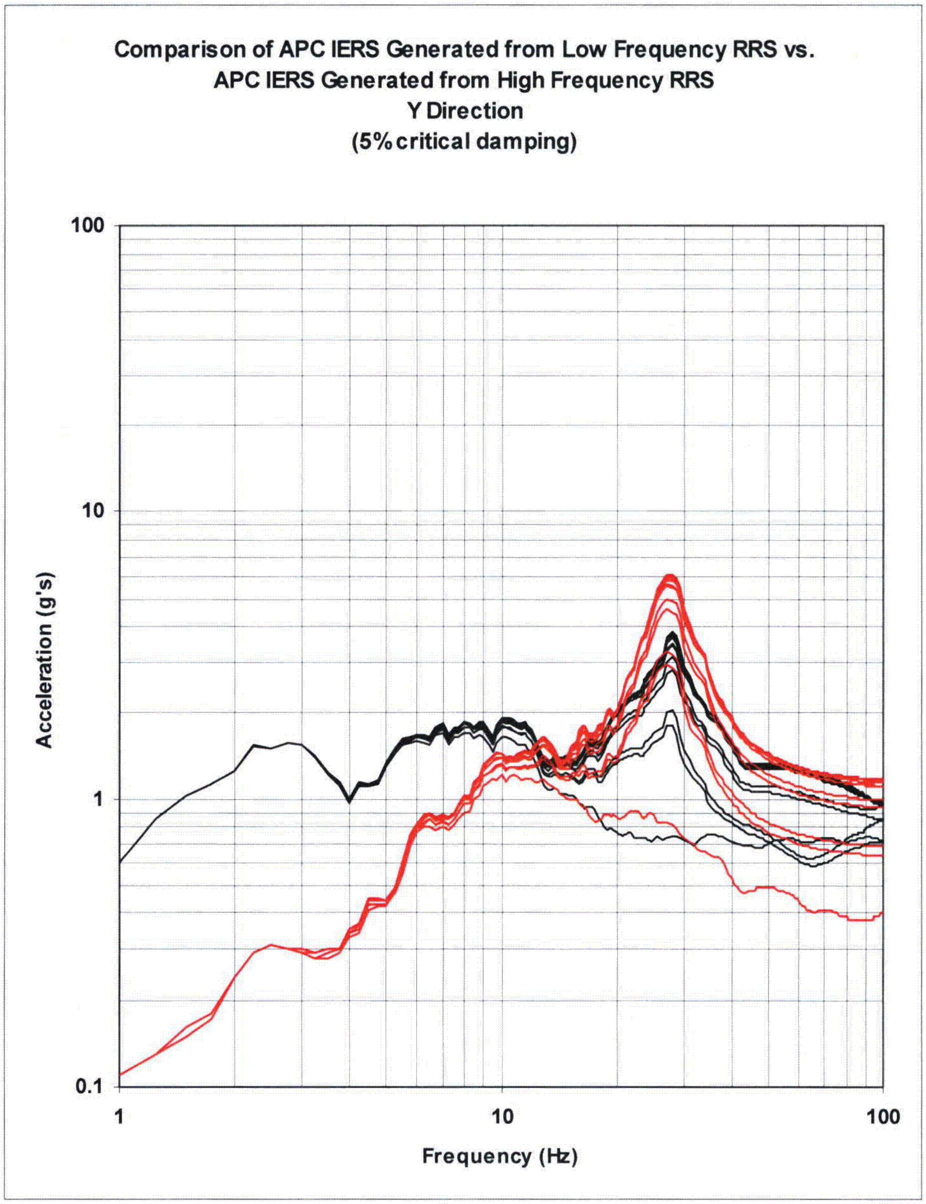


Figure 6.4.3.3.4-2: Comparison of APC Model IERS, Y-Direction (Front-Back) High Frequency IERS Shown in Red, Low Frequency IERS shown in Black (5% Critical Damping)

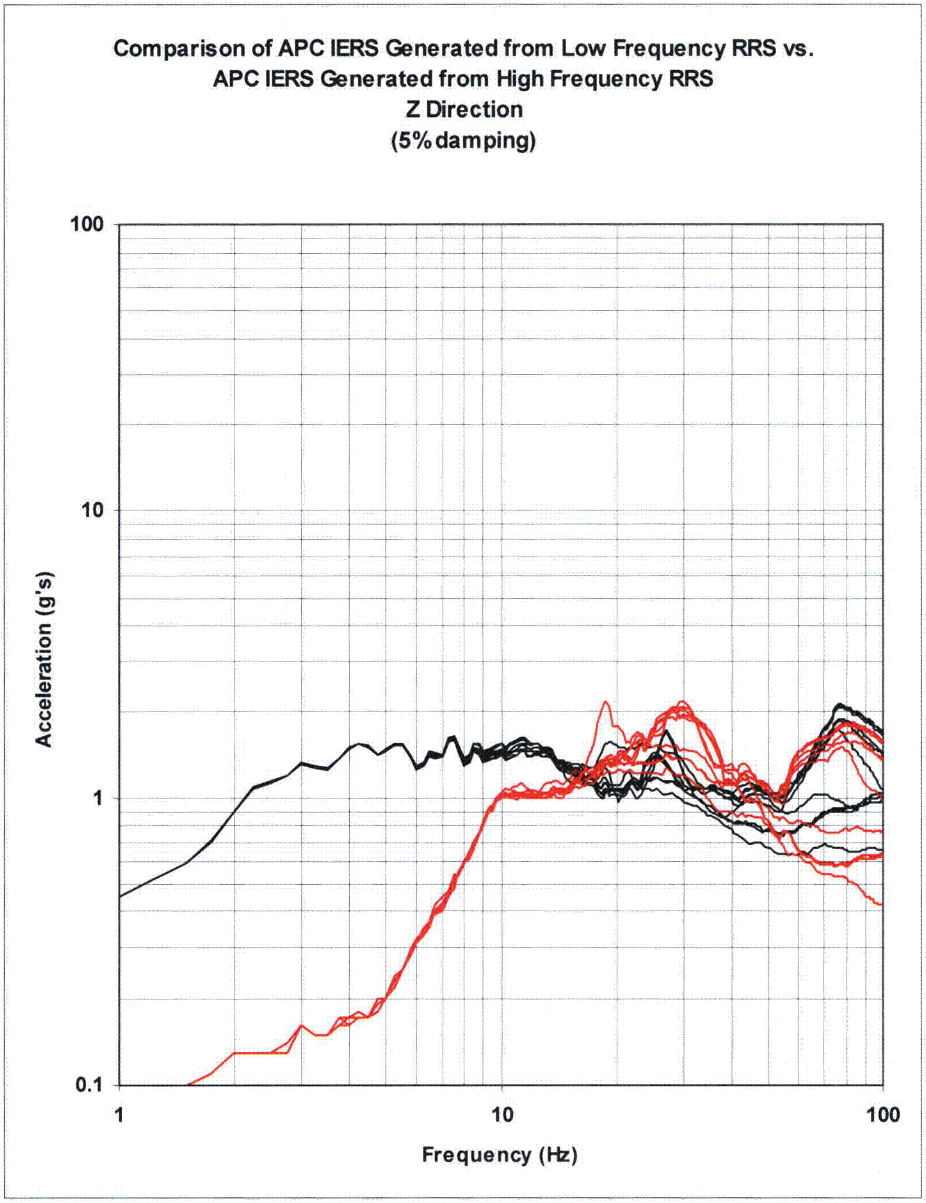


Figure 6.4.3.3.4-3: Comparison of APC Model IERS, Z-Direction (Vertical) High Frequency IERS Shown in Red, Low Frequency IERS shown in Black (5% Critical Damping)

6.4.3.3.5 PI Model

Figure 6.4.3.2-4 shows the PI 4 cabinet suite model. The natural frequencies are:

X-direction (Side-Side):	12.6 Hz
Y-direction (Front-Back):	19.3 Hz
Z-direction (Vertical):	>33 Hz

The response spectrum analysis determines the model displacements, loads, and stresses resulting from the input response spectra. Tables 6.4.3.3.5-1 and 6.4.3.3.5-2 compare the results of the response spectrum analysis using high frequency input with the results using low frequency input.

Table 6.4.3.3.5-1 shows that the maximum displacements of the structure are essentially equal between the low frequency seismic input and the high frequency seismic input).

In Table 6.4.3.3.5-2, while the bolts shear loads caused by the high-frequency input are slightly higher than the bolts shear loads caused by the low frequency input (314.6 lbs versus 288.9 lbs), the HF/LF ratio for the SRSS value between shear and tension is 0.92. This confirms the low frequency seismic input results envelop the results of the high frequency seismic inputs.

The time history analysis determined the IERS at the top corners of the cabinet models and the base node where the input time histories were applied to the model. Figures 6.4.3.3.5-1 through 6.4.3.3.5-3 show the comparison of the IERS developed using high frequency input with the IERS developed using low frequency input.

Table 6.4.3.3.5-1: Comparison of PI 4 Cabinet Model Maximum Cabinet Displacements

Spectra	Description	UX Max (Cabinet Side-to-Side)	UY Max (Cabinet Front-to-Back)	UZ Max (Cabinet Vertical)		Max. HF/LF Ratio
Low Frequency	Node:	67	9347	5751	10143	1.0
	Value	0.12	0.05	0.007	0.007	
High Frequency	Node:	67	9347	5751	10143	
	Value	0.09	0.05	0.006	0.006	

Table 6.4.3.3.5-2: Comparison of PI 4 Cabinet Model Maximum Mounting Bolt Loads

Spectra	Maximum Tension (lb)	Maximum Shear (lb)	SRSS (lb)	Ratio (HF/LF)
Low Frequency	1258.5	288.9	1291.2	0.92
High Frequency	1147.2	314.6	1189.6	

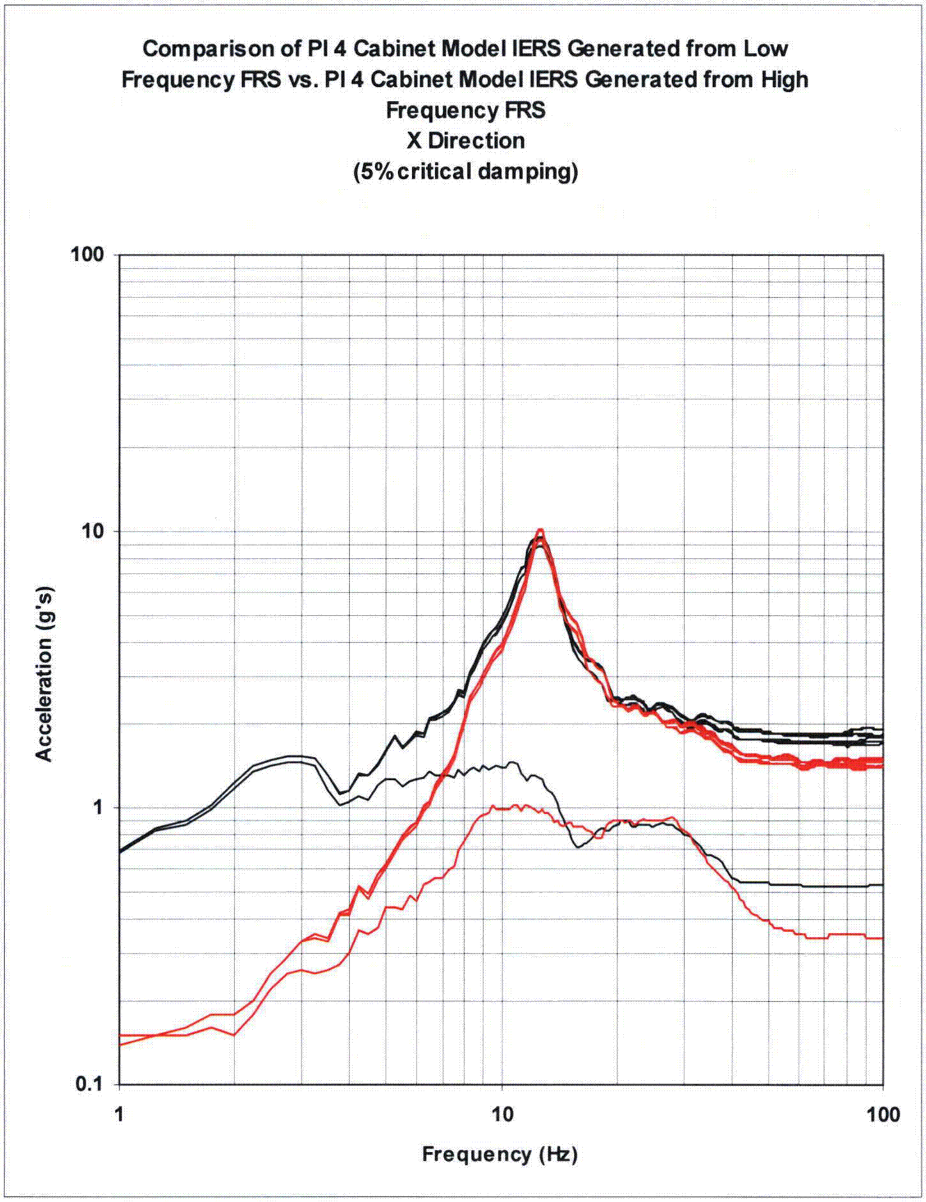


Figure 6.4.3.3.5-1: Comparison of PI 4 Cabinet Suite Model IERS, X-Direction (Side-Side) High Frequency IERS Shown in Red, Low Frequency IERS shown in Black (5% Critical Damping)

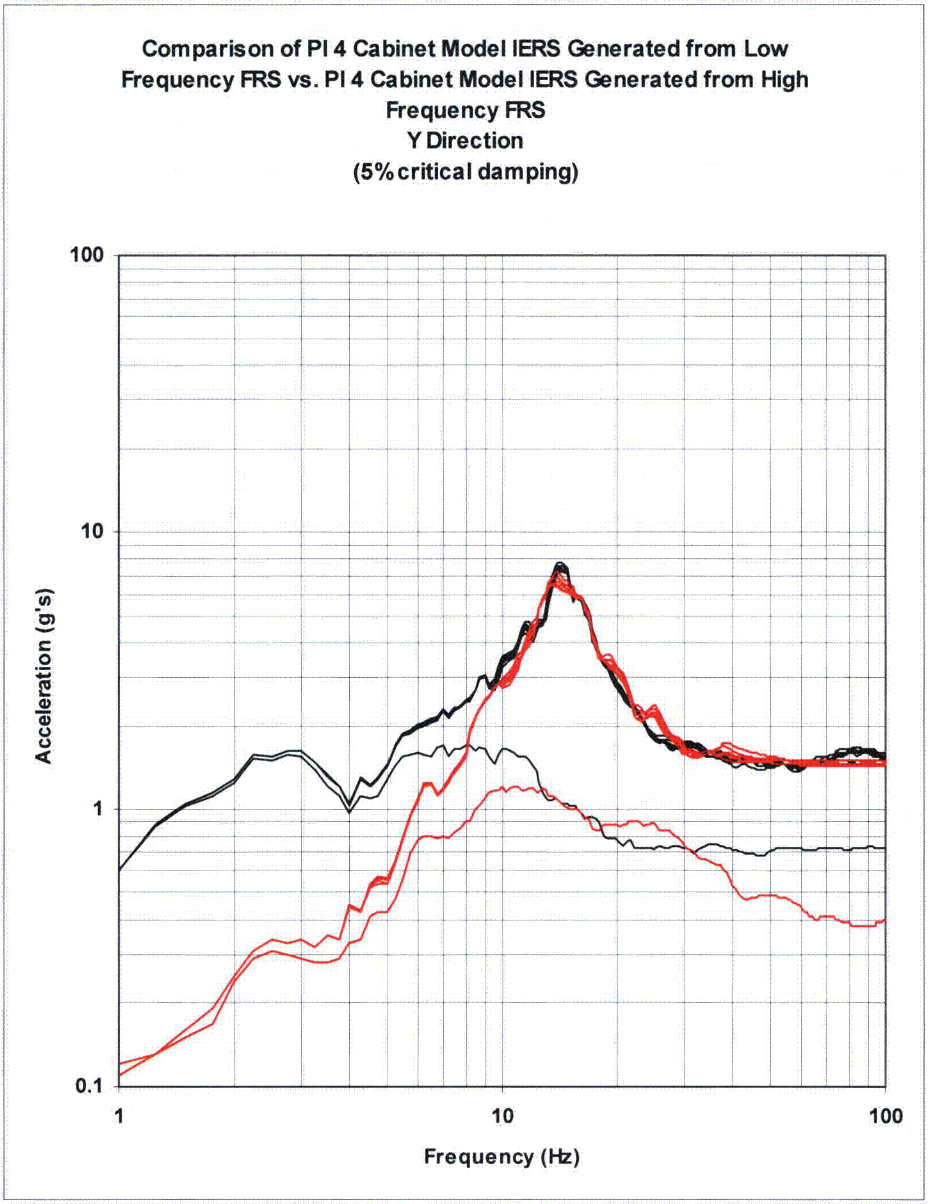


Figure 6.4.3.3.5-2: Comparison of PI 4 Cabinet Suite Model IERS, Y-Direction (Front-Back) High Frequency IERS Shown in Red, Low Frequency IERS shown in Black (5% Critical Damping)

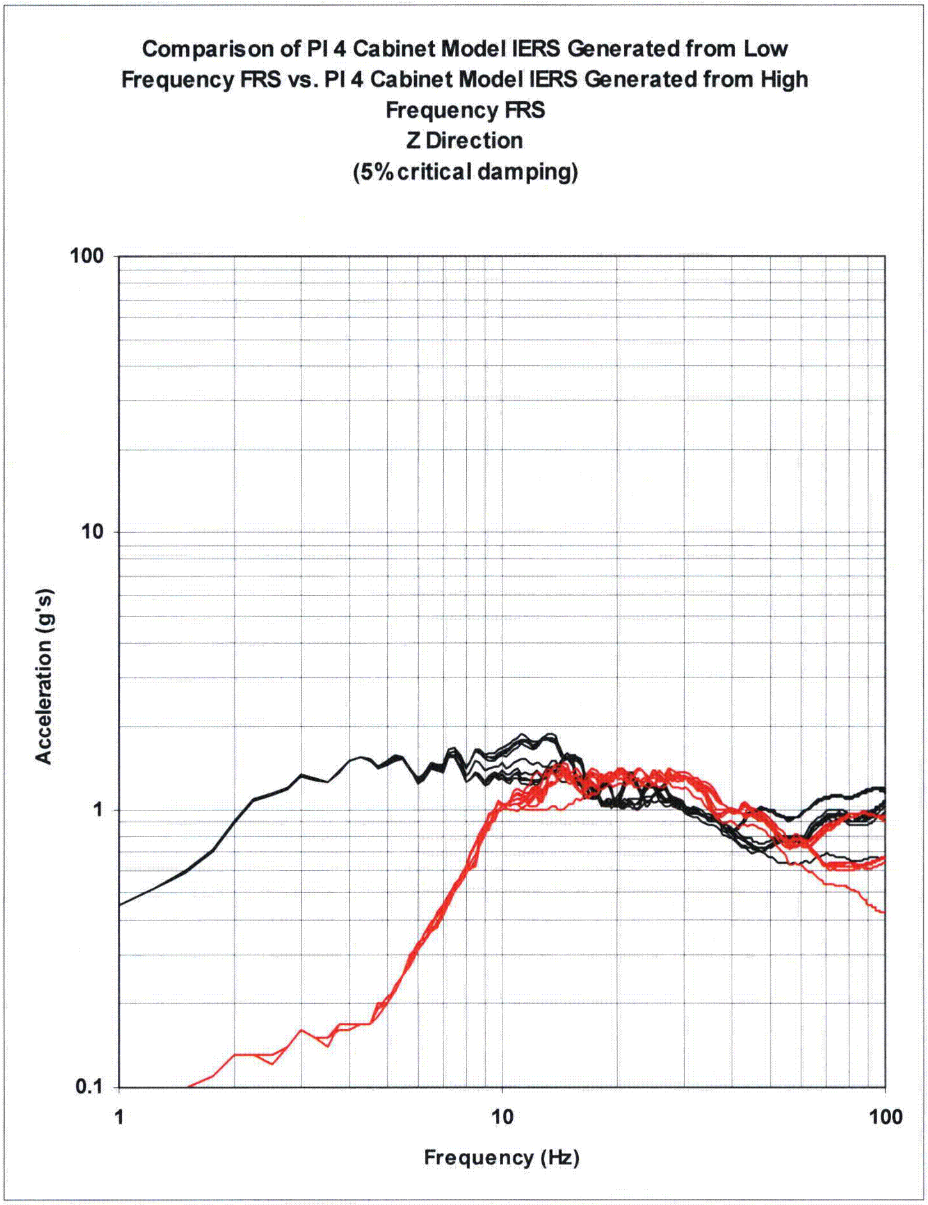


Figure 6.4.3.3.5-3: Comparison of PI 4 Cabinet Suite Model IERS, Z-Direction (Vertical) High Frequency IERS Shown in Red, Low Frequency IERS shown in Black (5% Critical Damping)

6.4.4 Review of Existing Seismic Test Data

This section presents the results of a study to evaluate low frequency seismic test programs to determine if high frequency excitation is exhibited in the frequency range of 25 to 50 Hz. Two different sets of test data were taken into consideration in this study. The first set was seismic testing performed to meet the standards required of safety-related equipment in IEEE Std. 344-1987 (Reference 6.4-3). Safety-related equipment is required to withstand five lower level seismic events followed by at least one Safe Shutdown Earthquake (SSE) event. The second set was testing performed to meet the Uniform Building Code (UBC) for commercial equipment supplied in essential industrial facilities. The following test data was reviewed:

a. The seismic test response spectra (TRS) in the frequency range of 25 to 50 Hz
b. A lower bound of the spectral acceleration in the frequency range of 25 to 50 Hz where structural integrity and functional operability were demonstrated.

6.4.4.1 Methodology

Fourteen test reports were reviewed for safety-related test programs which resulted in test data for over 20 test specimens. In addition, twenty test reports were reviewed for UBC testing resulting in test data for over 100 test specimens. The data was reviewed to determine the seismic levels where structural integrity and functional operability were demonstrated. For these successful seismic test runs, the lowest spectral accelerations in the frequency range of 25 to 50 Hz were collected in the three principal directions (front-to-back, side-to-side, and vertical). The average was then computed to determine spectral accelerations in the frequency range of interest. Use of the average is considered to be appropriate since the tests considered in the evaluation were not associated with fragility tests. The tests were conducted to seismic levels developed for the specific application and higher seismic levels may have been able to have been achieved by the tested equipment. This process was performed for both sets of testing and in each of the three principal axes.

6.4.4.2 Safety-Related Equipment Seismic Test Data Review

The test data was collected for the fourteen test reports based on the criteria in Section 6.4.4.1. The test reports were studied to calculate the acceptable seismic test levels. The seismic levels that the equipment experienced without anomalies based on the criteria in Section 6.4.4.1 are as follows:

Front-to-back:	2.50 g
Side-to-side:	2.64 g
Vertical:	2.65 g

Sample test response spectra (TRS) of selected test runs are shown in Figures 6.4.4.2-1 to 6.4.4.2-3 compared to the required response spectra (RRS) defined for the testing (which significantly exceed the AP1000 HRHF MCR floor response spectra shown in Figures 6.4.3.3.2-1 through 6.4.3.3.2-3).

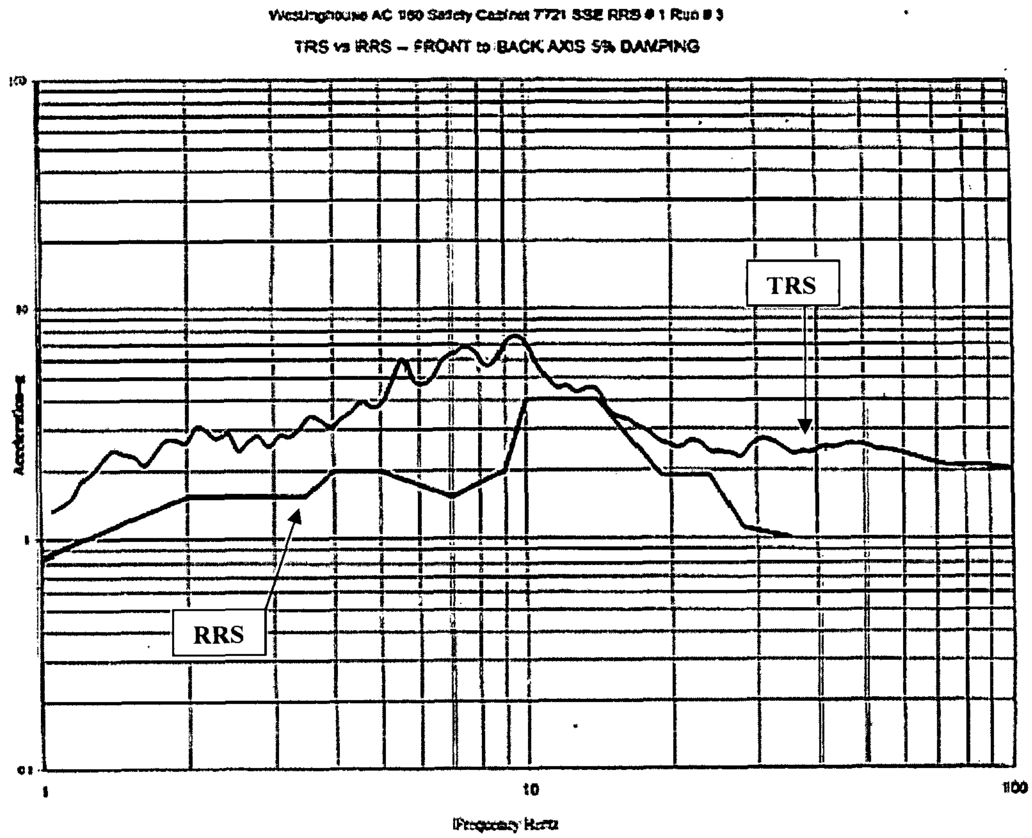


Figure 6.4.4.2-1: ANDI Test Report 6445 Test Run RRS #1 SSE 3 Front-to-Back

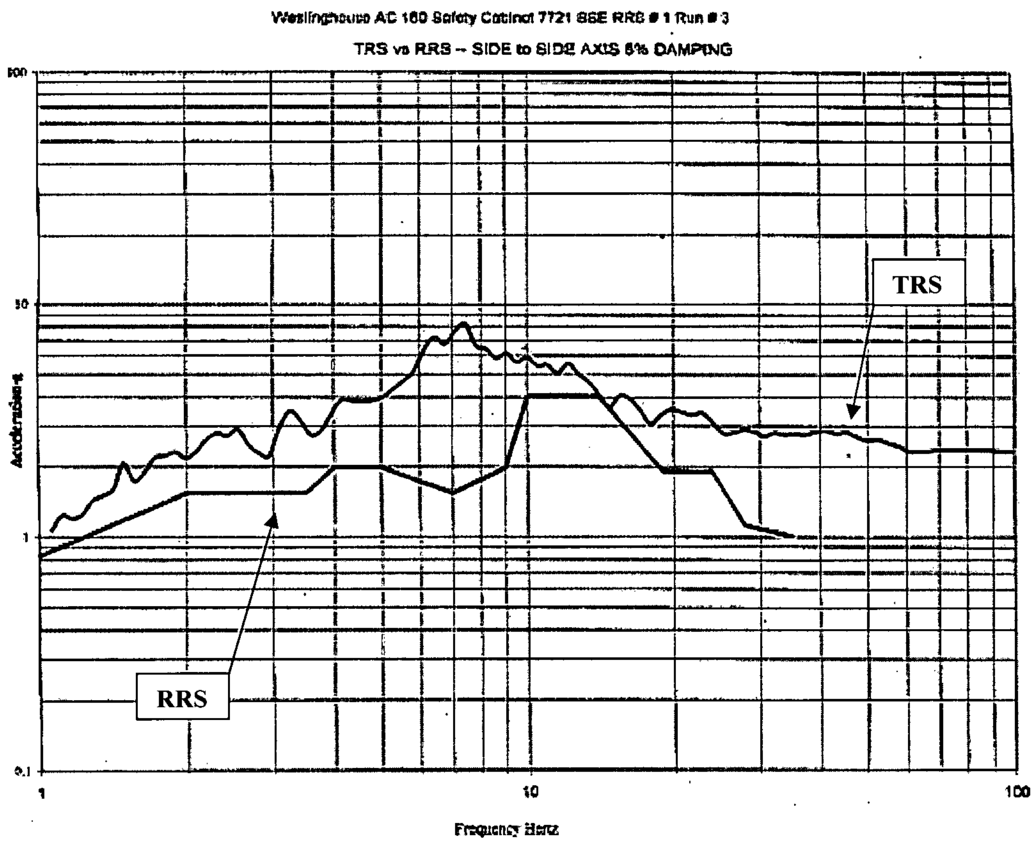


Figure 6.4.4.3-2: ANDI Test Report 6445 Test Run RRS #1 SSE 3
Side-to-Side

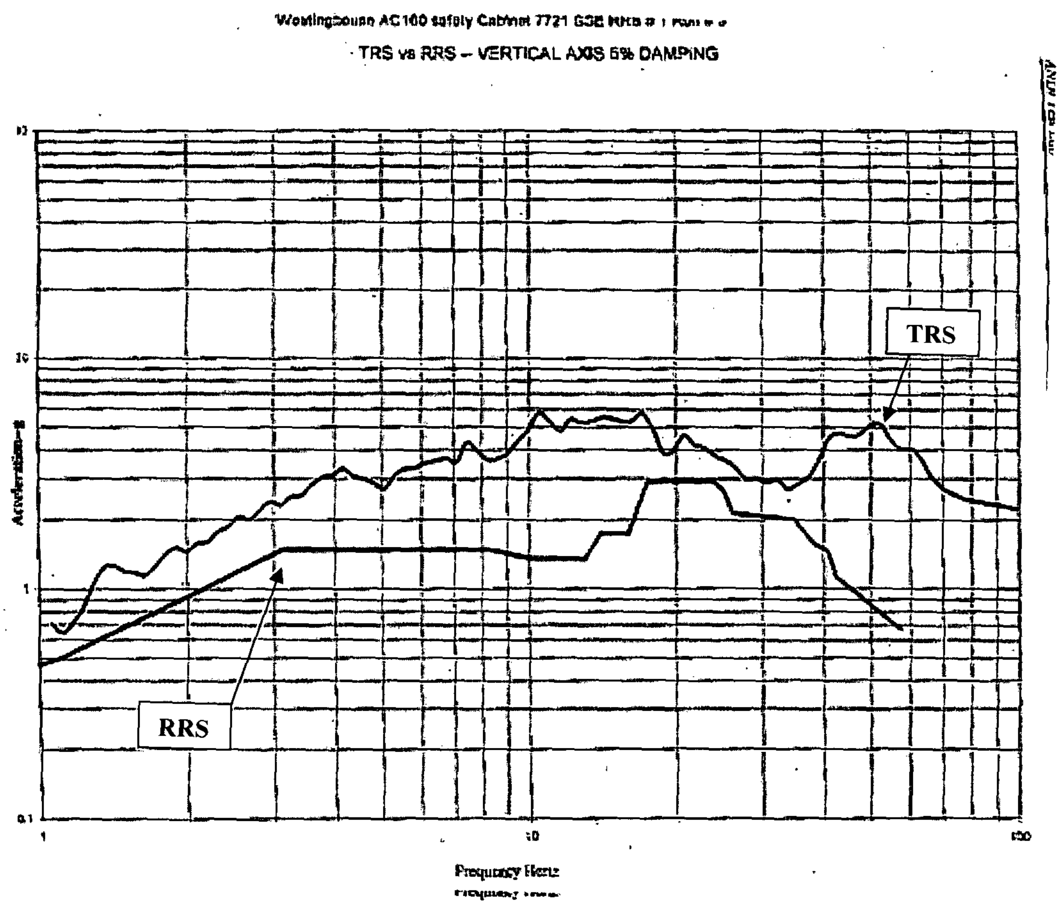


Figure 6.4.4.3-2: ANDI Test Report 6445 Test Run RRS #1 SSE 3 Vertical

6.4.4.3 UBC Test Data

For the UBC test programs, test data was collected for the twenty test reports based on the criteria in Section 6.4.4.1. The Test Response Spectra (TRS) at 5% critical damping were reviewed to determine the spectral accelerations in the frequency range of 25 to 50 Hz. Only test runs where structural integrity and functionality were demonstrated were used. The resultant average accelerations in the three principal directions are as follows:

Front-to-back:	1.61 g
Side-to-Side:	1.66 g
Vertical:	1.87 g

6.4.4.4 Seismic Test Data Review Conclusions

The data collected for the safety-related equipment shows higher spectral acceleration than the UBC data. To increase conservatism, the average between the UBC and safety-related equipment seismic spectral accelerations noted above were calculated and are listed below.

Front-to-Back:	2.06 g
Side-to-Side:	2.15 g
Vertical:	2.26 g

This data provides a conservative estimate of the spectral accelerations in the HF region without failure of the equipment. Therefore, it is concluded that spectral levels of 2.0 g's (at 5% critical damping) can be used as an upper bound for functionality of equipment in the 25 to 50 Hz frequency range without further testing or evaluation.

6.4.5 Screening Process

The groups of safety-related equipment considered for evaluation are those that may be sensitive to the high frequency input. This includes cabinet mounted equipment, field sensors, and appurtenances which may be sensitive to high frequency seismic inputs identified in Table 6.4.5-1. Evaluations have been performed to verify that these cabinets do not have excessive seismic demand on their mounted equipment, the cabinet designs do not require changes due to the high frequency input, and the cabinets will maintain their structural integrity and functional operability during and after the high frequency input.

Time history analyses of these typical safety-related cabinets were performed for both the CSDRS and the HRHF seismic inputs so that comparisons could be made to their seismic response from both seismic inputs. This analytical study is presented in Section 6.4.3. The study concluded that safety-related equipment may be screened and grouped as follows during the seismic qualification efforts to the AP1000 CSDRS:

<u>Screening Process</u>

<u>Group No. 1</u>:

Rugged equipment with dominant natural frequencies above 50 Hz. Seismic qualification of this group based on CSDRS seismic requirements is adequate and requires no additional evaluation for high frequency seismic inputs.

<u>Group No. 2</u>:

Cabinets and other equipment which exhibit dominant natural frequencies below HRHF exceedance range. Seismic qualification of this group based on CSDRS seismic requirements is adequate and requires no additional evaluation for high frequency seismic inputs.

<u>Group No. 3</u>:

Safety-related equipment which exhibit dominant natural frequencies in HRHF exceedance range. The safety-related equipment will be subjected to supplemental high frequency seismic evaluation to verify acceptability.

Table 6.4.5-1: Potential Sensitive Equipment List

• **Equipment or components with moving parts and required to perform a switching function during the seismic event (e.g. low and medium voltage circuit breakers, contactors, auxiliary switches, molded case circuit breakers, motor control center starters, and pneumatic control assemblies)**
• **Components with moving parts that may bounce or chatter such as relays and actuation devices (e.g. shunt trips)**
• **Unrestrained components**
• **Potentiometers**
• **Process switches and sensors (e.g., pressure/differential pressure, temperature, level, limit/position, and flow)**
• **Components with accuracy requirements that may drift due to seismic loading**
• **Interfaces such as secondary contacts**
• **Connectors and connections (including circuit board connections for digital and analog equipment)**

6.4.6 Seismic Treatment of Sensitive Equipment

Components and equipment determined to be high frequency sensitive with potential failure modes involving change of state, chatter, signal change/drift, and connection problems will be demonstrated to be acceptable through the performance of supplemental high frequency screening in accordance with the industry position white paper (Reference 6.4-4). Those high frequency sensitive components having failure modes associated with mounting, connections and fasteners, joints, and interface are considered to be qualified by traditional low frequency qualification testing per IEEE Std 344 and/or required quality assurance inspection and process/design controls.

The High frequency screening seismic test is intended as a supplemental evaluation to the required seismic qualification methods performed in accordance with IEEE Std. 344-1987 (Reference 6.4-3) for those plants which have high frequency exceedance of their CSDRS and which therefore require evaluation of potentially high frequency sensitive equipment and components. High frequency screening test should be conducted as a supplemental test to low frequency seismic excitation for equipment determined to have natural frequencies coinciding with the peak spectral acceleration of the high frequency RRS when that peak spectral acceleration is greater than 2.0 g (at 5% critical damping).

High frequency seismic testing of equipment determined to be sensitive (that is not screened out per Section 6.4.5) is the preferred screening test method to address HRHF seismic demand and will be conducted as a supplemental test to low frequency seismic excitation. High and low frequency seismic Required Response Spectra (RRS) are separate environments and an envelope RRS covering both would not be representative of the Design Basis Event (DBE). Testing to a High/Low Frequency Envelope RRS could prove destructive to both the equipment under test and the seismic test table.

The equipment should be subjected to the high frequency SSE testing after completion of the low frequency seismic testing. Low level cycling fatigue effects requirement should be justified by low frequency seismic input. No additional low level testing for high frequency excitation is required. One SSE high frequency seismic test will be performed to demonstrate functionality of equipment in its most sensitive electrical configuration.

Acceptance and qualification to the high frequency input is determined based on the comparison of the test levels that the components have been analyzed or tested to. For those equipment/components determined to have already been tested to high seismic levels in the high frequency region, no additional testing or justification is necessary. A review of seismic testing data is performed to verify that the tested seismic levels envelop the high frequency seismic demand. If these components cannot be shown to be acceptable based on this review, additional testing or justifications may be required to show acceptance.

In addition, the EPRI white paper (Reference 6.4-4) outlines other recommended generic screening procedures to assure that safety-related components which are sensitive to high frequency seismic demand are screened out or shown to be acceptable for their specific application.

6.4.7 Summary and Conclusions

The comparative analysis completed demonstrates that equipment exhibiting natural frequencies below HRHF exceedance range or above 50 Hz do not require any additional treatment for qualification to high frequency seismic requirements. Equipment that exhibits dominant natural frequencies which coincide with the peak spectral acceleration of the high frequency RRS will require additional evaluation to verify acceptability. Review of completed low frequency seismic test programs shows that the current qualification test methods envelop the seismic qualification of equipment for high frequency seismic inputs up to a 2.0 g peak spectral acceleration (at 5% critical damping) in the three orthogonal principal axes. This can be used to exclude additional seismic testing to high frequency based inputs below 2.0 g. High frequency seismic testing should be conducted as a supplemental test to low frequency seismic excitation for equipment determined to have natural frequencies coinciding with the peak spectral acceleration of the high frequency RRS when that peak spectral acceleration is greater than 2 g (at 5% critical damping).

7.0 General Conclusions

An evaluation was performed for portions of structures, components, and systems for the hard rock high frequency (HRHF) seismic response. Using the screening criteria applicable to the SSCs, the sample evaluated consisted of the following:

- Building Structures
  - Auxiliary Building
  - Shield Building
  - Containment Internal Structures
- Primary Equipment

   - Reactor Vessel and Internals
   - Primary Component Supports
   - Reactor Coolant Loop Primary Equipment Nozzles

- Piping Systems

- Electro-Mechanical Equipment

Representative portions of the building structures are evaluated. Three locations in the Auxiliary Building were selected: the bottom of the wall where the shear would be large; a wall in the vicinity of a floor that is influenced by high frequency response; and a corner intersection of walls. Eight locations on the Shield Building were evaluated that are located on the east, west, north, and south sides. Three areas within the Containment Internal Structures were selected: the southwest wall of the refueling canal; west wall of the steam generator; and the CA02 module wall associated with the IRWST. In all cases it was determined that the loads associated with the CSDRS envelop the HRHF case.

The reactor vessel and internals is chosen for evaluation as representative of major equipment. From the analyses performed it was found that the CSDRS will have higher loads and stresses than those from the HRHF seismic response.

The primary component supports and the reactor coolant loop primary equipment nozzles were found to have the highest response from the CSDRS.

The piping systems that are the most sensitive to high frequency input were found to have smaller response from the HRHF input than that associated with the CSDRS seismic response.

It is concluded from the analyses and seismic tests performed in the past that the CSDRS results in higher loads and stresses than the HRHF. Therefore, it is acceptable to design for only the CSDRS. It is recognized that supplemental seismic testing of high frequency sensitive safety-related equipment or implementation of one of the other high frequency screening techniques as outlined in the EPRI White Paper (Reference 6.4-4) may be required to demonstrate acceptability under HRHF seismic demand conditions. The screening process described in Section 6.4.5 provides a method to address the potential for HF susceptibilities in equipment and components for those plants which have HF exceedance of the CSDRS. The recommended screening techniques in Reference 6.4-4 also assure that any potentially HF sensitive safety-related components are either screened out or shown to be acceptable for their specific application.

This Technical Report's results show consistency with industry positions and past EPRI reports that high frequency is non-damaging. The report describes the screening criteria used to select the set of sample cases that have been included and, together with other industry comparisons, provide sufficient basis to conclude that the HRHF spectra produces lower seismic loads than the CSDRS. Thus, it is sufficient to use the CSDRS seismic loads in the AP1000 design.

8.0 References

1.0-1 EPRI Draft White Paper, "Considerations for NPP Equipment and Structures Subjected to Response Levels Caused by High Frequency Ground Motions," Transmitted to NRC March 19, 2007.

2.0-1 APP-GW-S2R-010, Revision 1, "Extension of Nuclear Island Seismic Analysis to Soil Sites," Westinghouse Electric Company, LLC.

3.0-1 Ghiocel Predictive Technologies, Inc. (2006). *ACS-SASSI, An Advanced Computational Software for 3D Dynamic Analysis Including Soil-Structure Interaction*, Version 2.2, Pittsford, New York.

6.4-1 U.S. Atomic Energy Commission, Regulatory Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants," Revision 1, December 1973.

6.4-2 AP1000 Design Control Document, "Design of Structures, Components, Equipment and Systems," Revision 16.

6.4-3 IEEE Std. 344-1987, "IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations."

6.4-4 EPRI White Paper, "Seismic Screening of Components Sensitive to High Frequency Vibratory Motions," June 2007.

Appendix A – Revision 17 DCD Appendix 3I

Provided in this appendix is Appendix 3I as given in Design Control Document (DCD) 17.

3I.1 Introduction

The seismic analysis and design of the AP1000 plant is based on the Certified Seismic Design Response Spectra (CSDRS) shown in subsection 3.7.1.1. These spectra are based on Regulatory Guide 1.60 with an increase in the 25 hertz region. Ground Motion Response Spectra (GMRS) for some Central and Eastern United States rock sites show higher amplitude at high frequency than the CSDRS. Evaluations are described in this appendix for a GMRS with high frequency seismic input at a site where the nuclear island is founded on hard rock. The resulting spectra of this site is shown in Figure 3I.1-1 and Figure 3I.1-2 and compares this hard rock high frequency (HRHF) GMRS at the foundation level against the AP1000 CSDRS for both the horizontal and vertical directions for 5% damping. The HRHF GMRS exceed the CSDRS for frequencies above about 15 Hz.

High frequency seismic input is generally considered to be non-damaging as described in Reference I.1. The evaluation of the AP1000 nuclear island for high frequency input is based on the analysis of a limited sample of structures, components, supports, and piping to demonstrate that the high frequency seismic response is non-damaging. The evaluation includes building structures, reactor pressure vessel and internals, primary component supports, primary loop nozzles, piping, and equipment.

This appendix describes the methodology and criteria used in the evaluation to confirm that the high frequency input is not damaging to equipment and structures qualified by analysis for the AP1000 CSDRS. It provides supplemental criteria for selection and testing of equipment whose function might be sensitive to high frequency. The results of the high frequency evaluation demonstrating that the AP1000 plant is qualified for this type of input are documented in a technical report (Reference I.2). This report will provide a summary of the analysis and test results.

3I.2 High Frequency Seismic Input

Presented in Figures 3.I-1 and 3.I-2 is a comparison of the horizontal and vertical GMRS from the HRHF site and the AP1000 CSDRS. The HRHF GMRS presented is calculated at foundation level (39.5' below grade), at the upper most competent material and treated as an outcrop for calculation purposes.

For each direction, the HRHF GMRS exceeds the design spectra in higher frequencies (greater than 15 Hz horizontal and 20 Hz vertical). The spectra are used for the GMRS. If necessary, the HRHF GMRS spectra are enhanced at low frequencies so that GMRS fully envelopes all of the hard rock sites.

3I.3 NI Model Used To Develop High Frequency Response

The NI20 nuclear island model described in Appendix 3G is analyzed in SASSI using the HRHF time histories applied at foundation level to obtain the motion at the base. The NI20 model has sufficient mesh size to transmit the HRHF input up to 80 Hz. This was confirmed by comparing the dynamic response of the NI20 to that of the NI10 model, a model with a much finer mesh.

3I.4 Evaluation Methodology

The demonstration that the AP1000 nuclear power plant is qualified for the high frequency seismic response does not require the analysis of the total plant. The evaluations made are of representative systems, structures, and components, selected by screening, as potentially sensitive to high frequency input in locations where there were exceedances in the high frequency region. Acceptability of this sample is considered sufficient to demonstrate that the AP1000 is qualified.

The high frequency seismic analyses that are performed use time history or broadened response spectra. The analysis is not performed using the envelope spectra of the CSDRS and the GMRS. Separate analyses with each spectra are used.

The evaluations performed assess the ability of the system, structure, or component to maintain its safety function.

Supplementary analyses are performed as needed to show that high frequency floor response spectra exceedances are not damaging. These analyses can include: gap nonlinearities, material inelastic behavior, and multi-point response spectra analyses where the high frequency response excites a local part of the system. Tests on equipment are specified as needed where function cannot be demonstrated by analysis, or analysis is not appropriate.

3I.5 General Selection Screening Criteria

The following general screening criteria are used to identify representative AP1000 systems, structures, and components (SSCs) for the samples to be evaluated to demonstrate acceptability of the AP1000 nuclear power plant for the high frequency motion.

- Select systems, structures, and components based on their importance to safety. This includes the review of component safety function for the SSE event and its potential failure modes due to an SSE. Those components whose failure modes would result in safe shutdown are excluded.

- Select systems, structures, and components that are located in areas of the plant that experience large high frequency seismic response.

- Select systems, structures, and components that have significant modal response within the region of high frequency amplification. Significance is defined by such items as: modal mass; participation factor, stress and/or deflection.

- Select systems, structures, and components that have significant stress as compared to allowable when considering load combinations that include seismic.

3I.6 Evaluation

In this section, the portions of structures, components, and systems that are evaluated for the high frequency seismic response are identified. The sample to be evaluated based on the screening criteria applicable to the SSCs consists of the following:

- Building Structures
  - Auxiliary Building – 3 locations
  - Shield Building – 8 locations
  - CIS – 2 locations
- Primary Coolant Loop
  - Reactor Vessel and Internals
  - Primary Component Supports
  - Reactor Coolant Loop Primary Equipment Nozzles
- Piping Systems – at least two piping analysis packages
- Electro-Mechanical Equipment – Equipment that is potentially sensitive to high frequency input (see Table 3I.6-1)

These structures, systems, and equipment are discussed in more detail in the sections that follow.

3I.6.1 Building Structures

Maintaining the NI buildings structural integrity is important to the safety of the plant. Representative portions of buildings that are evaluated for the effect of high frequency input are selected based on those areas that can experience high seismic shear and moment loads due to the seismic event. Areas chosen are at the base of the Shield Building, in the vicinity of Auxiliary Building floors that have fundamental frequencies in the high frequency region, and the corners of the Auxiliary Building. Three locations are selected in the Auxiliary Building that reflects the bottom of a wall where the shear and moment would be large, a wall in the vicinity of a floor that is influenced by high frequency response, and a corner intersection of walls. Eight locations are evaluated on the Shield Building, four located at elevation 107' and four located at elevation 211'. These locations are located on the east, west, north and south sides. The southwest wall of the refueling canal is evaluated since it is a representative wall on the refueling canal. The CA02 wall in the CIS building is evaluated since it is a representative wall associated with the IRWST.

The evaluation consists of a comparison of the loads from the high frequency input to those obtained from the AP1000 design spectra, shown in Figures 3I.1-1 and 3I.1-2, for these representative building structures. The NI building structures are considered qualified for the high frequency input if the seismic loads from the Regulatory Guide 1.60 (modified) envelope those from the high frequency input. If there is any exceedance, this is evaluated further to confirm that the existing design is adequate.

3I.6.2 Primary Coolant Loop

A failure within the reactor coolant loop could challenge the integrity of the reactor coolant pressure boundary. Therefore, it is chosen for evaluation. The components evaluated are as follows:

- Reactor vessel and internals
- Reactor vessel supports
- Steam generator supports
- Reactor coolant loop primary equipment nozzles

The reactor vessel and internals are selected since they are important to safety and their analysis is representative of major primary components. The building structure below the reactor vessel supports is fairly stiff and there may be significant vertical amplification at the supports of the reactor pressure vessel. Further, reactor vessel internals have relatively complex structural systems including gap nonlinearities and sliding elements. Also, they may be sensitive to high frequency input as summarized below:

- Vertical and horizontal modes of the upper internals and the reactor vessel modes are in the relatively high frequency range.

- Additional high frequencies are associated with nonlinear impact

The evaluation consists of a comparison of the loads from the high frequency input to those obtained from the Regulatory Guide 1.60 (modified) input. Qualification is shown for the high frequency input if the seismic loads from the Regulatory Guide 1.60 (modified) envelope those from the high frequency input. If there is exceedance, then comparison is made for the combination of the seismic with the design basis pipe break loads and steady state loads. Qualification is then shown if the high frequency loads are relatively insignificant compared to the other loads, or there are no required design changes.

Maintaining the integrity of the reactor vessel and steam generator supports is important to preserving the primary component safety function. They are representative of supports on components, and see high loads.

The reactor coolant loop nozzles at the cold and hot leg interfaces of the reactor pressure vessel, reactor coolant pumps, and steam generators are important to include in the evaluation since these are critical areas of components.

The evaluation of the primary component supports and reactor coolant loop nozzles consists of a comparison of the loads from the high frequency input to those obtained from the Regulatory Guide 1.60 (modified) input. These items are considered qualified for the high frequency input if the seismic loads from the Regulatory Guide 1.60 (modified) envelope those from the high frequency input. If there is any exceedance, then an evaluation is made combining the high frequency loads with the other load components (e.g., thermal, pressure, dead) and a comparison made to the design loads. If the design loads envelope the load combinations that include the high frequency seismic input, then the nozzles and supports are considered qualified for the high frequency input.

3I.6.3 Piping Systems

Safety class piping analysis packages were reviewed and include a mixture of ASME Class 1, 2, and 3 piping systems. They typically contain at least one valve. The piping systems are mainly large bore of various size (3-inch diameter to 38-inch diameter), and some of small bore (2 inches and lower). The piping systems are in both the containment and auxiliary building.

The piping systems chosen for evaluation are those that are susceptible to high frequency as measured by their mass participation in the higher frequencies, are representative piping systems that contain valves and equipment nozzles, and are located in areas susceptible to high frequency HRHF GMRS spectra level response. At least two candidate piping analysis packages are identified for evaluation that meet these screening criteria.

The pipe stresses, nozzle loads, and valve end loads obtained from both the high frequency input and the Regulatory Guide 1.60 (modified) input are compared. Comparison is also made to the allowable with the seismic stresses combined with the other stresses associated with the seismic load combination that is applicable as necessary. If the high frequency seismic results are below those associated with the Regulatory Guide 1.60 (modified) results, or below the allowable limits, then the piping system is considered qualified. If necessary, more detailed supplementary analyses will be performed considering one or more of the following:

- Multi-point response spectra input
- Non-linear analysis with gap and material nonlinearities
- Calculation of actual support stiffness in locations where a minimum rigid value was used

3I.6.4 Electro-Mechanical Equipment Qualification

The groups of safety-related equipment considered for evaluation are those that may be sensitive to the high frequency input. This includes cabinet mounted equipment, field sensors, and appurtenants which may be sensitive to high frequency seismic inputs identified in Table 3I.6-1.

Sample safety-related cabinets have been identified that are typically sensitive to seismic input. Evaluations will be performed to verify these cabinets do not have excessive seismic demand on their mounted equipment, the cabinet designs do not require changes due to the high frequency input, and the cabinets will maintain their structural integrity during the high frequency input. Time history analyses of these cabinets are performed for both the Regulatory Guide 1.60 (modified) and the high frequency inputs so that comparisons can be made to their seismic response from both seismic inputs. This analytical study is to conclude that safety-related equipment may be screened and grouped as follows:

Screening Process

Group No. 1:

Rugged equipment with dominant natural frequencies above 50 Hz. Seismic qualification of this group based on CSDRS seismic requirements is adequate and requires no additional evaluation for high frequency seismic inputs.

Group No. 2:

Cabinets and other equipment which exhibit dominant natural frequencies below Hard Rock High Frequency (HRHF) exceedance range. Seismic qualification of this group based on CSDRS seismic requirements is adequate and requires no additional evaluation for high frequency seismic inputs.

Group No. 3:

Safety-related equipment which exhibit dominant natural frequencies in HRHF exceedance range. The safety-related equipment will be subjected to supplemental high frequency seismic evaluation to verify acceptability.

Qualification Process

In the high frequency screening process, the potential failure modes of high frequency sensitive component types and assemblies are important considerations. The following are potential failure modes of high frequency sensitive components/equipment.

- Inadvertent change of state
- Chatter
- Change in accuracy and drift in output signal or set-point
- Electrical connection failure or intermediacy (e.g., poor quality solder joints)
- Mechanical connection failure
- Mechanical misalignment/binding (e.g., latches, plungers)
- Fatigue failure (e.g., solder joints, ceramics, self-taping screws, spot welds)
- Improperly and unrestrained mounted components
- Inadequately secured/locked mechanical fasteners and connections

Components and equipment determined to be exposed to and are high frequency sensitive with potential failure modes involve change of state, chatter, signal change/drift and connection problems shall be demonstrated to be acceptable through the performance of supplemental high frequency qualification testing. Those high frequency sensitive component having failure modes associated with mounting, connections and fasteners, joints, and interface are considered to be qualified by traditional low frequency qualification testing per IEEE Std. 344 and/or required quality assurance inspection and process/design controls.

High frequency seismic testing for sensitive equipment will be conducted as a supplemental test to low frequency seismic excitation. High and low frequency seismic Required Response Spectra (RRS) are separate environments and an envelope RRS covering both would not be representative of the Design Basis Event (DBE). Testing to a High/Low Frequency Envelope RRS could prove destructive to both the equipment under test and the seismic test table.

When high frequency seismic testing is performed following a low frequency seismic testing, the equipment shall be subjected to the high frequency SSE testing after completion of the low frequency seismic testing. Low level cycling fatigue effects requirement shall be justified represented by low frequency seismic input. No additional low level testing for high frequency excitation is required. One SSE high frequency seismic test will be performed to demonstrate functionality of equipment in its most sensitive electrical configuration.

Acceptance and qualification to the high frequency input is determined based on the comparison of the test levels the components have been analyzed or tested to. For those equipment/components determined to have already been tested to high seismic levels in the high frequency region, no additional testing or justifications will be necessary. A review of seismic testing data is performed to verify that the tested seismic levels envelop the high frequency seismic demand. If these components cannot be shown to be acceptable based on this review, additional testing or justifications may be required to show qualification.

3I.7 References

1. EPRI Draft White Paper, "Considerations for NPP Equipment and Structures Subjected to Response Levels Caused by High Frequency Ground Motions," Transmitted to NRC March 19, 2007.

2. APP-GW-GLR-115, "Effect of High Frequency Seismic Content on SSCs," Westinghouse Electric Company LLC.

3. Personal correspondence related to approved incoherence function, Abramson – April 2007.

Table 3I.6-1: Potential Sensitive Equipment List
• Equipment or components with moving parts and required to perform a switching function during the seismic event (e.g., circuit breakers, contactors, auxiliary switches, molded case circuit breakers, motor control center starters, and pneumatic control assemblies) • Components with moving parts that may bounce or chatter such as relays and actuation devices (e.g., shunt trips) • Unrestrained components • Potentiometers • Process switches and sensors (e.g., pressure/differential pressure, temperature, level, limit/position, and flow) • Components with accuracy requirements that may drift due to seismic loading • Interfaces such as secondary contacts – Connectors and connections (including circuit board connections for digital and analog equipment)

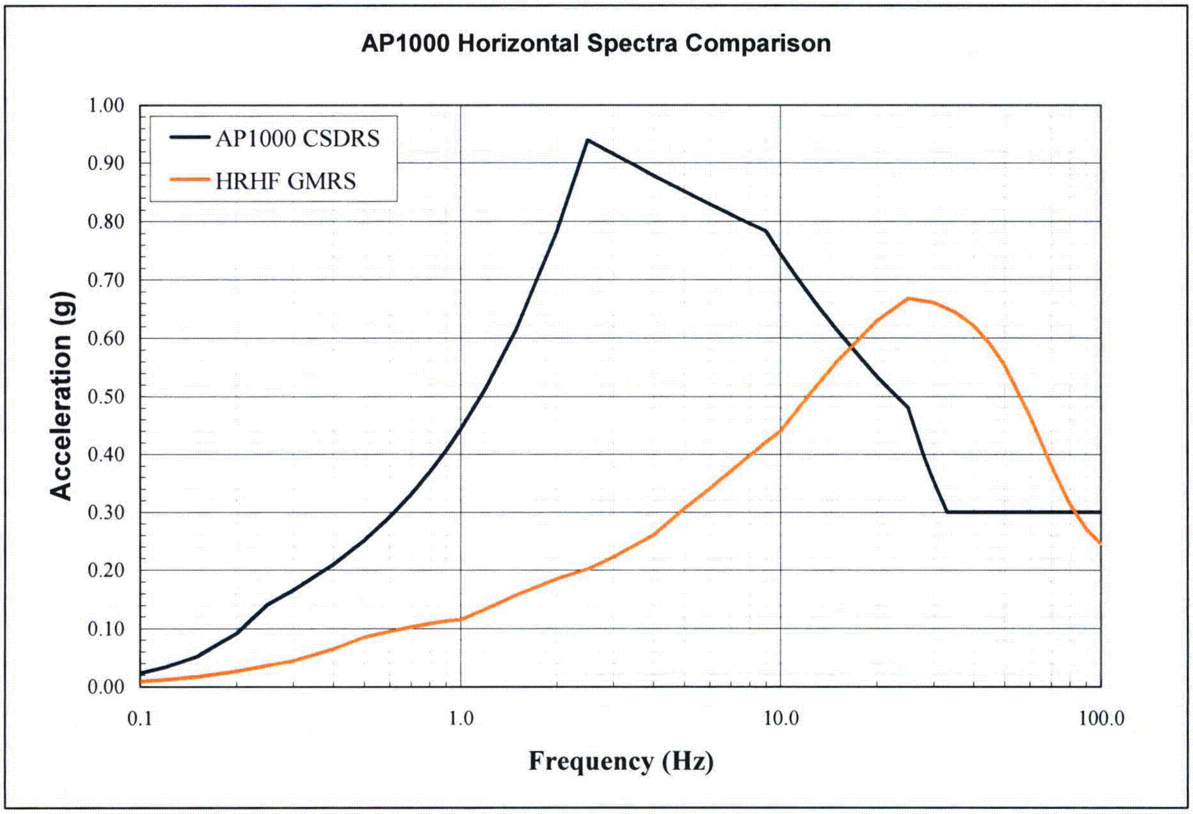


Figure 3I.1-1: Comparison of Horizontal AP1000 CSDRS and HRHF GMRS

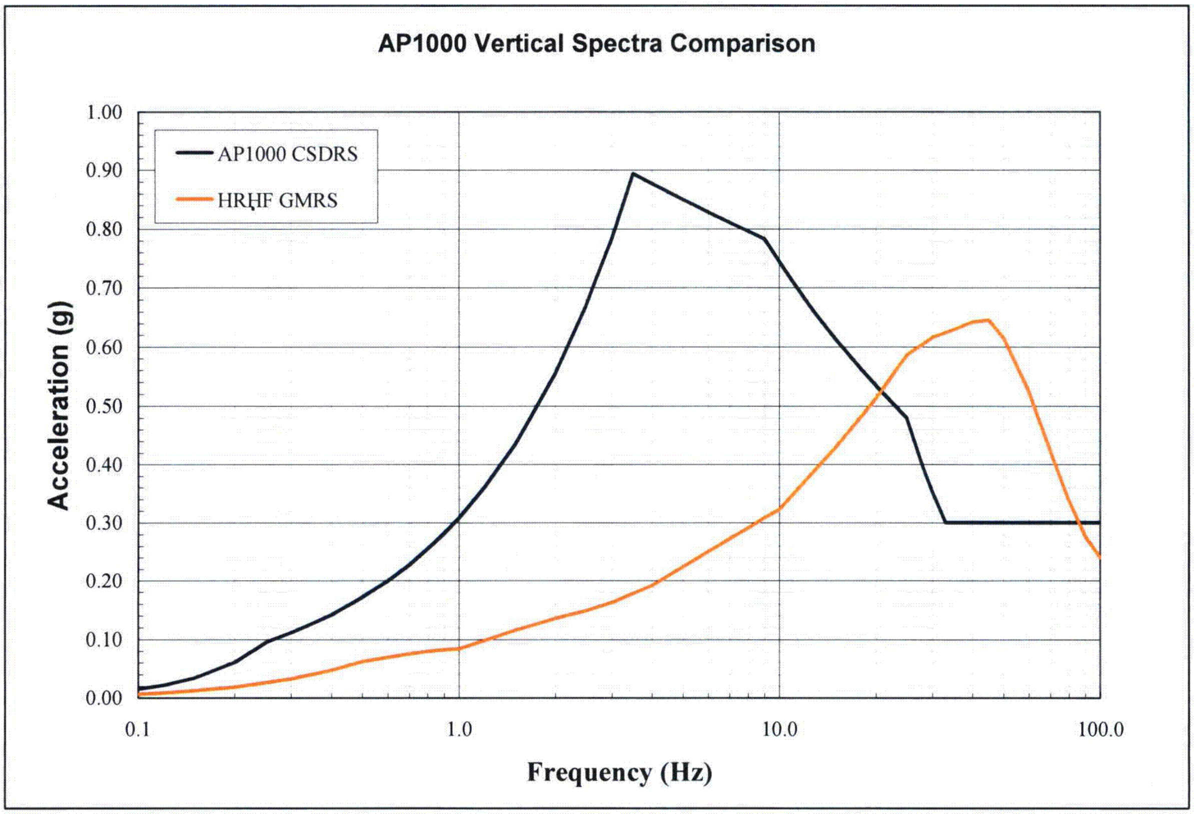


Figure 3I.1-2: Comparison of Vertical AP1000 CSDRS and HRHF GMRS