APPENDIX 3.7B – EVALUATION FOR HIGH FREQUENCY SEISMIC INPUT

3.7B.1 Overview

The seismic analysis and design of the APR1400 standard plant are based on the certified seismic design response spectra (CSDRS) described in Subsection 3.7.1.1.1. These spectra are based on NRC Regulatory Guide (RG) 1.60 with an increase in the 9 to 50 Hz frequency range. However, many of the envelope response spectra of the Central and Eastern United States (CEUS) rock sites show higher amplitude at higher frequency than the CSDRS. Response spectra having these characteristics are called hard rock high frequency (HRHF) ground motion response spectra (GMRS).

The APR1400 HRHF response spectra are shown in Figures 3.7B-1 and 3.7B-2 for the horizontal and vertical directions, respectively, and compared to the APR1400 CSDRS for both the horizontal and vertical directions for 5% damping. The HRHF response spectra exceed the CSDRS for frequencies above about 10 Hz. However, in general, as presented in EPRI Draft White Paper, "Considerations for NPP Equipment and Structures Subjected to Response Levels Caused by High Frequency Ground Motions" (Reference 1), the high frequency seismic input is regarded to be non-damaging.

The structures and equipment qualified by seismic analyses for the APR1400 CSDRS were evaluated for the potential to sustain damage from high frequency seismic input motion. The building structures, reactor pressure vessel and internals, primary component supports, primary loop nozzles, piping, and equipment are included in the evaluation of the APR1400 standard plant for HRHF response spectra to demonstrate that the seismic responses of the structures, components, supports, and piping for high frequency seismic input motion are non-damaging. In this evaluation, the seismic responses in the high frequency range of the structures due to high frequency seismic input motion are reduced first by considering the effects of spatial incoherence of seismic input motion.

This appendix summarizes the methodology and results of the evaluation for effects of HRHF response spectra on structures, systems, and components (SSCs) of the APR1400 standard plant. The detailed procedure and results of the evaluation are documented in Technical Report, APR1400-E-S-T-NR-13004-P (Reference 2).

3.7B.2 High Frequency Seismic Input

The comparisons of the HRHF horizontal and vertical response spectra with the APR1400 CSDRS are presented in Figures 3.7B-1 and 3.7B-2. The HRHF response spectra used for the evaluation are developed for the CEUS hard rock sites. The HRHF response spectra are higher than the CSDRS in the high frequency range from approximately 10 to 100 Hz.

The EPRI report published in June 2011, "Evaluation of Seismic Hazard at Central and Eastern US Nuclear Power Plant Sites" (Reference 3) is used to develop the APR1400 HRHF response spectra. In this EPRI report, the maximum and fractile GMRS for the 60 CEUS nuclear power plant sites, assuming that they are all hard rock sites, were developed. The 0.8-fractile, 5%-damped, horizontal composite envelope GMRS for CEUS hard-rock sites to achieve to the appropriate goal of non-exceedance probability is selected as the 5%-damped HRHF horizontal target response spectrum for application to the APR1400 standard plant evaluation as shown in Figure 3.7B-3.

The 5%-damped HRHF vertical target response spectrum is generated by multiplying the recommended V/H ratios for CEUS rock sites given in Table 4-5 of NUREG/CR-6728 (Reference 4) by the 5%-damped HRHF horizontal target response spectrum. The resulting 5%-damped HRHF vertical target response spectrum generated is plotted in Figure 3.7B-4.

The digitized values of the HRHF horizontal and vertical target response spectra are given in Tables 3.7B-1 and 3.7B-2, respectively.

The HRHF horizontal target response spectra for damping ratios other than 5%, namely, 2%, 3%, 7%, and 10% damping ratios, which are not specified in the EPRI report, are generated from the 5%-damped HRHF horizontal target response spectrum by multiplying the 5%-damped spectral values by the spectral ratios for the CEUS rock sites given in Table 1 in Appendix C of SRP 3.7.1 (Reference 5). For spectral frequencies not listed in Table 1, the ratios used follow a log-log amplitude-frequency linear interpolation. The HRHF horizontal target response spectrum for 4% damping ratio is generated by interpolating between the spectral values for 3% and 5% damping ratios on a log scale for the damping ratio and a linear scale for the spectral acceleration.

The HRHF vertical target response spectra for 2%, 3%, 4%, 7%, and 10% damping ratios are generated by multiplying the V/H ratios for the CEUS rock site conditions by the corresponding HRHF horizontal target response spectra.

The generated HRHF horizontal and vertical target response spectra for 2%, 3%, 4%, 5%, 7% and 10 percent damping ratios are shown in Figures 3.7-12 and 3.7-13 in Chapter 3, respectively. The guidelines and criteria described in NRC SRP Section 3.7.1, Rev. 3, for Option 1 Approach 1 (Reference 5) are used for generating a set of three-component acceleration time histories compatible with HRHF target response spectra. The generated HRHF horizontal and vertical acceleration time histories, named H1H and H2H for both horizontal directions and VTH for vertical direction, are plotted along with their integrated velocity and displacement time histories in Figures 3.7-14, 3.7-15, and 3.7-16 in Chapter 3, respectively. The comparisons of the time history response spectra with the corresponding HRHF horizontal and vertical target response spectra for each damping value are shown in Figures 3.7-17, 3.7-18, and 3.7-19 in Chapter 3.

3.7B.3 High Frequency Soil Profiles

Among the nine generic site-shear-wave-velocity profiles S1 through S9 developed for the APR1400 standard plant design, the site profiles that could be classified as hard rock sites are S8 and S9 cases. For the site profile S8, the depth of bedrock where the rock shear-wave velocity (Vs) is equal to 2,804 m/sec (9,200 ft/sec) is located at a depth of 61 m (200 ft). For the site profile S9, the depth of bedrock where the Vs is equal to 2,804 m/sec (9,200 ft/sec) is at a depth of 30.5 m (100 ft).

The site profile S9 is determined to more critical when subjected to the HRHF horizontal seismic input motion than the site profile S8, based on a comparison of the horizontal site response amplification transfer functions from the bedrock where Vs is equal to 2,084 m/sec (9,200 ft/sec) for the site profile S8 and those for the site profile S9. Therefore, the soil structure interaction (SSI) analysis using the HRHF seismic input motion is performed for the site profile S9.

3.7B.4 SSI Model

For the evaluation of HRHF seismic input motion, the nuclear island model described in Subsection 3.7.2 is analyzed using ACS SASSI computer program. Acceleration time histories compatible with the HRHF target response spectra are applied at the finished grade.

To incorporate spatial incoherence in the seismic input motions for SSI analysis using SASSI, the methodology developed by Tseng and Lilhanand as described in the 1997 EPRI report TR-102631 (Reference 6) is used. This methodology makes use of the hard-rock coherency functions for horizontal and vertical seismic ground motions developed by Abrahamson. The analysis considering spatial incoherence for the HRHF seismic input motions is performed. As a result of comparison between coherent and incoherent HRHF in-structure response spectra (ISRS), there is very little difference in the response spectra below 4 Hz. In the high frequency range above 30 Hz, the incoherent ISRS are lower than the coherent ISRS.

To estimate the significance of the HRHF response spectra, the CSDRS and HRHF seismic responses at selected major locations in nuclear island structures are compared. As a result of comparison, HRHF response spectra exceed the CSDRS response spectra mostly above the 10 Hz region. These are typical of comparative responses found throughout the APR1400 standard plant.

The exceedances of HRHF-based ISRS are evaluated to confirm that high frequency input has marginal effect on equivalent SSCs qualified by analysis for the APR1400 CSDRS.

3.7B.5 Evaluation Methodology

An evaluation of the representative APR1400 SSCs was performed to demonstrate that the APR1400 nuclear power plant is qualified for high frequency seismic response. Because an evaluation of the effect of HRHF seismic input on the total plant is not required, the SSCs that are potentially sensitive to high frequency input were selected by screening.

The soil structure interaction analyses for high frequency seismic input were performed using ACS SASSI.

The maintainability of the safety functions of the SSCs was assessed using high frequency seismic input to verify that the seismic response would be non-damaging.

3.7B.6 General Selection Screening Criteria

The following general screening criteria were used to identify representative APR1400 SSCs as selected samples that were evaluated to demonstrate acceptability of the APR1400 nuclear power plant for high frequency motion.

a. Importance to safety, including the component safety function for the safe shutdown earthquake (SSE) event and its potential failure modes due to an SSE. The components whose failure modes do not affect the ability to achieve safe shutdown are excluded.

b. Location in areas of the plant that are susceptible to large high frequency seismic inputs. The analyst verifies that the equipment or structure has seismic input that has high frequency response. The verification is made using the HRHF seismic response spectra at the equipment/structural attachment points.

c. Significant modal response within the region of high frequency amplification, as defined by items such as modal mass, participation factor, stress, and/or deflection. The analyst determines that the equipment or structure has dynamic response in the region of the seismic input associated with the high frequency amplified response that would result in significant stress or loads that are included in the load combinations.

d. Significant total stress as compared to allowable when considering load combinations that include seismic. This task complements the above activity where it is judged that the seismic stress due to equipment/structure response in the high frequency region is meaningful compared to the allowables and is therefore included in the load combinations.

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

a. Building structures

1) Reactor containment building internal structure

2) Reactor containment building containment structure

3) Auxiliary building

b. Reactor coolant system (RCS)

1) Reactor vessel internals and core

2) Component supports and nozzles of RCS

c. Piping system

d. Safety-related electrical equipment

3.7B.7 Evaluation

3.7B.7.1 Building Structures

Maintaining the structural integrity of the nuclear island structures is important to the safety of the plant. Representative portions of the building structures that were evaluated for the effect of high frequency input were selected based on the areas that could experience high seismic shear and moment loads in a seismic event.

The evaluation consisted of a comparison of the seismic loads and equivalent acceleration from high frequency input to those obtained from the APR1400 design CSDRS for the representative building structures. The nuclear island structures were considered to be qualified for high frequency input if the seismic loads and equivalent acceleration from the CSDRS enveloped those from the high frequency input.

3.7B.7.2 Reactor Coolant System

The reactor vessel internals (RVI) support the core and are therefore important to safety. RVI consist of complicated components whose natural frequencies are in the relatively high frequency range. RCS component supports were selected as one of the evaluation items because they support the RCS components to maintain the capability of the components to perform their intended safety-related functions. The nozzles were evaluated because piping failures generally occur at high stress locations, such as at the nozzles of a component, and they represent the sensitivity of the reactor coolant loop (RCL) piping to high frequency excitation. For selected items, the HRHF response was evaluated by comparing the design loads with the loads obtained from the HRHF seismic analyses. It is concluded that supports and nozzles are acceptable for the HRHF seismic loads if the design loads from the CSDRS enveloped those from the HRHF seismic analyses.

3.7B.7.2.1 Reactor Vessel Internals and Core

The RVI and core were selected because they are important to safety and their analysis is representative of major primary components. Because the natural frequencies of the RVI components are in the relatively high frequency range, the RVI may be sensitive to high frequency excitation.

A series of analyses was performed to obtain the response of the RVI and core to HRHF loads. The RVI HRHF analysis was done using the HRHF excitation of the reactor vessel (RV) obtained from the response of the reactor containment building and RCS to HRHF loads. Then, the response of the core was calculated using the detailed core model, and the core plate motion was obtained from the RVI analysis.

The time history analyses of the RVI and core were performed for each HRHF mode, and the responses of all modes were combined for the resultant response. The maximum response of each mode was used for the combination. The broadening of the input excitation was also considered for the RVI and core analyses by frequency variation as implemented for CSDRS loads.

3.7B.7.2.2 Component Supports and Nozzles of RCS

The purpose of RCS structural supports is to support the RCS components during normal operation and transients and during SSE and design basis accident conditions. RCS component supports are necessary to maintain the integrity of the RCS components to preserve their safety function. Support loads at all locations of RCS supports were compared.

The RV is supported by four vertical columns located under the vessel inlet nozzles. The columns are designed to be flexible to the horizontal direction to allow horizontal thermal expansion during heatup and cooldown. The columns also support the reactor vessel vertically.

The steam generator (SG) is supported at the bottom by a sliding base bolted to an integrally attached conical skirt. The sliding base rests on low friction bearings, which allow unrestrained thermal expansion of the RCS. Two keyways in the sliding base join with embedded keys to guide the movement of the SG during expansion and contraction of the RCS and also limit the movement of the bottom of the SG during SSE and branch line pipe break (BLPB) events.

The reactor coolant pump (RCP) supports consist of four vertical columns, four horizontal columns, and two horizontal snubbers.

The pressurizer (PZR) is supported by a cylindrical skirt that is welded to the pressurizer and bolted to the building structure. Four keys welded to the upper shell of pressurizer provide additional restraint for an SSE, pressurizer pilot-operated safety relief valve (POSRV) actuation, and BLPB conditions.

The RCS component nozzles of the RV, SG, and RCP were selected to be included in the evaluation because the nozzle of a component has higher potential for failure than other locations of the components, and the cold leg, hot leg, and crossover leg are relatively sensitive to high frequency when compared with the other components.

3.7B.7.3 Piping System

Because piping lines and piping supports throughout the plant are designed according to 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 depends on the following factors:

a. The local HRHF ISRS have exceedances in the high frequency range relative to the APR1400 CSDRS ISRS.

b. The piping system has modes or natural frequencies in the high frequency range.

c. The piping system layout includes valves or other concentrated masses that have closely spaced supports and therefore cause high local natural frequencies. This generally yields significant cumulative mass in the high frequency range.

The ASME Class 1, 2, and 3 piping systems are required to be evaluated for the HRHF seismic response spectra.

In the APR1400 plant, the design acceptance criteria (DAC) are applied to the piping design area. The COL applicant is to evaluate the HRHF response spectra (COL 3.7B (1)).

3.7B.7.4 Safety-Related Electrical Equipment

Safety-related electrical equipment is evaluated for the effect of high frequency input motion for safety of the plant. Representative items are selected for the evaluation because they are susceptible to high frequency seismic inputs. Susceptibility to excitation caused by high frequency input depends on the presence of the following factors:

a. The local HRHF ISRS exceed the APR1400 CSDRS ISRS in the high frequency range.

b. Safety-related equipment has modes or natural frequencies in the high frequency range.

c. Safety-related components have potential failure modes involving a change of state, chatter, signal change/drift, and/or connection problems.

Equipment with modes in the range of the high frequency response excitation is expected to experience higher loads and amplifications than equipment with modes outside a high frequency range. To support this expectation and determine the effect of high frequency seismic motion on APR1400 safety-related electrical equipment, the equipment configuration, location, stress analysis methodology, and equipment qualification testing procedures are reviewed.

The COL applicant is to evaluate the representative items listed in Table 3.7B-3 (COL 3.7B (1)).

3.7B.8 Combined License Information

COL 3.7B(1) The COL applicant is to evaluate the HRHF response spectra.

COL 3.7B(2) The COL applicant is to evaluate the representative items listed in Table 3.7B-2.

3.7B.9 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 2007.

2. APR1400 DC Technical Report, APR1400-E-S-T-NR-13004-P, "Evaluation of Effects of HRHF Response Spectra on SSCs of the APR1400 Standard Plant," Rev. 0, September 2013.

3. EPRI TR-1023389, "Evaluation of Seismic Hazards at Central and Eastern U.S. Nuclear Power Sites," Electric Power Research Institute, June 2011.

4. NUREG/CR-6728, "Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard- and Risk-consistent Ground Motion Spectra Guidelines," U.S. Nuclear Regulatory Commission, October 2001.

5. NRC Standard Review Plan 3.7.1, "Seismic Design Parameters," Rev. 3, NUREG-0800, U.S. Nuclear Regulatory Commission, March 2007.

6. EPRI TR-102631, "Soil-structure Interaction Analysis Incorporating Special Incoherence of Ground Motions," Electric Power Research Institute, October 1997.

Table 3.7B-1

5%-Damped HRHF Horizontal Target Response Spectrum

Freq. (Hz)	Sa (g)	Freq. (Hz)	Sa (g)	Freq. (Hz)	Sa (g)	Freq. (Hz)	Sa (g)
0.100	0.0144	2.800	0.4550	11.000	0.9471	61.000	0.8530
0.125	0.0225	2.900	0.4679	11.500	0.9674	64.000	0.8015
0.150	0.0323	3.000	0.4808	12.000	0.9873	65.000	0.7856
0.200	0.0431	3.150	0.4961	12.500	1.0067	67.000	0.7553
0.250	0.0539	3.300	0.5111	13.000	1.0245	70.000	0.7136
0.300	0.0647	3.450	0.5259	13.500	1.0420	73.000	0.6726
0.400	0.0862	3.600	0.5405	14.000	1.0591	75.000	0.6474
0.500	0.1078	3.800	0.5596	14.500	1.0759	76.000	0.6354
0.600	0.1271	4.000	0.5783	15.000	1.0924	79.000	0.6017
0.700	0.1452	4.200	0.5942	16.000	1.1150	80.000	0.5911
0.800	0.1622	4.400	0.6097	17.000	1.1367	82.000	0.5733
0.900	0.1780	4.600	0.6249	18.000	1.1575	85.000	0.5483
1.000	0.1960	4.800	0.6398	20.000	1.1969	88.000	0.5251
1.100	0.2153	5.000	0.6545	22.000	1.2168	90.000	0.5107
1.200	0.2346	5.250	0.6711	25.000	1.2441	91.000	0.5055
1.250	0.2442	5.500	0.6873	28.000	1.2376	94.000	0.4904
1.300	0.2535	5.750	0.7032	30.000	1.2336	97.000	0.4763
1.400	0.2720	6.000	0.7187	31.000	1.2274	100.000	0.4630
1.500	0.2905	6.250	0.7328	34.000	1.2102		
1.600	0.3056	6.500	0.7467	35.000	1.2048		
1.700	0.3205	6.750	0.7603	37.000	1.1866		
1.800	0.3351	7.000	0.7736	40.000	1.1615		
1.900	0.3497	7.250	0.7855	43.000	1.1262		
2.000	0.3640	7.500	0.7972	45.000	1.1046		
2.100	0.3747	7.750	0.8087	46.000	1.0896		
2.200	0.3852	8.000	0.8200	49.000	1.0476		
2.300	0.3955	8.500	0.8398	50.000	1.0345		
2.400	0.4056	9.000	0.8589	52.000	0.9970		
2.500	0.4156	9.500	0.8823	55.000	0.9458		
2.600	0.4288	10.000	0.9050	58.000	0.8997		
2.700	0.4420	10.500	0.9263	60.000	0.8715		

Table 3.7B-2

5%-Damped HRHF Vertical Target Response Spectrum

Freq. (Hz)	Sa (g)	Freq. (Hz)	Sa (g)	Freq. (Hz)	Sa (g)	Freq. (Hz)	Sa (g)
0.100	0.0108	2.800	0.3413	11.000	0.7187	61.000	0.9710
0.125	0.0169	2.900	0.3510	11.500	0.7381	64.000	0.9116
0.150	0.0242	3.000	0.3606	12.000	0.7572	65.000	0.8922
0.200	0.0323	3.150	0.3721	12.500	0.7759	67.000	0.8552
0.250	0.0404	3.300	0.3833	13.000	0.7935	70.000	0.8046
0.300	0.0485	3.450	0.3944	13.500	0.8108	73.000	0.7553
0.400	0.0647	3.600	0.4054	14.000	0.8278	75.000	0.7251
0.500	0.0809	3.800	0.4197	14.500	0.8445	76.000	0.7077
0.600	0.0953	4.000	0.4337	15.000	0.8610	79.000	0.6594
0.700	0.1089	4.200	0.4456	16.000	0.8858	80.000	0.6444
0.800	0.1217	4.400	0.4573	17.000	0.9097	82.000	0.6185
0.900	0.1335	4.600	0.4687	18.000	0.9329	85.000	0.5827
1.000	0.1470	4.800	0.4799	20.000	0.9882	88.000	0.5500
1.100	0.1615	5.000	0.4909	22.000	1.0335	90.000	0.5299
1.200	0.1759	5.250	0.5033	25.000	1.0948	91.000	0.5221
1.250	0.1832	5.500	0.5155	28.000	1.1322	94.000	0.4998
1.300	0.1901	5.750	0.5274	30.000	1.1556	97.000	0.4808
1.400	0.2040	6.000	0.5390	31.000	1.1628	100.000	0.4630
1.500	0.2179	6.250	0.5496	34.000	1.1881		
1.600	0.2292	6.500	0.5600	35.000	1.1963		
1.700	0.2403	6.750	0.5702	37.000	1.2040		
1.800	0.2514	7.000	0.5802	40.000	1.2199		
1.900	0.2622	7.250	0.5891	43.000	1.2198		
2.000	0.2730	7.500	0.5979	45.000	1.2177		
2.100	0.2810	7.750	0.6065	46.000	1.2114		
2.200	0.2889	8.000	0.6150	49.000	1.1765		
2.300	0.2966	8.500	0.6298	50.000	1.1632		
2.400	0.3042	9.000	0.6442	52.000	1.1238		
2.500	0.3117	9.500	0.6617	55.000	1.0698		
2.600	0.3216	10.000	0.6788	58.000	1.0210		
2.700	0.3315	10.500	0.6989	60.000	0.9910		

Table 3.7B-3 (1 of 2)

List of Potential Equipment to Evaluate Against High Frequency Seismic Input

Equipment	Description
125V DC 1E Battery	Battery
1E Battery Charger	Battery Charger
1E DC Control Center	Distribution Panels
Non-1E DC Control Center	
Ground Fault Monitoring Cabinet	
125V DC Distr. PNL	
480V 1E MCC	Motor Control Center
1E Regulating TR.	Transformer
1E Inverter	Inverter
1E AB 4.16KV SWGR	Switchgear
Spent Fuel Pool Level	Level Switches and Transfer
Floor Drain Sump Flooding Level	
CCW Sump Flooding Level	
SI Pump Room Flooding Level	
SC Pump Room Flooding Level	
CS Pump Room Flooding Level	
BOP RMS Cabinet (SRDC)	Radiation Monitor
MMIS-BOP MCR Consoles	Main Control Room
MMIS-BOP ESF-CCS (LCC & GCC)	
MMIS-BOP QIAS-N	
Flexible Hose	Active Hose

Table 3.7B-3 (2 of 2)

Equipment	Description
125V DC 1E Battery	Battery
1E Battery Charger	Battery Charger
1E DC Control Center	Distribution Panels
Non-1E DC Control Center	
Ground Fault Monitoring Cabinet	
125V DC Distr. PNL	
480V 1E MCC	Motor Control Center
1E Regulating TR.	Transformer
1E Inverter	Inverter
1E AB 4.16KV SWGR	Switchgear
Spent Fuel Pool Level	Level Switches and Transfer
Floor Drain Sump Flooding Level	
CCW Sump Flooding Level	
SI Pump Room Flooding Level	
SC Pump Room Flooding Level	
CS Pump Room Flooding Level	
BOP RMS Cabinet (SRDC)	Radiation Monitor
MMIS-BOP MCR Consoles	Main Control Room
MMIS-BOP ESF-CCS (LCC and GCC)	
MMIS-BOP QIAS-N	
Flexible Hose	Active Hose
Reactor Trip Switchgear	Switchgear
RCP Pump Speed	Speed Sensor
RCS Hot Leg Water Level	Transmitters
PZR Level	
PZR Wide Range Pressure	
PZR Narrow Range Pressure	
POSRV Motor Operated Isolation Valve	Active Valves
Pilot Operated Safety Relief Valve	
SIT Discharge Isolation	
PZR Level Reference Leg Temperature	Resistance Temperature Detector
SIT N2 Vent	Non-active Valve
SCS Heat Exchanger	Heat Exchanger
Safety Injection Tank	Tank

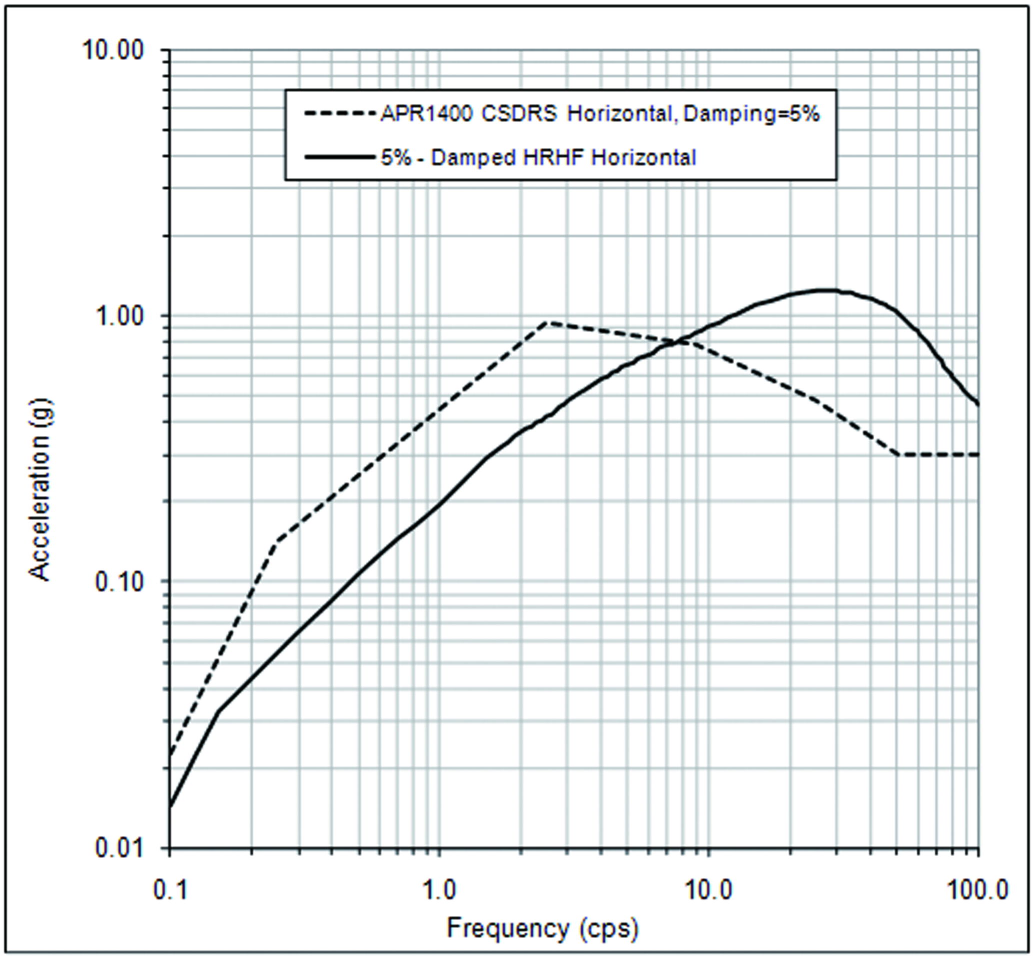

Figure 3.7B-1 Comparison of 5%-Damped HRHF and CSDRS Horizontal Target Response Spectra

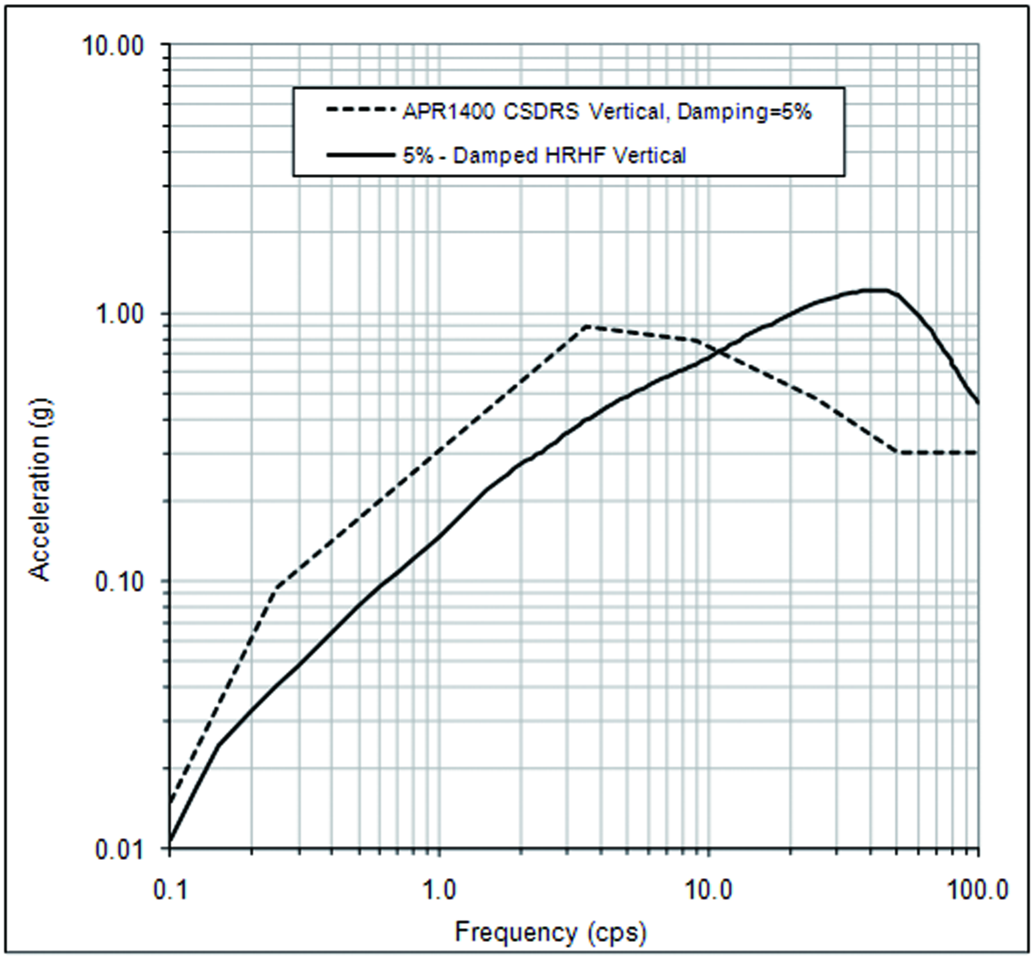

Figure 3.7B-2 Comparison of 5%-Damped HRHF and CSDRS Vertical Target Response Spectra

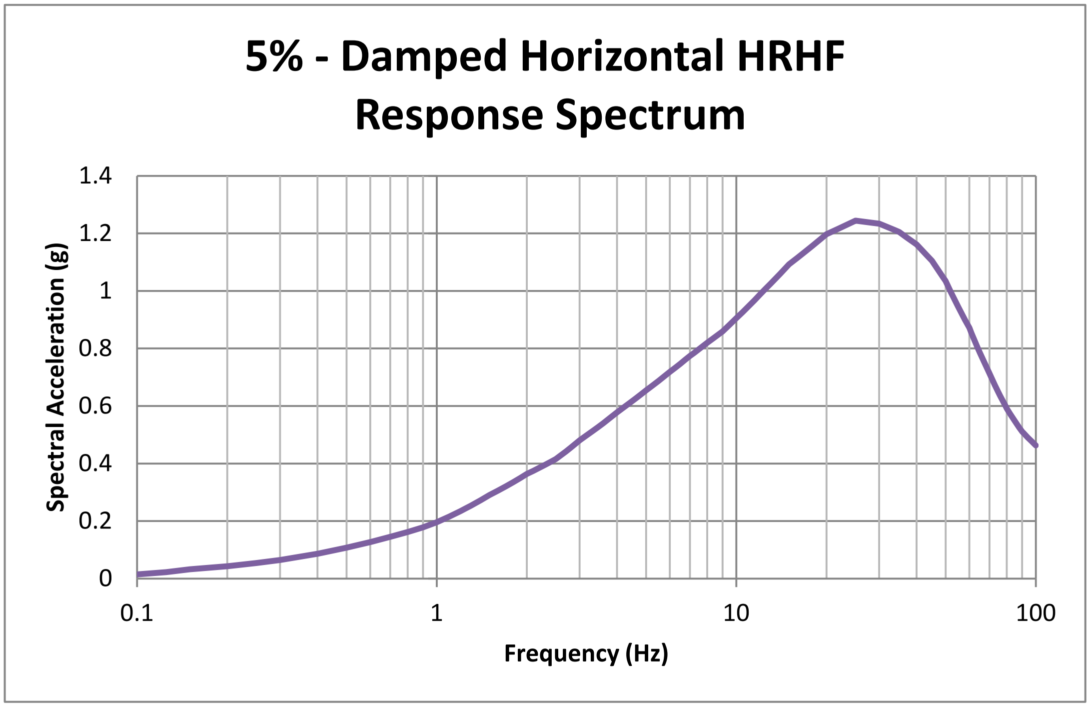

Figure 3.7B-3 5%-Damped HRHF Horizontal Target Response Spectrum

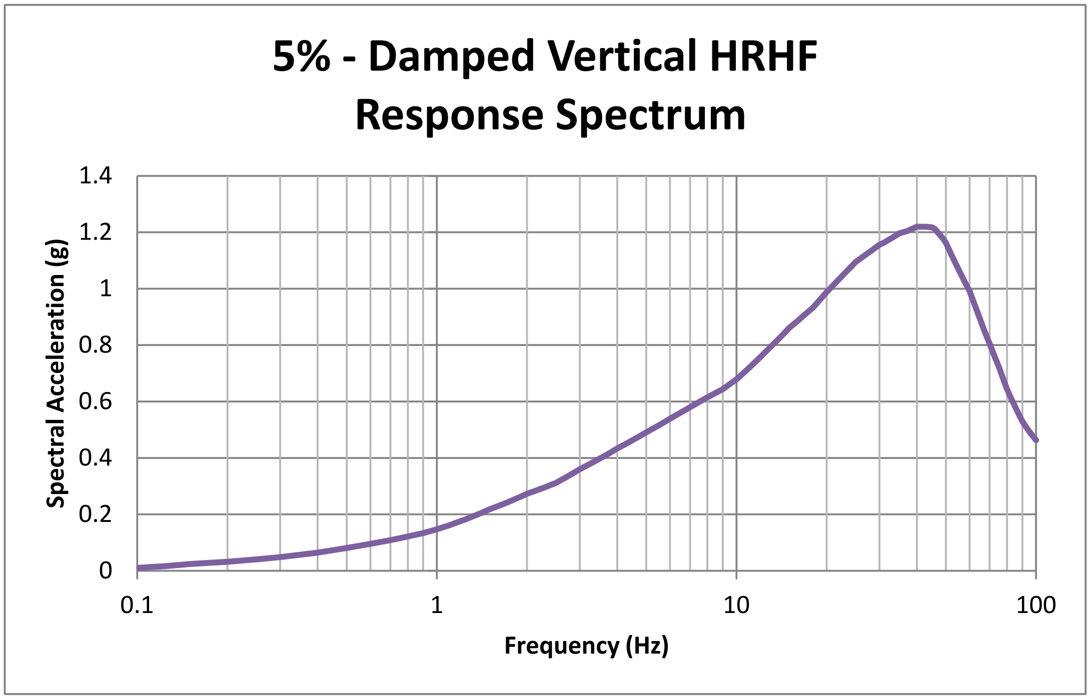

Figure 3.7B-4 5%-Damped HRHF Vertical Target Response Spectrum