4.0 PSFSV

4.1 Model Description and Analysis Approach

4.1.1 Structure Description and Model Development

The North Anna Unit 3 has two PSFSVs next to the Power Source Buildings (PS/Bs) referred to as the east and west vaults. These vaults are located to the south of the Reactor Building and to the east and west of the Turbine Building (T/B). Each PSFSV is a partially buried reinforced-concrete structure that will contain three fuel oil tanks. The structures consist of a mat slab, four exterior perimeter walls, two interior walls, a roof slab on metal deck and steel beams, a portion of the ESW Pipe tunnel adjacent to the PSFSV and fuel pipe access tunnels that provide access between the PSFSVs and the Power Source building. The interior walls separate each PSFSV into three compartments to house the three tanks. The east and west PSFSV are for the most part identical (except for some local differences regarding the partial ESWPT that is attached to the PSFSV). Since the east and west PSFSVs are nearly symmetric the SSI analysis only considered the configuration of the east vault to obtain the seismic responses and design demands of both the east and west vaults.

The underside of the roof of the PSFSVs is at a nominal elevation 306', with a varying top of roof due to the sloped roof. The roof slab thickness varies from 2 ft-0" to 3'-8". The top of mat elevation is 277'-9". The overall dimensions at the top of each PSFSV are 82 ft north-south by 86 ft east-west. There are three openings through the north wall of each PSFSV for entry to the fuel pipe access tunnels that extend over the top of the ESWPT and terminate at the Power Source Buildings (PS/Bs). The walkways are at the same elevation as the top of PSFSV mat.

The PSFSV structure models use as reference an orthogonal coordinate system with x-axis pointing north, y-axis pointing west, and a vertical z-axis pointing upward.

FSAR Figures 3.8-204, 3.8-212, 3.8-213, and 3.8-214 show the geometry of the PSFSV structures.

The materials and properties of the roof slab in the models are altered to reflect the cracked concrete properties for out of plane bending. The properties are reduced to one-half of the uncracked flexural stiffness. Un-cracked properties are considered for the in-plane stiffness. To achieve 1/2 flexural out-of-plane stiffness of the slab without reducing its in-plane stiffness or mass, the following element properties are assigned:

$$t_{cracked} = (C_F)^{0.5} \cdot t$$

$$E_{cracked} = [1/(C_F)^{0.5}] \cdot E_{concrete}$$

$$\rho_{cracked} = [1/(C_F)^{0.5}] \cdot \rho_{concrete}$$

where:

C_F = the factor for the reduction of flexural stiffness, taken as 1/2,

$t_{cracked}$ = the effective slab thickness to account for cracking

t = the gross section thickness

$\rho_{cracked}$ = the effective unit weight to offset the reduced stiffness and provide the same total mass

$\rho_{concrete}$ = unit weight of concrete

$E_{cracked}$ = effective modulus to account for the reduction in thickness that keeps the same axial stiffness while reducing the flexural stiffness by C_F

$E_{concrete}$ = modulus of elasticity of concrete.

Table 4.0-2 summarizes the material properties used for the FE models. Table 4.0-3 shows the structural component dimensions `and weights for the FE models.

Two set of seismic response analyses are employed: (1) ANSYS response spectrum analyses of a fixed base model to calculate seismic demands for design of structural members; and (2) ACS SASSI SSI analyses to calculate in structure response spectra (ISRS) used for design of seismic Category I and II subsystems, components and equipment.

The response spectra analyses use the 3D fine mesh finite element model of the PSFSV that is also used for the calculation of demands from gravity, soil pressures, wind, and other design loads. The detailed design model includes all relevant structural details including major openings and masses with adequate mesh refinement to accurately calculate structural demands at critical design locations. The model includes shell elements for the walls, roof and the basemat, mass elements for non-structural added mass and rigid beam elements for modeling of the emergency power fuel oil tanks and their supports. The three tanks are rigidly connected to the mat. Walls are modeled using gross section properties and geometrical positioned centerline to centerline.

The three tanks and their supports are considered to be rigid and full and have a total weight of 1155 kips. Varying levels of fuel oil in the fuel oil storage tanks were not considered because the power fuel storage vaults are supposed to be kept full prior to an emergency such as an SSE, therefore, full tanks is the normal operating fuel level for the tanks. The fuel oil tanks and supports that are procured are required to be designed based on the ISRS for the base slabs at the support points for the beam elements that model the tank supports.

The structural model for SSI analyses of PSFSV uses the same structural elements and masses as the ANSYS detailed to represent the walls, the roofs and the oil fuel tanks but uses a less refined mesh. The only difference is that the ACS SASSI structural model uses solid brick elements to represent the dynamic properties of the basemat and the block of fill concrete that supports the PSFSV structure. The detailed design model uses shell elements for the basemat and does not include the concrete fill. The two modes have consistent dynamic properties, mass and stiffness. The extent of the fill concrete in the SSI structural model is from elevation of 252’-2” where the control point of the input motion is defined up to the basement of the PSFSV located at elevation 277’-9”. Wall shell elements are overlain on the outside of the mat solid brick elements to provide flexural continuity of the walls at the mat.

The ANSYS detailed design model of the PSFSV is shown in Figures 4.0-1 through 4.0-3. Figure 4.0-7 shows the SASSI structural model. Table 4.0-1 identifies the element types used in the ANSYS detailed design model and ACS SASSI structural model. Table 4.0-2 provides

the model component material properties while Table 4.0-3 provides the weights of the model components as well as the total weight and the equivalent uniform bearing pressure.

4.1.2 ANSYS Design Static and Fixed Base Response Spectrum Analyses

The design analysis included the gravity, static earth pressures and surcharge, live, wind, tornado, and precipitation loads identified in Section 2.0 of this report. The seismic mass includes 25% of the live load. This includes the roof since 25% of the snow load governs over 75% of the normal winter precipitation load. The seismic design load also includes the dynamic and hydrodynamic effects of earthquake induced lateral soil pressures that are calculated as described in Section 2.4. This design of the PSFSV also does not consider pipe breaks or temperature effects.

The seismic analyses included a full modal analysis with a cut-off frequency of 100 Hz. The natural frequencies and descriptions of the associated modal responses of the fixed-base model are presented in Table 4.0-4 for the PSFSV.

The earthquake design response spectra data used with the ANSYS Design Model are shown in Figures 4.0-5 and 4.0-6. The input response spectra are based on the 5% damping ground response spectra obtained from the site response analysis and do not include the possible SSI effects. Additional margins are introduced in the design of the reinforced concrete members of the PSFSV in order to ensure that the design envelopes the SSI effects. The seismic design demands are calculated using the same response spectra analyses methodology as that used for the design of the UHSRS that is described in Section 3.0. The seismic design demands due to dynamic soil pressure are considered as an in-phase response and are added to the rigid response portion of the Lindley-Yow seismic analyses prior to the in-phase and out-of-phase components being combined using the SRSS method. The wall pressures due to hydrodynamic and soil inertia are calculated based on ASCE4 methodology as described in Section 2.4.

The structural demands of the PSFSV to seismic soil pressure and seismic inertia are then added to the effects of all other design loads discussed in Section 3.8.4.3 of US APWR DCD.

4.1.3 SASSI SSI Model and Analysis

The SSI analyses of the PSFSV model are performed using methods and approaches consistent with ASCE 4 (Reference 5) and accounting for the site-specific stratigraphy and subgrade conditions as well as the backfill conditions around the embedded PSFSV structures.

Consideration of a total of four profiles, each, for both the embedded and surface conditions assures that the enveloped results from all eight sets of SSI analyses capture all potential seismic effects of a wide range of site conditions. The profiles represent the UB, LB, and BE of soil properties. Best estimate profiles are developed for both the east and west vaults. The following summarizes the eight soil profiles utilized in the SSI analyses:

SSI Soil Profiles:

Designation	Description
SBEE	Surface Model – BE, East Vault
SBEW	Surface Model – BE, West Vault
SUBEW	Surface Model – UB Estimate
SLBEW	Surface Model – LB Estimate
EBE1	Embedded Model – BE, East Vault
EBE2	Embedded Model – BE West Vault
EUB	Embedded Model – UB Estimate
ELB	Embedded Model – LB Estimate

SSE structural damping values of Table 1 of RG 1.61 (Reference 7) are used in the site-specific SASSI analysis. The seismic response of the PSFSV results in high stress levels for the reinforced concrete members. That warrants the use of higher SSE damping values to account for the dissipation of energy due to material damping.

The surface SSI model of the PSFSV has a cut-off frequency of 50 Hz and 101 frequency points for all four soil profiles. For the embedded models, the shear wave passing frequency for all layers below the base slab, based on layer thickness of 1/5 wavelength, ranges from 12 Hz for ELB to 34 Hz for EUB. The SASSI analysis frequencies are selected to cover the range between 0.05 Hz and the cutoff frequency of 50 Hz. This frequency range includes the SSI frequency and primary structural frequencies. It is verified that as the transfer functions approached the zero frequency (static input), the co-directional transfer function approached unity while the cross-directional terms approached zero. Table 4.0-7 shows the cut-off frequencies and numbers of frequency points for the embedded soil profiles.

4.2 Analysis Results

Table 4.0-4 presents the natural frequencies obtained from the modal analyses of the ANSYS detailed design model. Table 4.0-10 presents a summary of SSI effects on the seismic response of the PSFSVS.

Table 4.0-6 provides the summary of maximum displacements relative to the PSFSV basemat obtained from the response spectra analyses of ANSYS detailed design model and the SASSI analyses of the SSI model. The table shows the correlation of the results obtained from the two types of analyses. The values presented for the maximum relative displacements represent the

envelope of the SSI analyses results of all soil cases considered. The SASSI analyses where the PSFSV is conservatively modeled as a structure supported by a 21.25 ft thick block of fill concrete resting on the surface of the rock subgrade provide the maximum relative displacement values that explains why in some cases SASSI analysis results exceed the ANSYS results.

Table 4.0-8 shows that the maximum displacements of the PSFSV relative to the free field ground motion are small (less than 0.10 inch), which confirms that the 4 inch gaps between the PSFSV and the adjacent structures and foundation are sufficient to ensure that no collision will occur during an earthquake.

Figures 4.0-14 through 4.0-16 provide profiles of the soil pressure distributions. These figures indicate that the upper bound soil profile for the embedded SSI model governs the out–of-plane pressure forces on the exterior walls.

Table 4.0-5 provides the ANSYS Design Model shears and reactions at the base of the walls. It is inaccurate to calculate the base reaction forces using the results of an SSRS combination of three directional response spectrum analysis results as in the procedure described above. This is due to the fact that the “directional” sense of forces and displacements is lost in the squaring procedure. The correct procedure to determine the total out-of-phase contribution to base reaction forces is to calculate the base reaction forces for each mode and then sum these modal values using the Lindley-Yow method. The total base shear and vertical reactions shown in Table 4.0-5 were determined in this manner.

Table 4.0-10 presents the overall factors of safety for the PSFSV structure against sliding, overturning and flotation.

4.3 ISRS for the PSFSVs

The enveloped broadened ISRS are developed from the results of the SSI analyses for each of the three orthogonal directions (east-west, north-south, vertical). Figures 4.0-8 through 4.0-10 present the 5 percent damping ISRS for the PSFSV roof, and Figures 4.0-11 through 4.0-13 the 5 percent damping ISRS for the PSFSV basemat.

ISRS are developed for each component using the following procedure (except for the vertical response of the tanks as described below):

1. Responses from the three components of the input motion for each profile are combined for each degree of freedom at each node of interest using the “square root sum of squares” (SRSS) method to account for cross-directional coupling effects in accordance with RG 1.122 (Reference 9).

2. Responses for each profile are combined yielding an enveloped maximum response spectra for each degree of freedom at each node.

3. The enveloped response spectra for each node in a particular component direction is enveloped and broadened to yield the ISRS for each degree of freedom for each component of the structure.

4. The vertical response of each of the three tanks is calculated by averaging the vertical response of the three nodes for each tank and then enveloping and broadening this average response from the eight profiles. This results in a vertical ISRS for each tank.

All results have been broadened by 15 percent. The spectra are used for the design of seismic Category I and II subsystems and components housed within or mounted to the PSFSVs.

Table 4.0-1 PSFSV Models Element Types

ANSYS Element Type	ACS SASSI Element Type	Use
SHELL181	Shell	Vertical (Wall)
SHELL181	Shell	Roof
SHELL181	3-D Solid Brick	Basemat
BEAM4	Beam	Tank
N/A	3-D Solid Brick	Fill Concrete
MASS21	N/A	Roof Additional dead load/ Roof 25% live load for seismic inertia load
COMBIN14	N/A	Soil springs

Table 4.0-2
PSFSV FE Model Component Properties

Component	Young's Modulus (ksi)	Poisson's Ratio	Unit Weight (kcf)	Damping Ratio	FE Thickness (ft)
Exterior Walls	3605	0.17	0.170(1)	0.07	2.5
Interior Walls	3605	0.17	0.2167(1)	0.07	1.5
Roof (2)	3605	0.17	0.2562(2)	0.07	2.27
Basemat	3605	0.17	0.1682(1)	0.07	5.5
Emergency Fuel Oil Tanks	Rigid	0.3	6.016(3)	0.07	N/A
Fill Concrete(4)	3,000	0.17	0.15	0.07(5)	N/A

Notes:

(1) The unit weight includes uniform equivalent dead loads of 50 psf on all interior surfaces.

(2) The values of E, thickness and unit weight are adjusted to consider cracked concrete properties of the roof slab for out-of-plane bending. Roof unit weight includes 50 psf (for either 50 psf pipe load or 25 percent of a 200 psf live load on the roof slab).

(3) The weight includes the weight of the emergency fuel oil tanks and the oil stored within. Tank supports are modeled as massless beams.

(4) Fill concrete with 3,000 psi minimum compressive strength was used in the SSI design calculations. The difference in properties versus those of the 2,500 psi minimum compressive strength specified in the FSAR has negligible impact on the analyses results.

(5) Damping coefficient used is consistent with the structural modeling.

Table 4.0-3
PSFSV FE Model Component Dimensions and Weights(1)

FE Component	Slab Width or Wall Height (ft)	Slab or Wall Length (ft)	Slab or Wall Thickness (ft)	Weight (kips)
North Exterior Wall	30.06	86	2.5	1,099
South Exterior Wall	30.06	86	2.5	1,099
West Exterior Wall	30.06	81.75	2.5	1,044
East Exterior Wall	30.06	81.75	2.5	1,044
West Interior Wall	30.06	81.75	1.5	799
East Interior Wall	30.06	81.75	1.5	799
Roof Slab	86 (east-west)	83.75 (north-south)	3.2(2)	4,186
Base mat	86 (east-west)	83.75 (north –south)	5.5	6,382
Tanks including full fuel oil content	N/A	N/A	N/A	1,155 x 3 = 3,465
Total Weight				19,917
Equivalent Weight (ksf) on Slab Area (83.75'x88')				2.7
Peak Dynamic Pressure(3) (ksf)				2.2

Notes:

(1) The width and length dimensions in the table have been adjusted from actual dimensions to suit the mesh pattern used for the FE model. The adjustments are minor and do not affect the accuracy of the analysis results.

(2) The actual roof slab thickness of 3.2 ft is adjusted to 1.414 ft in the FE model to account for its cracked properties, as discussed in Section 4.1 above.

(3) Peak dynamic pressure at corner elements, each representing less than 1 percent of the slab area, are as high as 4.1 ksf. Average peak pressure over total slab area is 0.7 ksf.

(4) Tunnel and Walkway weights are not shown in Table 4.0-3.

Table 4.0-4

PSFSV ANSYS Design Model Modal Analysis Summary

Total Weight of PSFSV = 29880 kips (929 kip-sec^2/ft mass)		
X-Direction (North-South) (Active Mass through 100 Hz = 457 kip-sec^2/ft)		
Frequency	**Mass Associated with Mode**	**% Mass Participation of X-Mass**
17.5	42.3	9%
22.9	124.2	27%
23.3	108.8	24%
30.5	22	5%
Y-Direction (East-West)(Active Mass through 100 Hz = 446 kip-sec2/ft)		
Frequency	**Mass Associated with Mode**	**% Mass Participation of Y-Mass**
13.9	91.1	20%
15.6	96.3	22%
18	45.6	10%
37.7	57.8	13%
Z-Direction Vertical (Active Mass through 100 Hz = 404 kip-sec2/ft)		
Frequency	**Mass Associated with Mode**	**% Mass Participation of Z-Mass**
16.7	10.7	3%
19.6	40.1	10%
24.5	23.2	6%
28.6	51.2	13%
29.1	14.3	4%
29.3	17	4%
67.5	25.6	6%

Table 4.0-5

ANSYS Design Model PSFSV Shears and Reactions at Base

ANSYS Primary Load Cases Reactions			
Description	**Fx (kip)**	**Fy (kip)**	**Fz (kip)**
Dead - Gravity - Self-weight and 50 psf typical on roof and walls for piping, etc. Does not include 25% Live load for seismic mass	0	0	29906
Live - 200 psf on Roof	0	0	3948
N-S Wind Windward and Leeward Faces	51	0	-118
S-N Wind Windward and Leeward Faces	-51	0	-113
N-S Wind Sidewall Pressures	0	0	0
E-W Wind Windward and Leeward Faces	0	-48	-115
W-E Wind Windward and Leeward Faces	0	48	-114
E-W Wind Sidewall Pressures	0	0	0
Internal Pressure / Suction	1	0	0
Static Earth Pressure	-62	0	0
Surcharge Load	-39	0	0
N-S Dynamic - Earthquake Pressure / w Hydrodynamic	1011	0	0
S-N Dynamic - Earthquake Pressure / w Hydrodynamic	-1238	0	0
E-W Dynamic - Earthquake Pressure / w Hydrodynamic	0	-1977	0
W-E Dynamic - Earthquake Pressure / w Hydrodynamic	0	1977	0
Accidental Torsion	0	0	0
Tornado N-S Wind Windward and Leeward Faces	175	0	-401
Tornado S-N Wind Windward and Leeward Faces	-175	0	-383
Tornado N-S Wind Sidewall Pressures	0	0	0
Tornado E-W Wind Windward and Leeward Faces	0	-162	-392
Tornado W-E Wind Windward and Leeward Faces	0	162	-387
Tornado E-W Wind Sidewall Pressures	0	0	0
Tornado Pressure Drop	4	0	0
Total N-S Seismic Inertia and Soil	18883	444	412
Total E-W Seismic Inertia and Soil	361	14763	287
Total Vertical (Z) Seismic Inertia and Soil	392	301	14421

Table 4.0-6

PSFSV Model Displacement Summary at Various Nodal Locations

Displacement Location Description	Maximum x-displacement (in.)		Maximum y-displacement (in.)		Maximum z-displacement (in.)	
	SASSI	ANSYS	SASSI	ANSYS	SASSI	ANSYS
Vault Roof SE Corner	0.029	0.024	0.038	0.027	0.021	0.013
Exterior East Wall Upper, Center	0.027	0.015	0.057	0.068	0.008	0.002
South Wall Upper, Center	0.034	0.034	0.039	0.019	0.009	0.003
Vault Roof NW Corner	0.028	0.023	0.043	0.034	0.019	0.012
Interior West Wall Upper, Center	0.032	0.021	0.057	0.051	0.010	0.006
Roof Center	0.033	0.030	0.057	0.047	0.034	0.054

Note: Displacements are relative to the center of the basemat

Table 4.0-7

Cut-Off Frequencies and Numbers of Frequency Points

Soil Profile	Maximum (Cut-Off) Frequency (Hz)	Number of Frequency Points
EBE1	20	41
EBE2	21	43
ELB	12	25
EUB	34	69

Table 4.0-8
PSFSV SASSI Model Out-of Plane Maximum Displacements for Outer Walls Relative to Free Field Ground Motion

Component	**Maximum N-S (X) displacement (in.)**	**Maximum E-W (Y) displacement (in.)**
Vault West Wall	-	0.090
Vault East Wall	-	0.091
Vault South Wall	0.082	-

Note: The maximum relative displacements presented above envelope all of the considered site conditions and all of the selected nodes for each component.

Table 4.0-9

PSFSV SASSI Results of Seismic Response

SSI Effect	Observed Response
Rock Subgrade	The rock subgrade has insignificant SSI effect on the PSFSV seismic response due to the high stiffness of the subgrade. The results of the SASSI analyses showed a modes amplification of the response in north-south (global Y) direction due to SSI effects. The structural natural frequencies obtained from SASSI analyses of the surface foundation characterizes the seismic response.
Backfill Embedment	The embedment effects significantly reduce the seismic response of PSFSV structures. This results in lower maximum relative displacements and accelerations. The properties of the backfill embedment soil affects the overall seismic response of the structure, in particular local amplification of the transfer functions at the basemat level resulting in peaks in the amplification transfer functions at the backfill soil column fundamental frequencies of 2.9 Hz, 4.9 Hz and 8 Hz. The backfill side-soil SSI effects amplify locally the ISRS computed at the basemat level in low frequency ranges that correspond to backfill soil column frequencies up to 15 Hz.
Scattering Effects	The dynamic properties mismatch between the backfill and the rock results in reflection of the seismic waves within the backfill stratum. Multiple modes characterize the backfill soil column that can have some effect on the PSFSV response when their frequencies are close to the structural frequencies. Pronounced high frequency content characterizes the site-specific motion at North Anna Unit 3 site. The intensity of the ground motion is relatively small at frequencies that are near the natural frequency of the PSFSV structures. The higher modes of vibration govern the structural response resulting in smaller displacement and stresses than those generated by the standard plant design CSDRS.

Table 4.0-10

Load Combinations and Factor of Safety for PSFSVs

Building/Structure(1)	Load Combination (per SRP 3.8.5)	Overturning(3) (Fs_{ot})	Sliding(3) (FS_{sl})	Flotation (FS_{fl})
PSFSVs	D + H + W	10.7 (1)	17.9 (1)	N/A
	D + H + E_s	1.6	1.1 (2)	N/A
	D + H + W_t	9.3 (1)	15.6 (1)	N/A
	D + F_b	N/A	N/A	2.5 (1)

Notes:

(1) The value shown is based on the conservative assumption that all three oil tanks are empty

(2) Conservative since reinforcement dowels into underlying are used to prevent sliding of the PSFSV.

(3) Overturning and Sliding factors of safety are based on site-specific groundwater levels.

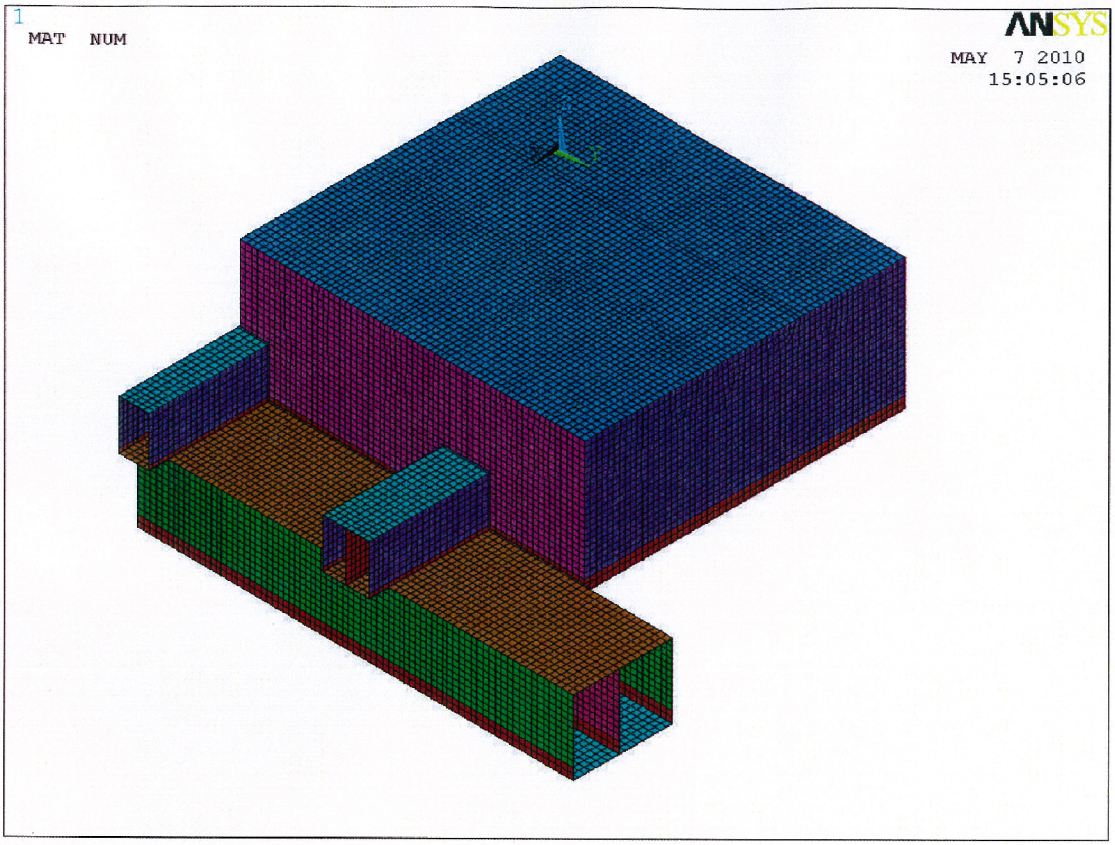


Figure 4.0-1

ANSYS Fixed Base Model of the PSFSV

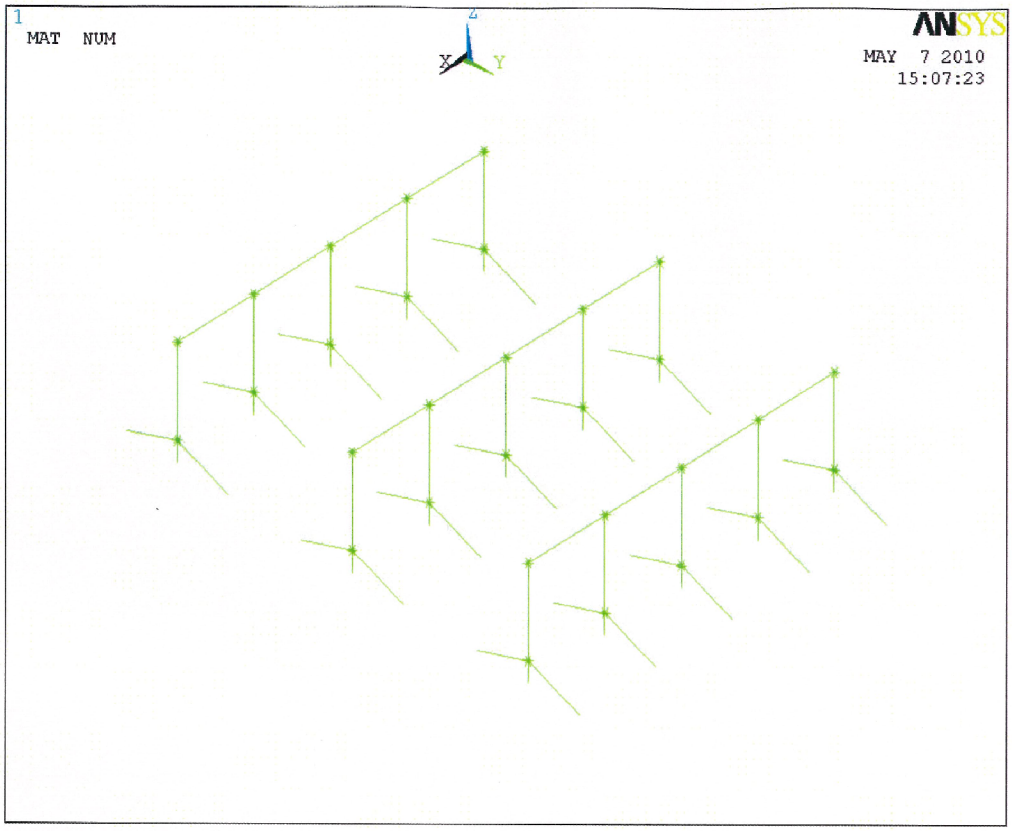


Figure 4.0-2

ANSYS Fixed Base Model - Beam Elements Used to Model the Fuel Tanks

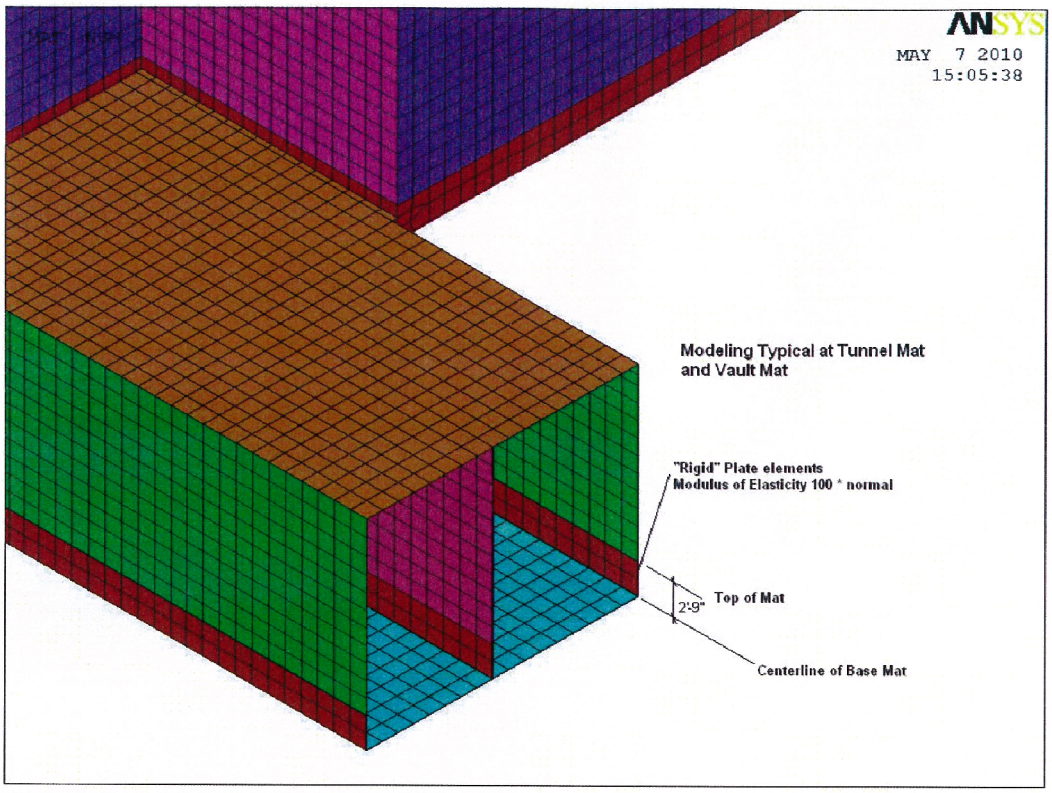


Figure 4.0-3

ANSYS Fixed Base Model

Isometric View of the ESW Pipe Tunnel Showing Modeling Data

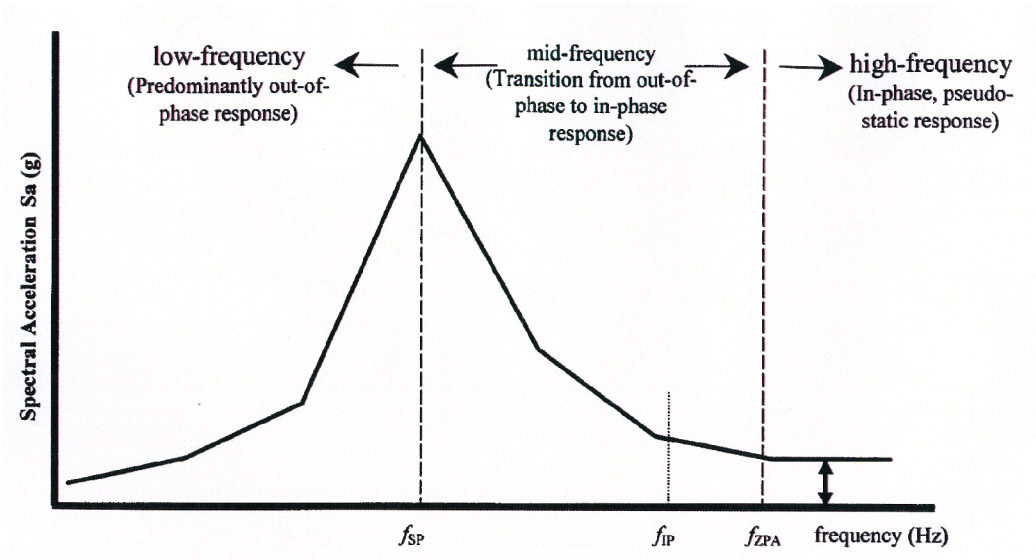


Figure 4.0-4

Depiction of Lindley-Yow Response Spectra Curve

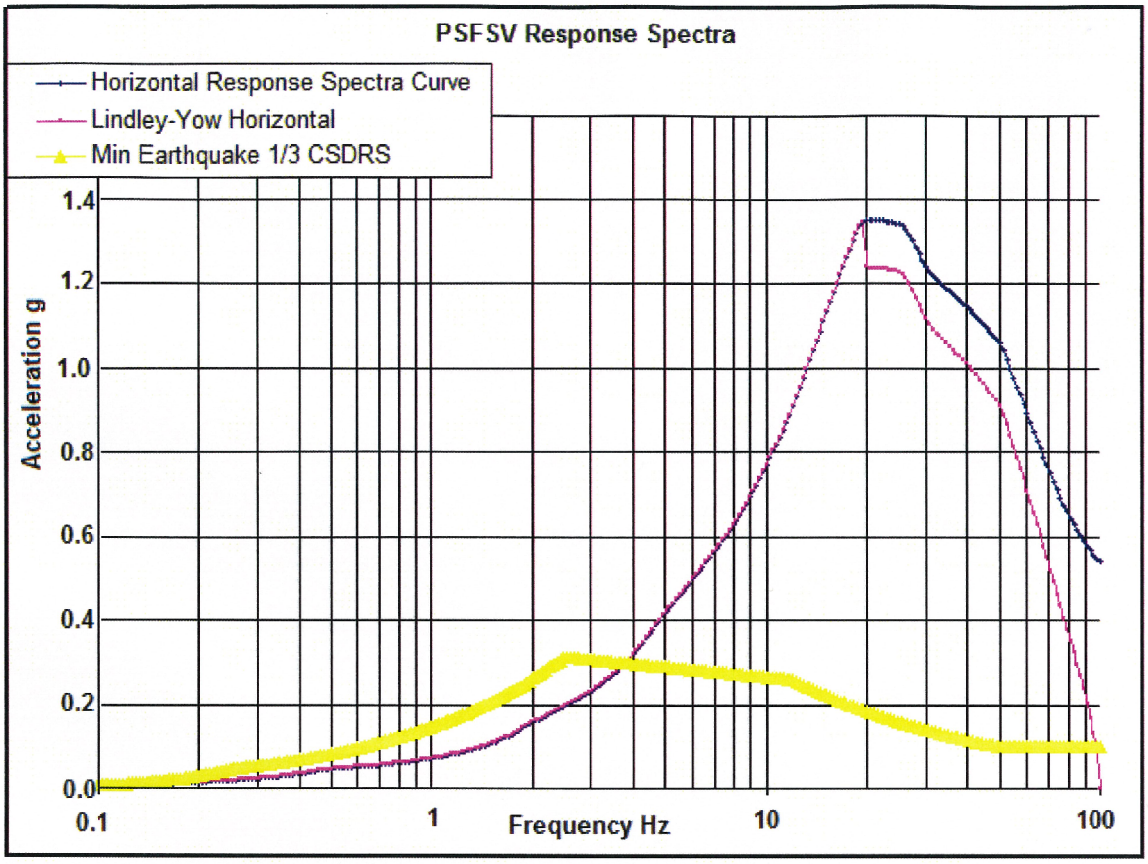


Figure 4.0-5

PSFSV: Horizontal Response Spectra Curve for Fixed Base Analysis

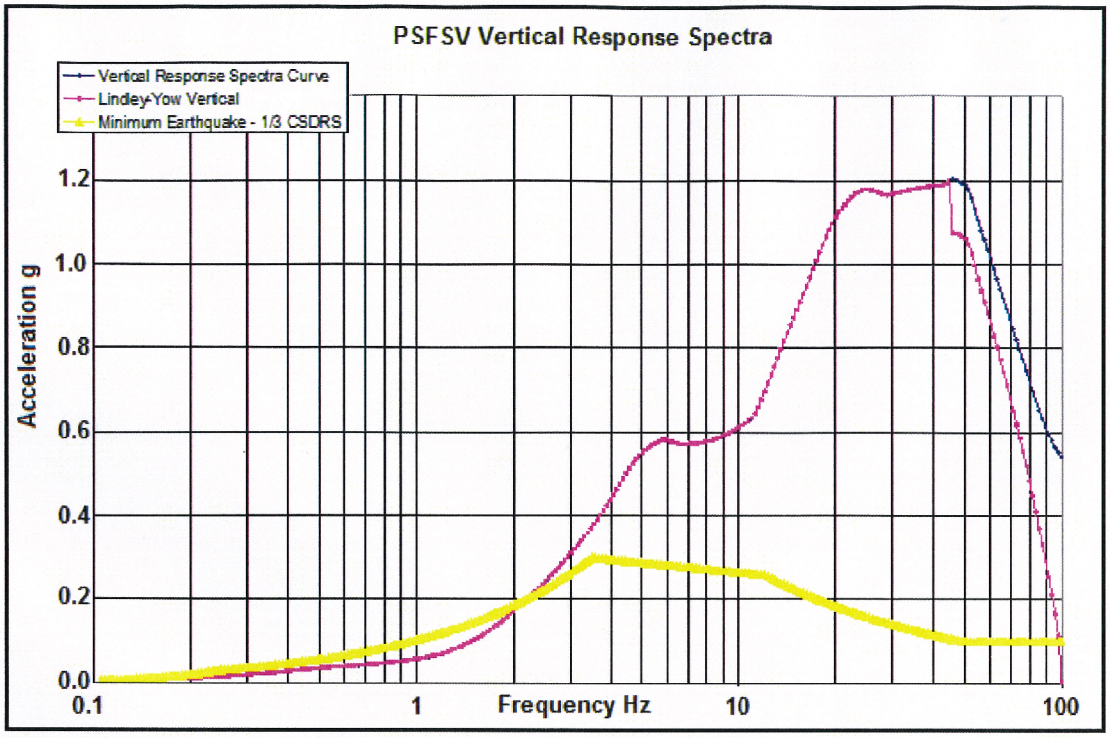
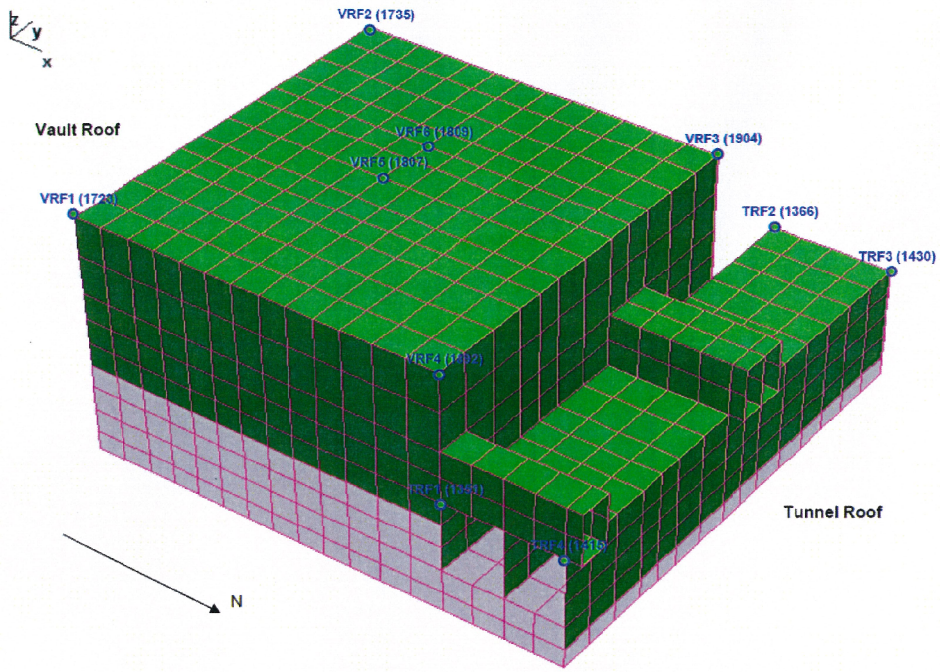
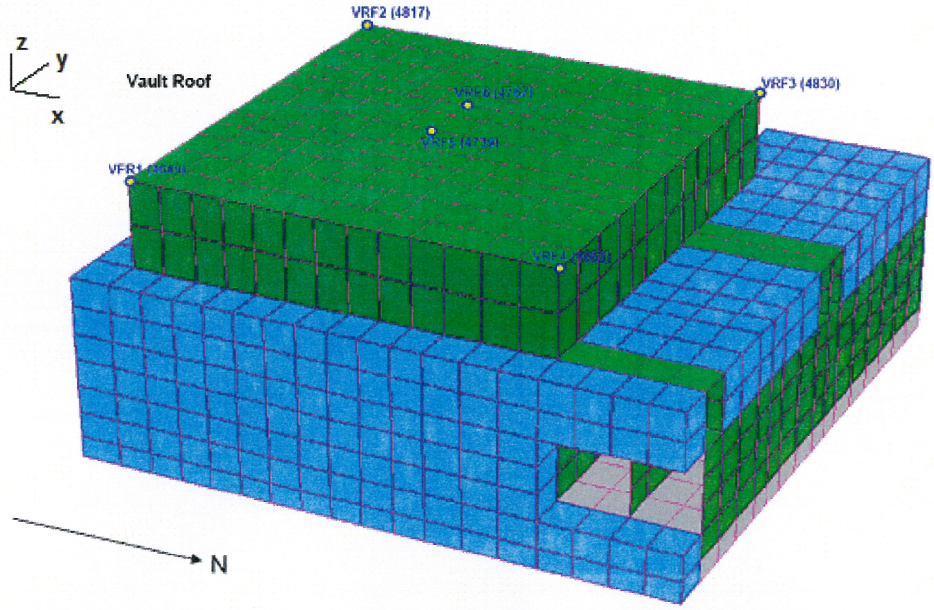


Figure 4.0-6

PSFSV: Vertical Response Spectra Curve for Fixed Base Analysis



Surface Foundation



Embedded Foundation

Figure 4.0-7

SASSI Model of the PSFSV

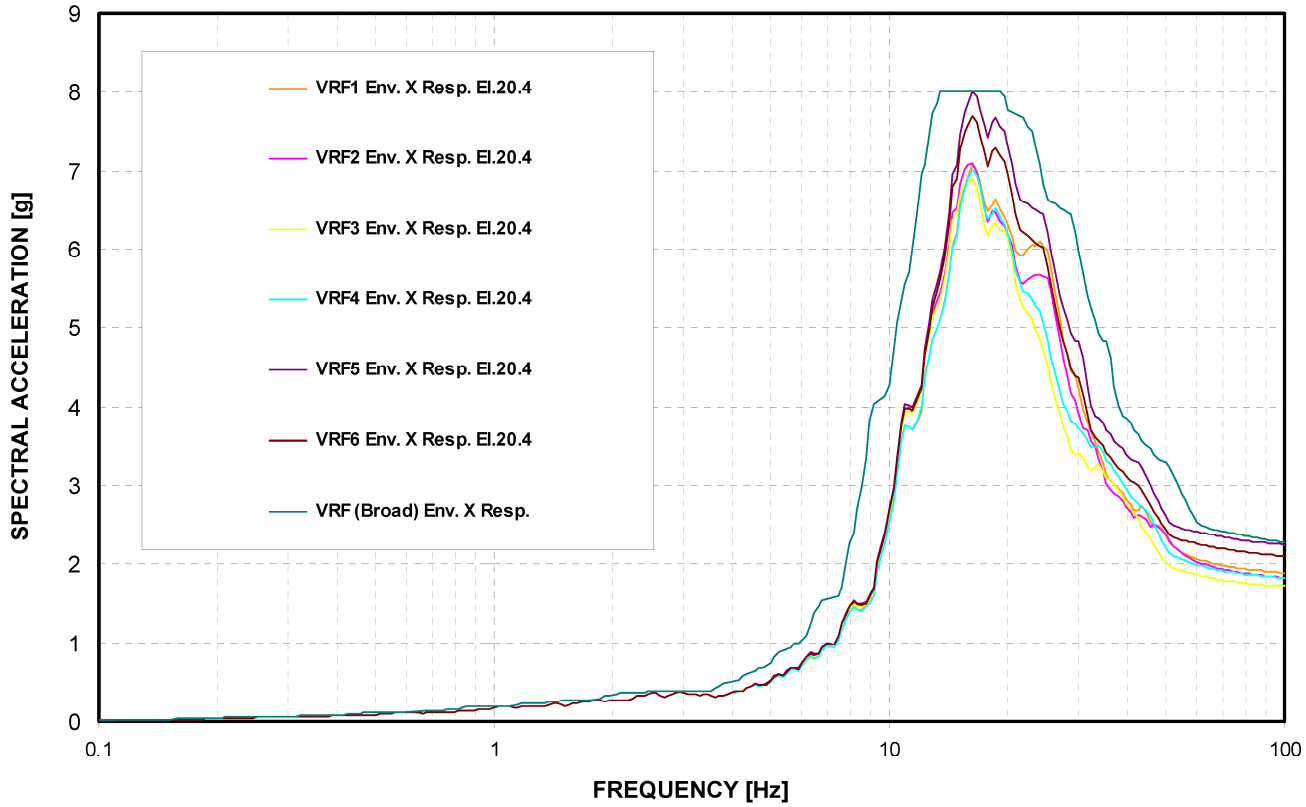


Figure 4.0-8

X Direction (NS) 5% Damping ARS of PSFSV Roof

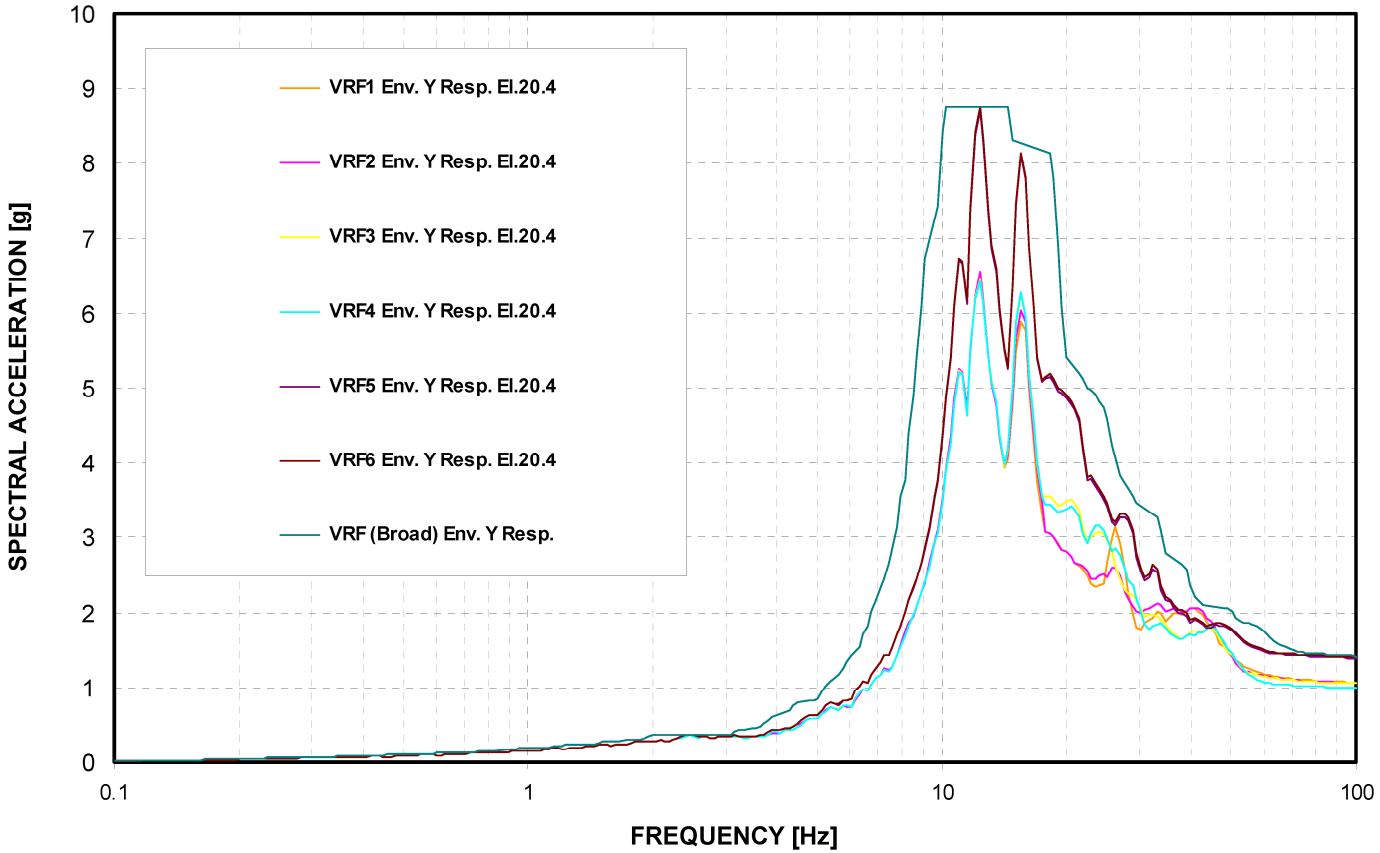


Figure 4.0-9

Y Direction (EW) 5% Damping ARS of PSFSV Roof

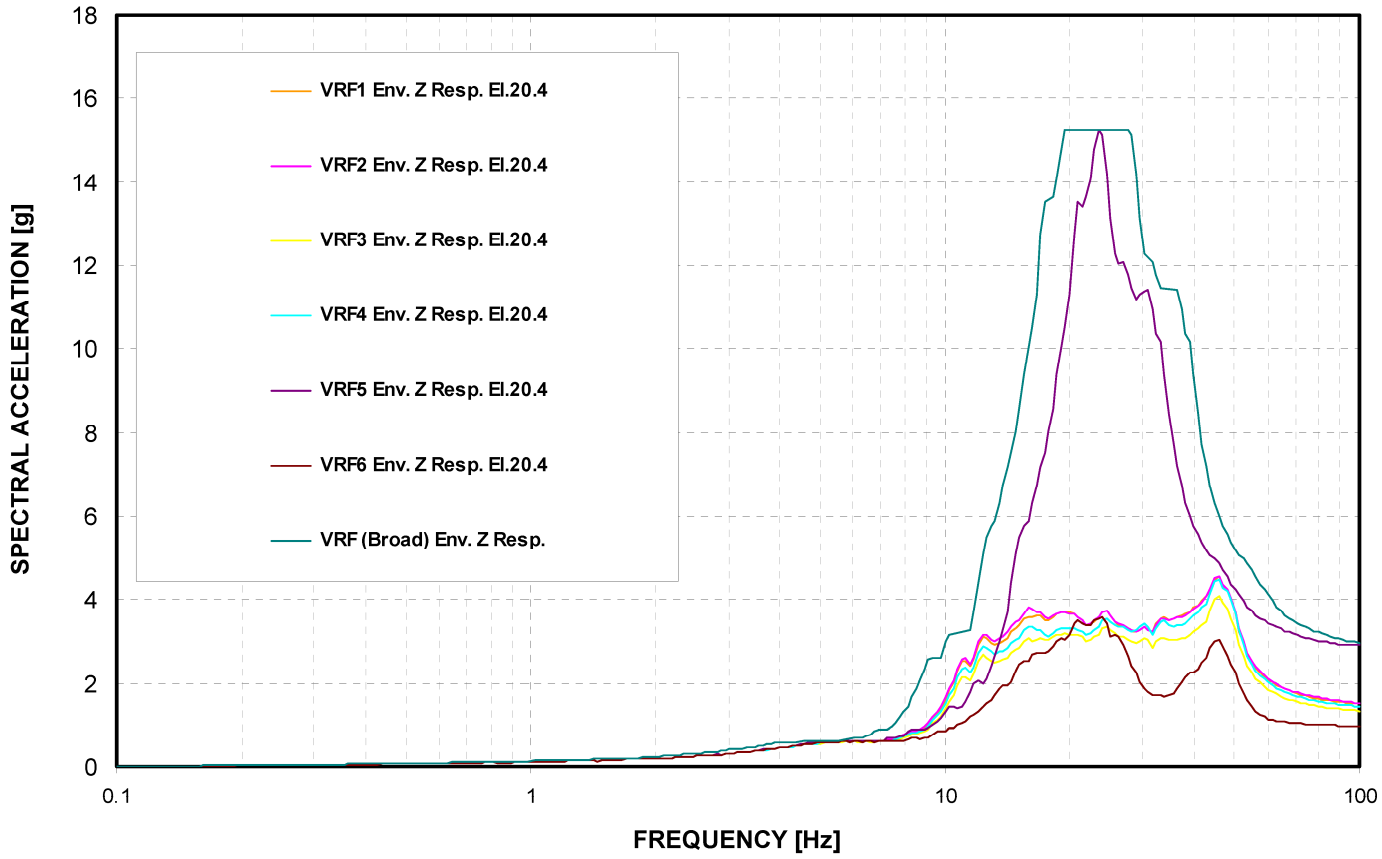


Figure 4.0-10

Z Direction (Vertical) 5% Damping ARS of PSFSV Roof

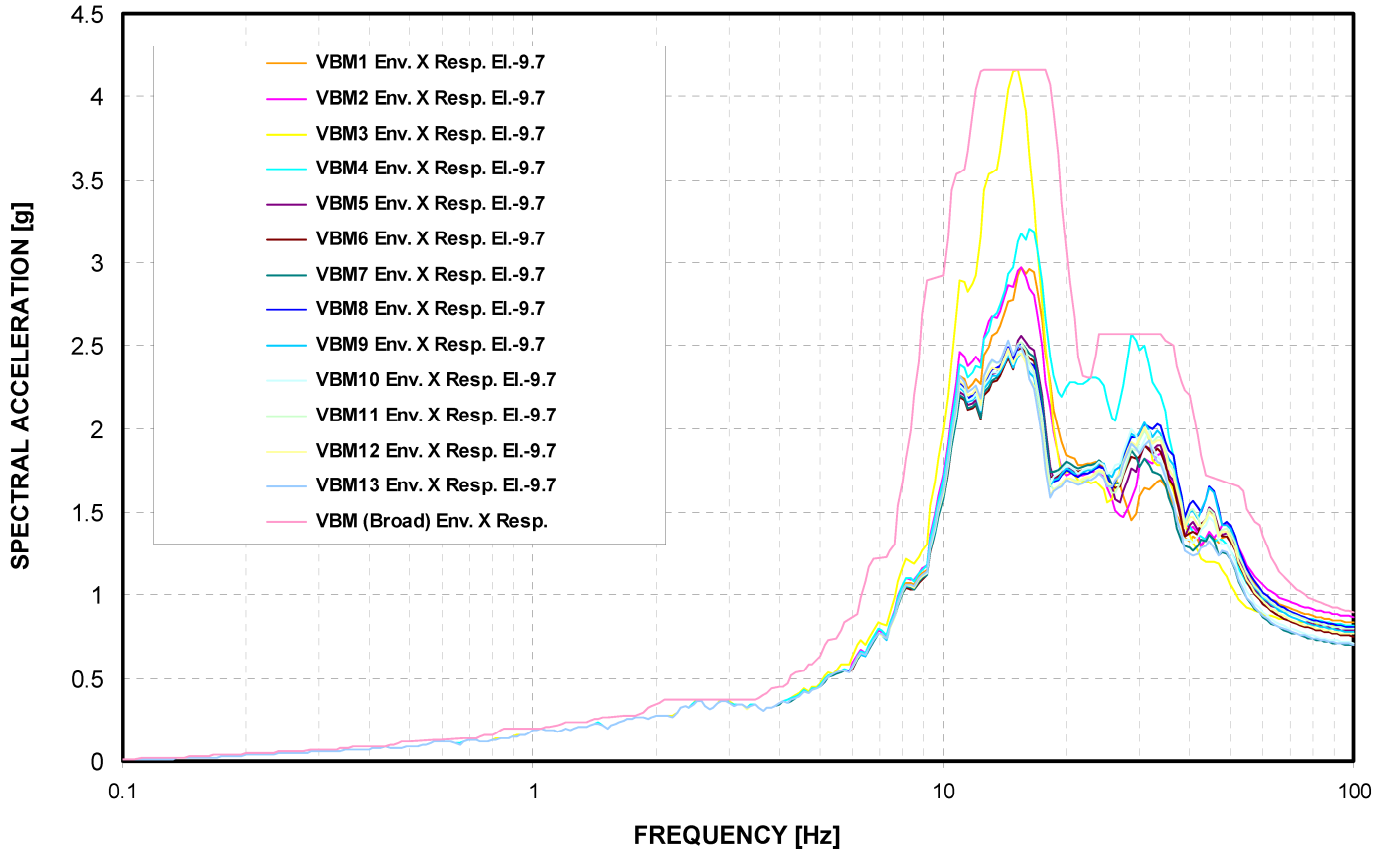


Figure 4.0-11

X Direction (NS) 5% Damping ARS of PSFSV Basemat

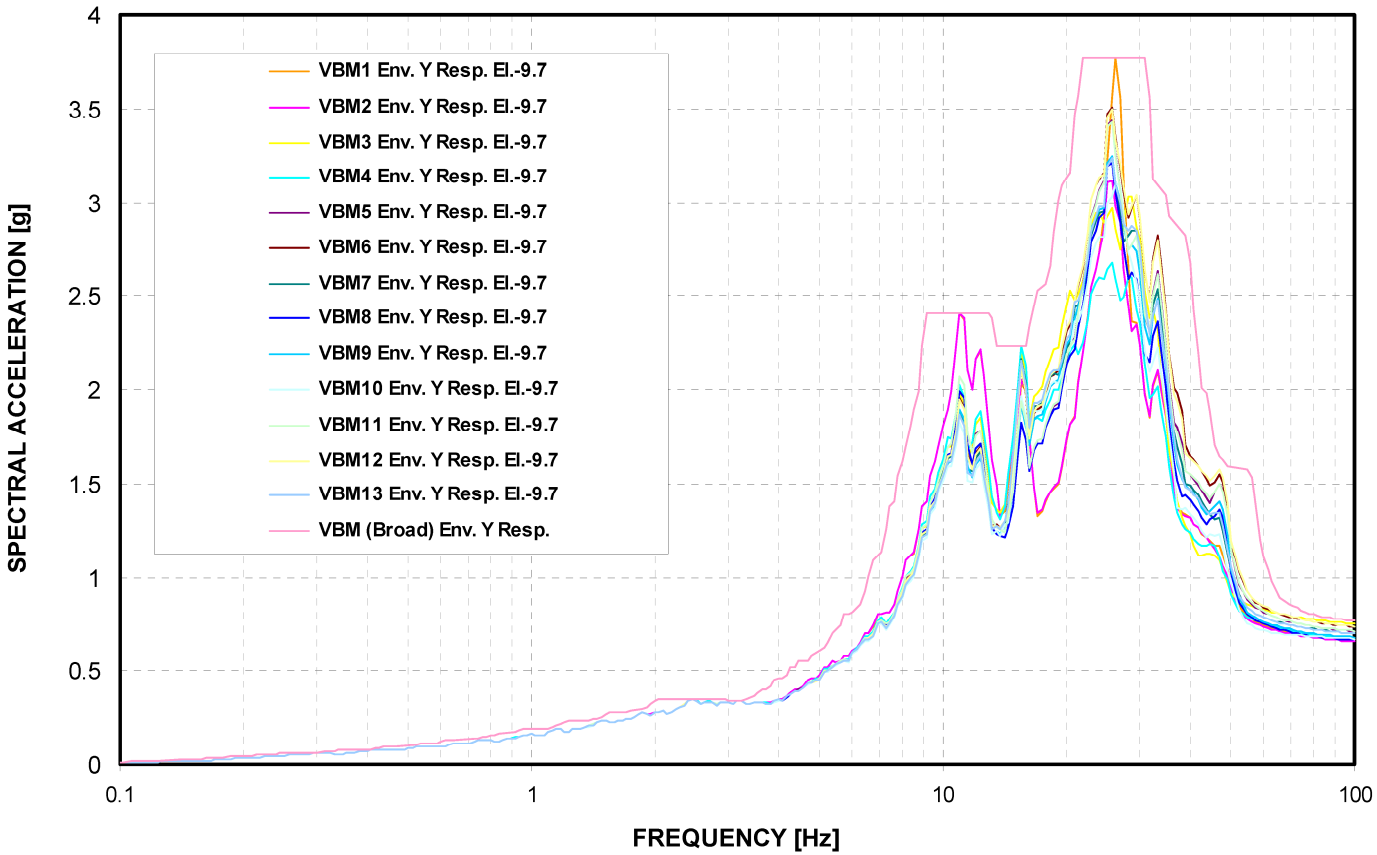


Figure 4.0-12

Y Direction (EW) 5% Damping ARS of PSFSV Basemat

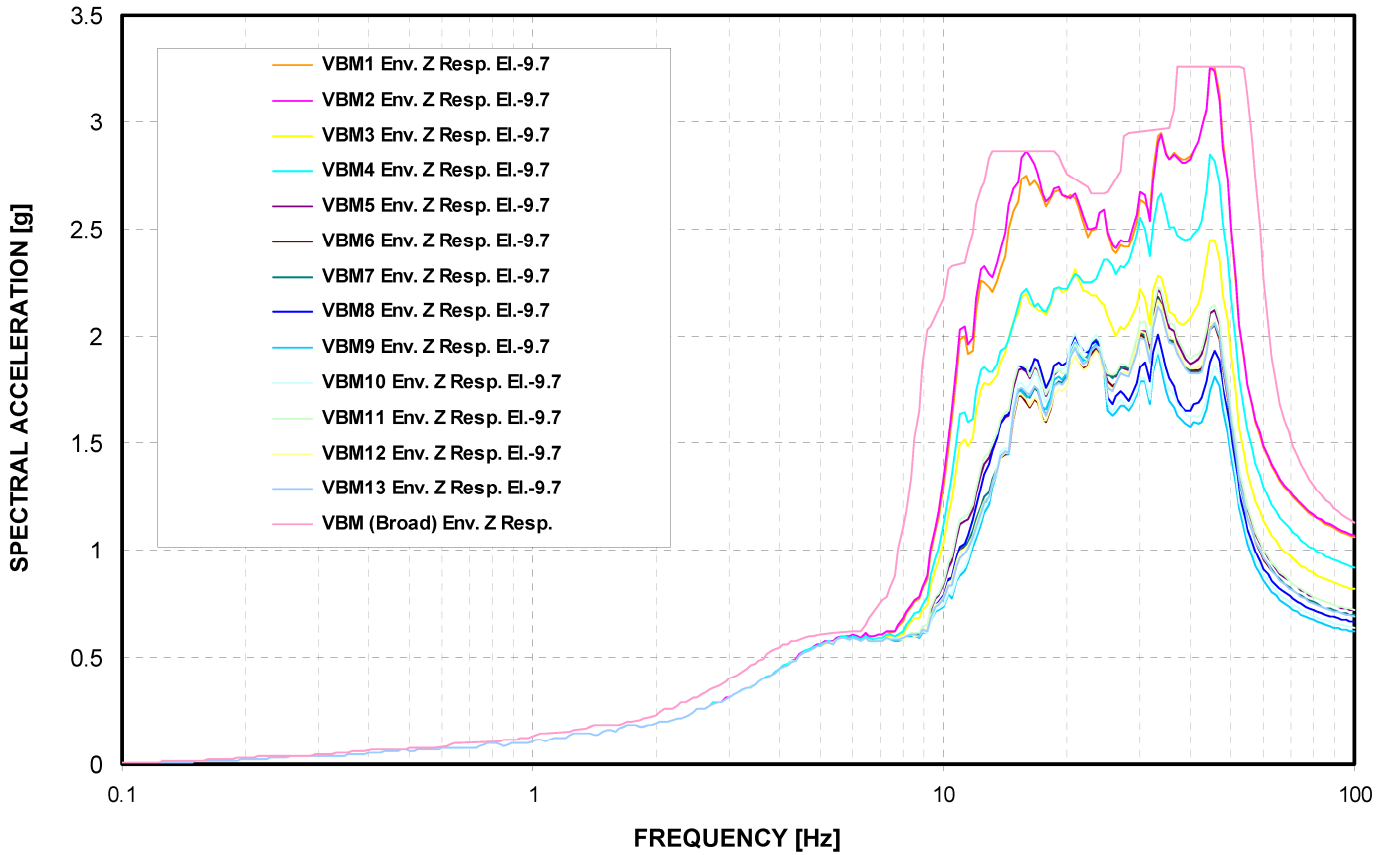


Figure 4.0-13

Z Direction (Vertical) 5% Damping ARS of PSFSV Basemat

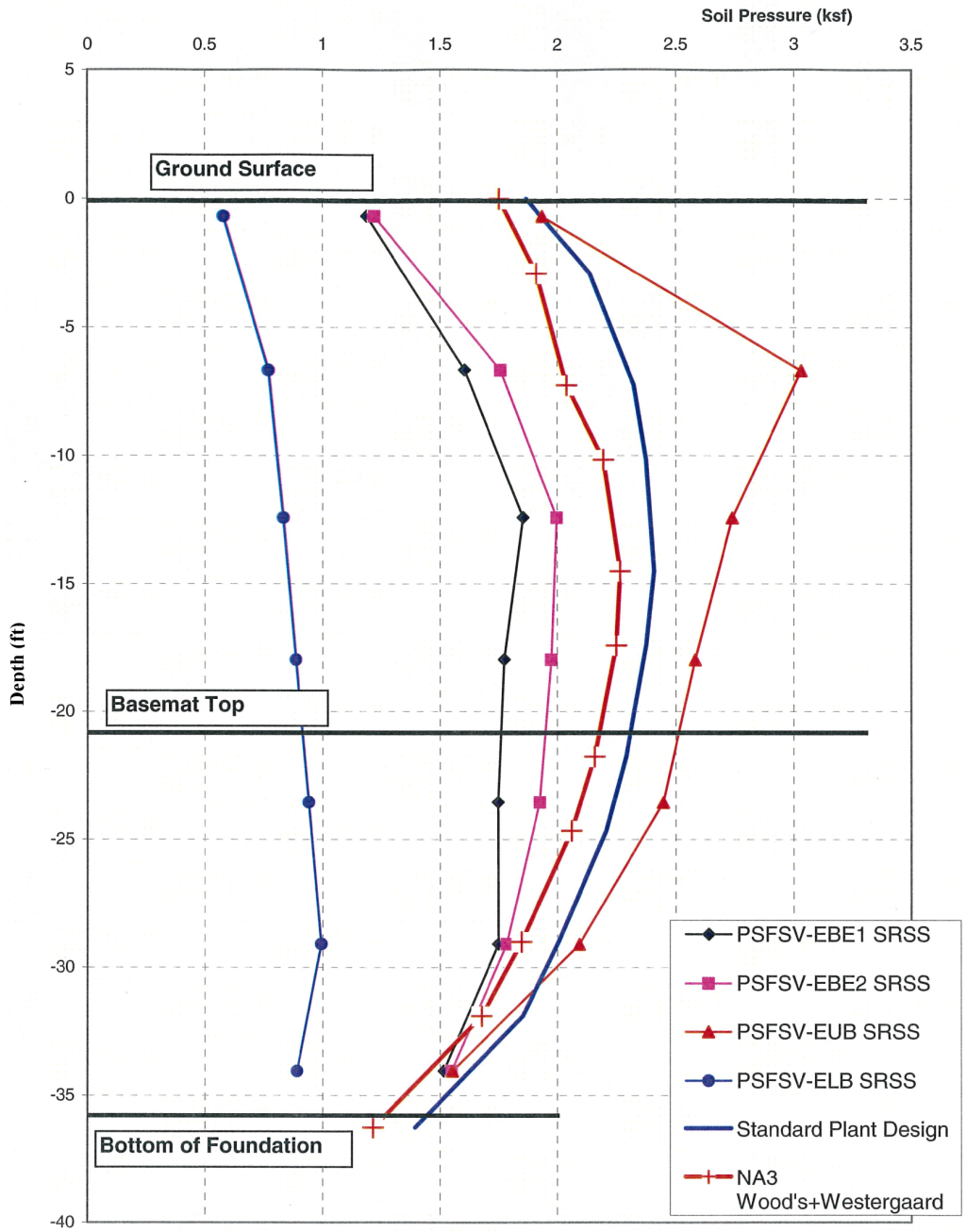


Figure 4.0-14

PSFSV Wall Y1, EW Direction Soil Pressure Distribution Diagram

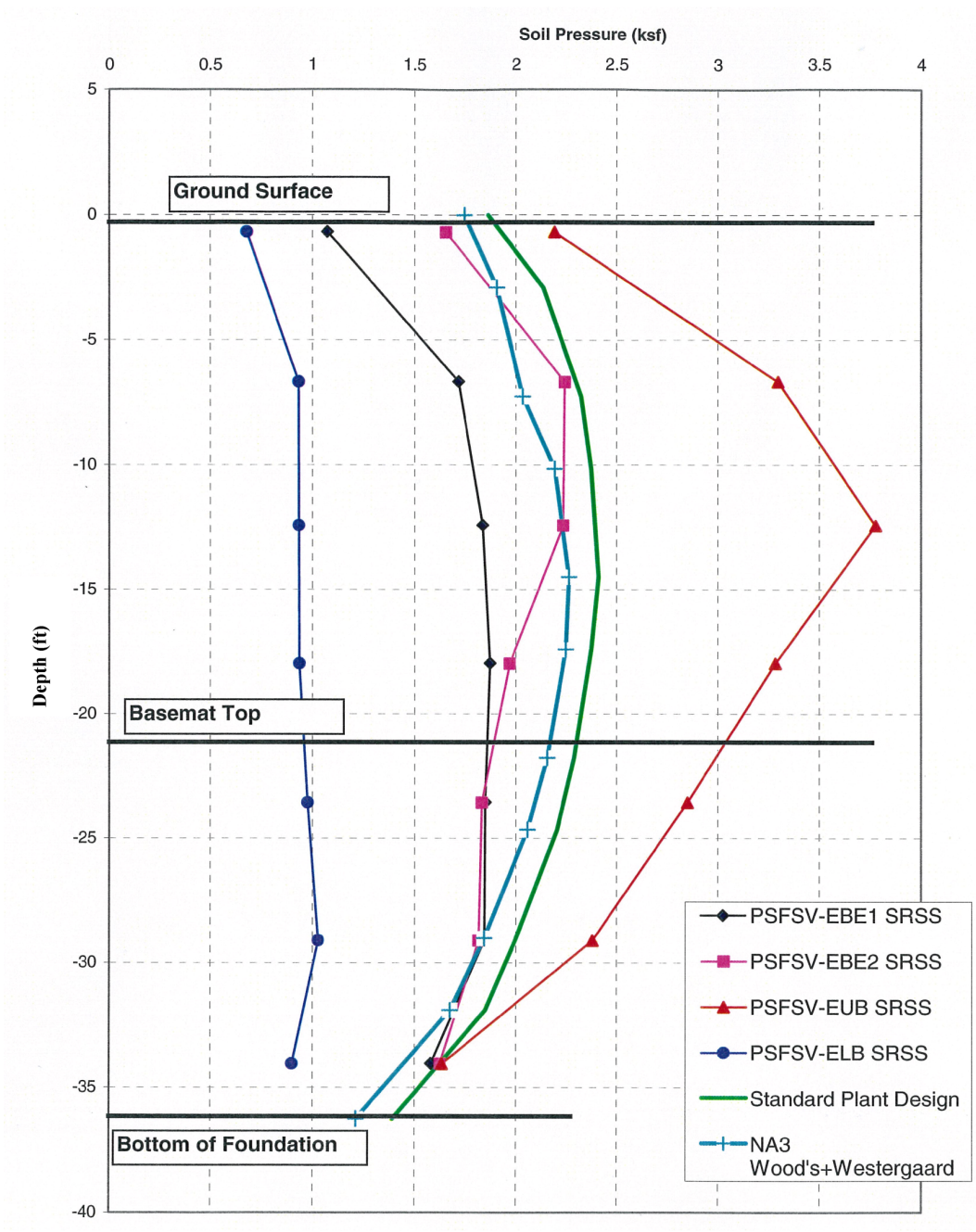


Figure 4.0-15

PSFSV Wall Y2, EW Direction Soil Pressure Distribution Diagram

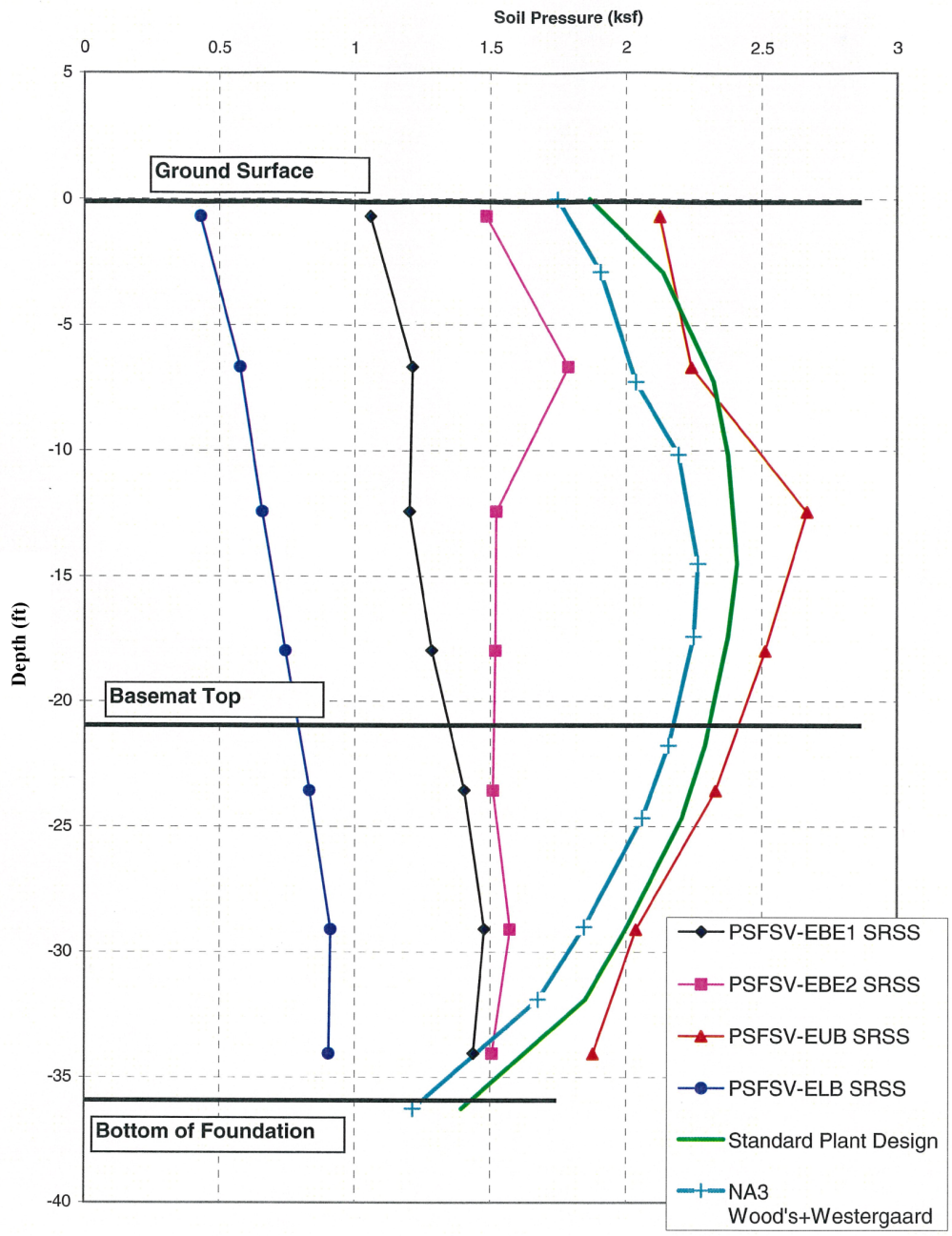


Figure 4.0-16

PSFSV Wall X1, NS Direction Soil Pressure Distribution Diagram

5.0 ESWPT and UHSRS Pipe Chase

5.1 Model Description and Analysis Approach

The ESWPT is divided into segments separated by expansion joints that prevent interaction between them during seismic events. FSAR Figure 3.8-201 shows the plant layout with the extent of each ESWPT segment. Segments 1a-N and 1a-S run in the north-south direction and are located east of the R/B complex. Segment 1b with its straight and skewed portions runs in the north-south direction and is located west of the R/B complex. These segments are completely buried in backfill on all sides except for segment 1a-S that is adjacent to the East Power Source Building. The SSI analyses of ESWPT segment 1a-S consider the tunnel as a surface foundation due to the presence of a four (4) inch gap separating the tunnel from the adjacent PS/B..

Segment 2 of the ESWPT runs in the east-west direction. Segment 2 is located underneath the north end of the T/B. The exterior walls and the roof of segment 2 are not in contact with soil.

The portion of the ESWPT that is located between the PSFSVs and PS/Bs is cast together with the basemat of the PSFSVs and are referred to as the PSFSV tunnels, as shown in FSAR Figures 3.8-212 and 3.8-213.

The structure located between the UHSRS B and C is a partially embedded pipe chase that is part of the UHSRS, and this structure is therefore labeled as the “UHSRS pipe chase”. The pipe chase portions integrally attached to the UHSRS are designed as part of their respective UHSRS as previously mentioned in Section 1.0 and shown in FSAR Figures 3.8-206, 3.8-208, 3.8-209, and 3.8-210.

Two set of seismic response analyses are employed:

1. ANSYS response spectrum analyses of a fixed base model to calculate seismic demands for design of structural members for “UHSRS pipe chase” and ESWPT Segment 2; and
2. ACS SASSI SSI analyses to calculate ISRS used for design of seismic Category I and II subsystems, components and equipment. The ACS SASSI analyses of Segments 1a-S, 1a-N and 1b provide maximum accelerations of the roof, interior and exterior wall and base slab of the tunnel. These maximum acceleration results serve as basis for development of equivalent static demands (inertia forces) that are used for the design of the structural members.

The results for maximum relative displacements obtained from ANSYS response spectra analyses and ACS-SASSI analyses of ESWPT Segment 2 and UHSRS pipe chase are compared to verify and confirm the accuracy of responses obtained from the two different types of analyses.

5.1.1 SSI Model and Analysis

In order to address differences in geometry/configuration, site conditions, input motion and loading, the SSI analyses of the ESWPT use a total of four models: one each for segments 1a-N, 1a-S, 1b, and 2. As previously addressed, there are also SSI models for the UHSRS pipe chase, the PSFSV which includes a pipe passage/tunnel for the essential service water piping, and the UHSRS model which includes a pipe chase for the essential service water piping. The SSI analyses considers tunnel segments 1a-N and 1b as underground structures with subgrade at the bottom and backfill soil in contact with the exterior walls and roof of the tunnel. The seismic response of the ESWPT segments 1a-S and 2 are obtained from the SSI analyses of surface foundations without soil at the sides and the top of the tunnel. The SSI analysis of the UHSRS pipe chase uses a SASSI model of a partially embedded structure. ESWPT segments adjacent to the UHSRS and the PSFSVs are connected to the UHSRS and PSFSV structures and analyzed using integrated models as described in Sections 3.0 and 4.0. However, the acceleration response spectra results obtained from the SSI analyses of the PSFSV segments of the tunnel and UHSRS pipe chases are used for development of ISRS defining seismic demands for design of seismic Category I and II components and equipment located anywhere in the ESPWT or UHSRS pipe chases (see detail discussion in Section 5.3).

The SSI models for all ESWPT segments with the exception of the UHSRS and PSFSV portions are shown in Figures 5.0-1 through 5.0-4. The SSI model for the UHSRS pipe chase is shown in Figure 5.0-5. Shell elements model the roof, interior and exterior walls and the basemat. Brick elements model the backfill and fill concrete below the ESWPT basemat. Where the shell elements and brick elements are connected, the shell elements extend into the brick elements to transmit nodal rotations. The extended elements shares nodes with the corresponding face of the solid elements and are massless.

Tables 5.0-1, 5.0-2 and 5.0-3, respectively, present the material properties, geometry and types of elements assigned to the structural components of the SASSI FE models of ESWPT Segments 1a, 1b and 2 and UHSRS pipe chase. Table 5.0-4 presents the fixed base natural frequencies of ESWPT segment 2 and UHSRS pipe chase. The material properties of the walls, roof and base slabs of ESWPT Segments 1a and 1b are adjusted to consider the cracked concrete properties (adjusted values are not shown in the aforementioned tables). The out-plane stiffness for those members are reduced to one half of the uncracked flexural stiffness. Refer to Section 4.1.1 for description of the methodology used to adjust the material and geometrical properties of the members to take into account for cracked flexural stiffness. SSE damping values are used in the site-specific SASSI analysis.

Table 5.0-5 provides a summary of the main characteristics of the SSI models and analyses for the ESWPT and UHSRS pipe chase. For each set of SSI analyses, the table presents the profiles used of soil strain compatible dynamic properties as described in Section 2.4 and the type of SSI analyses. The listed maximum frequencies show the ability of the different models to transmit seismic waves with high frequency. Table 5.0-5 also presents for each set of SSI analyses the total number of frequencies of analyses used and the cut off frequency.

The results of the SASSI analyses are validated through reviews of the transfer functions and other output to make sure that adequate frequencies of analyses are used for calculation. It was verified that as the transfer functions approached the zero frequency, the co-directional transfer

function approached unity while the cross-directional terms approached zero. Transfer functions are examined for each analysis to verify that the interpolation was reasonable and that the expected structural responses were observed. Transfer functions, spectra, accelerations, and soil pressures are compared between the various soil profiles used in analyses to verify that the responses are reasonably similar between these cases except for the expected trends due to soil frequency changes.

The SASSI analyses produce results including peak accelerations, in-structure response spectra, seismic element demands, and seismic soil pressures. All results from SSI analyses represent the envelope of all soil conditions. The SASSI analysis results are used to produce the ISRS and provide confirmation of the inputs to the ANSYS design model.

5.1.2 ANSYS Static and Response Spectrum Analyses

The structural components in the ANSYS models used for static and response spectra analyses are modeled with finite elements that have the same properties and configuration as the ACS SASSI models. ANSYS shell type element 181 is used for roof, floor slab, exterior and interior walls. The 9'-11" thick foundation of ESWPT segment 2 is modeled by ANSYS SOLID45 elements. COMBIN14 type elements are used to model the soil springs representing the stiffness of the subgrade under the foundation base.

The seismic demands for design of the tunnel structural members are obtained from two types of ANSYS analyses:

1. Equivalent static analyses of ESWPT Segments 1a and 1b.
2. Response spectra analyses of segment 2 and UHSRS pipe chase.

The static analyses use input seismic forces that include self inertial loads and dynamic soil pressures on exterior walls and the roof of the tunnel. The seismic soil pressure demands are applied on the structural elements as equivalent static pressures. The pressures applied are of larger magnitude compared to the calculated elastic solution used in ASCE 4-98 based on J.H. Wood, 1973 (Reference 5) following the methodology described in Section 2.4. The magnitude and distribution of the dynamic pressures are validated through comparison with the SSI analyses results for dynamic pressures. Soil above the tunnel is accounted for with a shear force applied at the interface of the tunnel roof and the soil above. The magnitude of the horizontal load acting on the tunnel roof due to the soil above is estimated as the maximum possible friction force acting on the roof/soil interface.

The Lindley-Yow method of combining modal responses, as described in Section 3.1.8, is used for the response spectra analyses of ESWPT segment 2 and UHSRS pipe chase. The input ground acceleration response spectra used for the analyses of ESWPT Segment 2 is identical to the spectra shown in Figures 4.0-5 and 4.0-6 and used for the analyses of PSFSV. Figure 2.0-23 presents the five percent damping input ground response spectra for response spectra analysis of the UHSRS Pipe Chase.

Demands calculated from the equivalent static accelerations and soil pressure analyses performed in ANSYS for all tunnel segments are combined to produce the maximum demands in each direction. The maximum demands for each direction of motion are then combined

spatially by 100-40-40 combination rule and then combined with the demands due to other design loads and load combinations per requirements of Section 3.8 of US APWR DCD (Reference 13).

5.2 Seismic Analysis Results

The results of equivalent static analysis performed using ANSYS FE models serve as the basis for structural evaluation of the tunnel segments. In general, the bottom of the tunnel is 259.08 ft and the water table is located at 283.00 ft. Therefore dynamic structural analysis included load combinations that included lateral and uplift hydrostatic forces and seismic loads simultaneously. The segments 1a and 1b have 2 feet thick basemats, side walls and roof slab (shown in Section D-D, FSAR Figure 3.8-203). All segments are designed for the same load combinations, but due to differing geometry the values of some of the loads (seismic, hydrodynamic soil pressure, live load etc) varied. The resulting moments and shears also varied. The S-E corner of segment 1a (extends approx. 65 feet north from the PSFSV) requires drilled-in anchors into the fill concrete and the rock stratum at the ends and a a shear key into the rock stratum at the center of the section (see Section DD-DD in FSAR Figure 3.8-203). Similar detail is also required at the “pipe chase”, with the bottom of the base slab at water table (see Section E-E in FSAR Figure 3.8-202). FSAR Figure 3.8-205, Section F-F shows the special section at the R/B and T/B interface.

Table 5.0-4 presents the natural frequencies and descriptions of the associated modal responses obtained from the fixed-base ANSYS analysis of the straight portion of the ESWPT located below T/B. Table 5.0-12 also present first five modes information for Segment 2 and UHSRS pipe chase segment. These frequencies were compared to the frequencies calculated from the transfer functions for the SASSI model to confirm adequacy of the SASSI model to represent dynamic behavior of the tunnels. Table 5.0-6 presents a summary of SSI effects on the seismic response of the ESWPT segments.

The maximum absolute nodal accelerations obtained from the SSI analyses of the ESWPT models are presented in Tables 5.0-7a to 5.0-7e. The results are presented for each of the major ESWPT components and envelope all backfill conditions described above. The maximum accelerations have been obtained by combining cross-directional contributions (i.e. X-response due to X-input, X-response due to Y-input, and X-response due to Z-input) in accordance with RG 1.92 (Reference 10) using SRSS.

The forces and moments in Tables 5.0-8, and 5.0-9 represent demands produced from ANSYS seismic analyses. These results include the combined demands from seismic inertia and seismic soil pressure and the combinations of all directions of input motion. Table 5.0-10 compares the maximum displacement relative to the basemat obtained from fixed-base spectrum analysis and SSI analysis for pipe chase and Segment 2. In vertical direction, ANSYS fixed-base spectrum results envelope SSI results. In the other two direction displacements are practically in same order. The comparison of the maximum relative displacements validates the accuracy of the results obtained from the two types of seismic response analysis.

Table 5.0-11 presents the results of the SSI analyses for peak displacements relative to the free field ground motion. The displacements are well below 1 inch, whereas the seismic gap provided between the structures is 4 inches, precluding the possibility of any seismic interaction.

Table 5.0-13 presents the maximum pressures below the basemat of the ESWPT which are well below the allowable bearing capacity.

Figure 5.0-7 presents the soil pressure distribution obtained from SSI analysis for a typical section of Segment 1a-N as discussed in section 2.4. Curves ELB SRSS, EBE-EPS SRSS, and EUB are the SSI analysis earth pressure distributions for LB, BE, UB soil profiles, respectively. The figure also shows in green the hand calculation results of dynamic lateral pressures that is used as input for structural design of the tunnel walls. The figure indicates that dynamic lateral pressures on the wall that used in the design envelope the SSI analysis results.

Table 5.0-14 presents the overall factors of safety of the ESWPT 1a an1b against sliding, overturning and flotation.

5.3 ISRS for the ESWPT and UHSRS Pipe Chase

The enveloped broadened ISRS calculated in SASSI analyses for all the segments of the ESWPT are presented in Figures 5.0-6 (Sht. 1 thru 36). The ESWPT segments are grouped (see FSAR Figure 3.8-201) as follows:

- Group 1 comprising UHSRS pipe chase between UHS units B and C; and the two UHSRS portions of the ESWPT
- Group 2 comprising segments 1a-N, 1b, 2 and the west PSFSV portion of ESWPT and
- Group 3 comprising segment 1a-S and the east PSFSV portion of ESWPT.

For each of these groups, ISRS are developed for the horizontal and vertical directions for the ESWPT base slab, roof, external and internal walls for 5 percent damping. The ISRS are resultant spectra, which have been combined using SRSS to account for cross-directional coupling effects in accordance with RG 1.122 (Reference 9). The ISRS include the envelope of the site conditions. All results have been broadened 15% and will be used for the design of seismic Category I and II subsystems and components housed within or mounted to the various ESWPT segments. . As mentioned above, the ESWPT portion attached to the west PSFSV was analyzed as fully embedded while the one attached to the east PSFSV and separated from the PSB by a four inch gap was analyzed as a surface tunnel. As a result, Group 3 ISRS are developed using an envelope of the surface and embedded acceleration response spectra while in the case of Group 2, only the embedded acceleration response spectra were used to develop the ISRS.

Table 5.0-1
ESWPT Segments 1a and 1b FE Model Component Properties

Component	Concrete Strength (psi)	E (ksi)	Poisson Ratio	Unit Weight (kcf)	Damping Ratio	Width or Height x Thickness (ft) (2)	Element Type
Roof	5,000	4,030	0.17	0.225(1)	0.07	23x2	Shell
Base slab	5,000	4,030	0.17	0.200(1)	0.07	23x2	Shell
Exterior Walls	5,000	4,030	0.17	0.175(1)	0.07	16.67x2	Shell
Interior Walls	5,000	4,030	0.17	0.250(1)	0.07	16.67x1	Shell
Fill Concrete(3)	3,000	3,125	0.17	0.15	0.07(4)	Width/ height, and thickness vary as required	Brick

Notes:

(1) The unit weight includes equivalent uniform dead loads due to piping and other supported components, and 25% of applicable live load for dynamic analysis purposes. A pipe load of 150 psf is considered on the roof slab and 50 psf is considered on all other interior surfaces. The applicable floor live load is 200 psf.

(2) The width or height of the component is adjusted from actual dimensions to suit the mesh pattern used for the FE model. The adjustments are minor and do not affect the accuracy of the analysis results. Actual component dimensions are shown in FSAR Figures 3.8-202, 3.8-203, and 3.8-205.

(3) Properties are presented for fill concrete that is part of the SSI structural model and has a limited horizontal extent. Fill concrete with 3,000 psi minimum compressive strength was used in the SSI calculations. The difference in properties versus those of the 2,500 psi minimum compressive strength specified in the FSAR has negligible impact on the analyses results.

(4) Damping coefficient used is consistent with the structural modeling.

Table 5.0-2
ESWPT Segment 2 FE Model Component Properties

Component	Concrete Strength (psi)	E (ksi)	Poisson Ratio	Unit Weight (kcf)	Damping Ratio	Width or Height x Thickness (ft) (2)	Element type
Roof	5,000	4,030	0.17	0.225(1)	0.07	23x2	Shell
Base slab	5,000	4,030	0.17	0.200(1)	0.07	23x2	Shell
Exterior Walls	5,000	4,030	0.17	0.175(1)	0.07	16.67x2	Shell
Interior Walls	5,000	4,030	0.17	0.250(1)	0.07	16.67x1	Shell
Fill Concrete(3)	3,000	3,125	0.17	0.15	0.07(4)	32.17x9.91	Brick

Notes:

(1) The unit weight includes equivalent dead loads due to piping and other supported components, and 25% of applicable live load for dynamic analysis purposes. A pipe load of 150 psf is considered on the roof slab and service tunnel roof, and 50 psf is considered on all other interior surfaces. The applicable floor live load is 200 psf for the base slab.

(2) The width of the component is adjusted from actual dimensions to suit the mesh pattern used for the FE model. The adjustments are minor and do not affect the accuracy of the analysis results. Actual component dimensions are shown in FSAR Figures 3.8-202, 3.8-203, and 3.8-205.

(3) Properties are presented for fill concrete that is part of the SSI structural model and has a limited horizontal extent. Fill concrete with 3,000 psi minimum compressive strength was used in the SSI calculations. The difference in properties versus those of the 2,500 psi minimum compressive strength specified in the FSAR has negligible impact on the analyses results.

(4) Damping coefficient used is consistent with the structural modeling.

Table 5.0-3
UHSRS Pipe Chase FE Model Component Properties

Component	Concrete Strength (psi)	E (ksi)	Poisson Ratio	Unit Weight (kcf)	Damping Ratio	Width or Height x Thickness (ft) (2)	Element Type
Roof	5,000	4,030	0.17	0.225(1)	0.07	25x2	Shell
Base slab	5,000	4,030	0.17	0.200(1)	0.07	25x2	Shell
Exterior Walls	5,000	4,030	0.17	0.175(1)	0.07	10.67x2	Shell
Interior Walls	5,000	4,030	0.17	0.250(1)	0.07	10.67x1	Shell
Fill Concrete(3)	3,000	3,125	0.17	0.15	0.07(4)	25x3	Brick

Notes:

(1) The unit weight includes equivalent dead loads due to piping and other supported components, and 25% of applicable live load for dynamic analysis purposes. A pipe load of 150 psf is considered on the roof slab and service tunnel roof, and 50 psf is considered on all other interior surfaces. The applicable floor live load is 200 psf for the base slab.

(2) The width of the component is adjusted from actual dimensions to suit the mesh pattern used for the FE model. The adjustments are minor and do not affect the accuracy of the analysis results. Actual component dimensions are shown in FSAR Figures 3.8-202, 3.8-203, and 3.8-205.

(3) Properties are presented for fill concrete that is part of the SSI structural model and has a limited horizontal extent. Fill concrete with 3,000 psi minimum compressive strength was used in the SSI calculations. The difference in properties versus those of the 2,500 psi minimum compressive strength specified in the FSAR has negligible impact on the analyses results.

(4) Damping coefficient used is consistent with the structural modeling.

Table 5.0-4
ESWPT Structural Frequencies

Model	Frequency (Hz)	Description
ESWPT Segment 2	8.27	Tunnel racking in transverse direction due to shear deformation
	31.03	Tunnel rocking about longitudinal axis at bottom of foundation
UHSRS Pipe Chase	15.81	Tunnel racking in transverse direction due to shear deformation
	42.20	Tunnel rocking about longitudinal axis at bottom of foundation

Note: Natural frequencies and effective masses were calculated in ANSYS using the same mesh as used for SASSI analyses.

Table 5.0-5

Matrix of ESWPT and UHSRS Pipe Chase SSI Analyses

Segment	Soil Profile	Model	Foundation Type	Max. Frequency (Hz)		Frequency of Analysis	
				FE Mesh	Soil Layer	Total No.	Cut-off Freq. (Hz)
ESWPT Segment 1a-N	LB -Entire ESWPT	Fully Embedded Model	2' thick Base Slab on Fill Concrete	24	24	52	25
	BE - East of R/B			41	41	87	40
	UB -Entire ESWPT			66	66	100	50
ESWPT Segment 1b	LB -Entire ESWPT	Fully Embedded Model	2' thick Base Slab on Fill Concrete	18	18	51	25
	BE - West of R/B Complex			29	29	87	40
	UB -Entire ESWPT			50	50	100	50
UHSRS Pipe Chase	LB	Embedded Foundation	2' thick Base Slab on Fill Concrete	41	41	100	50
	BE			61	61	100	50
	UB			90	90	100	50
ESWPT Segment 1a-S	LB -West and East PS/B	Surface Foundation	9.91' thick Basemat on Concrete fill or Rock III/IV	178	60	100	50
	BE - West PS/B			364	73	100	50
	BE - East PS/B			229	73	100	50
	UB - West and East PS/B			446	90	100	50
ESWPT Segment 2	LB -West and East PS/B	Surface Foundation	9.91' thick Basemat on Concrete fill or Rock III/IV	178	60	100	50
	BE - West PS/B			364	73	100	50
	BE - East PS/B			229	73	100	50
	UB - West and East PS/B			446	90	100	50

Table 5.0-6
SASSI Results for ESWPT Seismic Response

SSI Effect	Observed Response
Rock Subgrade	The rock subgrade has insignificant SSI effect on the ESWPT seismic response.
Backfill	The properties of the backfill determine the overall response of the buried ESWPT structure. The backfill soil frequencies that are in the range from 2.5 Hz for lower bound to 7.2 Hz for high bound, characterize the ESWPT horizontal response. Frequencies of 9.9 Hz for lower bound, to 22 Hz for upper bound characterize the vertical response of the ESWPT.
Motion Scattering Effects	Motion scattering effects are inherent in the SASSI analysis results. The dynamic properties mismatch between the backfill and the rock results in reflection of the seismic waves within the backfill stratum. Consequently, multiple modes characterize the backfill soil column and effect the ESWPT response when their frequencies are close to the structural frequencies.

Table 5.0-7a
ESWPT Segment 1aN SASSI FE Model Component Peak Accelerations(1)

Component	Transverse Direction (g)	Longitudinal Direction (g)	Vertical Direction (g)
Base Slab	0.65	0.411	0.488
Roof Slab	0.946	0.415	1.171
Interior Walls	0.993	0.415	0.852
Exterior Walls	1.195	0.408	0.529

Table 5.0-7b
ESWPT Segment 1aS SASSI FE Model Component Peak Accelerations(1)

Component	Transverse Direction (g)	Longitudinal Direction (g)	Vertical Direction (g)
Base Slab	0.723	0.572	0.596
Roof Slab	1.262	1.698	2.648
Interior Walls	2.892	1.647	1.99
Exterior Walls	1.892	3.496	2.648

Table 5.0-7c
ESWPT Segment 1b SASSI FE Model Component Peak Accelerations(1)

Component	Transverse Direction (g)	Longitudinal Direction (g)	Vertical Direction (g)
Base Slab	0.751	0.524	0.616
Roof Slab	1.059	1.081	1.091
Interior Walls	1.333	0.404	0.601
Exterior Walls	1.366	0.446	0.699

Table 5.0-7d
ESWPT Segment 2 SASSI FE Model Component Peak Accelerations(1)

Component	Transverse Direction (g)	Longitudinal Direction (g)	Vertical Direction (g)
Base Slab	0.667	0.613	0.57
Roof Slab	0.719	1.193	1.115
Interior Walls	0.719	1.193	1.031
Exterior Walls	0.715	1.123	0.741

Table 5.0-7e
UHSRS Pipe Chase SASSI FE Model Component Peak Accelerations(1)

Component	Transverse Direction (g)	Longitudinal Direction (g)	Vertical Direction (g)
Base Slab	0.745	0.677	0.935
Roof Slab	1.839	0.839	1.303
Interior Walls	1.834	0.835	1.092
Exterior Walls	1.829	0.814	0.992

Note:

(1) For structural design using the loads and load combinations in Section 3.8, the seismic loads are obtained by applying to the ESWPT segment a statically equivalent uniform acceleration that envelopes the above accelerations and a dynamic soil pressure.

Table 5.0-8
ESWPT Segment 1 FE Model Maximum Component Seismic Forces and Moments

Component		Maximum Component Forces and Moments							
		N_V (k/ft)	N_L (k/ft)	Q_V (k/ft)	Q_L (k/ft)	In-plane Shear (k/ft)	M_V (k-ft/ft)	M_L (k-ft/ft)	M_{VL} (k-ft/ft)
Base Slab	+ / -	63.52	16.97	75.92	8.99	8.84	254.35	45.65	9.28
Roof Slab	+ / -	36.33	10.01	32.56	9.54	7.80	205.93	35.93	5.96
Interior Walls	+ / -	58.68	7.99	13.80	4,98	10.15	69.31	12.64	2.25
Exterior Walls	+ / -	65.98	11.94	68.76	8.65	16.76	265.33	44.59	8.39

Notes:

1. The forces and moments shown above are for Segment 1a and 1b with the exclusion of the regions at the ends and around the “kink” area where local effect produces concentrated forces higher than those shown above and require special details in design.
2. The forces and moments are obtained by combination of the three orthogonal directions used in the model by the Newmark 100%-40%-40% method.
3. In the table above the vertical and longitudinal directions define the plane of the walls. N stands for axial force, Q for out-of-plane shear and M for moment. The M_V results in normal stresses in the vertical direction of the wall and similarly, M_L results in normal stresses in the longitudinal (horizontal) direction of the wall, and M_{VL} is the torsional moment on the wall. The Q_V is out-of-plane shear force acting on horizontal cross section of the wall, and Q_L is out-of-plane shear force acting on a vertical cross section of the wall. For the roof slab and base slab the vertical axis is oriented along the east-west direction and the longitudinal along the north-south direction.

Table 5.0-9

ESWPT Segment 2 FE Model Maximum Component Seismic Forces and Moments

Component		Maximum Component Forces and Moments							
		N_V (k/ft)	N_L (k/ft)	Q_V (k/ft)	Q_L (k/ft)	In-plane Shear (k/ft)	M_V (k-ft/ft)	M_L (k-ft/ft)	M_{VL} (k-ft/ft)
Roof Slab	+/-	6.00	30.28	8.28	1.60	5.39	33.35	5.73	1.30
Interior Walls	+/-	32.54	14.97	2.15	0.59	7.45	8.31	1.50	0.25
Exterior Walls	+/-	31.84	27.90	7.23	1.30	11.52	40.32	6.92	1.19

Notes:

1. The forces and moments shown above envelope all subgrade profiles. The forces and moments are used for structural design as described in Section 3.8.
2. The forces and moments are obtained by combination of the three orthogonal directions used in the model by the Newmark 100%-40%-40% method.
3. In the table above the vertical and longitudinal directions define the plane of the walls. N stands for axial force, Q for out-of-plane shear and M for moment. The M_V results in normal stresses in the vertical direction of the wall and similarly, M_L results in normal stresses in the longitudinal (horizontal) direction of the wall, and M_{VL} is the torsional moment on the wall. The Q_V is out-of-plane shear force acting on horizontal cross section of the wall, and Q_L is out-of-plane shear force acting on a vertical cross section of the wall.

Table 5.0-10
ESWPT Maximum Seismic Relative Displacements for All Enveloped Conditions

ESWPT Segment	Longitudinal Direction (in)		Transverse (in)		Vertical (in)	
	SASSI	ANSYS	SASSI	ANSYS	SASSI	ANSYS
UHSRS Pipe Chase	0.0024	0.00215	0.0468	0.045	0.003	0.0243
Segment 2	0.0049	0.00454	0.0877	0.100	0.0016	0.0144

Table 5.0-11
ESWPT Maximum Seismic Displacements Relative to Free Field Motion

ESWPT Segment	Longitudinal Direction (in)	Transverse (in)	Vertical (in)
Segment 2	0.0025	0.0478	0.0024
UHSRS Pipe Chase	0.0093	0.0894	0.0013

Note:

The reported transverse and vertical displacements are at the edge of separation joints.

Table 5.0-12
ESWPT Dynamic Properties (Sheet 1 of 2)

UHSRS PIPE CHASE				
MODAL PROPERTIES OF FIRST 5 MODES, X-DIRECTION				
MODE	**FREQUENCY (HZ)**	**PERIOD (SEC)**	**PARTICIPATION FACTOR**	**EFFECTIVE MASS (KIPS*SEC^2/FT)**
1	15.81	6.33E-02	6.32E+00	3.99E+01
5	42.20	2.37E-02	-1.31E+00	1.70E+00
4	37.59	2.66E-02	1.75E-01	3.06E-02
8	50.59	1.98E-02	1.44E-01	2.09E-02
3	34.57	2.89E-02	-5.86E-14	3.44E-27
MODAL PROPERTIES OF FIRST 5 MODES, Y-DIRECTION				
MODE	**FREQUENCY (HZ)**	**PERIOD (SEC)**	**PARTICIPATION FACTOR**	**EFFECTIVE MASS (KIPS*SEC^2/FT)**
6	47.46	2.11E-02	5.97E+00	3.56E+01
3	34.57	2.89E-02	5.09E+00	2.59E+01
7	48.84	2.05E-02	-1.65E+00	2.73E+00
2	28.69	3.49E-02	-1.46E-01	2.13E-02
4	37.59	2.66E-02	-1.61E-14	2.58E-28
MODAL PROPERTIES OF FIRST 5 MODES, Z-DIRECTION				
MODE	**FREQUENCY (HZ)**	**PERIOD (SEC)**	**PARTICIPATION FACTOR**	**EFFECTIVE MASS (KIPS*SEC^2/FT)**
4	37.59	2.66E-02	8.14E+00	6.63E+01
5	42.20	2.37E-02	7.62E-01	5.81E-01
8	50.59	1.98E-02	-5.50E-01	3.02E-01
1	15.81	6.33E-02	-4.73E-02	2.23E-03
6	47.46	2.11E-02	2.22E-14	4.91E-28

Table 5.0-12
ESWPT Dynamic Properties (Sheet 2 of 2)

ESWPT SEGMENT 2				
MODAL PROPERTIES OF FIRST 5 MODES, X-DIRECTION				
MODE	**FREQUENCY (HZ)**	**PERIOD (SEC)**	**PARTICIPATON FACTOR**	**EFFECTIVE MASS (KIPS*SEC^2/FT)**
1	8.27	1.21E-01	1.18E+01	1.38E+02
6	30.13	3.32E-02	1.05E+01	1.10E+02
14	38.49	2.60E-02	1.75E+00	3.06E+00
7	31.25	3.20E-02	-6.81E-01	4.63E-01
12	35.78	2.79E-02	6.48E-01	4.20E-01
MODAL PROPERTIES OF FIRST 5 MODES, Y-DIRECTION				
MODE	**FREQUENCY (HZ)**	**PERIOD (SEC)**	**PARTICIPATION FACTOR**	**EFFECTIVE MASS (KIPS*SEC^2/FT)**
5	29.29	3.41E-02	1.31E+01	1.72E+02
20	40.92	2.44E-02	-1.14E+01	1.31E+02
11	34.48	2.90E-02	-9.64E+00	9.29E+01
8	31.71	3.15E-02	6.23E-01	3.88E-01
25	43.01	2.33E-02	3.43E-01	1.18E-01
MODAL PROPERTIES OF FIRST 5 MODES, Z-DIRECTION				
MODE	**FREQUENCY (HZ)**	**PERIOD (SEC)**	**PARTICIPATION FACTOR**	**EFFECTIVE MASS (KIPS*SEC^2/FT)**
9	31.92	3.13E-02	1.61E+01	2.59E+02
7	31.25	3.20E-02	1.26E+01	1.58E+02
6	30.13	3.32E-02	1.48E+00	2.19E+00
23	42.75	2.34E-02	-1.76E-01	3.09E-02
12	35.78	2.79E-02	-5.12E-02	2.62E-03

Table 5.0-13
ESWPT Maximum Dynamic Bearing Pressure

	Peak Design(2) (ksf)	**Average Dynamic(3) (ksf)**
Segment 1(1)	114.58	71.64
Segment 2	16.81	10.53

Notes:

(1) This pressure represents the pressure at segment 1a south near PSB, where tunnel is exposed in one side. The pressure is at the concrete fill.
(2) Peak design pressure is the highest pressure at the tip of the compression side on the foundation base.
(3) Average dynamic pressure is the average pressure on the compression side of the foundation base according to the concrete stress strain curve as adopted in the tradition concrete design.

Table 5.0-14

Load Combinations and Factor of Safety for ESWPT

Building/Structure(1)	Load Combination (per SRP 3.8.5)	Overturning(2) (Fs_{ot})	Sliding(2) (FS_{sl})	Flotation (FS_{fl})
ESWPT	D + H + W	N/A	N/A	N/A
	D + H + E_s(1)	1.1	1.18	N/A
	D + H + W_t	N/A	N/A	N/A
	D + F_b	N/A	N/A	1.59

Notes:

(1) The factor of safety is governed by ESWPT Segment 1a and 1b.

(2) Overturning and Sliding factors of safety are based on site-specific groundwater levels.

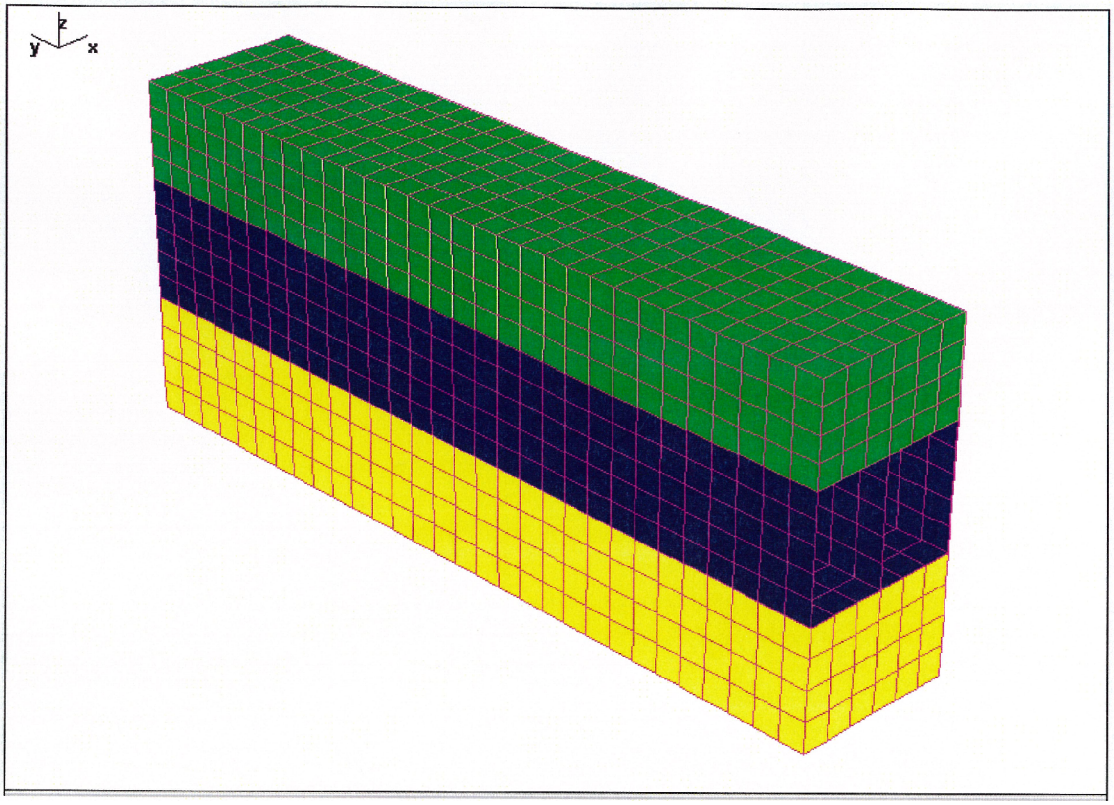


Figure 5.0-1

SASSI Model of ESWPT Segment 1aN (Excluding Backfill Elements at Two Sides)

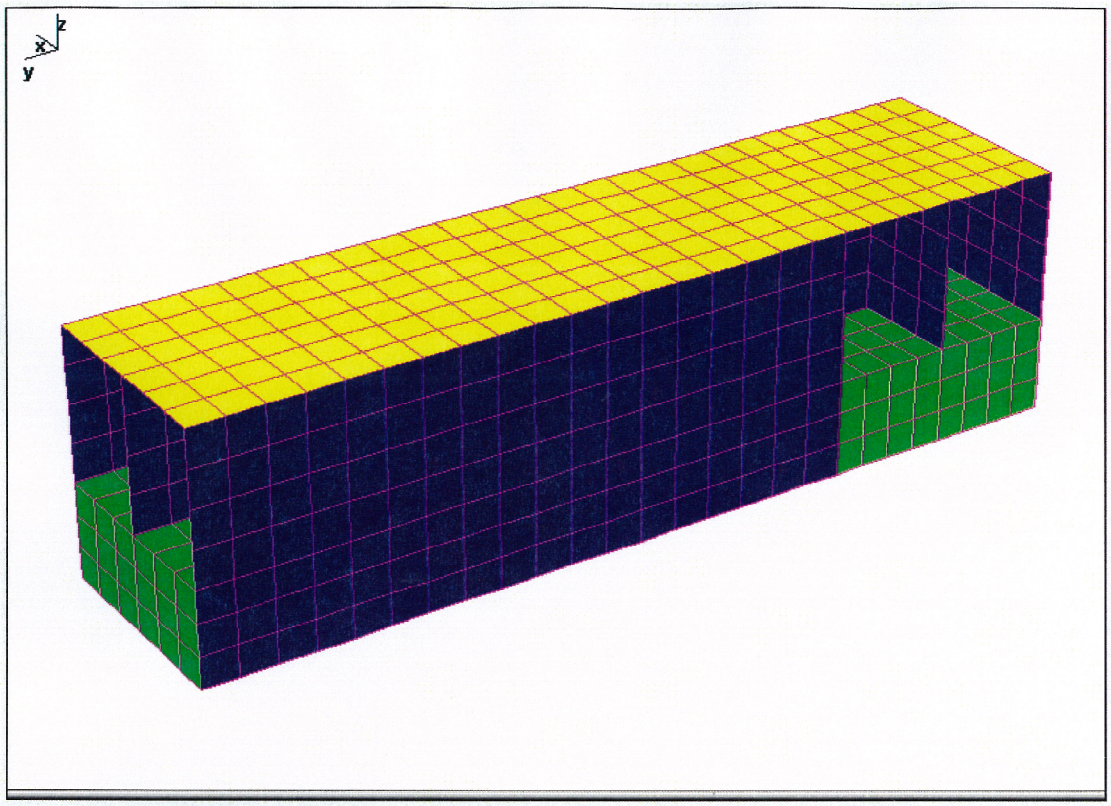


Figure 5.0-2

SASSI Model of ESWPT Segment 1a S (Excluding Elements Representing Backfill)

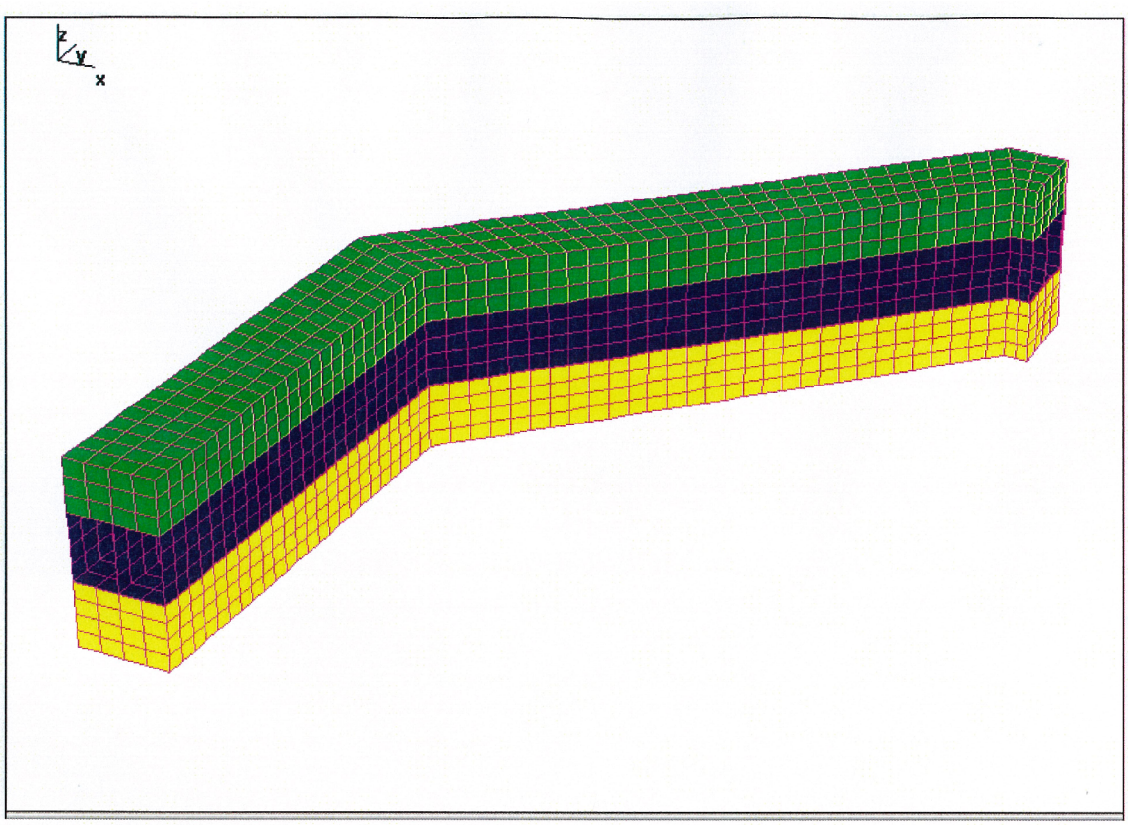


Figure 5.0-3

SASSI Model of ESWPT Segment 1b (Excluding Backfill Elements at Two Sides)

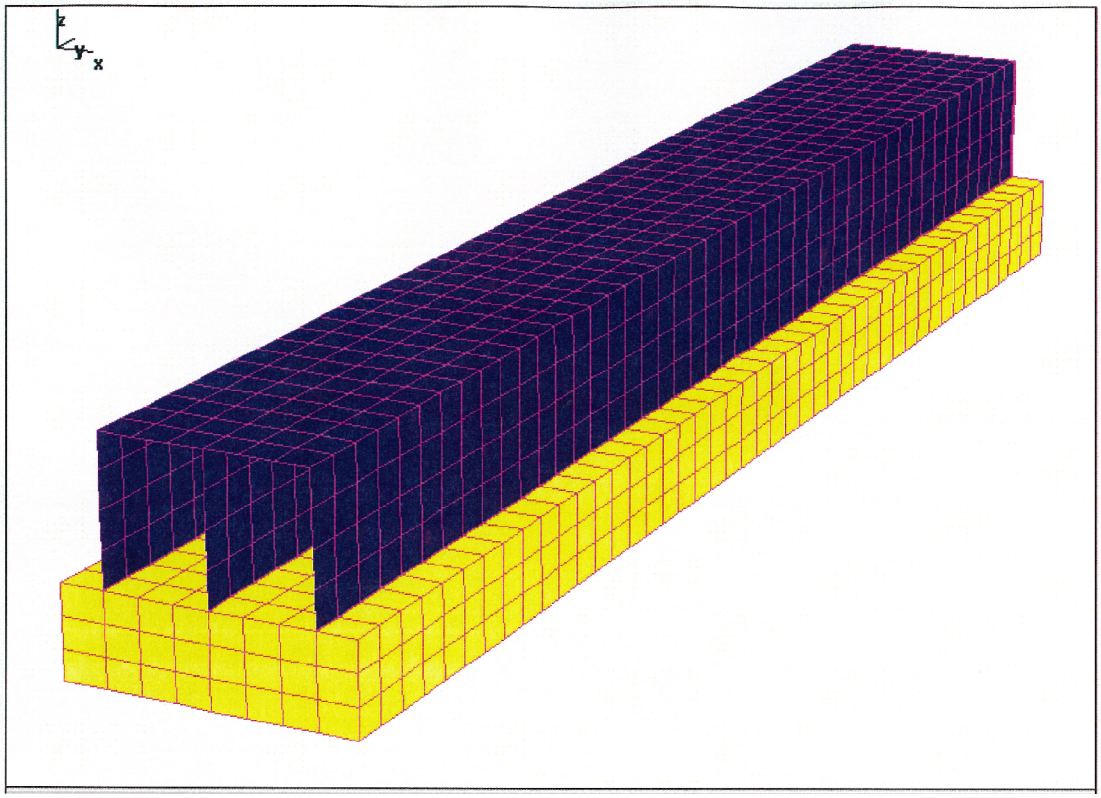


Figure 5.0-4

SASSI Model of ESWPT Segment 2 (Excluding Backfill Elements)

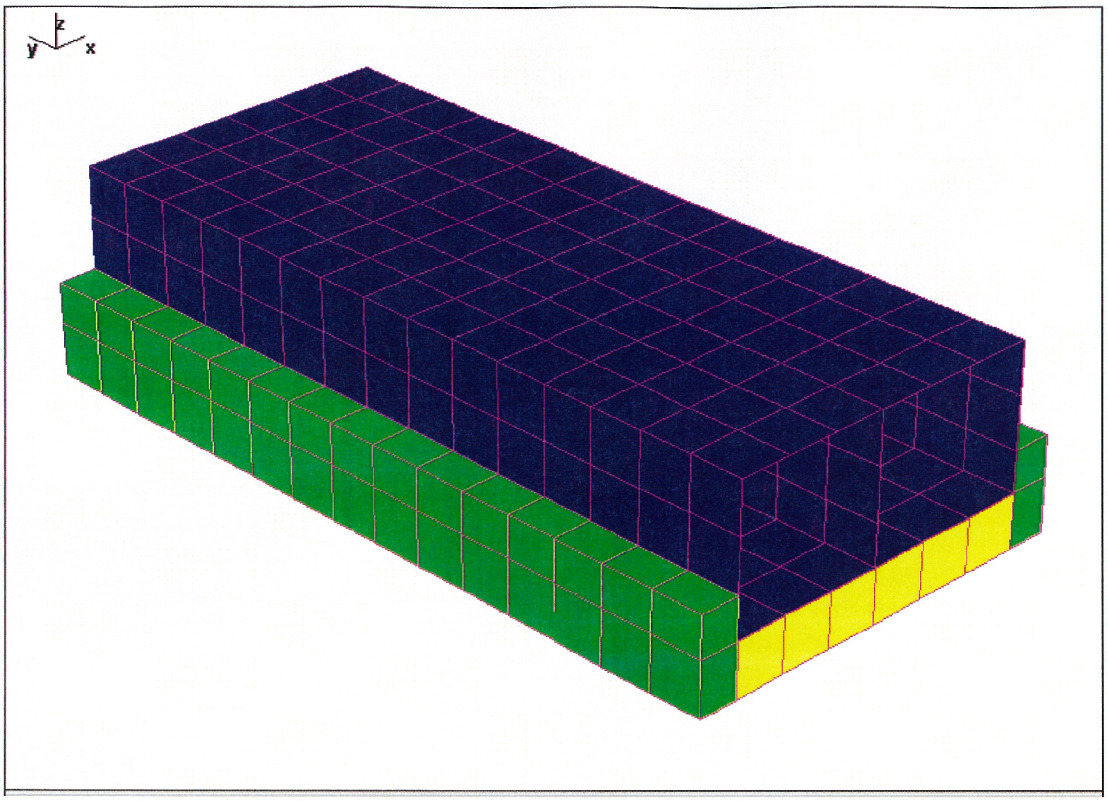


Figure 5.0-5

SASSI Model of UHSRS Pipe Chase (Including Embedment Soil Elements)

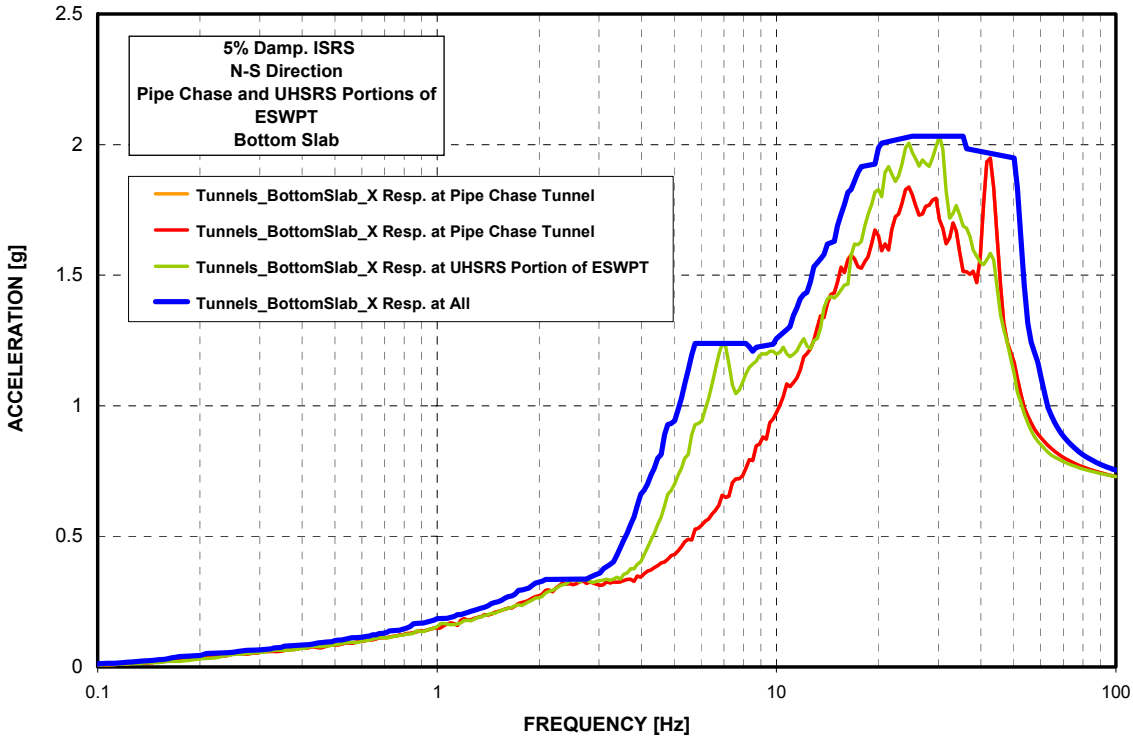


Figure 5.0-6 (Sheet 1 of 36)

ISRS

(ESWPT Group 1, N-S Direction, Mat Slab)

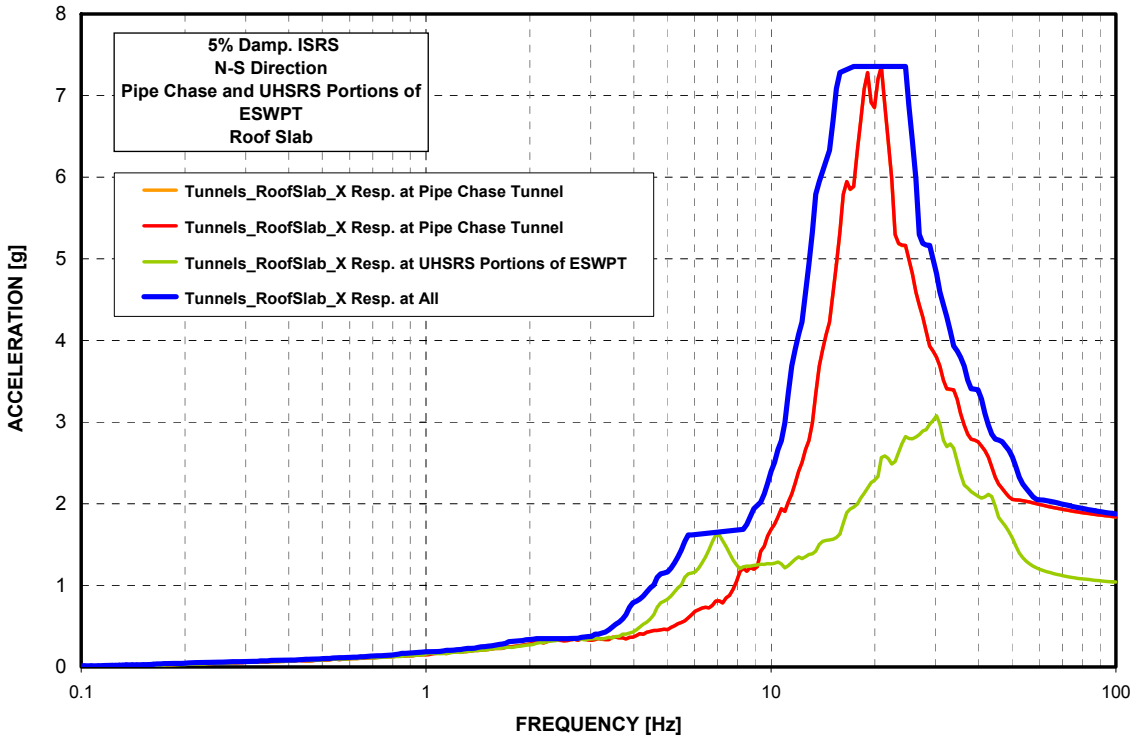


Figure 5.0-6 (Sheet 2 of 36)

ISRS

(ESWPT Group 1, N-S Direction, Roof Slab)

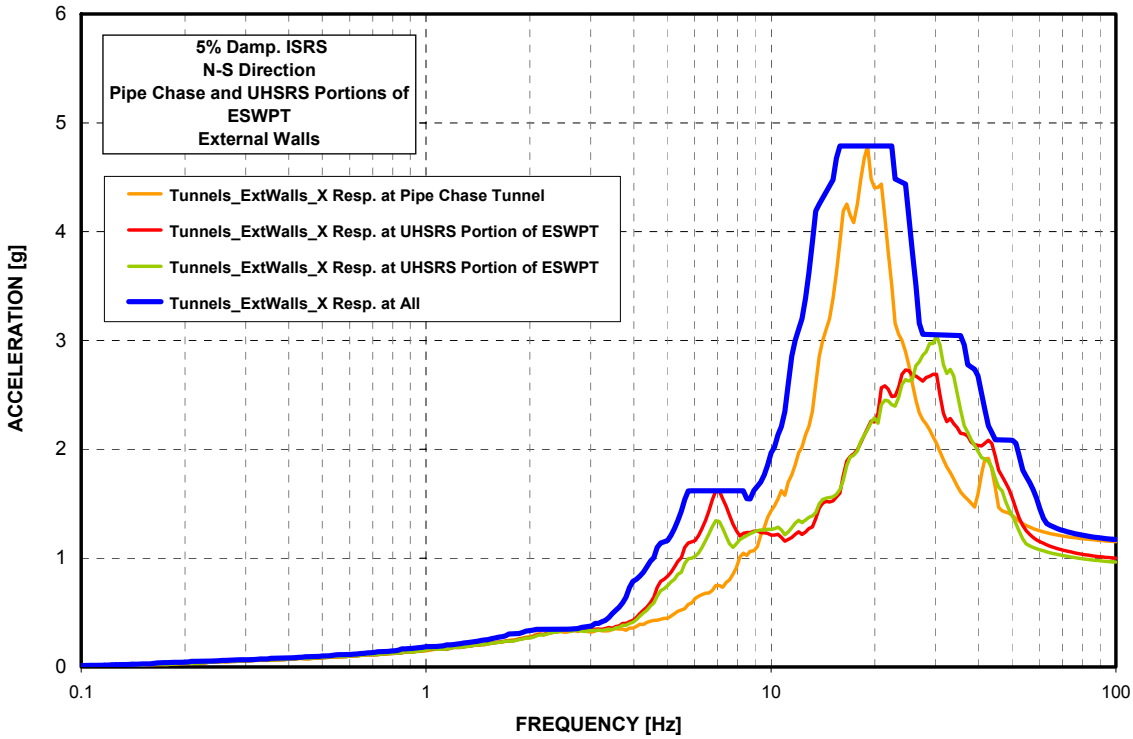


Figure 5.0-6 (Sheet 3 of 36)

ISRS

(ESWPT Group 1, N-S Direction, External Walls)

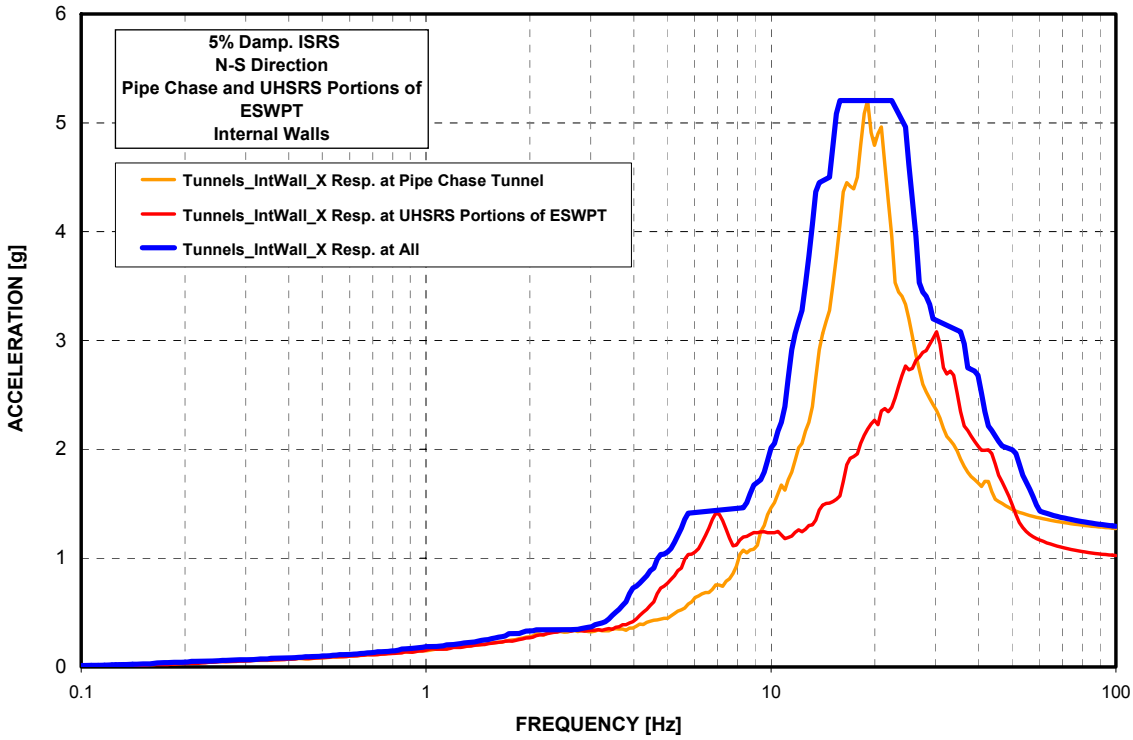


Figure 5.0-6 (Sheet 4 of 36)

ISRS

(ESWPT Group 1, N-S Direction, Internal Walls)

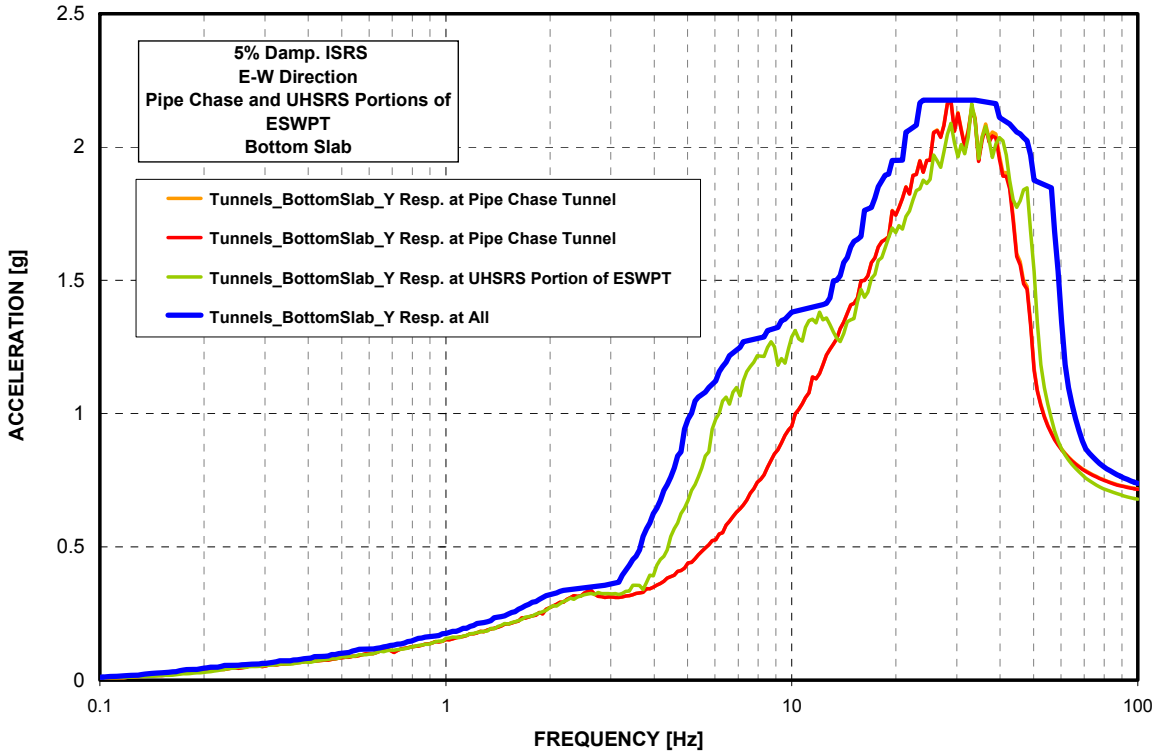


Figure 5.0-6 (Sheet 5 of 36)

ISRS

(ESWPT Group 1, E-W Direction, Mat Slab)

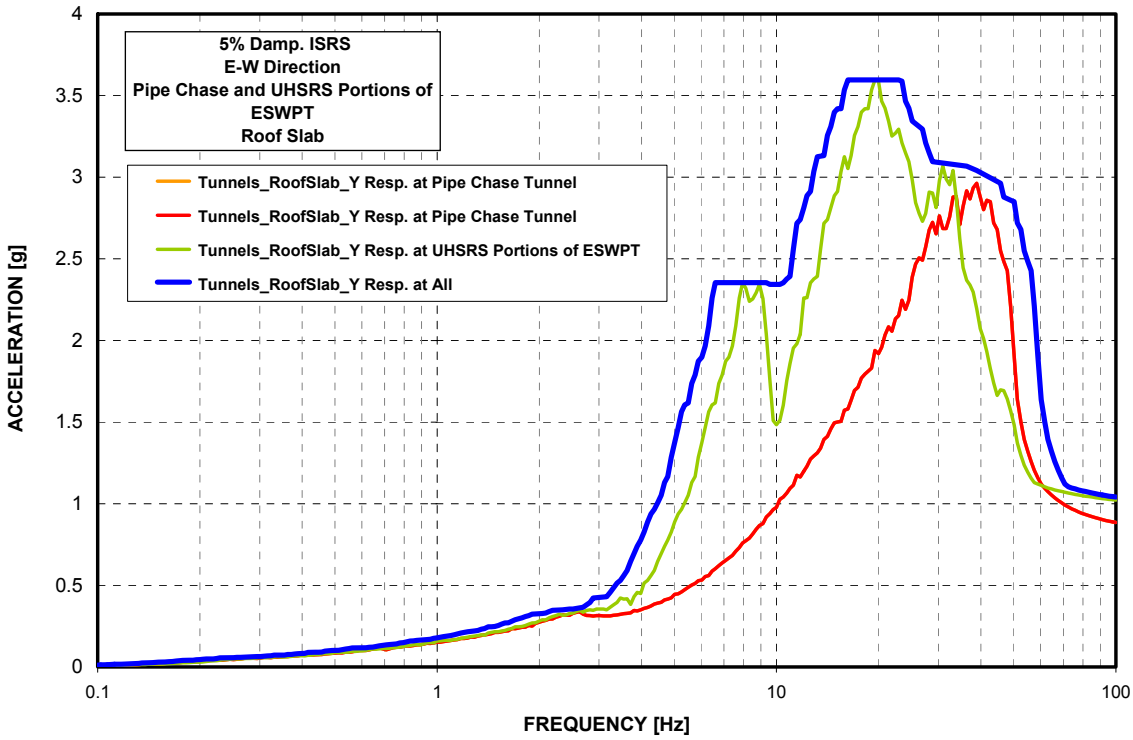


Figure 5.0-6 (Sheet 6 of 36)

ISRS

(ESWPT Group 1, E-W Direction, Roof Slab)

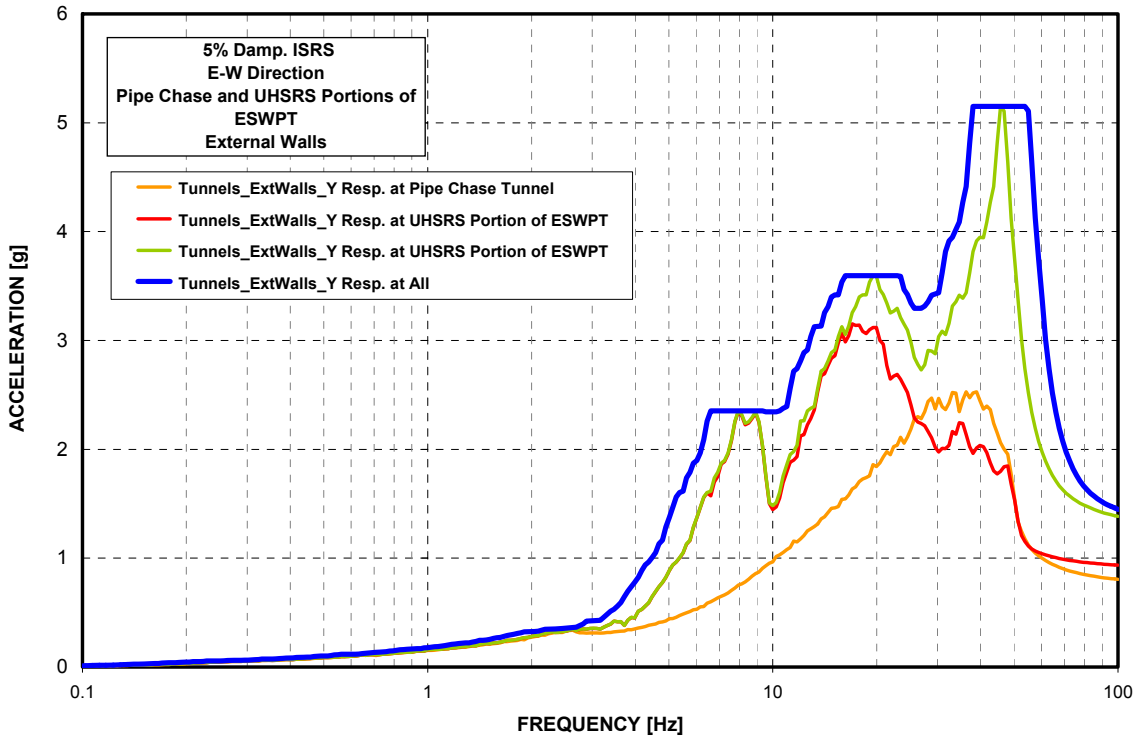


Figure 5.0-6 (Sheet 7 of 36)

ISRS

(ESWPT Group 1, E-W Direction, External Walls Slab)

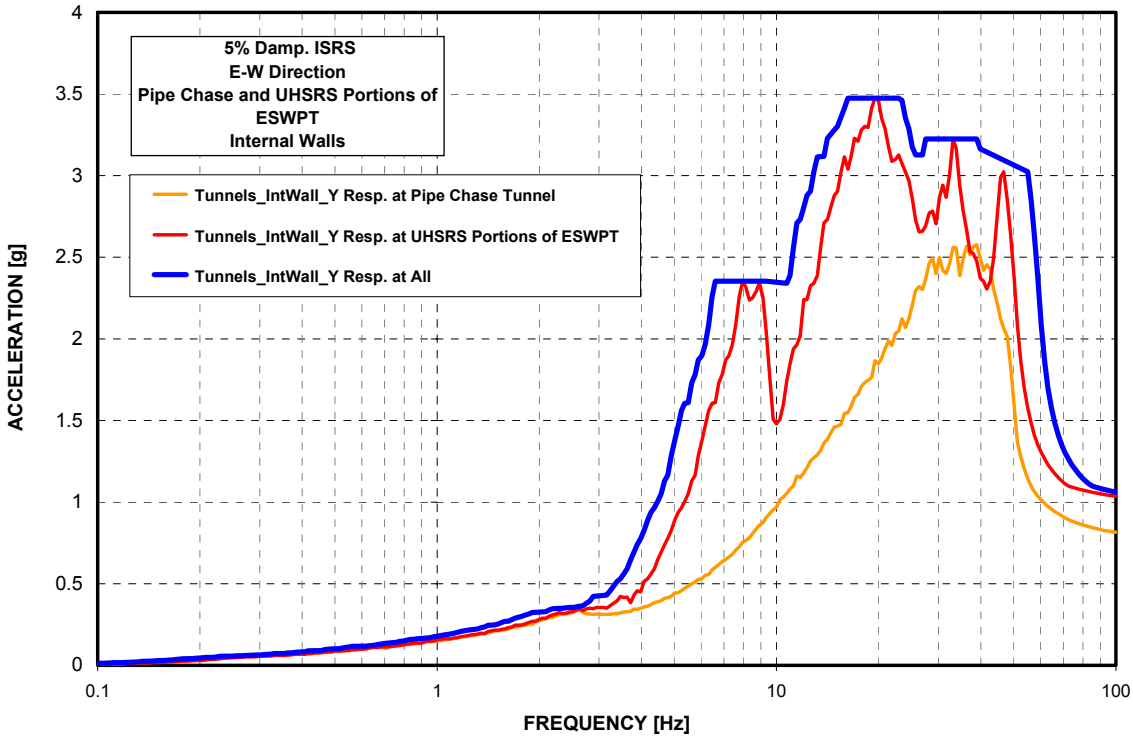


Figure 5.0-6 (Sheet 8 of 36)

ISRS

(ESWPT Group 1, E-W Direction, Internal Walls Slab)

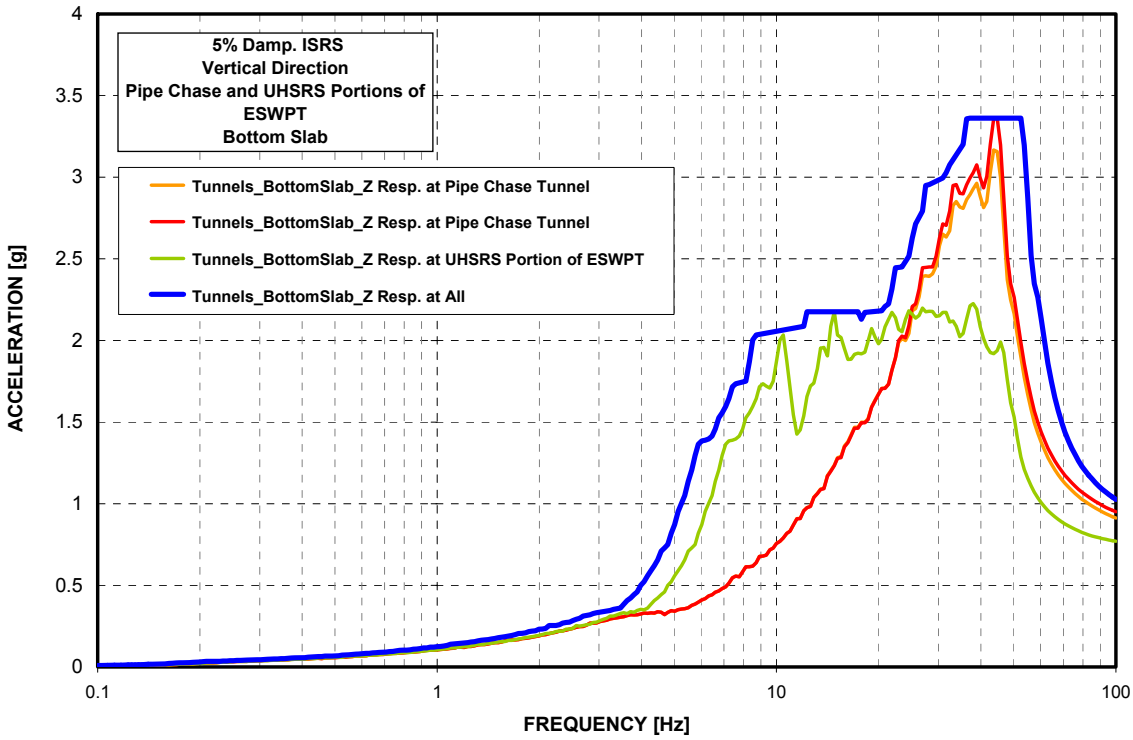


Figure 5.0-6 (Sheet 9 of 36)

ISRS

(ESWPT Group 1, Vertical Direction, Mat Slab)

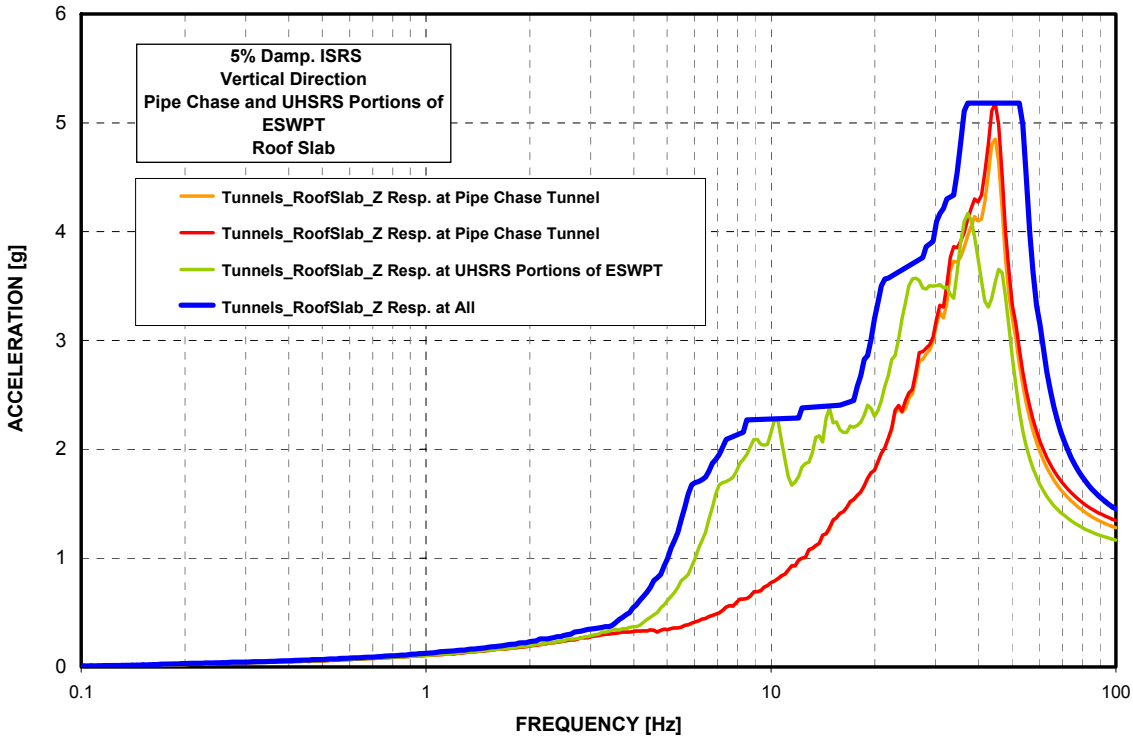


Figure 5.0-6 (Sheet 10 of 36)

ISRS

(ESWPT Group 1, Vertical Direction, Roof Slab)

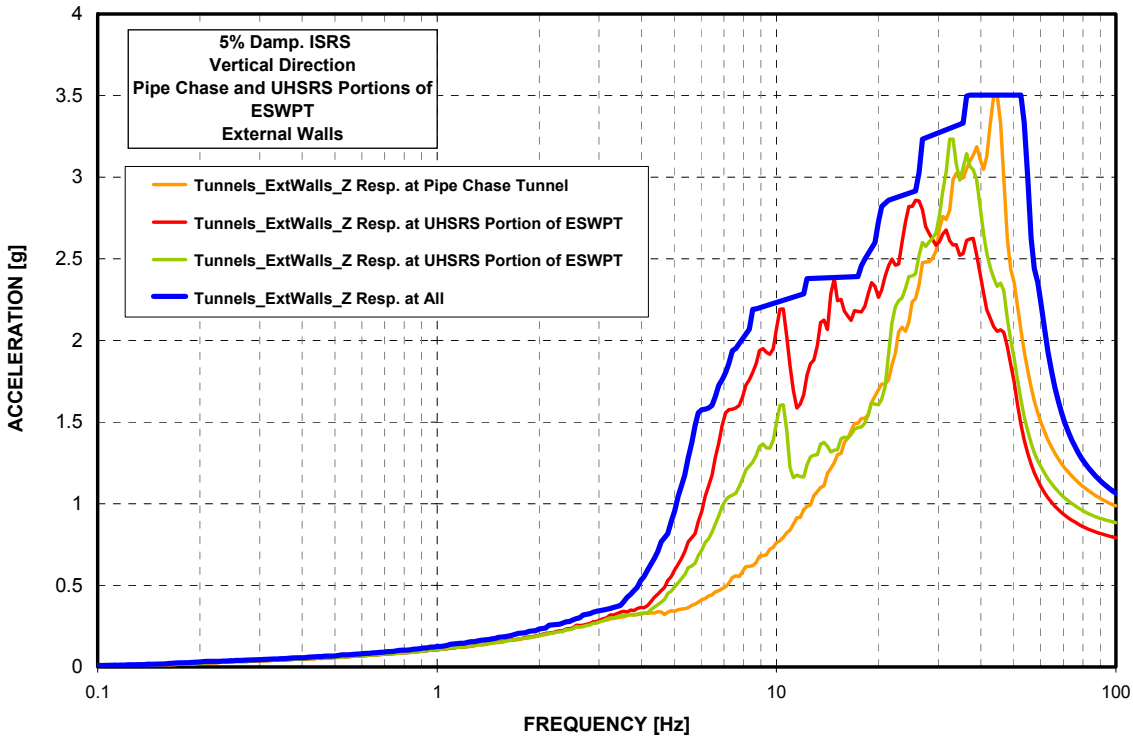


Figure 5.0-6 (Sheet 11 of 36)

ISRS

(ESWPT Group 1, Vertical Direction, External Walls)

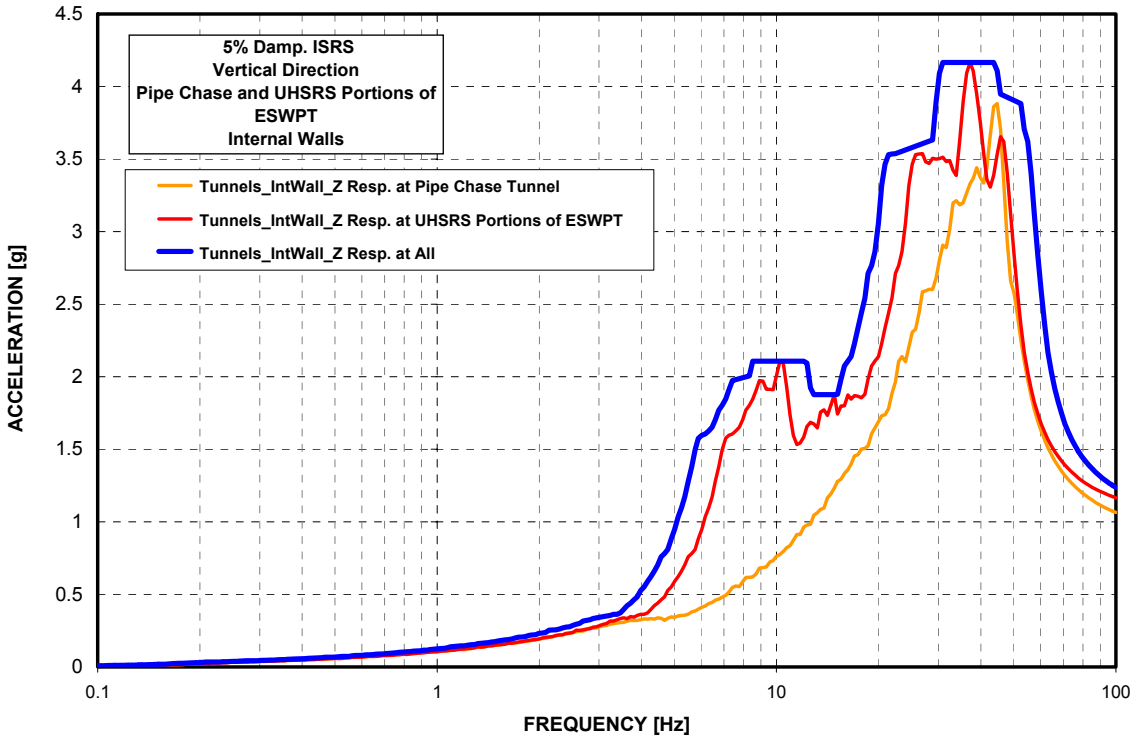


Figure 5.0-6 (Sheet 12 of 36)

ISRS

(ESWPT Group 1, Vertical Direction, Internal Walls)

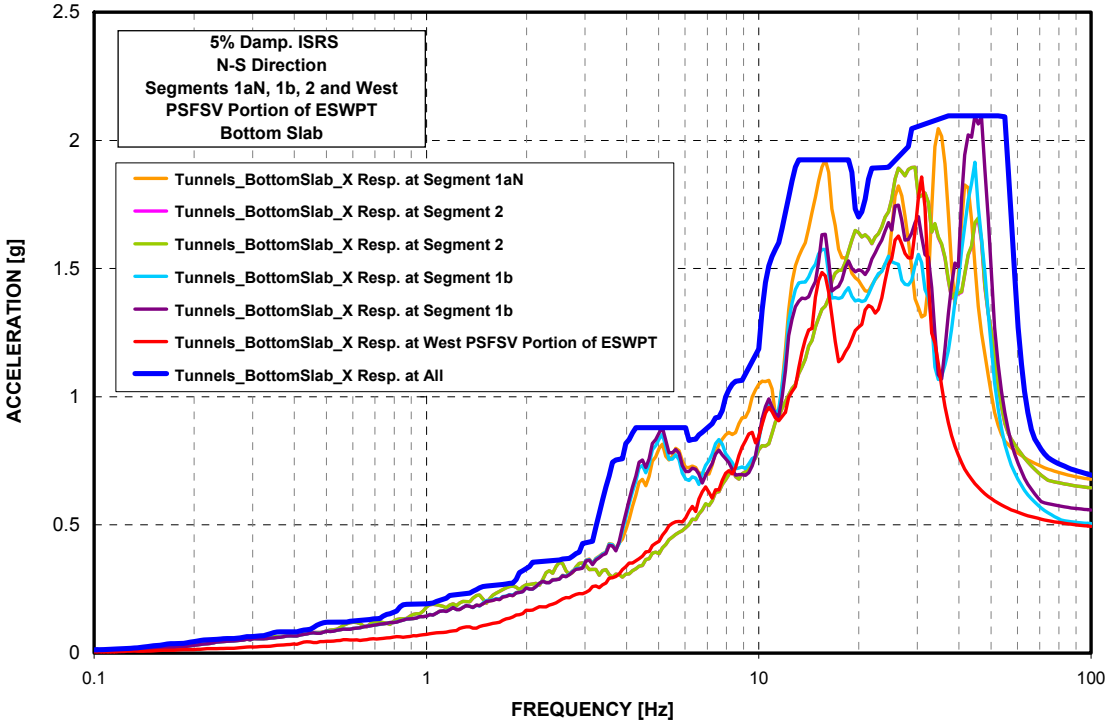


Figure 5.0-6 (Sheet 13 of 36)

ISRS

(ESWPT Group 2, N-S Direction, Mat Slab)

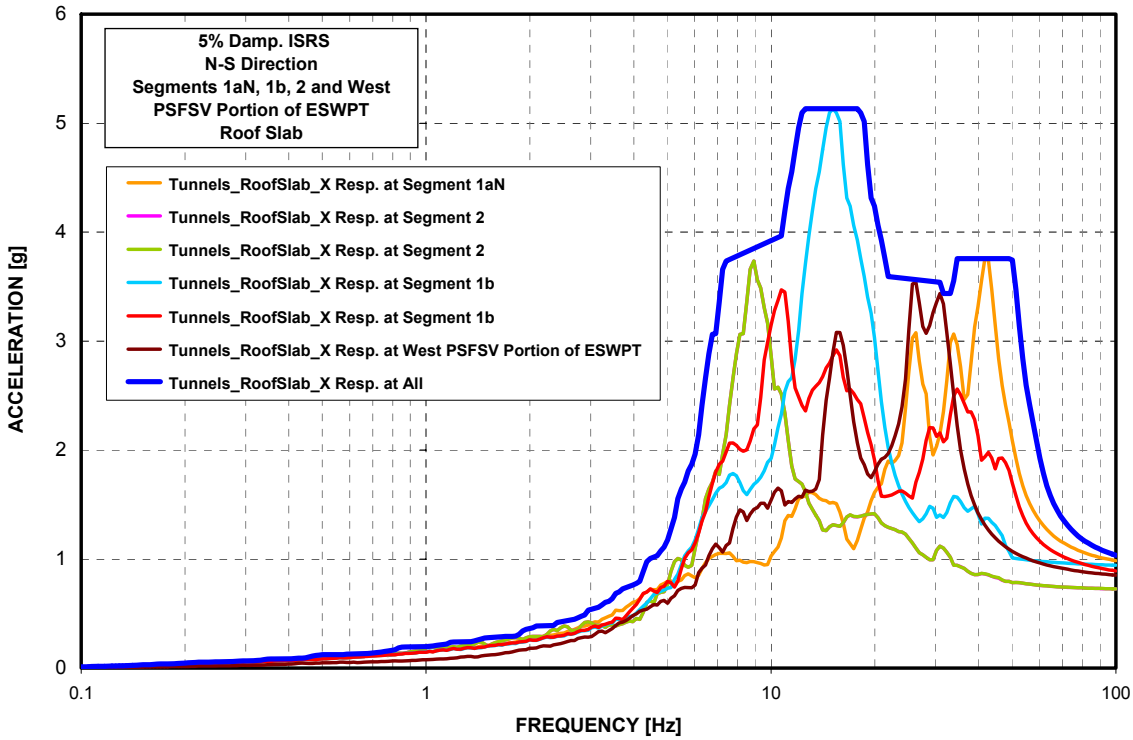


Figure 5.0-6 (Sheet 14 of 36)

ISRS

(ESWPT Group 2, N-S Direction, Roof Slab)

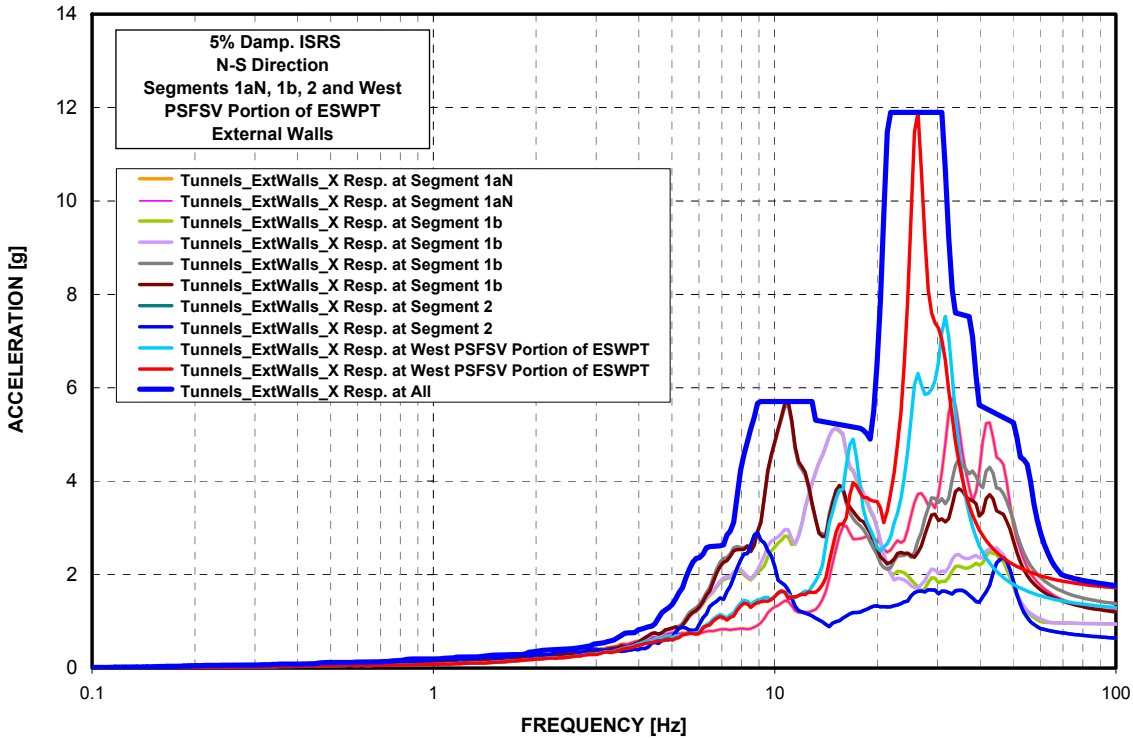


Figure 5.0-6 (Sheet 15 of 36)

ISRS

(ESWPT Group 2, N-S Direction, External Walls)

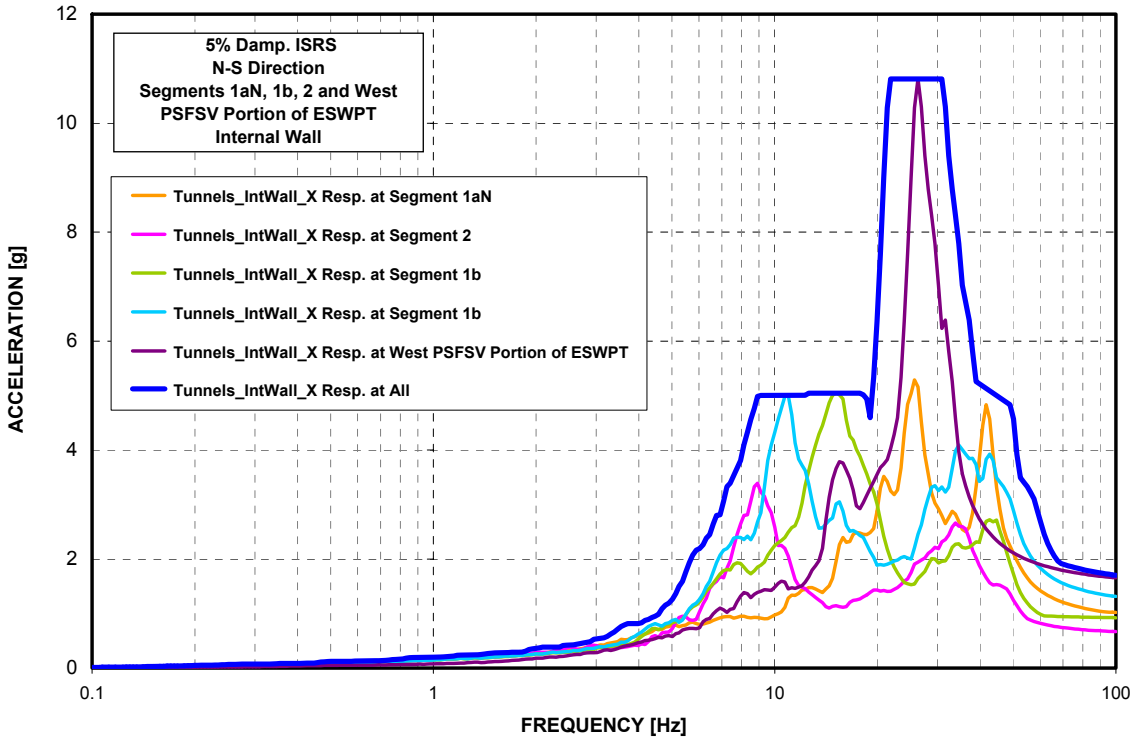


Figure 5.0-6 (Sheet 16 of 36)

ISRS

(ESWPT Group 2, N-S Direction, Internal Walls)

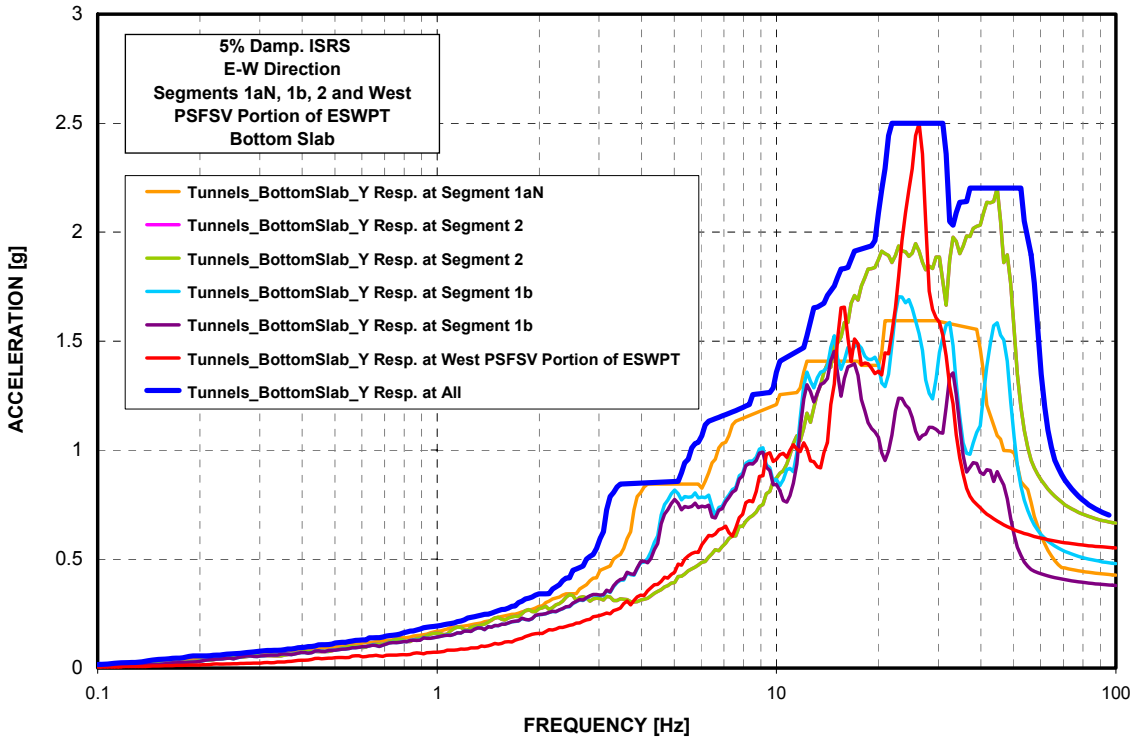


Figure 5.0-6 (Sheet 17 of 36)

ISRS

(ESWPT Group 2, E-W Direction, Mat Slab)

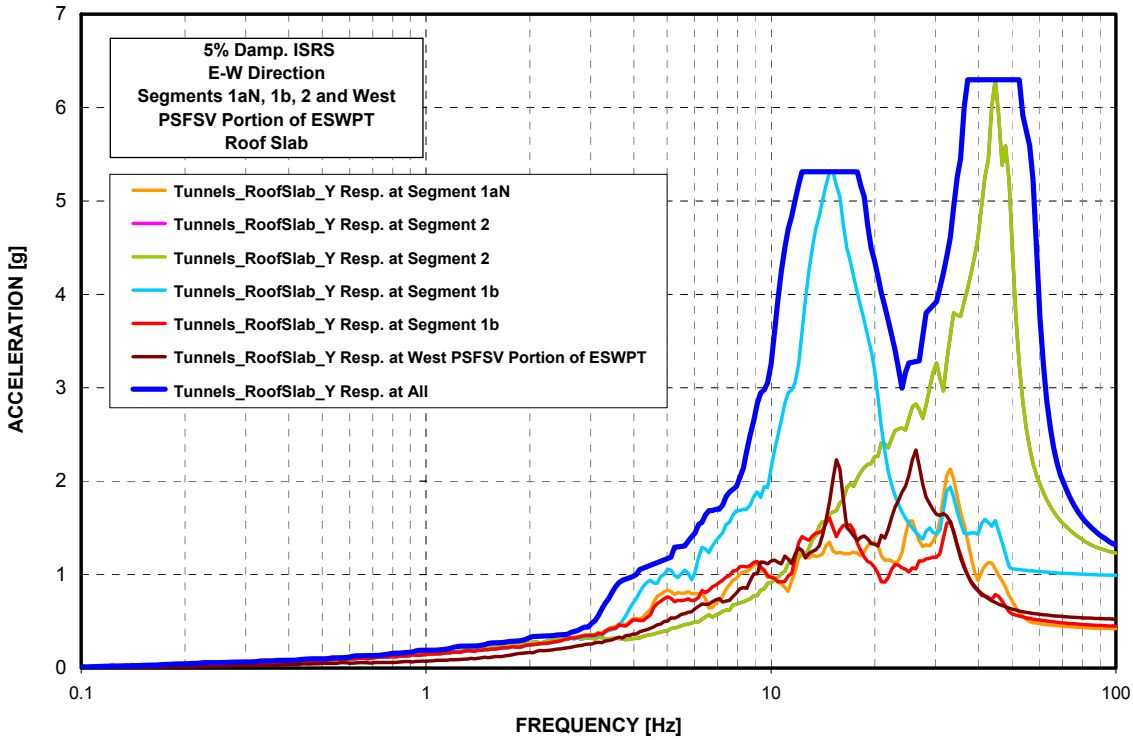


Figure 5.0-6 (Sheet 18 of 36)

ISRS

(ESWPT Group 2, E-W Direction, Roof Slab)

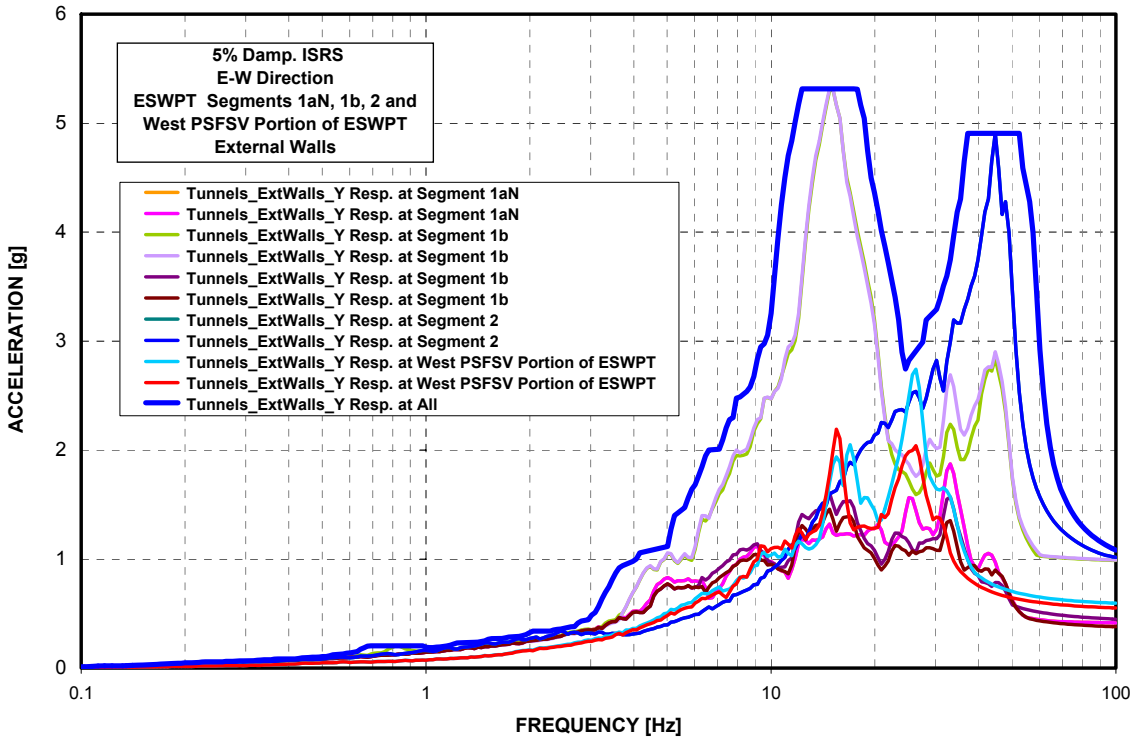


Figure 5.0-6 (Sheet 19 of 36)

ISRS

(ESWPT Group 2, E-W Direction, External Walls)

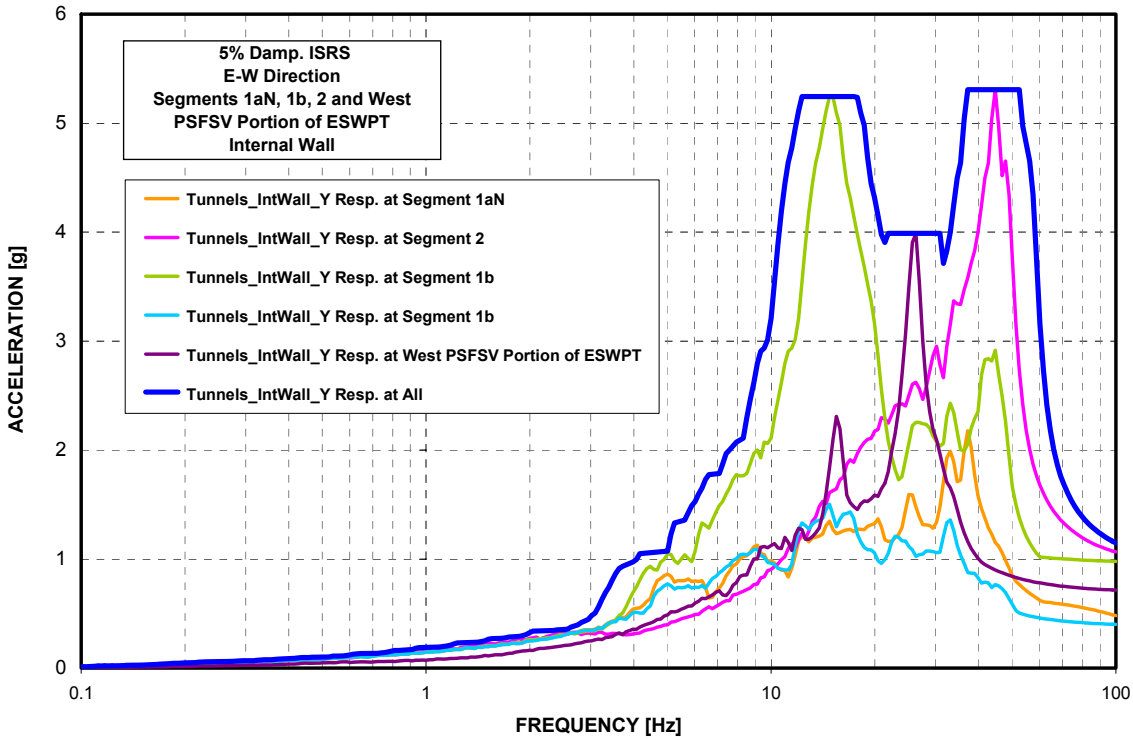


Figure 5.0-6 (Sheet 20 of 36)

ISRS

(ESWPT Group 2, E-W Direction, Internal Walls)

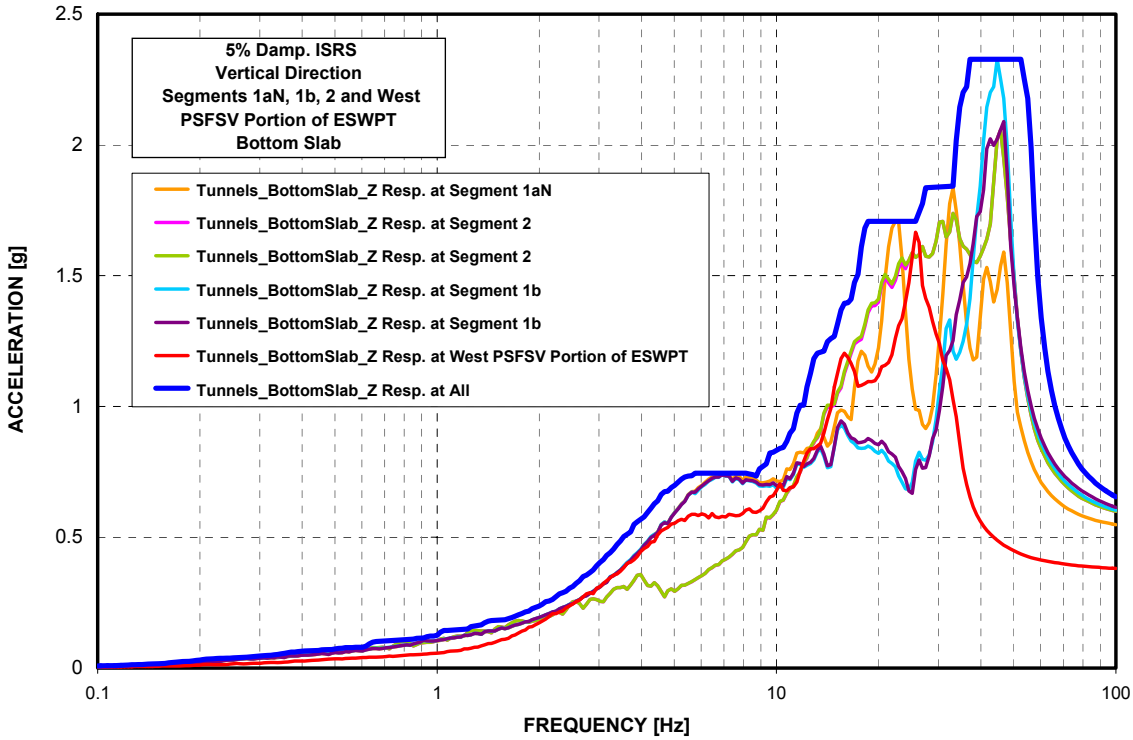


Figure 5.0-6 (Sheet 21 of 36)

ISRS

(ESWPT Group 2, Vertical Direction, Mat Slab)

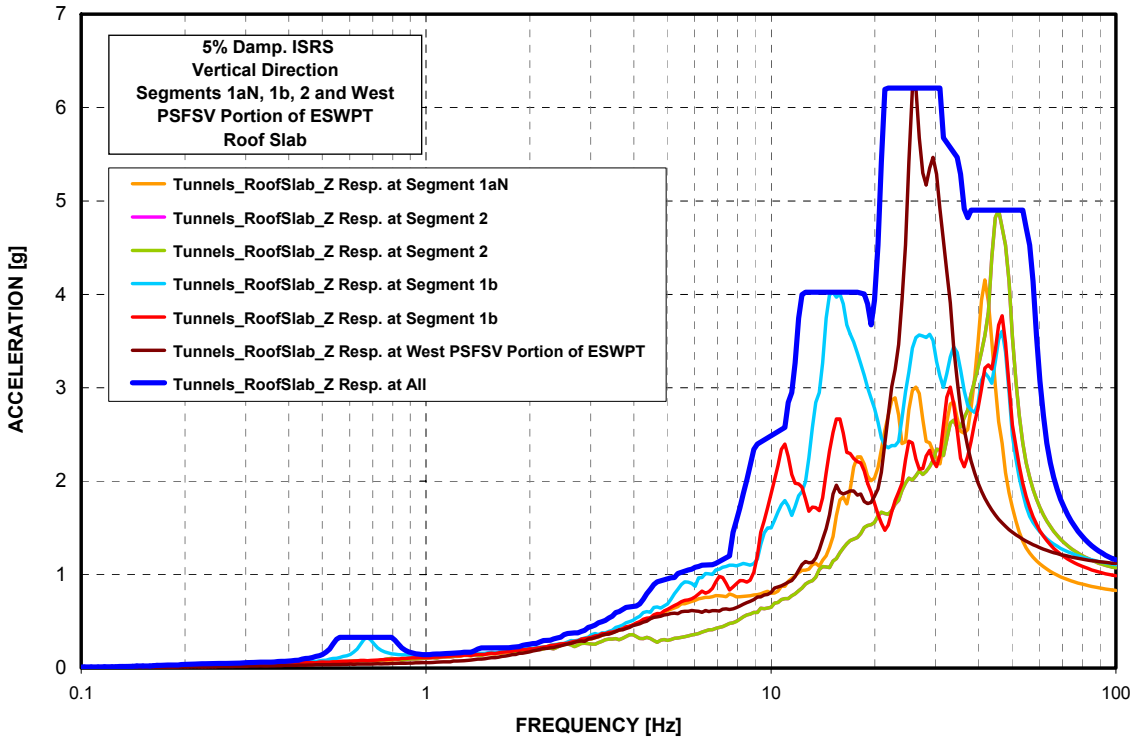


Figure 5.0-6 (Sheet 22 of 36)

ISRS

(ESWPT Group 2, Vertical Direction, Roof Slab)

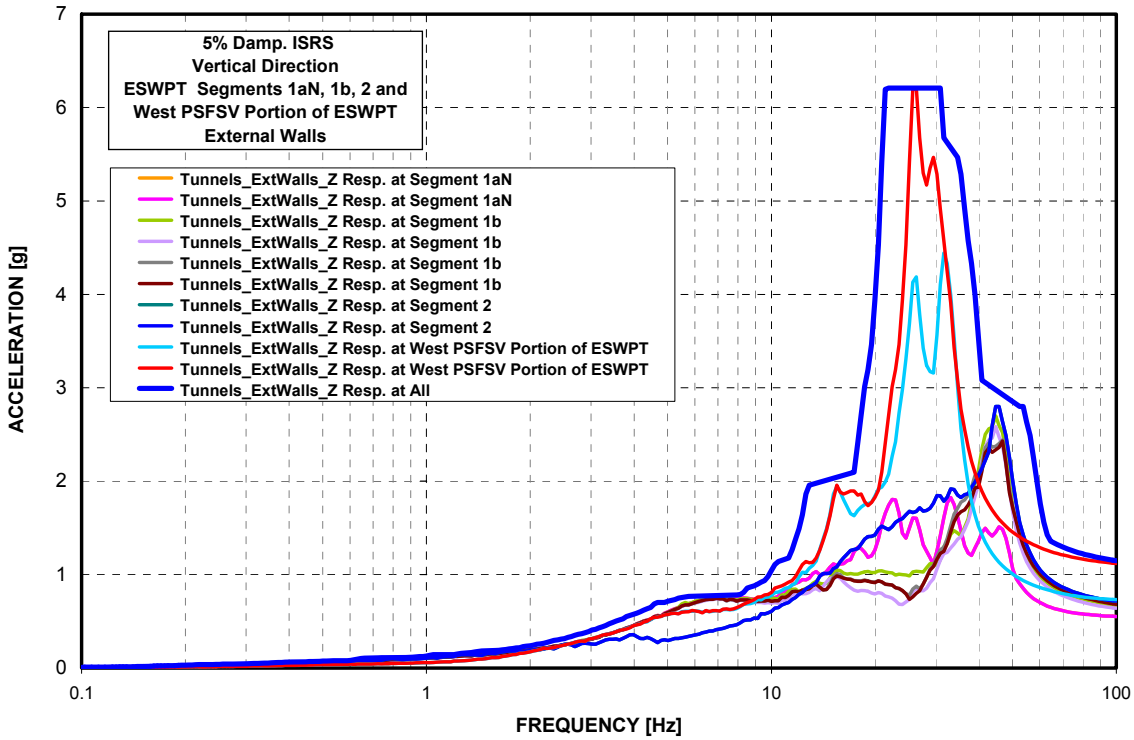


Figure 5.0-6 (Sheet 23 of 36)

ISRS

(ESWPT Group 2, Vertical Direction, External Walls)

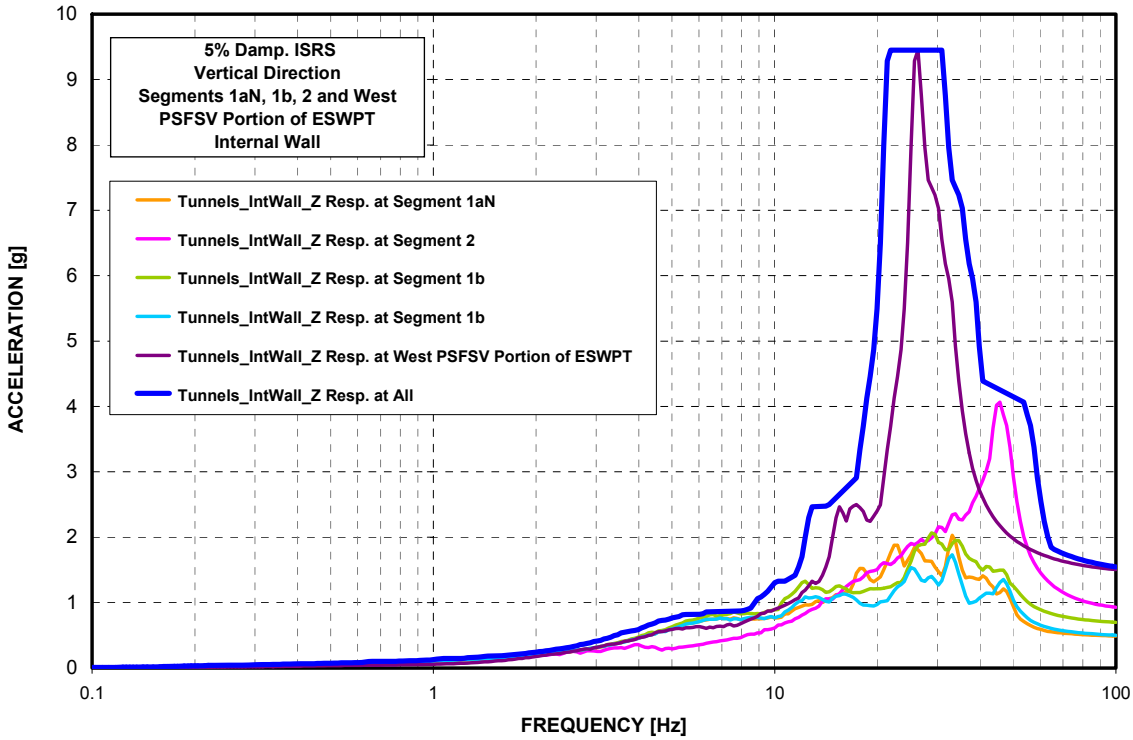


Figure 5.0-6 (Sheet 24 of 36)

ISRS

(ESWPT Group 2, Vertical Direction, Internal Walls)

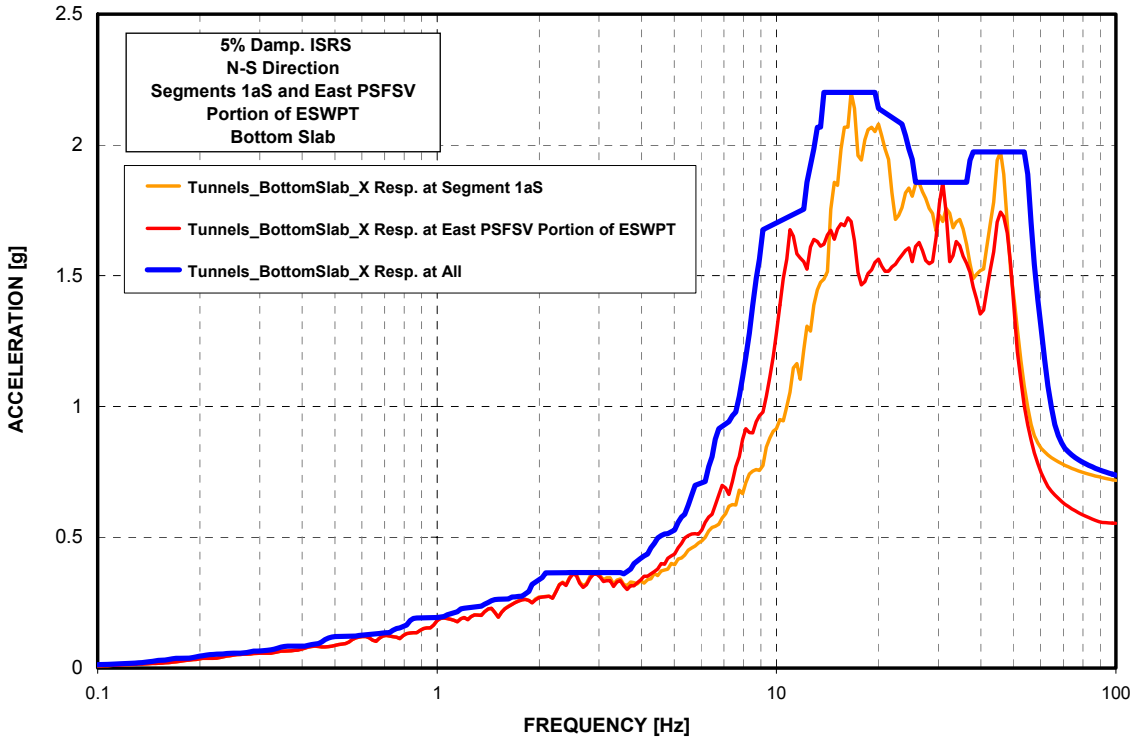


Figure 5.0-6 (Sheet 25 of 36)

ISRS

(ESWPT Group 3, N-S Direction, Mat Slab)

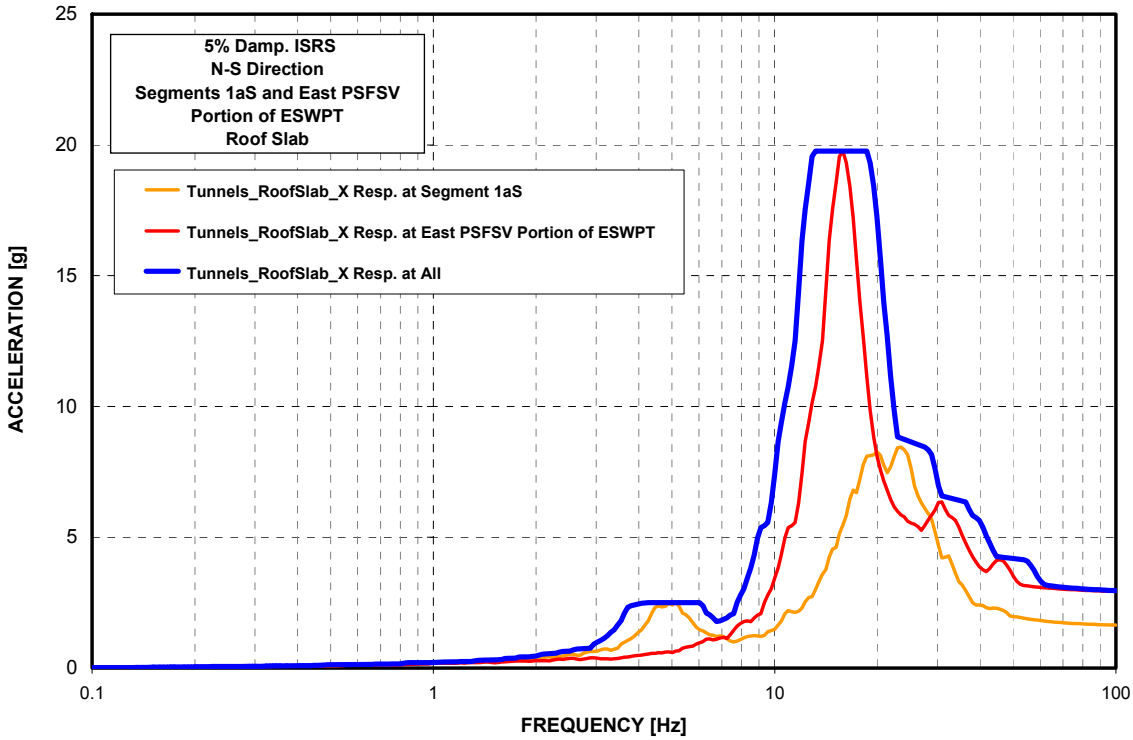


Figure 5.0-6 (Sheet 26 of 36)

ISRS

(ESWPT Group 3, N-S Direction, Roof Slab)

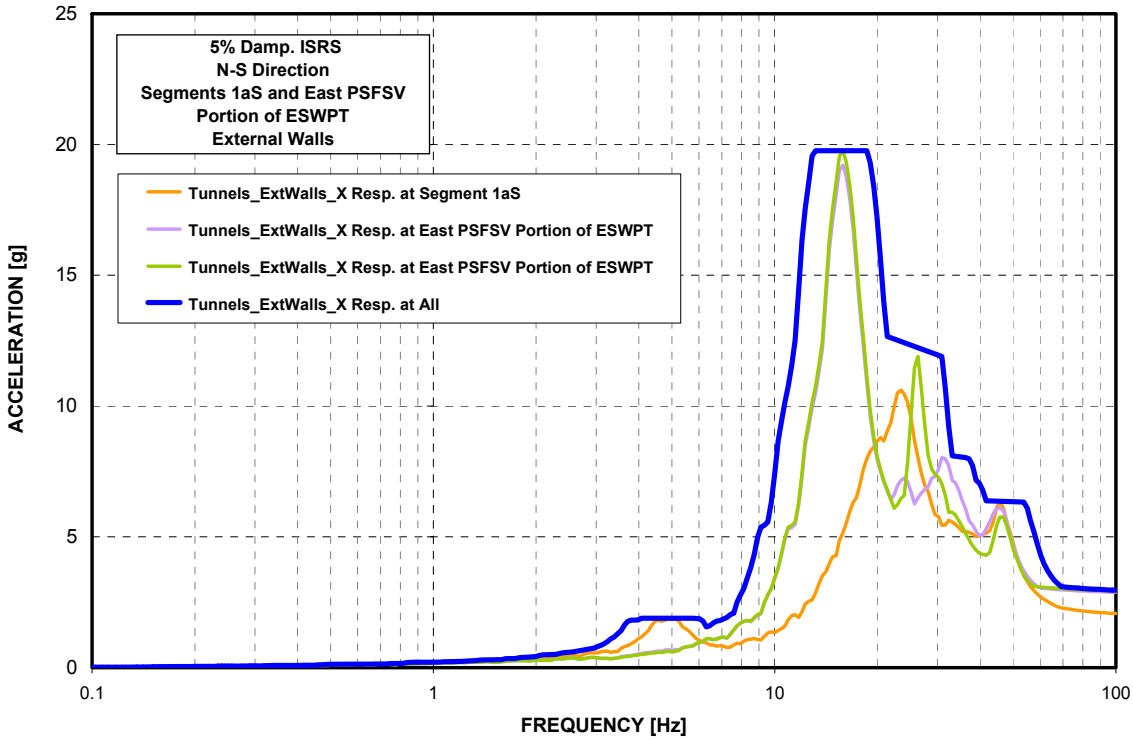


Figure 5.0-6 (Sheet 27 of 36)

ISRS

(ESWPT Group 3, N-S Direction, External Walls)

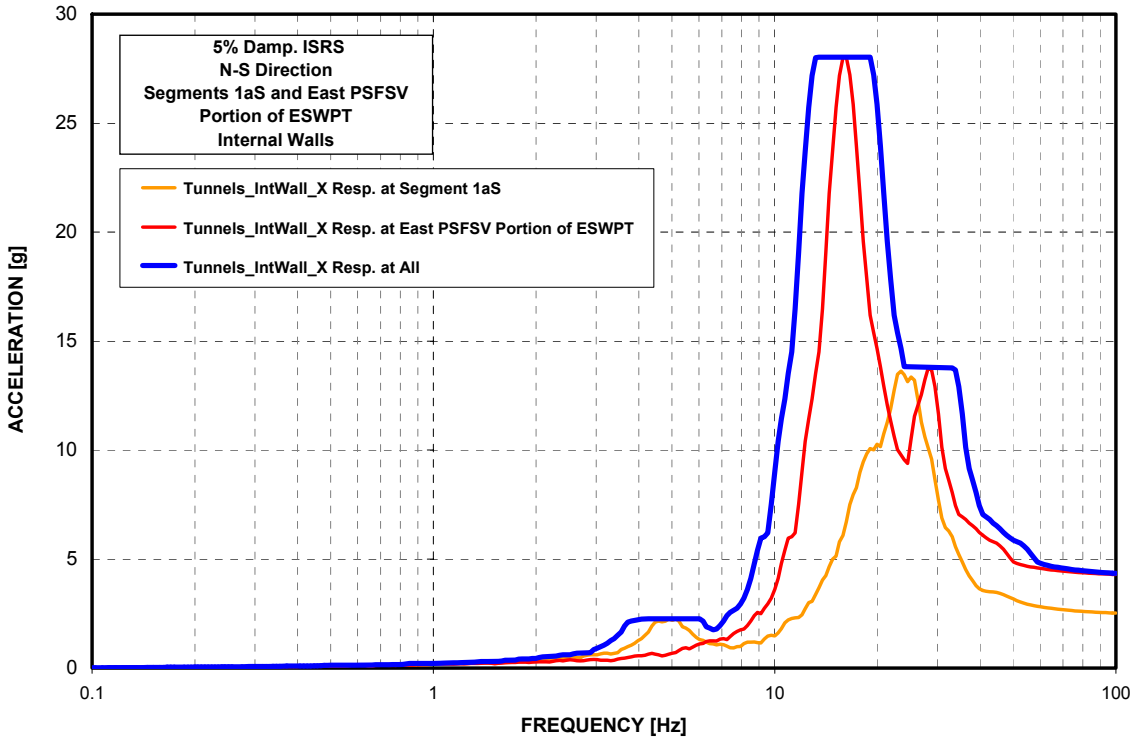


Figure 5.0-6 (Sheet 28 of 36)

ISRS

(ESWPT Group 3, N-S Direction, Internal Walls)

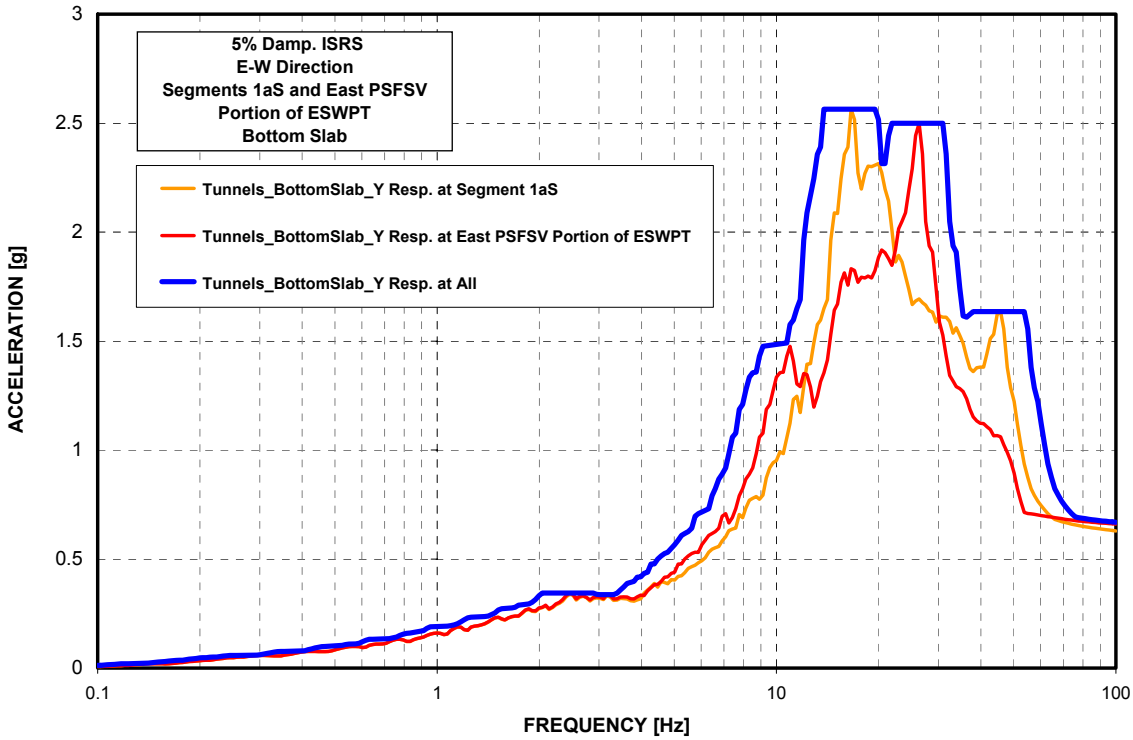


Figure 5.0-6 (Sheet 29 of 36)

ISRS

(ESWPT Group 3, E-W Direction, Mat Slab)

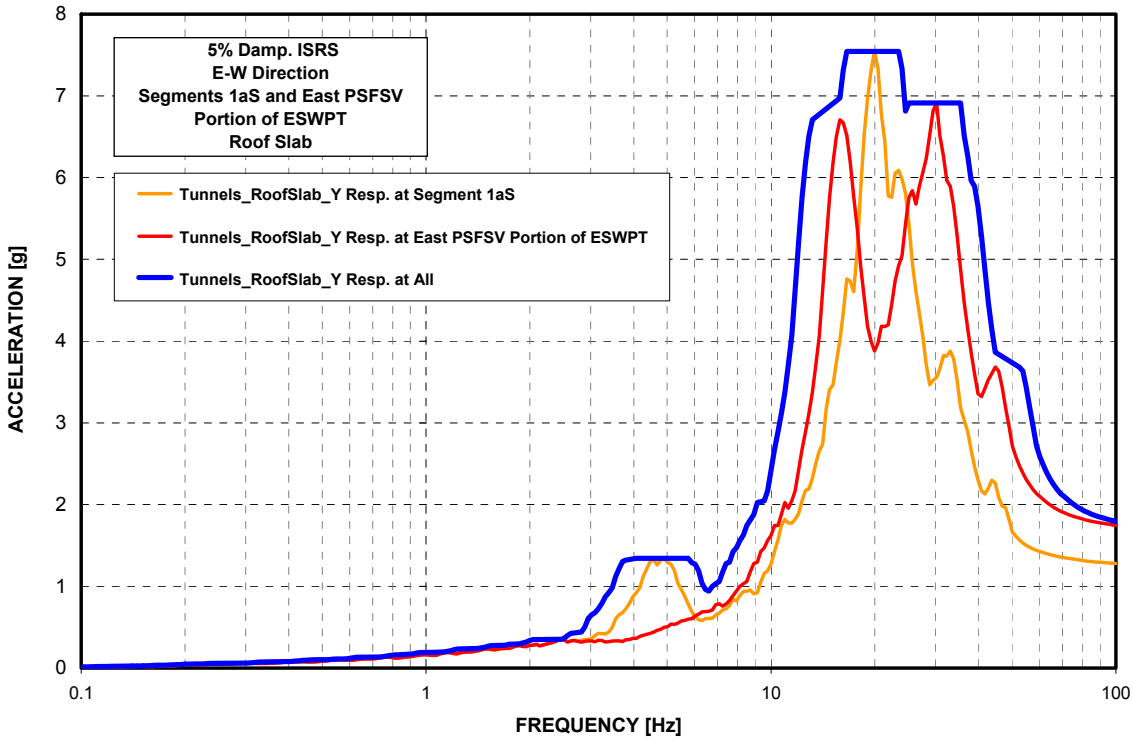


Figure 5.0-6 (Sheet 30 of 36)

ISRS

(ESWPT Group 3, E-W Direction, Roof Slab)

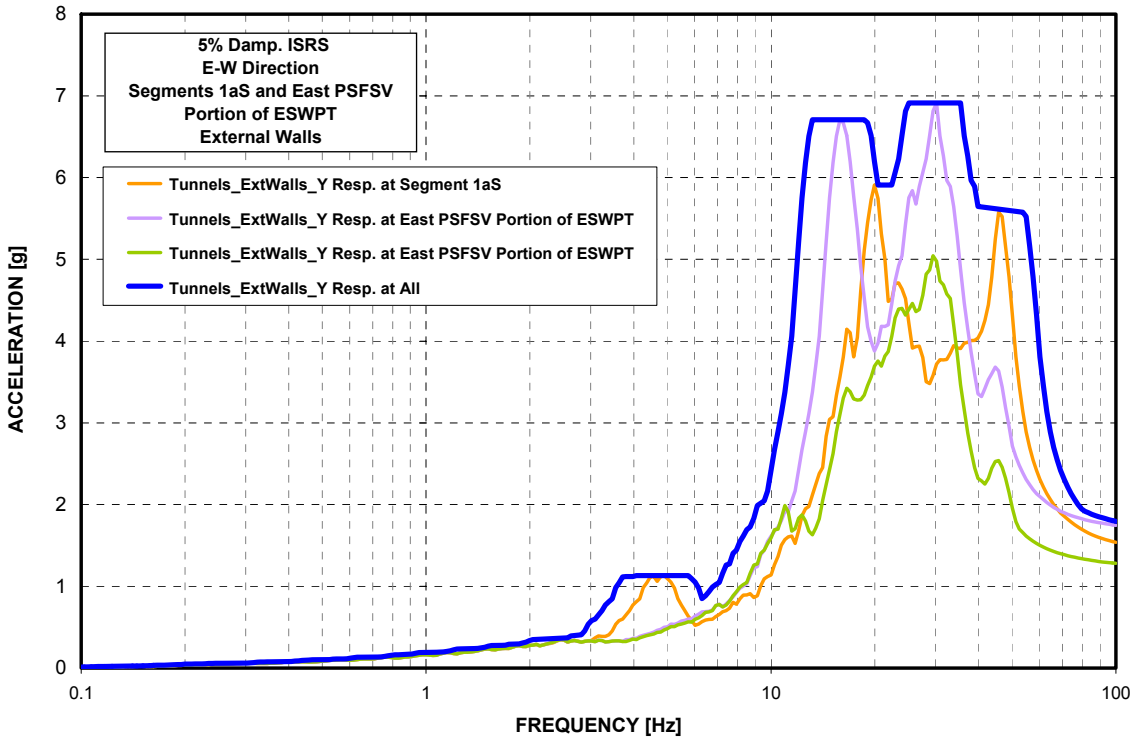


Figure 5.0-6 (Sheet 31 of 36)

ISRS for ESWPT Group 3, E-W Direction, External Walls

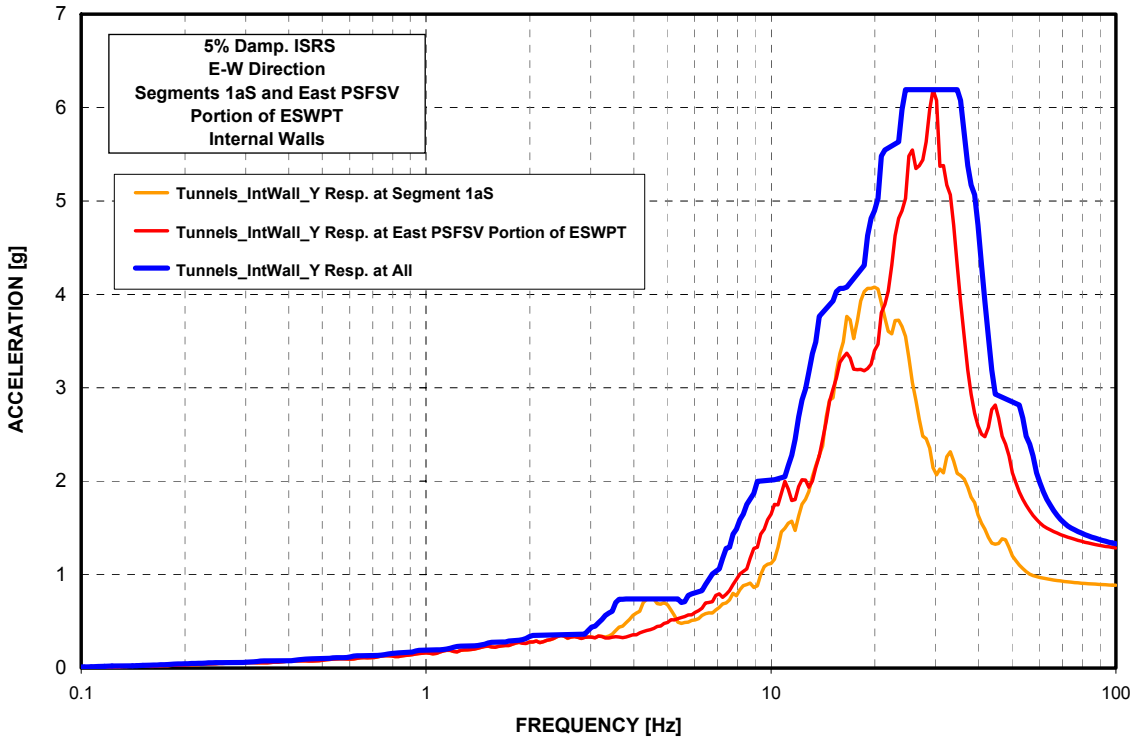


Figure 5.0-6 (Sheet 32 of 36)

ISRS for ESWPT Group 3, E-W Direction, Internal Walls

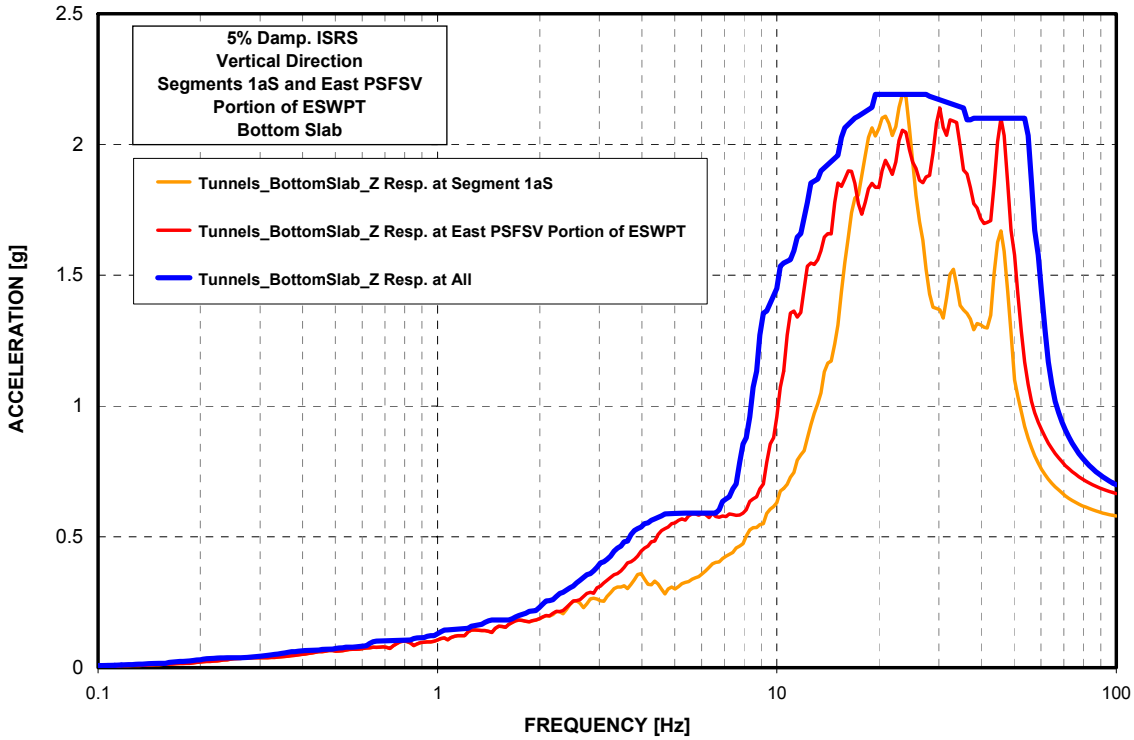


Figure 5.0-6 (Sheet 33 of 36)

ISRS

(ESWPT Group 3, Vertical Direction, Mat Slab)

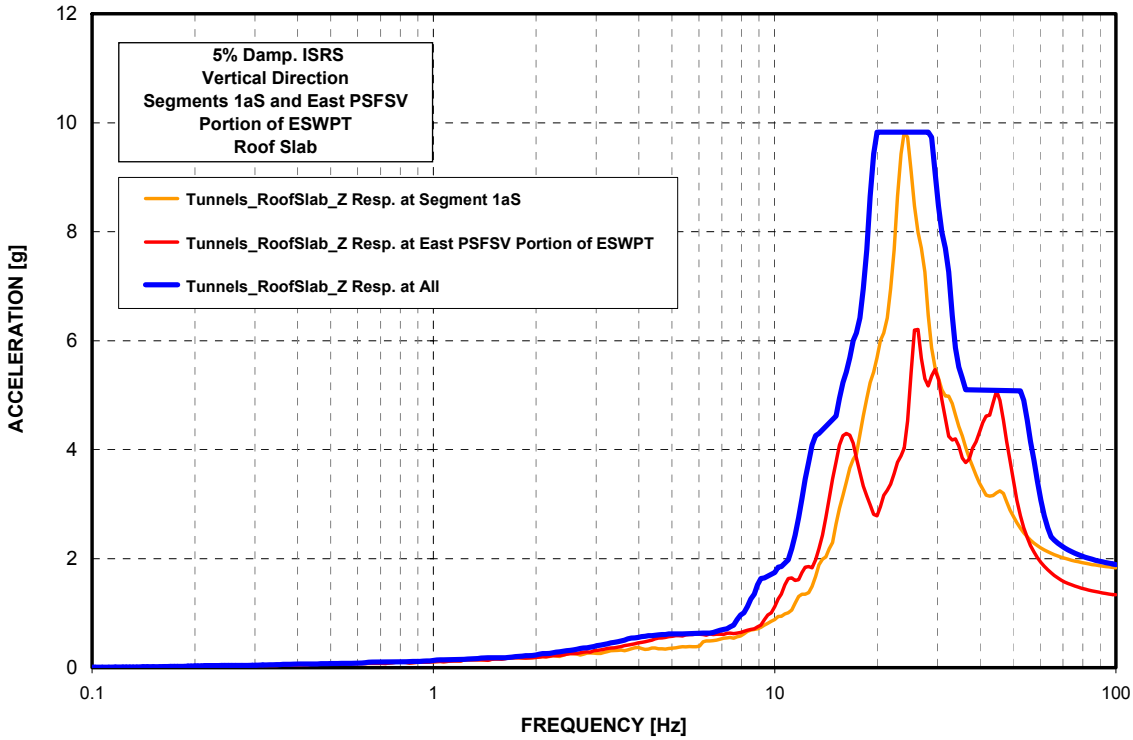


Figure 5.0-6 (Sheet 34 of 36)

ISRS

(ESWPT Group 3, Vertical Direction, Roof Slab)

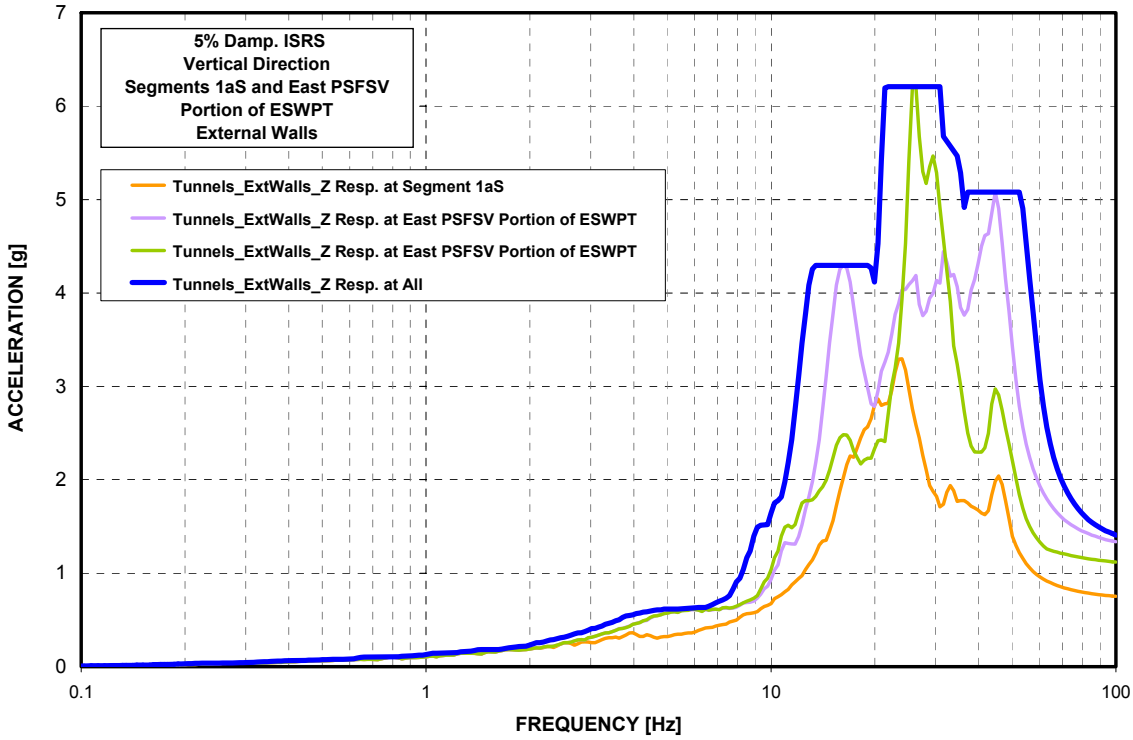


Figure 5.0-6 (Sheet 35 of 36)

ISRS

(ESWPT Group 3, Vertical Direction, External Walls)

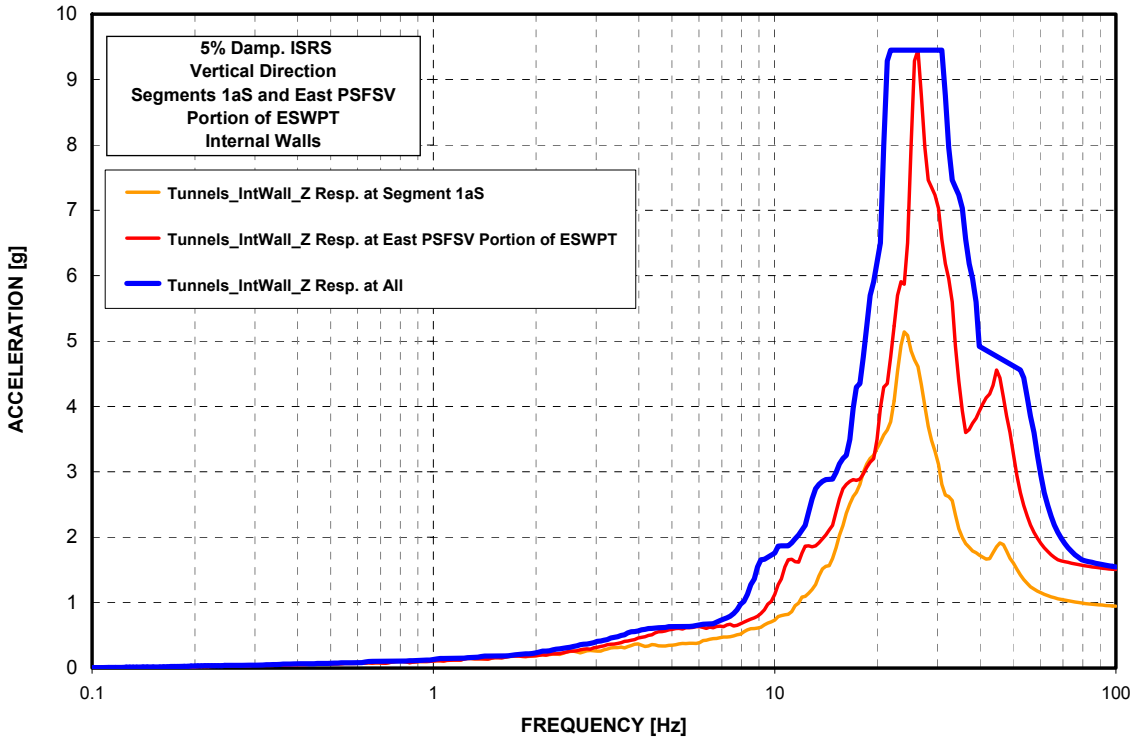


Figure 5.0-6 (Sheet 36 of 36)

ISRS

(ESWPT Group 3, Vertical Direction, Internal Walls)

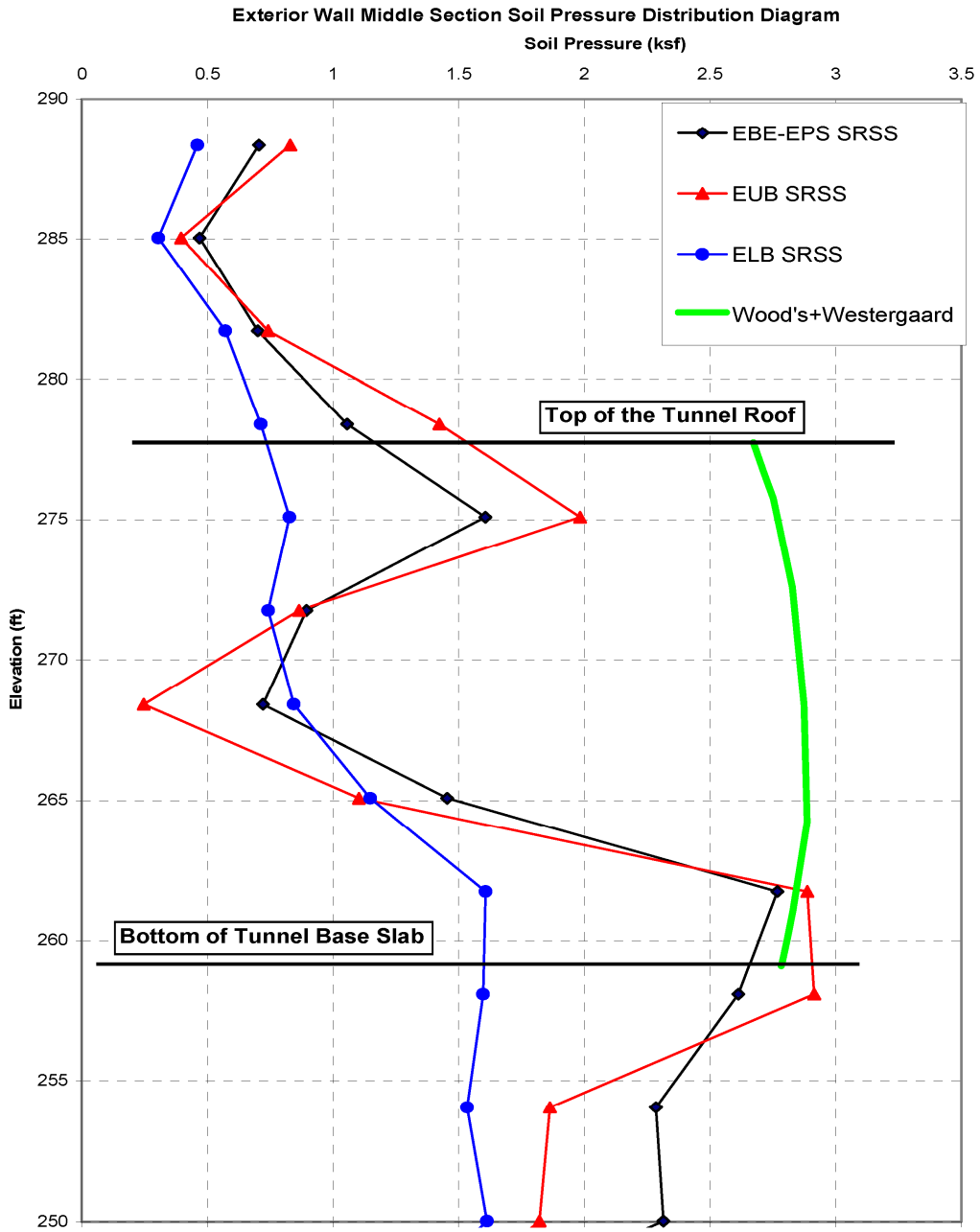


Figure 5.0-7

Seismic Lateral Pressure Distribution Diagram (Segment 1a, Middle Section)

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