CP COL 3.7(3)
CP COL 3.7(26)
CP COL 3.8(29)

APPENDIX 3LL

MODEL PROPERTIES AND SEISMIC ANALYSIS RESULTS FOR ESWPT

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

Acronyms	Definitions
3D	three-dimensional
BE	best estimate
ESW	essential service water
ESWPT	essential service water pipe tunnel
FE	finite element
FIRS	foundation input response spectra
HB	high bound
ISRS	in-structure response spectra
LB	lower bound
OBE	operating-basis earthquake
PCCV	prestressed concrete containment vessel
PSFSV	power source fuel storage vault
R/B	reactor building
SRSS	square root sum of the squares
SSI	soil-structure interaction
UB	upper bound
UHS	ultimate heat sink
UHSRS	ultimate heat sink related structure

3LL MODEL PROPERTIES AND SEISMIC ANALYSIS RESULTS FOR ESWPT

3LL.1 Introduction

This Appendix discusses the seismic analysis of the essential service water pipe tunnel (ESWPT). The computer program SASSI (Reference 3LL-1) serves as the platform for the soil-structure interaction (SSI) analyses. The three-dimensional (3D) finite element (FE) models used in SASSI are condensed from FE models with finer mesh patterns initially developed using the ANSYS computer program (Reference 3LL-2). The dynamic analysis of the SASSI 3D FE model in the frequency domain provides results for the ESWPT seismic response that include SSI effects. The SASSI model results for maximum accelerations and seismic soil pressures are used as input to the ANSYS models for performing the detailed structural design, including loads and load combinations in accordance with the requirements of Section 3.8. The SASSI analysis and results presented in this Appendix include site-specific SSI effects such as the layering of the subgrade, flexibility, and embedment of the ESWPT structure, and scattering of the input control design motion. Due to the low seismic response at the Comanche Peak Nuclear Power Plant site and the lack of high-frequency exceedances, the SASSI capability to consider incoherence of the input control motion is not implemented in the design of the ESWPT.

3LL.2 Model Description and Analysis Approach

The ESWPT is modeled with three separate models, each model representing a physical portion of the ESWPT. Tunnel Segment 1 represents a typical straight north-south tunnel segment buried in backfill soil. Tunnel Segment 2 represents east-west segments adjacent to the ultimate heat sink related structures (UHSRS). Two tornado missile shields extend from the top of this segment to protect the essential service water (ESW) piping and openings into the ultimate heat sink (UHS). The FE model for Segment 3 represents east-west segments adjacent to the power source fuel storage vault (PSFSV) and includes elements representing the fuel pipe access tunnels that extend across the top of the ESWPT. The FE models for each of the three ESWPT segments are shown in Figures 3LL-1 through 3LL-6 as overall and cutaway views. Tables 3LL-1, 3LL-2, and 3LL-3 present the properties assigned to the structural components of the SASSI FE models for Segments 1, 2, and 3, respectively. Detailed descriptions and figures of the ESWPT including actual dimensions are contained in Section 3.8. Shell elements model the roof, interior, and exterior walls, and basemat. Brick elements model the backfill and fill concrete below the ESWPT basemat.

The input motion for the SASSI model analysis is developed using the site-specific foundation input response spectra (FIRS) discussed in Subsection 3.7.1.1. The earthquake input motion for SASSI is developed by converting the outcrop motion of the FIRS to within-layer motion. Site-specific strain-compatible backfill and rock properties are used in determining the within-layer motion. This process is described further in Appendix 3NN.

The ESWPT model is developed and analyzed using methods and approaches consistent with ASCE 4 (Reference 3LL-3) and accounting for the site-specific stratigraphy and subgrade conditions described in Chapter 2, as well as the backfill conditions around the embedded portions of the ESWPT.

The input within-layer motion and strain-compatible backfill properties for the SASSI analysis are developed from site response analyses described in Section 3NN.2 of Appendix 3NN by using the site-specific foundation input response spectra (FIRS) discussed in Subsection 3.7.1.1. The properties of the supporting media (rock) as well as the site-specific strain-compatible backfill properties used for the SASSI analysis of the ESWPT are the same as those presented in Appendix 3NN for the reactor building (R/B)-prestressed concrete containment vessel (PCCV)-containment internal structure SASSI analyses. The typical properties for a granular engineered backfill are adopted as the best estimate (BE) values for the dynamic properties of the backfill. Four profiles, lower bound (LB), BE, upper bound (UB), and high bound (HB) of input backfill properties are developed for the SASSI analyses considering the different coefficient of variation. The LB and BE backfill profiles are combined with corresponding LB and BE rock subgrade profiles, and the UB and HB backfill profiles are combined with the UB rock subgrade profile. Four sets of SASSI analyses are performed on each segment of the ESWPT embedded in backfill with BE, LB, UB, and HB properties.

ESWPT Segment 2 is additionally analyzed considering partial separation of the backfill from the exterior shielding walls above the roof slab. Separation is modeled by reducing the shear wave velocity by a factor of 10 for those layers of backfill that are determined to be separated. The potential for separation of the backfill along Segment 2 is determined using an iterative approach that compares peak soil pressure results for the BE condition to the at-rest soil pressure. The analyses also consider unbalanced fill conditions where applicable, such as for Segment 2 of the ESWPT along the interface with the UHSRS. Consideration of these conditions assures that the enveloped results presented herein capture all potential seismic effects of a wide range of backfill properties and conditions in combination with the site-specific supporting media conditions.

Operating-basis earthquake (OBE) structural damping values of Chapter 3 Table 3.7.1-3(b), such as 4 percent damping for reinforced concrete, are used in the site-specific SASSI analysis. This is consistent with the requirements of Section 1.2 of RG 1.61 (Reference 3LL-4) for structures on sites with low seismic responses where the analyses consider a relatively narrow range of site-specific subgrade conditions.

3LL.3 Seismic Analysis Results

Table 3LL-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 (Segment 1 Model). These frequencies were compared to the frequencies calculated from the transfer functions for the SASSI model to confirm adequacy of the coarser mesh SASSI model to represent dynamic behavior of the tunnels. Table 3LL-5 presents a summary of SSI effects on the seismic response of the ESWPT segments.

The maximum absolute nodal accelerations obtained from the time history analyses of the ESWPT models are presented in Tables 3LL-6 to 3LL-8. 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 in accordance with RG 1.92 (Reference 3LL-5) using the square root sum of the squares (SRSS) method.

Tables 3LL-9, 3LL-10, and 3LL-11 present the maximum seismic design forces and moments that represent the envelope of the results for all considered site conditions. The forces and moments are obtained by combination of the three orthogonal directions used in the model by the Newmark 100%-40%-40% method. The seismic design forces are applied to the ANSYS model for structural design of members and components. For structural design, the accidental torsion load case results in increased shear in the outer walls, which is included in the values reported in Tables 3LL-9, 3LL-10, and 3LL-11. Note that addition of the torsion by scaling the seismic demands results in shear demand in the outer walls that meets or exceeds the accidental torsion requirements for design.

Table 3LL-12 summarizes the resulting maximum displacements for enveloped seismic loading conditions for each of the three segments of the ESWPT.

Table 3LL-13 presents the maximum pressures below the basemat of the ESWPT.

3LL.4 In-Structure Response Spectra (ISRS)

The enveloped broadened ISRS are presented in Figures 3LL-7, 3LL-8, and 3LL-9 for ESWPT Segments 1, 2, and 3, respectively. The spectra are presented for the horizontal and vertical directions for the ESWPT base slab and roof for 0.5 percent, 2 percent, 3 percent, 4 percent, 5 percent, 7 percent, 10 percent, and 20 percent damping. The ISRS for the roof of the PSFSV access tunnels are also presented in Figure 3LL-9. 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 3LL-6). The ISRS include the envelope of the four site conditions (BE, LB, UB, and HB) with and without backfill separation from the structure. All results have been broadened by 15 percent and all valleys removed. The shape of the spectra presented herein can be simplified by further enveloping of peaks for the design of seismic category I and II subsystems and components housed within or mounted to the ESWPT and PSFSV access tunnels. It is permitted to perform 15 percent peak clipping of the spectra presented herein in accordance with ASCE-4 (Reference 3LL-3) during the design process for spectra with damping values less than 10 percent. For the design of seismic category I and II subsystems and components mounted to the ESWPT walls, it is required to account for the effects of out-of-plane wall flexibility.

3LL.5 References

3LL-1 *An Advanced Computational Software for 3D Dynamic Analysis Including Soil Structure Interaction,* ACS SASSI Version 2.2, Ghiocel Predictive Technologies, Inc., July 23, 2007.

3LL-2 ANSYS Release 11.0, SAS IP, Inc. 2007.

3LL-3 *Seismic Analysis of Safety-Related Nuclear Structures,* American Society of Civil Engineers, ASCE 4-98, Reston, Virginia, 2000.

3LL-4 *Damping Values for Seismic Design of Nuclear Power Plants*, Regulatory Guide 1.61, Rev. 1, U.S. Nuclear Regulatory Commission, Washington, DC, March 2007.

3LL-5 *Combining Responses and Spatial Components in Seismic Response Analysi*s, Regulatory Guide 1.92, Rev. 2, U.S. Nuclear Regulatory Commission, Washington, DC, July 2006.

3LL-6 *Development of Floor Design Response Spectra for Seismic Design of Floor-supported Equipment or Components*, Regulatory Guide 1.122, Rev. 1, U.S. Nuclear Regulatory Commission, Washington, DC, February 1978.

Table 3LL-1

ESWPT Segment 1 FE Model Component Properties

Components	Material	E (ksi)	Poisson's Ratio	Unit Weight (kcf)	Damping Ratio	Width or Height x Thickness (ft)	Element type
Roof	5,000 psi concrete	4,030	0.17	0.225(1)	0.04	23 x 2	Shell
Base slab	5,000 psi concrete	4,030	0.17	0.200(1)	0.04	23 x 2	Shell
Exterior Walls	5,000 psi concrete	4,030	0.17	0.175(1)	0.04	16.67 x 2	Shell
Interior Walls	5,000 psi concrete	4,030	0.17	0.250(1)	0.04	16.67 x 1	Shell
Fill Concrete	3,000 psi concrete	3,125	0.17	0.15	0.04	23 x 10.08	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 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 Section 3.8 Figure 3.8-203 and 3.8-205.

Table 3LL-2
ESWPT Segment 2 FE Model Component Properties

Components	Material	E (ksi)	Poisson's Ratio	Unit Weight (kcf)	Damping Ratio	Width or Height x Thickness (ft) (2)	Element type
Roof	5,000 psi concrete	4,030	0.17	0.21(1)	0.04	23 x 2.5	Shell
Base slab	5,000 psi concrete	4,030	0.17	0.19(1)	0.04	34 x 2.5	Shell
Exterior Walls	5,000 psi concrete	4,030	0.17	0.175(1)	0.04	17.17 x 2	Shell
Interior Walls	5,000 psi concrete	4,030	0.17	0.250(1)	0.04	17.17 x 1	Shell
Basin Missile Shield Walls	5,000 psi concrete	4,030	0.17	0.15	0.4	32 x 2	Shell
Basin Missile Shield Roof Slab	5,000 psi concrete	4,030	0.17	0.15	0.4	11.5 x 2 x 95	Shell
Pump House Missile Shield Walls	5,000 psi concrete	4,030	0.17	0.1875(1)	0.04	26 x 2	Brick
Pump House Missile Shield Roof Slab	5,000 psi concrete	4,030	0.17	0.1875(1)	0.04	10 x 2 x 23	Brick
Fill Concrete	3,000 psi concrete	3,125	0.17	0.15	0.04	34 x 9.83	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 tunnel roof slab, 75 psf on the pump house missile shield surfaces, 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 Section 3.8 Figure 3.8-202.

Table 3LL-3

ESWPT Segment 3 FE Model Component Properties

Components	Material	E (ksi)	Poisson's Ratio	Unit Weight (kcf)	Damping Ratio	Width or Height x Thickness (ft) (2)	Element type
Roof	5,000 psi concrete	4,030	0.17	0.225(1)	0.04	23 x 2	Shell
Base slab	5,000 psi concrete	4,030	0.17	0.200(1)	0.04	23 x 2	Shell
Exterior Walls	5,000 psi concrete	4,030	0.17	0.175(1)	0.04	16.67 x 2	Shell
Interior Walls	5,000 psi concrete	4,030	0.17	0.250(1)	0.04	16.67 x 1	Shell
Service Tunnel Roof	5,000 psi concrete	4,030	0.17	0.344(1)	0.4	Width varies x 2	Shell
Service Tunnel Outer Walls	5,000 psi concrete	4,030	0.17	0.175(1)	0.04	13.25 x 2	Shell
Service Tunnel Inner Walls	5,000 psi concrete	4,030	0.17	0.217(1)	0.4	13.25 x 1.5	Shell
Fill Concrete	3,000 psi concrete	3,125	0.17	0.15	0.04	23 x 10.08	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 and service tunnel roof. Also, additional backfill dead load of 187.5 psf due to fill above elevation 822 is considered on the service tunnel roof.
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 Section 3.8 Figures 3.8-203 and 3.8-204.

Table 3LL-4

ESWPT Structural Frequencies

Frequency (Hz)	Comments
7.3	Tunnel racking (due to shear deformation) in transverse direction
31.3	Local out of plane response of interior wall

Notes:

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

Table 3LL-5

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 analyses of ESWPT Segment 1 show that the aboveground part of the structure has small effect on the response of the underground tunnel. The backfill soil frequencies that are in the range from 3 Hz for lower bound to 9 Hz for high bound, characterize the ESWPT horizontal response for all three segments. Frequencies of 7 Hz for lower bound, to 17 Hz for high bound characterize the vertical response of the ESWPT.
Backfill soil separation	The potential for backfill separation of ESWPT Segment 2 results in a small increase in the structural peak amplification.
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. Consequentially, multiple modes characterize the backfill soil column and affect the ESWPT response when their frequencies are close to the structural frequencies.

Table 3LL-6

ESWPT Segment 1 SASSI FE Model Component Peak Accelerations[1] (g)

Component	Transverse Direction	Longitudinal Direction	Vertical Direction
Base Slab	0.12	0.12	0.15
Roof Slab	0.24	0.14	0.19
Interior Walls	0.26	0.13	0.17
Exterior Walls	0.24	0.14	0.16

Notes:

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 3LL-7

ESWPT Segment 2 SASSI FE Model Component Peak Accelerations[3] (g)

Component	Transverse Direction	Longitudinal Direction	Vertical Direction
Base Slab	0.13	0.12	0.13
Roof Slab	0.36	0.16	0.21
Interior Walls	0.35	0.14	0.16
Exterior Walls	0.35	0.14	0.15
Pump House Pipe Missile Shield	0.95[1]	0.46[1]	0.19
Air Intake Missile Shield	0.83[2]	0.21[2]	1.09

Notes:

1) The transverse direction for the pipe missile shield is the east-west direction; the longitudinal direction is the north-south direction.
2) The transverse direction for the duct missile shield is the north-south direction; the longitudinal direction is the vertical direction.
3) For structural design using the loads and load combinations in Section 3.8, design accelerations are determined separately using a response spectra analysis of the Segment 2 ANSYS FE model using as input the enveloped accelerations shown above, and a dynamic soil pressure.

Table 3LL-8

ESWPT Segment 3 SASSI FE Model Component Peak Accelerations[4] (g)

Component	Transverse Direction	Longitudinal Direction	Vertical Direction
Base Slab	0.12[1]	0.12[1]	0.13[1]
Roof Slab	0.50[1]	0.16[1]	0.21[1]
Interior Walls	0.50[3]	0.19	0.20
Exterior Walls	0.50[3]	0.16	0.15
PSFSV Service Tunnel Walls	0.32[2]	0.38[2]	0.15
PSFSV Service Tunnel Roof	0.32[2]	0.38[2]	0.16

Notes:

1) The transverse direction for the base slab and roof is the north-south direction; the longitudinal direction is the east-west direction.
2) The transverse direction for the PSFSV service tunnel walls and roof is the east-west direction; the longitudinal direction is the north south direction.
3) For interior and exterior walls, the transverse direction is the out-of-plane direction.
4) 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 3LL-9

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	+	4.75	2.38	8.83	1.77	1.07	32.60	5.56	1.00
	-	7.86	2.87	8.83	1.77	1.07	39.40	6.70	1.00
Roof Slab	+	0.33	1.06	4.22	2.15	0.83	22.60	0.72	0.72
	-	4.19	1.42	4.22	2.15	0.83	29.00	4.90	0.72
Interior Walls	+	5.57	0.79	1.91	1.08	0.58	9.55	1.62	0.29
	-	4.89	0.66	1.91	1.08	0.63	9.55	1.62	0.29
Exterior Walls	+	7.91	1.28	7.68	2.09	2.14	36.61	6.19	1.01
	-	8.57	1.17	7.68	2.09	2.14	36.61	6.19	1.01

Notes:

1) The forces and moments shown above envelope all four subgrade shear wave velocity conditions (LB, BE, UB, and HB). 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. 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 3LL-10

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)
Base Slab	+/-	44.99	29.32	93.44	25.14	31.03	128.74	31.82	21.56
Roof Slab	+/-	85.48	31.38	39.62	22.41	62.82	88.21	51.33	14.78
Interior Walls	+/-	58.08	141.34	12.03	4.23	62.54	22.46	7.20	2.00
Exterior Walls	+/-	76.65	216.05	47.54	24.29	76.22	142.71	30.27	17.35
Pump House Pipe Missile Shield Walls	+/-	69.99	34.46	22.68	9.29	42.20	40.75	10.93	4.64
Pump House Pipe Missile Shield Roof	+/-	1.77	24.75	1.93	3.82	7.56	7.63	10.63	4.35
Air Intake Missile Shield	+/-	46.51	18.70	18.10	9.81	23.18	31.91	14.45	6.49

Notes:

1) The forces and moments shown above envelope all four subgrade shear wave velocity conditions (LB, BE, UB, and HB) and any effects due to soil separation. 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. For Segment 2 a response spectra analysis was performed and combined with the absolute value of dynamic soil pressure. The demands obtained from this combination were found to envelope the SASSI demands.
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 north-south direction and the longitudinal in the east-west direction.

Table 3LL-11

ESWPT Segment 3 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	+	29.25	26.53	58.48	21.90	25.42	54.31	23.73	15.30
	-	31.50	29.59	56.36	24.43	25.52	53.70	21.08	15.78
Roof Slab	+	32.24	59.80	22.30	19.00	35.79	46.43	25.12	7.47
	-	37.42	61.68	22.42	19.00	36.54	46.57	28.26	7.19
Interior Walls	+	59.24	93.26	12.02	4.27	36.67	18.08	5.62	1.94
	-	53.12	98.64	11.12	3.92	38.67	18.21	5.76	1.88
Exterior Walls	+	30.48	95.00	20.16	15.99	45.89	66.74	69.98	11.48
	-	31.06	98.80	19.29	16.49	46.23	65.90	67.39	11.48
PSFSV Service Tunnel Walls	+	32.95	10.05	12.16	5.94	19.81	40.35	8.50	3.64
	-	32.62	10.21	13.76	5.70	19.47	39.74	7.82	3.78
PSFSV Service Tunnel Roof	+	10.79	6.21	8.69	20.78	4.28	12.17	21.25	2.21
	-	11.80	6.56	8.63	20.69	4.44	16.00	20.98	2.17

Notes:

1) The forces and moments shown above envelope all four subgrade shear wave velocity conditions (LB, BE, UB, and HB). 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. For the roof slab and base slab the vertical axis is oriented along the north-south direction and the longitudinal in the east-west direction.

Table 3LL-12

ESWPT Maximum Seismic Displacements for All Enveloped Conditions

ESWPT Segment	Longitudinal Direction (in)	Transverse (in)	Vertical (in)
1	0.002	0.11	0.003
2	0.09(1)	0.18	0.05(2)
3	0.10(1)	0.19	0.01

Notes:

1) The reported displacement are the north-south displacement at edge of separation joints that is about 10 ft south or north of north or south tunnels respectively. The maximum longitudinal (east-west) displacement of the east-west part of Segment 2 or 3 tunnel is less than 0.002 inches.
2) The maximum vertical occurs at the edge of separation joint edge 10 ft south of the east-west part of the tunnel, which is due to rocking behavior of the tunnel with tall shielding walls.

Table 3LL-13

Bearing Pressures Below ESWPT (ksf)

	Peak Single Element(1)	Peak Design(2)	Average Dynamic(3)
Segment 1	4.4	4.4	2.1
Segment 2	16.6	8.8	2.2
Segment 3	17.5	5.7	2.5

Notes:

1) Peak single element pressure represents corner pressures on elements representing less than 1% of the slab area.
2) Peak design pressure is the edge envelope pressure excluding the corner peaks, to be used for design.
3) Average dynamic pressure is the average of peak values for every element below the base slab.

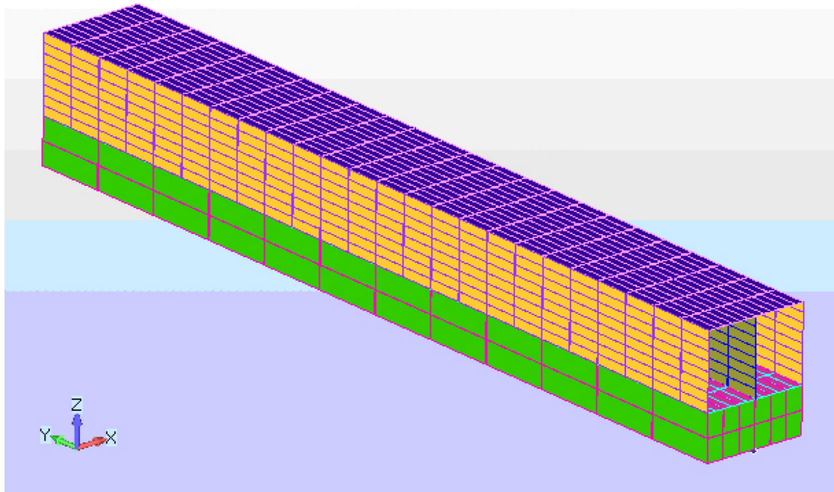


Figure 3LL-1 Overall SASSI Model of ESWPT Segment 1 (Excluding elements representing backfill)

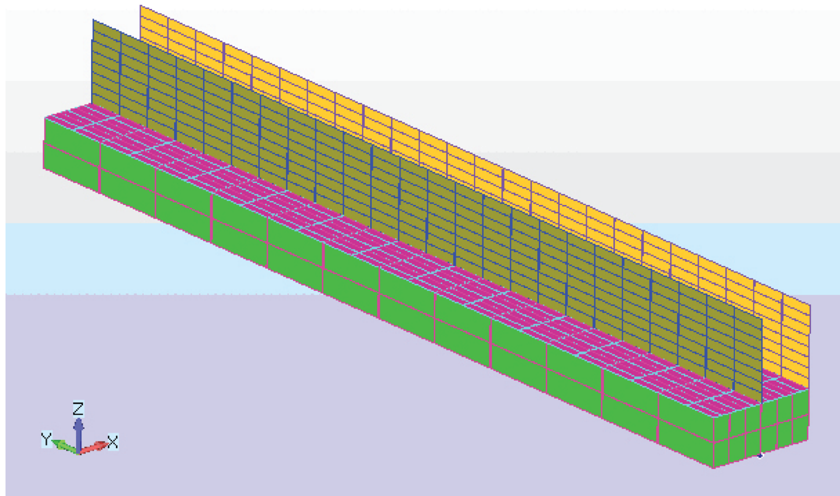


Figure 3LL-2 Cutaway View of SASSI Model of ESWPT Segment 1 (Excluding backfill, roof, and one side wall elements)

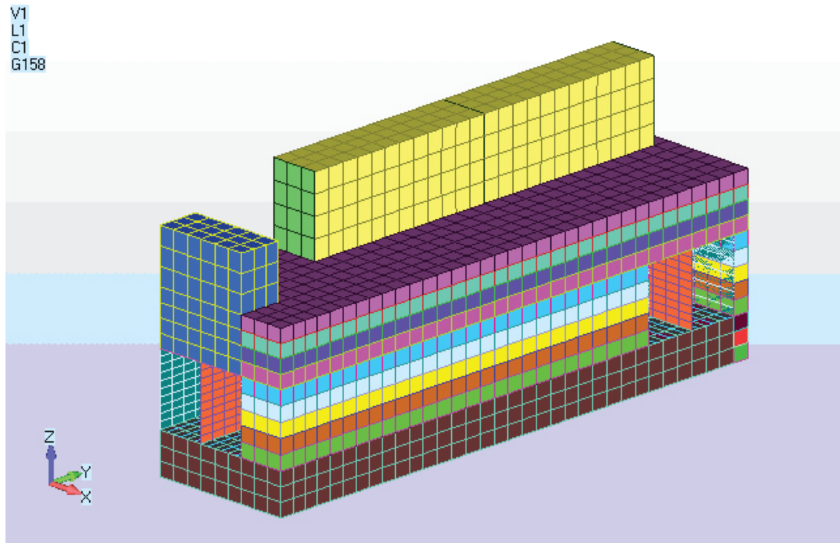


Figure 3LL-3 Overall View of SASSI Model of ESWPT Segment 2 (Including backfill elements)

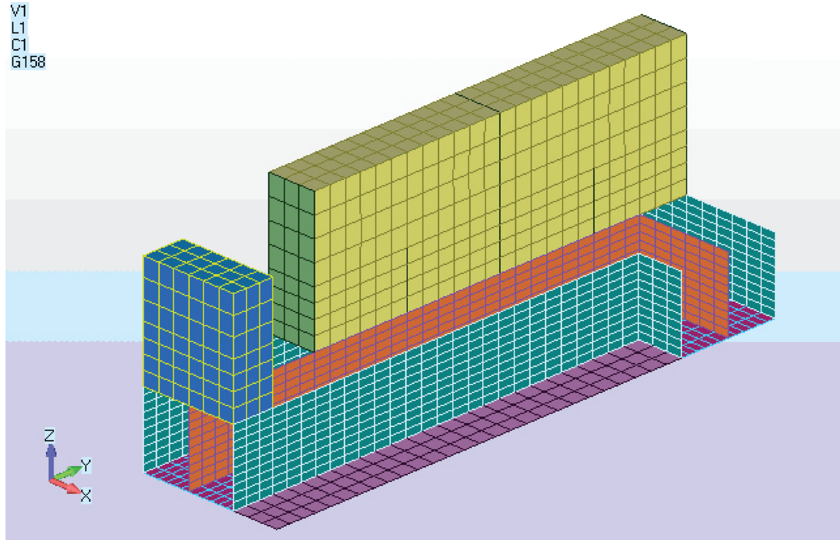


Figure 3LL-4 Cutaway View of SASSI Model of ESWPT Segment 2 (Excluding backfill, concrete fill, and roof slab)

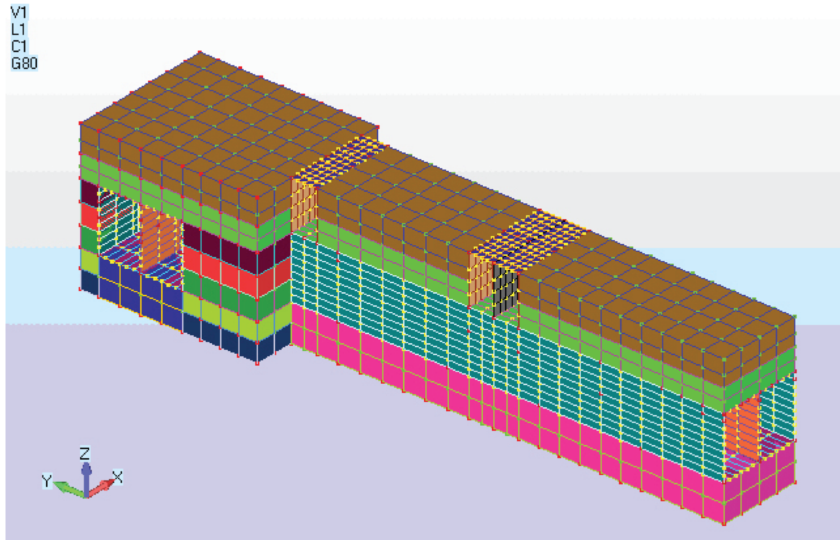


Figure 3LL-5 Overall View of SASSI Model of ESWPT Segment 3 (Including PSFSV tunnel elements)

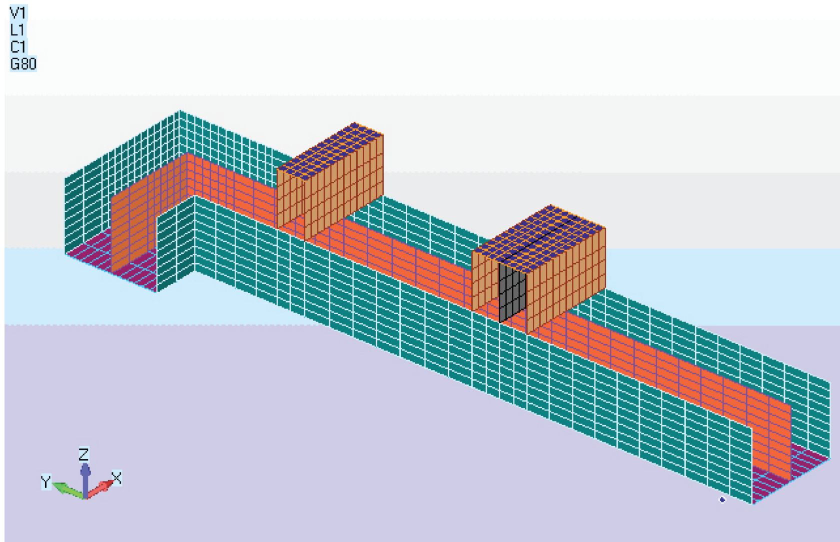


Figure 3LL-6 Cutaway View of SASSI Model of ESWPT Segment 3
(Excluding backfill, concrete fill, and roof elements)

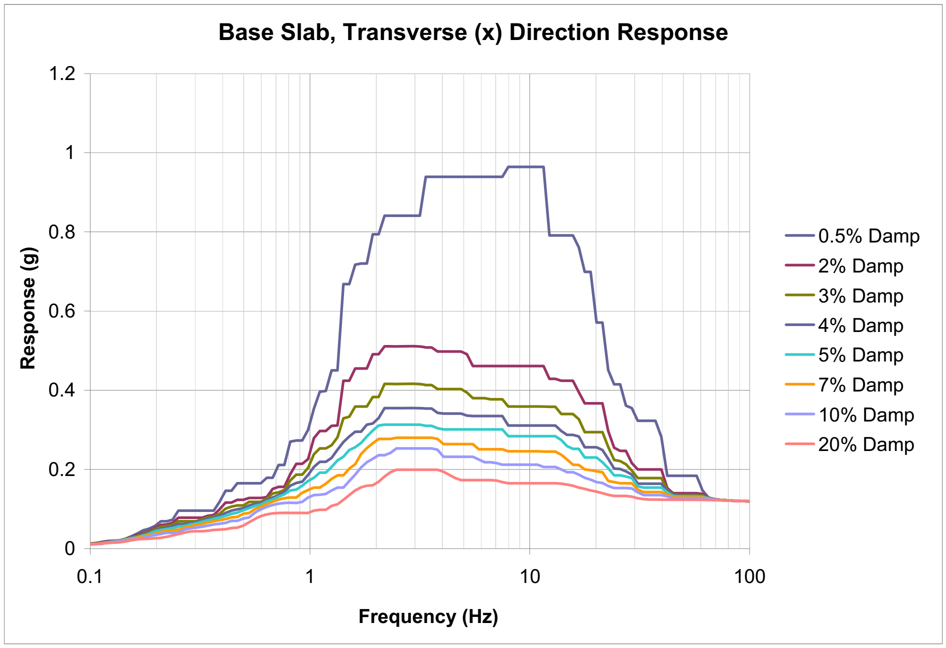


Figure 3LL-7 ISRS for ESWPT Segment 1 (Sheet 1 of 6)

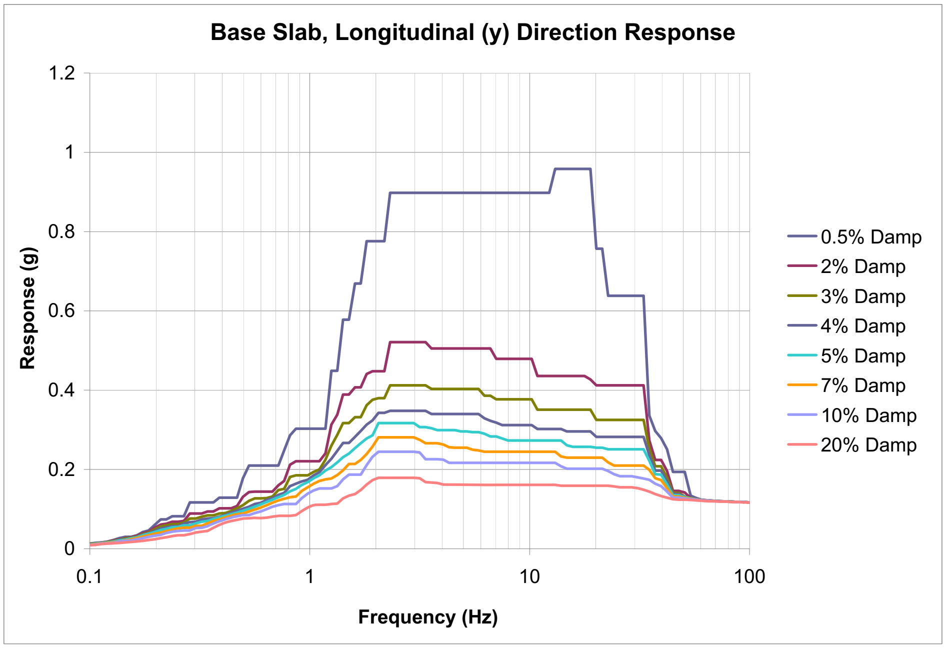


Figure 3LL-7 ISRS for ESWPT Segment 1 (Sheet 2 of 6)

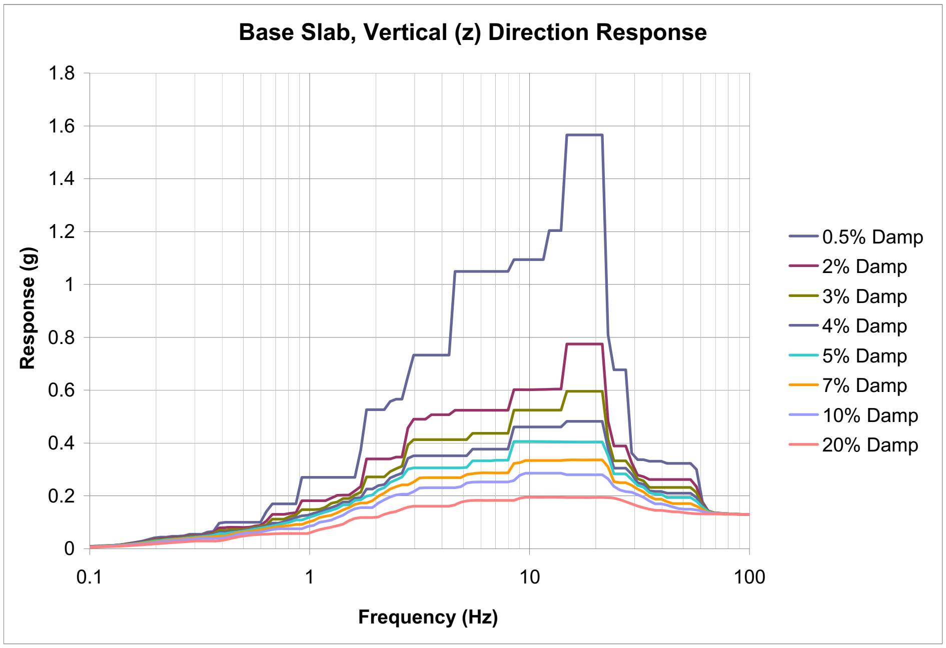


Figure 3LL-7 ISRS for ESWPT Segment 1 (Sheet 3 of 6)

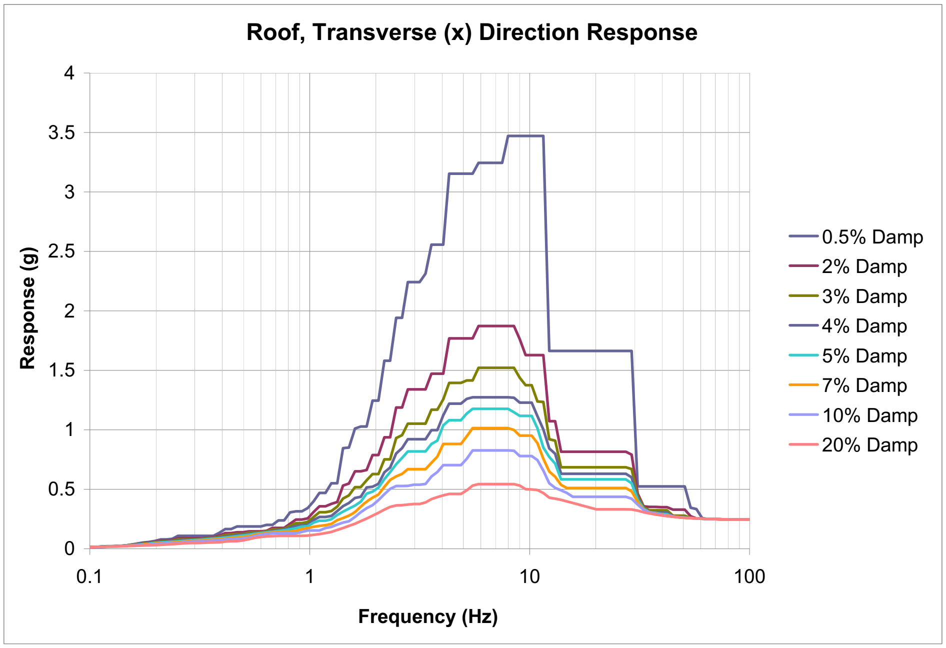


Figure 3LL-7 ISRS for ESWPT Segment 1 (Sheet 4 of 6)

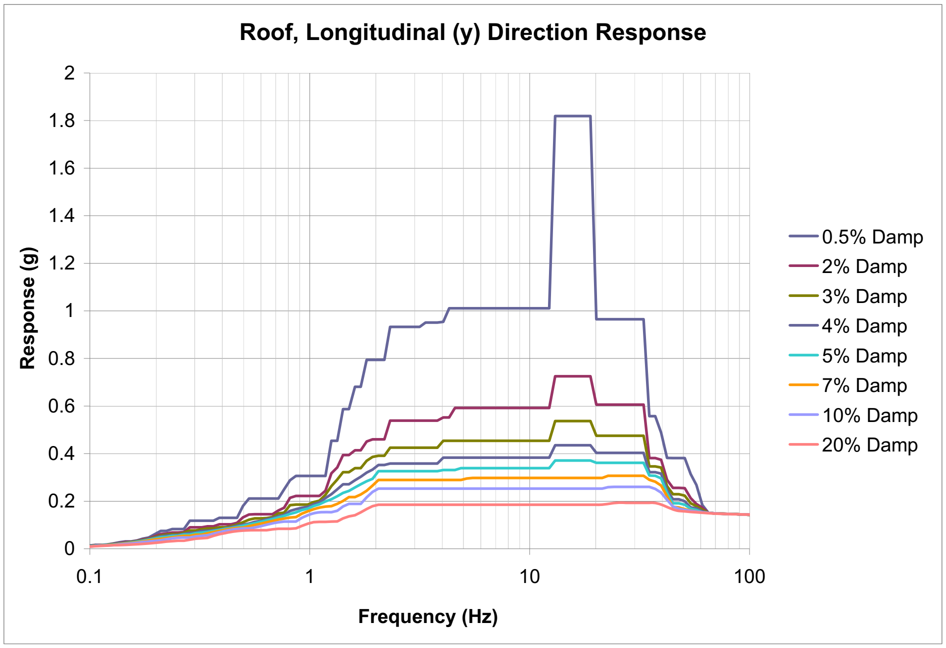


Figure 3LL-7 ISRS for ESWPT Segment 1 (Sheet 5 of 6)

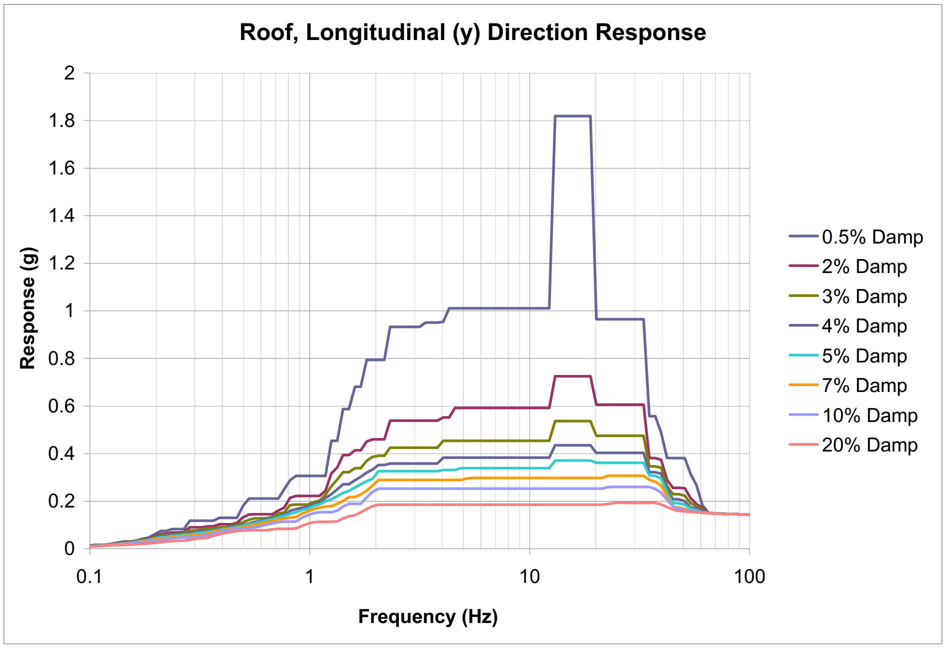


Figure 3LL-7 ISRS for ESWPT Segment 1 (Sheet 6 of 6)

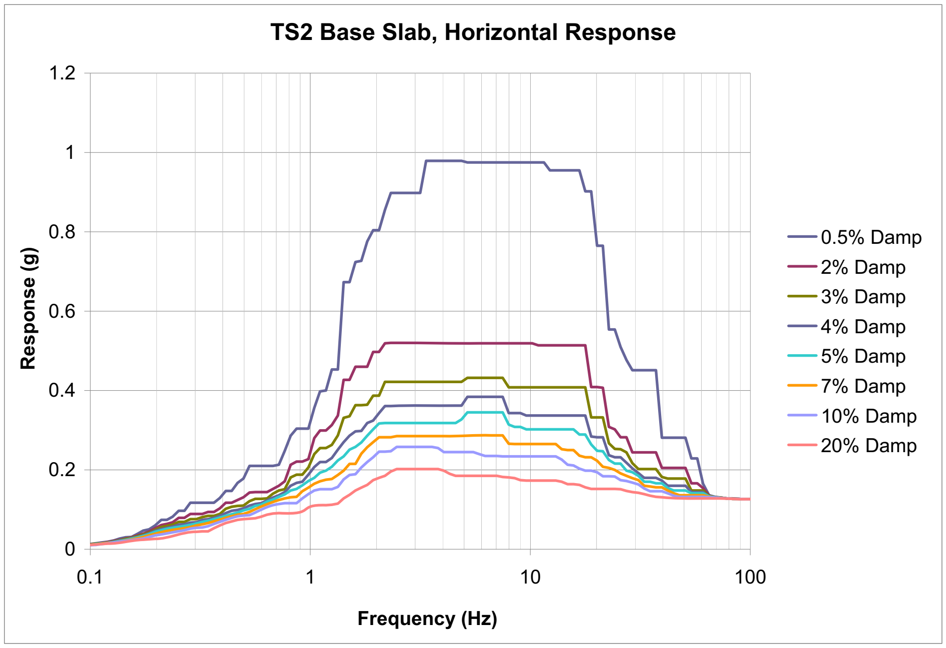


Figure 3LL-8 ISRS for ESWPT Segment 2 (Sheet 1 of 4) (enveloped response for east-west and north-south directions)

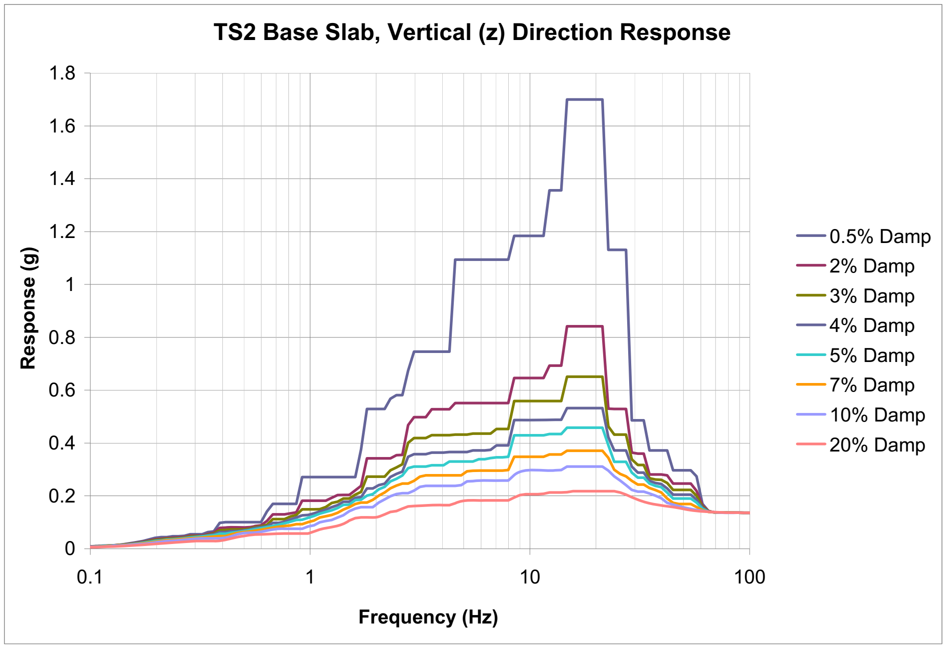


Figure 3LL-8 ISRS for ESWPT Segment 2 (Sheet 2 of 4)

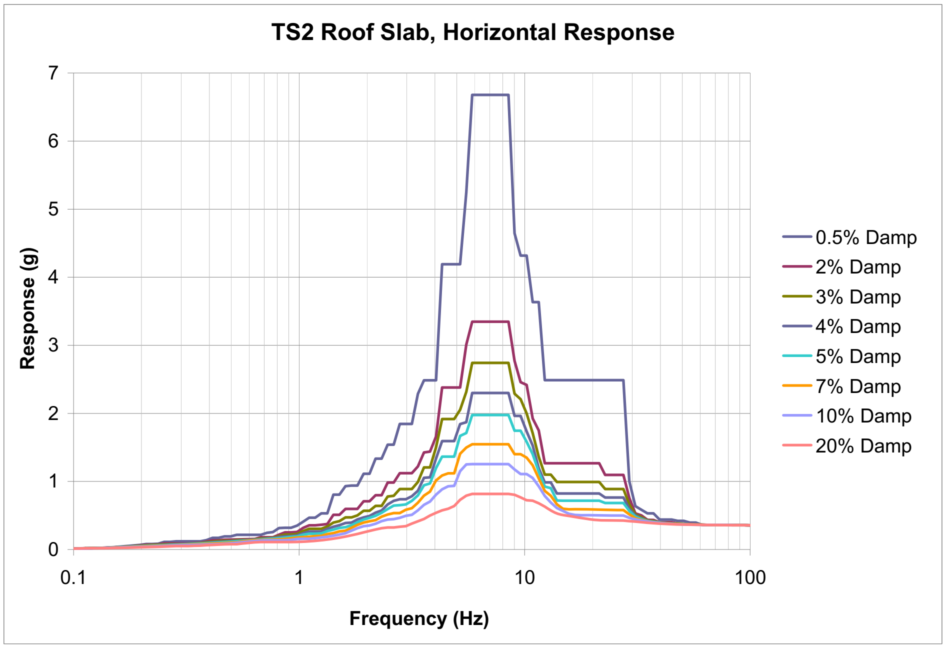


Figure 3LL-8 ISRS for ESWPT Segment 2 (Sheet 3 of 4) (enveloped response for the east-west and north-south directions)

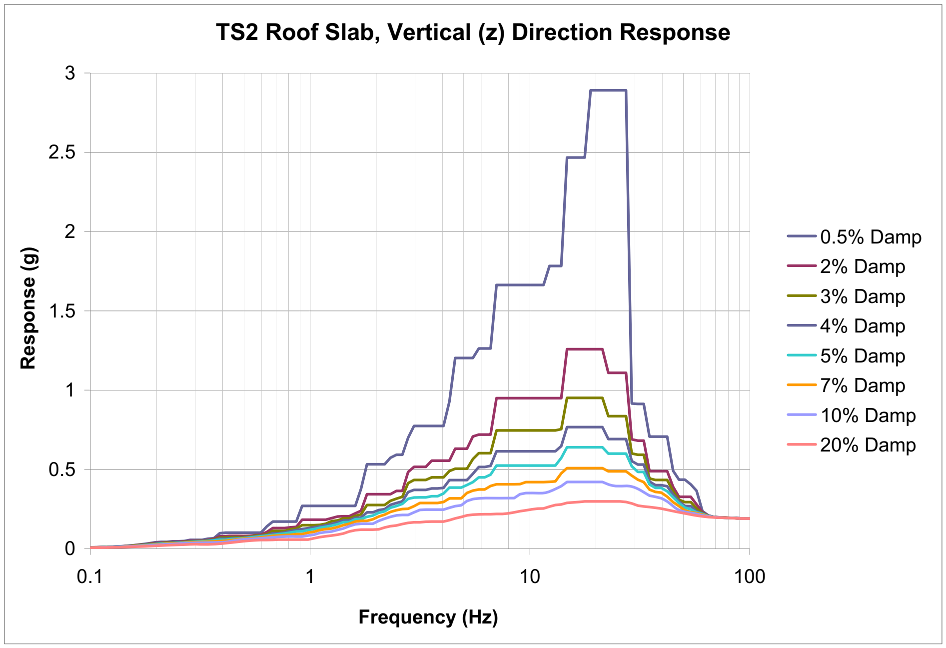


Figure 3LL-8 ISRS for ESWPT Segment 2 (Sheet 4 of 4)

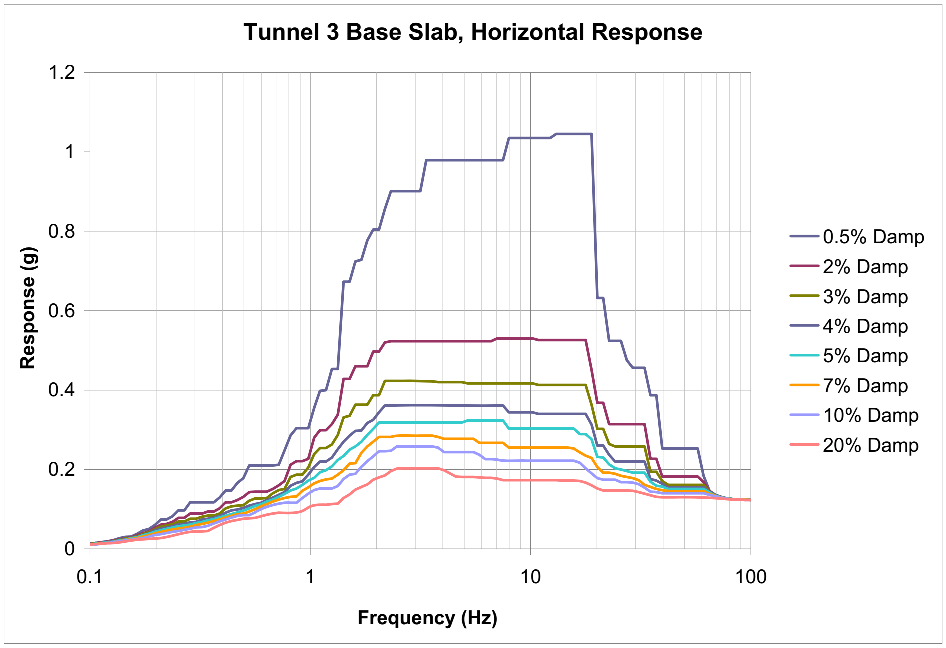


Figure 3LL-9 ISRS for ESWPT Segment 3 (Sheet 1 of 6) (enveloped north-south and east-west response)

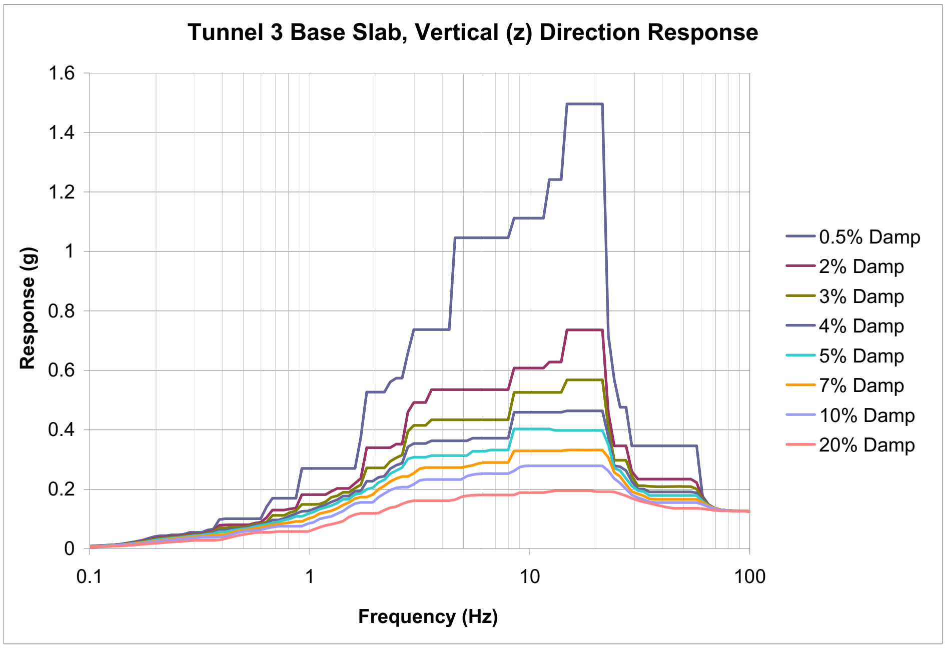


Figure 3LL-9 ISRS for ESWPT Segment 3 (Sheet 2 of 6)

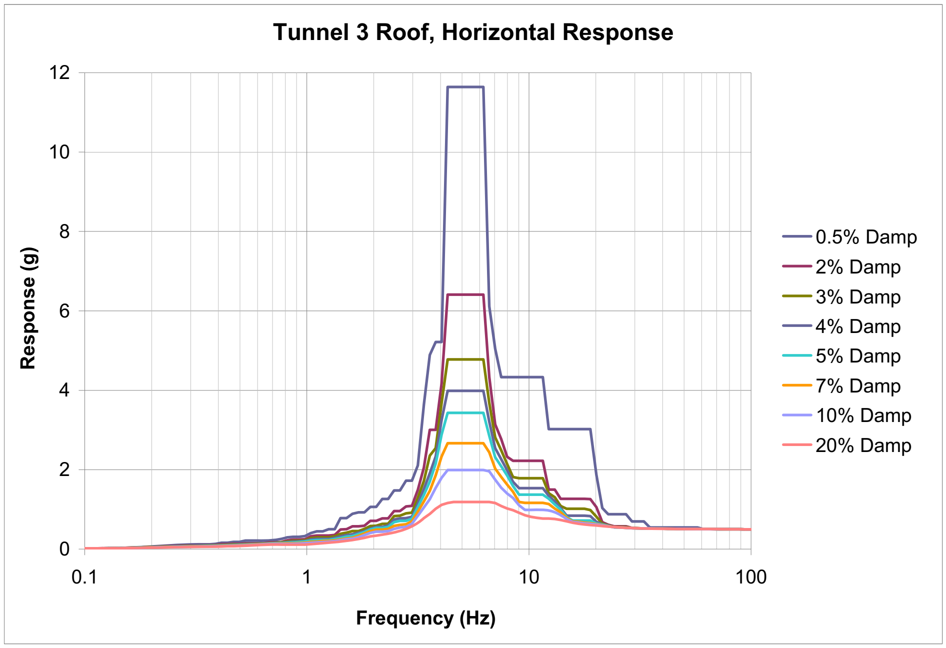


Figure 3LL-9 ISRS for ESWPT Segment 3 (Sheet 3 of 6) (enveloped north-south and east-west response)

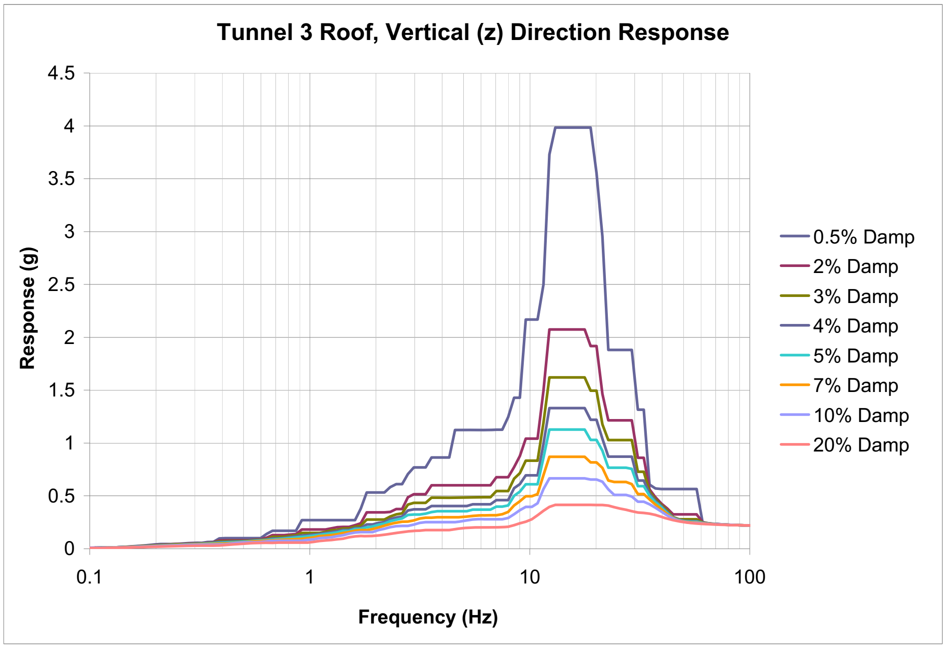


Figure 3LL-9 ISRS for ESWPT Segment 3 (Sheet 4 of 6)

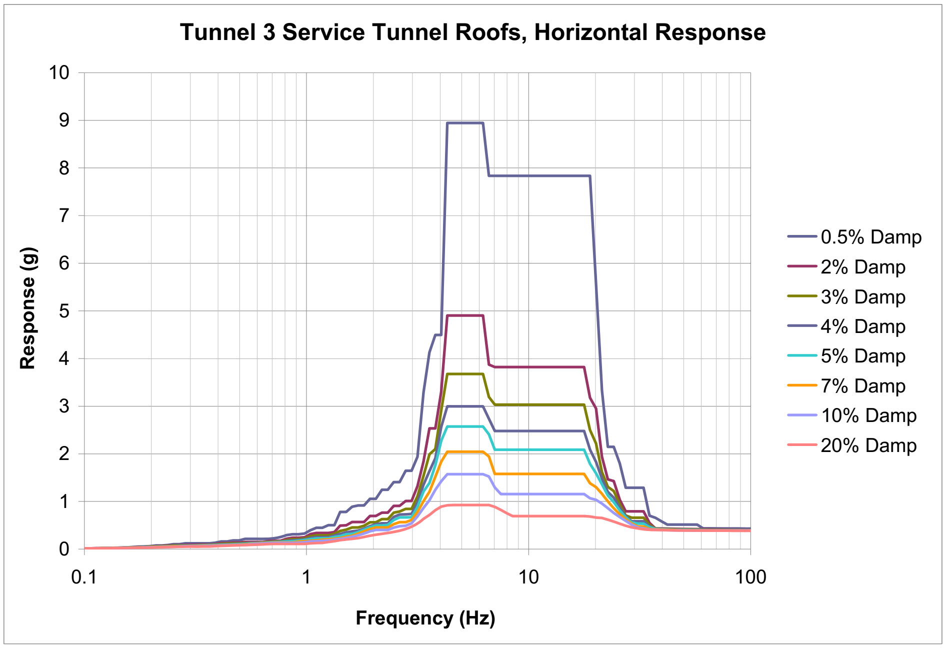


Figure 3LL-9 ISRS for Roofs of Service Tunnels Crossing ESWPT Segment 3 (Sheet 5 of 6) (enveloped response for north-south and east-west directions)

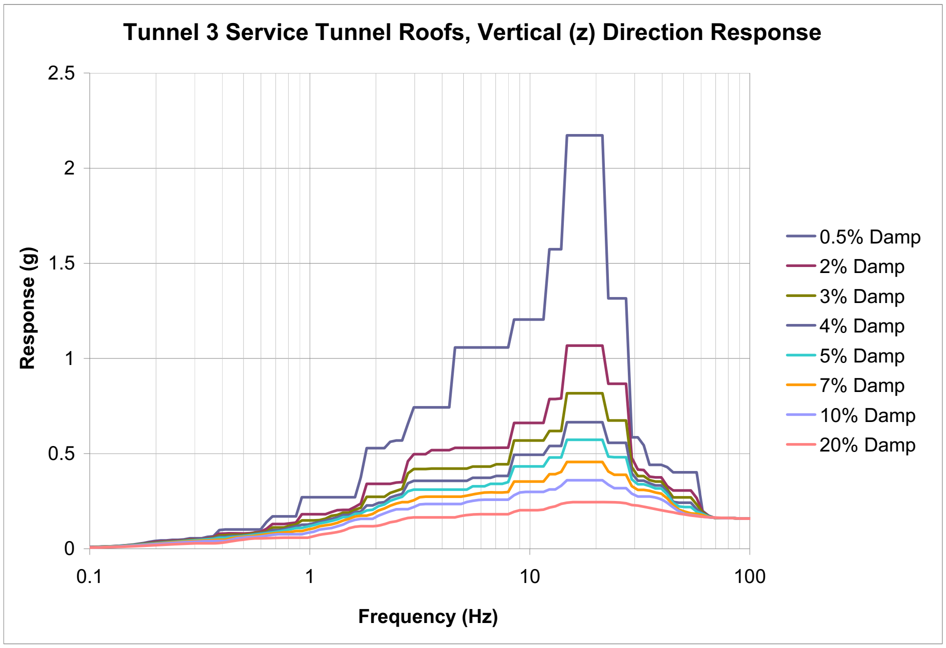


Figure 3LL-9 ISRS for Roofs of Service Tunnels Crossing ESWPT Segment 3 (Sheet 6 of 6)

CP COL 3.7(3)
CP COL 3.7(12)
CP COL 3.7(26)
CP COL 3.8(29)

APPENDIX 3MM

MODEL PROPERTIES AND SEISMIC ANALYSIS RESULTS FOR PSFSVs

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

Acronyms	Definitions
3D	three-dimensional
BE	best estimate
FE	finite element
FIRS	foundation input response spectra
HB	high bound
ISRS	in-structure response spectra
LB	lower bound
OBE	operating-basis earthquake
PSFSV	power source fuel storage vault
SRSS	square root sum of the squares
SSI	soil-structure interaction
UB	upper bound

3MM MODEL PROPERTIES AND SEISMIC ANALYSIS RESULTS FOR PSFSVs

3MM.1 Introduction

This Appendix discusses the seismic analysis of the power source fuel storage vaults (PSFSVs). The computer program SASSI (Reference 3MM-1) serves as the platform for the soil-structure interaction (SSI) analyses. The three-dimensional (3D) finite element (FE) models used in the SASSI are condensed from FE models with finer mesh patterns initially developed using the ANSYS computer program (Reference 3MM-2). Further, the translation of the model from ANSYS to SASSI is confirmed by comparing the results from the modal analysis of the fixed base structure in ANSYS and the SASSI analysis of the model resting on a half-space with high stiffness. The close correlation between the SASSI transfer function results with the ANSYS eigenvalues results ensures the accuracy of the translation.

The SASSI 3D FE model is dynamically analyzed to obtain seismic results including SSI effects. The SASSI model results including seismic soil pressures are used as input to the ANSYS models for performing the detailed structural design including loads and load combinations in accordance with the requirements of Section 3.8. The SASSI analysis and results presented in this Appendix include site-specific effects such as the layering of the subgrade, embedment of the PSFSVs, flexibility of the basemat and subgrade, and scattering of the input control design motion. Due to the low seismic response at the Comanche Peak Nuclear Power Plant site and lack of high-frequency exceedances, the SASSI capability to consider incoherence of the input control motion is not implemented in the design of the PSFSVs.

3MM.2 Model Description and Analysis Approach

The FE model for the PSFSV is shown in Figure 3MM-1. Table 3MM-1 presents the properties assigned to the structural components of the SASSI FE model. Table 3MM-2 summarizes the SASSI FE model structural component dimensions and weights. Detailed descriptions and figures of the PSFSV are contained in Section 3.8.

Shell elements are used for the roof, interior and exterior walls, brick elements are used for the base mat, and beam elements are used to represent the emergency power fuel oil tanks and their supports, which are connected to the basemat. Walls are modeled using gross section properties at the centerline. The tapered east wall of the vault is modeled at the centerline of the top portion of the wall. The change in thickness is modeled using the average thickness of the wall at each element layer. The materials and properties of the roof slab are changed to reflect the cracked concrete properties for out of plane bending. The cracked concrete properties are modeled for one-half of the uncracked flexural stiffness of the roof. Un-cracked properties are considered for the in-plane stiffness and the mass of the roof (Reference 3MM-3). Therefore, to achieve 1/2 flexural out-of-plane stiffness of the slab without reducing its in-plane stiffness, the following element properties are assigned:

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

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

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

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

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

$\gamma_{concrete}$ = 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.

The natural frequencies and descriptions of the associated modal responses of the fixed-base model are presented in Table 3MM-3 for the PSFSV and these frequencies are compared to structural frequencies calculated from the transfer functions of the SASSI model.

The PSFSV model is developed and analyzed using methods and approaches consistent with ASCE 4 (Reference 3MM-3) and accounting for the site-specific stratigraphy and subgrade conditions described in Chapter 2, as well as the backfill conditions around the embedded PSFSVs. The PSFSV structure is modeled using three orthogonal axes: a y-axis pointing south, an x-axis pointing west, and a z-axis pointing up. The east and west PSFSVs are nearly symmetric; backfill is present on the south and east sides of the east vault and on the south and west sides of the west vault. Due to symmetry, SSI analysis is performed only on the east vault, and the responses are deemed applicable to the west vault.

The input within-layer motion and strain-compatible backfill properties for the SASSI analysis are developed from site response analyses described in Section 3NN.2 of Appendix 3NN by using the site-specific foundation input response spectra (FIRS) discussed in Subsection 3.7.1.1. The properties of the supporting media (rock) as well as the site-specific strain-compatible backfill properties used for the SASSI analysis of the PSFSVs are the same as those presented in Appendix 3NN for the R/B-PCCV-containment internal structure SASSI analyses. To account for uncertainty in the site-specific properties, several sets of dynamic properties of the rock and the backfill are considered, including best estimate (BE), lower bound (LB), and upper bound (UB) properties. For backfill, an additional high bound (HB) set of properties is also used to account for expected uncertainty in the backfill properties.

The above four sets of soil dynamic properties are applied for analysis of the PSFSV structure considering full embedment within the backfill, partial separation of the backfill, and a surface foundation condition without the presence of any backfill. The backfill separation is modeled by reducing the shear wave velocity by a factor of 10 for those layers of backfill that are determined to be separated. The potential for separation of backfill is determined using an iterative approach that compares the peak envelope soil pressure results to the at-rest soil pressure. Consideration of all these conditions assures that the enveloped results presented herein capture all potential seismic effects of a wide range of backfill properties and conditions in combination with the site-specific supporting media conditions.

Operating-basis earthquake (OBE) structural damping values of Chapter 3 Table 3.7.1-3(b), such as 4 percent damping for reinforced concrete, are used in the site-specific SASSI analysis. This is consistent with the requirements of Section 1.2 of RG 1.61 (Reference 3MM-4) for structures on sites with low seismic responses where the analyses consider a relatively narrow range of site-specific subgrade conditions.

3MM.3 Seismic Analysis Results

Table 3MM-4 presents a summary of SSI effects on the seismic response of the PSFSV. The maximum absolute nodal accelerations obtained from the time history analyses of the PSFSV models are presented in Table 3MM-5. The results are presented for each of the major PSFSV components and envelope all site conditions described above. The maximum accelerations have been obtained by combining cross-directional contributions in accordance with RG 1.92 (Reference 3MM-5) using the square root sum of the squares (SRSS) method.

The seismic design forces and moments are presented in Table 3MM-6. The force and moment values represent the enveloped seismic results for all site conditions considered in the analysis. These results are calculated from ANSYS design model subjected to the enveloped of accelerations and dynamic lateral soil pressure from all calculated SASSI analyses. Accidental torsion is accounted by increasing the wall shears given in Table 3MM-6. The walls seismic base shear was increased to account for accidental torsion and total seismic base shear to be resisted by in plane shear of walls. The total adjusted wall shear forces used for design are presented in Figure 3MM-2. For structural design of members and components, the design seismic forces due to three different components of the earthquake are combined using the Newmark 100% - 40% – 40% method.

The PSFSV displacements due to seismic loading are less than 0.07 inch. Table 3MM-7 summarizes the resulting maximum displacements for enveloped seismic loading conditions.

3MM.4 In-Structure Response Spectra (ISRS)

The enveloped broadened ISRS are presented in Figure 3MM-3 for the PSFSV base slab and roof for each of the three orthogonal directions (east-west, north-south, vertical) for 0.5 percent, 2 percent, 3 percent, 4 percent, 5 percent, 7 percent, 10 percent and 20 percent damping. The ISRS for each orthogonal direction are resultant spectra which have been combined using SRSS to account for cross-directional coupling effects in accordance with RG 1.122 (Reference 3MM-6). The ISRS include the envelope of the 11 site conditions (BE, LB, UB, and HB with and without backfill separation from the structure, and the no-fill surface foundation condition with BE, LB, and UB subgrade conditions). All results have been broadened by 15 percent and all valleys removed. The spectra can be used for the design of seismic category I and II subsystems and components housed within or mounted to the PSFSV. It is permitted to perform 15 percent peak clipping of the spectra for damping values below 10 percent in accordance with ASCE-4 (Reference 3MM-3). For the design of seismic category I and II subsystems and components mounted to the PSFSV walls, it is required to account for the effects of out-of-plane wall flexibility.

3MM.5 References

3MM-1 *An Advanced Computational Software for 3D Dynamic Analysis Including Soil Structure Interaction,* ACS SASSI Version 2.2, Ghiocel Predictive Technologies, Inc., July 23, 2007.

3MM-2 ANSYS Release 11.0, SAS IP, Inc. 2007.

3MM-3 *Seismic Analysis of Safety-Related Nuclear Structures*. American Society of Civil Engineers, ASCE 4-98, Reston, Virginia, 2000.

3MM-4 *Damping Values for Seismic Design of Nuclear Power Plants*, Regulatory Guide 1.61, Rev. 1, U.S. Nuclear Regulatory Commission, Washington, DC, March 2007.

3MM-5 *Combining Responses and Spatial Components in Seismic Response Analysis,* Regulatory Guide 1.92, Rev. 2, U.S. Nuclear Regulatory Commission, Washington, DC, July 2006.

3MM-6 *Development of Floor Design Response Spectra for Seismic Design of Floor-supported Equipment or Components*, Regulatory Guide 1.122, Rev. 1, U.S. Nuclear Regulatory Commission, Washington, DC, February 1978.

Table 3MM-1

FE Model Component Properties

Components	Material	E (ksi)	Poisson's Ratio	Unit Weight (kcf)	Damping Ratio	FE Thickness (ft)	Element type
Exterior Walls	5,000 psi concrete	4,030	0.17	0.170(1)	0.04	2.5	Shell
Exterior Tapered Wall	5,000 psi concrete	4,030	0.17	0.170(1)	0.04	3.14 to 4.38	Shell
Interior Walls	5,000 psi concrete	4,030	0.17	0.2167(1)	0.04	1.5	Shell
Roof (2)	5,000 psi concrete	5,696	0.17	0.2475(2)	0.04	1.414	Shell
Base slab	5,000 psi concrete	4,030	0.17	0.1577(1)	0.04	6.5	Brick
Emergency Fuel Oil Tanks	Steel	29,000	0.3	5.28(3)	0.04	N/A	Beam

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 as discussed in Appendix Subsection 3MM.2. 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 unit weight includes the weight of the emergency fuel oil tanks and the oil stored within. Tank supports are modeled as massless beams.

Table 3MM-2

SASSI 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	40	83.5	2.5	1,330
South Exterior Wall	40	83.5	2.5	1,420
West Exterior Wall	40	75.5	2.5	1,284
East Exterior Wall	40	75.5	Varies from 4.5 at bottom to 2.5 at top	1,926
West Interior Wall	40	75.5	1.5	982
East Interior Wall	40	75.5	1.5	982
Roof Slab	83.5 (east-west)	75.5 (north-south)	2[2]	2,206
Base mat	83.5 (east-west)	75.5 (north –south)	6.5	6,462
Tanks including full fuel oil content	N/A	N/A	N/A	1,162 x 3 = 3,486
Total Weight	40	83.5	2.5	20,078
Equivalent Weight (ksf) on Slab Area (78'x88')				2.9
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. Actual component dimensions are shown in Section 3.8 Figures 3.8-212, 3.8-213, and 3.8-214.
2) The actual roof slab thickness of 2 ft is adjusted to 1.414 ft in the FE model to account for its cracked properties, as discussed in Appendix Subsection 3MM.2.
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.

Table 3MM-3

SASSI FE Model Natural Frequencies[(1)]

Frequency (Hz)	Comments
12.7	East-west response, interior walls out-of plane
15.5	East-west response, exterior walls out-of plane
18.3	East-west response, walls in plane
18.9	Vertical response, roof slab
23.7	North-south response, overall structure

Notes:

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

Table 3MM-4

SASSI Results for PSFSV Seismic Response

SSI Effect	Observed Response
Rock Subgrade	The rock subgrade has insignificant SSI effect on the PSFSV seismic response. Instead, the structural natural frequencies obtained from SASSI analyses of the surface foundation characterize the response, due to the high stiffness of the rock and the small weight of the foundation.
Backfill Embedment	The properties of the backfill embedment affect the overall response of PSFSV structure. Backfill soil frequencies, in the range of 4 Hz for lower bound to 8 Hz for high bound, characterize the PSFSV horizontal response. Frequencies of 7 Hz for lower bound, 11 Hz for best estimate, 14 Hz for upper bound, and 17 Hz for high bound, characterize the vertical response of the backfill. The peaks increase in magnitude as the frequency of the backfill approaches that of the PSFSV structure.
Backfill soil separation	The effects of backfill soil separation on the PSFSV response are small.
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.

Table 3MM-5

SASSI FE Model Component Peak Accelerations

Component	N-S Acceleration (g) (+/- Y Direction)	E-W Acceleration (g) (+/- X Direction)	Vertical (g) (+/- Z Direction)
North Exterior Wall	0.18	0.18	0.13
South Exterior Wall	0.21	0.17	0.13
West Exterior Wall	0.16	0.42	0.13
East Exterior Wall	0.15	0.26	0.13
West Interior Wall	0.17	0.67	0.13
East Interior Wall	0.17	0.67	0.13
Roof Slab	0.17	0.21	0.63
Basemat	0.11	0.12	0.12

Notes:

1) The peak accelerations presented above envelope all of the considered site conditions, i.e. PSFSV embedded in BE, LB, UB, and HB backfill with and without soil separation, as well as the PSFSV supported by a surface foundation.
2) For structural design using the loads and load combinations in Section 3.8, the seismic loads are obtained by applying uniform accelerations to the PSFSV structure. This approach captured effects due to localized peak accelerations presented above. The uniform accelerations are applied as follows: For the horizontal direction a uniform acceleration of 0.25g was applied. For the vertical direction a uniform acceleration of 0.15g was applied. These accelerations were applied to all elements in the vault (including tanks). An additional distributed load corresponding to 0.40g was applied to the two interior walls and the east wall to account for increased local out-of-plane accelerations obtained from the SASSI analysis. An additional distributed load corresponding to 0.50g was applied to all the roof slabs to account for increased local accelerations obtained from the SASSI analysis. Seismic load also includes seismic backfill pressures on the sides of the PSFSV walls.

Table 3MM-6

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)	S_W (k/ft)	M_V (k-ft/ft)	M_L (k-ft/ft)	M_{VL} (k-ft/ft)
South Exterior Wall	+	65.07	54.87	14.32	23.61	41.24	25.70	28.28	13.42
	-	87.05	63.09	10.58	24.39	24.18	39.11	68.79	14.45
North Exterior Wall	+	22.62	6.88	4.06	2.02	29.98	9.37	27.50	3.60
	-	19.94	15.12	19.53	3.54	19.54	12.38	15.04	4.68
West Exterior Wall	+	20.07	17.25	19.82	5.27	19.90	76.89	26.73	29.56
	-	15.06	27.82	14.26	13.00	14.06	119.32	48.10	30.14
East Exterior Wall	+	13.82	24.29	6.40	4.71	16.40	34.89	32.23	7.53
	-	16.42	17.29	6.28	5.52	14.10	37.00	14.21	8.06
West Interior Wall	+	25.13	4.29	9.18	5.27	18.51	18.97	11.95	3.38
	-	17.33	31.42	5.31	4.95	13.27	19.53	12.14	3.28
East Interior Wall	+	12.04	4.14	5.20	9.63	17.96	18.75	14.01	3.92
	-	12.87	32.65	6.50	7.75	8.89	19.75	16.26	3.56
Roof Slab	+	25.64	20.19	9.78	6.72	21.22	19.77	8.82	6.74
	-	43.10	20.47	10.99	7.73	17.65	21.19	20.59	7.06
Basemat	+	13.71	19.23	18.68	25.70	21.67	176.90	154.34	58.57
	-	21.55	19.61	18.42	26.43	21.07	84.34	157.24	59.04

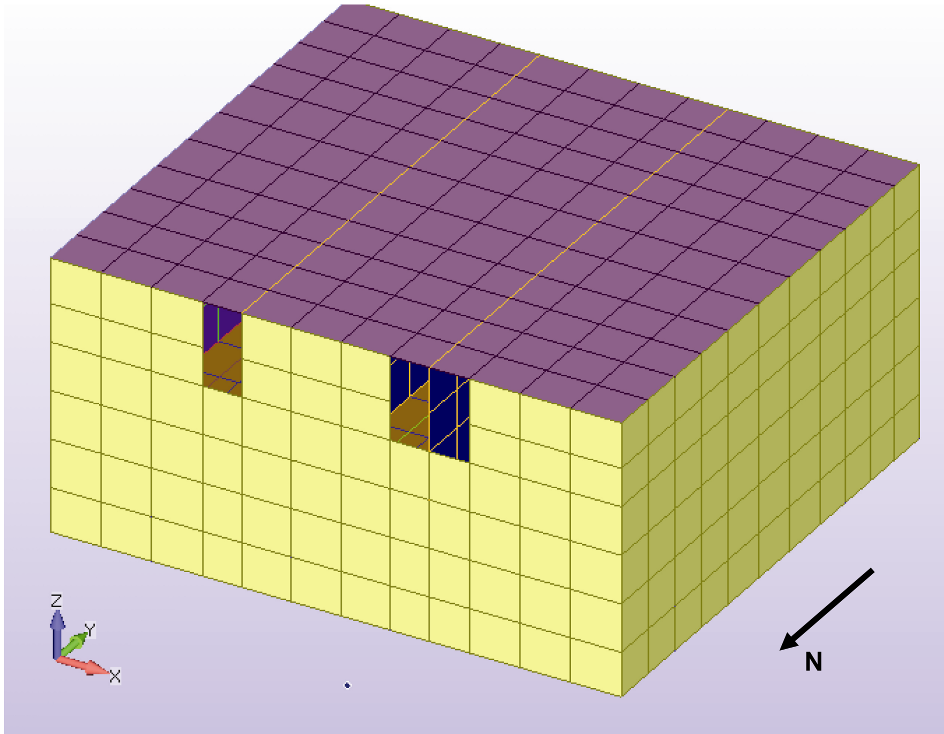
Notes:

1) The forces and moments shown above envelope the all four subgrade site conditions (LB, BE, UB, and HB) and any effects due to soil separation.
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, S_W for in-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 in the north-south direction

Table 3MM-7

PSFSV Maximum Displacements for All Enveloped Conditions

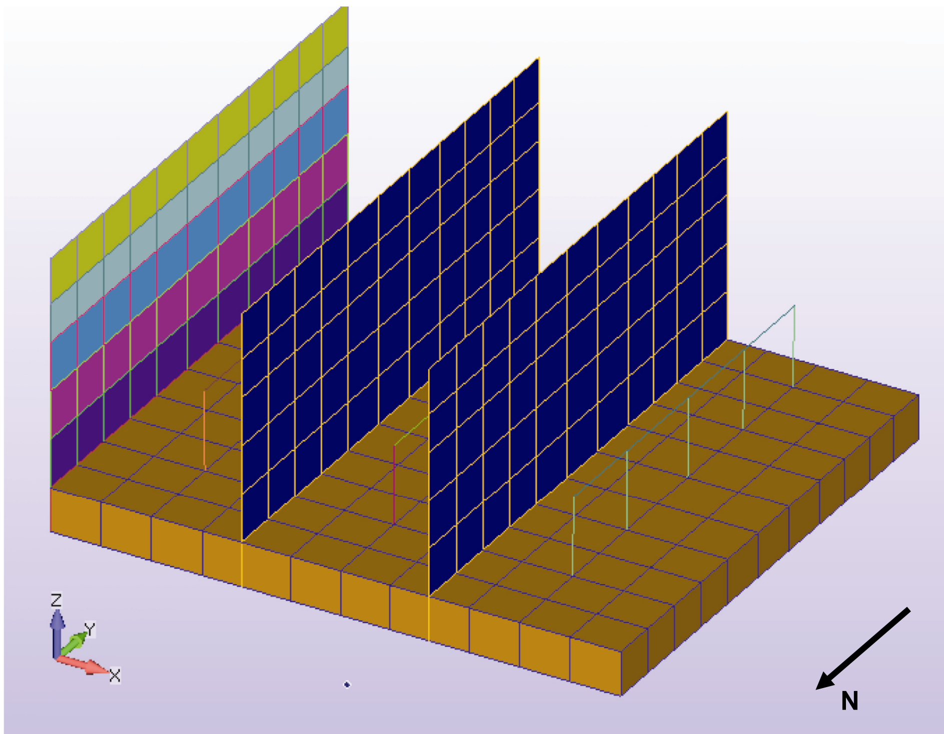
Component	Maximum Displacement (inches)	Description
Roof slab	0.05	Horizontal displacement equivalent to story drift; occurs at edge of slab near center of wall
East exterior wall	0.07	Horizontal (out-of-plane) displacement near center of wall
West exterior wall	0.05	Horizontal (out-of-plane) displacement near center of wall



Notes:

1) The vault pipe/access tunnel openings are on the north exterior wall as shown in the model above.

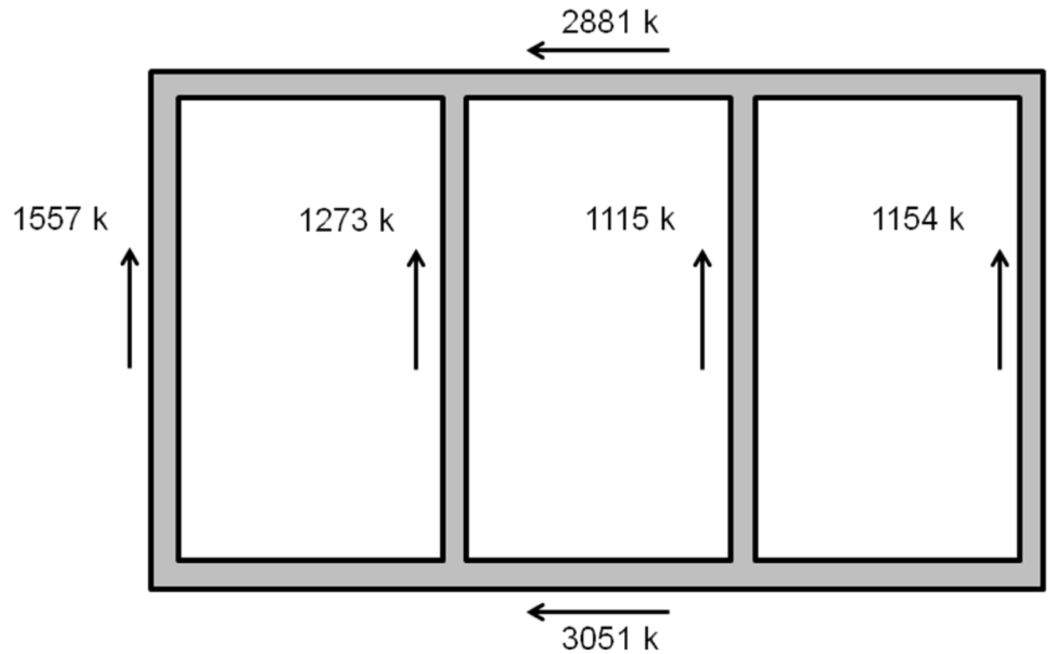
Figure 3MM-1 Overall SASSI Model of PSFSV (Sheet 1 of 2)



Notes:

1) The steel elements representing the tank are shown above as column and beams. The tank supports are modeled as beam elements oriented in the east-west direction and located at the base of each tank column element.

Figure 3MM-1 Overall SASSI Model of PSFSV (Sheet 2 of 2, Cutaway View of SASSI Model of PSFSV)



Notes:

1) The seismic shear forces shown above are computed at the bottom of each wall at the interface with the foundation mat and account for accidental eccentricity and total seismic base shear to be resisted by in plane shear of walls.

Figure 3MM-2 Maximum Seismic Base Shear Forces in Wall

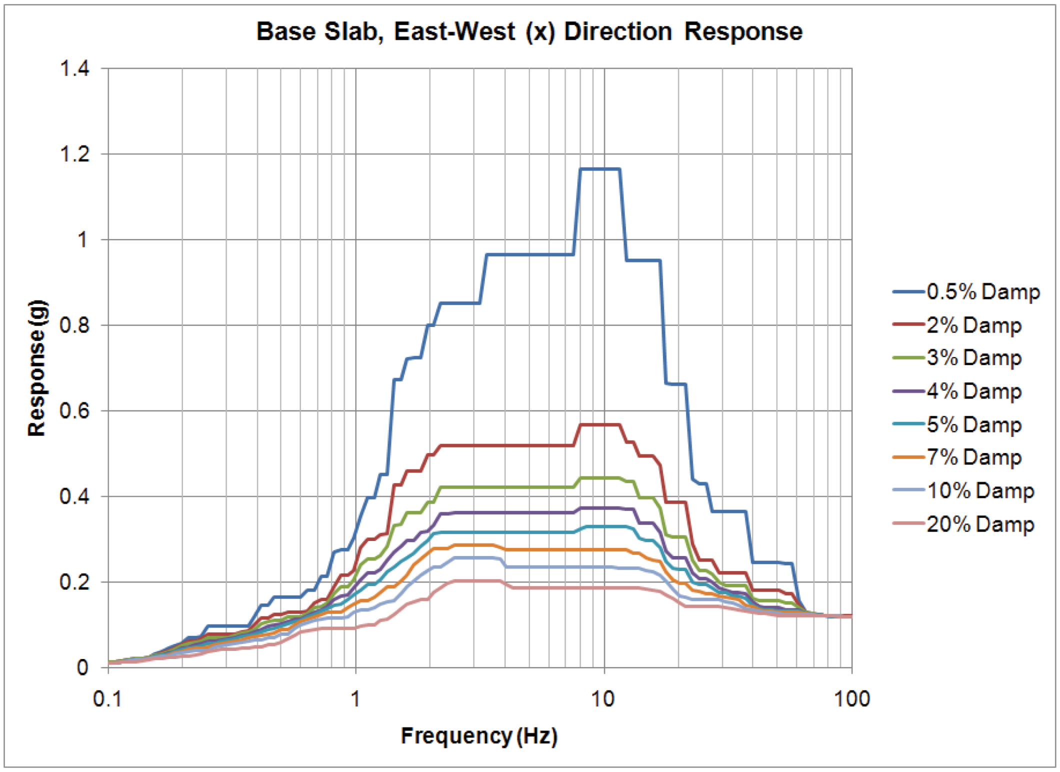


Figure 3MM-3 ISRS for PSFSV (Sheet 1 of 6)

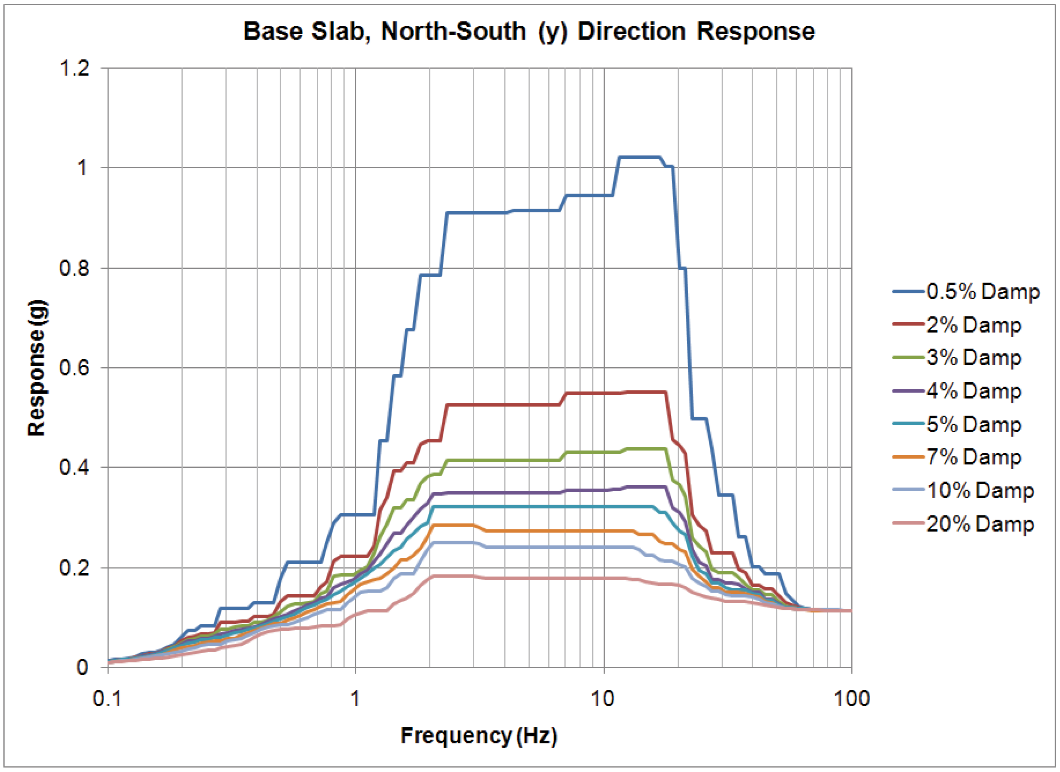


Figure 3MM-3 ISRS for PSFSV (Sheet 2 of 6)

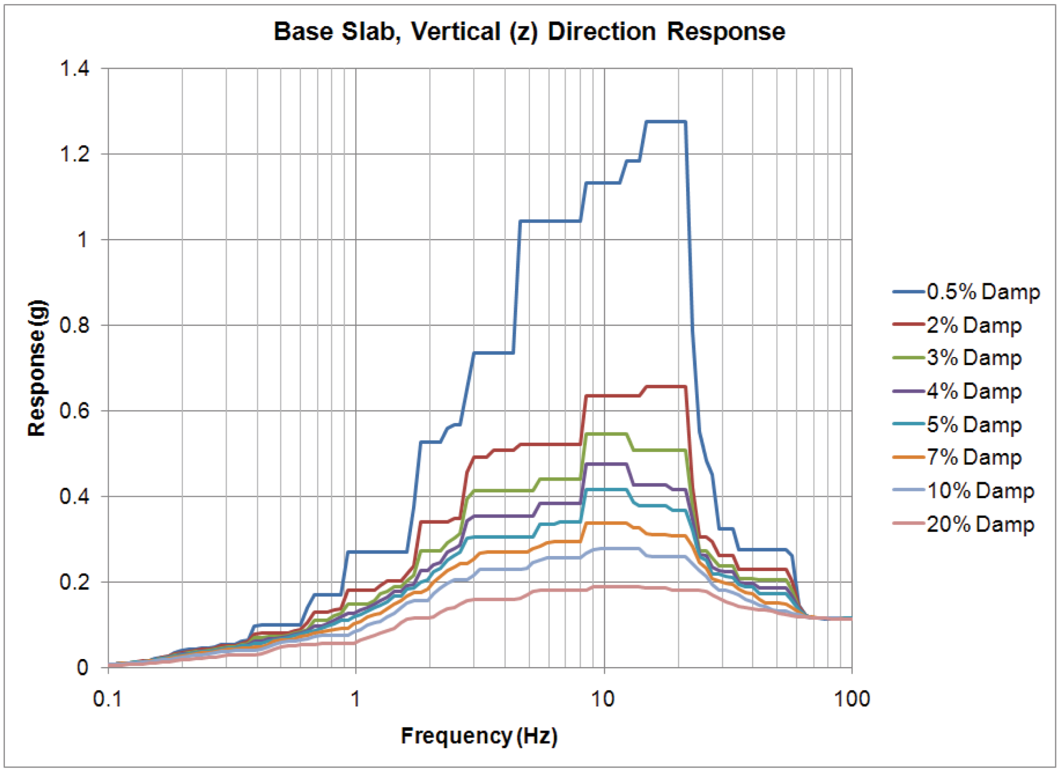


Figure 3MM-3 ISRS for PSFSV (Sheet 3 of 6)

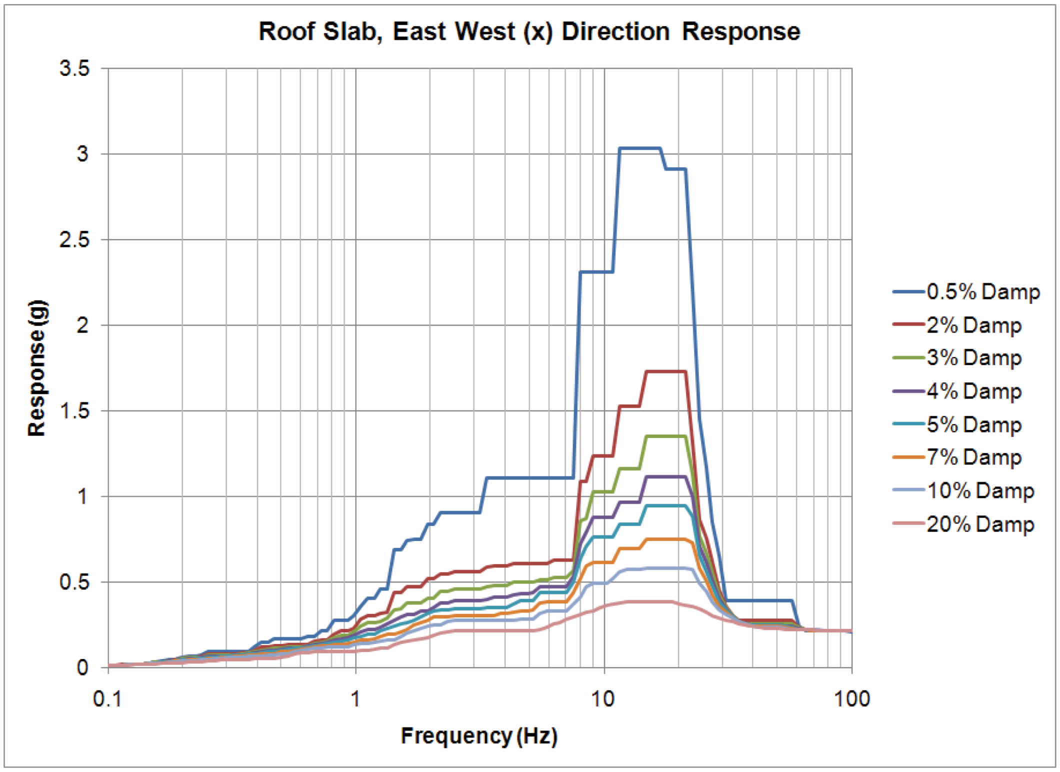


Figure 3MM-3 ISRS for PSFSV (Sheet 4 of 6)

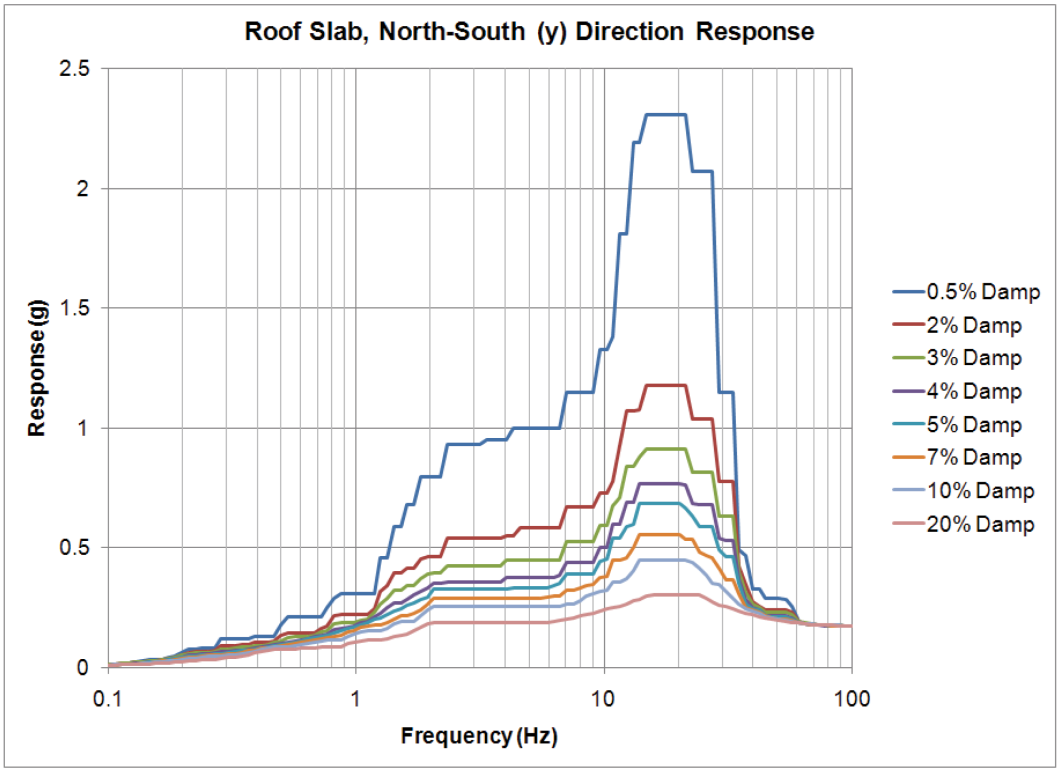


Figure 3MM-3 ISRS for PSFSV (Sheet 5 of 6)

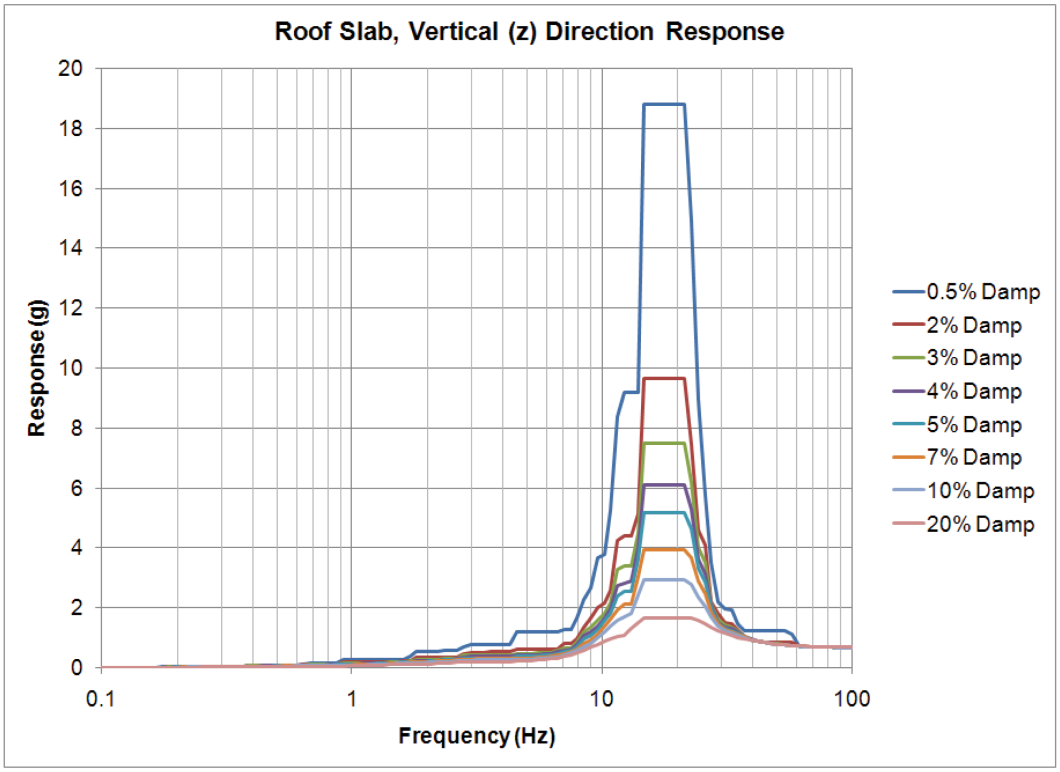


Figure 3MM-3 ISRS for PSFSV (Sheet 6 of 6)

CP COL 3.7(20)
CP COL 3.7(23)
CP COL 3.7(25)

APPENDIX 3NN

MODEL PROPERTIES AND SEISMIC ANALYSIS RESULTS R/B-PCCV-CONTAINMENT INTERNAL STRUCTURE

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

ACRONYMS AND ABBREVIATIONS

Acronyms	Definitions
3D	three-dimensional
ARS	acceleration response spectra
BE	best estimate
COV	coefficient of variation
CSDRS	certified seismic design response spectra
DCD	Design Control Document
FE	finite element
EBE	embedded best estimate
ELB	embedded lower bound
EHB	embedded high bound
EUB	embedded upper bound
FH/A	fuel handling area
GMRS	ground motion response spectra
HB	high bound
ISRS	in-structure response spectra
LB	lower bound
OBE	operating-basis earthquake
PCCV	prestressed concrete containment vessel
R/B	reactor building
SBE	surface best estimate
SLB	surface lower bound
SUB	surface upper bound
SRSS	square root sum of the squares
SSE	safe-shutdown earthquake
SSI	soil-structure interaction
UB	upper bound

3NN SASSI MODEL PROPERTIES AND SEISMIC ANALYSIS RESULTS FOR R/B-PCCV-CONTAINMENT INTERNAL STRUCTURE

3NN.1 Introduction

This Appendix documents the SASSI site-specific analysis of the US-APWR prestressed concrete containment vessel (PCCV), containment internal structure, and reactor building (R/B) including the fuel handling area (FH/A) of Comanche Peak Nuclear Power Plant Units 3 and 4.

As stated in Subsection 3.7.2.4.1, site-specific soil-structure interaction (SSI) analyses are performed to validate the US-APWR standard plant seismic design, and to confirm that site-specific SSI effects are enveloped by the lumped parameter SSI analysis described in Subsection 3.7.2.4. The SASSI computer program (Reference 3NN-1) serves as a computational platform for the site-specific SSI analysis. SASSI is used to model the overall stiffness and mass inertia properties of the R/B-PCCV-containment internal structure and the following SSI site-specific effects:

- Layering of the rock subgrade.
- Foundation flexibility.
- Embedment of the foundation and layering of backfill material.
- Scattering of the input control design motion.

The SASSI program provides a frequency domain solution of the SSI model response based on the complex response method and finite element (FE) modeling technique. The SASSI analyses of the US-APWR standard plant employ the subtraction method of sub-structuring to capture the above-listed SSI effects. Due to the low seismic response at the Comanche Peak site and lack of high-frequency exceedances, the SASSI analyses do not consider incoherence of the input control motion.

The SASSI site-specific analyses are conducted using methods and approaches consistent with ASCE 4 (Reference 3NN-2). This Appendix documents the SASSI analysis of the R/B-PCCV-containment internal structure and demonstrates that the in-structure response spectra (ISRS) developed from the SASSI analysis results are enveloped by the standard plant seismic design.

3NN.2 Seismological and Geotechnical Considerations

The R/B-PCCV-containment internal structure of Units 3 and 4 will be constructed on a rock subgrade by removing the native soil above the top of the limestone layer with shear wave velocity exceeding 5000 fps that is located at nominal elevation of 782 ft. A thin layer of fill concrete will be placed on the top of the limestone to level the surface below the building basemat established at nominal elevation of 783 ft.-2 in. Fill concrete will be also placed below the surface mat located at the north-east corner of the FH/A under the central portion of the mat underneath the PCCV. The foundation will be backfilled with a 40 ft. thick layer of engineered fill material to establish the nominal elevation of the plant ground surface at 822 ft.

Besides the best estimate (BE) values, the site-specific analyses address the variation of the subgrade properties by considering lower bound (LB) and upper bound (UB) properties. The LB and UB properties represent a coefficient of variation (COV) on the subgrade shear modulus of 0.65, the value of variation that was also used in Chapter 2 for development of ground motion response spectra (GMRS). The typical properties for a granular engineered backfill are adopted as the BE values for the dynamic properties of the backfill. Four profiles, LB, BE, UB, and high bound (HB) of input backfill properties are developed for the SASSI analyses considering the different coefficient of variation. The LB and BE backfill profiles are combined with corresponding LB and BE rock subgrade profiles, and the UB and HB backfill profiles are combined with the UB rock subgrade profile. The profiles address the possibility of stiffer backfill, and the project specifications limit the minimum shear wave velocity of the backfill material to 600 ft/s for 0 to 3 ft. depth, 720 ft/s for 3 to 20 ft. depth, and 900 ft/s for 20 to 40 ft. depth. Table 3NN-1 presents the COV on shear modulus used for development of different soil profiles.

Due to the small intensity of the seismic motion and the high stiffness of the rock, the SSI analyses use rock subgrade input properties derived directly from the measured low-strain values, i.e., the dynamic properties of the rock subgrade are considered strain-independent (Refer to FSAR Chapter 2 for further discussion). The SSI analyses use input stiffness and damping properties of the backfill that are compatible to the strains generated by the design input motion. The strain-compatible backfill properties are obtained from site response analyses of the four backfill profiles using two horizontal acceleration time histories compatible to the GMRS that are applied as outcrop motion on the surface of the rock subgrade at nominal elevation of 782 ft.

The compression or P-wave velocity is developed for the rock and the backfill from the strain-compatible shear or S-wave velocity (Vs) and the measured value of the Poisson’s ratio. The SSI analyses use identical values for the shear S-wave and compression P-wave velocity damping. Figure 3NN-1, Figure 3NN-2 and Figure 3NN-3 present, respectively, the rock subgrade LB, BE and UB profiles for shear (S) wave velocity (Vs), compression (P) wave velocity (Vp) and material damping. Figure 3NN-4, Figure 3NN-5 and Figure 3NN-6 present in solid lines the results of the site response analyses for the profiles of strain-compatible backfill properties. The plots also show with dashed lines the backfill profiles that were modified to match the geometry of the mesh of the SASSI basement model. The presented input S and P wave profiles are modified using the equal arrival time averaging method.

The minimum design spectra, tied to the shapes of the certified seismic design response spectra (CSDRS) and anchored at 0.1g, define the safe-shutdown earthquake (SSE) design motion for the seismic design of category I structures that is specified as outcrop motion at the top of the limestone at nominal elevation of 782 ft. Two statistically independent time histories H1 and H2 are developed compatible to the horizontal design spectrum, and a vertical acceleration time history V is developed compatible to the vertical design spectrum. The SASSI analysis requires the object motion to be defined as within-layer motion. The site response analyses convert the design motion that is defined as outcrop motion (or motion at the free surface) to within-layer (or base motion) that depends on the properties of the backfill above the rock surface. The site response analyses provide for each considered backfill profile, two horizontal acceleration time histories of the design motion within the top limestone rock layer that are used as input in the SASSI analyses of embedded foundation. The outcrop horizontal time histories are used as input for the SASSI analyses of surface foundations. The time history of the vertical outcrop accelerations serves as input for both surface and embedded foundations. The time step of the acceleration time histories used as input for the SASSI analysis is 0.005 sec.

3NN.3 SASSI Model Description and Analysis Approach

Figure 3NN-7 shows the three-dimensional SASSI FE model used for site-specific seismic analysis of the US-APWR R/B-PCCV-containment internal structure of Units 3 and 4. The SASSI structural model uses lumped-mass-stick models of the PCCV, containment internal structure, and R/B to represent the stiffness and mass inertia properties of the building above the ground elevation. A three-dimensional (3D) FE model, presented in Figure 3NN-8, represents the building basement and the floor slabs at ground elevation.

The model is established with reference to the Cartesian coordinate system with origin established 2 ft.-7 in. below the ground surface elevation at the center of the PCCV foundation. The origin location corresponds to the location of the coordinate system used as reference for the seismic analysis of the standard plant presented in Section 3.7. The orientation of the Z-axis is upward. The orientation of the standard plant model is modified such that the positive X-axis is oriented northward and the Y-axis is oriented westward.

The geometry and the properties of the lumped-mass-stick models representing the above ground portion of the building are identical to those of the lumped mass stick model used for the R/B-PCCV-containment internal structure seismic analysis, as addressed in Appendix 3H. SASSI 3D beam and spring elements with cross sectional properties identical to those of the standard plant models represent stiffness properties. All of the modeling characteristics present in the standard plant lumped mass stick models for the R/B-PCCV-containment internal structure are the same as for the SASSI model, with the exception of minor adjustments for compatibility with SASSI, described as follows. The rigid links in the lumped mass stick models that connect different nodal points at the same floor elevation are replaced with SASSI 3D beam elements with high stiffness properties.

The major coordinates that define the geometry of the FE basement model are listed in Table 3NN-2 to Table 3NN-5. 3NN-6 presents the types of SASSI finite elements used to model the different structural members in the basement model. The table also presents the stiffness and mass inertia properties assigned to each group of finite elements. The stiffness and damping properties assigned to each material of the SASSI model are listed in Table 3NN-7. The site-specific SASSI analysis uses the operating-basis earthquake (OBE) damping values of Chapter 3, Table 3.7.1-3(b), which is consistent with the requirements of Section 1.2 of RG 1.61 (Reference 3NN-4) for structures on sites with low seismic responses where the analyses consider a relatively narrow range of site-specific subgrade conditions.

SASSI solid FE elements, shown in Figure 3NN-9, model the stiffness and mass inertia properties of the building basemat. The modeling of the thick central part of the basemat supporting the PCCV and containment internal structure is simplified to minimize the size of the SASSI model as shown in Figure 3NN-10. Rigid shell elements connect the thick portion of the basemat with the floor slabs at the ground elevation. Rigid 3D beam elements connect the PCCV and containment internal structure lumped-mass stick models to the rigid shell elements as shown in Figure 3NN-13 and Figure 3NN-14. Massless shell elements are added at the top of the basemat solid element to accurately model the bending stiffness of the central part of the mat. Figure 3NN-11 shows the solid FE elements representing the stiffness and mass inertia of the fill concrete placed under the central elevated part of the basemat and under the surface mat at the northeast corner of the building.

SASSI 3D shell elements model the basement shear walls, the surface mat under the northeast corner of the R/B, and the R/B slabs at ground floor elevation. The elastic modulus and unit weight assigned to the material of the shell elements modeling the R/B basement shear walls shown in Figure 3NN-12 are adjusted to account for the different height of walls and reductions of stiffness due to the openings. Table 3NN-8 lists the adjusted material properties assigned to the shell elements of the walls with openings.

Rigid 3D beam elements connect the top of the basement shear walls with lumped-mass stick model representing the above ground portion of the R/B and FH/A. This modeling approach enables the R/B-FH/A to be connected to the flexible part of the building basement and decoupled from the thick central part that serves as foundation to the PCCV and containment internal structure part of the building.

In addition to the weights assigned to the lumped-mass-stick models of the US-APWR standard plant summarized in Table 3H.2-10 of Appendix 3H, the SASSI model used for site specific analyses includes the weight of 47,085 kips pertaining to the fill concrete placed beneath the building basemat. The combined total weight of the R/B, containment internal structure, and PCCV including the basemat and the fill concrete is 781,685 kips. The equivalent uniform pressure under the building foundation is 11.86 ksf. In the SASSI model of the basement, unit mass weight is assigned only to the 3D shell elements modeling the shear walls of R/B and to the portion of the basemat represented by 3D brick elements. Table 3NN-9 presents the weights assigned to the elements of the basement structural members. The remaining weight of the basement is lumped at a single node that, as shown in Figure 3NN-10, is connected to the central portion of the foundation by rigid beams. As shown in Table 3NN-10, the magnitude and the location of the lumped mass are calculated such that, when combined with the mass inertia properties of the mat and walls, the FE model duplicates the overall lumped mass inertia properties assigned to the standard plant lumped mass stick model at basement node BS01.

Four layers of SASSI solid elements, shown Figure 3NN-15, are used to represent the stiffness and the mass inertia of the excavated backfill soil. Figure 3NN-4, Figure 3NN-5, and Figure 3NN-6 show in dashed lines the input strain-compatible properties assigned to the different layers of excavated soil elements.

The results of a SASSI analysis in which fixed-base conditions are simulated by attaching the lumped-mass-stick models to a rigid foundation resting on a rigid rock subgrade, verify the accuracy of the conversion of the standard plant lumped-mass-stick models into SASSI. An additional verification analysis is performed on the combined SASSI model resting on the surface of rigid half-space to identify the dynamic properties of the SASSI model. Table 3NN-11 presents the frequencies that characterize the different modes of response of the structural models. In the table, the results of the two verification SASSI analyses are compared with the results of the fixed base modal analysis of the model presented in Appendix 3H.

3NN.4 Seismic Analysis Results

The buildings surrounding the R/B (including FH/A), PCCV, and containment internal structures are separated by expansion joints to prevent their interaction during an earthquake. A part of the building foundation is embedded in backfill of engineered granular material. The site-specific SSI analyses address the effects of these site-specific conditions by considering both surface foundation and foundation basement embedded in backfill that is modeled as infinite in the horizontal direction. Seven sets of SASSI analyses are performed that consider the following site conditions:

1. SLB - Foundation without backfill resting on the surface of the rock subgrade profile with LB properties.
2. SBE - Foundation without backfill resting on the surface of the rock subgrade profile with BE properties.

3. SUB - Foundation without backfill resting on the surface the rock subgrade profile with UB properties.

4. ELB - Foundation embedded in backfill with LB properties resting on the surface of the rock subgrade profile with LB properties.

5. EBE - Foundation embedded in backfill with BE properties resting on the surface of the rock subgrade profile with BE properties.

6. EUB - Foundation embedded in backfill with UB properties resting on the surface of the rock subgrade profile with UB properties.

7. EHB - Foundation embedded in backfill with high bound HB properties resting on the surface of the rock subgrade profile with UB properties.

Each set of SASSI runs includes three runs where the input motion is applied to the models at top of the rock subgrade in North-South (NS), East-West (EW) and vertical direction. The responses obtained for the earthquake components in the three global orthogonal directions are combined in accordance with RG 1.92 (Reference 3NN-3) using the square root sum of the squares (SRSS) method.

Table 3NN-12, Table 3NN-13, and Table 3NN-14 present maximum absolute accelerations (zero period acceleration values) at lumped-mass locations of the R/B-PCCV-containment internal structure in NS, EW, and vertical direction, respectively. The results obtained from each set of SASSI analysis are listed together with the enveloped value from all of the considered site conditions.

Table 3NN-15 presents the influence of different SSI effects on the response of the PCCV, R/B, and containment internal structures.

3NN.5 In-Structure Response Spectra (ISRS)

The site-specific SASSI analysis provides results for the 5 percent damping acceleration response spectra (ARS) at all lumped mass locations for the three orthogonal directions. The ARS results for the three components of the input earthquake are combined using the SRSS method and compared with the US-APWR standard plant ISRS. Figure 3NN-16, Figure 3NN-20 and Figure 3NN-24 compare of the ARS results for seismic response in three directions at ground elevation at the nominal center of the basement (mass location CV00) with the corresponding CSDRS. The comparison of the ARS results for the response at the top of PCCV (mass node CV11) with the corresponding ISRS are shown in Figure 3NN-17, Figure 3NN-21, and Figure 3NN-25. Figure 3NN-18, Figure 3NN-22, and Figure 3NN-26 present the comparison of ISRS and ARS results for the containment internal structure response at lumped mass location IC18. The ARS results for the response of R/B structure at lumped mass location RE05 are presented in Figure 3NN-19, TFigure 3NN-23 and Figure 3NN-27. The ISRS envelope by a high margin all of the ARS results at all lumped mass locations, which confirms the validity of the US-APWR R/B-PCCV-containment internal structure standard plant seismic design for the Comanche Peak Units 3 and 4 site.

3NN.6 References

3NN-1 *An Advanced Computational Software for 3D Dynamic Analysis Including Soil Structure Interaction,* ACS SASSI Version 2.2, Ghiocel Predictive Technologies, Inc., July 23, 2007.

3NN-2 *Seismic Analysis of Safety-Related Nuclear Structures,* American Society of Civil Engineers, ASCE 4-98, Reston, Virginia, 2000.

3NN-3 *Combining Responses and Spatial Components in Seismic Response Analysis*, Regulatory Guide 1.92, Rev. 2, U.S. Nuclear Regulatory Commission, Washington, DC, July 2006.

3NN-4 *Damping Values for Seismic Design of Nuclear Power Plants*, Regulatory Guide 1.61, Rev. 1, U.S. Nuclear Regulatory Commission, Washington, DC, March 2007.

Table 3NN-1

Variation in Input Soil Properties

Stratum	Coefficient Of Variation on Shear Modulus		
	Lower Bound (LB)	Upper Bound (LB)	High Bound (HB)
Backfill	0.69	0.69	1.25
Rock Subgrade	0.65	0.65	0.65

Table 3NN-2

Basement Model Z Coordinates (Bottom to Top)

Z (ft)	Elevation (ft)	Description
-37.420	782.00	Basemat Bottom
-24.083	795.34	Bottom of Basemat under Reactor
2.583	822.00	Ground Elevation

Table 3NN-3

Basement Model X-Coordinates (South to North)

X (ft)	Column Line	Description
-161.67	LR	South Exterior Wall
-139.33	K1R	R/B South Basement Wall
-127.00	KR	R/B South Basement Wall
-106.00	J1R	E-W Interior Wall R/B South Basement
-94.00	JR	Reactor Basemat South End
-39.08	D1R & ER	Reactor Basement South Edge
0.00	FR	Reactor E-W Centerline
39.08	GR & G2R	Reactor Basement North Edge
94.00	CR	North Interior Wall
102.25	BR	Reactor Basemat North End
124.42	A1R	Basement Exterior Wall under Fuel Handling Area Surface Mat
147.25	AR	Basement North Exterior Wall

Table 3NN-4

Basement Model Y-Coordinates (East to West)

Y (ft)	Column Line	Description
-106.67	11R	Basement East External Wall
-92.167	10R	Reactor Basemat East End
-85.667	9bR	R/B Basement N-S Interior Wall
-70.00	9R	R/B Basement N-S Interior Wall
-48.75	8aR & 8R	Reactor Basement East Edge
-43.917	8R	N-S External Wall under Fuel Handling Area Surface Mat
-38.833	7R	R/B Basement N-S Interior Wall
0.00	6R	Reactor N-S Centerline
17.833	5aR	Tendon Gallery Access Exterior Wall
39.333	4bR	Tendon Gallery Access West Wall
39.333	5R	R/B Basement N-S Interior Wall
48.75	5R & 4aR	Reactor Basement West Edge
63.71	4R	Fuel Handling Area N-S Interior Wall
70.000	3R	R/B Basement N-S Interior Wall
86.583	2aR	Fuel Handling Area and R/B N-S Interior Wall
92.167	2R	Reactor Basemat West End
106.67	1R	Basement West External Wall

Table 3NN-5

Basement Model Radial Coordinates

R (ft)	Description
0.00	Reactor Center
9.86	Reactor Pit Radius
59.00	Radius of Elevated Part of Reactor Foundation
71.83	Tendon Gallery Inner Radius
80.42	Tendon Gallery Outer Radius
93.50	Reactor Foundation Radius

Table 3NN-6

Finite Elements Assigned to Basement Model

Structural Member	Element	Mass	Stiffness
Upper Portion of Reactor Mat	Shell	Weightless	Concrete f_c=4000psi
Fuel Handling Area Surface Basemat	Shell	Weightless	Concrete f_c =4000psi
NS Exterior Walls	Shell	Concrete (adjusted)	Concrete f_c =4000psi (adjusted)
EW Exterior Walls	Shell	Concrete (adjusted)	Concrete f_c =4000psi (adjusted)
NS Basement Inner Shear Walls	Shell	Concrete (adjusted)	Concrete f_c =4000psi (adjusted)
EW Basement Inner Shear Walls	Shell	Concrete (adjusted)	Concrete f_c =4000psi (adjusted)
Connecting Shells	Shell	Weightless	Rigid
Ground Floor Slabs	Shell	Weightless	Concrete f_c =4000psi
Basemat	Solid	Concrete (adjusted)	Concrete f_c =4000psi (adjusted)
Fill Concrete	Solid	Concrete	Concrete f_c =3000psi
Rigid Rim at top of Reactor Mat	Beam	Weightless	Rigid
PCCV stick Rigid Connection	Beam	Weightless	Rigid
Containment Internal Structure Stick Rigid Connection	Beam	Weightless	Rigid
R/B-Fuel Handling Area Stick Rigid Connection	Beam	Weightless	Rigid
BS01 Lumped Mass Rigid Connection	Beam	Weightless	Rigid

Table 3NN-7

Input Material Properties

Structural Component	Concrete Compressive Strength (psi)	Young's Modulus ($x10^5$ ksf)	Poisson's Ratio	Damping OBE
PCCV	7,000	6.86	0.17	3%
R/B including FH/A, and Basement	4,000	5.191	0.17	4%
Containment Internal Structure	4,000	5.191	0.17	4%
Fill Concrete	3,000	4.496	0.17	4%

Table 3NN-8

Adjusted Material Properties of Basement Shear Walls with Openings

Wall Location	Wall Dimensions (ft)			Openings Dimensions (ft)		Stiffness Ratios		Adjusted	
	Thick.	Width	Height	Width	Height	Outplane	Inplane	E (x10^5 ksf)	w (kcf)
CL-1R segment AR-CR	3.33	53.25	27.25	8.33	8.33	0.812	0.800	4.153	0.146
CL-1R segment CR-JR CL-11R segment CR-JR	3.33	188.0	27.25	8.33	8.33	0.902	0.940	4.880	0.146
CL-1R segment JR-KR CL-11R segment JR-KR	3.33	45.33	27.25	6.66	8.33	0.823	0.807	4.189	0.146
CL-1R segment KR-LR CL-11R segment KR-LR	3.33	33.0	27.25	6.66	8.33	0.779	0.738	3.833	0.146
CL-2R segment CR-ER CL-10R segment CR-ER	2.67	55.92	26.58	3,6.6,9	6.6,10,14.41	0.750	0.672	3.490	0.149
CL-2R segment GR-JR CL-10R segment GR-JR	2.67	55.92	26.58	7.5,6.6,3	14.41,10,6.6	0.727	0.610	3.167	0.149
CL-CR segments 1R-2R & 10R-11R	3.33	12.83	26.58	6.66	8.33	0.551	0.676	2.902	0.150
CL-J1R segments 2aR-3R & 9bR-9R	2.67	16.58	25.92	3.33	6.66	0.927	0.814	4.223	0.146
CL-J1R segments 3R-5R & 7R-9R	1.67	31.17	25.92	6.66	8.33	0.950	0.866	4.494	0.146
CL-J1R segments 5R-6R & 6R-7R	1.67	38.83	25.92	6.66	8.33	0.931	0.838	4.353	0.146
CL-K1R segments 1R-2aR & 11R-9bR	2.00	18.32	25.92	3.33	6.66	0.944	0.873	4.530	0.146

Table 3NN-9

Weights Assigned to Basement Structural Members in SASSI FE Model

FE Component	Weight (kips)
EW Exterior Walls	8370
NS Exterior Walls	5871
NS Interior Walls	7337
EW Interior Walls	5167
Basemat	75855
Fill Concrete	47085
Weight assigned to basement	102600
Total Weight including fill concrete	149685

Table 3NN-10

Basement Mass Inertia

Component	Mass ($k\text{-}s^2/ft$)	I_{mx} ($k\text{-}s^2\text{-}ft$)	I_{my} ($k\text{-}s^2\text{-}ft$)	I_{mz} ($k\text{-}s^2\text{-}ft$)	Center of Mass (ft)		
					X	Y	Z
FE Mass	3186.3	16,649,068	30,226,708	46,335,404	-21.71	2.27	-25.10
Lumped Mass	1720.5	1,552,795	6,425,121	7,960,663	25.94	-1.69	-24.92
DCD BS01	4906.8	18,245,342	39,251,208	56,935,818	-5.00	0.88	-25.04

Table 3NN-11

Dynamic Properties of SASSI Model

Response		Characteristic Frequency (Hz)		
Model	**Direction**	**DCD Lumped Mass Stick Model**	**SASSI Above Ground Stick Models**	**SASSI Combined FE Model**
PCCV	NS	4.57	4.59	4.54
		12.93	13.01	12.94
	EW	4.57	4.59	4.52
		12.93	13.04	12.96
	Vertical	12.54	12.62	12.45
		22.96	23.12	23.05
R/B-FH/A	NS	5.29	5.30	5.20
		10.48	10.05	10.15
	EW	6.34	6.17	5.69
		13.13	12.20	11.55
	Vertical	16.94	16.60	15.58
Containment Internal Structure	NS	5.73	5.74	5.71
		9.42	9.35	9.23
	EW	6.25	6.20	6.20
		9.12	9.10	8.99
	Vertical	20.76	20.68	20.12
		25.12	25.95	24.85

Table 3NN-12

Maximum Accelerations in NS Direction

Structure	Lumped Mass	El. (ft)	Site Profile							Env.
			SLB	SBE	SUB	ELB	EBE	EUB	EHB	
PCCV	CV11	230.2	0.496	0.595	0.722	0.495	0.493	0.661	0.653	0.722
	CV10	225.0	0.481	0.586	0.707	0.481	0.485	0.648	0.639	0.707
	CV09	201.7	0.434	0.540	0.629	0.409	0.446	0.582	0.569	0.629
	CV08	173.1	0.384	0.476	0.559	0.346	0.395	0.508	0.505	0.559
	CV07	145.6	0.374	0.407	0.494	0.335	0.341	0.448	0.446	0.494
	CV06	115.5	0.356	0.375	0.417	0.321	0.305	0.374	0.380	0.417
	CV05	92.2	0.324	0.342	0.346	0.295	0.284	0.311	0.321	0.346
	CV04	76.4	0.292	0.306	0.313	0.268	0.260	0.281	0.293	0.313
	CV03	68.3	0.272	0.286	0.293	0.251	0.244	0.264	0.275	0.293
	CV02	50.2	0.223	0.235	0.239	0.207	0.204	0.217	0.227	0.239
	CV01	25.3	0.163	0.159	0.164	0.154	0.147	0.139	0.158	0.164
	CV00	1.9	0.129	0.124	0.128	0.114	0.126	0.123	0.118	0.129
Containment Internal Structure	IC09	139.5	0.913	1.054	1.156	0.819	0.869	0.976	0.911	1.156
	IC08	112.3	0.507	0.574	0.627	0.497	0.494	0.520	0.523	0.627
	IC18	110.8	0.482	0.546	0.595	0.477	0.470	0.493	0.499	0.595
	IC61	96.6	0.266	0.305	0.349	0.233	0.301	0.287	0.266	0.349
	IC62	96.6	0.272	0.301	0.347	0.238	0.300	0.294	0.267	0.347
	IC05	76.4	0.224	0.252	0.278	0.189	0.237	0.219	0.209	0.278
	IC07	76.4	0.224	0.252	0.278	0.189	0.237	0.219	0.209	0.278
	IC15	59.2	0.199	0.207	0.221	0.164	0.195	0.193	0.187	0.221
	IC04	50.2	0.186	0.189	0.201	0.155	0.178	0.177	0.176	0.201
	IC14	45.7	0.177	0.179	0.189	0.148	0.169	0.169	0.162	0.189
	IC03	35.6	0.156	0.159	0.163	0.135	0.151	0.151	0.150	0.163
	IC02	25.3	0.139	0.139	0.142	0.127	0.135	0.133	0.132	0.142
	IC01	16.0	0.132	0.132	0.132	0.120	0.131	0.128	0.124	0.132
	IC00	1.9	0.129	0.124	0.128	0.114	0.127	0.124	0.119	0.129
R/B-FH/A	FH08	154.5	0.606	0.701	0.780	0.586	0.892	0.742	0.723	0.892
	FH07	125.7	0.384	0.444	0.506	0.396	0.557	0.450	0.472	0.557
	RE05	115.5	0.218	0.250	0.277	0.210	0.252	0.325	0.260	0.325
	RE04	101.0	0.192	0.213	0.254	0.175	0.209	0.307	0.228	0.307
	RE41	101.0	0.205	0.229	0.263	0.189	0.217	0.303	0.238	0.303
	RE42	101.0	0.209	0.232	0.283	0.190	0.225	0.298	0.236	0.298
	FH06	101.0	0.247	0.289	0.322	0.239	0.331	0.284	0.295	0.331
	RE03	76.4	0.178	0.191	0.222	0.162	0.189	0.233	0.195	0.233
	RE02	50.2	0.163	0.173	0.183	0.144	0.174	0.190	0.163	0.190
	RE01	25.3	0.144	0.154	0.159	0.136	0.155	0.157	0.136	0.159
	RE00	3.6	0.127	0.125	0.127	0.115	0.118	0.126	0.121	0.127

Table 3NN-13

Maximum Accelerations in EW Direction

Structure	Lumped Mass	El. (ft)	Site Profile							Env.
			SLB	SBE	SUB	ELB	EBE	EUB	EHB	
PCCV	CV11	230.2	0.565	0.713	0.854	0.538	0.552	0.704	0.691	0.854
	CV10	225.0	0.555	0.699	0.837	0.532	0.541	0.689	0.678	0.837
	CV09	201.7	0.510	0.635	0.757	0.506	0.491	0.620	0.616	0.757
	CV08	173.1	0.445	0.544	0.644	0.427	0.420	0.526	0.528	0.644
	CV07	145.6	0.389	0.448	0.526	0.366	0.349	0.427	0.439	0.526
	CV06	115.5	0.321	0.347	0.405	0.298	0.276	0.327	0.341	0.405
	CV05	92.2	0.283	0.306	0.319	0.253	0.237	0.269	0.280	0.319
	CV04	76.4	0.249	0.276	0.280	0.220	0.212	0.237	0.243	0.280
	CV03	68.3	0.230	0.259	0.261	0.202	0.199	0.221	0.223	0.261
	CV02	50.2	0.185	0.214	0.213	0.163	0.169	0.188	0.181	0.214
	CV01	25.3	0.133	0.151	0.153	0.120	0.136	0.139	0.128	0.153
	CV00	1.9	0.119	0.118	0.117	0.102	0.111	0.120	0.111	0.120
Containment Internal Structure	IC09	139.5	0.920	1.034	1.108	0.790	0.965	1.054	0.937	1.108
	IC08	112.3	0.511	0.561	0.622	0.480	0.540	0.569	0.552	0.622
	IC18	110.8	0.484	0.532	0.593	0.461	0.514	0.541	0.527	0.593
	IC61	96.6	0.333	0.353	0.373	0.241	0.279	0.294	0.287	0.373
	IC62	96.6	0.333	0.353	0.373	0.241	0.279	0.294	0.287	0.373
	IC05	76.4	0.254	0.260	0.262	0.189	0.218	0.223	0.232	0.262
	IC07	76.4	0.256	0.264	0.266	0.198	0.212	0.216	0.226	0.266
	IC15	59.2	0.192	0.197	0.204	0.167	0.182	0.184	0.200	0.204
	IC04	50.2	0.175	0.180	0.182	0.159	0.173	0.170	0.183	0.183
	IC14	45.7	0.164	0.168	0.168	0.150	0.164	0.159	0.171	0.171
	IC03	35.6	0.144	0.146	0.146	0.130	0.146	0.134	0.143	0.146
	IC02	25.3	0.126	0.131	0.128	0.112	0.129	0.127	0.124	0.131
	IC01	16.0	0.123	0.124	0.123	0.107	0.119	0.123	0.118	0.124
	IC00	1.9	0.119	0.118	0.117	0.102	0.111	0.120	0.112	0.120
R/B-FH/A	FH08	154.5	0.350	0.413	0.455	0.320	0.425	0.482	0.462	0.482
	FH07	125.7	0.292	0.304	0.343	0.264	0.327	0.442	0.350	0.442
	RE05	115.5	0.271	0.317	0.383	0.247	0.308	0.337	0.333	0.383
	RE04	101.0	0.230	0.267	0.337	0.234	0.267	0.285	0.284	0.337
	RE41	101.0	0.246	0.306	0.382	0.247	0.285	0.326	0.319	0.382
	RE42	101.0	0.241	0.288	0.364	0.242	0.272	0.310	0.306	0.364
	FH06	101.0	0.245	0.247	0.282	0.223	0.267	0.287	0.266	0.287
	RE03	76.4	0.198	0.206	0.229	0.194	0.217	0.221	0.207	0.229
	RE02	50.2	0.174	0.179	0.185	0.161	0.180	0.195	0.168	0.195
	RE01	25.3	0.149	0.151	0.146	0.137	0.144	0.167	0.139	0.167
	RE00	3.6	0.126	0.125	0.125	0.114	0.115	0.136	0.113	0.136

Table 3NN-14

Maximum Accelerations in Vertical Direction

Structure	Lumped Mass	El. (ft)	Site Profile SLB	SBE	SUB	ELB	EBE	EUB	EHB	Env.
PCCV	CV11	230.2	0.437	0.482	0.515	0.362	0.394	0.626	0.430	0.626
	CV10	225.0	0.388	0.420	0.448	0.323	0.341	0.543	0.334	0.543
	CV09	201.7	0.313	0.327	0.349	0.230	0.240	0.398	0.249	0.398
	CV08	173.1	0.271	0.283	0.302	0.185	0.220	0.327	0.212	0.327
	CV07	145.6	0.255	0.266	0.284	0.174	0.212	0.303	0.203	0.303
	CV06	115.5	0.227	0.237	0.253	0.163	0.196	0.263	0.187	0.263
	CV05	92.2	0.201	0.209	0.223	0.152	0.179	0.232	0.170	0.232
	CV04	76.4	0.180	0.188	0.201	0.144	0.166	0.209	0.158	0.209
	CV03	68.3	0.169	0.177	0.188	0.138	0.159	0.196	0.149	0.196
	CV02	50.2	0.148	0.154	0.159	0.127	0.141	0.166	0.132	0.166
	CV01	25.3	0.128	0.132	0.133	0.117	0.122	0.130	0.120	0.133
	CV00	1.9	0.110	0.112	0.113	0.111	0.110	0.108	0.122	0.122
Containment Internal Structure	IC09	139.5	0.199	0.220	0.264	0.242	0.232	0.275	0.249	0.275
	IC08	112.3	0.192	0.214	0.253	0.231	0.222	0.263	0.235	0.263
	IC18	110.8	0.190	0.213	0.252	0.229	0.220	0.261	0.233	0.261
	IC61	96.6	0.160	0.181	0.205	0.176	0.180	0.203	0.198	0.205
	IC62	96.6	0.160	0.182	0.209	0.173	0.178	0.208	0.195	0.209
	IC05	76.4	0.121	0.133	0.146	0.144	0.143	0.163	0.134	0.163
	IC07	76.4	0.157	0.178	0.208	0.181	0.184	0.204	0.178	0.208
	IC15	59.2	0.112	0.122	0.132	0.131	0.129	0.146	0.123	0.146
	IC04	50.2	0.108	0.117	0.126	0.123	0.122	0.136	0.117	0.136
	IC14	45.7	0.106	0.113	0.122	0.119	0.117	0.131	0.117	0.131
	IC03	35.6	0.106	0.107	0.112	0.116	0.112	0.118	0.119	0.119
	IC02	25.3	0.107	0.109	0.109	0.114	0.108	0.107	0.119	0.119
	IC01	16.0	0.109	0.111	0.111	0.112	0.108	0.105	0.121	0.121
	IC00	1.9	0.110	0.112	0.113	0.111	0.110	0.107	0.122	0.122
R/B-FH/A	FH08	154.5	0.318	0.361	0.392	0.363	0.401	0.501	0.408	0.501
	FH07	125.7	0.290	0.330	0.358	0.331	0.373	0.473	0.374	0.473
	RE05	115.5	0.264	0.294	0.312	0.262	0.306	0.325	0.322	0.325
	RE04	101.0	0.245	0.273	0.286	0.241	0.291	0.308	0.309	0.309
	RE41	101.0	0.314	0.354	0.371	0.348	0.420	0.512	0.400	0.512
	RE42	101.0	0.259	0.292	0.325	0.274	0.309	0.354	0.305	0.354
	FH06	101.0	0.265	0.300	0.332	0.302	0.342	0.438	0.345	0.438
	RE03	76.4	0.131	0.140	0.148	0.164	0.182	0.228	0.174	0.228
	RE02	50.2	0.124	0.127	0.127	0.153	0.164	0.205	0.154	0.205
	RE01	25.3	0.117	0.119	0.119	0.143	0.147	0.172	0.141	0.172
	RE00	3.6	0.111	0.114	0.115	0.135	0.134	0.139	0.126	0.139

Table 3NN-15

SASSI Results for R/B-PCCV-Containment Internal Structure Seismic Response

SSI Effect	Observed Response
Rock Subgrade	The rock subgrade, due to its high stiffness, has insignificant SSI effect on the seismic response of PCCV, R/B, and containment internal structures. The structural natural frequencies characterize the response obtained from SASSI analyses of the surface foundation.
Backfill Embedment	The embedment affects the overall response of the PCCV, R/B, and containment internal structure. In general, the horizontal response of the structures is reduced due to the dissipation of energy in the backfill. The reduction is more pronounced for cases of soft backfill, which has higher values of strain-compatible material damping.
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. The response of the backfill is characterized by multiple modes that magnify the response of the structure as their frequencies approach the structural frequencies. These resonance effects are most pronounced in the vertical direction is for stiffer backfill with low material damping.
Basement Flexibility	The flexibility of the basement shear walls has some effect on the structural response. Due to the flexibility of the shear walls under the R/B, and FH/A, their response at ground elevation is decoupled from the response of PCCV and containment internal structures that are supported directly on the central thick portion of the basemat.

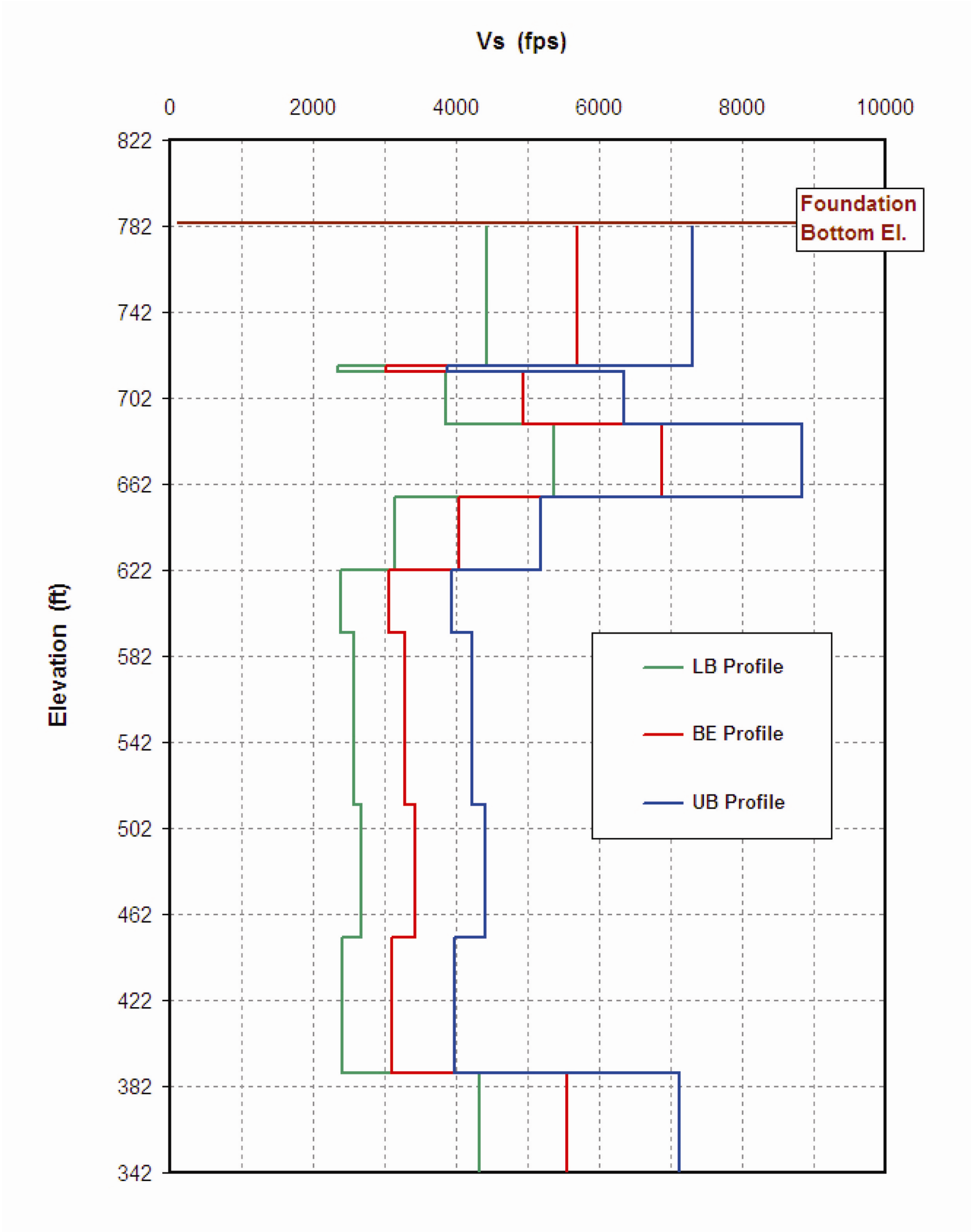


Figure 3NN-1 Rock Subgrade S-Wave Velocity Profiles

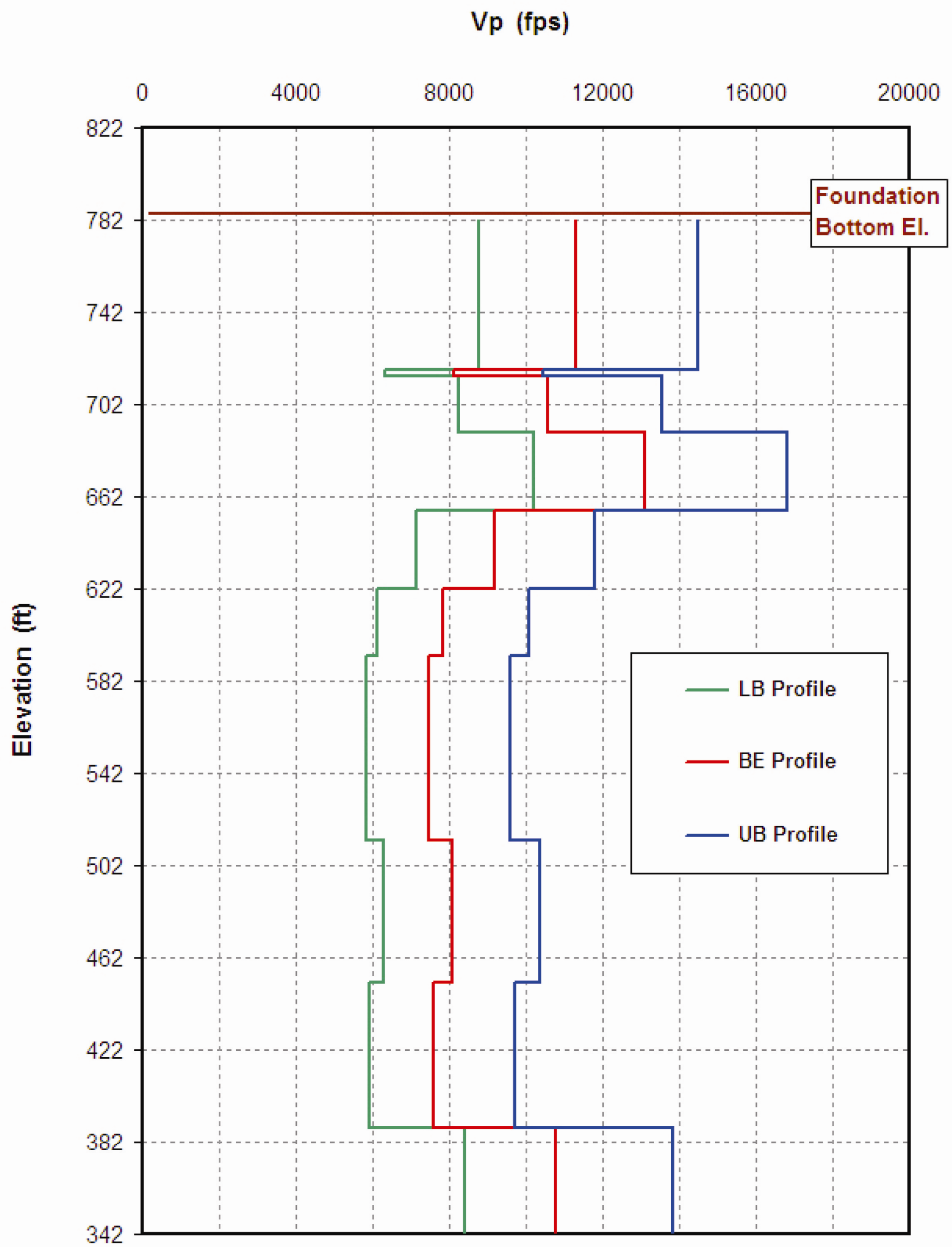


Figure 3NN-2 Rock Subgrade P-Wave Velocity Profiles

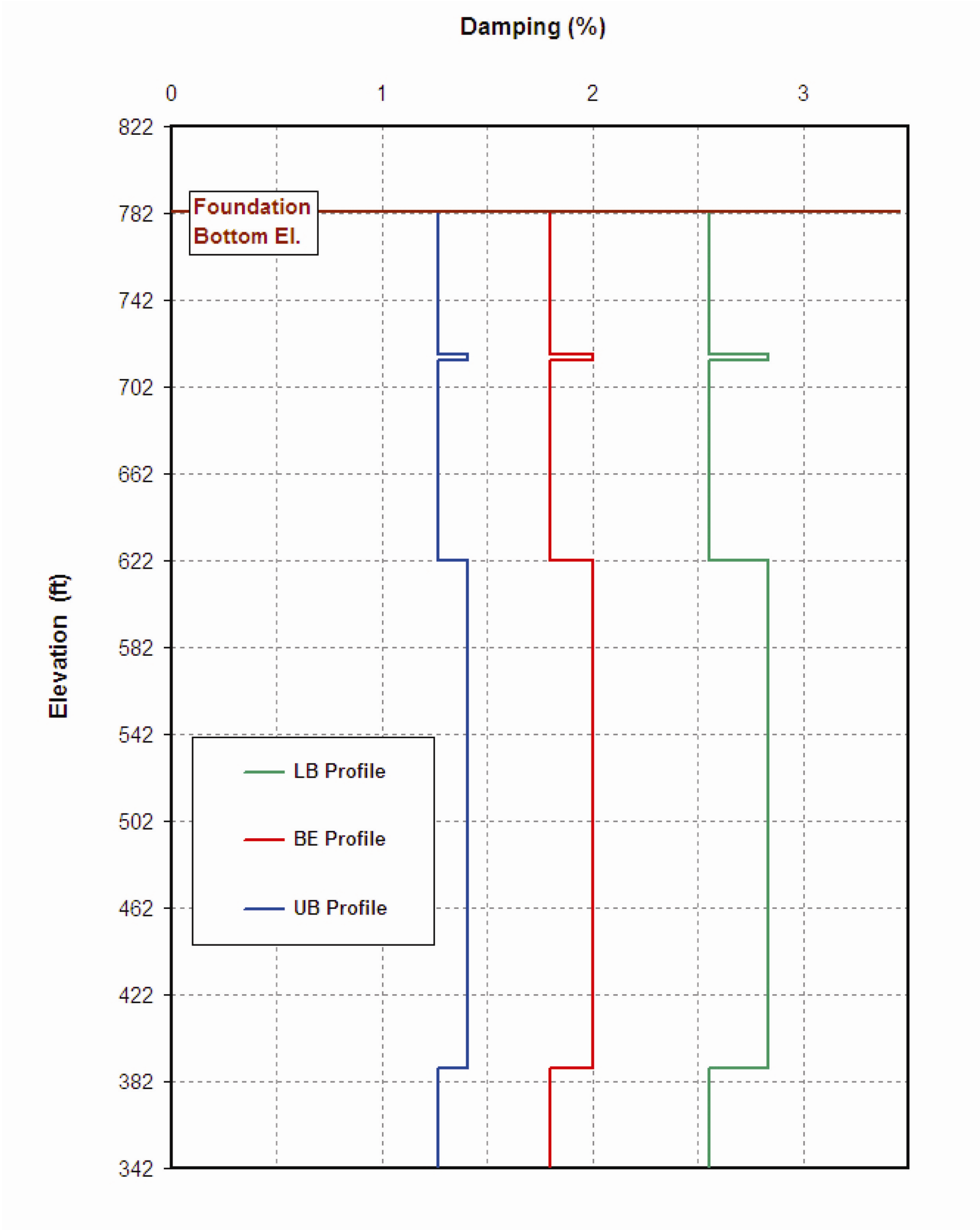


Figure 3NN-3 Rock Subgrade Damping Profiles

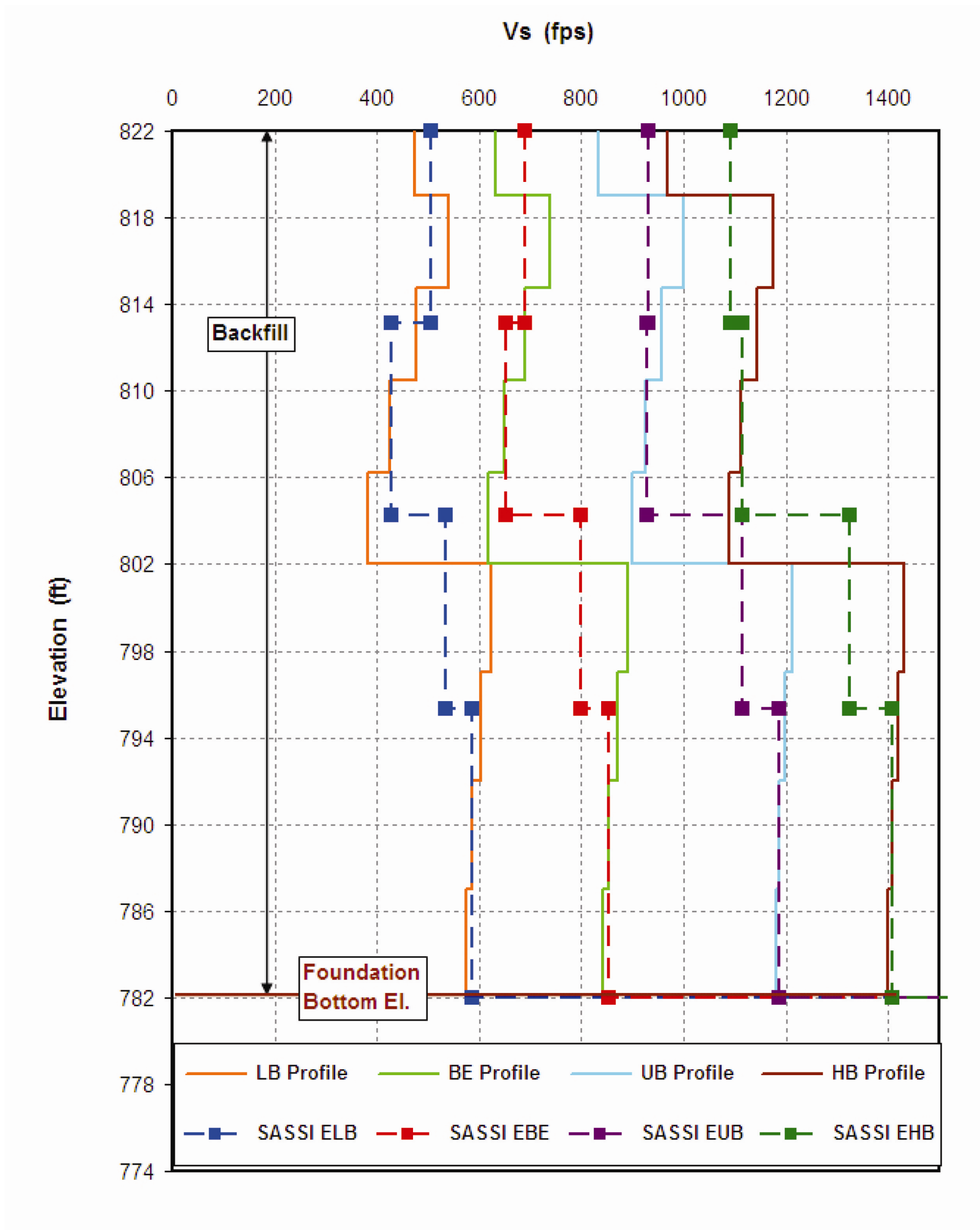


Figure 3NN-4 Backfill Strain-Compatible S-Wave Velocity Profiles

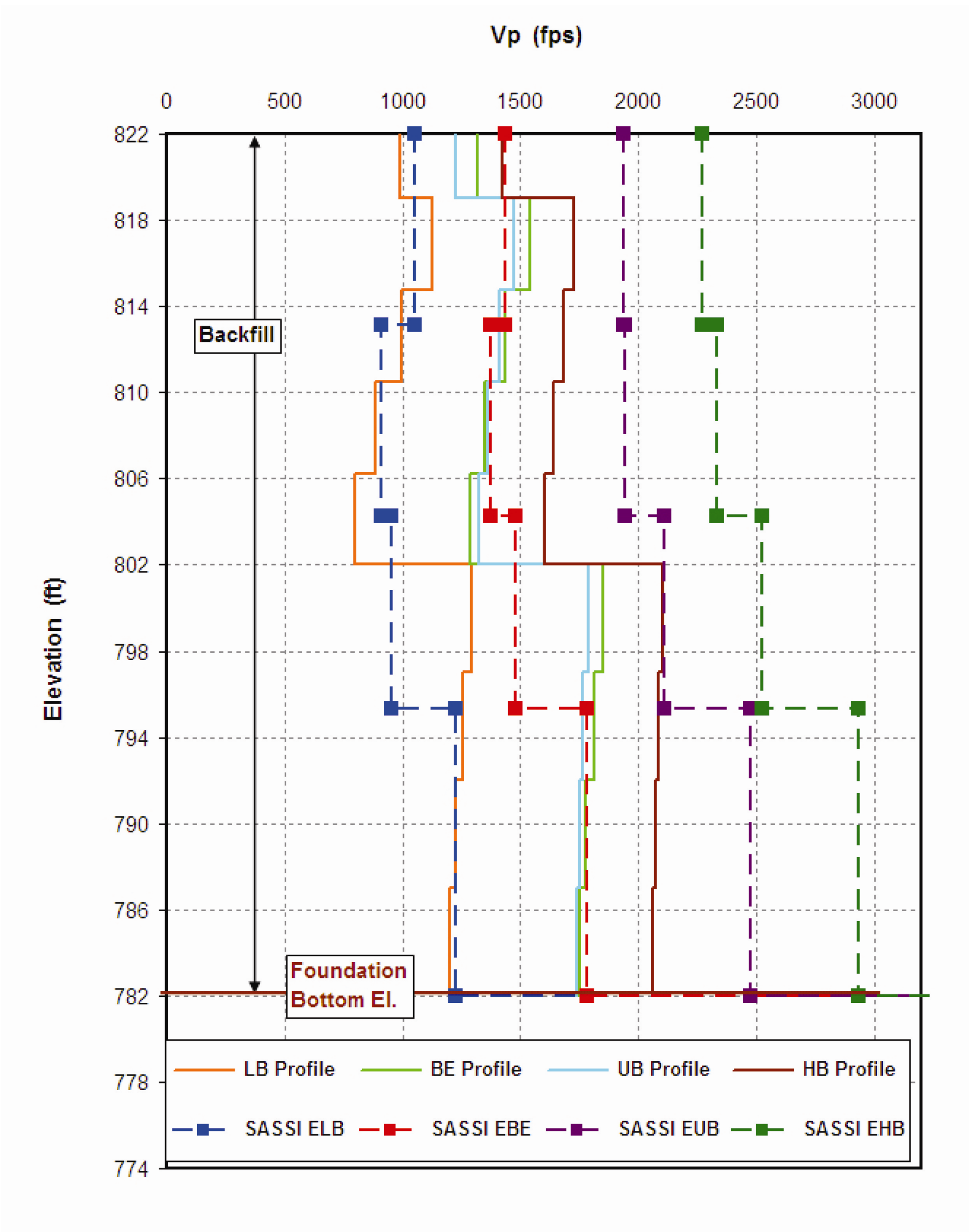


Figure 3NN-5 Backfill Strain-Compatible P-Wave Velocity Profiles

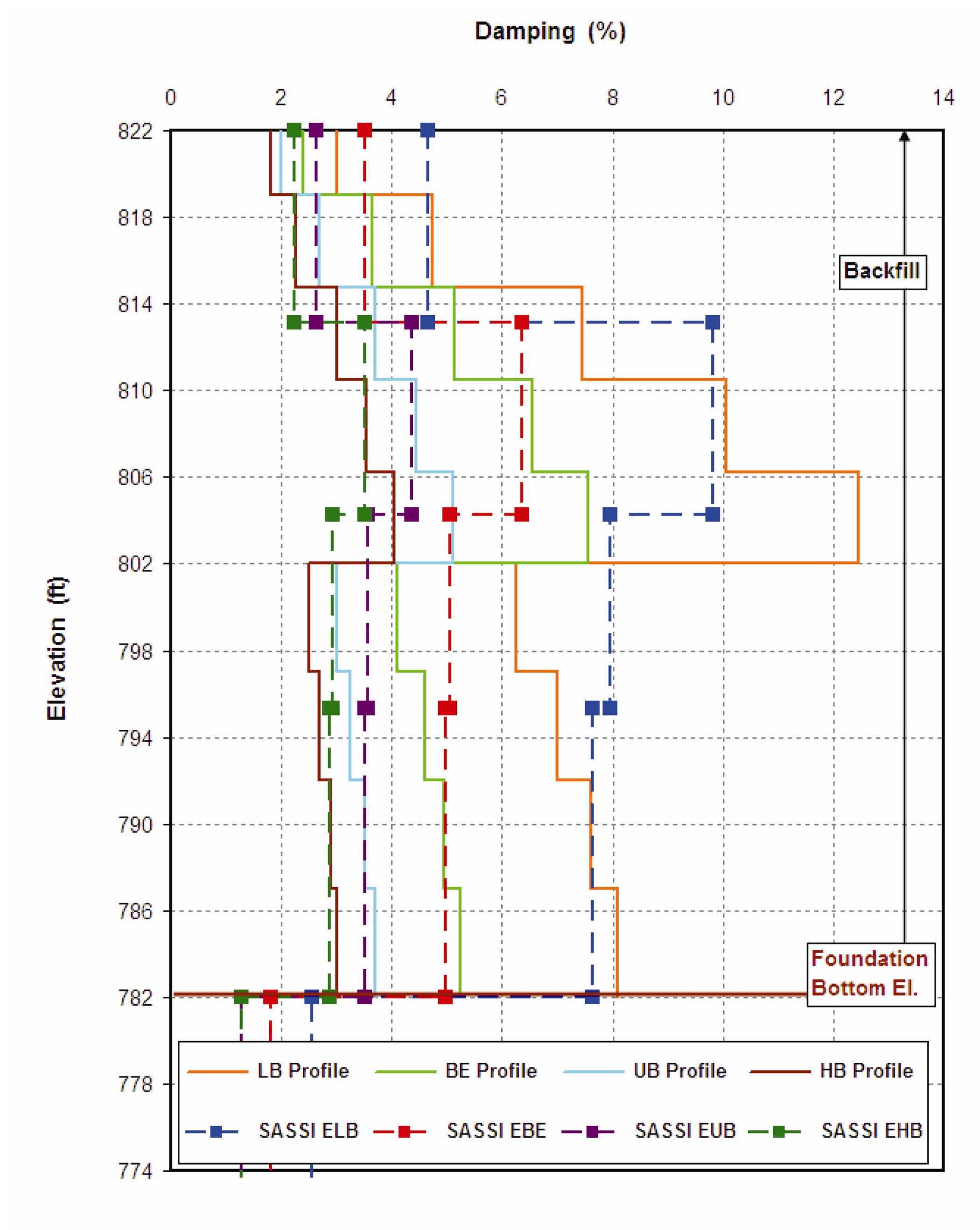


Figure 3NN-6 Backfill Strain-Compatible Damping Profiles