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Ref. # 10 CFR 52

November 24, 2009

U. S. Nuclear Regulatory Commission
Document Control Desk
Washington, DC 20555
ATTN: David B. Matthews, Director
Division of New Reactor Licensing

SUBJECT: COMANCHE PEAK NUCLEAR POWER PLANT, UNITS 3 AND 4
DOCKET NUMBERS 52-034 AND 52-035
RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION NO. 2879

Dear Sir:

Luminant Generation Company LLC (Luminant) herein submits the response to Request for Additional Information No. 2879 for the Combined License Application for Comanche Peak Nuclear Power Plant Units 3 and 4. The affected Final Safety Analysis Report pages are included with the responses.

Should you have any questions regarding these responses, please contact Don Woodlan (254-897-6887, Donald.Woodlan@luminant.com) or me.

The commitments made in this letter are specified on page 3.

I state under penalty of perjury that the foregoing is true and correct.

Executed on November 24, 2009.

Sincerely,

Luminant Generation Company LLC

RDBirdf for

Rafael Flores

Attachments
1. Response to Request for Additional Information No. 2879 (CP RAI #60)
2. Project Report, "Dynamic Profile," TXUT-001-PR-007, Revision 2
3. SASSI Model of US-APWR Reactor Building, 4DS-CP34-20080048 Rev.1, Mitsubishi Heavy Industries, LTD, September 17, 2008
4. Site Specific SSI Analysis of US-APWR Reactor Building, SSI-12-05-100-003 Rev. C, URS, November 13, 2009.

D090
NRO

cc: Stephen Monarque w/all attachments

Electronic Distribution w/Attachment 1

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Regulatory Commitments in this Letter

This communication contains the following new or revised commitments which will be completed or incorporated into the CPNPP licensing basis as noted. The Commitment Number is used by Luminant for internal tracking.

Number	Commitment	Due Date/Event
6811	The COLA FSAR will be revised to incorporate as necessary the results of the MHI SSI analyses.	COLA Revision 2
6821	The site-specific SSI analyses of the R/B will be revised to address the changes in the building basement configuration and design enhancements. The FSAR will be revised in COLA Revision 2 to include the SSI analyses that will provide SASSI calculated dynamic earth pressures for direct comparison. FSAR Sections 3.7 and 3.8 and Appendix 3NN will be revised in the next COLA revision to address the basemat configuration and design embedments and to provide SASSI calculated dynamic earth pressures.	COLA Revision 2
6831	Because of the large ratio of the standard plant input motion versus the site-specific input motion, the assumptions for the standard plant design of the A/B and T/B were considered to envelope the critical responses of the non-uniform site-specific soil column profiles, and were not validated by performing site-specific SSI analyses. SSI analyses for A/B and T/B in generic standard soil input will be performed by May 2010.	May 2010

Attachment 1

Response to Request for Additional Information No. 2879 (CP RAI #60)

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

Comanche Peak, Units 3 and 4

Luminant Generation Company LLC

Docket Nos. 52-034 and 52-035

RAI NO.: 2879 (CP RAI #60)

SRP SECTION: 03.07.02 - Seismic System Analysis

QUESTIONS for Structural Engineering Branch 1 (AP1000/EPR Projects) (SEB1)

DATE OF RAI ISSUE: 9/15/2009

QUESTION NO.: 03.07.02-1

NUREG-0800, Standard Review Plan (SRP) 3.7.2, "Seismic System Analysis," establishes the criteria the NRC staff will use to evaluate whether an applicant meets the NRC's regulations.

In order to evaluate the site response analyses supporting the Comanche Peak Nuclear Power Plant combined license application (COLA), the NRC staff needs the following detailed information for both the site-independent and site-specific analyses:

1. The name and revision of the software used for the site response analysis.
2. The elevation at which the control motions are defined.
3. The response spectra corresponding to the control motions.
4. The low-strain and strain-compatible free-field properties including the shear moduli, the unit weights, the damping ratios, and the layer thicknesses for the soil column for all cases considered.
5. The cut-off frequencies used in the analyses.
6. The soil column natural frequencies determined from the site response analyses.
7. The free-field amplification spectra from the site response analyses at critical elevations in the soil columns.
8. The strain levels in the soil columns.

ANSWER:

<u>Site-Independent Analysis</u>

The standard design documented in the DCD is based on generic soil profiles that assume that the properties are compatible to the strains generated by the design ground motion defined by certified seismic design response spectra (CSDRS). No site response analyses were performed for the standard design seismic response analyses.

Site-Specific Analysis

Additional details of the site-specific site response analysis were provided in the following responses:

- RAI No. 2876 (CP RAI #55) Questions 03.07.01-2 and 03.07.01-3 (Luminant letter TXNB-09058 dated Oct. 26, 2009) (ML093010366)
- RAI No. 1889 (CP RAI #11) Question 02.05.02-8 (Luminant letter TXNB-09042, dated Sep 10, 2009) (ML092820486)
- FSAR Subsection 2.5.2, issue 1 in resolution of docketing issues regarding FSAR Subsections 2.5.1, 2.5.2, and 2.5.4 (partial) (Luminant letter TXNB-08028, dated Nov. 5, 2008) (ML083120279)
- RAI No. 2929 (CP RAI #22) Question 02.05.04-14 (Luminant letter TXNB-09049, dated Sep 28, 2009) (ML092740182)

The issues raised in the RAI No. 2876 (CP RAI #55) Questions 03.07.01-2 and 03.07.01-3 are addressed below.

1. The name and revision of the software used for the site response analysis.

   The program used for the site-response calculations for the GMRS is RVTSITE Version 1.2. This program uses the same equivalent-linear formulation of the soil-column dynamics as the SHAKE program (Schnabel and Seed, 1972; Idriss and Sun, 1992), and it uses a random-vibration theory representation of the motions. Further details and references on the methodology are provided in the response to RAI No. 2876 (CP RAI #55) Question 03.07.01-2.

2. The elevation at which the control motions are defined.
   The elevations of the GMRS calculations and the 4 FIRS calculations are presented in FSAR Subsections 2.5.2.6.1 and 2.5.2.6.2. These elevations are:

   - GMRS/FIRS1: 782 ft
   - FIRS2: 787 ft
   - FIRS3: 822 ft
   - FIRS4: 822 ft
   - FIRS4-CoV50: 822 ft

3. The response spectra corresponding to the control motions.

   The response spectra for the GMRS and 4 FIRS calculations are discussed in FSAR Subsections 2.5.2.6.1 and 2.5.2.6.2 and presented within the following figures and tables:

   - GMRS/FIRS1: Table 2.5.2-236 and Figure 2.5.2-247
   - FIRS2: Table 2.5.2-237 and Figure 2.5.2-248
   - FIRS3: Table 2.5.2-237 and Figure 2.5.2-249
   - FIRS4: Table 2.5.2-237 and Figure 2.5.2-250
   - FIRS4-CoV50: Table 2.5.2-237 and Figure 2.5.2-251

   FSAR Subsection 3.7.1.1 has been revised to incorporate this response.

4. The low-strain and strain-compatible free-field properties including the shear moduli, the unit weights, the damping ratios, and the layer thicknesses for the soil column for all cases considered.

As described in FSAR Subsection 2.5.2.5, the properties of the soil column used for the GMRS and FIRS calculations are presented within Table 2.5.2-227.

5. The cut-off frequencies used in the analyses.

The site response analysis is conducted between the frequencies of 0.1 to 100 Hz, as described in FSAR Subsection 2.5.2.6.1.1. This subsection was revised in FSAR Update Tracking Report, Revision 0, Technical Correction Version, attached Luminant letter TXNB-09005, April 2, 2009 (ML091120280). This spectral frequency range encompasses all the energy of the rock ground motions for earthquakes in Central and Eastern United States and meets the requirements in Subsection 3.4 “Hazard Assessment” in Item C “Regulatory Position” of Regulatory Guide 1.208.

FSAR Subsection 2.5.2.6.1.1 has been revised to incorporate this response.

6. The soil column natural frequencies determined from the site response analyses.

The natural frequency of the GMRS soil column is 0.29 Hz (corresponding to a period of 3.5 seconds). This value is also representative of the soil columns employed for the various FIRS soil columns.

FSAR Subsection 2.5.2.6.1.1 has been revised to incorporate this response.

7. The free-field amplification spectra from the site response analyses at critical elevations in the soil columns.

The free-field amplification factors were calculated at the GMRS and FIRS elevations for the site-specific analysis. As discussed in FSAR Subsection 2.5.2.6, these amplification factors are presented within the following figures and tables:

- GMRS/FIRS1: Table 2.5.2-231 and Figure 2.5.2-233
- FIRS2: Table 2.5.2-232 and Figure 2.5.2-235
- FIRS3: Table 2.5.2-233 and Figure 2.5.2-236
- FIRS4: Table 2.5.2-234 and Figure 2.5.2-237
- FIRS4-CoV50: Table 2.5.2-235 and Figure 2.5.2-238

8. The strain levels in the soil columns.

Figures 1 and 2 present the peak strain in the upper 500 ft of the GMRS/FIRS1 soil column for the 1×10^{-4} and 1×10^{-5} broad-band (BB) spectra, respectively (see FSAR Subsection 2.5.2.5.2 for details of the BB spectra). The maximum value of the logarithmic-mean strain (over the 60 synthetic profiles) in the entire GMRS/FIRS1 profile for the 1×10^{-4} spectrum is approximately 0.0035% and occurs at a depth of approximately 390 ft in the profile. The maximum value of the logarithmic-mean strain in the entire GMRS/FIRS1 profile for the 1×10^{-5} spectrum is approximately 0.0075% and also occurs at a depth of approximately 390 ft in the profile.

Figures 3 and 4 present the peak strain in the upper 50 ft of the FIRS4 soil column for the 1×10^{-4} and 1×10^{-5} broad-band (BB) spectra, respectively (see FSAR Subsection 2.5.2.5.2 for details of the BB spectra). As described in FSAR Subsection 2.5.2.6, the FIRS4 site profile consists of compacted fill overlying the stiff limestone that is the outcrop of the GMRS/FIRS1 profile. As such, the peak strains within most of the FIRS4 profile are similar to the peak strains within the GMRS/FIRS1 profile with the exception of peak strains within the fill (i.e., the upper 40 ft). Therefore, Figures 3 and 4 only show the peak strains within the upper 50 ft of the FIRS4 profile. The maximum value of the logarithmic-mean strain in the FIRS4 profile for the 1x10^{-4} spectrum is approximately 0.006% and occurs at depths of approximately 17 and 37 ft in the profile. The maximum value of the logarithmic-mean strain in the FIRS4 profile for the 1x10^{-5} spectrum is approximately 0.016% and also occurs at depths of approximately 17 and 37 ft in the profile.

Figures 1 through 4 below have been incorporated in FSAR Subsection 2.5. References and text descriptions of these figures have been incorporated in FSAR Subsection 2.5.2.5.2.3.

For clarification and information to the reviewer, FSAR Subsection 3.7.1.1 was revised to provide reference to Subsections 2.5.2.5 and 2.5.2.6 for the calculation of GMRS and FIRS in the response to RAI 2876 (CP RAI #55), Question 03.07.01-2 (see attached marked-up page 3.7-2).

References

Idriss, I., and Sun, J.I., 1992, Users Manual for SHAKE91.

Schnabel, S. and Seed, H.B., 1972, SHAKE- A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites, Report No. 72-12, Earthquake Engineering Research Center (EERC).

Impact on R-COLA

See attached marked-up FSAR Draft Revision 1 pages 2.0-12, 2.5-114, 2.5-115, 2.5-116, 2.5-117, 2.5-119, 2.5-120, 2.5-121, 2.5-122, 2.5-123, 2.5-124, 2.5-126, Figures 2.5.2-253, 2.5.2-254, 2.5.2-255, and 2.5.2-256, and page 3.7-2.

Impact on S-COLA

None.

Impact on DCD

None.

Attachments

Figure 1 - Maximum strain for upper 500 ft of GMRS/FIRS1 profiles 1x10^{-4} broad-band spectra

Figure 2 - Maximum strain for upper 500 ft of GMRS/FIRS1 profiles 1x10^{-5} broad-band spectra

Figure 3 – Maximum strain for upper 50 ft of FIRS4 profiles 1x10^{-4} broad-band spectra

Figure 4 - Maximum strain for upper 50 ft of FIRS4 profiles 1x10^{-5} broad-band spectra

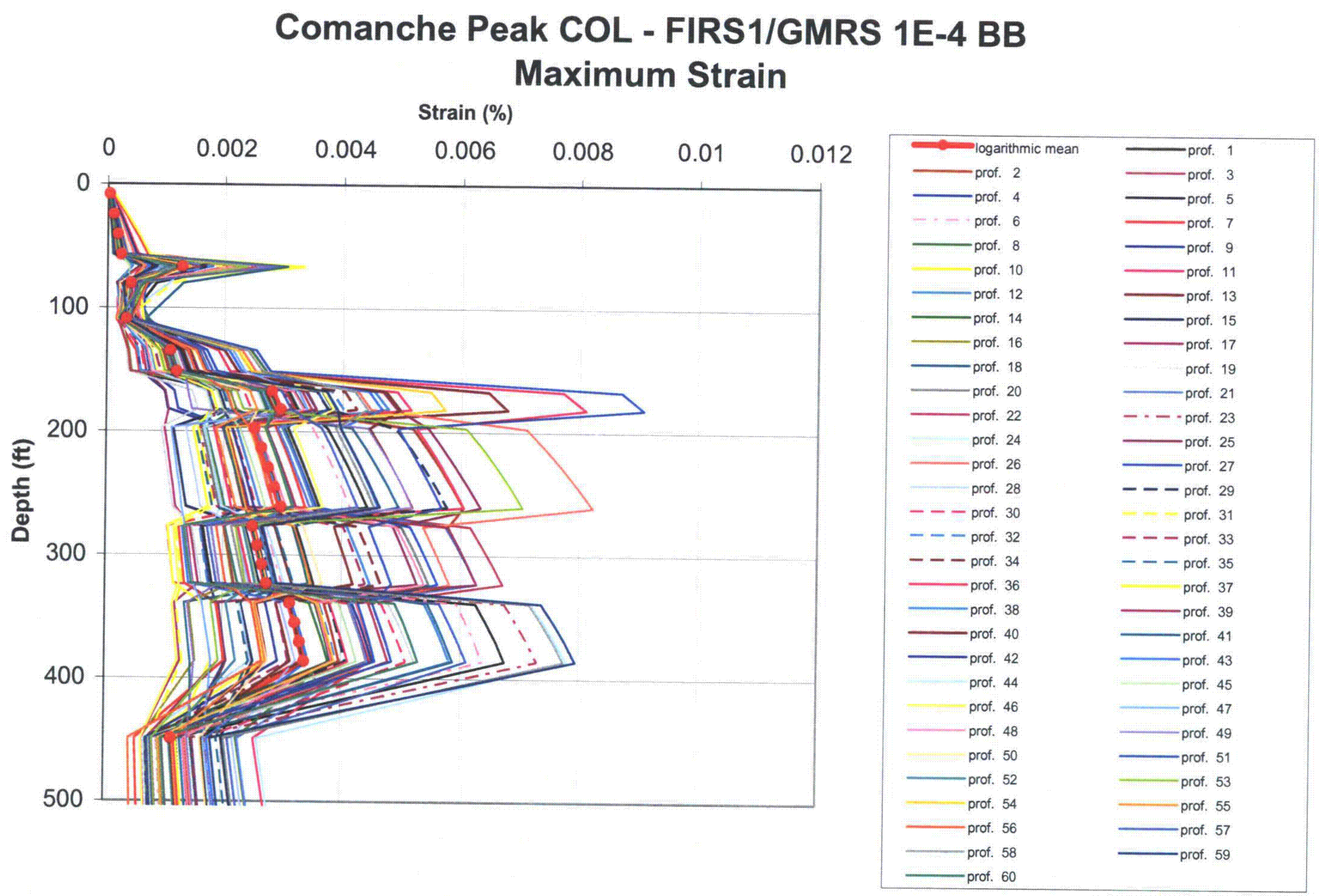

Figure 1: Maximum strain for upper 500 ft of GMRS/FIRS1 profiles $1\text{x}10^{-4}$ broad-band spectra

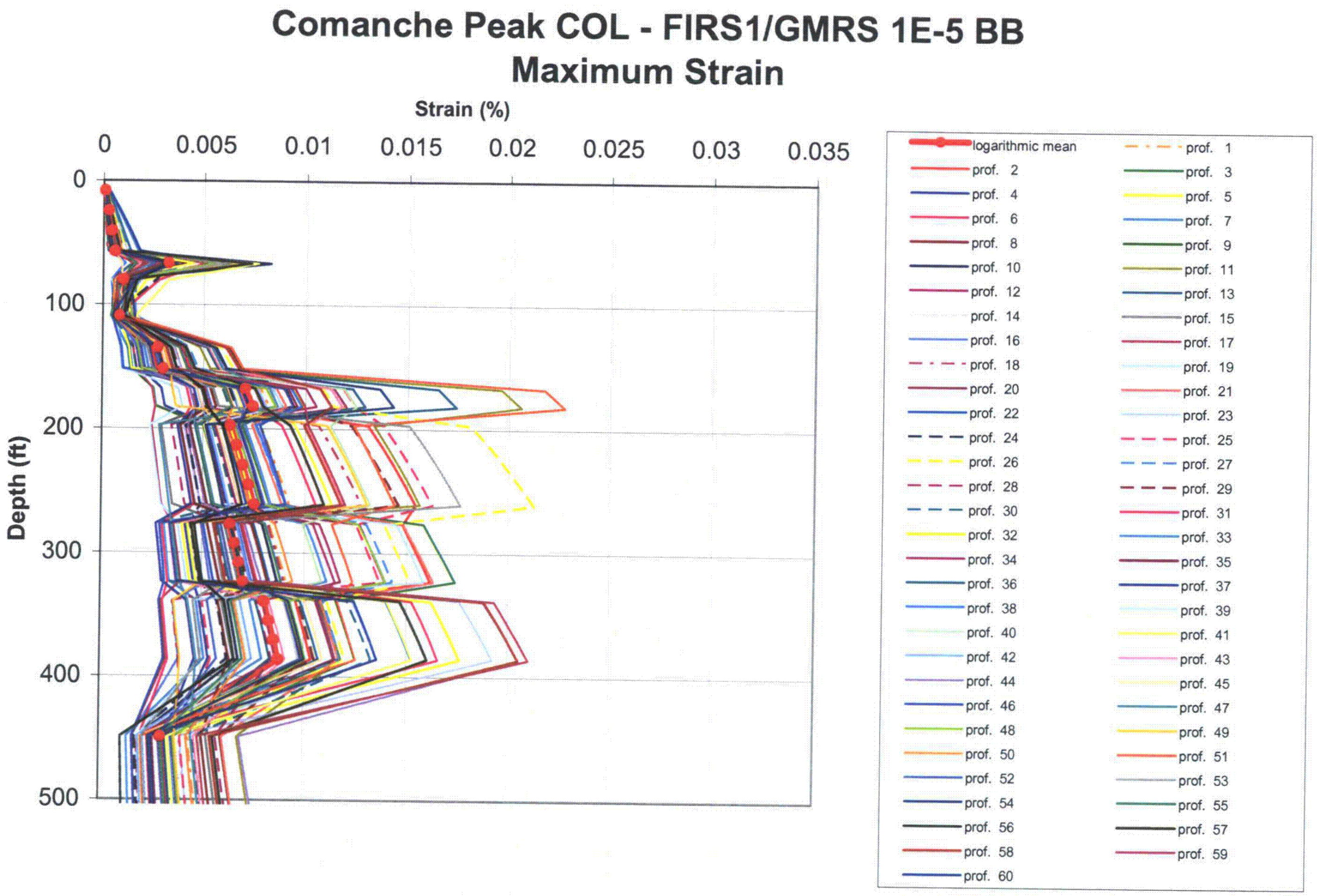

Figure 2: Maximum strain for upper 500 ft of GMRS/FIRS1 profiles $1x10^{-5}$ broad-band spectra

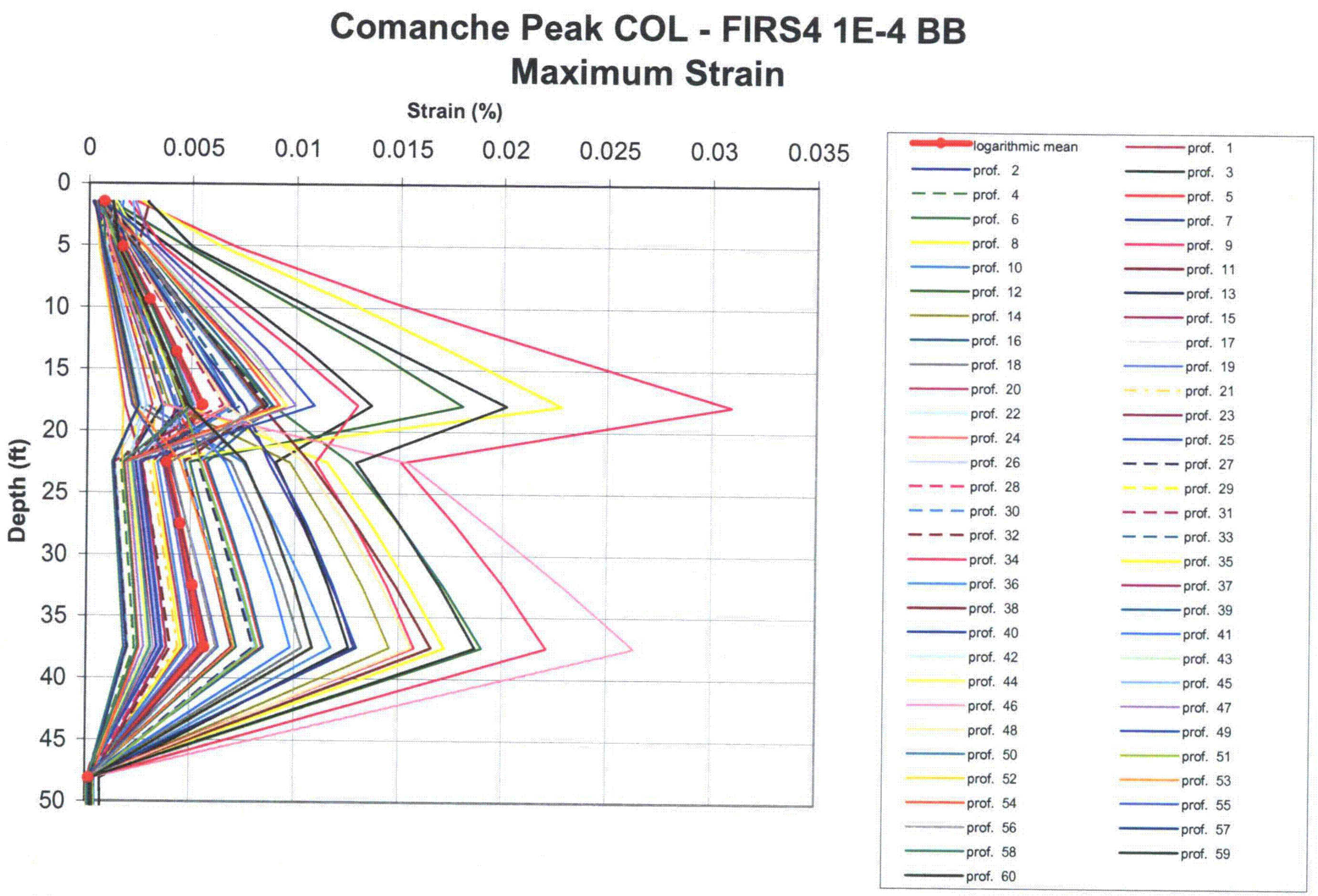

Figure 3: Maximum strain for upper 50 ft of FIRS4 profiles 1×10^{-4} broad-band spectra

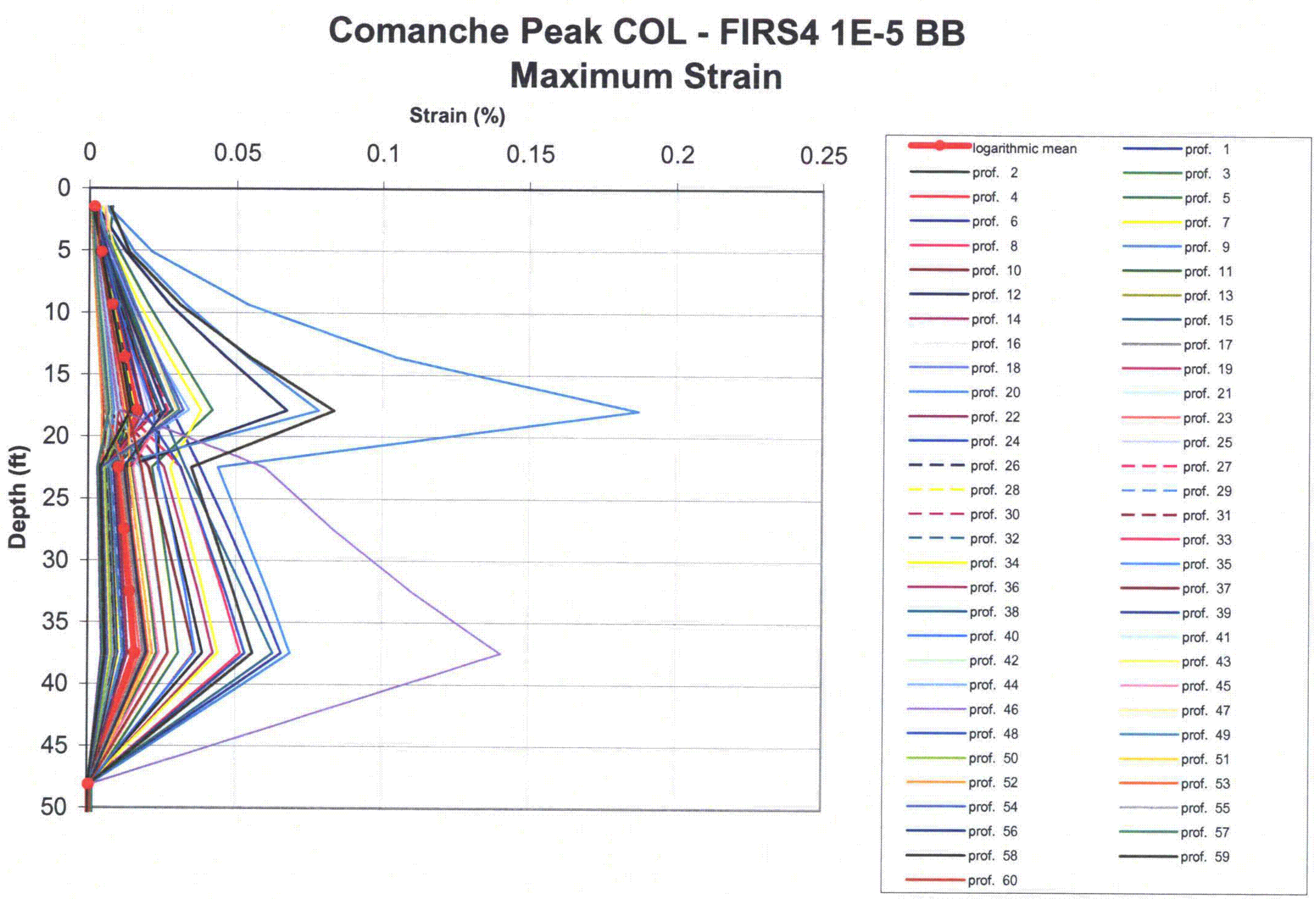

Figure 4: Maximum strain for upper 50 ft of FIRS4 profiles $1x10^{-5}$ broad-band spectra

Table 2.0-1R (Sheet 11 of 12)
Key Site Parameters

CP COL 2.1(1)
CP COL 2.2(1)
CP COL 2.3(1)
CP COL 2.3(2)
CP COL 2.3(3)
CP COL 2.4(1)
CP COL 2.5(1)

SSE (certified seismic design) vertical ground response spectra	RG 1.60, enhanced spectra in high frequency range (see Figure 3.7.1-2)	For vertical FIRS motions, the same considerations used for the GMRS were used for the FIRS. That is, for large source-to-site distances, results in ~~the US-APWR DCD~~NUREG/CR-6728 indicate that V/H ratios will be less than unity for all frequencies. V/H ratios are likely to be considerably less than unity at frequencies below 5 Hz. Appendix J of ~~the DCD~~NUREG/CR-6728 indicates that for distances exceeding 40 km, soil sites in both the WUS and CEUS will have V/H ratios of 0.5 or less. Thus it is reasonable to assume that vertical FIRS will be enveloped by the vertical minimum DCD spectrum.
Potential for surface tectonic deformation at site	None within the exclusion area boundary	No potential tectonic surface deformation has been identified at the site.
Subsurface stability – average static bearing capacity	15,000 lb/ft^2	The average bearing capacity of the foundation bearing stratum meets or exceeds the DCD requirement
Subsurface stability – average dynamic bearing capacity, normal conditions plus SSE	95,000 lb/ft^2	The average dynamic bearing capacity of the foundation bearing stratum meets or exceeds the DCD requirement
Subsurface stability – minimum shear wave velocity at SSE input at ground surface	1000 ft/s	The site stratigraphy has a measured velocity in excess of 1000 ft/sec
Subsurface stability – shear wave velocity for defining firm rock	3500 ft/s	The site meets the minimum 3500ft/sec for a firm rock site

CTS-00916
CTS-00916

Smooth rock UHRS were developed from the UHRS amplitudes in Table 2.5.2-219, using controlling earthquake Mw and R values shown in Table 2.5.2-220 and using the hard rock spectral shapes for CEUS earthquake ground motions recommended in NUREG/CR-6728. Separate spectral shapes were developed for high frequencies (HF) and low frequencies (LF). In order to accurately reflect the UHRS values calculated by the PSHA as shown in Table 2.5.2-220, the HF spectral shape was anchored to the UHRS values from Table 2.5.2-220 at 100 Hz, 25 Hz, 10 Hz, and 5 Hz. In between these frequencies, the spectrum was calculated using shapes anchored to the next higher and lower frequency and weighting those shapes. The weighting was based on the inverse logarithmic difference between the intermediate frequency and the next higher or lower frequency. This technique provided a smooth, realistic spectral shape at these intermediate frequencies. Below 5 Hz, the HF shape was extrapolated from 5 Hz.

For the LF spectral shape a similar procedure was used except that the LF spectral shape was anchored to the UHRS values at all seven ground motion frequencies for which hazard calculations were made (100 Hz, 25 Hz, 10 Hz, 5 Hz, 2.5 Hz, 1 Hz, and 0.5 Hz). Anchoring the LF spectral shape to all frequencies was necessary because otherwise the LF spectral shape exceeded the HF spectral shape at high frequencies. The use of a LF shape with amplitudes higher than the HF UHRS amplitudes would not be appropriate because this would overdrive the soil column. Anchoring the LF spectrum to the UHRS amplitudes at all frequencies ensures that appropriate ground motions are represented. The lack of fit of the LF spectral shape to the HF UHRS amplitudes results from distant, large earthquakes that contribute to seismic hazard at this site, with ground motion ε values greater than unity. In these cases, the spectral shapes of NUREG/CR-6728 are not appropriate and the LF spectrum needs to be anchored to the HF UHRS amplitudes. RCOL2_02.05.02-18

Figures 2.5.2-229 through 2.5.2-231 show the smooth horizontal HF and LF UHRS calculated in this way for 10^{-4}, 10^{-5}, and 10^{-6} annual frequencies of exceedance, respectively. As mentioned previously, these spectra accurately reflect the UHRS amplitudes in Table 2.5.2-219 that were calculated for the seven spectral frequencies at which PSHA calculations were done. Because the HF and LF spectra were scaled to the same high-frequency amplitudes, they are very similar at high frequencies and differ only for frequencies below 5 Hz. As a result of these similarities, a broad-banded spectrum was used as input to site response calculations, using the envelope of the HF and LF spectra shown in Figures 2.5.2-229 through 2.5.2-231.

2.5.2.5 Seismic Wave Transmission Characteristics of the Site

CP COL 2.5(1) Replace the content of DCD Subsection 2.5.2.5 with the following.

The subsurface conditions necessary to predict and model the seismic wave transmission characteristics for CPNPP Units 3 and 4 were determined from both site–specific and regional data. This data included both stratigraphic and representative shear and compressional wave measurements that were used to CTS-00916 develop the site profile and is summarized in Table 2.5.2-227. A detailed discussion of the data and methodology for developing the stratigraphy and corresponding dynamic properties used to define the dynamic profile for the site is provided in Subsection 2.5.4.4.2.2. RCOL2_02.05.02-8 CTS-00916

The profile is divided into the shallow profile (surface to about 500 ft) and the deep profile (about 500 ft to "basement"). The shallow profile represents depth to which extensive characterization has been performed. The lateral and vertical control on the subsurface strata (layering) was defined primarily on lithology and material properties. The velocity measurements in the shallow profile have been developed from 15 suspension logs from borings drilled as part of the foundation exploration described in Subsection 2.5.4.4.2.1. RCOL2_02.05.02-8

The foundation basemats of all ~~category 1~~seismic Catergory I structures will be founded on a limestone unit (denoted as Layer C in Subsection 2.5.4), with the exception of ~~category 1~~seismic Category I electrical duct banks that will be embedded in compacted fill adjacent to the nuclear island. Excavation to Layer C will remove the shallower units (layers A, B1, and B2) and, where the top of Layer C is below the bottom of the elevation, fill concrete will be placed to achieve the bottom of basemat elevation. The average thickness of Layer C is greater than 60 ft and dips less than 1°. The average shear wave velocity of Layer C is greater than 5800 ft/sec, as determined from the 15 suspension log borings. Profiles for development of the GMRS and FIRS are detailed in Subsection 2.5.2.6 and provide the criteria for exclusion or inclusion of specific layers including fill concrete and compacted fill. CTS-00916 CTS-00916 RCOL2_02.05.02-7

The deep profile was characterized from regional wells and maps. Strata that define the deep profile are based primarily on lithology and stratigraphic surfaces projected to the CPNPP site to estimate the elevation. Velocity data for the deep profile was limited to only a few wells and consisted primarily of compressional wave velocities except where shear wave velocity data was available from a single well as discussed in the following section on uncertainties. Basement was defined as the depth at which a shear wave velocity of 9200 ft/sec and greater was achieved. Basement was therefore defined as the top of the Ellenburger limestone located at a depth of about 5300 ft at the site. The Ellenburger is a regionally extensive unit with an estimated shear wave velocity of nearly 11,000 ft/sec.

2.5.2.5.1 Aleatory and Epistemic Uncertainity

RCOL2_02.05.02-8

The shallow profile has been extensively characterized from over 150 geotechnical borings and geologic mapping of the area. The profile has been stratified based on vertical changes in lithology that can be mapped laterally from boring to boring. Standard deviations for the top of each shallow profile layer are less than 2 ft for the upper 200 ft of the profile. The standard deviation for the layers defining the shallow profile from about 200 ft to about 500 ft range from about 1 to 5 ft. Velocity data for the shallow profile acquired from 15 suspension borings demonstrated a strong correlation between the layering and places where simulated down-hole travel time gradient "breaks" occurred.

The deep profile was developed from regional wells and results in a higher uncertainity in both the layering (stratigraphy) and velocity measurements. Shear wave velocity measurements were available from a single well located about 6 mi from the site and ~~was~~were limited to the Barnett Shale (a shale unit at a depth of about 5000 ft) for a total depth interval of about 4000 ft (about 5000 ft depth to about 9000 ft depth). This data was used to develop a linear extrapolation to estimate shear wave velocity from available pressure wave velocities from other wells to complete the deep profile. Thus, the epistemic uncertainty for the deep profile is much greater than for the shallow profile. See Subsection 2.5.4.4.2.2 for detailed discussion. CTS-00916

The deep profile lacks a statistical basis for estimating a robust standard deviation for all layer velocities. The coefficient of variation (CoV=standard deviation/mean) calculated as 31% for the Atoka formation demonstrated the highest CoV for all deep profile layers. Therefore, the variability in velocity was calculated at 31% for all deep profile layers. The velocity range for the shallow profile was defined as 25% of the mean velocity of each layer. Subsection 2.5.4.4.2.2 provides a detailed discussion of the data and methodology for development of the dynamic profile.

Table 2.5.2-227 summarizes the layer properties including depth, thickness, velocities and assigned variabilities based on the aleatory and epistemic uncertainties discussed.

2.5.2.5.2 Description of Site Response Analysis CTS-00515

The site response analysis was conducted in three steps that are common to analyses of this type. First, the site geology and geotechnical properties were reviewed and used to generate multiple synthetic profiles of site characteristics. Second, sets of rock spectra were selected to represent rock ground motions corresponding to mean annual exceedence frequencies of 10^{-4}, 10^{-5}, and 10^{-6}. Finally, site response was calculated using an equivalent-linear technique, using the multiple synthetic profile and the sets of rock spectra representing input motions. These three steps are described in detail in the following sections.

2.5.2.5.2.1 Generation of Synthetic Profiles CTS-00515

To account for the epistemic and aleatory uncertainties in the site's dynamic properties, multiple of 60 synthetic profiles were generated using the stochastic model developed by Toro (Reference 2.5-432), with some modifications to account for the conditions at the Comanche Peak site. These synthetic profiles represent the site column from the top of the bedrock to the elevations where the GMRS and the various FIRS are defined (see Subsection 2.5.2.6). Bedrock is defined as having a shear-wave velocity of 9,200 fps, in order to achieve consistency with the ~~new~~2004 EPRI attenuation equations used for the rock hazard calculations (Reference 2.5-401). For each site column, this stochastic RCOL2_03.07.02-1 model uses as inputs the following quantities: (1) the median shear-wave velocity profile, which is equal to the base-case profile given in Table 2.5.2-227; (2) the standard deviation of ln(Vs) (the natural logarithm of the shear-wave velocity) as a function of depth, which is calculated from the values in Table 2.5.2-227; (3) the correlation coefficient between ln(Vs) in adjacent layers, which is taken from generic results for rock in Toro (Reference 2.5-432). Layer thickness was not randomized because the site's stratigraphy is very uniform. CTS-00515

The correlation coefficient between ln(Vs) in adjacent layers is estimated using the inter-layer correlation model from Toro (Reference 2.5-432) for USGS category A. In the log-normal randomization model used to calculate the synthetic Vs for each layer, it is possible for the synthetic Vs in the deeper formations to be greater than 9,200 fps. When this happens for a certain synthetic profile, the randomization scheme sets that Vs to 9,200 fps and defines the corresponding depth to be the depth to bedrock for that synthetic profile.

Figure 2.5.2-240 illustrates the Vs value for the first 10 synthetic profiles for the GMRS/FIRS1 site column. Figure 2.5.2-241 compares the median of these 60 Vs profiles to the Vs ±1 sigma Variability values given in Table 2.5.2-227, indicating excellent agreement. The difference in the mean_+sigma values below 800 m is a consequence of imposing the 9200 fps upper bound dictated by the bedrock Vs(see above). Figures 2.5-242 and 2.5-243 show analogous results for top portion the FIRS4 site column. RCOL1_03.07.02-1 CTS-00916

The best-estimate values for the damping ratio and for the stiffness degradation (G/Gmax) are given in Table 2.5.2-227. Except for the fill at the top of the FIRS4 soil column, materials are assumed to behave linearly (strain-independent), with constant damping and G/Gmax=1. The uncertainty in damping is specified as 35%, (following the generic values in EPRI, Reference 2.5-387) and the uncertainty in G/Gmax for fill is specified as 15% at $3x10^{-3}$% strain (following the generic values given by ~~Constantino~~, ~~(~~Reference 2.5-433). The correlation coefficient between ln(G/Gmax) and ln(damping) in the fill is specified as -0.75. This implies that in synthetic profiles where the fill has higher than average G/Gmax, the fill tends to have lower than average damping. The degradation and damping properties are treated as fully correlated among layers in the same geological unit, but independent between different units. Figure 2.5.2-244 shows the damping ratios for the Strawn formation in the 60 synthetic profiles corresponding to FIRS1. Similarly, Figure 2.5.2-245 shows the G/Gmax and damping ratios for the 60 synthetic profiles corresponding to FIRS4. A sensitivity study that evaluates the effect of using strain-dependent shear-modulus degradation (G/Gmax) and damping ratio, instead of using constant shear-modulus degradation (G/Gmax =1) and constant damping ratio. Results from this study indicate that the spectra at the top of the profile obtained with the constant material properties are slightly higher than those obtained with strain-dependent properties (Reference TXUT-001-PR-007). The profile with constant material properties was used to develop all FIRS (GMRS/FIRS1, FIRS2, FIRS2, FIRS4, and FIRS4_CoV50), as presented in Subsection 2.5.2.6, and to develop the inputs for the SSI analysis in Subsection 3.7.2. RCOL2_03.07.02-5 RCOL2_03.07.02-5 CTS-00515 RCOL2_03.07.02-5 (see, for example, Rathje and Ozboy, Reference 2.5-435) and using stress-drop and crustal Vs values typical of the eastern United States. The effective strain ratio is calculated using the expression (M-1)/10 (Reference 2.5-434). Values smaller than 0.5 or greater than 0.65 were brought into the 0.5-0.65 range, which is the range recommended by Kramer (Reference 2.5-436). The calculated values of duration and effective strain ratio are given in Table 2.5.2-230. CTS-00515

For each site column and each rock-motion input, separate site response calculations were performed for the corresponding 60 synthetic profiles. These results for each combination of input motion and site column were then used to calculate the logarithmic mean and standard deviation of the amplification factor. Results for the various site columns, and for the 10^{-4}, 10^{-5}, and 10^{-6} BB inputs, are given in Figures 2.5.2-233 and 2.5.2-235 through 2.5.2-238. Tabular results are provided in Tables 2.5.2-231 through 2.5.2-235.

~~No graphs showing peak strain vs. depth are included here because all materials, except the fill at the top of the FIRS4 and FIRS4_CoV50 columns, are treated as behaving linearly (see "Generation of Synthetic Profiles" above). The logarithmic mean (over the 60 synthetic profiles) values of the peak strain in the fill are approximately 0.004%, 0.01%, and 0.03%, for the~~ $\cancel{10^{-4}}$, $\cancel{10^{-5}}$, ~~and~~ $\cancel{10^{-6}}$ ~~inputs, respectively.~~ RCOL2_03.07.02-1

Figure 2.5.2-253 and Figure 2.5.2-254 present the peak strain in the upper 500 ft of the GMRS/FIRS1 soil column for the $1x10^{-4}$ and $1x10^{-5}$ broad band (BB) spectra, respectively. The maximum value of the logarithmic-mean strain (over the 60 synthetic profiles) in the entire GMRS/FIRS1 profile for the $1x10^{-4}$ spectrum is approximately 0.0035% ad occurs at a depth of approximately 390 ft in the profile. The maximum value of the logarithmic-mean strain in the entire GMRS/FIRS1 profile for the $1x10^{-5}$ spectrum is approximately 0.0075% and also occurs at a depth of approximately 390 ft in the profile.

Figure 2.5.2-255 and Figure 2.5.2-256 present the peak strain in the upper 50 ft of the FIRS4 soil column for the $1x10^{-4}$ broad-band (BB) spectra, respectively. As described in FSAR Subsection 2.5.2.6, the FIRS4 site profile consists of compacted fill overlying the stiff limestone that is the outcrop of the GMRS/FIRS1 profile. As such, the peak strains within most of the FIRS4 profile are similar to the peak strains within the GMRS/FIRS1 profile with the exception of peak strains within the fill (i.e., the upper 40 ft).

Therefore, Figure 2.5.2-255 and Figure 2.5.2-256 only show the peak strains within the upper 50 ft of the FIRS4 profile. The maximum value of the logarithmic-mean strain in the FIRS4 profile for the $1x10^{-4}$ spectrum is approximately 0.006% and occurs at depths of approximately 17 and 37 ft in the profile. The maximum value of the logarithmic-mean strain in the FIRS4 profile for the $1x10^{-5}$ spectrum is approximately 0.016% and also occurs at depths of approximately 17 and 37 ft in the profile.

The logarithmic mean value of the peak strain in the fill is approximately 0.03% for the 10^{-6} inputs. RCOL2_03.07.02-1

In addition, Figure 2.5.2-246 compares the median amplification factors obtained for GMRS/FIRS1 site column using the 10^{-4} HF and BB rock inputs. Although Figure 2.5.2-246 shows that the BB spectrum gives larger amplification factors for frequencies above 3 Hz, the effect of this difference on the 10^{-4} site hazard will be negligible because most of the 10^{-4} hazard at all frequencies comes from distant events (see Figures 2.5.2-~~221~~223 and 2.5.2-~~222~~224). These distant events will generate a BB rock spectrum. The effect of a difference in amplification factors at ~~10-5~~10^{-5} would be somewhat larger (and would result in lower mean site spectra) because roughly 40% of the ~~10-5~~10^{-5} hazard comes from local, small-magnitude events (see Figures 2.5.2-~~223~~225 and 2.5.2-~~224~~226). As a result, use of the BB amplification factors for all magnitude-distance combinations in the soil-hazard calculations (Subsection 2.5.2.6.1.1) yields slightly conservantive hazard results at 10^{-5}, resulting in slightly conservative estimates of the design spectrum. CTS-00515 CTS-00916 CTS-00916 RCOL2_02.05.02-8

2.5.2.6 Ground Motion and Site Response Analysis

CP COL 2.5(1) Replace the content of DCD Subsection 2.5.2.6 with the following.

Four FIRS have been identified for the CPNPP Units 3 and 4 and are calculated for both the Safe Shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE) where OBE=(1/3)SSE. The SSE is the envelope of the GMRS and the minimum earthquake requirements of 10 CFR 50 Appendix S, based on the shape of the Certified Site Design Response Spectra (CSDRS) scaled down to a PGA of 0.1 g. The CSDRS is itself a modified RG 1.60 shape formed by shifting the control points at 9 Hz and 33 Hz to 12 Hz and 50 Hz, respectively.

2.5.2.6.1 Ground Motion Response Spectrum (GMRS)

All category 1 structures as well as the Turbine Building will be founded directly on a stiff limestone (Layer C) at elevation 782 ft. Thus the GMRS/FIRS1 (referred to hereafter as GMRS) represents the top of stiff limestone (Layer C) at, or slightly below, foundation basemat elevation for the following safety-related ~~facilities~~and seismic Category II structures: CTS-00916

- Reactor Building
- Ultimate Heat Sink
- Turbine Building
- Auxiliary Building
- Essential Service Water Pipe Tunnel

- Power Source Fuel Storage Vaults
- East and West Power Source Buildings

In some cases, slight amounts of over-excavation will be required below the planned foundation subgrade elevations to reach the stiff limestone (Layer C). In these cases, a relatively thin layer of fill concrete will be placed on the cleaned limestone sub-excavation and extended to the foundation subgrade elevation. The thickness of the fill concrete will potentially range from about 0 ft to less than 2 ft.

Ground motion response spectra (GMRS) were calculated for horizontal and vertical motion by the methods discussed below.

2.5.2.6.1.1 Horizontal GMRS Spectrum

~~The GMRS for horizontal motion was calculated for~~A seismic hazard calculation was made using the site amplification factors for the GMRS elevation, which is elevation 782 ft (top of Layer C). Figure 2.5.2-233 shows the median amplification factor (AF) and logarithmic standard deviation of AF for this elevation, using broad-banded input motions (the envelope of the spectra in Figures 2.5.2-229 through 2.5.2-231). This calculation was made at the seven spectral frequencies at which ground motion equations were available from the 2004 EPRI study (Reference 2.5-401) (100 Hz, 25 Hz, 5 Hz, 2.5 Hz, 1 Hz, and 0.5 Hz). RCOL2_03.07.02-1

The seismic hazard for horizontal motion was calculated by integrating the horizontal amplification factors shown in Figure 2.5.2-233 with the rock hazard and applying the CAV filter. This corresponds to Approach 3 in the NRC standard, NUREG/CR-6769.

The horizontal GMRS was developed from the horizontal UHRS using the approach described in ASCE/SEI Standard 43-05 (Reference 2.5-371) and Regulatory Guide 1.208. The ASCE/SEI Standard 43-05 (Reference 2.5-371) approach defines the GMRS using the site-specific UHRS, which is defined for Seismic Design Category SDC-5 at a mean 10^{-4} annual frequency of exceedance. The procedure for computing the GMRS is as follows.

For each spectral frequency at which the UHRS is defined, a slope factor A_R is determined from:

$$A_R=SA(10^{-5})/SA(10^{-4}) \qquad \text{(Equation 5)}$$

where $SA(10^{-4})$ is the spectral acceleration SA at a mean UHRS exceedance frequency of 10^{-4}/yr (and similarly for $SA(10^{-5})$). A design factor (DF) is defined based on A_R, which reflects the slope of the mean hazard curve between 10^{-4} and

10^{-5} mean annual frequencies of exceedance. The DF at each spectral frequency is given by:

$$DF= 0.6(A_R)^{0.80} \qquad \text{(Equation 6)}$$

and

$$GMRS = \max[SA(10^{-4}) \times \max(1, DF), 0.45 \times SA(10^{-5})] \text{(Equation 7)}$$

The derivation of DF is described in detail in the Commentary to ASCE/SEI Standard 43-05 and in Regulatory Guide 1.208.

For the CPNPP Units 3 and 4 site, the horizontal hazard curves for GMRS elevation roll over at low amplitudes to an annual frequency of exceedance less than 10^{-4}. This means that the frequency of damaging ground motions ~~at the GMRS elevation~~ is less than 10^{-4}. Under these conditions, the GMRS is calculated from Equation 7 above as 0.45 x SA(10^{-5}). Table 2.5.2-228 shows the 10^{-5} ground motion at the seven spectral frequencies for which ground motion equations are available, and shows the GMRS calculated as 0.45 x SA(10^{-5}). RCOL2_03.07.02-1

~~Figure 2.5.2-234 shows the horizontal GMRS spectrum taken from Table 2.5.2-228, plotted with the horizontal CSDRS. This shows that the GMRS down to 0.5 Hz is enveloped by the CSDRS. As a result, extensive fitting of spectral shapes between the seven spectral frequencies indicated in Table 2.5.2-213 is not undertaken.~~ RCOL2_03.07.02-1

~~A seismic hazard calculation was made using the site amplification factors for the GMRS and four FIRS conditions (FIRS2, FIRS3, FIRS4, and FIRS4 CoV50). These calculations were made at the seven spectral frequencies at which ground motion equations were available from the EPRI (2004) study (100 Hz, 25 Hz, 10 Hz, 5Hz, 2.5 Hz, 1Hz,and 0.5 Hz). The CAV filter was applied for these calculations, and at all spectral frequencies, the 1E-4 amplitudes were zero (i.e. the highest hazard at low amplitudes was less than 1E-4). As a result, the GMRS and FIRS amplitudes were determined from (for example) GMRS = 0.45 x SA(l0-5) where SA(l0-5) is the spectral acceleration for l0-5 annual frequency of exceedence.~~ CTS-00516

The horizontal ~~1E-5~~10^{-5} and GMRS spectra were calculated at 39 frequencies between 0.1 Hz and 100 Hz for the GMRS elevation. This spectral frequency range encompasses all the energy of the rock ground motions for earthquakes in the Central and Eastern United States and meets the requirements in Subsection 3.4 "Hazard Assessment" in item C "Regulatory Position" of Regulatory Guide 1.208. The natural frequency of the GMRS soil column is 0.29 Hz. Because of the very flat appearance of the spectra at the seven spectral frequencies at which CTS-00916 RCOL2_03.07.02-1 hazard calculations were made, log-log interpolation between available hazard values was used, with the exception of the following frequency ranges.

1 Hz to 5Hz: Within this frequeney range, a peak inside spectra occurs at 2.5 Hz, reflecting a site amplification at about 2 Hz. To reflect this amplification, the ~~1E-5~~10^{-5} spectral amplitude at 2.5 Hz was broadened using rock spectral shapes from NUREG/CR-6728 and using the broad-banded values of M=~~7.7~~7.5 and R=~~890~~650 km for ~~1E-5~~10^{-5} (on which the site amplification calculations were based). This is an acceptable approximation given that the rock spectrum is decreasing between 2.5 and 1 Hz. CTS-00916 CTS-00516 RCOL2_03.07.02-1

0.5 Hz to 0.1 Hz: Below 0.5 Hz, the assumption was made that spectral accelerations are proportional to f down to ~~0.125 Hz (where f is frequency), and are proportional to f^2 between 0.125 Hz and~~ 0.1 Hz. This is a common assumption for spectral shapes at low frequencies for the site region. RCOL2_03.07.02-1

~~Spectra for the four FIRS conditions (FIRS2, FIRS3, FIRS4, and FIRS4-CoV50 were calculated in a similar way. Note that the FIRS3 spectra have peaks at about 2 Hz and 10 Hz, and that the FIRS4 and FIRS4-CoV50 spectra have peaks at about 1.5 Hz and 5 Hz. These peaks were broadened in an approximate way similar to the procedure used for the GMRS.~~

These GMRS spectrum is~~and FIRS spectra are~~ plotted in Figures 2.5.2-247 along with the 10^{-5} UHRS ~~through 2.5.2.-251 with the 1E-5 spectrum for each condition also plotted~~. Table 2.5.2-236 shows the numerical values for the ~~1E-5~~10^{-5} and GMRS spectra~~, and Table 2.5.2-237 shows the numerical values for the 1E-5 and FIRS spectra~~.

2.5.2.6.1.2 Vertical GMRS Spectrum

Vertical motions at the CPNPP Units 3 and 4 site are addressed by reviewing results in NUREG/CR-6728 for V/H ratios at deep soil sites, for both the western US (WUS) and the CEUS. Example results presented in the ~~US-APWR DCD~~NUREG/CR-6728 indicate that for earthquakes >40 km from a deep soil site, V/H ratios are expected to be less than unity for all frequencies (Figures J-31 and J-32 in Appendix J of the ~~DCD~~NUREG/CR-6728). For the 10^{-5} ground motion, expected distances from deaggregation are greater than 100 km (Table 2.5.2-220). Any exceedance of unity occurs for high frequencies (>10 Hz) for short source-to-site distances. Also, for ground motions with peak horizontal accelerations <0.2g, the recommended V/H ratios for hard rock conditions are less than unity; see Table 4-5 of the ~~DCD~~NUREG/CR-6728. The conclusion is that V/H ratios for the CPNPP Units 3 and 4 site will be less than unity for all spectral frequencies. Therefore, the vertical GMRS will be below the horizontal GMRS shown in Figure 2.5.2-233. CTS-00916 CTS-00916 CTS-00916

Figure 2.5.2-234 shows that the horizontal DCD spectrum exceeds the horizontal GMRS. The vertical DCD spectrum equals or does not exceed the horizontal DCD

Vertical GMRS and FIRS spectra were developed using vertical-to-horizontal (V/H) ratios. NUREG/CR-6728 and RG 1.60 indicate proposed V/H ratios for design spectra for nuclear facilities, and these V/H ratios are plotted in Figure 2.5.2-252. The V/H ratios in Figure 2.5.2-252 taken from NUGREG/CR-6728 (the blue curve) are recommended for hard sites in the CEUS. The Comanche Peak site is a deep, soft-rock site with shales and limestones near the surface having shear-wave velocities of about 2600 fps, and the V/H ratios for this site condition will be similar to those for hard roick sites. CTS-00516 CTS-00916

Based on these comparisons, it is concluded that the applicable V/H ratios at the Comanche Peak site will be ≤ 1.0 at all spectral frequencies between 100 Hz and 0.1 Hz. As a conservative assumption, the V /H ratio is assumed to be equal to 1.0 at all spectral frequencies. This assumption is also plotted in Figure 2.5.2-252.

The result of this assumption is that the spectra plotted in Figures 2.5.2-247 through 2.5.2-251 for the GMRS and four FIRS conditions apply to both the horizontal and vertical motions.

Tables 2.5.2-236 and 2.5.2-237 document (respectively) the 10^{-5} UHRS and GMRS, and the 10^{-5} UHRS and FIRS. Because V /H is assumed to be equal to unity, these spectra apply to both horizontal and vertical motions.

2.5.2.6.2 Foundation Input Response Spectrum

Site response analyses were conducted for an additional four cases (FIRS 2, FIRS 3, FIRS 4_CoV30, and FIRS 4_CoV50) to consider foundation input response spectra for specific conditions different from the GMRS elevation. These four cases are as follows:

FIRS 2 - Set at elevation 787 ft.

This FIRS represents generic site response conditions for structures resting on fill concrete layer in which the fill concrete thickness and horizontal extent away from the edge of the foundation is significant and thus modeled as a horizontally infinite layer.

- FIRS 2 analysis demonstrates that the response at the top of the fill concrete remains well below the minimum earthquake and does not apply to any specific structure.

The FIRS 2 profile consists of 5 ft of fill concrete placed over a sub-excavated stiff limestone (Layer C) surface at elevation 782 ft. Fill concrete with compressive strength ranging from 2,500 psi to 4,400 psi is considered by using a mean shear wave velocity of 6800 fps with a range of +/- 500 fps. See Table 2.5.2-227 for properties used for FIRS 2 analysis. Note that the site-specific soil-structure interaction analyses described in Subsection 3.7.2 model the fill concrete under the category 1 foundations as part of the structural model.

FIRS4_CoV50: elevation 822 ft. This profile is the same as for FIRS 4 except it uses a coefficient of variation (CoV) of 50% (instead of 30%) for the Vs of the fill material.

Figures 2.5.2-235 through 2.5.2-238 show median amplification factors and logarithmic standard deviations for these four FIRS cases, for the 10^{-4}, 10^{-5}, and 10^{-6} broadband input motions.

The seismic hazard for each FIRS case was calculated by integrating the horizontal amplification factors shown in Figures 2.5.2-235 through 2.5.2-238 with the rock hazard and applying the CAV filter. This is an analogous calculation to the calculation of hazard for the GMRS elevation. For all FIRS cases the hazard curves at low amplitudes rolled over to an annual frequency of exceedance that was less than 10^{-4}. As was the case for the GMRS, the FIRS spectra were calculated using the 10^{-5} UHRS and applying the factor from Eq. 2.5.2-3; i.e., FIRS = 0.45 × SA(10^{-5}).

Figure 2.5.2-239 plots the four horizontal FIRS and compares them to the horizontal minimum DCD spectrum. The minimum DCD spectrum envelops all four FIRS, down to frequencies of 0.5 Hz. For this reason, detailed spectral shapes were not fit to the FIRS spectra between the seven spectral frequencies for which ground motion equations are available. Values of the horizontal 10^{-5} UHRS and FIRS are shown in Table 2.5.2-229 for the seven spectral frequencies.

Smooth horizontal spectra for the four FIRS conditions (FIRS2, FIRS3, FIRS4, and FIRS4-CoV50) were calculated in a manner similar to the way in which the smooth GMRS was calculated, as described om Section 2.5.2.6.1.1. Note that the FIRS3 spectra have peaks at about 2.5 Hz and 10 Hz, and that the FIRS4 and FIRS4-CoV50 spectra have peaks at about 1.5 Hz and 5 Hz. These peaks were broadened in an approximate way similar to the procedure used for the GMRS. RCOL2_03.07.02-1

The FIRS spectra are plotted in Figures 2.5.2-248 through 2.5.2-251 with the 10^{-5} spectrum for each condition also plotted. Table 2.5.2-237 shows the numerical values for the 10^{-5} and FIRS spectra.

For vertical FIRS motions, the same considerations used for the GMRS were used for the FIRS. That is, for large source-to-site distances, results in the ~~US-APWR DCD (Reference 2.5.2-288)~~NUREG/CR-6728 indicate that V/H ratios will be less than unity for all frequencies. V/H ratios are likely to be considerably less than unity at frequencies below 5 Hz. Appendix J of ~~Ref 2.5.2-288~~NUREG/CR-6728 indicates that for distances exceeding 40 km, soil sites in both the WUS and CEUS will have V/H ratios of 0.5 or less. Thus, it is reasonable to assume that vertical FIRS will be enveloped by the vertical minimum DCD spectrum. CTS-00916 CTS-00916

RCOL2_03.07.02-1

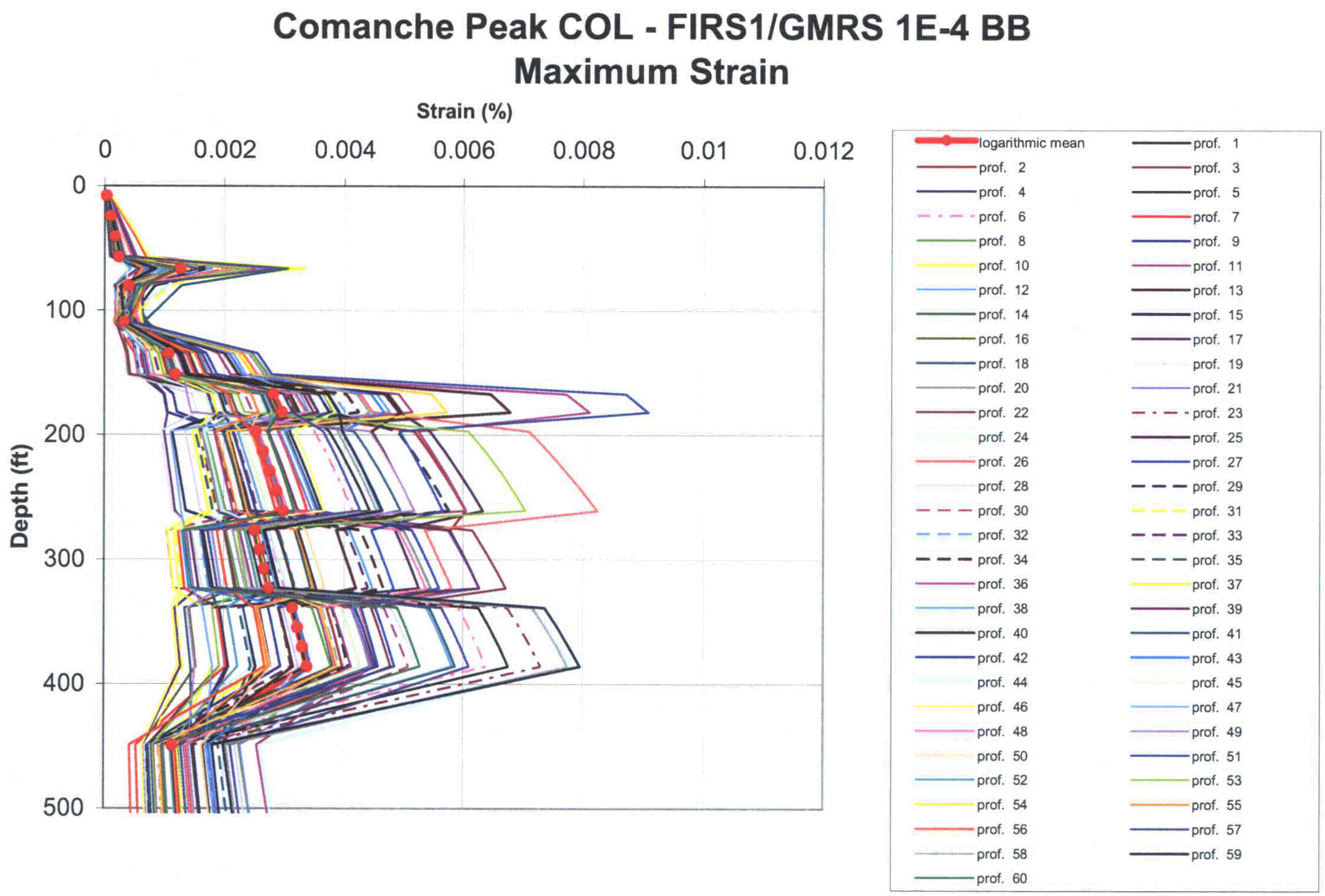

Figure 2.5.2-253 Maximum strain for upper 500 ft of GMRS/FIRS1 profiles $1x10^{-4}$ broad-band spectra

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.07.02-1

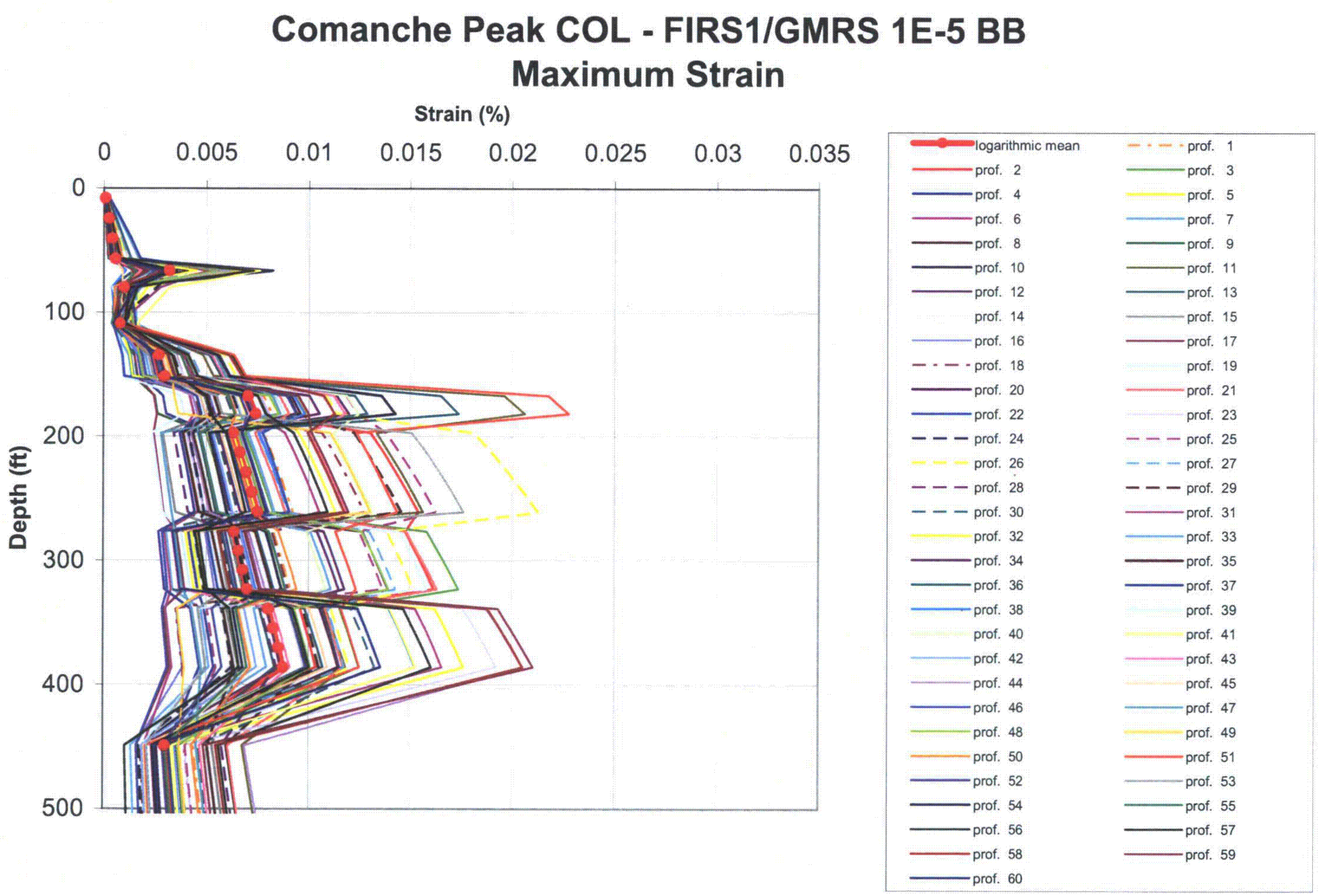

Figure 2.5.2-254 Maximum strain for upper 500 ft of GMRS/FIRS1 profiles 1×10^{-5} broad-band spectra

RCOL2_03
.07.02-1

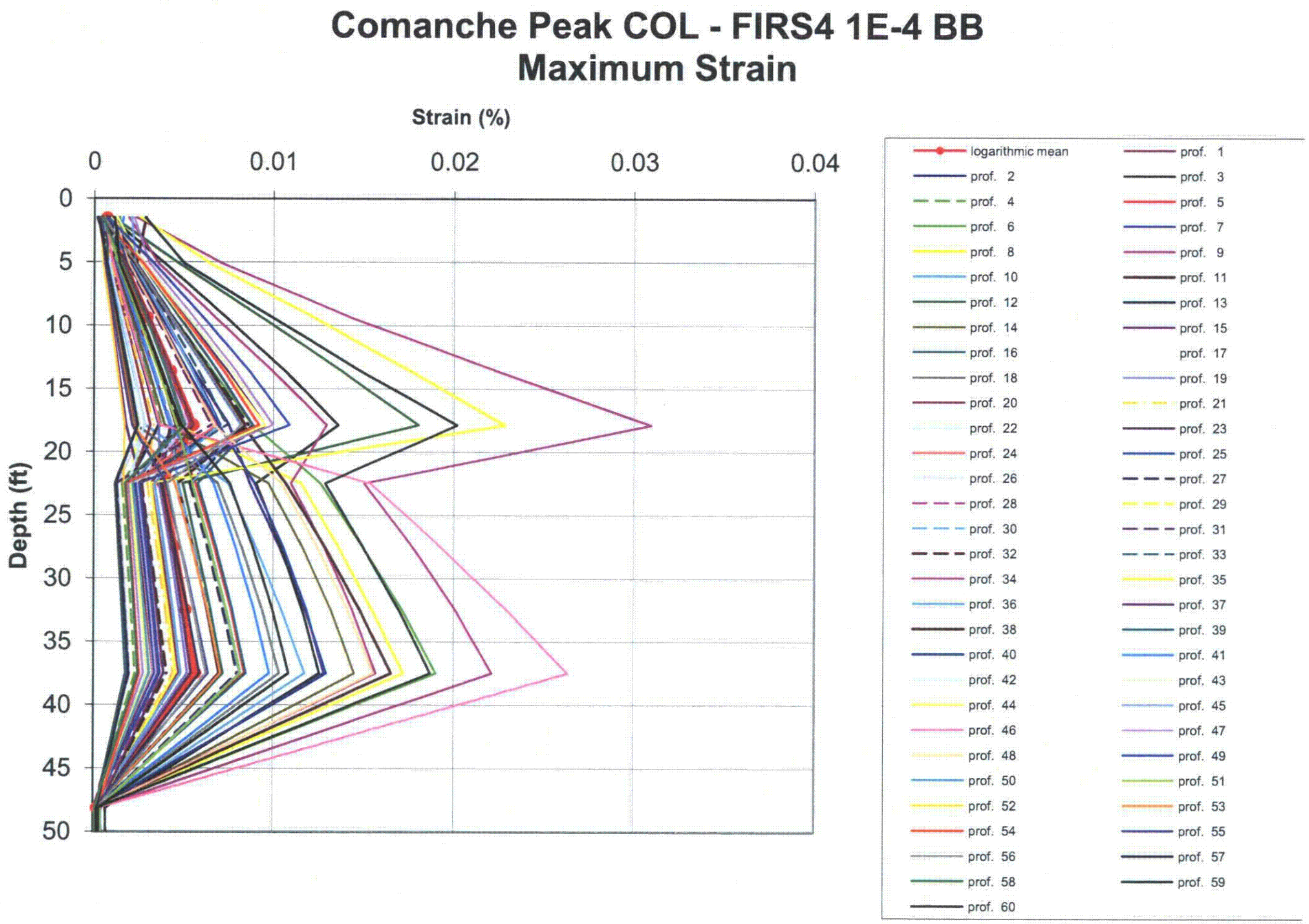

Figure 2.5.2-255 Maximum strain for upper 50 ft of GMRS/FIRS4 profiles $1x10^{-4}$ broad-band spectra

RCOL2_03.07.02-1

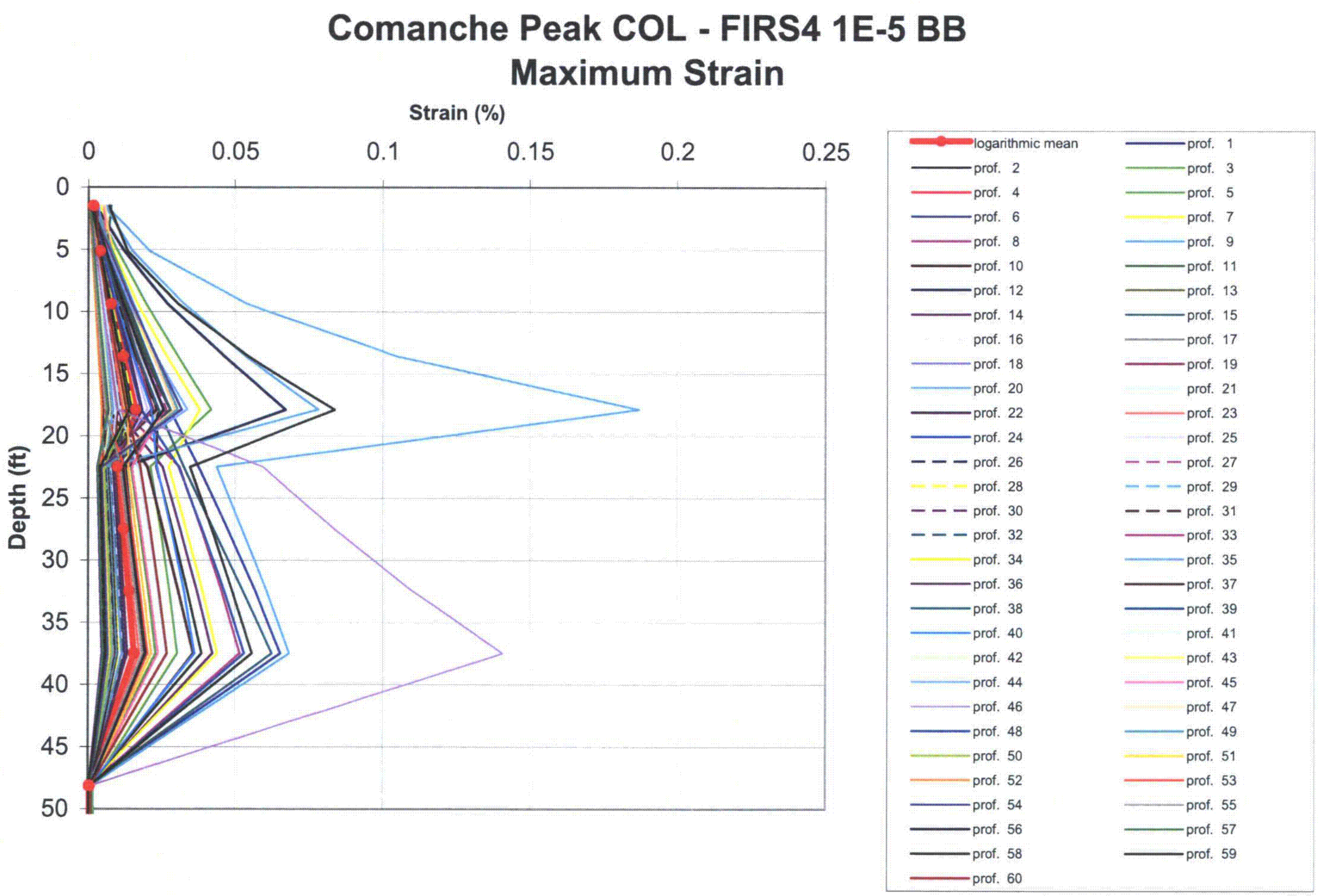

Figure 2.5.2-256 Maximum strain for upper 50 ft of GMRS/FIRS4 profiles $1x10^{-5}$ broad-band spectra

CP COL 3.7(22) Replace the last sentence of the ninth paragraph in DCD Subsection 3.7.1.1 with the following.

The CPNPP is not in a high seismic area, is not founded on hard rock, and the site-specific seismic GMRS and FIRS demonstrate that there are no high frequency exceedances of the CSDRS that could create damaging effects.

CP COL 3.7(5) Replace the last two sentences of the sixteenth paragraph in DCD Subsection 3.7.1.1 with the following.

The site-specific horizontal response spectra are obtained from site-specific response analyses performed in accordance with RG 1.208 (Reference 3.7-3) and account for upward propagation of the GMRS. ~~The nominal GMRS and horizontal response spectra~~The calculation of the GMRS and FIRS is outlined in Subsections 2.5.2.5 and 2.5.2.6, respectively. Subsections 2.5.2.5 and 2.5.2.6 document the site response methodology used, the soil properties used, and the methodology for calculating the GMRS. The nominal GMRS and FIRS for 5 percent damping resulting from these site-specific response analyses are shown in Figure 3.7-201. The spectra shown in Figure 3.7-201 represent nominal spectra for the following site-specific conditions: RCOL2_03.07.01-2 RCOL2_03.07.02-1

FIRS1 = the nominal GMRS, at the top of the stiff limestone (nominal elevation 782') described in ~~Chapter 2~~Subsections 2.5.2.5 and 2.5.2.6. The R/B-prestressed concrete containment vessel (PCCV)-containment internal structure, PS/Bs, UHSRS, PSFSVs, ESWPT, and A/B are founded directly on this limestone layer, have a thin layer of fill concrete placed between the top of limestone and bottom of mat foundation, and/or the fill concrete is analyzed in SASSI (Reference 3.7-17) as part of the seismic structural model. RCOL2_03.07.02-1

FIRS2 = the nominal response spectrum for structures located on a layer of fill concrete placed between the top of the limestone at nominal elevation 782' and bottom of the structure's foundation. Note that a comparison of FIRS1 and FIRS2 shows that the presence of several feet of fill concrete does not result in amplification of the ground motion seismic response, and is well below the minimum design earthquake.

FIRS3 = nominal response spectrum corresponding to typical plant grade elevation 822' for shallow-embedment structures founded on native, in-situ, undisturbed materials occurring below plant grade as described in ~~Chapter 2~~Subsections 2.5.2.5 and 2.5.2.6. FIRS3 does not apply currently to any plant structures. FIRS3 represents the free-field ground motion. RCOL2_03.07.02-1

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

Comanche Peak, Units 3 and 4

Luminant Generation Company LLC

Docket Nos. 52-034 and 52-035

RAI NO.: 2879 (CP RAI #60)

SRP SECTION: 03.07.02 - Seismic System Analysis

QUESTIONS for Structural Engineering Branch 1 (AP1000/EPR Projects) (SEB1)

DATE OF RAI ISSUE: 9/15/2009

QUESTION NO.: 03.07.02-2

NUREG-0800, Standard Review Plan (SRP) 3.7.2, "Seismic System Analysis," establishes the criteria the NRC staff will use to evaluate whether an applicant meets the NRC's regulations.

In appendix 3NN (page 3NN-2) of the COLA, Luminant states that the soil-structure interaction (SSI) analyses uses input stiffness and damping properties of the backfill that are compatible to the strains generated by the design input motion and that these properties are obtained from site response analysis using time histories that are applied as outcrop motion on the surface of the rock subgrade.

In order for the NRC staff to evaluate the suitability of the soil column properties and seismic input, describe in detail how the strain-compatible backfill properties are generated. At a minimum, the description should include the program used, the output options specified (within versus outcrop motion), the soil column configuration used for each site response analysis, and the soil properties used for each of the site response analyses used to support the computer model SASSI analyses listed in Section 3NN.4.

ANSWER:

Two sets of site response analyses were performed that provide the dynamic properties of the embedment material as a function of the strains generated by the input ground motion. The first set of backfill properties was obtained from the site response analyses that are used to develop the FIRS at grade elevation. Site response analyses of 60 randomly generated profiles were performed using the program RVTSITE v. 1.2. This program uses the same equivalent-linear methodology for 1-D wave propagation analysis as the original SHAKE program (Schnabel and Seed, 1972; Idriss and Sun, 1992). The backfill properties obtained from the site response analyses of random profiles are not used as input for the SSI analysis since the intensity of the input motion is smaller than the intensity of the minimum design earthquake adopted as site-specific design ground motion for CPNPP Units 3 and 4.

The second set of site response analyses were performed using the SOIL module of the ACS SASSI v. 2.2 program to obtain stiffness and damping properties of the backfill that are compatible with the CPNPP Units 3 and 4 design ground motion. The SOIL module utilizes standard methodology for seismic site response analysis that is identical to the methodology used in the SHAKE family of computer programs. The following four S-wave velocity profiles were considered for the engineered backfill as described in FSAR Table 3NN-1:

- Best Estimate (BE) corresponding to typical values for granular backfill
- Lower Bound (LB) with variance for the backfill shear modulus of minus 0.69 from BE values
- Upper Bound (UB) with variance for the backfill shear modulus of plus 0.69 from BE values
- Higher Bound (HB) with variance for the backfill shear modulus of plus 1.25 from BE values

The BE strain compatible backfill properties were obtained from the equivalent linear site response analyses of a profile consisting of 40 ft thick backfill layer with BE properties resting on top of the rock subgrade with BE properties. Similarly, the LB and UB backfill strain compatible properties were obtained from the analyses of soil/rock columns with LB and UB properties of the backfill and rock subgrade. The HB strain compatible properties were obtained from the site response analyses of a profile consisting of 40 ft thick backfill layer with HB properties resting on top of the rock subgrade with UB properties.

Two site response analyses were performed for each of the four profiles using the two horizontal acceleration time histories compatible to the horizontal spectra of the input design ground motion. The input design ground motion matches the RG 1.60 minimum spectra anchored to 0.1g peak acceleration and envelopes the site-specific FIRS spectra. The input motion was applied as outcrop motion at the surface of the rock subgrade at a nominal elevation of 782 ft. The degradation curves presented in Figure 2.5.2-232, which are derived based on standard EPRI shear modulus reduction and damping curves for granular fill, were used to model the non-linear properties of the embedment soil. The curves' values of the soil shear modulus and the damping as function of shear strain are listed in Table 2.5.2-227of the FSAR. Rock properties were input as elastic (not strain dependent).

ACS SASSI SOIL calculated strain-compatible fill properties using 65% of the peak strain value for selection of effective soil strain. The results for the strain compatible backfill properties obtained from the two horizontal site response analyses were averaged to obtain the backfill profiles used as input for the site-specific SSI analyses. The compression or P-wave velocity (Vp) is calculated from the strain compatible shear or S-wave velocity (Vs) and the Poisson's ratio (ν) of 0.35 by using the following equation:

$$Vp = Vs \cdot \sqrt{2 \cdot \frac{1-\nu}{1-2\nu}}$$

FSAR Subsection 3NN.2 is revised to reflect this response.

Table 1 presents the material properties of the backfill material used as input for the site-specific SSI analyses.

References

Idriss, I., and Sun, J.I., 1992, Users Manual for SHAKE91.

Schnabel, S. and Seed, H.B., 1972, SHAKE- A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites, Report No. 72-12, Earthquake Engineering Research Center (EERC)

Impact on R-COLA

See attached marked-up FSAR Draft Revision 1 pages 3NN-2, 3NN-3, and 3NN-21.

Impact on S-COLA

None.

Impact on DCD

None.

Attachment

Table 1 - Backfill Strain Compatible Properties

Table 1 - Backfill Strain Compatible Properties

Elevation (ft)	Unit Weight (pcf)	Poisson's Ratio	S-Wave Velocity (fps)				P-Wave Velocity (fps)				Damping Ratio (%)			
			LB	BE	UB	HB	LB	BE	UB	HB	LB	BE	UB	HB
822	125	0.35	475	633	834	969	990	1317	1740	2017	3.00	2.40	2.00	1.80
819	125	0.35	540	739	999	1174	1125	1539	2080	2444	4.75	3.65	2.70	2.25
815	125	0.35	477	691	958	1143	994	1438	1993	2379	7.45	5.15	3.70	3.00
811	125	0.35	425	649	925	1113	885	1351	1926	2316	10.05	6.55	4.45	3.55
806	125	0.35	383	618	900	1088	797	1287	1874	2265	12.45	7.55	5.10	4.05
802	125	0.35	623	890	1213	1431	1296	1854	2526	2978	6.25	4.10	3.00	2.50
797	125	0.35	603	871	1199	1419	1256	1814	2497	2954	7.00	4.60	3.25	2.70
792	125	0.35	587	855	1188	1409	1223	1779	2473	2932	7.60	4.95	3.50	2.90
787	125	0.35	576	842	1180	1400	1199	1753	2456	2915	8.10	5.25	3.70	3.00
782	Top of Limestone (Foundation Bottom)													

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~~0.69~~, 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. RCOL2_03.07.02-5

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~~Subsection 2.5.2.5.2.1 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. RCOL2_03.07.02-5

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 by using the following equation:~~.~~ RCOL2_03.07.02-2

$$Vp = Vs \cdot \sqrt{2 \cdot \frac{1-\nu}{1-2\nu}}$$

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 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. Table 3NN-16 provides the strain-compatible backfill properties, used for the SASSI analysis for LB, BE, UB, and HB embedment conditions. RCOL2_03.07.02-2

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

RCOL2_03.
7.02-2

Table 3NN-16

Backfill Strain Compatible Properties

Elevation (ft)	Unit Weight (pcf)	Poisson's Ratio	S-Wave Velocity (fps)				P-Wave Velocity (fps)				Damping Ratio (%)			
			LB	LB	UB	HB	LB	BE	UB	HB	LB	BE	UB	HB
822	125	0.35	475	633	834	969	990	1317	1740	2017	3.00	2.40	2.00	1.80
819	125	0.35	540	739	999	1174	1125	1539	2080	2444	4.75	3.65	2.70	2.25
815	125	0.35	477	691	958	1143	994	1438	1993	2379	7.45	5.15	3.70	3.00
811	125	0.35	425	649	925	1113	885	1351	1926	2316	10.05	6.55	4.45	3.55
806	125	0.35	383	618	900	1088	797	1287	1874	2265	12.45	7.55	5.10	4.05
802	125	0.35	623	890	1213	1431	1296	1854	2526	2978	6.25	4.10	3.00	2.50
797	125	0.35	603	871	1199	1419	1256	1814	2497	2954	7.00	4.60	3.25	2.70
792	125	0.35	587	855	1188	1409	1223	1779	2473	2932	7.60	4.95	3.50	2.90
787	125	0.35	576	842	1180	1400	1199	1753	2456	2915	8.10	5.25	3.70	3.00
782	Top of Limestone (Foundation Bottom)													

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

Comanche Peak, Units 3 and 4

Luminant Generation Company LLC

Docket Nos. 52-034 and 52-035

RAI NO.: 2879 (CP RAI #60)

SRP SECTION: 03.07.02 - Seismic System Analysis

QUESTIONS for Structural Engineering Branch 1 (AP1000/EPR Projects) (SEB1)

DATE OF RAI ISSUE: 9/15/2009

QUESTION NO.: 03.07.02-3

In Appendix 3NN (page 3NN-3) of the COLA, Luminant states that the site response analyses converts the design motion that is defined as outcrop motion to within-layer motion that depends on the properties of the overlying backfill above the rock surface. In order for the NRC staff to evaluate the suitability of the seismic input, describe in detail how the conversion from outcrop motion to within motion was performed. At a minimum, the description should include the program used, the output options specified (within versus outcrop motion), the soil column used to generate each spectrum, and the soil properties used to generate each spectrum.

Also, given that SSI analyses use input stiffness and damping properties of the backfill that are compatible to the strains generated by the design input motion, address whether the above process leads to whole column within motion being used as input to the SASSI model.

ANSWER:

Model properties and seismic analysis results for the UHSRS, ESWPT, PSFSVs and R/B-PCCV-CIS are presented in FSAR Appendices 3KK, 3LL, 3MM and 3NN, respectively. The dynamic soil properties used in the SSI analyses of the backfill in the R/B area are provided in the response to Question 03.07.02-2 of this RAI. The response also discusses the methodology for determining the properties and how outcrop motion was converted to within-layer motion.

Time history motions "mhi_h1a.acc" "mhi_h2a.acc" for horizontal motions and "Mhi_va.acc" for vertical motions match the minimum design spectra, which are tied to the shape of the standard plant CSDRS and anchored to 0.1 g peak acceleration, and envelope the site-specific FIRS spectra.

Five analyses cases were considered:

- No backfill – corresponding to the surface foundation on top of the limestone with no backfill
- Best Estimate (BE) corresponding to typical values for granular backfill
- Lower Bound (LB) with variance for the backfill shear modulus of minus 0.69 from BE values

- Upper Bound (UB) with variance for the backfill shear modulus of plus 0.69 from BE values
- Higher Bound (HB) with variance for the backfill shear modulus of plus 1.25 from BE

For the no backfill condition, the motions that match the minimum design spectra were applied as input motion for the SASSI analyses at the surface of the limestone with no backfill modeled.

For all other cases, backfill is modeled and input time histories are applied at the top of the limestone layer. When the earthquake motion is input below the ground surface, the SASSI analysis requires the object motion to be defined as within-layer motion.

SOIL module of ACS SASSI v. 2.2 was used to develop both the strain compatible fill properties (discussed in the second part of the response to this RAI, Question 03.07.02-2) and in-layer time history motion. The time history motions "mhi_h1a.acc" and "mhi_h2a.acc" were input as outcrop on the top of limestone, as described in the response to RAI 2876 (CP RAI #55) Question 3.7.1-1(Luminant letter TXNB-09058 dated Oct. 26, 2009)(ML093010366). ACS SASSI SOIL calculated strain-compatible fill properties using 65% of the peak strain value for selection of effective soil strain. The ACS SASSI SOIL module also calculated in-layer acceleration time histories at the top of the rock layer, which were saved for use as input to the SSI analysis. Because of the differences in soil profiles, the in-layer motion is different for each soil case resulting in the generation of 8 horizontal time history files representing the two directions of motion for the four soil cases in addition to the two outcrop motions.

The vertical acceleration time history compatible to the vertical FIRS representing the vertical outcrop motion at top of the limestone was used for all SSI analyses. The acceleration response spectra of the outcrop motion envelop that of the in-layer motion, thus resulting in conservative results for the response of the structures due to vertical component of the input design motion.

Impact on R-COLA

None.

Impact on S-COLA

None.

Impact on DCD

None.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

Comanche Peak, Units 3 and 4

Luminant Generation Company LLC

Docket Nos. 52-034 and 52-035

RAI NO.: 2879 (CP RAI #60)

SRP SECTION: 03.07.02 - Seismic System Analysis

QUESTIONS for Structural Engineering Branch 1 (AP1000/EPR Projects) (SEB1)

DATE OF RAI ISSUE: 9/15/2009

QUESTION NO.: 03.07.02-4

NUREG-0800, Standard Review Plan (SRP) 3.7.2, "Seismic System Analysis," establishes the criteria the NRC staff will use to evaluate whether an applicant meets the NRC's regulations.

In Appendix 3NN, Figure 3NN-1 shows that in the upper 200 ft of the limestone, the maximum and minimum shear wave speeds for each profile differ by more than a factor of two. This suggests that the soil site may not be uniform for the purposes of performing frequency-independent impedance function SSI analysis.

Provide the technical basis and justification for the assumption of a uniform soil site that was used in the SSI analysis of the standard plane facilities and estimate the error that may have been introduced through the use of this assumption.

ANSWER:

The final consideration of site soil and the impact of soil layering is not available at this time but will be addressed as described below.

The standard seismic design documented in US-APWR DCD Revision 1 was based on results of seismic response analyses that used frequency independent lumped parameters to account for the soil-structure interaction (SSI) effects and was based on the assumption of uniform material properties of the subgrade. In order to conservatively account for uncertainties related to the simplified modeling of the SSI and the subgrade layering, the DCD seismic response analyses used SSI damping coefficients for the two horizontal translational degrees of freedom (DOF) that are 60% lower than the theoretical values calculated for uniform sites. In order to explicitly address the effects of soil layering on the standard seismic design of Category I structures, US-APWR DCD Revision 2 will be revised to include seismic response analyses of generic layered sites in the next DCD revision. Soil structure interaction (SSI) analyses will be performed using the technology specified for the site-specific SSI analysis in order to account for the frequency dependence of the SSI impedance and the flexibility of the foundations. The tentative schedule for completion of the analyses that was established at the time of

MHI's meeting with NRC on November 16, 2009 is May 2010.

US-APWR DCD mandates that the COL applicant use the most up-to-date methodology to address the frequency dependence of the SSI impedances on a site-specific basis and assure through stringent checks of the seismic response that the Standard Design envelopes the site-specific conditions. The intent is to address, among other things, the effects of site layering on a site specific basis rather than considering a large variety of generic layered soil profiles in the DCD. The DCD can only partially represent the specific conditions since variations are very difficult to capture by generic soil profiles. In order to address the concerns that the NRC staff raised during the telephone conference on September 24, 2009 with regard to the review of the DCD Revision 1, MHI has decided that the standard design seismic analyses will be revised to address the frequency dependence of the SSI and include a number of layered sites in the next DCD revision.

The COLA FSAR will be revised to incorporate as necessary the results of the MHI SSI analyses.

Impact on R-COLA

None.

Impact on S-COLA

None.

Impact on DCD

None.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

Comanche Peak, Units 3 and 4

Luminant Generation Company LLC

Docket Nos. 52-034 and 52-035

RAI NO.: 2879 (CP RAI #60)

SRP SECTION: 03.07.02 - Seismic System Analysis

QUESTIONS for Structural Engineering Branch 1 (AP1000/EPR Projects) (SEB1)

DATE OF RAI ISSUE: 9/15/2009

QUESTION NO.: 03.07.02-5

It is stated in Section 3.7.2.4.1 of the COLA that the dynamic properties of the rock subgrade at Comanche Peak Nuclear Power Plant (CPNPP), Units 3 and 4 are considered to be strain independent because the mean shear wave velocity of the top 400 ft of the subgrade below the SC-I and SC-2 structures is greater than 3,500 ft/s. Typically, the value of 3,500 ft/s is used as guidance for developing a lower boundary in an SSI model. In contrast, the shear wave velocity assigned to "generic rock" per Regulatory Guide 1.208, "A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion," is the much higher value of 9,200 ft/s.

In order for the NRC staff to evaluate the impact of treating the subgrade material as strain independent, quantify the effects of this assumption on critical response parameters in the SSI analyses.

ANSWER:

As stated in RG 1.208, Appendix E, rock is defined in the Central and Eastern United States (CEUS) as material having a shear wave velocity of 9200 ft/s. Thus, the site response analysis was performed from the top of rock (Vs greater than 9200 ft/s at a depth of about 5265 ft) to the specific seismic Category I (SC-1) and seismic Category II (SC-2) embedment depths defined as Foundation Input Response Spectra described in FSAR Subsections 2.5.2.5 and 2.5.2.6. Site-specific and regional data indicate that the CPNPP site is underlain by a sequence of limestones, shales and sandstones with shear wave (Vs) velocities greater than about 5800 ft/s (see Figure 3NN-1) which is still greater than the value of 3500 ft/s as defined for rock per ASCE 4-98.

Appendix 2 of Project Report TXUT-001-PR-007 revision 2 which was submitted to NRC by Luminant letter TXNB-09049 (ML092740182) on September 28, 2009 presents a sensitivity study that evaluates the effect of using strain-dependent shear-modulus degradation (G/G_{max}) and damping ratio, instead of using constant shear-modulus degradation (G/G_{max} =1) and constant damping ratio. Results from this study indicated that the spectra at the top of the profile obtained with the constant material properties are slightly higher than those obtained with strain-dependent properties. The profile with constant material properties was used to develop all FIRS (GMRS/FIRS1, FIRS2, FIRS3, FIRS4, FIRS4_CoV50), as presented in Subsection 2.5.2.6.

FSAR Subsection 2.5.2.5.2.1 and Section 3NN.2 have been revised to incorporate this response.

Impact on R-COLA

See attached marked-up FSAR Draft Revision 1 pages 2.5-117 and 3NN-2.

Impact on S-COLA

None.

Impact on DCD

None.

Attachment

Project Report, "Dynamic Profile," TXUT-001-PR-007, Revision 2 (Attachment 2 to this letter) model uses as inputs the following quantities: (1) the median shear-wave velocity profile, which is equal to the base-case profile given in Table 2.5.2-227; (2) the standard deviation of ln(Vs) (the natural logarithm of the shear-wave velocity) as a function of depth, which is calculated from the values in Table 2.5.2-227; (3) the correlation coefficient between ln(Vs) in adjacent layers, which is taken from CTS-00515 generic results for rock in Toro (Reference 2.5-432). Layer thickness was not randomized because the site's stratigraphy is very uniform.

The correlation coefficient between ln(Vs) in adjacent layers is estimated using the inter-layer correlation model from Toro (Reference 2.5-432) for USGS category A. In the log-normal randomization model used to calculate the synthetic Vs for each layer, it is possible for the synthetic Vs in the deeper formations to be greater than 9,200 fps. When this happens for a certain synthetic profile, the randomization scheme sets that Vs to 9,200 fps and defines the corresponding depth to be the depth to bedrock for that synthetic profile.

Figure 2.5.2-240 illustrates the Vs value for the first 10 synthetic profiles for the GMRS/FIRS1 site column. Figure 2.5.2-241 compares the median of these 60 Vs profiles to the Vs ±1 sigma Variability values given in Table 2.5.2-227, indicating RCOL1_03.07.02-1 excellent agreement. The difference in the mean_+sigma values below 800 m is a CTS-00916 consequence of imposing the 9200 fps upper bound dictated by the bedrock Vs(see above). Figures 2.5-242 and 2.5-243 show analogous results for top portion the FIRS4 site column.

The best-estimate values for the damping ratio and for the stiffness degradation (G/Gmax) are given in Table 2.5.2-227. Except for the fill at the top of the FIRS4 soil column, materials are assumed to behave linearly (strain-independent), with RCOL2_03.07.02-5 constant damping and G/Gmax=1. The uncertainty in damping is specified as 35%, (following the generic values in EPRI, Reference 2.5-387) and the uncertainty in G/Gmax for fill is specified as 15% at $3x10^{-3}$% strain (following the generic values given by Constantino, (Reference 2.5-433). The correlation RCOL2_03.07.02-5 coefficient between ln(G/Gmax) and ln(damping) in the fill is specified as -0.75. This implies that in synthetic profiles where the fill has higher than average G/Gmax, the fill tends to have lower than average damping. The degradation and damping properties are treated as fully correlated among layers in the same geological unit, but independent between different units. Figure 2.5.2-244 shows the damping ratios for the Strawn formation in the 60 synthetic profiles corresponding to FIRS1. Similarly, Figure 2.5.2-245 shows the G/Gmax and damping ratios for the 60 synthetic profiles corresponding to FIRS4. A sensitivity CTS-00515 study that evaluates the effect of using strain-dependent shear-modulus RCOL2_03.07.02-5 degradation (G/Gmax) and damping ratio, instead of using constant shear-modulus degradation (G/Gmax =1) and constant damping ratio. Results from this study indicate that the spectra at the top of the profile obtained with the constant material properties are slightly higher than those obtained with strain-dependent properties (Reference TXUT-001-PR-007). The profile with constant material properties was used to develop all FIRS (GMRS/FIRS1, FIRS2, FIRS2, FIRS4, and FIRS4_CoV50), as presented in Subsection 2.5.2.6, and to develop the inputs for the SSI analysis in Subsection 3.7.2.

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~~0.69~~, 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. RCOL2_03.07.02-5

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~~Subsection 2.5.2.5.2.1 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. RCOL2_03.07.02-5

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 by using the following equation:~~.~~ RCOL2_03.07.02-2

$$Vp = Vs \cdot \sqrt{2 \cdot \frac{1-\nu}{1-2\nu}}$$

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

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

Comanche Peak, Units 3 and 4

Luminant Generation Company LLC

Docket Nos. 52-034 and 52-035

RAI NO.: 2879 (CP RAI #60)

SRP SECTION: 03.07.02 - Seismic System Analysis

QUESTIONS for Structural Engineering Branch 1 (AP1000/EPR Projects) (SEB1)

DATE OF RAI ISSUE: 9/15/2009

QUESTION NO.: 03.07.02-6

It is stated in Section 2.4.1 of Technical Report MUAP-08002 (R0), '*Enhanced Information for PS/B Design*', which is listed as Ref. 3.7-33 of the US-APWR design certification document (DCD), that site-specific SSI analysis will be performed to validate the site-independent SSI analysis and the assumptions used for the standard plant design. According to FSAR Table 3.7.2-1R of the CPNPP COLA, a model SASSI analysis of the SC-I PS/Bs has not been performed.

Explain how the assumptions used for the standard plant design and frequency-independent impedance function SSI analysis documented in Ref. 3.7-33 of the US-APWR DCD are validated in the absence of a site-specific SSI analysis.

ANSWER:

The standard plant PS/Bs are designed with an SSE corresponding to the CSDRS, which is anchored at a 0.3 g PGA. The site-specific SSE is the same shape but tied to 0.1 g. Because of the large ratio of the standard plant input motion versus the site-specific input motion, the design of the PS/Bs is not validated by performing site-specific SSI analyses. Instead, the design is considered suitable based on the large margin by which the R/B standard plant in-structure response spectra (ISRS) envelope the ISRS obtained from the site-specific SSI analysis for the R/B, as documented in Appendix 3NN. Therefore, site-specific analysis of SSI effects for the PS/Bs at CPNPP site is not required based on the comparisons of the R/B standard plant ISRS versus site-specific ISRS documented in Appendix NN.

FSAR Subsection 3.7.2.4.1 has been revised to incorporate this response.

<u>Impact on R-COLA</u>

See attached marked-up FSAR Draft Revision 1 page 3.7-10.

<u>Impact on S-COLA</u>

None.

Impact on DCD

None.

simulates fixed base conditions. The results of the SASSI analysis are demonstrated to match the results from the time history analyses of fixed base lump mass stick models.

CP COL 3.7(23) Replace the third sentence of the ninth paragraph in DCD Subsection 3.7.2.4.1 with the following.

The results of the site-specific SSI analysis documented in Appendix 3NN demonstrate that the standard plant broadened ISRS contained in Appendix 3I for the R/B-PCCV-containment internal structure are enveloped by a high margin. Considering the low site-specific seismic response (based on FIRS tied to 0.1 g versus standard plant CSDRS tied to 0.3 g), it is concluded from the review of the Appendix 3NN results that the R/B basemat seismic pressures and basement walls lateral soil pressures are also enveloped by the US-APWR standard design.

The range of subgrade properties considered in the A/B and T/B SSI lumped parameter models envelope site-specific variations related to subgrade stratigraphy and foundation flexibility. Since the basemat embedment effects are neglected, this also yields conservative results which envelope the site-specific responses.

The standard plant PS/Bs are designed with an SSE corresponding to the standard plant CSDRS, which is anchored at a 0.3g PGA. Because of the large ratio of the standard plant input motion versus the site-specific input motion, the design of the PS/Bs is not validated by performing site-specific SSI analyses. Instead, the design is considered suitable based on the large margin by which the R/B standard plant ISRS envelope the ISRS obtained from the site-specific SSI analysis for the R/B, as documented in Appendix 3NN. Therefore, site-specific analysis of SSI effects for the PS/Bs at CPNPP site is not required based on the comparisons of the R/B standard plant ISRS versus site-specific ISRS documented in Appendix NN. RCOL2_03.07.02-6

3.7.2.8 Interaction of Non-Category I Structures with Seismic Category I Structures

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CP COL 3.7(10) Replace the last sentence of the fifth paragraph in DCD Subsection 3.7.2.8 with the following.

Structure-to-structure interactions, which could potentially influence the measured seismic response levels, will not occur because the R/B and PS/B are both founded on the same very stiff limestone layer and are separated by expansion joints which prevent seismic interaction.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

Comanche Peak, Units 3 and 4

Luminant Generation Company LLC

Docket Nos. 52-034 and 52-035

RAI NO.: 2879 (CP RAI #60)

SRP SECTION: 03.07.02 - Seismic System Analysis

QUESTIONS for Structural Engineering Branch 1 (AP1000/EPR Projects) (SEB1)

DATE OF RAI ISSUE: 9/15/2009

QUESTION NO.: 03.07.02-7

Section 3.7.2.4.1 of the CPNPP COLA states that the top of the water table is no higher than elevation 780 ft for the purposes of seismic analysis. According to FSAR Section 3.7.2 of the CPNPP COLA, the top of the limestone layer is at elevation 782 ft. This implies that the water table is at least 2 ft below plant grade, which is inconsistent with US-APWR DCD Tier 1, FSAR Table 2.1-1, where the maximum water table is shown as 1 ft below grade. Provide clarification for the apparent inconsistency between the COLA and DCD Sections.

ANSWER:

The DCD parameters in Table 2.0-1 contemplate groundwater at an elevation that is 1 ft below plant finish grade. For the COL Applicant to be enveloped by the assumed DCD parameter, the depth of the groundwater table at the site must be greater than or equal to 1 foot below the finished plant grade. The plant finish grade for the CPNPP site is elevation 822 ft. As discussed in FSAR Subsections 2.4.12, 2.5.4, and 2.5.5, the permanent groundwater table at the CPNPP Units 3 and 4 site is anticipated to be below an elevation of about 760 ft (about 62 feet below plant yard grade). However, the groundwater level is assumed to be at elevation 780 ft, about 42 ft below grade, for analysis purposes. This groundwater elevation is enveloped by the DCD standard plant parameters and is not inconsistent with them.

The results for the seismic response obtained from the site-specific SSI analyses envelope the effects of the ground water table, which is below the bottoms of seismic category I foundations, which rest on top of the Glen Rose limestone. The P-wave velocity of the limestone material is higher than the P-wave velocity of water which is approximately 5,000 fps. Further discussion on groundwater level is presented in RAI No. 2929 (CP RAI #22) Question 02.05.04-7 attached to Luminant letter TXNB-09042 (dated September 10, 2009) (ML092820486) and RAI No. 2929 (CP RAI #22) Question 2.5.4-11 attached to Luminant letter TXNB-09035 (dated August 28, 2009) (ML092440357).

Impact on R-COLA

None.

Impact on S-COLA

None.

Impact on DCD

None.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

Comanche Peak, Units 3 and 4

Luminant Generation Company LLC

Docket Nos. 52-034 and 52-035

RAI NO.: 2879 (CP RAI #60)

SRP SECTION: 03.07.02 - Seismic System Analysis

QUESTIONS for Structural Engineering Branch 1 (AP1000/EPR Projects) (SEB1)

DATE OF RAI ISSUE: 9/15/2009

QUESTION NO.: 03.07.02-8

In response to combined license information COL 3.7(23), Luminant stated, in FSAR Section 3.7.2.4.1 of the COLA, that the results of Appendix 3NN demonstrate that the soil pressures on the reactor building (R/B) lateral walls and basemat are enveloped by the US-APWR standard design. This conclusion appears to be based on a comparison of in-structure response spectra (ISRS) from the standard plant R/B model to the ISRS of the site-specific SASSI R/B model as shown in Appendix 3NN. The standard plant R/B SSI model is a surface-founded model with seismic input represented by the certified seismic design response spectra (CSDRS). The site-specific R/B SSI model is SASSI model with partial embedment with the seismic input represented by the minimum required response spectra, which are defined by the shape of the CSDRS anchored at 0.1*g*.

In order for the NRC staff to evaluate the statement regarding soil pressures on the lateral walls and basemat of the R/B, the following information should be provided:

1. A quantitative evaluation of how much of the difference in the ISRS between the standard plant SSI model and the site-specific SSI model is due to the difference in seismic input, and how much is due to the presence of embedment in the site-specific model.
2. A more thorough explanation of how conclusions regarding soil pressures along the lateral walls and basemat are drawn given that the standard plant SSI model is founded on the surface of the soil.

ANSWER:

1) The results of the soil structure interaction (SSI) analyses, discussed in Section 7.3 of Calculation 4DS-CP34-20080048, indicate that the interaction of the subgrade with the common mat foundation has only a small effect on the seismic response of the R/B complex structures as a result of the relatively high stiffness of the supporting limestone. Tables 6, 7 and 8 of Calculation SSI-12-05-100-003 summarize the results from different SASSI analyses for maximum accelerations. The tables below (Tables 1 through 3) compare the envelopes of the maximum acceleration results obtained from the analyses of surface and embedded foundation

in the three directions of the input ground motion. The last column in the tables presents the ratio between the envelopes of the embedded foundation results with the envelopes of the surface foundation results and serves as an indicator of the embedment effects. The comparisons indicate that the embedment in general lowers the maximum horizontal accelerations. Exceptions are some portions of the building, in particular the Fuel Handling Area (FH/A), where the embedment resulted in magnified maximum horizontal accelerations due to local resonance effects. The comparison of the maximum acceleration results indicates that the reflection of the P-waves in the embedment soil resulting from the stiffness mismatch between the backfill and subgrade magnifies the vertical accelerations of R/B complex structures. Table 3NN-15 provides further observations on embedment effects.

Appendices A, B and C in Calculation SSI-12-05-100-003, respectively, present the calculated responses of the R/B, PCCV and CIS structures at selected lumped mass locations in terms of transfer function and 5% acceleration response spectra (ARS). The comparison of the ARS results obtained from the different SASSI runs shows that the embedment can affect the magnitude of the peak spectral responses. In general, the embedment reduces the peaks of the spectra representing the response of the structures in the horizontal direction. The figures also show that the peaks of the vertical spectra can be significantly magnified due to the mismatch between the stiffness properties of the embedment and the rock subgrade.

FSAR Tables 3NN-12 through 3NN-14 have been revised to incorporate this response.

2) The standard design of the US-APWR R/B complex is based on the Scott and Wood solutions for maximum dynamic earth pressures as presented in ASCE 4-98 and by using design ground motion input that is derived from the CSDRS which is three times the magnitude of the design ground motion at the CPNPP site. The site-specific design of UHSRS and PSFSV, for which the depth of embedment is identical to that of the R/B complex foundation, uses dynamic soil pressures calculated using the same methodology, with the only difference being that the calculated maximum dynamic earth pressures are based on the site-specific design ground motion. The results for dynamic earth pressures obtained from the site-specific SASSI analyses of the UHSRS and PSFSV are enveloped by the dynamic earth pressures calculated by the Wood's solution. Therefore, it can be concluded that the standard design of the R/B complex basement walls is adequate. This is based on the fact that the standard considers dynamic earth pressures that are based on design ground motion with magnitude three times the magnitude of the site-specific ground motion using methodology that provided enveloping results for the dynamic pressures on the walls of the site-specific facilities.

   The site-specific SSI analyses of the R/B will be revised to address the changes in the building basement configuration and design enhancements. The FSAR will be revised in COLA Revision 2 to include the SSI analyses that will provide SASSI calculated dynamic earth pressures for direct comparison. FSAR Sections 3.7 and 3.8 and Appendix 3NN will be revised in the next COLA revision to address the basemat configuration and design embedments and to provide SASSI calculated dynamic earth pressures.

Impact on R-COLA

See attached marked-up FSAR Draft Revision 1 pages 3NN-6, 3NN-17, 3NN-18, and 3NN-19.

Impact on S-COLA

None.

Impact on DCD

None.

Attachments

Table 1 - Maximum accelerations in NS Direction (SSRS of three Earthquake Directions)

Table 2 - Maximum accelerations in EW Direction (SSRS of three Earthquake Directions)

Table 3 - Maximum accelerations in Vertical Direction (SSRS of three Earthquake Directions)

SASSI Model of US-APWR Reactor Building, 4DS-CP34-20080048 Rev.1, Mitsubishi Heavy Industries, LTD, September 17, 2008 (Attachment 3 to this letter)

Site Specific SSI Analysis of US-APWR Reactor Building, SSI-12-05-100-003 Rev. C, URS, November 13, 2009 (Attachment 4 to this letter)

Table 1 Maximum accelerations in NS Direction (SSRS of three Earthquake Directions)

Node	El. (ft)	Surface Foundation (g)				Embedded Foundation (g)					Embed. / Surf.
		SLB	SBE	SUB	Env.	ELB	EBE	EUB	EHB	Env.	
CV11	230.2	0.50	0.60	0.72	0.72	0.50	0.49	0.66	0.65	0.66	92%
CV10	225.0	0.48	0.59	0.71	0.71	0.48	0.49	0.65	0.64	0.65	92%
CV09	201.7	0.43	0.54	0.63	0.63	0.41	0.45	0.58	0.57	0.58	93%
CV08	173.1	0.38	0.48	0.56	0.56	0.35	0.40	0.51	0.51	0.51	91%
CV07	145.6	0.37	0.41	0.49	0.49	0.34	0.34	0.45	0.45	0.45	91%
CV06	115.5	0.36	0.38	0.42	0.42	0.32	0.31	0.37	0.38	0.38	91%
CV05	92.2	0.32	0.34	0.35	0.35	0.30	0.28	0.31	0.32	0.32	93%
CV04	76.4	0.29	0.31	0.31	0.31	0.27	0.26	0.28	0.29	0.29	94%
CV03	68.3	0.27	0.29	0.29	0.29	0.25	0.24	0.26	0.28	0.28	94%
CV02	50.2	0.22	0.24	0.24	0.24	0.21	0.20	0.22	0.23	0.23	95%
CV01	25.3	0.16	0.16	0.16	0.16	0.15	0.15	0.14	0.16	0.16	96%
CV00	1.9	0.13	0.12	0.13	0.13	0.11	0.13	0.12	0.12	0.13	98%
IC09	139.5	0.91	1.05	1.16	1.16	0.82	0.87	0.98	0.91	0.98	84%
IC08	112.3	0.51	0.57	0.63	0.63	0.50	0.49	0.52	0.52	0.52	83%
IC18	110.8	0.48	0.55	0.60	0.60	0.48	0.47	0.49	0.50	0.50	84%
IC61	96.6	0.27	0.31	0.35	0.35	0.23	0.30	0.29	0.27	0.30	86%
IC62	96.6	0.27	0.30	0.35	0.35	0.24	0.30	0.29	0.27	0.30	86%
IC05	76.4	0.22	0.25	0.28	0.28	0.19	0.24	0.22	0.21	0.24	85%
IC07	76.4	0.22	0.25	0.28	0.28	0.19	0.24	0.22	0.21	0.24	85%
IC15	59.2	0.20	0.21	0.22	0.22	0.16	0.20	0.19	0.19	0.20	88%
IC04	50.2	0.19	0.19	0.20	0.20	0.16	0.18	0.18	0.18	0.18	89%
IC14	45.7	0.18	0.18	0.19	0.19	0.15	0.17	0.17	0.16	0.17	89%
IC03	35.6	0.16	0.16	0.16	0.16	0.14	0.15	0.15	0.15	0.15	93%
IC02	25.3	0.14	0.14	0.14	0.14	0.13	0.14	0.13	0.13	0.14	95%
IC01	16.0	0.13	0.13	0.13	0.13	0.12	0.13	0.13	0.12	0.13	99%
IC00	1.9	0.13	0.12	0.13	0.13	0.11	0.13	0.12	0.12	0.13	98%
FH08	154.5	0.61	0.70	0.78	0.78	0.59	0.89	0.74	0.72	0.89	114%
FH07	125.7	0.38	0.44	0.51	0.51	0.40	0.56	0.45	0.47	0.56	110%
RE05	115.5	0.22	0.25	0.28	0.28	0.21	0.25	0.33	0.26	0.33	117%
RE04	101.0	0.19	0.21	0.25	0.25	0.18	0.21	0.31	0.23	0.31	121%
RE41	101.0	0.21	0.23	0.26	0.26	0.19	0.22	0.30	0.24	0.30	115%
RE42	101.0	0.21	0.23	0.28	0.28	0.19	0.23	0.30	0.24	0.30	105%
FH06	101.0	0.25	0.29	0.32	0.32	0.24	0.33	0.28	0.30	0.33	103%
RE03	76.4	0.18	0.19	0.22	0.22	0.16	0.19	0.23	0.20	0.23	105%
RE02	50.2	0.16	0.17	0.18	0.18	0.14	0.17	0.19	0.16	0.19	104%
RE01	25.3	0.14	0.15	0.16	0.16	0.14	0.16	0.16	0.14	0.16	99%
RE00	3.6	0.13	0.13	0.13	0.13	0.12	0.12	0.13	0.12	0.13	99%

Table 2 Maximum accelerations in EW Direction (SSRS of three Earthquake Directions)

Node	El. (ft)	Surface Foundation (g)				Embedded Foundation (g)					Embed. / Surf.
		SLB	SBE	SUB	Env.	ELB	EBE	EUB	EHB	Env.	
CV11	230.2	0.57	0.71	0.85	0.85	0.54	0.55	0.70	0.69	0.70	82%
CV10	225.0	0.56	0.70	0.84	0.84	0.53	0.54	0.69	0.68	0.69	82%
CV09	201.7	0.51	0.64	0.76	0.76	0.51	0.49	0.62	0.62	0.62	82%
CV08	173.1	0.45	0.54	0.64	0.64	0.43	0.42	0.53	0.53	0.53	82%
CV07	145.6	0.39	0.45	0.53	0.53	0.37	0.35	0.43	0.44	0.44	83%
CV06	115.5	0.32	0.35	0.41	0.41	0.30	0.28	0.33	0.34	0.34	84%
CV05	92.2	0.28	0.31	0.32	0.32	0.25	0.24	0.27	0.28	0.28	88%
CV04	76.4	0.25	0.28	0.28	0.28	0.22	0.21	0.24	0.24	0.24	87%
CV03	68.3	0.23	0.26	0.26	0.26	0.20	0.20	0.22	0.22	0.22	85%
CV02	50.2	0.19	0.21	0.21	0.21	0.16	0.17	0.19	0.18	0.19	88%
CV01	25.3	0.13	0.15	0.15	0.15	0.12	0.14	0.14	0.13	0.14	91%
CV00	1.9	0.12	0.12	0.12	0.12	0.10	0.11	0.12	0.11	0.12	101%
IC09	139.5	0.92	1.03	1.11	1.11	0.79	0.97	1.05	0.94	1.05	95%
IC08	112.3	0.51	0.56	0.62	0.62	0.48	0.54	0.57	0.55	0.57	91%
IC18	110.8	0.48	0.53	0.59	0.59	0.46	0.51	0.54	0.53	0.54	91%
IC61	96.6	0.33	0.35	0.37	0.37	0.24	0.28	0.29	0.29	0.29	79%
IC62	96.6	0.33	0.35	0.37	0.37	0.24	0.28	0.29	0.29	0.29	79%
IC05	76.4	0.25	0.26	0.26	0.26	0.19	0.22	0.22	0.23	0.23	89%
IC07	76.4	0.26	0.26	0.27	0.27	0.20	0.21	0.22	0.23	0.23	85%
IC15	59.2	0.19	0.20	0.20	0.20	0.17	0.18	0.18	0.20	0.20	98%
IC04	50.2	0.18	0.18	0.18	0.18	0.16	0.17	0.17	0.18	0.18	101%
IC14	45.7	0.16	0.17	0.17	0.17	0.15	0.16	0.16	0.17	0.17	102%
IC03	35.6	0.14	0.15	0.15	0.15	0.13	0.15	0.13	0.14	0.15	100%
IC02	25.3	0.13	0.13	0.13	0.13	0.11	0.13	0.13	0.12	0.13	98%
IC01	16.0	0.12	0.12	0.12	0.12	0.11	0.12	0.12	0.12	0.12	99%
IC00	1.9	0.12	0.12	0.12	0.12	0.10	0.11	0.12	0.11	0.12	101%
FH08	154.5	0.35	0.41	0.46	0.46	0.32	0.43	0.48	0.46	0.48	106%
FH07	125.7	0.29	0.30	0.34	0.34	0.26	0.33	0.44	0.35	0.44	129%
RE05	115.5	0.27	0.32	0.38	0.38	0.25	0.31	0.34	0.33	0.34	88%
RE04	101.0	0.23	0.27	0.34	0.34	0.23	0.27	0.29	0.28	0.29	85%
RE41	101.0	0.25	0.31	0.38	0.38	0.25	0.29	0.33	0.32	0.33	85%
RE42	101.0	0.24	0.29	0.36	0.36	0.24	0.27	0.31	0.31	0.31	85%
FH06	101.0	0.25	0.25	0.28	0.28	0.22	0.27	0.29	0.27	0.29	102%
RE03	76.4	0.20	0.21	0.23	0.23	0.19	0.22	0.22	0.21	0.22	97%
RE02	50.2	0.17	0.18	0.19	0.19	0.16	0.18	0.20	0.17	0.20	105%
RE01	25.3	0.15	0.15	0.15	0.15	0.14	0.14	0.17	0.14	0.17	111%
RE00	3.6	0.13	0.13	0.13	0.13	0.11	0.12	0.14	0.11	0.14	108%

Table 3 Maximum accelerations in Vertical Direction (SSRS of three Earthquake Directions)

Node	El. (ft)	Surface Foundation (g)				Embedded Foundation (g)					Embed. / Surf.
		SLB	SBE	SUB	Env.	ELB	EBE	EUB	EHB	Env.	
CV11	230.2	0.44	0.48	0.52	0.52	0.36	0.39	0.63	0.43	0.63	122%
CV10	225.0	0.39	0.42	0.45	0.45	0.32	0.34	0.54	0.33	0.54	121%
CV09	201.7	0.31	0.33	0.35	0.35	0.23	0.24	0.40	0.25	0.40	114%
CV08	173.1	0.27	0.28	0.30	0.30	0.19	0.22	0.33	0.21	0.33	108%
CV07	145.6	0.26	0.27	0.28	0.28	0.17	0.21	0.30	0.20	0.30	107%
CV06	115.5	0.23	0.24	0.25	0.25	0.16	0.20	0.26	0.19	0.26	104%
CV05	92.2	0.20	0.21	0.22	0.22	0.15	0.18	0.23	0.17	0.23	104%
CV04	76.4	0.18	0.19	0.20	0.20	0.14	0.17	0.21	0.16	0.21	104%
CV03	68.3	0.17	0.18	0.19	0.19	0.14	0.16	0.20	0.15	0.20	104%
CV02	50.2	0.15	0.15	0.16	0.16	0.13	0.14	0.17	0.13	0.17	104%
CV01	25.3	0.13	0.13	0.13	0.13	0.12	0.12	0.13	0.12	0.13	98%
CV00	1.9	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12	108%
IC09	139.5	0.20	0.22	0.26	0.26	0.24	0.23	0.28	0.25	0.28	104%
IC08	112.3	0.19	0.21	0.25	0.25	0.23	0.22	0.26	0.24	0.26	104%
IC18	110.8	0.19	0.21	0.25	0.25	0.23	0.22	0.26	0.23	0.26	104%
IC61	96.6	0.16	0.18	0.21	0.21	0.18	0.18	0.20	0.20	0.20	99%
IC62	96.6	0.16	0.18	0.21	0.21	0.17	0.18	0.21	0.20	0.21	100%
IC05	76.4	0.12	0.13	0.15	0.15	0.14	0.14	0.16	0.13	0.16	112%
IC07	76.4	0.16	0.18	0.21	0.21	0.18	0.18	0.20	0.18	0.20	98%
IC15	59.2	0.11	0.12	0.13	0.13	0.13	0.13	0.15	0.12	0.15	111%
IC04	50.2	0.11	0.12	0.13	0.13	0.12	0.12	0.14	0.12	0.14	108%
IC14	45.7	0.11	0.11	0.12	0.12	0.12	0.12	0.13	0.12	0.13	107%
IC03	35.6	0.11	0.11	0.11	0.11	0.12	0.11	0.12	0.12	0.12	106%
IC02	25.3	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12	109%
IC01	16.0	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12	109%
IC00	1.9	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12	108%
FH08	154.5	0.32	0.36	0.39	0.39	0.36	0.40	0.50	0.41	0.50	128%
FH07	125.7	0.29	0.33	0.36	0.36	0.33	0.37	0.47	0.37	0.47	132%
RE05	115.5	0.26	0.29	0.31	0.31	0.26	0.31	0.33	0.32	0.33	104%
RE04	101.0	0.25	0.27	0.29	0.29	0.24	0.29	0.31	0.31	0.31	108%
RE41	101.0	0.31	0.35	0.37	0.37	0.35	0.42	0.51	0.40	0.51	138%
RE42	101.0	0.26	0.29	0.33	0.33	0.27	0.31	0.35	0.31	0.35	109%
FH06	101.0	0.27	0.30	0.33	0.33	0.30	0.34	0.44	0.35	0.44	132%
RE03	76.4	0.13	0.14	0.15	0.15	0.16	0.18	0.23	0.17	0.23	154%
RE02	50.2	0.12	0.13	0.13	0.13	0.15	0.16	0.21	0.15	0.21	161%
RE01	25.3	0.12	0.12	0.12	0.12	0.14	0.15	0.17	0.14	0.17	145%
RE00	3.6	0.11	0.11	0.12	0.12	0.14	0.13	0.14	0.13	0.14	121%

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 values for the surface and embedded foundation ~~from all of the considered~~ site conditions. The last column in the tables presents the ratio between the envelopes of the embedded foundation results with the envelopes of the surface foundation results that serves as an indicator of the embedment effects. The comparisons indicate that the embedment in general lowers the maximum horizontal accelerations. Exceptions are some portions of the building, in particular the Fuel Handling Area (FH/A), where the embedment resulted in magnified maximum horizontal accelerations due to local resonance effects. The comparison of the maximum acceleration results indicates that the reflection of the P-waves in the embedment soil resulting from the stiffness mismatch between the backfill and subgrade magnifies the vertical accelerations of R/B complex structures. RCOL2_03.07.02-8

Table 3NN-12

Maximum Accelerations in NS Direction

Structure	Lumped Mass	El. (ft)	~~Site Profile~~Surface Foundation (g)				Embedded Foundation (g)						Embed. /Surf
			SLB	SBE	SUB	Env.	ELB	EBE	EUB	EHB	Env.	~~Env.~~	
PCCV	CV11	230.2	0.496	0.595	0.722	0.72	0.495	0.493	0.661	0.653	0.66	~~0.722~~	92%
	CV10	225.0	0.481	0.586	0.707	0.71	0.481	0.485	0.648	0.639	0.65	~~0.707~~	92%
	CV09	201.7	0.434	0.540	0.629	0.63	0.409	0.446	0.582	0.569	0.58	~~0.629~~	93%
	CV08	173.1	0.384	0.476	0.559	0.56	0.346	0.395	0.508	0.505	0.51	~~0.559~~	91%
	CV07	145.6	0.374	0.407	0.494	0.49	0.335	0.341	0.448	0.446	0.45	~~0.494~~	91%
	CV06	115.5	0.356	0.375	0.417	0.42	0.321	0.305	0.374	0.380	0.38	~~0.417~~	91%
	CV05	92.2	0.324	0.342	0.346	0.35	0.295	0.284	0.311	0.321	0.32	~~0.346~~	93%
	CV04	76.4	0.292	0.306	0.313	0.31	0.268	0.260	0.281	0.293	0.29	~~0.313~~	94%
	CV03	68.3	0.272	0.286	0.293	0.29	0.251	0.244	0.264	0.275	0.28	~~0.293~~	94%
	CV02	50.2	0.223	0.235	0.239	0.24	0.207	0.204	0.217	0.227	0.23	~~0.239~~	95%
	CV01	25.3	0.163	0.159	0.164	0.16	0.154	0.147	0.139	0.158	0.16	~~0.164~~	96%
	CV00	1.9	0.129	0.124	0.128	0.13	0.114	0.126	0.123	0.118	0.13	~~0.129~~	98%
Containment Internal Structure	IC09	139.5	0.913	1.054	1.156	1.16	0.819	0.869	0.976	0.911	0.98	~~1.156~~	84%
	IC08	112.3	0.507	0.574	0.627	0.63	0.497	0.494	0.520	0.523	0.52	~~0.627~~	83%
	IC18	110.8	0.482	0.546	0.595	0.60	0.477	0.470	0.493	0.499	0.50	~~0.595~~	84%
	IC61	96.6	0.266	0.305	0.349	0.35	0.233	0.301	0.287	0.266	0.30	~~0.349~~	86%
	IC62	96.6	0.272	0.301	0.347	0.35	0.238	0.300	0.294	0.267	0.30	~~0.347~~	86%
	IC05	76.4	0.224	0.252	0.278	0.28	0.189	0.237	0.219	0.209	0.24	~~0.278~~	85%
	IC07	76.4	0.224	0.252	0.278	0.28	0.189	0.237	0.219	0.209	0.24	~~0.278~~	85%
	IC15	59.2	0.199	0.207	0.221	0.22	0.164	0.195	0.193	0.187	0.20	~~0.221~~	88%
	IC04	50.2	0.186	0.189	0.201	0.20	0.155	0.178	0.177	0.176	0.18	~~0.201~~	89%
	IC14	45.7	0.177	0.179	0.189	0.19	0.148	0.169	0.169	0.162	0.17	~~0.189~~	89%
	IC03	35.6	0.156	0.159	0.163	0.16	0.135	0.151	0.151	0.150	0.15	~~0.163~~	93%
	IC02	25.3	0.139	0.139	0.142	0.14	0.127	0.135	0.133	0.132	0.14	~~0.142~~	95%
	IC01	16.0	0.132	0.132	0.132	0.13	0.120	0.131	0.128	0.124	0.13	~~0.132~~	99%
	IC00	1.9	0.129	0.124	0.128	0.13	0.114	0.127	0.124	0.119	0.13	~~0.129~~	98%
R/B-FH/A	FH08	154.5	0.606	0.701	0.780	0.78	0.586	0.892	0.742	0.723	0.89	~~0.892~~	114%
	FH07	125.7	0.384	0.444	0.506	0.51	0.396	0.557	0.450	0.472	0.56	~~0.557~~	110%
	RE05	115.5	0.218	0.250	0.277	0.28	0.210	0.252	0.325	0.260	0.33	~~0.325~~	117%
	RE04	101.0	0.192	0.213	0.254	0.25	0.175	0.209	0.307	0.228	0.31	~~0.307~~	121%
	RE41	101.0	0.205	0.229	0.263	0.26	0.189	0.217	0.303	0.238	0.30	~~0.303~~	115%
	RE42	101.0	0.209	0.232	0.283	0.28	0.190	0.225	0.298	0.236	0.30	~~0.298~~	105%
	FH06	101.0	0.247	0.289	0.322	0.32	0.239	0.331	0.284	0.295	0.33	~~0.331~~	103%
	RE03	76.4	0.178	0.191	0.222	0.22	0.162	0.189	0.233	0.195	0.23	~~0.233~~	105%
	RE02	50.2	0.163	0.173	0.183	0.18	0.144	0.174	0.190	0.163	0.19	~~0.190~~	104%
	RE01	25.3	0.144	0.154	0.159	0.16	0.136	0.155	0.157	0.136	0.16	~~0.159~~	99%
	RE00	3.6	0.127	0.125	0.127	0.13	0.115	0.118	0.126	0.121	0.13	~~0.127~~	99%

RCOL2_03.07.2-8

Table 3NN-13

Maximum Accelerations in EW Direction

RCOL2_03.07.2-8

Structure	Lumped Mass	El. (ft)	~~Site Profile~~Surface Foundation (g)				Embedded Foundation (g)						
			SLB	SBE	SUB	Env.	ELB	EBE	EUB	EHB	Env.	~~Env.~~	Embed. /Surf
PCCV	CV11	230.2	0.565	0.713	0.854	0.85	0.538	0.552	0.704	0.691	0.70	~~0.854~~	82%
	CV10	225.0	0.555	0.699	0.837	0.84	0.532	0.541	0.689	0.678	0.69	~~0.837~~	82%
	CV09	201.7	0.510	0.635	0.757	0.76	0.506	0.491	0.620	0.616	0.62	~~0.757~~	82%
	CV08	173.1	0.445	0.544	0.644	0.64	0.427	0.420	0.526	0.528	0.53	~~0.644~~	82%
	CV07	145.6	0.389	0.448	0.526	0.53	0.366	0.349	0.427	0.439	0.44	~~0.526~~	83%
	CV06	115.5	0.321	0.347	0.405	0.41	0.298	0.276	0.327	0.341	0.34	~~0.405~~	84%
	CV05	92.2	0.283	0.306	0.319	0.32	0.253	0.237	0.269	0.280	0.28	~~0.319~~	88%
	CV04	76.4	0.249	0.276	0.280	0.28	0.220	0.212	0.237	0.243	0.24	~~0.280~~	87%
	CV03	68.3	0.230	0.259	0.261	0.26	0.202	0.199	0.221	0.223	0.22	~~0.261~~	85%
	CV02	50.2	0.185	0.214	0.213	0.21	0.163	0.169	0.188	0.181	0.19	~~0.214~~	88%
	CV01	25.3	0.133	0.151	0.153	0.15	0.120	0.136	0.139	0.128	0.14	~~0.153~~	91%
	CV00	1.9	0.119	0.118	0.117	0.12	0.102	0.111	0.120	0.111	0.12	~~0.120~~	101%
Containment Internal Structure	IC09	139.5	0.920	1.034	1.108	1.11	0.790	0.965	1.054	0.937	1.05	~~1.108~~	95%
	IC08	112.3	0.511	0.561	0.622	0.62	0.480	0.540	0.569	0.552	0.57	~~0.622~~	91%
	IC18	110.8	0.484	0.532	0.593	0.59	0.461	0.514	0.541	0.527	0.54	~~0.593~~	91%
	IC61	96.6	0.333	0.353	0.373	0.37	0.241	0.279	0.294	0.287	0.29	~~0.373~~	79%
	IC62	96.6	0.333	0.353	0.373	0.37	0.241	0.279	0.294	0.287	0.29	~~0.373~~	79%
	IC05	76.4	0.254	0.260	0.262	0.26	0.189	0.218	0.223	0.232	0.23	~~0.262~~	89%
	IC07	76.4	0.256	0.264	0.266	0.27	0.198	0.212	0.216	0.226	0.23	~~0.266~~	85%
	IC15	59.2	0.192	0.197	0.204	0.20	0.167	0.182	0.184	0.200	0.20	~~0.204~~	98%
	IC04	50.2	0.175	0.180	0.182	0.18	0.159	0.173	0.170	0.183	0.18	~~0.183~~	101%
	IC14	45.7	0.164	0.168	0.168	0.17	0.150	0.164	0.159	0.171	0.17	~~0.171~~	102%
	IC03	35.6	0.144	0.146	0.146	0.15	0.130	0.146	0.134	0.143	0.15	~~0.146~~	100%
	IC02	25.3	0.126	0.131	0.128	0.13	0.112	0.129	0.127	0.124	0.13	~~0.131~~	98%
	IC01	16.0	0.123	0.124	0.123	0.12	0.107	0.119	0.123	0.118	0.12	~~0.124~~	99%
	IC00	1.9	0.119	0.118	0.117	0.12	0.102	0.111	0.120	0.112	0.12	~~0.120~~	101%
R/B-FH/A	FH08	154.5	0.350	0.413	0.455	0.46	0.320	0.425	0.482	0.462	0.48	~~0.482~~	106%
	FH07	125.7	0.292	0.304	0.343	0.34	0.264	0.327	0.442	0.350	0.44	~~0.442~~	129%
	RE05	115.5	0.271	0.317	0.383	0.38	0.247	0.308	0.337	0.333	0.34	~~0.383~~	88%
	RE04	101.0	0.230	0.267	0.337	0.34	0.234	0.267	0.285	0.284	0.29	~~0.337~~	85%
	RE41	101.0	0.246	0.306	0.382	0.38	0.247	0.285	0.326	0.319	0.33	~~0.382~~	85%
	RE42	101.0	0.241	0.288	0.364	0.36	0.242	0.272	0.310	0.306	0.31	~~0.364~~	85%
	FH06	101.0	0.245	0.247	0.282	0.28	0.223	0.267	0.287	0.266	0.29	~~0.287~~	102%
	RE03	76.4	0.198	0.206	0.229	0.23	0.194	0.217	0.221	0.207	0.22	~~0.229~~	97%
	RE02	50.2	0.174	0.179	0.185	0.19	0.161	0.180	0.195	0.168	0.20	~~0.195~~	105%
	RE01	25.3	0.149	0.151	0.146	0.15	0.137	0.144	0.167	0.139	0.17	~~0.167~~	111%
	RE00	3.6	0.126	0.125	0.125	0.13	0.114	0.115	0.136	0.113	0.14	~~0.136~~	108%

Table 3NN-14

Maximum Accelerations in Vertical Direction

Structure	Lumped Mass	El. (ft)	~~Site Profile~~Surface Foundation (g)				Embedded Foundation (g)					~~Env.~~	Embed. /Surf
			SLB	SBE	SUB	Env.	ELB	EBE	EUB	EHB	Env.		
PCCV	CV11	230.2	0.437	0.482	0.515	0.52	0.362	0.394	0.626	0.430	0.63	~~0.626~~	122%
	CV10	225.0	0.388	0.420	0.448	0.45	0.323	0.341	0.543	0.334	0.54	~~0.543~~	121%
	CV09	201.7	0.313	0.327	0.349	0.35	0.230	0.240	0.398	0.249	0.40	~~0.398~~	114%
	CV08	173.1	0.271	0.283	0.302	0.30	0.185	0.220	0.327	0.212	0.33	~~0.327~~	108%
	CV07	145.6	0.255	0.266	0.284	0.28	0.174	0.212	0.303	0.203	0.30	~~0.303~~	107%
	CV06	115.5	0.227	0.237	0.253	0.25	0.163	0.196	0.263	0.187	0.26	~~0.263~~	104%
	CV05	92.2	0.201	0.209	0.223	0.22	0.152	0.179	0.232	0.170	0.23	~~0.232~~	104%
	CV04	76.4	0.180	0.188	0.201	0.20	0.144	0.166	0.209	0.158	0.21	~~0.209~~	104%
	CV03	68.3	0.169	0.177	0.188	0.19	0.138	0.159	0.196	0.149	0.20	~~0.196~~	104%
	CV02	50.2	0.148	0.154	0.159	0.16	0.127	0.141	0.166	0.132	0.17	~~0.166~~	104%
	CV01	25.3	0.128	0.132	0.133	0.13	0.117	0.122	0.130	0.120	0.13	~~0.133~~	98%
	CV00	1.9	0.110	0.112	0.113	0.11	0.111	0.110	0.108	0.122	0.12	~~0.122~~	108%
Containment Internal Structure	IC09	139.5	0.199	0.220	0.264	0.26	0.242	0.232	0.275	0.249	0.28	~~0.275~~	104%
	IC08	112.3	0.192	0.214	0.253	0.25	0.231	0.222	0.263	0.235	0.26	~~0.263~~	104%
	IC18	110.8	0.190	0.213	0.252	0.25	0.229	0.220	0.261	0.233	0.26	~~0.261~~	104%
	IC61	96.6	0.160	0.181	0.205	0.21	0.176	0.180	0.203	0.198	0.20	~~0.205~~	99%
	IC62	96.6	0.160	0.182	0.209	0.21	0.173	0.178	0.208	0.195	0.21	~~0.209~~	100%
	IC05	76.4	0.121	0.133	0.146	0.15	0.144	0.143	0.163	0.134	0.16	~~0.163~~	112%
	IC07	76.4	0.157	0.178	0.208	0.21	0.181	0.184	0.204	0.178	0.20	~~0.208~~	98%
	IC15	59.2	0.112	0.122	0.132	0.13	0.131	0.129	0.146	0.123	0.15	~~0.146~~	111%
	IC04	50.2	0.108	0.117	0.126	0.13	0.123	0.122	0.136	0.117	0.14	~~0.136~~	108%
	IC14	45.7	0.106	0.113	0.122	0.12	0.119	0.117	0.131	0.117	0.13	~~0.131~~	107%
	IC03	35.6	0.106	0.107	0.112	0.11	0.116	0.112	0.118	0.119	0.12	~~0.119~~	106%
	IC02	25.3	0.107	0.109	0.109	0.11	0.114	0.108	0.107	0.119	0.12	~~0.119~~	109%
	IC01	16.0	0.109	0.111	0.111	0.11	0.112	0.108	0.105	0.121	0.12	~~0.121~~	109%
	IC00	1.9	0.110	0.112	0.113	0.11	0.111	0.110	0.107	0.122	0.12	~~0.122~~	108%
R/B-FH/A	FH08	154.5	0.318	0.361	0.392	0.39	0.363	0.401	0.501	0.408	0.50	~~0.501~~	128%
	FH07	125.7	0.290	0.330	0.358	0.36	0.331	0.373	0.473	0.374	0.47	~~0.473~~	132%
	RE05	115.5	0.264	0.294	0.312	0.31	0.262	0.306	0.325	0.322	0.33	~~0.325~~	104%
	RE04	101.0	0.245	0.273	0.286	0.29	0.241	0.291	0.308	0.309	0.31	~~0.309~~	108%
	RE41	101.0	0.314	0.354	0.371	0.37	0.348	0.420	0.512	0.400	0.51	~~0.512~~	138%
	RE42	101.0	0.259	0.292	0.325	0.33	0.274	0.309	0.354	0.305	0.35	~~0.354~~	109%
	FH06	101.0	0.265	0.300	0.332	0.33	0.302	0.342	0.438	0.345	0.44	~~0.438~~	132%
	RE03	76.4	0.131	0.140	0.148	0.15	0.164	0.182	0.228	0.174	0.23	~~0.228~~	154%
	RE02	50.2	0.124	0.127	0.127	0.13	0.153	0.164	0.205	0.154	0.21	~~0.205~~	161%
	RE01	25.3	0.117	0.119	0.119	0.12	0.143	0.147	0.172	0.141	0.17	~~0.172~~	145%
	RE00	3.6	0.111	0.114	0.115	0.12	0.135	0.134	0.139	0.126	0.14	~~0.139~~	121%

RCOL2_03.07.2-8

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

Comanche Peak, Units 3 and 4

Luminant Generation Company LLC

Docket Nos. 52-034 and 52-035

RAI NO.: 2879 (CP RAI #60)

SRP SECTION: 03.07.02 - Seismic System Analysis

QUESTIONS for Structural Engineering Branch 1 (AP1000/EPR Projects) (SEB1)

DATE OF RAI ISSUE: 9/15/2009

QUESTION NO.: 03.07.02-9

In response to COL 3.7(23), Luminant stated, in FSAR Section 3.7.2.4.1 of the COLA, that the range of subgrade properties considered in the auxiliary building (A/B) and turbine building (T/B) SSI lumped parameter models envelope site-specific variations related to subgrade stratigraphy and foundation flexibility.

Explain specifically what is meant by saying that the lumped parameter models "envelope" site-specific variations in these parameters. What variables or parameters are compared to draw this conclusion? Also, provide a demonstration that the response of a series of uniform soil columns with a range of subgrade properties "envelopes" the critical responses of non-uniform site-specific soil column profiles.

ANSWER:

The SSI lumped parameter A/B and T/B models consider sets of subgrade translational and rotational spring constants that are based on shear wave velocities of 3,500 ft/s and 6,500 ft/s. These shear wave velocity values envelope the average shear wave velocity of about 5,800 ft/s that was calculated for the site-specific subgrade stratigraphy to a depth of approximately 400 ft below the bottoms of the foundations. The standard plant A/B and T/B are designed with an SSE corresponding to the CSDRS tied to 0.3 g PGA. The site-specific SSE used for seismic design and analyses is the same shape but tied to 0.1 g. Further, this shape envelopes by a large margin the theoretical FIRS that are developed for the site, as demonstrated in Figure 3.7-201. Because of the large ratio of the standard plant input motion versus the site-specific input motion, the assumptions for the standard plant design of the A/B and T/B were considered to envelope the critical responses of the non-uniform site-specific soil column profiles, and were not validated by performing site-specific SSI analyses. SSI analyses for A/B and T/B in generic standard soil input will be performed by May 2010. May 2010 was selected as a tentative schedule at the time of MHI's meeting with NRC on November 16, 2009. This meeting was held in order to address the concerns the NRC staff raised in the September 24, 2009 telephone conference regarding the review of the DCD Revision 1.

FSAR Subsection 3.7.2.4.1 has been revised to incorporate this response.

Impact on R-COLA

See attached marked-up FSAR Draft Revision 1 page 3.7-10.

Impact on S-COLA

None.

Impact on DCD

None.

The SSI lumped parameter A/B and T/B models consider sets of subgrade translational and rotational spring constants that are based on shear wave velocities of 3,500 ft/s and 6,500 ft/s. These shear wave velocity values envelope the average shear wave velocity of about 5,800 ft/s that was calculated for the site-specific subgrade stratigraphy to a depth of approximately 400 ft below the bottoms of the foundations. The standard plant A/Bs and T/Bs are designed with an SSE corresponding to the CSDRS tied to 0.3 g PGA. The site-specific SSE used for seismic design and analyses is the same shape but tied to 0.1 g. Further, this shape envelopes by a large margin the theoretical FIRS that are developed for the site, as demonstrated in Figure 3.7-201. Because of the large ratio of the standard plant input motion versus the site-specific input motion, the assumptions for the standard plant design of the A/Bs and T/Bs were considered to envelope the critical responses of the non-uniform site-specific soil column profiles, and were not validated by performing site-specific SSI analyses.

with the following:

The results of the site-specific SSI analysis documented in Appendix 3NN demonstrate that the standard plant broadened ISRS contained in Appendix 3I for the R/B-PCCV-containment internal structure are enveloped by a high margin. Considering the low site-specific seismic response (based on FIRS tied to 0.1 g versus standard plant CSDRS tied to 0.3 g), it is concluded from the review of the Appendix 3NN results that the R/B basemat seismic pressures and basement walls lateral soil pressures are also enveloped by the US-APWR standard design.

The range of subgrade properties considered in the A/B and T/B SSI lumped parameter models envelope site-specific variations related to subgrade stratigraphy and foundation flexibility. Since the basemat embedment effects are neglected, this also yields conservative results which envelope the site-specific responses. RCOL2_03.07.02-9

The standard plant PS/Bs are designed with an SSE corresponding to the standard plant CSDRS, which is anchored at a 0.3g PGA. Because of the large ratio of the standard plant input motion versus the site-specific input motion, the design of the PS/Bs is not validated by performing site-specific SSI analyses. Instead, the design is considered suitable based on the large margin by which the R/B standard plant ISRS envelope the ISRS obtained from the site-specific SSI analysis for the R/B, as documented in Appendix 3NN. Therefore, site-specific analysis of SSI effects for the PS/Bs at CPNPP site is not required based on the comparisons of the R/B standard plant ISRS versus site-specific ISRS documented in Appendix NN. RCOL2_03.07.02-6

3.7.2.8 Interaction of Non-Category I Structures with Seismic Category I Structures

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CP COL 3.7(10) Replace the last sentence of the fifth paragraph in DCD Subsection 3.7.2.8 with the following.

Structure-to-structure interactions, which could potentially influence the measured seismic response levels, will not occur because the R/B and PS/B are both founded on the same very stiff limestone layer and are separated by expansion joints which prevent seismic interaction.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

Comanche Peak, Units 3 and 4

Luminant Generation Company LLC

Docket Nos. 52-034 and 52-035

RAI NO.: 2879 (CP RAI #60)

SRP SECTION: 03.07.02 - Seismic System Analysis

QUESTIONS for Structural Engineering Branch 1 (AP1000/EPR Projects) (SEB1)

DATE OF RAI ISSUE: 9/15/2009

QUESTION NO.: 03.07.02-10

In response to COL 3.7(23), Luminant, in Section 3.7.2.4.1 of the COLA, stated because the embedment effects are neglected in the site-independent SSI analyses of the A/B and T/B, this yields conservative results that envelope the site specific responses.

In order for the NRC staff to evaluate the SSI analyses of the A/B and T/B, explain specifically what is meant by saying that the results of the site-independent SSI analyses envelope site specific responses. Describe what variables or parameters are compared to draw this conclusion and explain the basis for this conclusion given that site-specific SSI analyses of the A/B and T/B are not reported in the COLA.

ANSWER:

Please refer to the response to Question 03.07.02-9 above.

Impact on R-COLA

None.

Impact on S-COLA

None.

Impact on DCD

None.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

Comanche Peak, Units 3 and 4

Luminant Generation Company LLC

Docket Nos. 52-034 and 52-035

RAI NO.: 2879 (CP RAI #60)

SRP SECTION: 03.07.02 - Seismic System Analysis

QUESTIONS for Structural Engineering Branch 1 (AP1000/EPR Projects) (SEB1)

DATE OF RAI ISSUE: 9/15/2009

QUESTION NO.: 03.07.02-11

NUREG-0800, Standard Review Plan (SRP) 3.7.2, "Seismic System Analysis," establishes the criteria the NRC staff will use to evaluate whether an applicant meets the NRC's regulations.

In order for the NRC staff to evaluate the structural analyses of the ultimate heat sink related structures (UHSRS), essential service water pipe tunnel (ESWPT), power source fuel storage vault (PSFSV), and R/B-pre-stressed concrete containment vessel (PCCV)-containment internal structure (CIS), describe the roles of ANSYS and SASSI models in each of the analyses described in COLA, FSAR Appendices 3KK, 3LL, 3MM, and 3NN. In each case, at a minimum, the description should include the type of analysis (e.g. static, response spectrum, frequency domain SSI), the input and output for each code, and how the results of the two codes are integrated in the analysis. Separate descriptions should be provided for each of the analyses documented in Appendices 3KK, 3LL, 3MM, and 3NN.

ANSWER:

The response is presented in four parts, one for each appendix:

COLA FSAR Appendix 3KK – Model Properties and Seismic Analysis Results for UHSRS:

The analyses performed for Appendix 3KK are discussed below and summarized in a table following the discussion.

Frequency domain soil structure interaction analyses performed using SASSI were run for six soil conditions representing the following soil conditions:

1. Best estimate with soil bonded to structure,
2. Lower bound with separated soil elements,
3. Best estimate with separated soil elements,
4. Upper bound with separated soil elements

5. High bound with separated soil elements, and
6. Lower bound rock with no fill.

The SSI models were analyzed in SASSI with the applied input motion matching site-specific design response spectra from site-response analysis. The SASSI model used OBE damping values for structural materials based on Table 2 of RG 1.61 to allow for spectra generation with no further study of damping in accordance with Section 1.2 of RG 1.61 "Special Consideration for In-Structure Response Spectra Generation". The resulting output from SASSI is therefore conservative for the design where higher damping levels are allowed based on Table 1 of RG 1.61. The SASSI analyses produce results including peak accelerations, in-structure response spectra, and seismic soil pressures. All results from SSI analyses represent the envelope of the six soil conditions. The SASSI analyses results were used to produce the final response spectra and provide confirmation of the design spectra and seismic soil pressures used in ANSYS.

ANSYS analyses were used to calculate the structural demands of the UHSRS to seismic soil pressure and seismic motion including hydrodynamic effects. The response spectra and soil pressure cases discussed below were analyzed for two boundary conditions: (1) fixed base and (2) on soil springs.

For seismic motion, the ANSYS analyses used response spectra analyses using the site specific 5% damped design response spectra. These spectra are conservative relative to the 7% damping allowed for structural design in Table 1 of RG 1.61. Hydrodynamic effects were included in the response spectra analysis by modeling the fluid mass impulsive component using directional masses on the walls and slab and convective components using directional masses connected to the walls using directional springs. The response spectra input was modified to address the low damping of hydrodynamic modes by using 0.5% damped spectra values in the low frequency region (<1Hz) where convective hydrodynamic modes exist based on SRP 3.7.3. Modal combination was performed using the RG. 1.92 Combination Method B.

For seismic soil pressure cases, analyzed statically in ANSYS, seismic soil pressure demands were applied to the structural elements as equivalent static pressures. Where the pressure represents the peak seismic soil pressures shown to be conservative when compared to the calculated elastic solution used in ASCE 4-98 based on J.H. Wood, 1973 and the SASSI results.

Demands calculated from the response spectra and soil pressure analyses performed in ANSYS were combined on an absolute basis to produce the maximum demands for each direction of motion and these directions were then combined spatially by 100-40-40 percent combination rule (Eq. 13 of RG 1.92).

A comparison of the SASSI generated site-specific in-structure response spectra at the base slab to the ANSYS input spectra shows that the input used for the ANSYS response spectra analyses is conservative. A comparison of the SASSI generated soil pressures with the soil pressures used for the seismic soil pressure analyses performed in ANSYS demonstrates that the applied loading is conservative.

See the attachment "Analyses performed for Appendix KK" below.

COLA FSAR Appendix 3LL – Model Properties and Seismic Analysis Results for ESWPT:

The analyses performed for Appendix 3LL are discussed below and summarized in a table following the discussion.

Frequency domain soil structure interaction analyses performed using SASSI were run for four soil conditions for tunnel segments 1 and 3 and eight for tunnel segment 2 to account for possible soil separation of the vertical portions of this segment as follows:

1. Best estimate,
2. Lower bound,
3. Upper bound,
4. High bound,
5. Best estimate with separated fill (segment 2 only),
6. Lower bound with separated fill (segment 2 only),
7. Upper bound with separated fill (segment 2 only),
8. High bound with separated fill (segment 2 only),

The SSI models were analyzed in SASSI with the applied input motion matching site-specific design response spectra from site-response analysis. The SASSI model used OBE damping values for structural materials based on Table 2 of RG 1.61 to allow for spectra generation with no further study of damping in accordance with Section 1.2 of RG 1.61 "Special Consideration for In-Structure Response Spectra Generation". The resulting output from SASSI is therefore conservative for design where higher damping levels are allowed based on Table 1 of RG 1.61. 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 the soil conditions. The SASSI analyses results were used to produce the final response spectra and provide confirmation of the ANSYS design input demands, output result demands.

ANSYS analyses were used to calculate the structural demands of the ESWPT to seismic soil pressure and seismic motion. Seismic motion was analyzed in ANSYS using response spectra analyses for segment 2. For segments 1 and 3, equivalent static accelerations were applied to represent the seismic loads.

For seismic motion demand calculation of segment 2, the response spectra analyses were performed in ANSYS using the site specific 5% damped design response spectra. Modal combination was performed in accordance with RG 1.91 Combination Method B. These spectra are conservative relative to the 7% damping allowed for structural design in Table 1 of RG 1.61.

For the seismic motion demand calculation of segments 1 and 3, an equivalent static lateral load was applied based on the peak accelerations calculated in SASSI. The accelerations applied are conservative relative to the peak accelerations calculated in SASSI as the envelope over all soil cases of peak nodal accelerations.

For all tunnel segments, seismic soil pressure was analyzed statically in ANSYS. The seismic soil pressure demands were applied on the structural elements as equivalent static pressures, where the applied pressure represents the peak seismic soil pressures. The pressures applied were shown to be conservative when compared to the calculated elastic solution used in ASCE 4-98 based on J.H. Wood, 1973 and the SASSI results.

Demands calculated from the response spectra and soil pressure analyses performed in ANSYS for segment 2 were combined on an absolute basis to produce the maximum demands for each direction of motion and these directions were then combined spatially by 100-40-40 percent combination rule (Eq. 13 of RG 1.92).

Demands calculated from the equivalent static accelerations and soil pressure analyses performed in ANSYS for segments 1 and 3 were combined to produce the maximum demands in each direction. The maximum demands for each direction of motion and these directions were then combined spatially by 100-40-40 percent combination rule (Eq. 13 of RG 1.92).

To confirm the design input and results from the ANSYS model, the in-structure response spectra at the base slab was compared to the input spectra used as input to the ANSYS model for segment 2, the soil pressures from SASSI were compared to the soil pressures used as input to the ANSYS model, and the plate stresses from SASSI were compared to those calculated in ANSYS.

See the attachment "Analyses performed for Appendix LL" below.

COLA FSAR Appendix 3MM – Model Properties and Seismic Analysis Results for PSFSVs:

The analyses performed for Appendix 3MM are discussed below and summarized in a table following the discussion.

Frequency domain soil structure interaction analyses performed using SASSI were run for nine soil conditions to account for soil variation and possible soil separation as follows:

1. Best estimate,
2. Lower bound,
3. Upper bound,
4. High bound,
5. Best estimate with separated fill,
6. Lower bound with separated fill,
7. Upper bound with separated fill,
8. High bound with separated fill,
9. Lower bound with fill.

The SSI models were analyzed in SASSI with the applied input motion matching site-specific design response spectra from site-response analysis. The SASSI model used OBE damping values for structural materials based on Table 2 of RG 1.61 to allow for spectra generation with no further study of damping in accordance with Section 1.2 of RG 1.61 "Special Consideration for In-Structure Response Spectra Generation". The resulting output from SASSI is therefore conservative for design where higher damping levels are allowed based on Table 1 of RG 1.61. The SASSI analyses produce results including peak accelerations, in-structure response spectra, and seismic soil pressures. All results from SSI analyses represent the envelope of the nine soil conditions. The SASSI analyses results were used to produce the final response spectra and provide confirmation of the ANSYS design input demands, and output result demands.

ANSYS analyses were used to calculate the structural demands of the PSFSV to seismic soil pressure and seismic motion. Seismic motion was analyzed in ANSYS by applying equivalent static lateral loads. The accelerations applied were conservative relative to the peak accelerations calculated in SASSI.

The seismic soil pressure was analyzed statically in ANSYS. The seismic soil pressure demands were applied on the structural elements as equivalent static pressures, where the applied pressure represents the peak seismic soil pressures. The pressures applied were shown to be conservative when compared to the calculated elastic solution used in ASCE 4-98 based on J.H. Wood, 1973 and the SASSI results.

Demands from the equivalent static accelerations and soil pressure analyses performed in ANSYS were combined to produce the maximum demand in each direction. The maximum demands for each direction of motion and these directions were then combined spatially by 100-40-40 percent combination rule (Eq. 13 of RG 1.92).

See the attachment "Analyses performed for Appendix MM" below.

COLA FSAR Appendix 3NN – Model Properties and Seismic Analysis Results for R/B, PCCV, CIS:

Per the requirements of US-APWR DCD (Reference 5.1), site-specific Soil-Structure Interaction (SSI) analyses were performed on the reactor buildings (R/B) and nuclear island of CPNPP Units 3 and 4 to validate the competency of the standard seismic design and address site-specific SSI effects.

The ACS SASSI v 2.2 computer program was the computational platform for these analyses. The program employs the complex response method and finite element (FE) technique to solve for the seismic response of the SSI system in frequency domain. The response is calculated at selected frequency of analysis and then interpolated for the range of frequencies of interest. Per DCD requirements, the cut off frequency of analysis is set at 50 Hz which includes the significant structural frequencies. The Fast Fourier Transformation (FFT) and inverse FFT technique is used to transform the input motion and the nodal responses of the system between the frequency and time domain.

Figure 3NN-7 of the COLA shows the complete SASSI model of the US-APWR Reactor Building (R/B) that was developed for site specific SSI analyses of the CPNPP Units 3 and 4. Three lumped-mass-stick models of the Prestressed Concrete Containment Vessel (PCCV), Containment Internal Structures (CIS) and Reactor Building (R/B) represent the stiffness and mass inertia properties of the building above the ground elevation. A 3-D Finite Element (FE) model represents the building basement and the floor slabs at ground elevation. At ground elevation, the PCCV and CIS lumped-mass-stick model are rigidly connected to the thick central portion of the building basemat. Rigid beams connect the basement shear walls with the lumped-mass-stick model representing the above ground portion of the R/B and FH/A structure.

The SASSI analysis of CPNPP Units 3 and 4 reactor building (R/B) employ the subtraction method to obtain the SSI impedance. All the nodes at the contact of the building basement with the rock subgrade and the backfill soil serve as interaction nodes. The design earthquake is input at the center of the reactor foundation at the bottom of the foundation nominal elevation of 782 ft where the GMRS for CPNPP Units 3 and 4 is defined. The S-waves propagating upward represent the two horizontal components of the design earthquake motion H1 and H2 that are applied in N-S and E-W direction, respectively. The vertical component of the design earthquake (V) is represented by vertically propagating P-waves. The three components of the earthquake are applied to the model separately.

Acceleration time histories compatible to the horizontal and vertical GMRS were used directly as input ground motion for the SASSI analyses of surface foundation. The SASSI analyses of embedded foundation used acceleration time histories representing the within earthquake motion at the surface of the limestone below the backfill. The analysis of each backfill profile uses a separate set of two horizontal acceleration time histories obtained from the free field site response analyses. The outcrop time history developed from the vertical GMRS is used as input vertical earthquake motion. The use of input outcrop accelerations yields conservative results for the structural response due to the vertical component of the design earthquake.

The site-specific SSI analyses of US-APWR standard plant consider the following seven site profiles:

1. SLB - Foundation without backfill resting on the surface of the rock subgrade profile with lower bound (LB) properties.

2. SBE - Foundation without backfill resting on the surface of the rock subgrade profile with best estimate (BE) properties.

3. SUB - Foundation without backfill resting on the surface the rock subgrade profile with upper bound (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.

The common basement foundation of PCCV, CIS and R/B structures of CPNPP Units 3 and 4 rests on the top of the limestone layer at 782 ft nominal elevation. The top 398 ft of rock subgrade that consists of interchanging layers of limestone, shale and sandstone with varying material properties are modeled in SASSI as semi-infinite visco-elastic layers. The deep Strawn rock formation consisting of hard shales with beds of limestone and sandstone is modeled as an infinite half space with visco-elastic properties.

The results of the site-specific SSI analysis of reactor building demonstrated that the ISRS that served as basis for the seismic design of the standard plant are much higher than the ARS obtained from site-specific SSI analysis, thus confirming that the DCD standard seismic design of the US-APWR is valid for the R/B-PCCV-CIS in the CPNPP Units 3 and 4.

As discussed in Appendix 3NN, Figures 3NN-16 through 3NN-27 present a comparison of the 5% damping ARS results and the US-APWR standard plant ISRS of the R/B-PCCV-CIS at lumped mass locations obtained from the site-specific SSI analysis of the CPNPP Units 3 and 4. These figures indicate that the ISRS envelopes by a wide margin the ARS results, thus confirming that the DCD standard seismic design of US-APWR is valid for the R/B-PCCV-CIS in the CPNPP Units 3 and 4.

The ANSYS program is used in the design of the concrete and steel components of a facility using SASSI results, and other input. Since the SASSI analyses indicated the standard DCD seismic design is valid for the R/B-PCCV-CIS in the CPNPP Units 3 and 4, ANSYS was not employed in the seismic evaluations discussed in Appendix 3NN.

Impact on R-COLA

See attached marked-up FSAR Draft Revision 1 pages 3KK-3, 3KK-6, 3KK-17, 3LL-2, 3LL-3, 3LL-4, 3LL-20, 3MM-3, 3MM-4, 3MM-5, 3MM-6, and 3MM-14.

Impact on S-COLA

None.

Impact on DCD

None.

Attachments

Analyses performed for Appendix KK

Analyses performed for Appendix LL

Analyses performed for Appendix MM

SASSI Model of Reactor Building, 4DS-CP34-20080048 Rev.1, Mitsubishi Heavy Industries, LTD, September 17, 2008 (Attachment 3 to this letter)

Site Specific SSI Analysis of US-APWR Reactor Building, SSI-12-05-100-003 Rev. C, URS, November 13, 2009 (Attachment 4 to this letter).

Analyses performed for Appendix KK:

Model	Loading Case	Analysis Method	Program	Input	Output	Three Components Combination	Modal Combination (for Dynamic Analyses)
Three-dimensional UHSRS FE Model	Seismic motion	Time history soil-structure interaction analysis in frequency domain using sub-structuring technique	SASSI	Time history input matching site-specific design response spectra from site-response analysis, site-specific soil profiles.	Peak accelerations, in-structure response spectra, soil pressures	SRSS	N/A
Three-dimensional UHSRS FE Model	Seismic soil pressure	Static	ANSYS	Peak soil pressures based on ASCE 4-98, separate analysis for each direction of pressure.	Element and section demands	Added on absolute basis to seismic structural response demands in same direction and spatially combined by Newmark 100-40-40 percent combination rule	N/A
Three-dimensional UHSRS FE Model	Seismic motion	Response Spectra Analysis	ANSYS	Site specific design response spectra 5% damped, modified to 0.5% damping at convective hydrodynamic modes.	Element and section demands	Combined by Newmark 100-40-40 percent combination rule	RG 1.92 Combination Method B

Analyses performed for Appendix LL:

Model	Loading Case	Analysis Method	Program	Input	Output	Three Components Combination	Modal Combination (for Dynamic Analyses)
Three-dimensional ESWPT FE Model	Seismic soil pressure	Static	ANSYS	Peak soil pressures based on ASCE 4-98, separate analysis for each direction of pressure.	Element and section demands	Added to seismic demands in same direction and combined by Newmark 100-40-40 percent combination rule	N/A
Three-dimensional ESWPT FE Model	Seismic motion Segment 1 and 3	Static	ANSYS	Peak accelerations that envelope results of SASSI	Element and section demands	Combined by Newmark 100-40-40 percent combination rule	N/A
Three-dimensional ESWPT FE Model	Seismic motion segment 2	Response Spectra Analysis	ANSYS	Site specific design response spectra 5% damped.	Element and section demands	Combined by Newmark 100-40-40 percent combination rule	RG 1.92 Combination Method B
Three-dimensional ESWPT FE Model	Seismic motion	Time history soil-structure interaction analysis in frequency domain using sub-structuring technique	SASSI	Time history input matching site-specific design response spectra from site-response analysis, site-specific soil profiles	Peak accelerations, in-structure response spectra, element forces, soil pressures.	SRSS	N/A

Analyses performed for Appendix MM:

Model	Loading Case	Analysis Method	Program	Input	Output	Three Components Combination	Modal Combination (for Dynamic Analyses)
Three-dimensional PSFSVs FE Model	Seismic motion	Time history soil-structure interaction analysis in frequency domain using sub-structuring technique	SASSI	Time history input matching site-specific design response spectra from site-response analysis, site-specific soil profiles	Peak accelerations, in-structure response spectra	SRSS	N/A
Three-dimensional PSFSVs FE Model	Seismic soil pressure	Static	ANSYS	Peak soil pressures based on ASCE 4-98, separate analysis for each direction of pressure.	Element and section demands	Added to seismic demands in same direction and combined by Newmark 100-40-40 percent combination rule	N/A
Three-dimensional PSFSVs FE Model	Seismic motion	Static	ANSYS	Peak accelerations that envelope results of SASSI	Element and section demands	Combined by Newmark 100-40-40 percent combination rule	N/A

309') recommended by SRP 3.7.2. A ten layer half-space is used below the lower boundary is the SASSI analysis consistent with SASSI manual recommendations. The SASSI half-space simulation consists of additional layers with viscous dashpots added at the base of the half-space. The half-space layer has a thickness of 1.5 Vs/ f where Vs is the shear wave velocity of the half-space and f is the frequency of the analysis and it is divided by the selected number of layers in the half-space. RCOL2_03.07.02-16

The cutoff frequencies for all cases are greater than 37 Hz and a minimum of 57 frequencies are analyzed for SSI analyses. The SASSI analysis frequencies are selected to cover the range between 1 Hz and the cutoff frequency. This frequency range includes the SSI frequency and primary structural frequencies. The 1 Hz lower limit was shown to be low enough to be outside the range of SSI or structural mode amplification. It was 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.

The UHSRS analyses were verified by the following methods:

- Comparison of eigenvalue analysis results between a coarser mesh (used for SASSI SSI analyses) and a finer mesh (used for ANSYS design analyses), the results are presented in Table 3KK-8.

- Review of SASSI transfer functions to verify that interpolation was reasonable and that expected structural responses were observed. All SASSI output results were compares between soil profiles to verify reasonably similar responses between the cases.

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 3KK-4) for structures on sites with low seismic responses where the analyses consider a relatively narrow range of site-specific subgrade conditions. The SASSI analyses produce results including peak accelerations, in-structure response spectra, and seismic soil pressures. All results from SSI analyses represent the envelope of the six soil conditions. The SASSI analyses results are used to produce the final response spectra and provide confirmation of the design spectra and seismic soil pressures used in ANSYS. RCOL2_03.07.02-11

Shell elements are used to model the basemat and brick elements are used for the concrete fill that is present beneath basemat. Beam elements are used for the concrete beams, that support slabs and equipment in the structure, and for the concrete columns in the cooling towers. Beam elements are also used to model the steel members in the UHSRS. Shell elements are used for the reinforced concrete walls and elevated slabs. Walls are modeled using gross section properties at the centerline. All roof slabs and elevated slabs (pump room, fan slab, missile shield protection) are considered as cracked with an out-of-plane rigid modes, using the low frequency correction α=0 for frequencies below the peak of the spectra. Periodic modal response is combined using the grouping method. Spatial combination is performed using the Newmark 100-40-40 percent combination rule. RCOL2_03.07.03-2

The peak sloshing height in any hydrodynamic region is equal to 1.91 ft. This height includes spatial combination of sloshing in each region using the Newmark 100-40-40 percent directional combination rule. The nominal freeboard height to the top of the basin walls and underside of the pump room slab is equal to 4 feet. Therefore, loss of water or uplifting pressures on the pump house slab is not a concern since adequate clearance is provided to allow this amount of sloshing.

The fine mesh ANSYS model is used for the calculation of both seismic and non-seismic demands for design. The seismic structural demands of the UHSRS are calculated from the seismic soil pressure and seismic inertia including hydrodynamic effects which are then added to all other design loads discussed in Section 3.8.4.3. Seismic inertial responses are calculated using response spectra analyses in ANSYS using the site specific design response spectra. Hydrodynamic effects are included in the response spectra analysis as described above except that the convective mass is included in the analysis using point masses and uni-directional springs which are attached to the end walls of each hydrodynamic region at the height of the convective pressure distribution centroid, h_c (see Table 3KK-7). The mass is equal to the convective mass (W_c) noted in the table and the springs are assigned stiffness such that the mass-spring system has a frequency equal to the convective frequency (f_c) noted in the table. Separate mass-spring systems are provided for all hydrodynamic regions. RCOL2_03.07.02-11

For seismic soil pressure cases, analyzed statically in ANSYS, seismic soil pressure demands are applied to the structural elements as equivalent static pressures. The equivalent trapezoidal pressures applied are larger than the resultant pressures calculated by ASCE 4-98 elastic solution based on J.H. Wood, 1973 and the enveloped of SASSI results.

Demands calculated from the response spectra and soil pressure analyses performed in ANSYS are combined on an absolute basis to produce the maximum demands for each direction of motion.

3KK.3 Seismic Analysis Results

Table 3KK-2 presents the natural frequencies of the UHSRS FE structural model used for the SASSI analysis. Table 3KK-3 presents a summary of SSI effects on the seismic response of the UHSRS. The maximum absolute nodal accelerations obtained from the SASSI analyses are presented in Table 3KK-4 for key UHSRS locations. The results envelope all site conditions considered. The maximum accelerations have been obtained by combining cross-directional contributions in accordance with RG 1.92 (Reference 3KK-6) using the square root sum of the squares (SRSS) method.

RCOL2_03.07.02-11

Table 3KK-8

Summary of Analyses Performed

Model	Loading Case	Analysis Method	Program	Input	Output	Three Components Combination	Modal Combination (for Dynamic Analyses)
Three-dimensional UHSRS FE Model	Seismic motion	Time history soil-structure interaction analysis in frequency domain using sub-structuring technique	SASSI	Time history input matching site-specific design response spectra from site-response analysis, site-specific soil profiles.	Peak accelerations, in-structure response spectra, soil pressures	SRSS	N/A
Three-dimensional UHSRS FE Model	Seismic soil pressure	Static	ANSYS	Peak soil pressures based on ASCE 4-98, separate analysis for each direction of pressure.	Element and section demands for design	Added on absolute basis to seismic structural response demands in same direction and spatially combined by Newmark 100-40-40 percent combination rule	N/A
Three-dimensional UHSRS FE Model	Seismic base spectra	Response Spectra Analysis	ANSYS	Site specific design response spectra 5% damped, modified to 0.5% damping at convective hydrodynamic modes.	Element and section demands for design	Combined by Newmark 100-40-40 percent combination rule	RG 1.92 Combination Method B

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 for all four soil property cases 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~~by comparing 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.

RCOL2_03.07.02-11

RCOL2_03.07.02-11

The location of the lower boundary used in the SASSI analysis is greater than 710 feet below grade. The depth is greater than the embedment plus twice the depth of the largest base dimensions (i.e. 192' x 2 + 31' = 415' for Tunnel 1) recommended by SRP 3.7.2 A ten layer half-space is used below the lower boundary in the SASSI analysis consistent with SASSI manual recommendations. The SASSI half-space simulation consists of additional layers with viscous dashpots added at the base of the half-space. The half-space layer has a thickness of 1.5 Vs/ f where Vs is the shear wave velocity of the half-space and f is

RCOL2_03.07.02-16

the frequency of analysis and it is divided by the selected number of layers in the half-space. RCOL2_03.07.02-16

The maximum shear wave passing frequency for all layers below the base slab and concrete fill, based on layer thicknesses of 1/5 wavelength, ranges from 30.6 Hz for LB to 50.4 Hz for HB. The passing frequency for the backfill ranges from 11.6 Hz for LB to 44.9 Hz for HB. The cutoff frequencies for all cases are greater than 29.3Hz and a minimum of 39 frequencies are analyzed for SSI analyses.

For the ESWPT analyses performed, benchmarking is performed to validate the results of the SASSI models. The natural frequencies of Tunnel Segment 1 are calculated for the FE model used for the SSI interaction analysis performed in SASSI (coarse model) and a more refined FE model (ANSYS) used for the analysis of all static load cases (detailed model) and compared. Tunnel 1 is deemed representative of the coarse and fine mesh models of all tunnel segments. For this analysis both models have all nodes at the intersection of mat slab and the walls fixed against translation. Results show close comparison between the calculated frequencies.

The tunnels are simple structures and responses are significantly influenced by the surrounding soil, producing frequencies of peak response in the embedded SASSI model that do not match the eigenvalue analysis of the fixed base structure without soil which limits the ability to compare transfer functions. Therefore, the response of these structures are checked primarily through model and analysis input file checks and reviews of the transfer functions and other output to make sure that adequate frequencies are used for calculation. The SASSI analysis frequencies are selected to cover the range between around 1 Hz and the cutoff frequency. This frequency range includes the SSI frequency and primary structural frequencies. The 1 Hz lower limit is low enough to be outside the range of SSI or structural mode amplification. It was 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. Initially, the frequencies are selected evenly spaced. Frequencies are added as needed to produce smooth interpolation of the transfer functions and accurately capture peaks. As verification, additional frequencies are added to observe that the results did not change. 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.

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. The SASSI analyses produce results including peak RCOL2_03.07.02-11 accelerations, in-structure response spectra, seismic element demands, and seismic soil pressures. All results from SSI analyses represent the envelope of the soil conditions. The SASSI analysis results are used to produce the final response spectra and provide confirmation of the inputs to the ANSYS design model. RCOL2_03.07.02-11

ANSYS analyses are used to calculate the structural demands of the ESWPT to seismic soil pressure and seismic inertia which are then added to all other design loads discussed in Section 3.8.

The seismic inertia demand of segment 2 are calculated using ANSYS, response spectra analyses with the site specific 5% damped design response spectra. Modal combination is performed in accordance with RG 1.91 Combination Method B. Analysis of the ESWPT produced 40 modes below 50 Hz. Table 3LL-15 lists five major structural frequencies for each direction of motion organized by mass participation. RCOL2_03.07.02-16

The seismic inertia demand of segments 1 and 3 are calculated using an equivalent static lateral load based on the enveloped peak accelerations calculated in SASSI for all soil cases. RCOL2_03.07.02-11

The seismic soil pressure demands are calculated statically in ANSYS. 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 and the enveloped SASSI results.

Demands calculated from the response spectra and soil pressure analyses performed in ANSYS for segment 2 are combined on an absolute basis to produce the maximum demands for each direction of motion and these directions are then combined spatially by 100-40-40 percent combination rule (Eq. 13 of RG 1.92).

Demands calculated from the equivalent static accelerations and soil pressure analyses performed in ANSYS for segments 1 and 3 are combined to produce the maximum demands in each direction. The maximum demands for each direction of motion and these directions are then combined spatially by 100-40-40 percent combination rule (Eq. 13 of RG 1.92).

To confirm the design input and results from the ANSYS model of tunnel segment 2 used for response spectra analysis, the enveloped in-structure response spectra at the base slab calculated in the SASSI analysis are compared to the input spectra. The enveloped soil pressures from SASSI are compared to the soil pressures used as input to the ANSYS model, and the plate stresses from SASSI are compared to those calculated in ANSYS. The comparisons show that the seismic loads used for design exceeded those based on results of the SASSI analysis.

RCOL2_03.07.02-11

Table 3LL-14

Summary of Analyses Performed

Model	Loading Case	Analysis Method	Program	Input	Output	Three Components Combination	Modal Combination (for Dynamic Analyses)
Three-dimensional ESWPT FE Model	Seismic soil pressure	Static	ANSYS	Peak soil pressures based on ASCE 4-98, separate analysis for each direction of pressure.	Element and section demands for design	Added to seismic demands in same direction and combined by Newmark 100-40-40 percent combination rule	N/A
Three-dimensional ESWPT FE Model	Seismic intertia Segment 1 and 3	Static	ANSYS	Peak accelerations that envelope results of SASSI.	Element and section demands for design	Combined by Newmark 100-40-40 percent combination rule	N/A
Three-dimensional ESWPT FE Model	Seismic intertia segment 2	Response Spectra Analysis	ANSYS	Site specific design response spectra 5% damped.	Element and section demands for design	Combined by Newmark 100-40-40 percent combination rule	RG 1.92 Combination Method B
Three-dimensional ESWPT FE Model	Seismic motion	Time history soil-structure interaction analysis in frequency domain using sub-structuring technique	SASSI	Time history input matching site-specific design response spectra from site-response analysis, site-specific soil profiles.	Peak accelerations, in-structure response spectra, element forces, soil pressure.	SRSS	N/A

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~~. An additional case representing a surface foundation condition using lower bound in-situ soil properties beneath the base slab without presence of any backfill is included.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~~by comparing the peak envelope soil pressure results to the at-rest soil pressure for the BE soil case. 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. RCOL2_03.07.02-11 RCOL2_03.07.02-11

The shear wave passing frequency for all layers below the base slab and concrete fill, based on layer thickness of 1/5 wavelength, ranges from 30.6Hz for LB to 50.4Hz for HB. The shear wave passing frequency for the backfill ranges from 11.4Hz for LB to 31.1Hz for HB. RCOL2_03.07.02-16

A ten-layer half-space is used in the SASSI analysis in accordance with the SASSI Manual recommendations. The SASSI half-space simulation consists of additional layers with viscous dashpots added at the base of the half-space. The half-space layer has a thickness of 1.5 Vs/ f where Vs is the shear wave velocity of the half-space and f is the frequency of analysis. The half-space is sub-divided by the selected number of layers in the half-space.

The lower boundary used in the SASSI analysis is 809 feet below grade. The depth is more than the embedment depth plus twice the depth of the largest base dimension (88' x 2 + 40' = 216') recommended by SRP 3.7.2. RCOL2_03.07.02-16

The cutoff frequencies for all cases are greater than 29.9Hz and a minimum of 48 frequencies are analyzed for SSI analyses. The SASSI analysis frequencies were selected to cover the range between around 1 Hz and the cutoff frequency. This frequency range includes the SSI frequency and primary structural frequencies. The 1 Hz lower limit is shown to be low enough to be outside the range of SSI or structural mode amplification. It was 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. Initially, the frequencies are selected evenly spaced. Frequencies are added as needed to produce smooth interpolation of the transfer functions and accurately capture peaks. As verification, additional frequencies were added to observe that the results did not change.

For the PSFSV analyses, benchmarking is performed to validate the results of the SASSI models for verification of both the mesh and the dynamic response. The mesh used for SASSI analyses is justified with respect to with the more refined design model by calculating eigenvalues and mode shapes for the models with each mesh using ANSYS and comparing the results. The comparisons show that the two models provide similar dynamic responses.

To verify the dynamic response, fixed base eigenvalue analysis is performed in ANSYS, and a corresponding fixed base analysis is performed in SASSI by placing the structure at the soil surface and setting the stiffness of the soil layers to high values to represent the fixed base condition. The fixed base ANSYS eigenvalues are compared to the transfer functions of the SASSI "fixed base" case to verify that the SASSI model exhibits the same dynamic response as the ANSYS model.

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

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.

The SASSI analyses produce results including peak accelerations, in-structure response spectra, and seismic soil pressures. All results from SSI analyses RCOL2_03.07.02-11 represent the envelope of the nine soil conditions. The SASSI analysis results are used to produce the final response spectra and provide confirmation of the ANSYS design input and output demands. RCOL2_03.07.02-11

ANSYS analyses are used to calculate the structural demands of the PSFSV to seismic soil pressure and seismic inertia which are then added to the effects of all other design loads discussed in Section 3.8.4.3. Seismic inertia is analyzed in ANSYS by applying equivalent static lateral loads. The equivalent static lateral loads applied are based on the enveloped peak accelerations calculated in SASSI. For reference, the modal properties of the ANSYS design model are provided in Table 3MM-9.

The seismic soil pressure is analyzed statically in ANSYS. The seismic soil pressure demands are applied on the structural elements as equivalent static pressures. The pressures applied are shown to be conservative when compared to the calculated elastic solution used in ASCE 4-98 based on J.H. Wood, 1973 and the enveloped SASSI results.

Demands from the equivalent static accelerations and soil pressure analyses performed in ANSYS are combined on an absolute basis to produce the maximum demand in each direction.

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~~SASSI 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. RCOL2_03.07.02-11

The seismic design forces and moments based on the ANSYS analysis 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. RCOL2_03.07.02-11

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 calculated in SASSI 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. RCOL2_03.07.02-11 RCOL2_03.07.02-15

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.

RCOL2_03.07.02-11

Table 3MM-8

Summary of Analyses Performed

Model	Loading Case	Analysis Method	Program	Input	Output	Three Components Combination
Three-dimensional PSFSVs FE Model	Seismic motion	Time history soil-structure interaction analysis in frequency domain using sub-structuring technique	SASSI	Time history input matching site-specific design response spectra from site-response analysis, site-specific soil profiles.	Peak accelerations, in-structure response spectra	SRSS
Three-dimensional PSFSVs FE Model	Seismic soil pressure	Static	ANSYS	Peak soil pressures based on ASCE 4-98, separate analysis for each direction of pressure.	Element and section demands	Added to seismic demands in same direction and combined by Newmark 100-40-40 percent combination rule
Three-dimensional PSFSVs FE Model	Seismic inertia	Static	ANSYS	Peak accelerations that envelope results of SASSI.	Element and section demands	Combined by Newmark 100-40-40 percent combination rule

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

Comanche Peak, Units 3 and 4

Luminant Generation Company LLC

Docket Nos. 52-034 and 52-035

RAI NO.: 2879 (CP RAI #60)

SRP SECTION: 03.07.02 - Seismic System Analysis

QUESTIONS for Structural Engineering Branch 1 (AP1000/EPR Projects) (SEB1)

DATE OF RAI ISSUE: 9/15/2009

QUESTION NO.: 03.07.02-12

NUREG-0800, Standard Review Plan (SRP) 3.7.2, "Seismic System Analysis," establishes the criteria the NRC staff will use to evaluate whether an applicant meets the NRC's regulations.

In order for the NRC staff to evaluate the methodology used in the SSI analysis of the ESWPT, describe how the results in COLA FSAR Tables 3LL-6, 3LL-7, and 3LL-8 were developed and how they were used in the analysis. The description should include a clarification of note 1 to Table 3LL-6, note 3 of Table 3LL-7, and note 4 of Table 3LL-8.

ANSWER:

The results in FSAR Table 3LL-6 are maximum enveloped peak accelerations generated from SSI analyses using SASSI. These values were applied as static equivalent seismic loads on tunnel segment 1 for generation of seismic demands in ANSYS.

The results in FSAR Table 3LL-7 are maximum enveloped peak accelerations generated from SSI analyses using SASSI. The results shown in FSAR Table 3LL-7 are reported for completeness but were not used as input in any other analyses. Seismic demands in ANSYS were generated using a response spectra analysis.

The results in FSAR Table 3LL-8 are maximum enveloped peak accelerations generated from SSI analyses using SASSI. These values were applied as static equivalent seismic loads on tunnel segment 3 for generation of seismic demands in ANSYS.

Note 1 of Table 3LL-6, note 3 of Table 3LL-7, and note 4 of Table 3LL-8 have been clarified in response to this RAI question.

<u>Impact on R-COLA</u>

See attached marked-up FSAR Draft Revision 1 pages 3LL-12, 3LL-13, and 3LL-14.

Impact on S-COLA

None.

Impact on DCD

None.

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 demands are calculated in ANSYS by applying these peak accelerations as statically equivalent loads across the entire component and combining with the demands calculated in ANSYS by applying an equivalent static seismic soil pressure.~~loads are obtained by applying to the ESWPT segment a statically equivalent uniform acceleration that envelopes the above accelerations and a dynamic soil pressure.~~ RCOL2_03.07.02-12

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, the seismic demands are calculated in ANSYS by response spectra analysis of the Segment 2 model using the site-specific design response spectra as input, and by combining the resulting demands with the demands calculated in ANSYS by applying an equivalent static seismic soil pressure.~~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.~~ RCOL2_03.07.02-12

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 demands are calculated in ANSYS using the peak accelerations as statically equivalent loads and combining them with the demands calculated in ANSYS by applying an equivalent static seismic soil pressure.~~loads are obtained by applying to the ESWPT segment a statically equivalent uniform acceleration that envelopes the above accelerations, and a dynamic soil pressure.~~ RCOL2_03.07.02-12

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

Comanche Peak, Units 3 and 4

Luminant Generation Company LLC

Docket Nos. 52-034 and 52-035

RAI NO.: 2879 (CP RAI #60)

SRP SECTION: 03.07.02 - Seismic System Analysis

QUESTIONS for Structural Engineering Branch 1 (AP1000/EPR Projects) (SEB1)

DATE OF RAI ISSUE: 9/15/2009

QUESTION NO.: 03.07.02-13

NUREG-0800, Standard Review Plan (SRP) 3.7.2, "Seismic System Analysis," establishes the criteria the NRC staff will use to evaluate whether an applicant meets the NRC's regulations.

In order for the NRC staff to evaluate the methodology used in the SSI analysis of the ESWPT, describe in detail how the results in COLA FSAR Tables 3LL-9, 3LL-10, 3LL-11, 3LL-12, and 3LL-13 were developed and how they are used in the analysis. The description should include whether the results were output from SASSI or ANSYS and if the results were used as input to either SASSI or ANSYS. The description should also include the loads, load combinations, and load distributions used for the structural evaluation and technical justification for why the selected loading leads to conservative results.

ANSWER:

The forces and moments in FSAR Tables 3LL-9, 3LL-10, and 3LL-11 represent seismic demands produced from ANSYS analyses as discussed in the answer to Question No. 03.07.02-11. These results include the combined demands from both seismic motion and seismic soil pressure and the combinations of all directions of input motion.

ANSYS analyses were used to calculate the structural demands of the ESWPT to seismic soil pressure and seismic motion. Seismic motion was analyzed in ANSYS using response spectra analyses for segment 2. For segments 1 and 3, equivalent static accelerations were applied to represent the seismic loads.

For seismic motion demand calculation of segment 2, the response spectra analyses were performed in ANSYS using the site specific 5% damped design response spectra. These spectra are conservative relative to the 7% damping allowed for structural design in Table 1 of RG 1.61.

For the seismic motion demand calculation of segments 1, and 3, an equivalent static lateral load was applied based on the peak accelerations calculated in SASSI. The accelerations applied were conservative relative to the peak accelerations calculated in SASSI as the envelope over all soil cases of peak nodal accelerations.

For all tunnel segments, seismic soil pressure was analyzed statically in ANSYS. The seismic soil pressure demands were applied on the structural elements as equivalent static pressures, where the applied pressure represents the peak seismic soil pressures. The pressures applied were shown to be conservative when compared to the calculated elastic solution used in ASCE 4-98 based on J.H. Wood, 1973 and the SASSI results.

Demands from the response spectra and soil pressure analyses performed in ANSYS for segment 2 (FSAR Table 3LL-10) were combined on an absolute basis to produce the maximum demands for each direction of motion and these directions were then combined spatially by 100-40-40 percent combination rule (Eq. 13 of RG 1.92).

Demands from the equivalent static accelerations and soil pressure analyses performed in ANSYS for segments 1 (FSAR Table 3LL-9) and 3 (FSAR Table 3LL-11) were combined to produce the maximum demands in each direction. The maximum demands for each direction of motion were then combined spatially by 100-40-40 percent combination rule (Eq. 13 of RG 1.92).

To confirm the design input and results from the ANSYS model, the in-structure response spectra at the base slab was compared to the input spectra used as input to the ANSYS model for segment 2, the soil pressures from SASSI were compared to the soil pressures used as input to the ANSYS model, and the plate stresses from SASSI were compared to those calculated in ANSYS.

The final load combinations used for the design are in accordance with ACI 349 and include the static load demands of dead load, live load, static earth load, wind load, tornado load (including tornado wind, tornado pressure effects, and tornado missile), and safe shutdown earthquake including dynamic soil pressures. Load combinations were performed to include full and reduced load factors where loads are permanent and full or zero load factors where loads may not exist in accordance with ACI 349. Combinations were performed in ANSYS to produce the final design demands.

Displacements provided in FSAR Table 3LL-12 are the peak displacements of the nodes calculated in the ANSYS seismic analyses representing the deflection calculated using the combined seismic ground motion and seismic soil pressure.
Soil pressures in FSAR Table 3LL-13 are calculated directly from SASSI analyses. Frequency domain soil structure interaction analyses performed using SASSI were run for four soil conditions for tunnel segments 1 and 3 and eight for tunnel segment 2 to account for possible soil separation of the vertical portions of this segment as follows:

1. Best estimate,
2. Lower bound,
3. Upper bound,
4. High bound,
5. Best estimate with separated fill (segment 2 only),
6. Lower bound with separated fill (segment 2 only),
7. Upper bound with separated fill (segment 2 only),
8. High bound with separated fill (segment 2 only),

The SSI models were analyzed with input motion matching site-specific design response spectra from site-response analysis. The SASSI model used OBE damping values for structural materials based on Table 2 of RG 1.61 to allow for spectra generation with no further study of damping in accordance with Section 1.2 of RG 1.61 "Special Consideration for In-Structure Response Spectra Generation". The resulting output from SASSI is therefore conservative for the design where higher damping levels are allowed based on Table 1 of RG 1.61. The SASSI analyses produced element stresses in the solid elements below the tunnels representing concrete fill, with the vertical stress representing bearing pressure below the tunnel. This vertical pressure is combined by SRSS for the three directions of input motion within each soil case and enveloped over all soil cases. The final result is reported in FSAR Table 3LL-13.

The design demands lead to conservative results because:

- The accelerations calculated in SASSI are based on 4% structural damping while a higher 7% damping is allowed by RG 1.61.
- The seismic equivalent static demand analyses in ANSYS uses conservative accelerations that envelope SASSI output peak accelerations.
- The seismic response spectra analyses are based on a 5% damped input spectra while a higher 7% damped spectra is allowed by RG 1.61.
- Seismic soil pressures have been demonstrated to be conservative with respect to the elastic solution and results from the SASSI analyses.

Impact on R-COLA

See attached marked-up FSAR Draft Revision 1 pages 3LL-5, 3LL-6, 3LL-15, 3LL-16, and 3LL-17

Impact on S-COLA

None.

Impact on DCD

None.

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~~<u>SASSI SSI</u> 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. RCOL2_03.07.02-13

<u>The forces and moments in </u>Tables 3LL-9, 3LL-10, and 3LL-11 <u>re</u>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~~<u>demands produced from ANSYS seismic analyses. These results include the combined demands from seismic intertia and seismic soil pressure and the combinations of all directions of input motion</u>. 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. RCOL2_03.07.02-13

<u>Displacements provided in </u>Table 3LL-12 ~~summarizes the resulting maximum displacements for enveloped seismic loading conditions for each of the three segments of the ESWPT~~<u>are the peak displacements of the nodes calculated in the ANSYS seismic analyses representing the deflection calculated using the combined seismic intertia and seismic soil pressure</u>. RCOL2_03.07.02-13

Table 3LL-13 presents the maximum pressures below the basemat of the ESWPT <u>calculated from SASSI analyses</u>.

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

The enveloped broadened ISRS <u>calculated in SASSI </u>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 RCOL2_03.07.02-13 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 (if applicable) 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. RCOL2_03.07.02-13 RCOL2_03.07.02-15

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 Analysis*, 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-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 include forces and moments due to seismic soil pressure that 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. RCOL2_03.07.02-13
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 include forces and moments due to seismic soil pressure that 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. RCOL2_03.07.02-13
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 include forces and moments due to seismic soil pressure that 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. RCOL2_03.07.02-13
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.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

Comanche Peak, Units 3 and 4

Luminant Generation Company LLC

Docket Nos. 52-034 and 52-035

RAI NO.: 2879 (CP RAI #60)

SRP SECTION: 03.07.02 - Seismic System Analysis

QUESTIONS for Structural Engineering Branch 1 (AP1000/EPR Projects) (SEB1)

DATE OF RAI ISSUE: 9/15/2009

QUESTION NO.: 03.07.02-14

In order for the NRC staff to evaluate the methodology used in the SSI analysis of the PSFSVs, describe in detail how the results in COLA FSAR Tables 3MM-6 (appendix 3MM) were developed and how they are used in the analysis. The description should include whether the results were output from SASSI or ANSYS and if the results were used as input to either SASSI or ANSYS. The description should also include the loads, load combinations, and load distributions used for the structural evaluation and technical justification for why the selected loading leads to conservative results.

ANSWER:

The forces and moments in FSAR Table 3MM-6 represent seismic demands produced from analyses using the program ANSYS. The results are maximum and minimum envelope forces and moments from all combined directions of input motion including both the seismic acceleration components and seismic soil pressures. The seismic accelerations were demonstrated to envelope the maximum accelerations calculated in SASSI that envelope all soil cases. Seismic soil pressures analyses are performed for each direction of pressure by applying a static equivalent pressure shown to be conservative in comparison to both SASSI analyses and to the peak seismic soil pressure calculated based on the elastic solution by J.H. Wood as described in ASCE 4-98.

The enveloped minimum and maximum seismic forces and moments are produced by combining the maximum forces and moments from the input response spectra on an absolute basis for each horizontal direction. Results from the three directions of input motion were combined spatially using the Newmark 100-40-40 percent combination rule described in SRP 1.92 Eq. 13. The results were then enveloped for all combinations of directions.

The final load combinations used for design are in accordance with ACI 349 and include the static load demands of dead load, live load, static earth load, wind load, tornado load (including tornado wind, tornado pressure effects, and tornado missile), and safe shutdown earthquake including dynamic soil pressures. Load combinations were performed to include full and reduced load factors where loads are permanent and full or zero load factors where loads may not exist in accordance with ACI 349. Combinations were performed in ANSYS to produce the final design demands.

The information provided in FSAR Table 3MM-6 leads to conservative results because:

- The accelerations calculated in SASSI are based on 4% structural damping while a higher 7% damping is allowed by RG 1.61.
- The demand analysis in ANSYS uses conservative accelerations that envelope SASSI output peak accelerations.
- Seismic soil pressures have been demonstrated to be conservative with respect to the elastic solution and results from the SASSI analyses.

Impact on R-COLA

See attached marked-up FSAR Draft Revision 1 page 3MM-12.

Impact on S-COLA

None.

Impact on DCD

None.

Table 3MM-6

Maximum Component Seismic Forces and Moments

		Maximum component forces and moments							
		N_V	N_L	Q_V	Q_L	S_W	M_V	M_L	M_{VL}
Component		**(k/ft)**	**(k/ft)**	**(k/ft)**	**(k/ft)**	**(k/ft)**	**(k-ft/ft)**	**(k-ft/ft)**	**(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 include forces and moments due to seismic soil pressure that envelope the all four subgrade ~~site~~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. RCOL2_03.07.02-14
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

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

Comanche Peak, Units 3 and 4

Luminant Generation Company LLC

Docket Nos. 52-034 and 52-035

RAI NO.: 2879 (CP RAI #60)

SRP SECTION: 03.07.02 - Seismic System Analysis

QUESTIONS for Structural Engineering Branch 1 (AP1000/EPR Projects) (SEB1)

DATE OF RAI ISSUE: 9/15/2009

QUESTION NO.: 03.07.02-15

FSAR Sections 3KK.4 and 3LL.4 of the COLA, Appendices 3KK and 3LL respectively, reference American Society of Civil Engineers (ASCE) 4-98 for justification of ISRS peak clipping. The NRC staff has not reviewed or endorsed ASCE 4-98 for generation of ISRS and this standard is currently being revised. Provide technical justification for spectral peak clipping recognizing that peak clipping is not discussed in RG 1.122, "Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components" (February 1978) or in SRP 3.7.2.

ANSWER:

The ISRS presented in Appendices 3KK, 3LL, and 3MM are enveloped broadened spectra in accordance with RG 1.122. Peak clipping was not performed in generation of the response spectra.

FSAR Appendix Sections 3KK.4 and 3LL.4, as well as Appendix Section 3MM, have been revised to remove the reference to peak clipping.

<u>Impact on R-COLA</u>

See attached marked-up FSAR Draft Revision 1 pages 3KK-8, 3LL-6, and 3MM-6.

<u>Impact on S-COLA</u>

None.

<u>Impact on DCD</u>

None.

base of the structure. The design analysis enveloped the demands from these two cases.

A comparison of the SASSI generated site-specific in-structure response spectra at the base slab to the ANSYS input spectra confirm that the input used for the ANSYS analyses is conservative. A comparison of the SASSI generated soil pressures with the soil pressures used for the seismic soil pressure analyses performed in ANSYS confirms that the applied loading used for design exceeds that calculated in the SASSI analyses. RCOL2_03.07.02-16

The seismic design forces and moments resulting from the design analysis are presented in Table 3KK-5 at key UHSRS locations. The force and moment values represent the enveloped results for the seismic demands for all soil cases considered in the SASSI analyses.

Table 3KK-6 summarizes the resulting maximum displacements for enveloped seismic loading conditions at key UHSRS locations obtained from the seismic analysis.

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

The enveloped broadened in-structure response spectra (ISRS) calculated in SASSI are presented in Figure 3KK-3 for the UHSRS base slab, pump room elevated slab, pump room roof slab, and cooling tower fan support slab 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 3KK-7). The ISRS include the envelope of the 6 site conditions (BE, LB, UB, and HB, ~~with and~~ BE without backfill separation from the structure, and the no-fill surface foundation condition with LB subgrade conditions). All results have been broadened by 15 percent and all valleys removed. ~~It is permitted to perform 15 percent peak clipping of the spectra presented herein in accordance with ASCE 4 (Reference 3KK-3) for spectra with less than 10 percent damping.~~ For the design of seismic category I and II subsystems and components mounted to the UHSRS walls, it is required to account for the effects of out-of-plane wall flexibility. RCOL2_03.07.02-15

3KK.5 References

3KK-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.

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

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

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 (if applicable) 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.

RCOL2_03.07.02-13

RCOL2_03.07.02-15

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 Analysis*, 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.

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

The enveloped broadened ISRS calculated in SASSI 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.

RCOL2_03.07.02-11

RCOL2_03.07.02-15

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.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

Comanche Peak, Units 3 and 4

Luminant Generation Company LLC

Docket Nos. 52-034 and 52-035

RAI NO.: 2879 (CP RAI #60)

SRP SECTION: 03.07.02 - Seismic System Analysis

QUESTIONS for Structural Engineering Branch 1 (AP1000/EPR Projects) (SEB1)

DATE OF RAI ISSUE: 9/15/2009

QUESTION NO.: 03.07.02-16

NUREG-0800, Standard Review Plan (SRP) 3.7.2, "Seismic System Analysis," establishes the criteria the NRC staff will use to evaluate whether an applicant meets the NRC's regulations.

In order to evaluate the site-specific SSI analyses reported in COLA FSAR Appendices 3KK, 3LL, 3MM, and 3NN, the NRC staff requests the following detailed information:

1. The natural frequencies of each of the structures in the fixed base condition.
2. The cutoff frequencies for each analysis.
3. The SASSI analysis frequencies used for each of the cases considered.
4. The basis for the selection of the SASSI analysis frequencies.
5. A comparison of transfer functions at critical locations to the selected analysis frequencies to determine the appropriateness of the frequency selection.
6. The soil layer thicknesses used in the SASSI analyses, and a demonstration that the layer thicknesses comply with the maximum layer thicknesses given by the "1/5 wavelength" guideline for SASSI analyses in each of the soil cases considered.
7. The location of the lower boundary used in the SASSI analyses.
8. The lower boundary condition used for the SASSI analyses.
9. A description of critical locations in the various structures under seismic loading.
10. A description of the benchmarking that was performed to validate the results of the SASSI models.

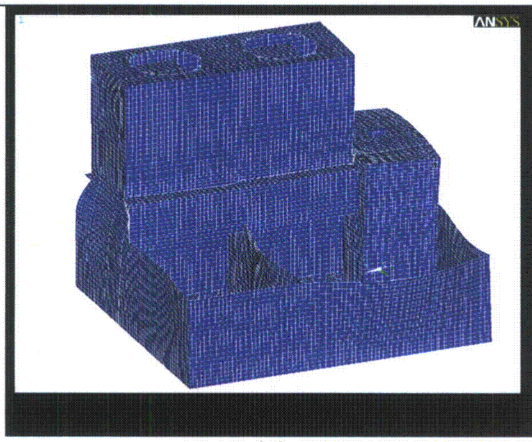
ANSWER:

Appendix KK – UHSRS

1. The analysis of the UHSRS produced more than 400 modes below 40 Hz. The modes include 16 convective fluid modes all under 0.7 Hz. Table 1 below lists 5 major structural frequencies for each direction of motion selected and organized by highest mass participation. Figures showing the mode shapes of these frequencies follow after Table 1.

Table 1 Major Structural Modes of UHSRS				
Major East-West (X) Direction Modes				
Mode	Frequency (Hz)	Period (sec)	Participation Factor	Effective Mass (kip sec^2/in)
24	6.8	0.148	7.07	50.00
23	6.6	0.153	2.93	8.59
19	4.2	0.241	2.89	8.34
64	13.2	0.076	1.81	3.28
63	13.2	0.076	1.71	2.91
Major North-South (Y) Direction Modes				
Mode	Frequency (Hz)	Period (sec)	Participation Factor	Effective Mass (kip sec^2/in)
26	7.4	0.136	5.86	34.40
52	11.5	0.087	2.44	5.98
69	13.9	0.072	2.33	5.41
23	6.6	0.153	2.06	4.25
53	11.7	0.085	1.87	3.51
Major Vertical Modes				
Mode	Frequency (Hz)	Period (sec)	Participation Factor	Effective Mass (kip sec^2/in)
108	17.4	0.058	2.15	4.64
47	10.7	0.094	2.05	4.19
60	12.9	0.078	2.04	4.15
127	19.8	0.050	1.80	3.23
75	14.8	0.068	1.79	3.20

Note: Coordinates (X,Y,Z) given in the table are the local coordinates of the structure.



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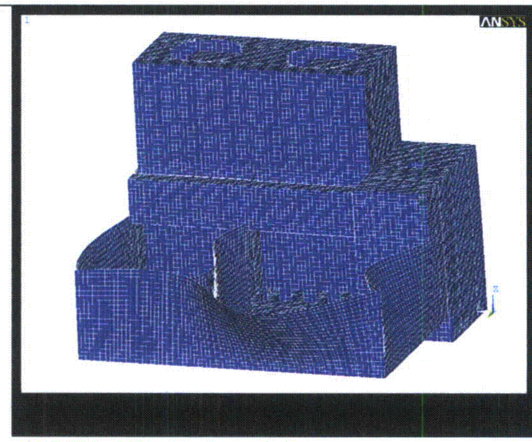

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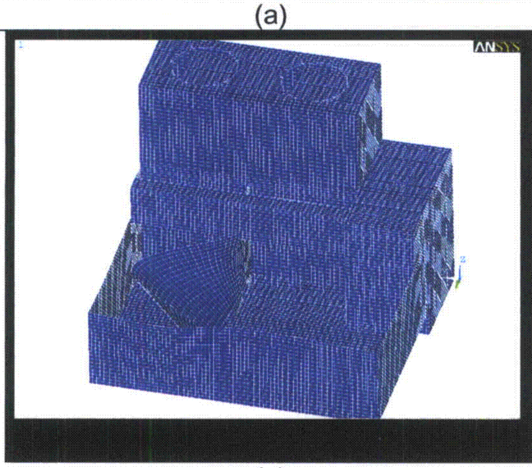
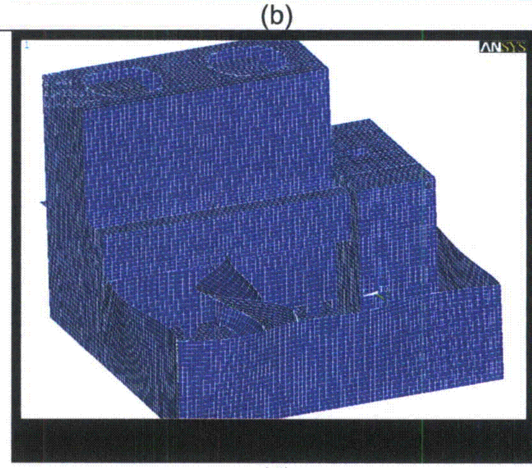
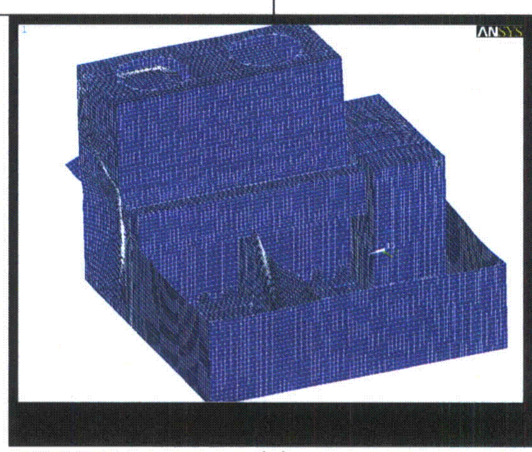


(c)

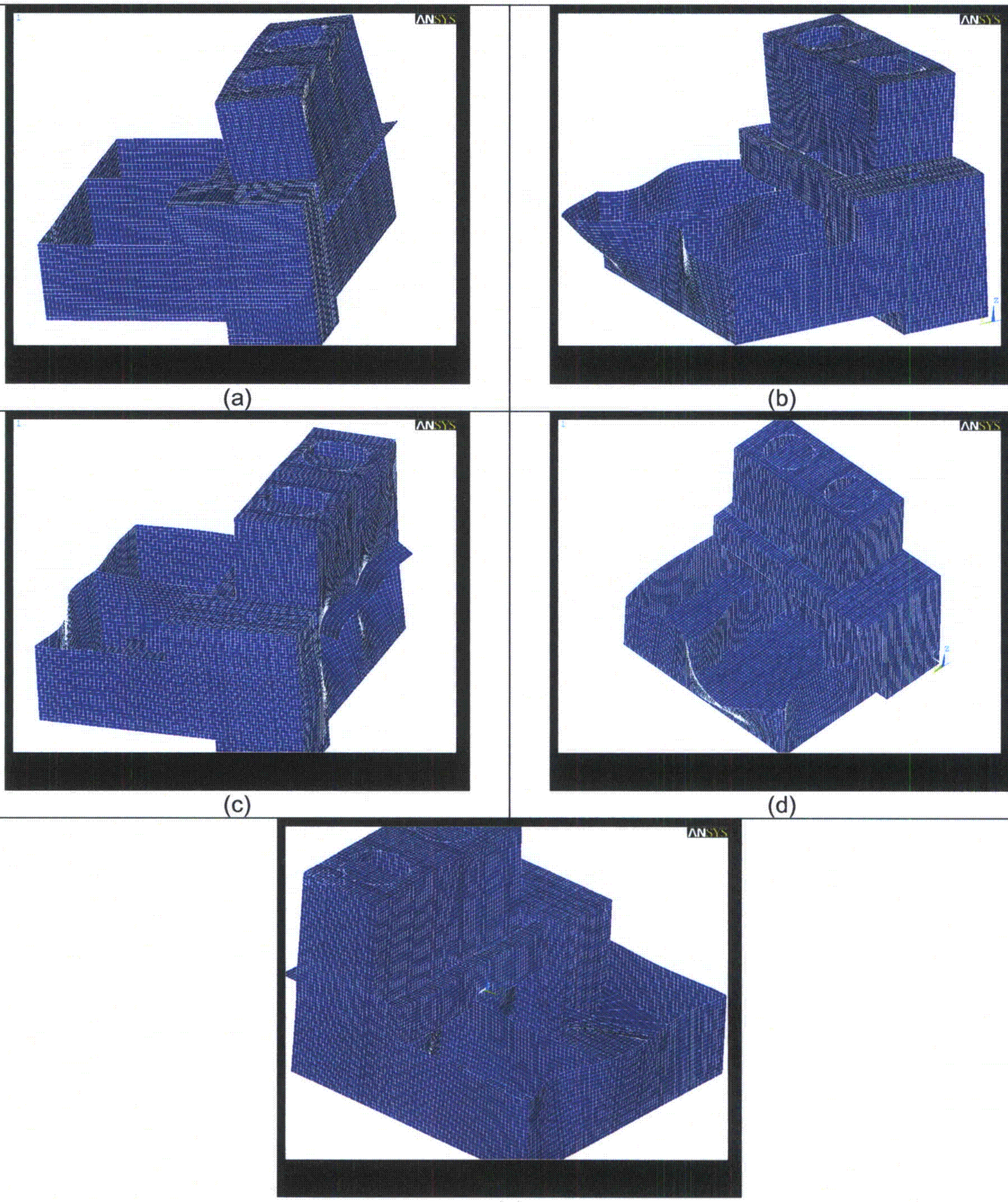


(d)

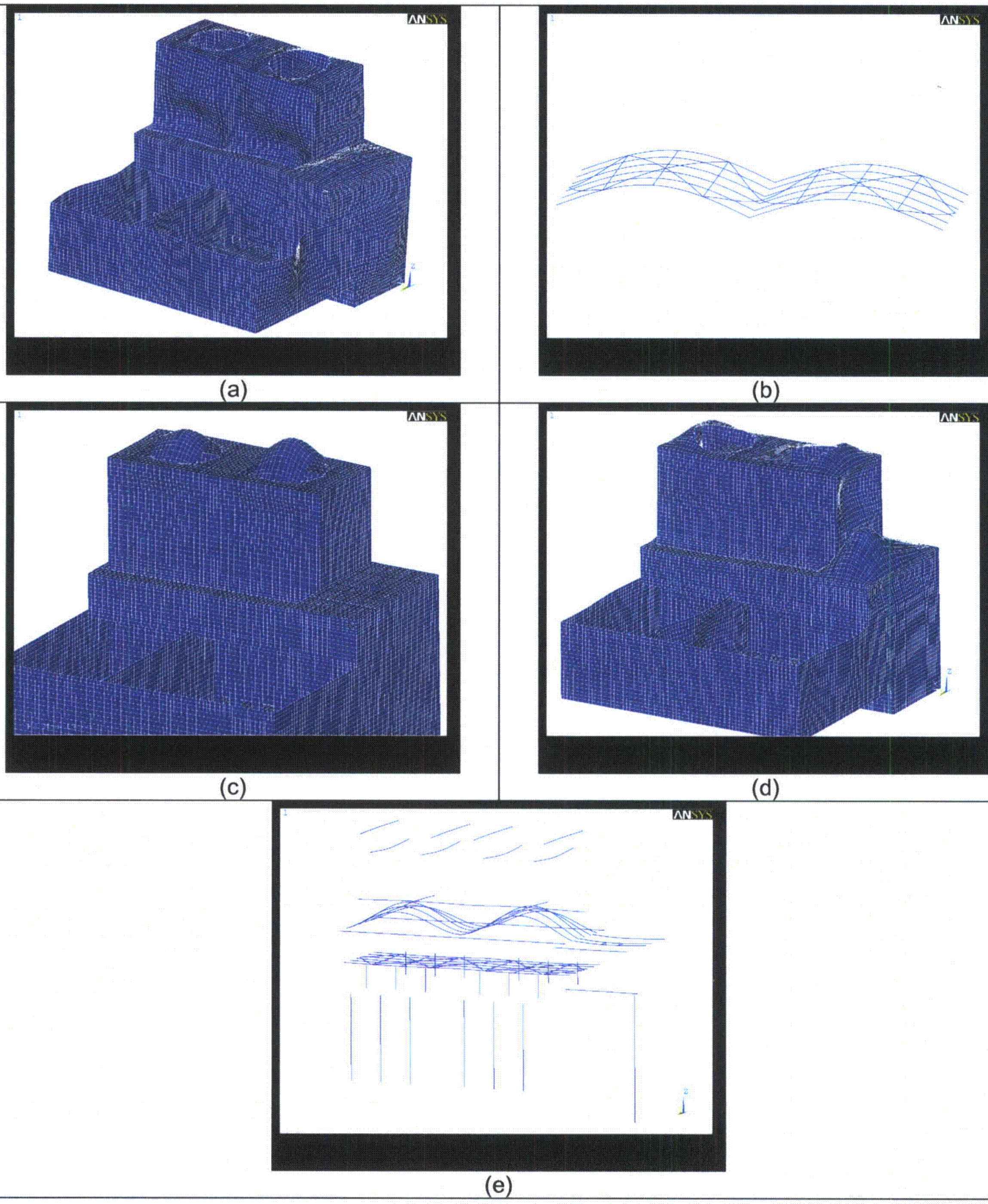


(e)

Major East-West Mode Shapes of UHSRS (a) Mode 24, f = 6.77 Hz, Lateral Sway Mode of Entire UHSRS, (b) Mode 23, f = 6.55 Hz, Basin Exterior Wall Out-of-Plane Mode, (c) Mode 19, f = 4.15 Hz, Basin Interior Wall Out-of-Plane Mode, (d) Mode 64, f = 13.2 Hz, Second Basin Interior Wall and Exterior Wall Mode, (e) Mode 63, f = 13.2 Hz, Higher Mode of UHSRS



Major North-South Mode Shapes of UHSRS (a) Mode 26, f = 7.37 Hz, Lateral Mode of Entire UHSRS, (b) Mode 52, f = 11.5 Hz, Basin 2 North Exterior Wall Out-of-Plane Mode, (c) Mode 69, f = 13.9 Hz, Basin South Exterior Wall Out-of-Plane Mode, (d) Mode 23, f = 6.55 Hz, Basin 1 North Exterior Wall Out-of-Plane Mode, (e) Mode 53, f = 11.7 Hz, Basin Interior and Exterior and Pump Room Baffle Wall Out-of-Plane Mode



Major Vertical Mode Shapes of UHSRS (a) Mode 108, f = 17.4 Hz, Cooling Towers and Pump Room Slabs Mode, (b) Mode 47, f = 10.7 Hz, Ceramic Fill Support Beams Mode, (c) Mode 60, f = 12.9 Hz, Cooling Tower Missile Protection Slabs Mode, (d) Mode 127, f = 19.8 Hz, Cooling Towers and Pump Room Slabs Mode, (e) Mode 75, f = 14.8 Hz, Mist Eliminator Support Beams Mode

2. The cutoff frequencies were:
    - Lower-bound, no fill: 50.7 Hz
    - Lower-bound, separated fill: 37.84 Hz
    - Best-estimate, non-separated fill: 38.5 Hz
    - Best-estimate, separated fill: 37.84 Hz
    - Upper-bound, separated fill: 48.83 Hz
    - High-bound, separated fill: 50.05 Hz

3. The frequencies selected are listed in Table 2 below:

Table 2 - Frequencies used in SASSI Analysis (Hz)

	Non-Separated	Separated Fill				Lower Bound No Fill
	Best Estimate	Lower Bound	Best Estimate	Upper Bound	High Bound	
1	1.22	1.22	1.22	1.22	1.22	1.22
2	1.83	1.83	1.83	1.83	1.83	1.83
3	2.44	2.44	2.44	2.44	2.44	2.44
4	3.05	3.05	3.05	3.05	3.05	3.05
5	3.66	3.66	3.66	3.66	3.66	3.66
6	4.27	4.27	4.27	4.27	4.27	4.27
7	4.88	4.88	4.57	4.88	4.57	4.88
8	5.18	5.49	4.88	5.18	4.88	5.49
9	5.49	6.10	5.18	5.49	5.49	6.10
10	6.10	6.71	5.49	6.10	6.10	6.71
11	6.71	7.32	6.10	6.71	6.71	7.32
12	7.32	7.94	6.71	7.01	7.01	7.94
13	7.94	8.55	7.01	7.32	7.32	8.55
14	8.55	9.16	7.32	7.94	7.94	9.16
15	9.16	9.77	7.94	8.55	8.23	9.77
16	9.77	10.38	8.55	9.16	8.55	10.38
17	10.38	10.99	9.16	9.77	9.16	10.99
18	10.99	11.60	9.77	10.38	9.77	11.60
19	11.28	12.21	10.38	10.99	10.38	12.21
20	11.60	12.82	10.99	11.60	10.99	12.82
21	12.21	13.43	11.60	12.21	11.60	13.43
22	12.82	14.04	12.21	12.82	12.21	14.04
23	13.43	14.33	12.82	13.43	12.82	14.65
24	14.04	14.65	13.43	14.04	13.43	15.26
25	14.65	15.26	14.04	14.65	14.04	15.87
26	15.26	15.87	14.65	15.26	14.65	16.48
27	15.87	16.48	15.26	15.87	15.26	17.09
28	16.48	17.09	15.55	16.48	15.87	17.70
29	17.09	17.70	15.87	17.09	16.48	18.31
30	17.70	18.31	16.48	17.70	17.09	18.92
31	18.31	18.92	17.09	18.31	17.38	19.53
32	18.92	19.53	17.70	18.92	17.70	20.14
33	19.53	20.14	18.31	19.53	18.31	20.75
34	20.14	20.75	18.92	20.14	18.92	21.36

Table 2 - Frequencies used in SASSI Analysis (Hz) (continued)						
	Non-Separated	Separated Fill				Lower Bound No Fill
	Best Estimate	Lower Bound	Best Estimate	Upper Bound	High Bound	
35	20.75	21.36	19.53	20.75	19.21	21.97
36	21.36	21.97	20.14	21.36	19.53	22.58
37	21.97	22.58	20.75	21.97	20.14	23.19
38	22.58	23.19	21.36	22.27	20.43	23.80
39	23.19	23.80	21.97	22.58	20.75	24.41
40	23.80	24.41	22.58	23.19	21.36	25.02
41	24.41	25.02	23.19	23.80	21.97	25.63
42	25.02	25.63	23.80	24.41	22.58	26.25
43	25.63	26.25	24.41	25.02	23.19	26.86
44	26.25	26.86	25.02	25.63	23.80	27.47
45	26.86	27.47	25.63	26.25	24.41	28.08
46	27.47	28.08	26.25	26.86	25.02	28.69
47	28.08	28.69	26.86	27.47	25.63	29.30
48	28.69	29.30	27.47	28.08	25.93	29.91
49	29.30	29.91	28.08	28.69	26.25	30.52
50	29.91	30.52	28.69	29.30	26.86	31.13
51	30.52	31.13	29.30	29.91	27.47	31.74
52	31.13	31.74	29.91	30.52	28.08	32.35
53	31.74	32.96	30.52	31.13	28.69	32.96
54	32.35	34.18	31.13	31.74	29.30	33.57
55	32.96	35.40	31.74	32.35	29.91	34.18
56	33.57	36.62	32.35	32.96	30.52	34.79
57	34.18	37.84	32.96	34.18	31.13	35.40
58	34.79		33.57	35.40	31.74	36.01
59	35.40		34.18	36.62	32.96	36.62
60	36.01		35.40	37.84	34.18	37.23
61	36.62		36.62	39.06	35.40	37.84
62	37.23		37.84	40.28	36.62	38.45
63	37.84			41.50	37.84	39.06
64	38.45			42.72	39.06	39.67
65				43.95	40.28	40.28
66				45.17	41.50	40.89
67				46.39	42.72	41.50
68				47.61	43.95	42.11
69				48.83	45.17	42.72
70					46.39	43.33
71					47.61	43.95
72					48.83	44.56
73					50.05	45.17
74						45.78
75						46.39
76						47.00
77						47.61

Table 2 - Frequencies used in SASSI Analysis (Hz) (continued)						
	Non-Separated	Separated Fill				Lower Bound No Fill
	Best Estimate	Lower Bound	Best Estimate	Upper Bound	High Bound	
78						48.22
79						49.44
80						50.05
81						50.66

4. The SASSI analysis frequencies were selected to cover the range between around 1 Hz and the cutoff frequency. This frequency range includes the SSI frequency and primary structural frequencies. The 1Hz lower limit was shown to be low enough to be outside the range of SSI or structural mode amplification. Initially, the frequencies are selected evenly spaced. Frequencies were added as needed to produce smooth interpolation of the transfer functions and accurately capture peaks. As verification, additional frequencies were added to observe that the results did not change.

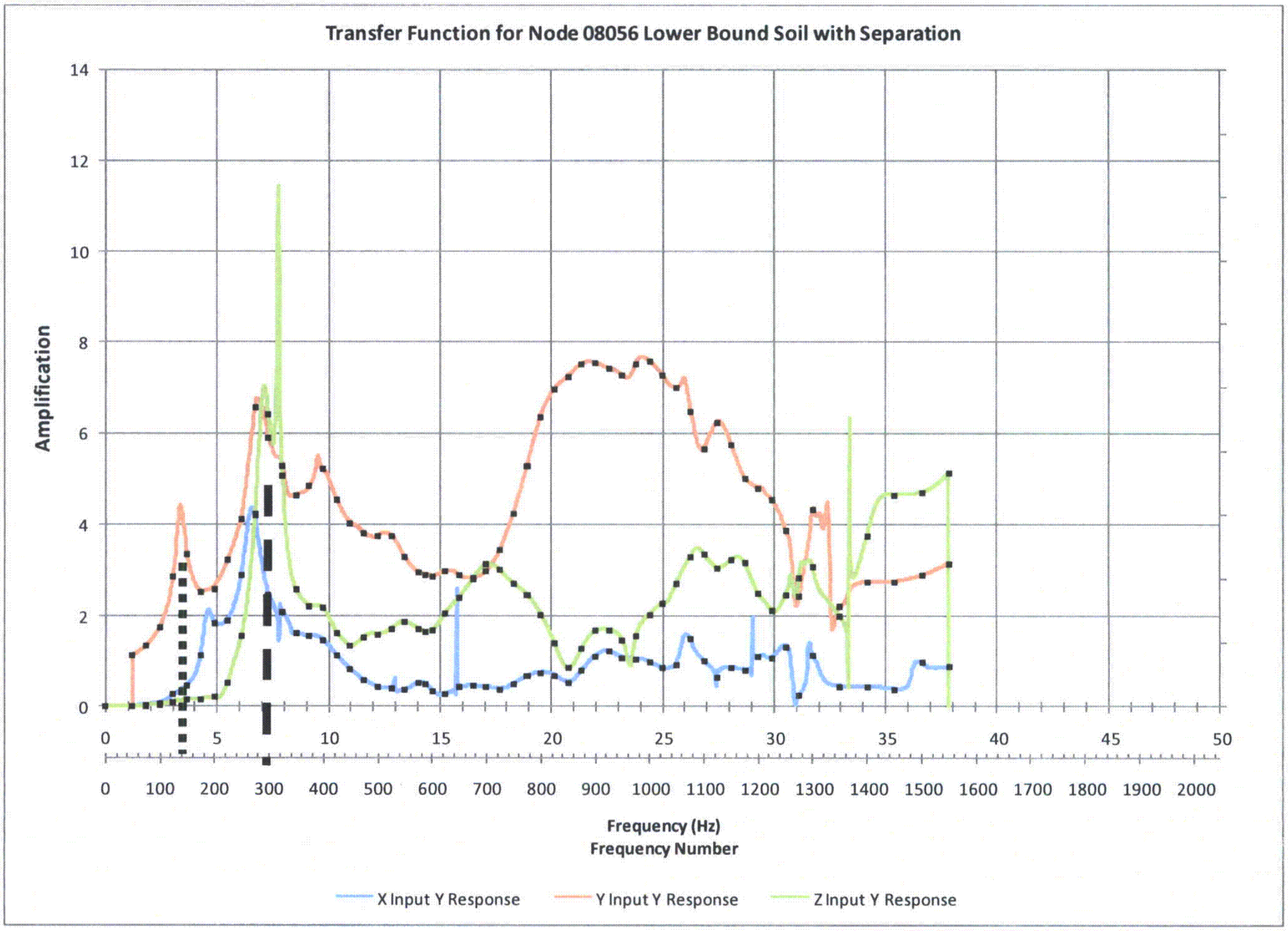
5. A comparison of transfer functions at several locations to the selected analysis frequencies to determine the appropriateness of the frequency selection is shown below:

   The transfer functions for the out-of-plane response of basin 1 north wall are shown in Figure 1 through Figure 4 and the transfer functions for the vertical response of the pump room elevated slab are shown in Figure 5 through Figure 8. For each location, transfer functions are shown for the four separated soil cases, and dashed vertical lines have been added to represent the structural frequency calculated in ANSYS for the fixed base condition and dotted vertical lines represent the soil frequency.

   A dominant structural mode for the wall is observed in Figure 1 through Figure 4 at around 7 Hz. Peaks representing the horizontal soil frequencies are observed at approximately 4 Hz for the lower bound case to 8 Hz for the high bound case. The amplitude of the transfer function increases as the soil frequency approaches the wall frequency and is largest for the high bound soil case. This trend is also observed in the acceleration response of this node on the basin 1 north wall (node 8056) with the maximum acceleration of 1.72 g occurring for the high bound soil case.

   The transfer functions for the out-of-plane response of basin 1 west wall are shown in Figure 9 through Figure 12. Response of this wall is similar to the basin 1 north wall since the same dominant mode (Mode 23 shown in the figures above) activates both walls. Peak X-direction response is also observed in the high bound soil case since the soil frequency is tuned to wall frequency.

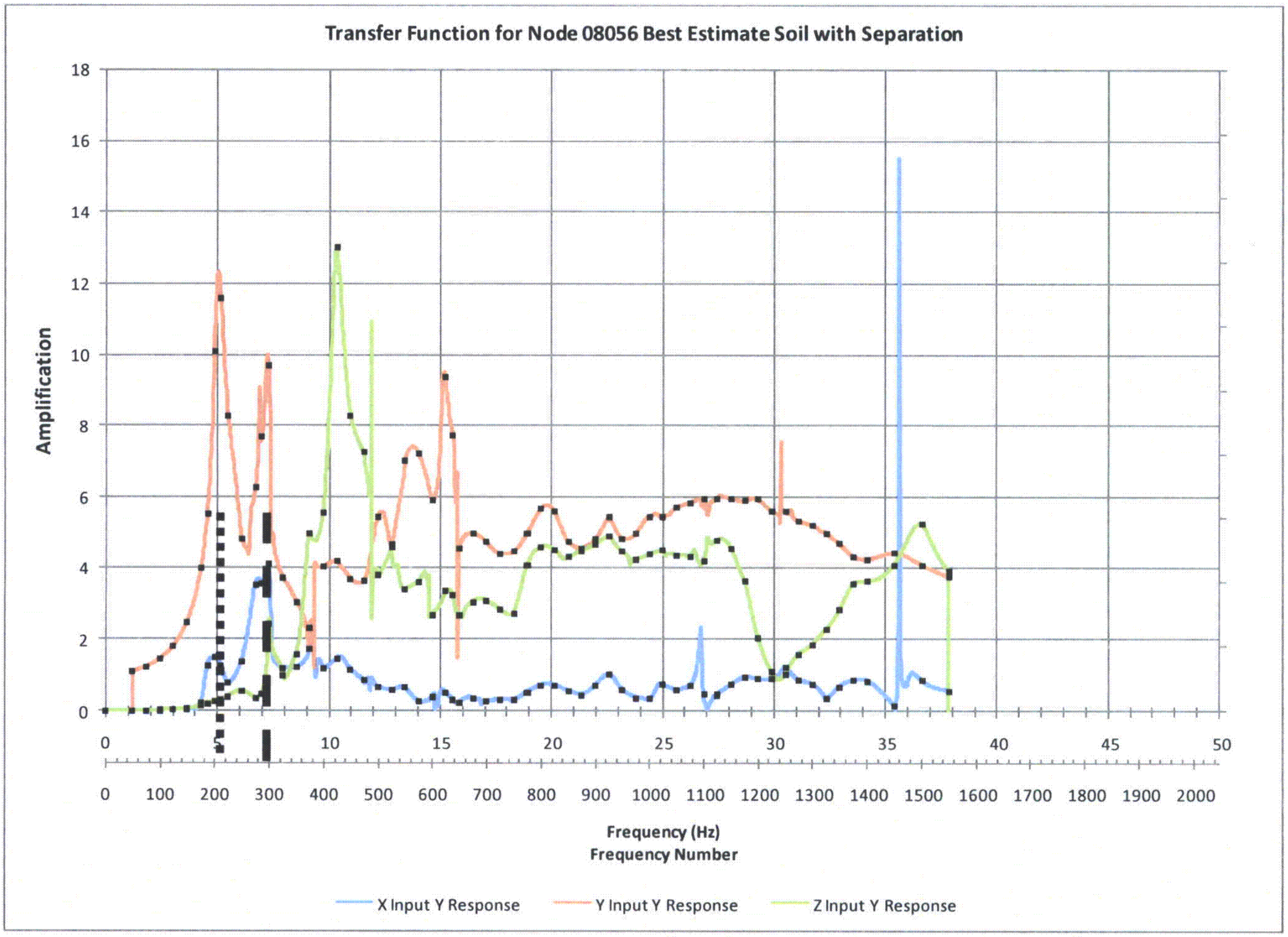
   Similar behavior of the pump room slab is seen in Figure 5 through Figure 8 for the vertical response. The slab has a vertical structural frequency at 15 Hz. The vertical soil frequencies range from 7 Hz for the lower bound, 11 Hz for best estimate, 14 Hz for upper bound, and 17 Hz for the high bound soil cases. For the upper bound soil case, the soil is nearly in-tune with the vertical frequency of the slab which results in a peak acceleration of 0.81 g at this node compared to 0.41-0.53 g for the other soil cases.



Note 1: Vertical dashed lines show major structural frequencies calculated in the ANSYS design model and vertical dotted lines show the soil frequency.

Note 2: Vertical lines at end of transfer functions and data point at origin represent blanks in EXCEL data and do not represent SASSI data.

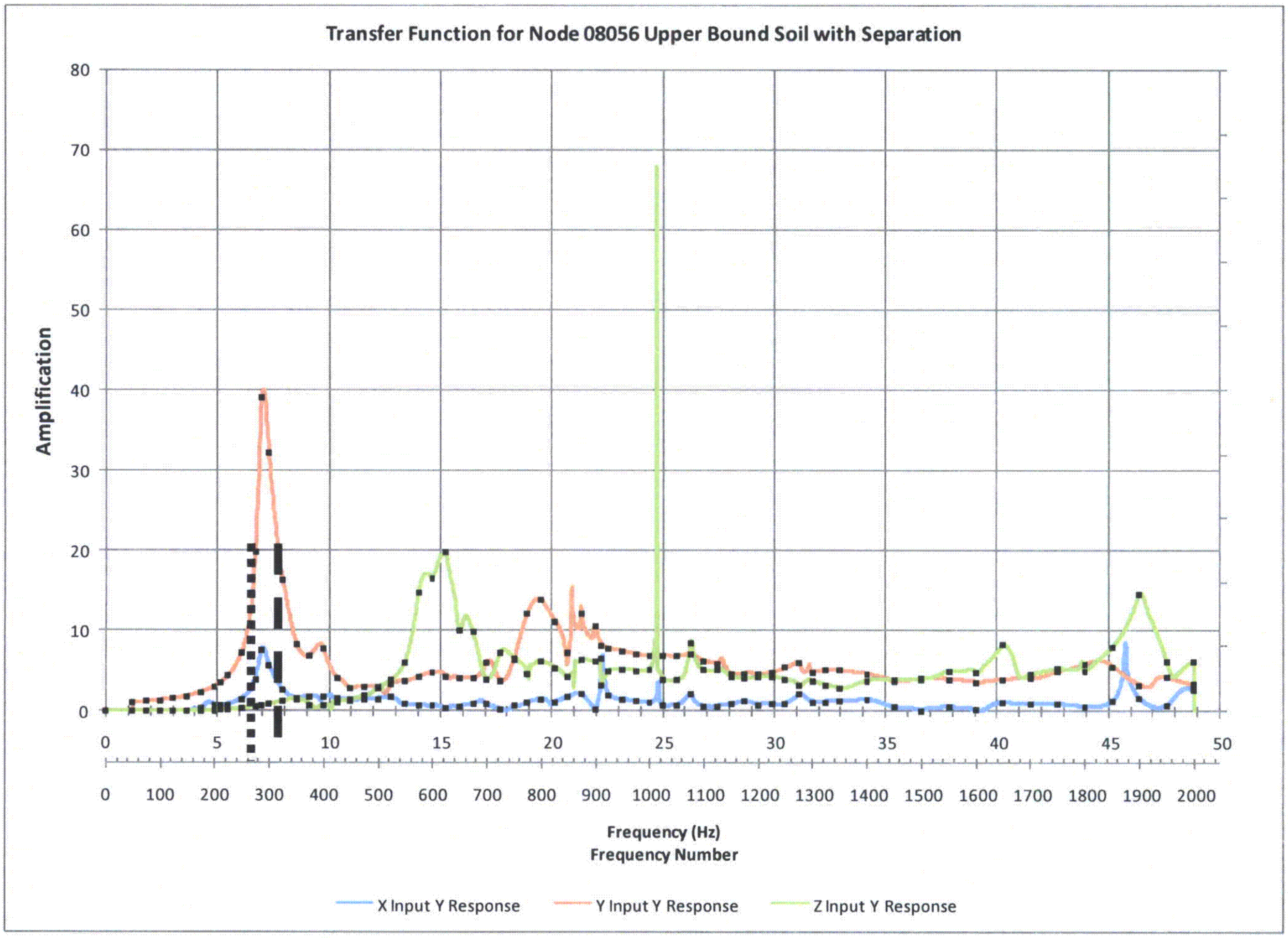
Figure 1 Transfer Function for Basin 1 North Wall, Soil Case LBsep, (Node 8056), Y-direction Response (Out-of-Plane)



Note 1: Vertical dashed lines show major structural frequencies calculated in the ANSYS design model and vertical dotted lines show the soil frequency.

Note 2: Vertical lines at end of transfer functions and data point at origin represent blanks in EXCEL data and do not represent SASSI data.

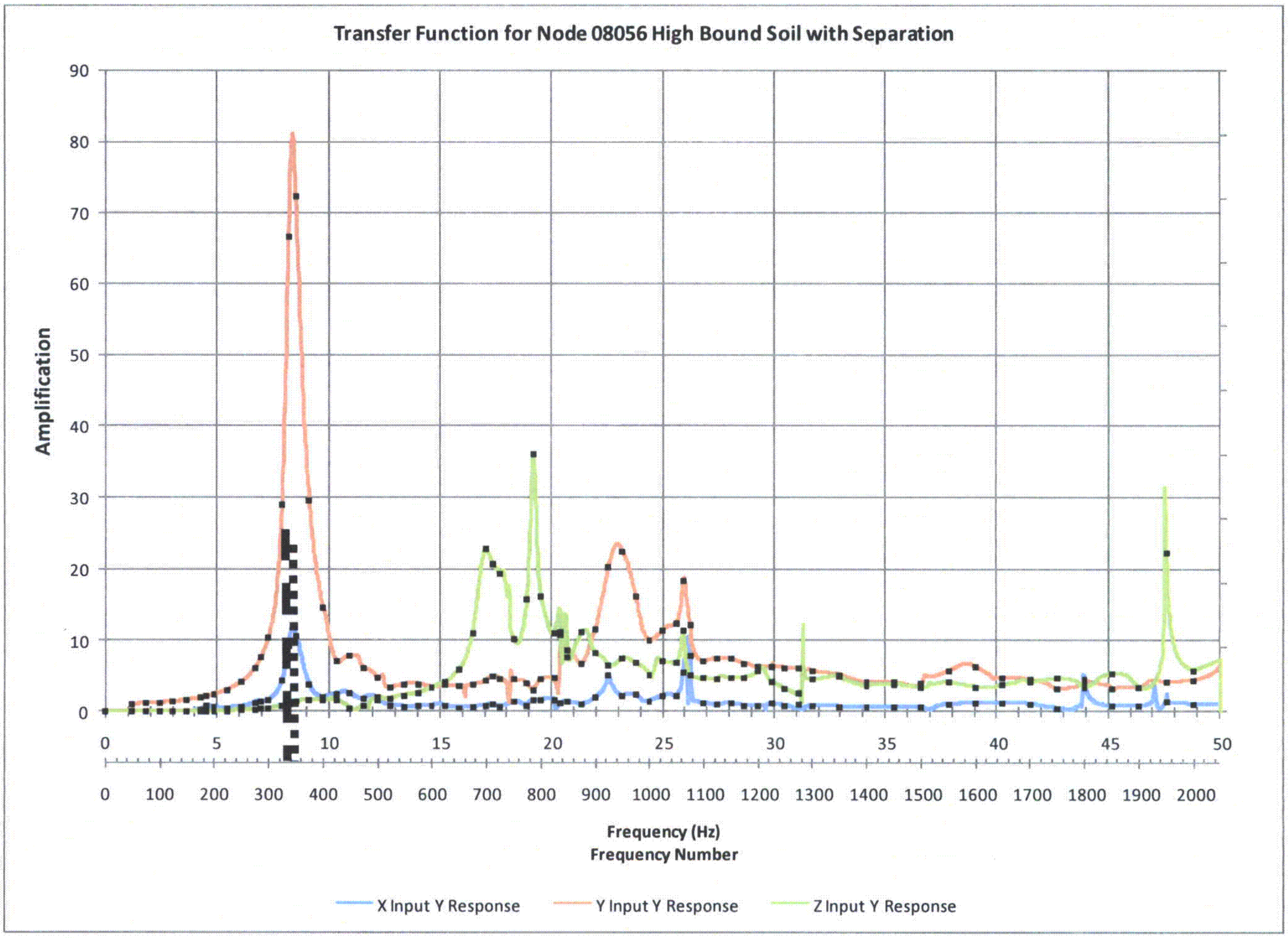
Figure 2 Transfer Function for Basin 1 North Wall, Soil Case BEsep, (Node 8056), Y-direction Response (Out-of-Plane)



Note 1: Vertical dashed lines show major structural frequencies calculated in the ANSYS design model and vertical dotted lines show the soil frequency.

Note 2: Vertical lines at end of transfer functions and data point at origin represent blanks in EXCEL data and do not represent SASSI data.

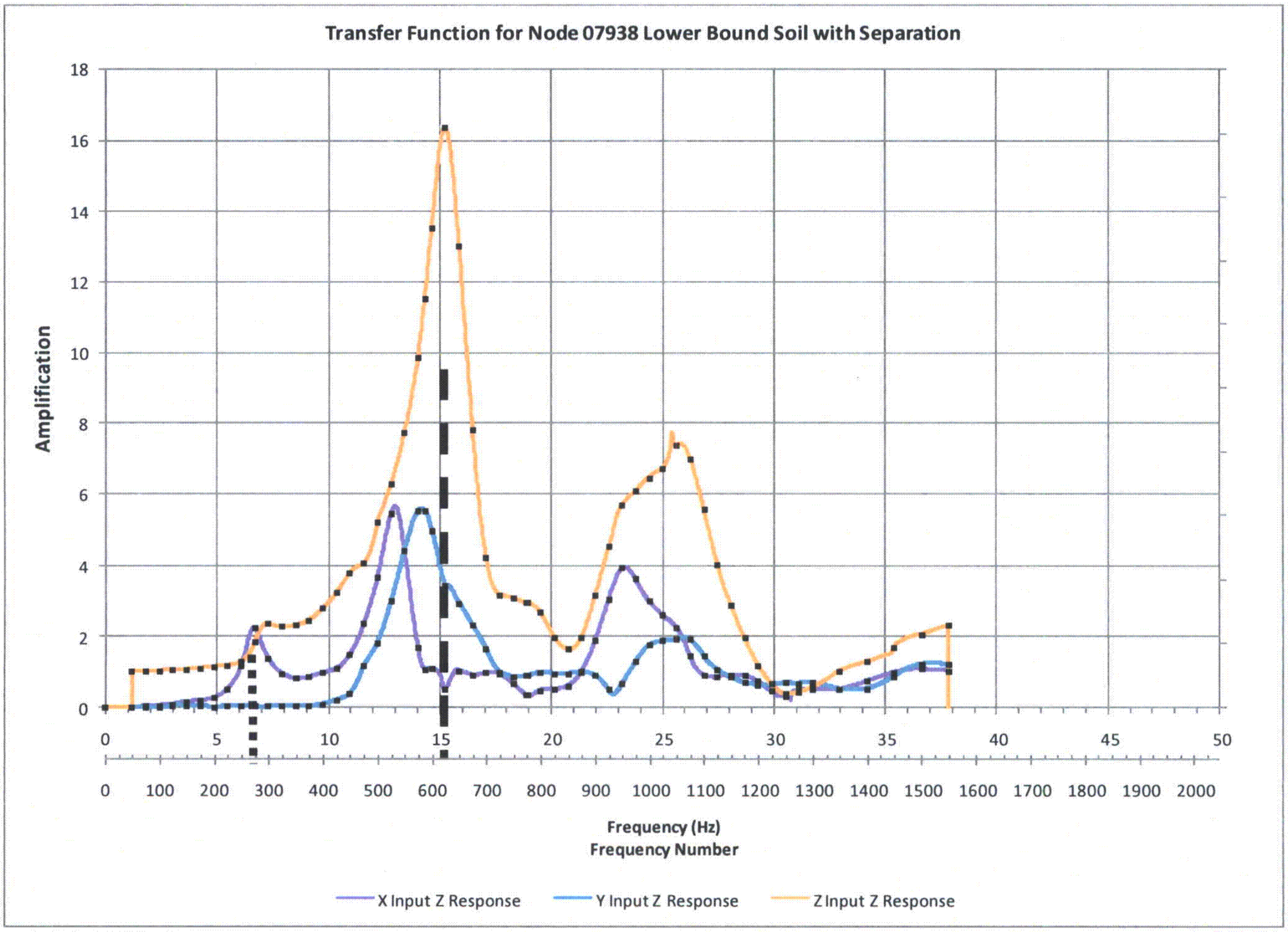
Figure 3 Transfer Function for Basin 1 North Wall, Soil Case UBsep, (Node 8056), Y-direction Response (Out-of-Plane)



Note 1: Vertical dashed lines show major structural frequencies calculated in the ANSYS design model and vertical dotted lines show the soil frequency.

Note 2: Vertical lines at end of transfer functions and data point at origin represent blanks in EXCEL data and do not represent SASSI data.

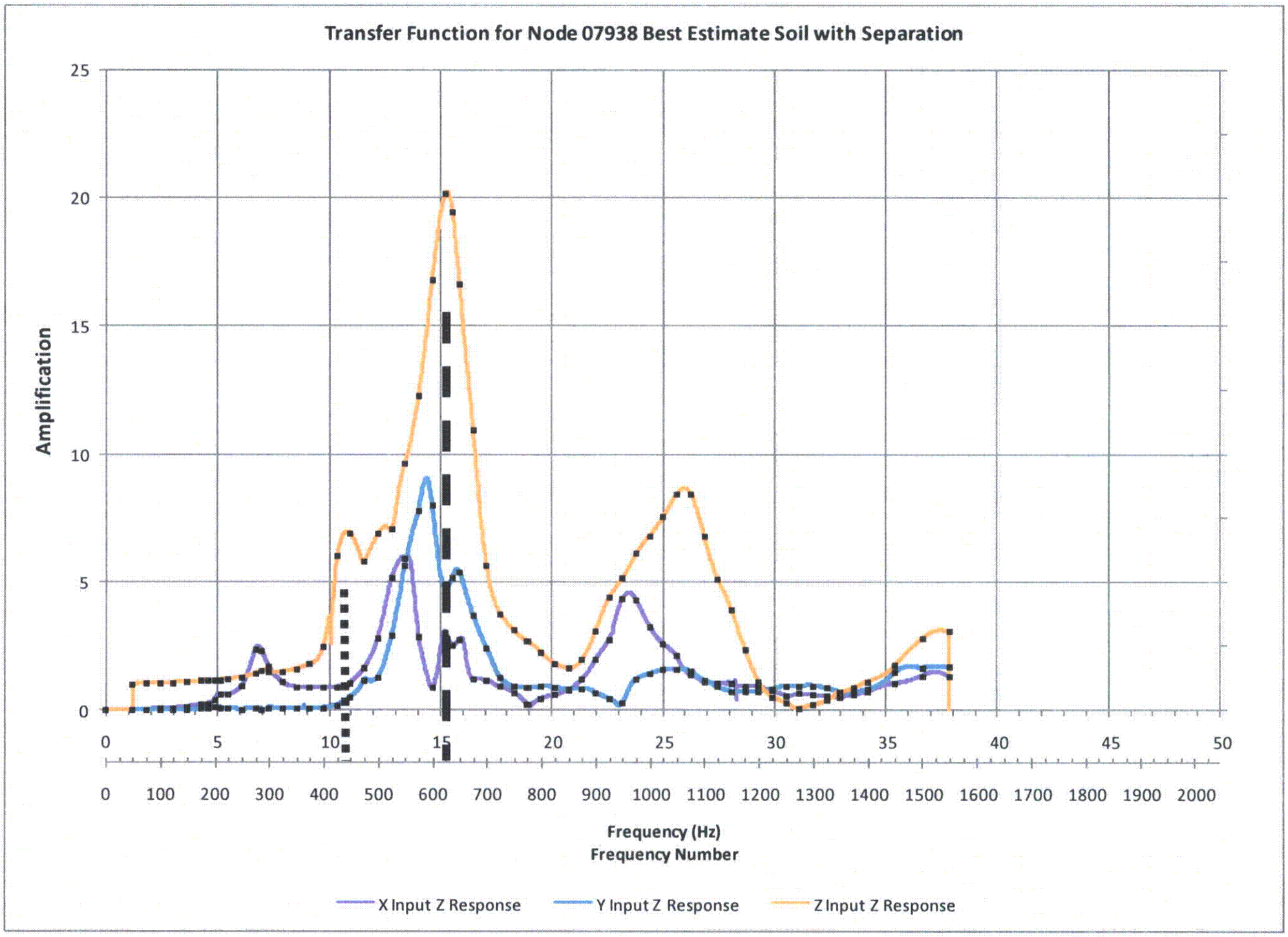
Figure 4 Transfer Function for Basin 1 North Wall, Soil Case HBsep, (Node 8056), Y-direction Response (Out-of-Plane)



Note 1: Vertical dashed lines show major structural frequencies calculated in the ANSYS design model and vertical dotted lines show the soil frequency.

Note 2: Vertical lines at end of transfer functions and data point at origin represent blanks in EXCEL data and do not represent SASSI data.

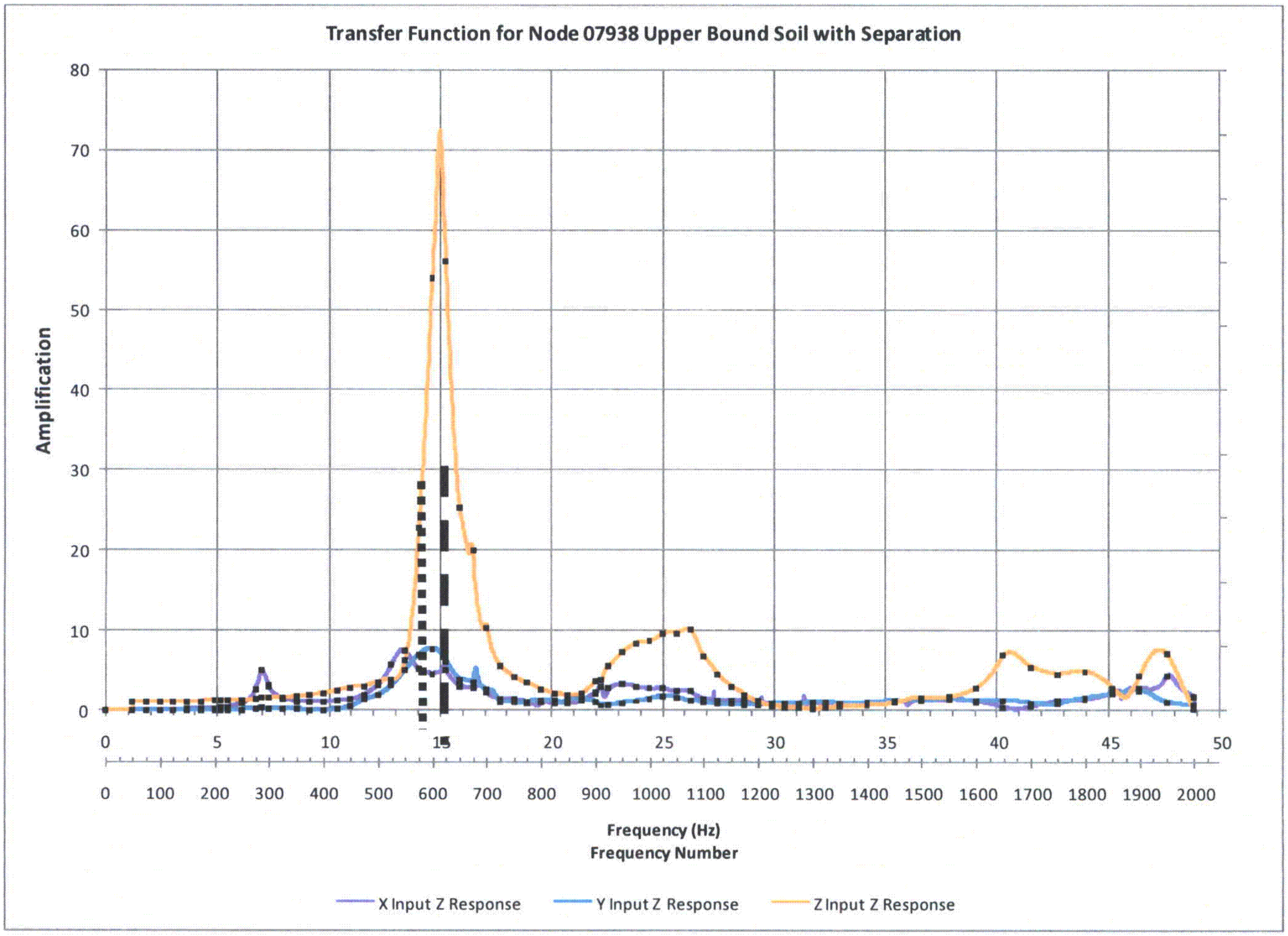
Figure 5 Transfer Function for Pump Room Elevated Slab, Soil Case LBsep, (Node 7938), Vertical Response



Note 1: Vertical dashed lines show major structural frequencies calculated in the ANSYS design model and vertical dotted lines show the soil frequency.

Note 2: Vertical lines at end of transfer functions and data point at origin represent blanks in EXCEL data and do not represent SASSI data.

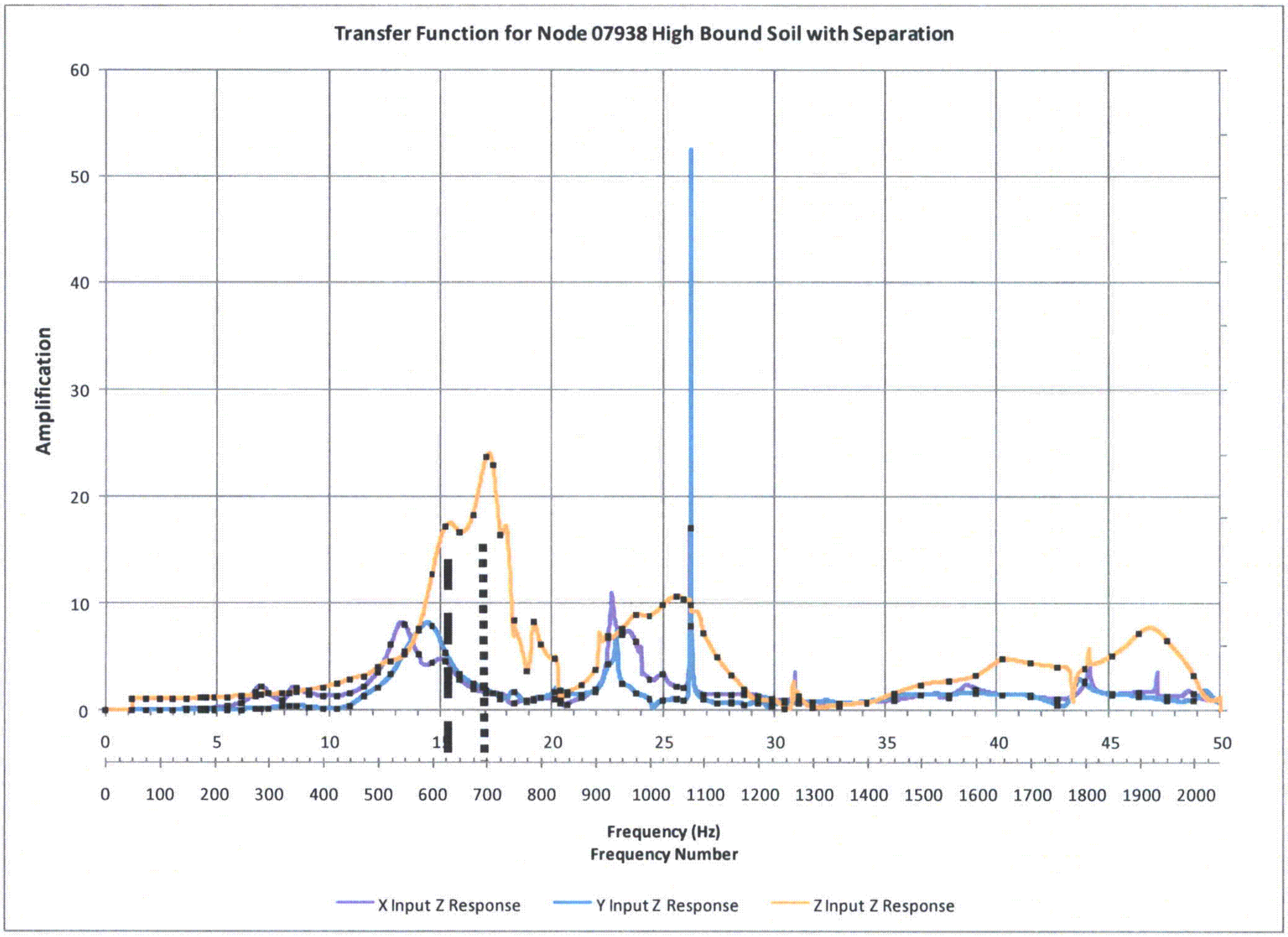
Figure 6 Transfer Function for Pump Room Elevated Slab, Soil Case BEsep, (Node 7938), Vertical Response



Note 1: Vertical dashed lines show major structural frequencies calculated in the ANSYS design model and vertical dotted lines show the soil frequency.

Note 2: Vertical lines at end of transfer functions and data point at origin represent blanks in EXCEL data and do not represent SASSI data.

Figure 7 Transfer Function for Pump Room Elevated Slab, Soil Case UBsep, (Node 7938), Vertical Response



Note 1: Vertical dashed lines show major structural frequencies calculated in the ANSYS design model and vertical dotted lines show the soil frequency.

Note 2: Vertical lines at end of transfer functions and data point at origin represent blanks in EXCEL data and do not represent SASSI data.

Figure 8 Transfer Function for Pump Room Elevated Slab, Soil Case HBsep, (Node 7938), Vertical Response

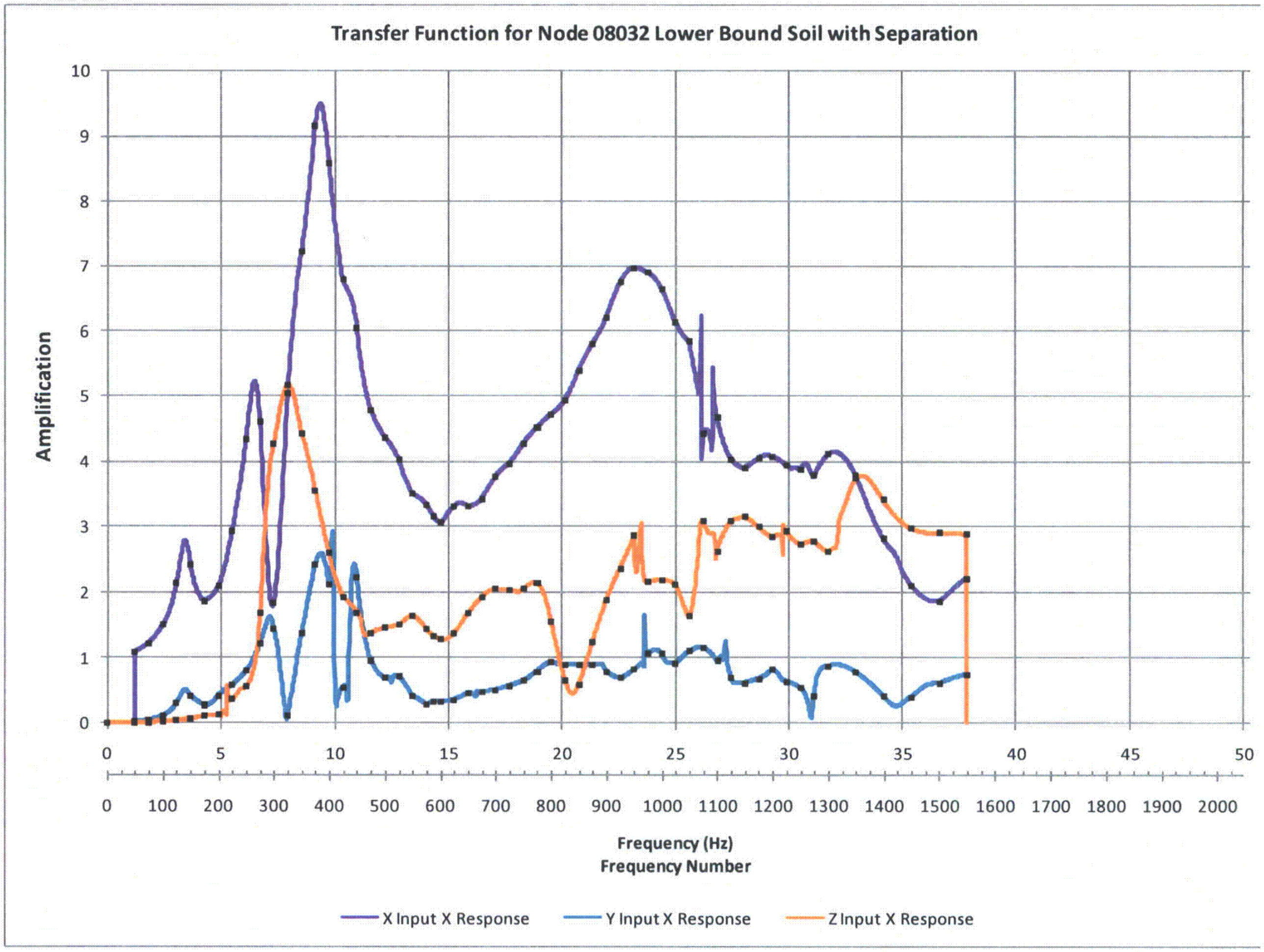


Figure 9 Transfer Function for Basin 1 West Wall, Soil Case LBsep, (Node 8032), X-direction Repsonse (Out-of-Plane)

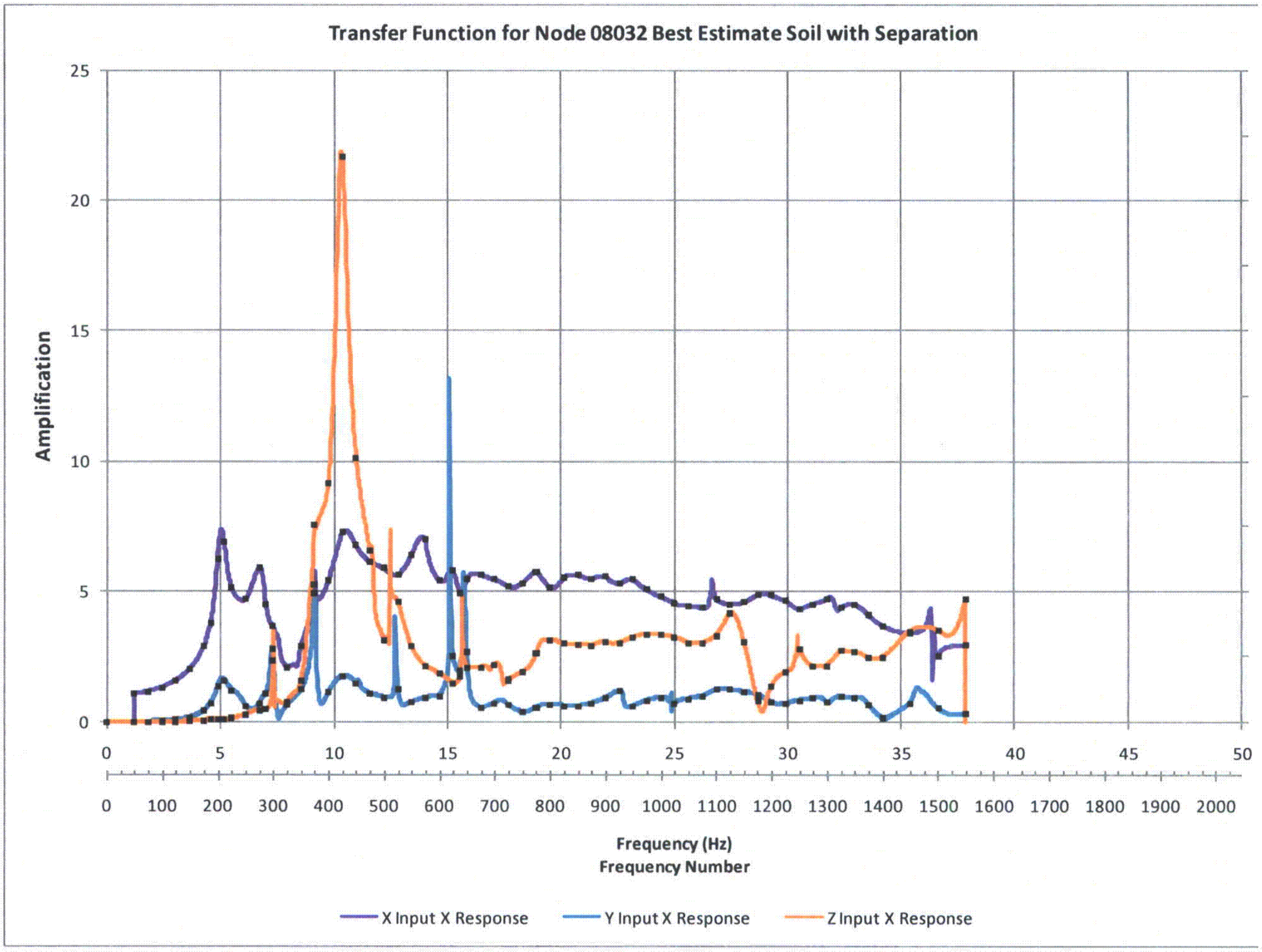


Figure 10 Transfer Function for Basin 1 West Wall, Soil Case BEsep, (Node 8032), X-direction Response (Out-of-Plane)

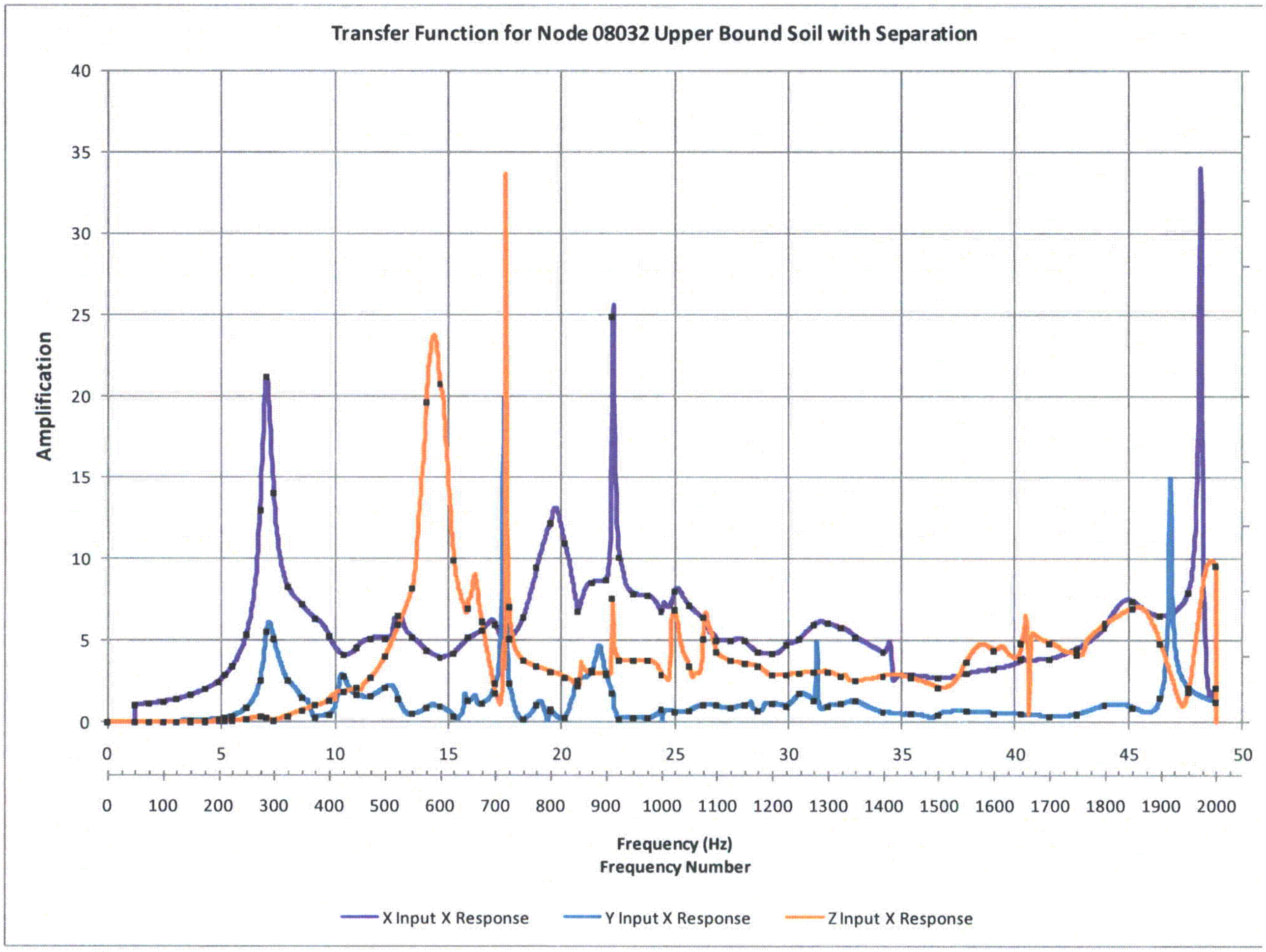


Figure 11 Transfer Function for Basin 1 West Wall, Soil Case UBsep, (Node 8032), X-direction Response (Out-of-Plane)

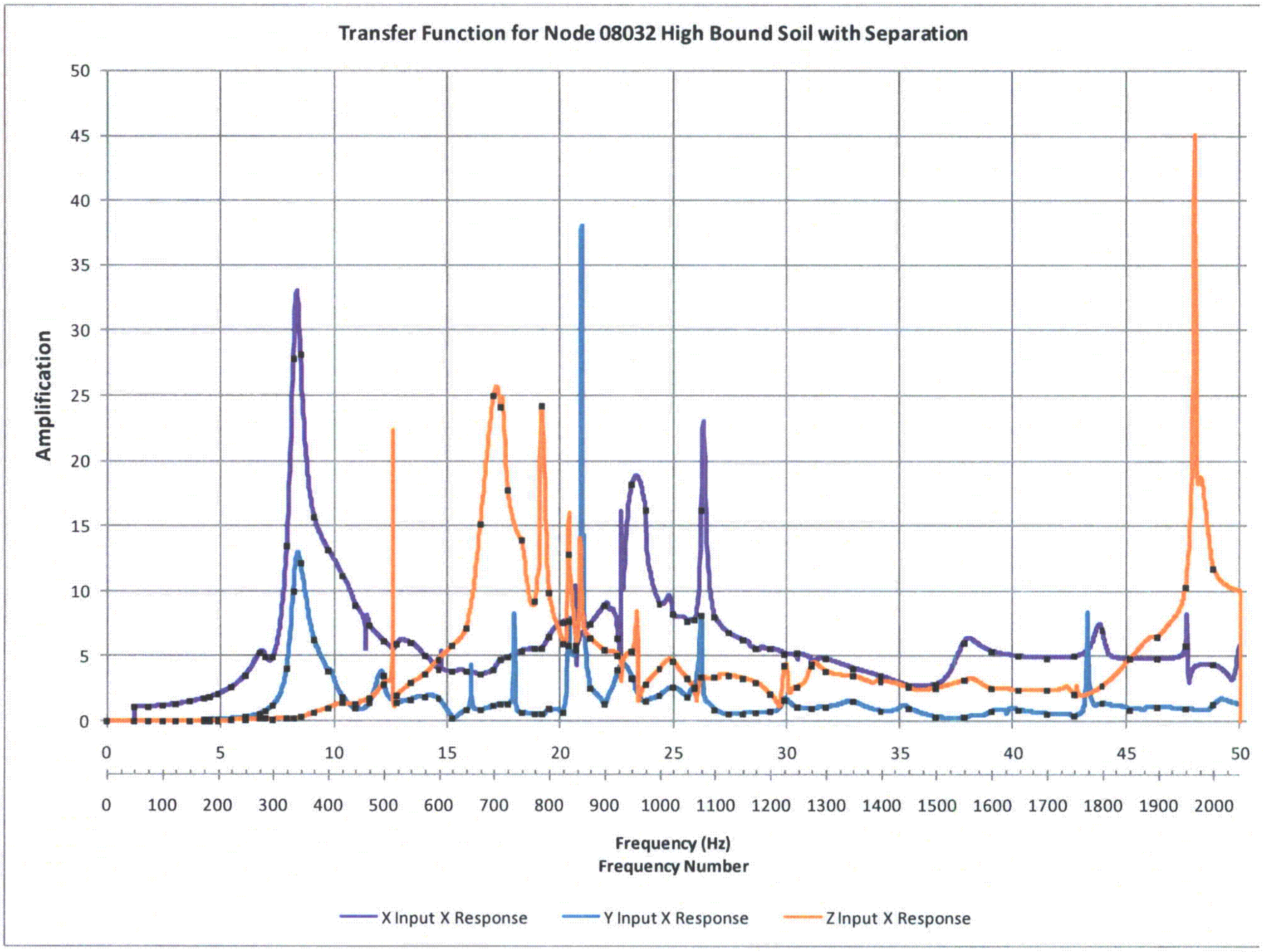


Figure 12 Transfer Function for Basin 1 West Wall, Soil Case HBsep, (Node 8032), X-direction Response (Out-of-Plane)

6. The soil layer thicknesses used in the SASSI analyses, and a demonstration that the layer thicknesses comply with the maximum layer thicknesses given by the "1/5 wavelength" guideline is shown in Table 3 and Table 4 below:

Table 3 SASSI Subsurface Properties

		Unit	Shear Wave Velocity (ft/s)				Compression Wave Velocity (ft/s)				Damping Ratio			
Layer	Thickness (ft)	Weight (ksf)	Lower Bound	Best Estimate	Upper Bound	High Bound	Lower Bound	Best Estimate	Upper Bound	High Bound	Lower Bound	Best Estimate	Upper Bound	High Bound
1	5.670	0.125	503.9	678.7	904.6	1055.8	1049.0	1412.8	1883.0	2197.8	0.0382	0.0299	0.0233	0.0201
2	5.660	0.125	493.4	703.6	968.8	1151.4	1027.1	1464.7	2016.7	2396.8	0.0670	0.0473	0.0342	0.0279
3	5.670	0.125	416.5	643.1	920.4	1108.0	866.9	1338.7	1916.0	2306.5	0.1050	0.0673	0.0457	0.0364
4	6.000	0.125	474.3	729.7	1033.7	1236.2	987.3	1518.9	2151.9	2573.4	0.0935	0.0583	0.0405	0.0328
5	6.000	0.125	609.7	877.5	1204.0	1423.0	1269.2	1826.6	2506.3	2962.2	0.0675	0.0443	0.0317	0.0263
6	5.000	0.125	590.6	858.0	1190.2	1410.7	1229.4	1786.0	2477.6	2936.7	0.0748	0.0488	0.0345	0.0286
7	6.000	0.125	577.8	844.3	1181.2	1401.7	1202.8	1757.6	2458.9	2917.8	0.0802	0.0520	0.0367	0.0298
8	6.000	0.155	4427.5	5685.0	7299.7	7299.7	8789.7	11286.1	14491.7	14491.7	0.0260	0.0180	0.0130	0.0130
9	10.250	0.155	4427.5	5685.0	7299.7	7299.7	8789.7	11286.1	14491.7	14491.7	0.0260	0.0180	0.0130	0.0130
10	16.250	0.155	4427.5	5685.0	7299.7	7299.7	8789.7	11286.1	14491.7	14491.7	0.0260	0.0180	0.0130	0.0130
11	16.250	0.155	4427.5	5685.0	7299.7	7299.7	8789.7	11286.1	14491.7	14491.7	0.0260	0.0180	0.0130	0.0130
12	16.250	0.155	4427.5	5685.0	7299.7	7299.7	8789.7	11286.1	14491.7	14491.7	0.0260	0.0180	0.0130	0.0130
13	3.000	0.135	2351.2	3019.0	3876.5	3876.5	6330.8	8128.9	10437.8	10437.8	0.0280	0.0200	0.0140	0.0140
14	24.000	0.155	3849.6	4943.0	6346.9	6346.9	8230.8	10568.6	13570.2	13570.2	0.0260	0.0180	0.0130	0.0130
15	34.000	0.155	5358.1	6880.0	8834.1	8834.1	10210.8	13111.0	16834.9	16834.9	0.0260	0.0180	0.0130	0.0130
16	17.000	0.150	3147.9	4042.0	5190.0	5190.0	7155.3	9187.6	11797.0	11797.0	0.0260	0.0180	0.0130	0.0130
17	17.000	0.150	3147.9	4042.0	5190.0	5190.0	7155.3	9187.6	11797.0	11797.0	0.0260	0.0180	0.0130	0.0130
18	14.500	0.130	2383.9	3061.0	3930.4	3930.4	6103.7	7837.3	10063.3	10063.3	0.0280	0.0200	0.0140	0.0140
19	14.500	0.130	2383.9	3061.0	3930.4	3930.4	6103.7	7837.3	10063.3	10063.3	0.0280	0.0200	0.0140	0.0140
20	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
21	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
22	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
23	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
24	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
25	15.500	0.140	2670.5	3429.0	4402.9	4402.9	6288.7	8074.9	10368.3	10368.3	0.0280	0.0200	0.0140	0.0140
26	15.500	0.140	2670.5	3429.0	4402.9	4402.9	6288.7	8074.9	10368.3	10368.3	0.0280	0.0200	0.0140	0.0140
27	15.500	0.140	2670.5	3429.0	4402.9	4402.9	6288.7	8074.9	10368.3	10368.3	0.0280	0.0200	0.0140	0.0140
28	15.500	0.140	2670.5	3429.0	4402.9	4402.9	6288.7	8074.9	10368.3	10368.3	0.0280	0.0200	0.0140	0.0140
29	15.750	0.145	2408.1	3092.0	3970.2	3970.2	5898.6	7573.8	9725.0	9725.0	0.0280	0.0200	0.0140	0.0140
30	15.750	0.145	2408.1	3092.0	3970.2	3970.2	5898.6	7573.8	9725.0	9725.0	0.0280	0.0200	0.0140	0.0140
31	15.750	0.145	2408.1	3092.0	3970.2	3970.2	5898.6	7573.8	9725.0	9725.0	0.0280	0.0200	0.0140	0.0140
32	15.750	0.145	2408.1	3092.0	3970.2	3970.2	5898.6	7573.8	9725.0	9725.0	0.0280	0.0200	0.0140	0.0140
33	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
34	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
35	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
36	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
37	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
38	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
39	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
40	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
41	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
42	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
43	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
44	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
45	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130

Table 4 Passing Frequency for 5 Points per Wavelength

		Shear Wave Frequncy (Hz)				Compression Wave Frequency (Hz)			
Layer	Thickness (ft)	Lower Bound	Best Estimate	Upper Bound	High Bound	Lower Bound	Best Estimate	Upper Bound	High Bound
1	5.670	17.8	23.9	31.9	37.2	37.0	49.8	66.4	77.5
2	5.660	17.4	24.9	34.2	40.7	36.3	51.8	71.3	84.7
3	5.670	14.7	22.7	32.5	39.1	30.6	47.2	67.6	81.4
4	6.000	15.8	24.3	34.5	41.2	32.9	50.6	71.7	85.8
5	6.000	20.3	29.3	40.1	47.4	42.3	60.9	83.5	98.7
6	5.000	23.6	34.3	47.6	56.4	49.2	71.4	99.1	117.5
7	6.000	19.3	28.1	39.4	46.7	40.1	58.6	82.0	97.3
8	6.000	147.6	189.5	243.3	243.3	293.0	376.2	483.1	483.1
9	10.250	86.4	110.9	142.4	142.4	171.5	220.2	282.8	282.8
10	16.250	54.5	70.0	89.8	89.8	108.2	138.9	178.4	178.4
11	16.250	54.5	70.0	89.8	89.8	108.2	138.9	178.4	178.4
12	16.250	54.5	70.0	89.8	89.8	108.2	138.9	178.4	178.4
13	3.000	156.7	201.3	258.4	258.4	422.1	541.9	695.9	695.9
14	24.000	32.1	41.2	52.9	52.9	68.6	88.1	113.1	113.1
15	34.000	31.5	40.5	52.0	52.0	60.1	77.1	99.0	99.0
16	17.000	37.0	47.6	61.1	61.1	84.2	108.1	138.8	138.8
17	17.000	37.0	47.6	61.1	61.1	84.2	108.1	138.8	138.8
18	14.500	32.9	42.2	54.2	54.2	84.2	108.1	138.8	138.8
19	14.500	32.9	42.2	54.2	54.2	84.2	108.1	138.8	138.8
20	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
21	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
22	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
23	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
24	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
25	15.500	34.5	44.2	56.8	56.8	81.1	104.2	133.8	133.8
26	15.500	34.5	44.2	56.8	56.8	81.1	104.2	133.8	133.8
27	15.500	34.5	44.2	56.8	56.8	81.1	104.2	133.8	133.8
28	15.500	34.5	44.2	56.8	56.8	81.1	104.2	133.8	133.8
29	15.750	30.6	39.3	50.4	50.4	74.9	96.2	123.5	123.5
30	15.750	30.6	39.3	50.4	50.4	74.9	96.2	123.5	123.5
31	15.750	30.6	39.3	50.4	50.4	74.9	96.2	123.5	123.5
32	15.750	30.6	39.3	50.4	50.4	74.9	96.2	123.5	123.5
33	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
34	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
35	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
36	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
37	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
38	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
39	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
40	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
41	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
42	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
43	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
44	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
45	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7

7. The location of the lower boundary used in the SASSI analysis is 759 feet below grade. This depth is more than twice the depth of the base dimension (131' x2 = 262') recommended by SRP 3.7.2.

8. A ten layer half-space is used in the SASSI analysis. The SASSI half-space simulation consists of additional layers with viscous dashpots added at the base of the half-space. The half-space layer has a thickness of 1.5 Vs/ f where Vs is the shear wave velocity of the half-space and f is the frequency of analysis and it is divided by the selected number of layers in the half-space. The SASSI manual recommends use of a ten layer half-space.

9. A description of critical locations in the various structures under seismic loading is provided below:

   The UHSRS primarily resists the seismic demand in shear. In the east-west direction the shear walls of the cooling tower are penetrated by large openings for air flow. These regions with numerous large openings represent the critical section for shear. A similar condition occurs in interior north-south and east-west basin walls where the walls have numerous large openings to allow water to flow. Higher shear and in-plane bending moment occurs in the piers between openings than in the solid wall sections.

   As a part of the east-west load path, some of the shear from the cooling tower is transferred into the roof of the pump house where the two meet, and this location receives high demands associated with that load transfer.

10. For the UHSRS analyses performed, the following benchmarking was performed to validate the results of the SASSI models:

    Comparison of the model with the mesh used for SASSI analyses was compared with the more refined design model. This comparison was performed by calculating eigenvalues and mode shapes for the models with each mesh and comparing the results. The comparisons showed that the two models provided similar dynamic responses.

    Comparison of the SASSI dynamic response to the ANSYS model response was performed. Fixed base eigenvalue analysis was performed in ANSYS. A corresponding fixed base analysis was performed in SASSI by placing the structure at the soil surface and setting the stiffness of the soil layers to high values to represent the fixed base condition. The fixed base ANSYS eigenvalues were then compared to the transfer functions of the SASSI "fixed base" case to verify that the SASSI model was exhibiting the same dynamic response.

    Transfer functions were 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 were compared between the various soil profiles used in analyses to verify that the responses were reasonably similar between these cases.

Appendix LL – ESWPT

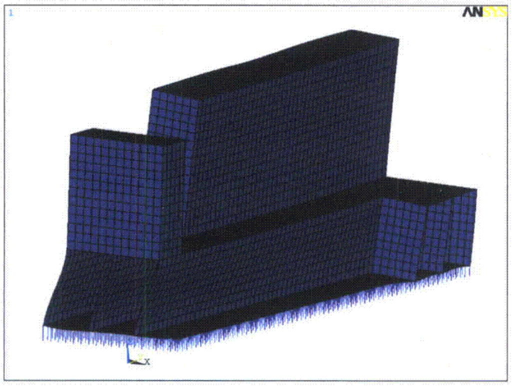
The ESWPT was divided into (3) different segments for the purpose of seismic analysis:

- Tunnel Segment 1: representative of typical straight tunnel segments with fill on all sides and above
- Tunnel Segment 2: adjacent to the Ultimate Heat Sink (UHS) structures. A tornado missile shield extends from the top of this segment to protect openings in the UHS
- Tunnel Segment 3: adjacent to the Power Source Fuel Storage Vault with fuel pipe access tunnels extending from the top

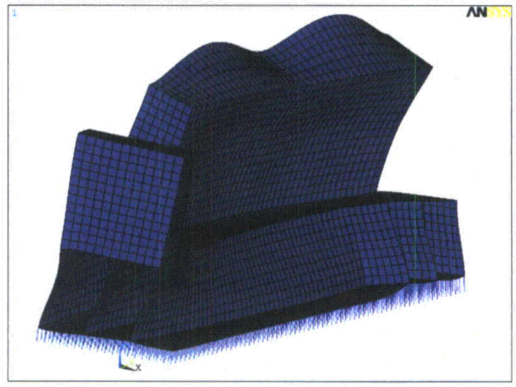
1. The analysis of the ESWPT tunnel segment 2 produced 40 modes below 50 Hz. Table 5 lists 5 major structural frequencies for each direction of motion selected and organized by highest mass participation. Figures showing the mode shapes of these frequencies follow after Table 5. Segments 1 and 3 have no above-ground portions and were analyzed using equivalent static accelerations and therefore do not have eigenvalue results from the ANSYS analyses.

Table 5 Major Structural Modes of Tunnel Segment 2 – Adjacent to UHS Structures				
Major North-South (X) Direction Modes				
Mode	Frequency (Hz)	Period (sec)	Participation Factor	Effective Mass (kip sec^2/ft)
1	5.5	0.183	12.78	163.46
5	15.0	0.067	-3.38	11.43
4	13.3	0.075	-3.15	9.90
13	26.2	0.038	1.40	1.95
40	49.0	0.020	-1.38	1.91
Major East-West (Y) Direction Modes				
Mode	Frequency (Hz)	Period (sec)	Participation Factor	Effective Mass (kip sec^2/ft)
6	17.5	0.057	9.76	95.21
21	32.0	0.031	-6.26	39.20
10	22.9	0.044	4.60	21.15
2	8.0	0.126	3.84	14.75
15	29.7	0.034	3.50	12.22
Major Vertical Modes				
Mode	Frequency (Hz)	Period (sec)	Participation Factor	Effective Mass (kip sec^2/ft)
13	26.2	0.038	-11.08	122.69
8	20.9	0.048	5.72	32.66
9	21.4	0.047	4.76	22.65
10	22.9	0.044	3.61	13.04
38	47.7	0.021	3.35	11.24

Note: Coordinates (X, Y, Z) given in the table are the local coordinates of the structure.



(a)



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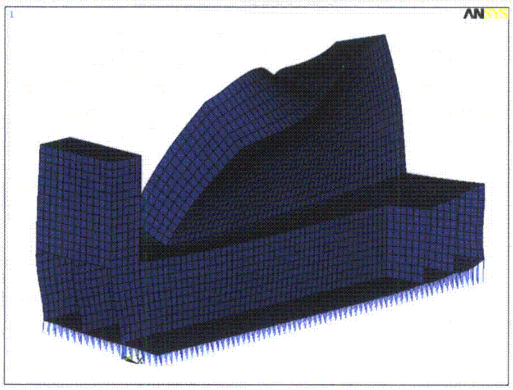

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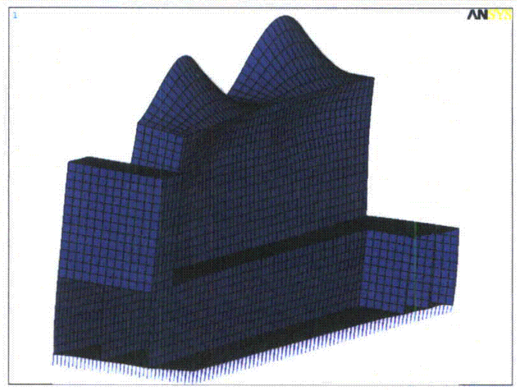

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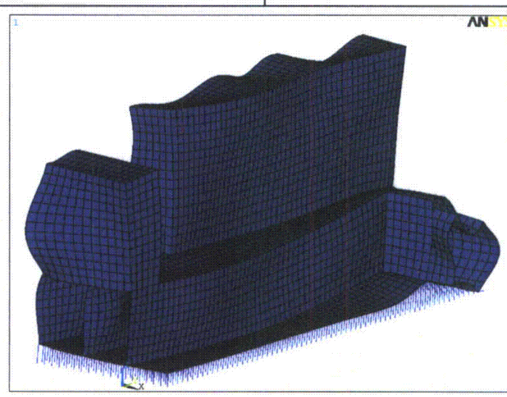
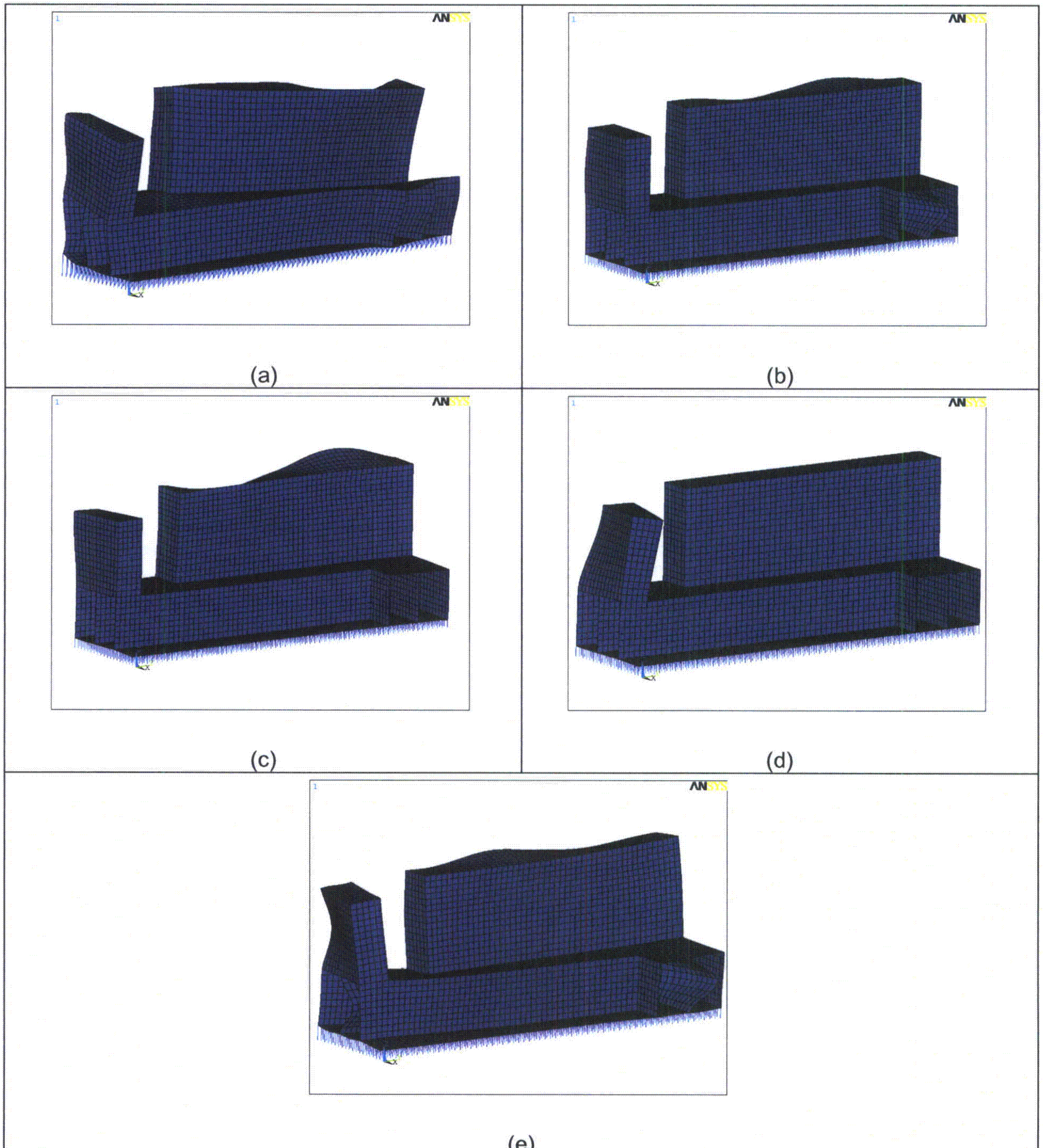
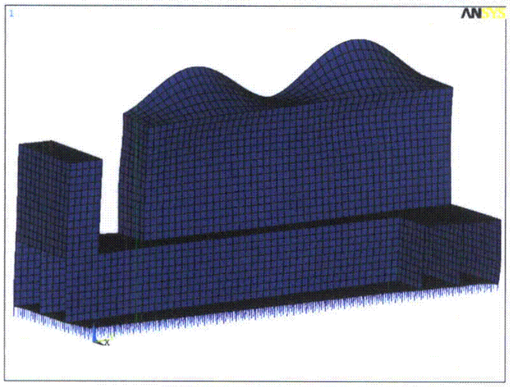


(e)

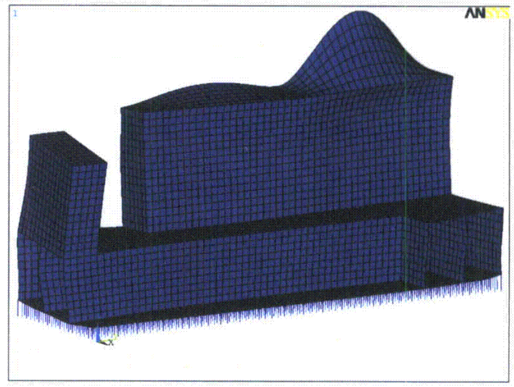
Major North-South Mode Shapes of ESWPT Segment 2 (a) Mode 1, f = 5.487 Hz, Modal Mass = 163.455 kip-sec^2/ft, (b) Mode 5, f = 15.02 Hz, Modal Mass = 11.432 kip-sec^2/ft, (c) Mode 4, f = 13.33 Hz, Modal Mass = 9.901 kip-sec^2/ft, (d) Mode 13, f = 26.24 Hz, Modal Mass = 1.953 kip-sec^2/ft, (e) Mode 40, f = 49.03 Hz, Modal Mass = 1.908 kip-sec^2/ft



Major East-West Mode Shapes of ESWPT Segment 2 (a) Mode 6, f = 17.52 Hz, Modal Mass = 95.205 kip-sec^2/ft, (b) Mode 21, f = 31.98 Hz, Modal Mass = 39.201 kip-sec^2/ft, (c) Mode 10, f = 22.86 Hz, Modal Mass = 21.148 kip-sec^2/ft, (d) Mode 2, f = 7.968 Hz, Modal Mass = 14.746 kip-sec^2/ft, (e) Mode 15, f = 29.7 Hz, Modal Mass = 12.215 kip-sec^2/ft



(a)



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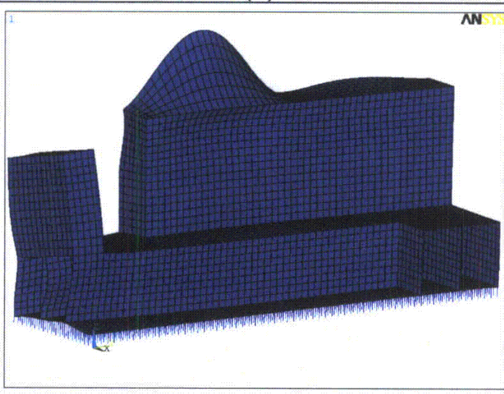

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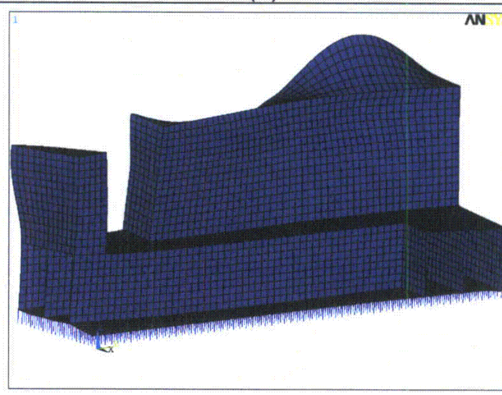

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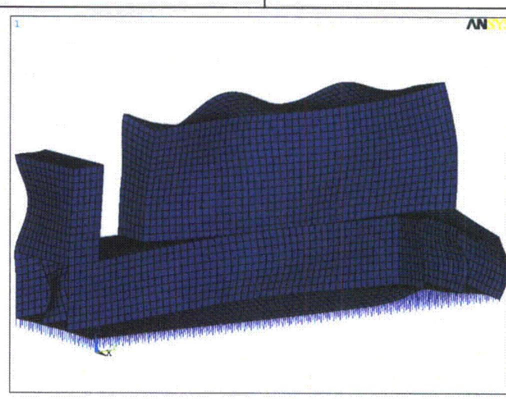


(e)

Major Vertical Mode Shapes of ESWPT Segment 2 (a) Mode 13, f = 26.24 Hz, Modal Mass = 122.688 kip-sec^2/ft, (b) Mode 8, f = 20.9 Hz, Modal Mass = 32.662 kip-sec^2/ft, (c) Mode 9, f = 21.36 Hz, Modal Mass = 22.653 kip-sec^2/ft, (d) Mode 10, f = 22.86 Hz, Modal Mass = 13.042 kip-sec^2/ft, (e) Mode 38, f = 47.69 Hz, Modal Mass = 11.244 kip-sec^2/ft

2. The cutoff frequencies were:
   - Tunnel Segment 1
     - Lower-bound, non-separated fill: 30.52 Hz
     - Best-estimate, non-separated fill: 39.06 Hz
     - Upper-bound, non-separated fill: 50.05 Hz
     - High-bound, non-separated fill: 50.05 Hz
   - Tunnel Segment 2
     - Lower-bound, non-separated fill: 30.03 Hz
     - Best-estimate, non-separated fill: 38.09 Hz
     - Upper-bound, non-separated fill: 49.80 Hz
     - High-bound, non-separated fill: 49.80 Hz
     - Lower-bound, separated fill: 30.03 Hz
     - Best-estimate, separated fill: 38.09 Hz
     - Upper-bound, separated fill: 49.80 Hz
     - High-bound, separated fill: 49.80 Hz
   - Tunnel Segment 3
     - Lower-bound, non-separated fill: 29.30 Hz
     - Best-estimate, non-separated fill: 38.45 Hz
     - Upper-bound, non-separated fill: 48.83 Hz
     - High-bound, non-separated fill: 50.05 Hz

3. The frequencies at which SASSI analysis was performed are listed in Table 6, Table 7, and Table 8 below:

Table 6. Tunnel Segment 1 - Frequencies used in SASSI Analysis (Hz)

	Tunnel Segment 1			
	Lower Bound	**Best Estimate**	**Upper Bound**	**High Bound**
1	1.22	1.22	1.22	1.22
2	1.83	1.83	1.83	1.83
3	2.44	2.44	2.44	2.44
4	3.05	3.05	3.05	3.05
5	3.66	3.66	3.66	3.66
6	4.27	4.27	4.27	4.27
7	4.88	4.88	4.88	4.88
8	5.49	5.49	5.49	5.49
9	6.10	6.10	6.10	6.10
10	6.71	6.71	6.71	6.71
11	7.32	7.32	7.32	7.32
12	7.94	7.94	7.94	7.94
13	8.55	8.55	8.55	8.55
14	9.16	9.16	9.16	9.16
15	9.77	9.77	9.77	9.77
16	10.38	10.38	10.38	10.38
17	10.99	10.99	10.99	10.99
18	11.60	11.60	11.60	11.60
19	12.21	12.21	12.21	12.21
20	12.82	12.82	12.82	12.82
21	13.43	13.43	13.43	13.43
22	14.04	14.04	14.04	14.04
23	14.65	14.65	14.65	14.65
24	15.26	15.26	15.26	15.26
25	15.87	15.87	15.87	15.87
26	16.48	16.48	16.48	16.48
27	17.09	17.09	17.09	17.09
28	17.70	17.70	17.70	17.70
29	18.31	18.31	18.31	18.31
30	18.92	18.92	18.92	18.92
31	19.53	19.53	19.53	19.53
32	20.14	20.14	20.14	20.14
33	20.75	20.75	20.75	20.75
34	21.36	21.36	21.36	21.36
35	21.97	21.97	21.97	21.97
36	22.58	22.58	22.58	22.58

Table 6. Tunnel Segment 1 - Frequencies used in SASSI Analysis (Hz) (continued)				
	Tunnel Segment 1			
	Lower Bound	Best Estimate	Upper Bound	High Bound
37	23.19	23.19	23.19	23.19
38	23.80	23.80	23.80	23.80
39	24.41	24.41	24.41	24.41
40	25.02	25.02	25.02	25.02
41	25.63	25.63	25.63	25.63
42	26.25	26.25	26.25	26.25
43	26.86	26.86	26.86	26.86
44	27.47	27.47	27.47	27.47
45	28.08	28.08	28.08	28.08
46	28.69	29.30	28.69	28.69
47	29.30	29.91	29.30	29.30
48	29.91	30.52	29.91	29.91
49	30.52	31.13	30.52	30.52
50		31.74	31.13	31.13
51		32.35	31.74	31.74
52		32.96	32.35	32.35
53		33.57	32.96	32.96
54		34.18	33.57	33.57
55		34.79	34.18	34.18
56		35.40	34.79	34.79
57		36.01	35.40	35.40
58		36.62	36.01	36.01
59		37.23	36.62	36.62
60		37.84	37.23	37.23
61		38.45	37.84	37.84
62		39.06	38.45	38.45
63			39.06	39.06
64			39.67	39.67
65			40.28	40.28
66			40.89	40.89
67			41.50	41.50
68			42.11	42.11
69			42.72	42.72
70			43.33	43.33
71			43.95	43.95
72			44.56	44.56
73			45.17	45.17
74			45.78	45.78

Table 6. Tunnel Segment 1 - Frequencies used in SASSI Analysis (Hz) (continued)				
	Tunnel Segment 1			
	Lower Bound	Best Estimate	Upper Bound	High Bound
75			46.39	46.39
76			47.00	47.00
77			47.61	47.61
78			48.22	48.22
79			48.83	48.83
80			49.44	49.44
81			50.05	50.05

Table 7. Tunnel Segment 2 - Frequencies used in SASSI Analysis (Hz)								
	Tunnel Segment 2 Non-Separated Fill				Tunnel Segment 2 Separated Fill			
	Lower Bound	Best Estimate	Upper Bound	High Bound	Lower Bound	Best Estimate	Upper Bound	High Bound
1	1.46	1.46	1.46	1.46	1.46	1.46	1.46	1.46
2	2.93	2.93	2.93	2.93	2.93	2.93	2.93	2.93
3	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66
4	4.39	4.39	4.39	4.39	4.39	4.39	4.39	4.39
5	5.13	5.13	5.13	5.13	5.13	5.13	5.13	5.13
6	5.86	5.86	5.86	5.86	5.86	5.86	5.86	5.86
7	6.59	6.59	6.59	6.59	6.59	6.59	6.59	6.59
8	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32
9	8.06	8.06	8.06	8.06	8.06	8.06	8.06	8.06
10	8.79	8.79	8.79	8.79	8.79	8.79	8.79	8.79
11	9.52	9.52	9.52	9.52	9.52	9.52	9.52	9.52
12	10.25	10.25	10.25	10.25	10.25	10.25	10.25	10.25
13	10.99	10.99	10.99	10.99	10.99	10.99	10.99	10.99
14	11.72	11.72	11.72	11.72	11.72	11.72	11.72	11.72
15	12.45	12.45	12.45	12.45	12.45	12.45	12.45	12.45
16	13.18	13.18	13.18	13.18	13.18	13.18	13.18	13.18
17	13.92	13.92	13.92	13.92	13.92	13.92	13.92	13.92
18	14.65	14.65	14.65	14.65	14.65	14.65	14.65	14.65
19	15.38	15.38	15.38	15.38	15.38	15.38	15.38	15.38
20	16.11	16.11	16.11	16.11	16.11	16.11	16.11	16.11
21	16.85	16.85	16.85	16.85	16.85	16.85	16.85	16.85
22	17.58	17.58	17.58	17.58	17.58	17.58	17.58	17.58
23	18.31	18.31	18.31	18.31	18.31	18.31	18.31	18.31
24	19.04	19.04	19.04	19.04	19.04	19.04	19.04	19.04

Table 7. Tunnel Segment 2 - Frequencies used in SASSI Analysis (Hz)

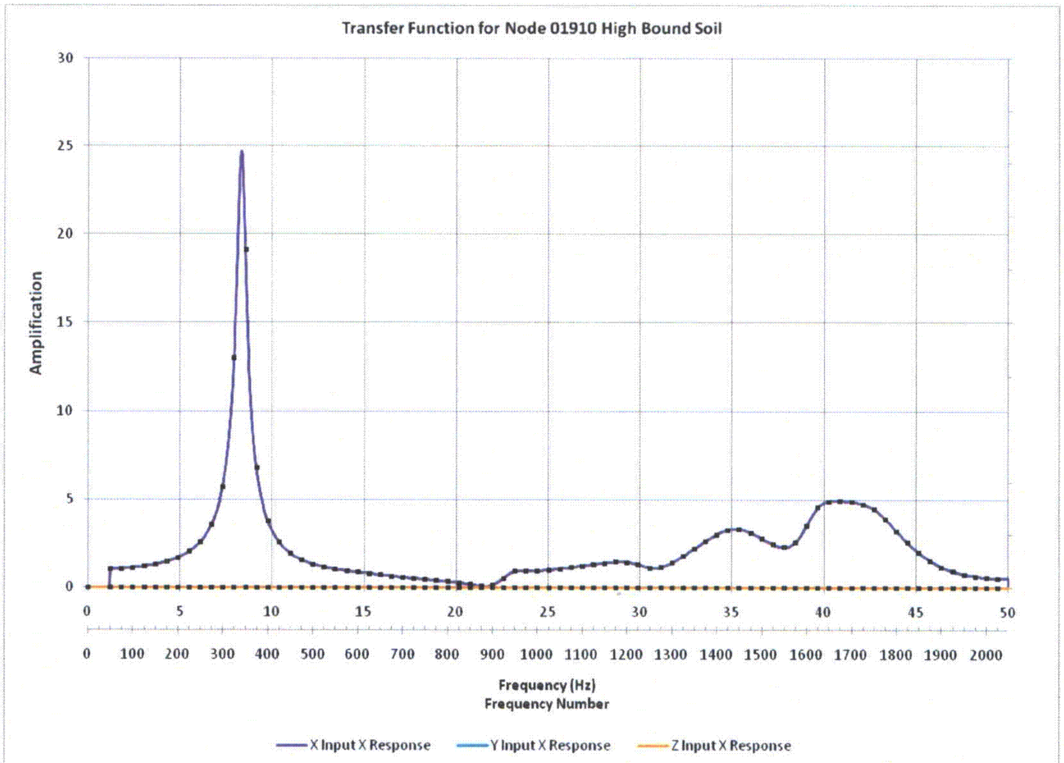
	Tunnel Segment 2 Non-Separated Fill				Tunnel Segment 2 Separated Fill			
	Lower Bound	Best Estimate	Upper Bound	High Bound	Lower Bound	Best Estimate	Upper Bound	High Bound
25	19.78	19.78	19.78	19.78	19.78	19.78	19.78	19.78
26	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
27	21.24	21.24	21.24	21.24	21.24	21.24	21.24	21.24
28	21.97	21.97	21.97	21.97	21.97	21.97	21.97	21.97
29	22.71	22.71	22.71	22.71	22.71	22.71	22.71	22.71
30	23.44	23.44	23.44	23.44	23.44	23.44	23.44	23.44
31	24.17	24.17	24.17	24.17	24.17	24.17	24.17	24.17
32	24.90	24.90	24.90	24.90	24.90	24.90	24.90	24.90
33	25.63	25.63	25.63	25.63	25.63	25.63	25.63	25.63
34	26.37	26.37	26.37	26.37	26.37	26.37	26.37	26.37
35	27.10	27.10	27.10	27.10	27.10	27.10	27.10	27.10
36	27.83	27.83	27.83	27.83	27.83	27.83	27.83	27.83
37	28.56	28.56	28.56	28.56	28.56	28.56	28.56	28.56
38	29.30	29.30	29.30	29.30	29.30	29.30	29.30	29.30
39	30.03	30.03	30.03	30.03	30.03	30.03	30.03	30.03
40		30.76	30.76	30.76		30.76	30.76	30.76
41		32.23	32.23	32.25		32.23	32.23	32.25
42		33.69	33.69	33.69		33.69	33.69	33.69
43		35.16	35.16	35.16		35.16	35.16	35.16
44		36.62	36.62	36.62		36.62	36.62	36.62
45		38.09	38.09	38.09		38.09	38.09	38.09
46			39.55	39.55			39.55	39.55
47			41.02	41.02			41.02	41.02
48			42.48	42.48			42.48	42.48
49			43.95	43.95			43.95	43.95
50			45.41	45.41			45.41	45.41
51			46.88	46.88			46.88	46.88
52			48.34	48.34			48.34	48.34
53			49.80	49.80			49.80	49.80

Table 8. Tunnel Segment 3 - Frequencies used in SASSI Analysis (Hz)				
	Tunnel Segment 3			
	Lower Bound	**Best Estimate**	**Upper Bound**	**High Bound**
1	1.22	1.22	1.22	1.22
2	1.83	1.83	1.83	1.83
3	2.44	2.44	2.44	2.44
4	3.05	3.05	3.05	3.05
5	3.66	3.66	3.66	3.66
6	4.27	4.27	4.27	4.27
7	4.88	4.88	4.88	4.88
8	5.49	5.49	5.49	5.49
9	6.10	6.10	6.10	6.10
10	6.71	6.71	6.71	6.71
11	7.32	7.32	7.32	7.32
12	7.94	7.94	7.94	7.94
13	8.55	8.55	8.55	8.55
14	9.16	9.16	9.16	9.16
15	9.77	9.77	9.77	9.77
16	10.38	10.38	10.38	10.38
17	10.99	10.99	10.99	10.99
18	11.60	11.60	11.60	11.60
19	12.21	12.21	12.21	12.21
20	12.82	12.82	12.82	12.82
21	13.43	13.43	13.43	13.43
22	14.04	14.04	14.04	14.04
23	14.65	14.65	14.65	14.65
24	15.26	15.26	15.26	15.26
25	15.87	15.87	15.87	15.87
26	16.48	16.48	16.48	16.48
27	17.09	17.09	17.09	17.09
28	17.70	17.70	17.70	17.70
29	18.31	18.31	18.31	18.31
30	18.92	18.92	18.92	18.92
31	19.53	19.53	19.53	19.53
32	20.14	20.14	20.14	20.14
33	20.75	20.75	20.75	20.75
34	21.36	21.36	21.36	21.36
35	21.97	21.97	21.97	21.97
36	22.58	22.58	22.58	22.58
37	23.19	23.19	23.19	23.19
38	23.80	23.80	23.80	23.80
39	24.41	24.41	24.41	24.41
40	25.02	25.02	25.02	25.02
41	25.63	25.63	25.63	25.63
42	26.25	26.25	26.25	26.25

Table 8. Tunnel Segment 3 - Frequencies used in SASSI Analysis (Hz) (continued)				
	Tunnel Segment 3			
	Lower Bound	Best Estimate	Upper Bound	High Bound
43	26.86	26.86	26.86	26.86
44	27.47	27.47	27.47	27.47
45	28.08	28.08	28.08	28.08
46	28.69	28.69	28.69	28.69
47	29.30	29.30	29.30	29.30
48		29.91	29.91	29.91
49		30.52	30.52	30.52
50		31.13	31.13	31.13
51		31.74	31.74	31.74
52		32.35	32.35	32.35
53		32.96	32.96	32.96
54		33.57	33.57	33.57
55		34.18	34.18	34.18
56		34.79	34.79	34.79
57		35.40	35.40	35.40
58		36.01	36.01	36.01
59		36.62	36.62	36.62
60		37.23	37.23	37.23
61		37.84	37.84	37.84
62		38.45	38.45	38.45
63			39.06	39.06
64			39.67	39.67
65			40.28	40.28
66			40.89	40.89
67			41.50	41.50
68			42.11	42.11
69			42.72	42.72
70			43.33	43.33
71			43.95	43.95
72			44.56	44.56
73			45.17	45.17
74			45.78	45.78
75			46.39	46.39
76			47.00	47.00
77			47.61	47.61
78			48.22	48.22
79			48.83	48.83
80				49.44
81				50.05

4. The SASSI analysis frequencies were selected to cover the range between around 1 Hz and the cutoff frequency. This frequency range includes the SSI frequency and primary structural frequencies. The 1Hz lower limit was shown to be low enough to be outside the range of SSI or structural mode amplification. Initially, the frequencies are selected evenly spaced. Frequencies were added as needed to produce smooth interpolation of the transfer functions and accurately capture peaks. As verification, additional frequencies were added to observe that the results did not change.

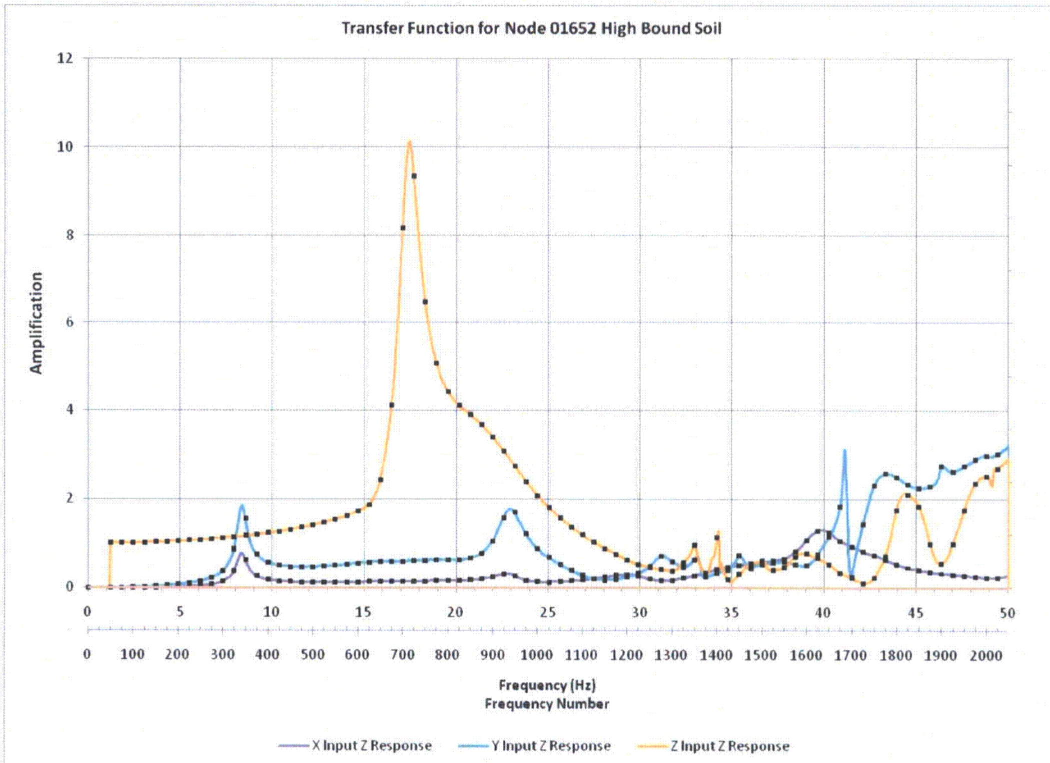
5. The tunnels are simple structures and responses will be significantly influenced by the surrounding soil, producing frequencies of peak response that do not match the eigenvalue analysis of the fixed base structure without soil which limits the ability to compare transfer functions. Therefore, the response of these structures were checked primarily through model and analysis input file checks and reviews of the transfer functions and other output to make sure that adequate frequencies were used for calculation, zero frequency and high frequencies were as expected, and that structural responses are observed.



Note 1: Data points represent calculated frequencies in SASSI. Lines are interpolated values in SASSI.

Note 2: Vertical lines at end of transfer functions and data point at origin represent blanks in EXCEL data and do not represent SASSI data.

Tunnel Segment 1, Roof Slab, X-Response Transfer Function for Node 01910 High Bound Soil



Note 1: Data points represent calculated frequencies in SASSI. Lines are interpolated values in SASSI.

Note 2: Vertical lines at end of transfer functions and data point at origin represent blanks in EXCEL data and do not represent SASSI data.

Tunnel Segment 1, Roof Slab, Z-Response Transfer Function for Node 01652 High Bound Soil

6. The soil layer thicknesses used in the SASSI analyses, and a demonstration that the layer thicknesses comply with the maximum layer thicknesses given by the "1/5 wavelength" guideline is shown in Tables 9 through 14 below:

Table 9 Tunnel Segment 1 - SASSI Subsurface Properties

Layer	Thickness (ft)	Unit Weight (ksf)	Shear Wave Velocity (ft/s)				Compression Wave Velocity (ft/s)				Damping Ratio			
			Lower Bound	Best Estimate	Upper Bound	High Bound	Lower Bound	Best Estimate	Upper Bound	High Bound	Lower Bound	Best Estimate	Upper Bound	High Bound
1	3.000	0.125	475.4	632.7	834.2	968.8	989.7	1317.1	1736.6	2016.8	0.0300	0.0240	0.0200	0.0180
2	4.250	0.125	540.3	739.1	999.2	1174.2	1124.8	1538.6	2080.0	2444.3	0.0475	0.0365	0.0270	0.0225
3	0.960	0.125	477.3	690.8	957.5	1142.8	993.7	1438.0	1993.2	2379.0	0.0745	0.0515	0.0370	0.0300
4	5.040	0.125	457.8	675.7	946.0	1132.1	953.1	1406.6	1969.2	2356.8	0.0835	0.0564	0.0396	0.0319
5	4.167	0.125	407.3	636.3	915.0	1102.7	847.8	1324.5	1904.8	2295.5	0.1101	0.0695	0.0471	0.0375
6	4.168	0.125	448.7	699.4	998.3	1197.2	934.1	1456.0	2078.2	2492.2	0.1009	0.0624	0.0430	0.0346
7	4.167	0.125	619.1	886.9	1210.8	1428.7	1288.7	1846.2	2520.5	2974.0	0.0639	0.0419	0.0305	0.0254
8	4.168	0.125	603.5	871.2	1199.4	1419.1	1256.2	1813.5	2496.7	2954.1	0.0700	0.0460	0.0325	0.0270
9	5.040	0.125	587.7	855.0	1188.1	1408.8	1223.4	1779.8	2473.3	2932.7	0.0759	0.0494	0.0350	0.0290
10	5.040	0.125	576.0	842.4	1179.9	1400.3	1199.1	1753.6	2456.2	2915.0	0.0810	0.0525	0.0370	0.0300
11	16.250	0.155	4427.5	5685.0	7299.7	7299.7	8789.7	11286.1	14491.7	14491.7	0.0260	0.0180	0.0130	0.0130
12	16.250	0.155	4427.5	5685.0	7299.7	7299.7	8789.7	11286.1	14491.7	14491.7	0.0260	0.0180	0.0130	0.0130
13	16.250	0.155	4427.5	5685.0	7299.7	7299.7	8789.7	11286.1	14491.7	14491.7	0.0260	0.0180	0.0130	0.0130
14	16.250	0.155	4427.5	5685.0	7299.7	7299.7	8789.7	11286.1	14491.7	14491.7	0.0260	0.0180	0.0130	0.0130
15	3.000	0.135	2351.2	3019.0	3876.5	3876.5	6330.8	8128.9	10437.8	10437.8	0.0280	0.0200	0.0140	0.0140
16	24.000	0.155	3849.6	4943.0	6346.9	6346.9	8230.8	10568.6	13570.2	13570.2	0.0260	0.0180	0.0130	0.0130
17	34.000	0.155	5358.1	6880.0	8834.1	8834.1	10210.8	13111.0	16834.9	16834.9	0.0260	0.0180	0.0130	0.0130
18	17.000	0.150	3147.9	4042.0	5190.0	5190.0	7155.3	9187.6	11797.0	11797.0	0.0260	0.0180	0.0130	0.0130
19	17.000	0.150	3147.9	4042.0	5190.0	5190.0	7155.3	9187.6	11797.0	11797.0	0.0260	0.0180	0.0130	0.0130
20	14.500	0.130	2383.9	3061.0	3930.4	3930.4	6103.7	7837.3	10063.3	10063.3	0.0280	0.0200	0.0140	0.0140
21	14.500	0.130	2383.9	3061.0	3930.4	3930.4	6103.7	7837.3	10063.3	10063.3	0.0280	0.0200	0.0140	0.0140
22	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
23	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
24	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
25	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
26	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
27	15.500	0.140	2670.5	3429.0	4402.9	4402.9	6288.7	8074.9	10368.3	10368.3	0.0280	0.0200	0.0140	0.0140
28	15.500	0.140	2670.5	3429.0	4402.9	4402.9	6288.7	8074.9	10368.3	10368.3	0.0280	0.0200	0.0140	0.0140
29	15.500	0.140	2670.5	3429.0	4402.9	4402.9	6288.7	8074.9	10368.3	10368.3	0.0280	0.0200	0.0140	0.0140
30	15.500	0.140	2670.5	3429.0	4402.9	4402.9	6288.7	8074.9	10368.3	10368.3	0.0280	0.0200	0.0140	0.0140
31	15.750	0.145	2408.1	3092.0	3970.2	3970.2	5898.6	7573.8	9725.0	9725.0	0.0280	0.0200	0.0140	0.0140
32	15.750	0.145	2408.1	3092.0	3970.2	3970.2	5898.6	7573.8	9725.0	9725.0	0.0280	0.0200	0.0140	0.0140
33	15.750	0.145	2408.1	3092.0	3970.2	3970.2	5898.6	7573.8	9725.0	9725.0	0.0280	0.0200	0.0140	0.0140
34	15.750	0.145	2408.1	3092.0	3970.2	3970.2	5898.6	7573.8	9725.0	9725.0	0.0280	0.0200	0.0140	0.0140
35	25.100	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
36	25.100	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
37	25.100	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
38	25.100	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
39	25.100	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
40	25.100	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
41	25.100	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
42	25.100	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
43	25.100	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
44	25.100	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
45	25.100	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130

Table 10 Tunnel Segment 2 - SASSI Subsurface Properties

Layer	Thickness (ft)	Unit Weight (ksf)	Shear Wave Velocity (ft/s)				Compression Wave Velocity (ft/s)				Damping Ratio			
			Lower Bound	Best Estimate	Upper Bound	High Bound	Lower Bound	Best Estimate	Upper Bound	High Bound	Lower Bound	Best Estimate	Upper Bound	High Bound
1	6.500	0.125	508.3	685.9	915.6	1069.6	1058.1	1427.7	1906.1	2226.5	0.0394	0.0307	0.0238	0.0204
2	6.500	0.125	470.4	685.8	954.4	1139.2	979.1	1427.6	1986.7	2371.4	0.0774	0.0530	0.0376	0.0304
3	6.868	0.125	398.9	630.1	910.1	1097.9	830.4	1311.7	1894.6	2285.4	0.1149	0.0715	0.0484	0.0385
4	6.868	0.125	610.4	878.1	1201.8	1419.3	1270.6	1827.9	2501.7	2954.4	0.0656	0.0429	0.0310	0.0258
5	6.704	0.125	595.2	862.7	1193.5	1413.7	1238.9	1795.8	2484.4	2942.9	0.0731	0.0478	0.0338	0.0280
6	6.560	0.125	578.6	845.2	1181.8	1402.2	1204.5	1759.5	2460.1	2919.0	0.0798	0.0518	0.0365	0.0298
7	16.250	0.155	4427.5	5685.0	7299.7	7299.7	8789.7	11286.1	14491.7	14491.7	0.0260	0.0180	0.0130	0.0130
8	16.250	0.155	4427.5	5685.0	7299.7	7299.7	8789.7	11286.1	14491.7	14491.7	0.0260	0.0180	0.0130	0.0130
9	16.250	0.155	4427.5	5685.0	7299.7	7299.7	8789.7	11286.1	14491.7	14491.7	0.0260	0.0180	0.0130	0.0130
10	16.250	0.155	4427.5	5685.0	7299.7	7299.7	8789.7	11286.1	14491.7	14491.7	0.0260	0.0180	0.0130	0.0130
11	3.000	0.135	2351.2	3019.0	3876.5	3876.5	6330.8	8128.9	10437.8	10437.8	0.0280	0.0200	0.0140	0.0140
12	24.000	0.155	3849.6	4943.0	6346.9	6346.9	8230.8	10568.6	13570.2	13570.2	0.0260	0.0180	0.0130	0.0130
13	34.000	0.155	5358.1	6880.0	8834.1	8834.1	10210.8	13111.0	16834.9	16834.9	0.0260	0.0180	0.0130	0.0130
14	17.000	0.150	3147.9	4042.0	5190.0	5190.0	7155.3	9187.6	11797.0	11797.0	0.0260	0.0180	0.0130	0.0130
15	17.000	0.150	3147.9	4042.0	5190.0	5190.0	7155.3	9187.6	11797.0	11797.0	0.0260	0.0180	0.0130	0.0130
16	14.500	0.130	2383.9	3061.0	3930.4	3930.4	6103.7	7837.3	10063.3	10063.3	0.0280	0.0200	0.0140	0.0140
17	14.500	0.130	2383.9	3061.0	3930.4	3930.4	6103.7	7837.3	10063.3	10063.3	0.0280	0.0200	0.0140	0.0140
18	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
19	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
20	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
21	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
22	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
23	15.500	0.140	2670.5	3429.0	4402.9	4402.9	6288.7	8074.9	10368.3	10368.3	0.0280	0.0200	0.0140	0.0140
24	15.500	0.140	2670.5	3429.0	4402.9	4402.9	6288.7	8074.9	10368.3	10368.3	0.0280	0.0200	0.0140	0.0140
25	15.500	0.140	2670.5	3429.0	4402.9	4402.9	6288.7	8074.9	10368.3	10368.3	0.0280	0.0200	0.0140	0.0140
26	15.500	0.140	2670.5	3429.0	4402.9	4402.9	6288.7	8074.9	10368.3	10368.3	0.0280	0.0200	0.0140	0.0140
27	15.750	0.145	2408.1	3092.0	3970.2	3970.2	5898.6	7573.8	9725.0	9725.0	0.0280	0.0200	0.0140	0.0140
28	15.750	0.145	2408.1	3092.0	3970.2	3970.2	5898.6	7573.8	9725.0	9725.0	0.0280	0.0200	0.0140	0.0140
29	15.750	0.145	2408.1	3092.0	3970.2	3970.2	5898.6	7573.8	9725.0	9725.0	0.0280	0.0200	0.0140	0.0140
30	15.750	0.145	2408.1	3092.0	3970.2	3970.2	5898.6	7573.8	9725.0	9725.0	0.0280	0.0200	0.0140	0.0140
31	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
32	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
33	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
34	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
35	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
36	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
37	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
38	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
39	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
40	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
41	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
42	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
43	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
44	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
45	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130

Table 11 Tunnel Segment 3 - SASSI Subsurface Properties

		Unit	Shear Wave Velocity (ft/s)				Compression Wave Velocity (ft/s)				Damping Ratio			
Layer	Thickness (ft)	Weight (ksf)	Lower Bound	Best Estimate	Upper Bound	High Bound	Lower Bound	Best Estimate	Upper Bound	High Bound	Lower Bound	Best Estimate	Upper Bound	High Bound
1	7.000	0.125	510.5	689.4	921.1	1076.4	1062.6	1435.1	1917.5	2240.8	0.0400	0.0311	0.0240	0.0206
2	6.250	0.125	463.6	680.3	949.8	1135.4	965.0	1416.2	1977.1	2363.5	0.0807	0.0548	0.0387	0.0312
3	5.557	0.125	400.9	631.6	911.3	1099.1	834.6	1314.8	1897.1	2287.9	0.1137	0.0710	0.0481	0.0383
4	5.556	0.125	548.9	813.5	1129.1	1340.2	1142.6	1693.3	2350.4	2789.9	0.0758	0.0484	0.0345	0.0283
5	5.557	0.125	605.6	873.3	1201.0	1420.4	1260.7	1818.0	2500.0	2956.9	0.0691	0.0454	0.0322	0.0268
6	5.040	0.125	587.7	855.0	1188.1	1408.8	1223.4	1779.8	2473.3	2932.7	0.0759	0.0494	0.0350	0.0290
7	5.040	0.125	576.0	842.4	1179.9	1400.3	1199.1	1753.6	2456.2	2915.0	0.0810	0.0525	0.0370	0.0300
8	16.250	0.155	4427.5	5685.0	7299.7	7299.7	8789.7	11286.1	14491.7	14491.7	0.0260	0.0180	0.0130	0.0130
9	16.250	0.155	4427.5	5685.0	7299.7	7299.7	8789.7	11286.1	14491.7	14491.7	0.0260	0.0180	0.0130	0.0130
10	16.250	0.155	4427.5	5685.0	7299.7	7299.7	8789.7	11286.1	14491.7	14491.7	0.0260	0.0180	0.0130	0.0130
11	16.250	0.155	4427.5	5685.0	7299.7	7299.7	8789.7	11286.1	14491.7	14491.7	0.0260	0.0180	0.0130	0.0130
12	3.000	0.135	2351.2	3019.0	3876.5	3876.5	6330.8	8128.9	10437.8	10437.8	0.0280	0.0200	0.0140	0.0140
13	24.000	0.155	3849.6	4943.0	6346.9	6346.9	8230.8	10568.6	13570.2	13570.2	0.0260	0.0180	0.0130	0.0130
14	34.000	0.155	5358.1	6880.0	8834.1	8834.1	10210.8	13111.0	16834.9	16834.9	0.0260	0.0180	0.0130	0.0130
15	17.000	0.150	3147.9	4042.0	5190.0	5190.0	7155.3	9187.6	11797.0	11797.0	0.0260	0.0180	0.0130	0.0130
16	17.000	0.150	3147.9	4042.0	5190.0	5190.0	7155.3	9187.6	11797.0	11797.0	0.0260	0.0180	0.0130	0.0130
17	14.500	0.130	2383.9	3061.0	3930.4	3930.4	6103.7	7837.3	10063.3	10063.3	0.0280	0.0200	0.0140	0.0140
18	14.500	0.130	2383.9	3061.0	3930.4	3930.4	6103.7	7837.3	10063.3	10063.3	0.0280	0.0200	0.0140	0.0140
19	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
20	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
21	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
22	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
23	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
24	15.500	0.140	2670.5	3429.0	4402.9	4402.9	6288.7	8074.9	10368.3	10368.3	0.0280	0.0200	0.0140	0.0140
25	15.500	0.140	2670.5	3429.0	4402.9	4402.9	6288.7	8074.9	10368.3	10368.3	0.0280	0.0200	0.0140	0.0140
26	15.500	0.140	2670.5	3429.0	4402.9	4402.9	6288.7	8074.9	10368.3	10368.3	0.0280	0.0200	0.0140	0.0140
27	15.500	0.140	2670.5	3429.0	4402.9	4402.9	6288.7	8074.9	10368.3	10368.3	0.0280	0.0200	0.0140	0.0140
28	15.750	0.145	2408.1	3092.0	3970.2	3970.2	5898.6	7573.8	9725.0	9725.0	0.0280	0.0200	0.0140	0.0140
29	15.750	0.145	2408.1	3092.0	3970.2	3970.2	5898.6	7573.8	9725.0	9725.0	0.0280	0.0200	0.0140	0.0140
30	15.750	0.145	2408.1	3092.0	3970.2	3970.2	5898.6	7573.8	9725.0	9725.0	0.0280	0.0200	0.0140	0.0140
31	15.750	0.145	2408.1	3092.0	3970.2	3970.2	5898.6	7573.8	9725.0	9725.0	0.0280	0.0200	0.0140	0.0140
32	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
33	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
34	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
35	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
36	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
37	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
38	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
39	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
40	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
41	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
42	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
43	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
44	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
45	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130

Table 12 Tunnel Segment 1 - Passing Frequency for 5 Points per Wavelength

		Shear Wave Frequncy (Hz)				Compression Wave Frequency (Hz)			
Layer	Thickness (ft)	Lower Bound	Best Estimate	Upper Bound	High Bound	Lower Bound	Best Estimate	Upper Bound	High Bound
1	3.000	31.7	42.2	55.6	64.6	66.0	87.8	115.8	134.5
2	4.250	25.4	34.8	47.0	55.3	52.9	72.4	97.9	115.0
3	0.960	99.4	143.9	199.5	238.1	207.0	299.6	415.3	495.6
4	5.040	18.2	26.8	37.5	44.9	37.8	55.8	78.1	93.5
5	4.167	19.5	30.5	43.9	52.9	40.7	63.6	91.4	110.2
6	4.168	21.5	33.6	47.9	57.4	44.8	69.9	99.7	119.6
7	4.167	29.7	42.6	58.1	68.6	61.9	88.6	121.0	142.7
8	4.168	29.0	41.8	57.6	68.1	60.3	87.0	119.8	141.8
9	5.040	23.3	33.9	47.1	55.9	48.5	70.6	98.1	116.4
10	5.040	22.9	33.4	46.8	55.6	47.6	69.6	97.5	115.7
11	16.250	54.5	70.0	89.8	89.8	108.2	138.9	178.4	178.4
12	16.250	54.5	70.0	89.8	89.8	108.2	138.9	178.4	178.4
13	16.250	54.5	70.0	89.8	89.8	108.2	138.9	178.4	178.4
14	16.250	54.5	70.0	89.8	89.8	108.2	138.9	178.4	178.4
15	3.000	156.7	201.3	258.4	258.4	422.1	541.9	695.9	695.9
16	24.000	32.1	41.2	52.9	52.9	68.6	88.1	113.1	113.1
17	34.000	31.5	40.5	52.0	52.0	60.1	77.1	99.0	99.0
18	17.000	37.0	47.6	61.1	61.1	84.2	108.1	138.8	138.8
19	17.000	37.0	47.6	61.1	61.1	84.2	108.1	138.8	138.8
20	14.500	32.9	42.2	54.2	54.2	84.2	108.1	138.8	138.8
21	14.500	32.9	42.2	54.2	54.2	84.2	108.1	138.8	138.8
22	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
23	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
24	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
25	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
26	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
27	15.500	34.5	44.2	56.8	56.8	81.1	104.2	133.8	133.8
28	15.500	34.5	44.2	56.8	56.8	81.1	104.2	133.8	133.8
29	15.500	34.5	44.2	56.8	56.8	81.1	104.2	133.8	133.8
30	15.500	34.5	44.2	56.8	56.8	81.1	104.2	133.8	133.8
31	15.750	30.6	39.3	50.4	50.4	74.9	96.2	123.5	123.5
32	15.750	30.6	39.3	50.4	50.4	74.9	96.2	123.5	123.5
33	15.750	30.6	39.3	50.4	50.4	74.9	96.2	123.5	123.5
34	15.750	30.6	39.3	50.4	50.4	74.9	96.2	123.5	123.5
35	25.100	34.4	44.2	56.7	56.7	66.9	85.9	110.3	110.3
36	25.100	34.4	44.2	56.7	56.7	66.9	85.9	110.3	110.3
37	25.100	34.4	44.2	56.7	56.7	66.9	85.9	110.3	110.3
38	25.100	34.4	44.2	56.7	56.7	66.9	85.9	110.3	110.3
39	25.100	34.4	44.2	56.7	56.7	66.9	85.9	110.3	110.3
40	25.100	34.4	44.2	56.7	56.7	66.9	85.9	110.3	110.3
41	25.100	34.4	44.2	56.7	56.7	66.9	85.9	110.3	110.3
42	25.100	34.4	44.2	56.7	56.7	66.9	85.9	110.3	110.3
43	25.100	34.4	44.2	56.7	56.7	66.9	85.9	110.3	110.3
44	25.100	34.4	44.2	56.7	56.7	66.9	85.9	110.3	110.3
45	25.100	34.4	44.2	56.7	56.7	66.9	85.9	110.3	110.3

Table 13 Tunnel Segment 2 - Passing Frequency for 5 Points per Wavelength

		Shear Wave Frequncy (Hz)				Compression Wave Frequency (Hz)			
Layer	Thickness (ft)	Lower Bound	Best Estimate	Upper Bound	High Bound	Lower Bound	Best Estimate	Upper Bound	High Bound
1	6.500	15.6	21.1	28.2	32.9	32.6	43.9	58.6	68.5
2	6.500	14.5	21.1	29.4	35.1	30.1	43.9	61.1	73.0
3	6.868	11.6	18.3	26.5	32.0	24.2	38.2	55.2	66.6
4	6.868	17.8	25.6	35.0	41.3	37.0	53.2	72.9	86.0
5	6.704	17.8	25.7	35.6	42.2	37.0	53.6	74.1	87.8
6	6.560	17.6	25.8	36.0	42.8	36.7	53.6	75.0	89.0
7	16.250	54.5	70.0	89.8	89.8	108.2	138.9	178.4	178.4
8	16.250	54.5	70.0	89.8	89.8	108.2	138.9	178.4	178.4
9	16.250	54.5	70.0	89.8	89.8	108.2	138.9	178.4	178.4
10	16.250	54.5	70.0	89.8	89.8	108.2	138.9	178.4	178.4
11	3.000	156.7	201.3	258.4	258.4	422.1	541.9	695.9	695.9
12	24.000	32.1	41.2	52.9	52.9	68.6	88.1	113.1	113.1
13	34.000	31.5	40.5	52.0	52.0	60.1	77.1	99.0	99.0
14	17.000	37.0	47.6	61.1	61.1	84.2	108.1	138.8	138.8
15	17.000	37.0	47.6	61.1	61.1	84.2	108.1	138.8	138.8
16	14.500	32.9	42.2	54.2	54.2	84.2	108.1	138.8	138.8
17	14.500	32.9	42.2	54.2	54.2	84.2	108.1	138.8	138.8
18	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
19	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
20	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
21	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
22	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
23	15.500	34.5	44.2	56.8	56.8	81.1	104.2	133.8	133.8
24	15.500	34.5	44.2	56.8	56.8	81.1	104.2	133.8	133.8
25	15.500	34.5	44.2	56.8	56.8	81.1	104.2	133.8	133.8
26	15.500	34.5	44.2	56.8	56.8	81.1	104.2	133.8	133.8
27	15.750	30.6	39.3	50.4	50.4	74.9	96.2	123.5	123.5
28	15.750	30.6	39.3	50.4	50.4	74.9	96.2	123.5	123.5
29	15.750	30.6	39.3	50.4	50.4	74.9	96.2	123.5	123.5
30	15.750	30.6	39.3	50.4	50.4	74.9	96.2	123.5	123.5
31	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
32	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
33	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
34	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
35	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
36	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
37	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
38	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
39	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
40	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
41	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
42	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
43	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
44	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
45	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7

Table 14 Tunnel Segment 3 - Passing Frequency for 5 Points per Wavelength

		Shear Wave Frequncy (Hz)				Compression Wave Frequency (Hz)			
Layer	Thickness (ft)	Lower Bound	Best Estimate	Upper Bound	High Bound	Lower Bound	Best Estimate	Upper Bound	High Bound
1	7.000	14.6	19.7	26.3	30.8	30.4	41.0	54.8	64.0
2	6.250	14.8	21.8	30.4	36.3	30.9	45.3	63.3	75.6
3	5.557	14.4	22.7	32.8	39.6	30.0	47.3	68.3	82.3
4	5.556	19.8	29.3	40.6	48.2	41.1	61.0	84.6	100.4
5	5.557	21.8	31.4	43.2	51.1	45.4	65.4	90.0	106.4
6	5.040	23.3	33.9	47.1	55.9	48.5	70.6	98.1	116.4
7	5.040	22.9	33.4	46.8	55.6	47.6	69.6	97.5	115.7
8	16.250	54.5	70.0	89.8	89.8	108.2	138.9	178.4	178.4
9	16.250	54.5	70.0	89.8	89.8	108.2	138.9	178.4	178.4
10	16.250	54.5	70.0	89.8	89.8	108.2	138.9	178.4	178.4
11	16.250	54.5	70.0	89.8	89.8	108.2	138.9	178.4	178.4
12	3.000	156.7	201.3	258.4	258.4	422.1	541.9	695.9	695.9
13	24.000	32.1	41.2	52.9	52.9	68.6	88.1	113.1	113.1
14	34.000	31.5	40.5	52.0	52.0	60.1	77.1	99.0	99.0
15	17.000	37.0	47.6	61.1	61.1	84.2	108.1	138.8	138.8
16	17.000	37.0	47.6	61.1	61.1	84.2	108.1	138.8	138.8
17	14.500	32.9	42.2	54.2	54.2	84.2	108.1	138.8	138.8
18	14.500	32.9	42.2	54.2	54.2	84.2	108.1	138.8	138.8
19	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
20	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
21	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
22	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
23	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
24	15.500	34.5	44.2	56.8	56.8	81.1	104.2	133.8	133.8
25	15.500	34.5	44.2	56.8	56.8	81.1	104.2	133.8	133.8
26	15.500	34.5	44.2	56.8	56.8	81.1	104.2	133.8	133.8
27	15.500	34.5	44.2	56.8	56.8	81.1	104.2	133.8	133.8
28	15.750	30.6	39.3	50.4	50.4	74.9	96.2	123.5	123.5
29	15.750	30.6	39.3	50.4	50.4	74.9	96.2	123.5	123.5
30	15.750	30.6	39.3	50.4	50.4	74.9	96.2	123.5	123.5
31	15.750	30.6	39.3	50.4	50.4	74.9	96.2	123.5	123.5
32	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
33	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
34	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
35	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
36	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
37	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
38	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
39	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
40	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
41	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
42	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
43	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
44	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
45	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7

7. The location of the lower boundary used in the SASSI is:
   - Tunnel Segment 1: 710.1 feet below grade.
   - Tunnel Segment 2: 809 feet below grade.
   - Tunnel Segment 3: 784 feet below grade.

   While the tunnels are light structures with very little depth of influence, each of these depths is more than twice the depth of the base dimension as recommended by SRP 3.7.2.

8. A ten layer half-space is used in the SASSI analysis. The SASSI half-space simulation consists of an additional layers with viscous dashpots added at the base of the half-space. The halfspace layer has a thickness of 1.5 Vs/ f where Vs is the shear wave velocity of the half-space and f is the frequency of analysis and it is divided by the selected number of layers in the half-space. The SASSI manual recommends use of a ten layer half-space.

9. A description of critical locations in the various structures under seismic loading is provided below:

The ESWPT typically are designed to resist in-plane shear due to longitudinal lateral demand, out-of-plane flexure and shear in walls for transverse lateral demand, and vertical demand resulting in out-of-plane flexure and shear in the roof slab and at the slab wall intersections.

At tunnel segment 2, additional demand occurs as follows:

- At the intersections of the above ground missile protection shields where boundary and chord reinforcement will be provided in the walls and roof slab of the tunnel to resist the concentrated demands and distribute them to the rest of the structure.
- The above ground structures and unbalanced soil loading results in an overturning that is resisted in part by an extension of the base slab to activate more vertical soil load and the tunnel shape at the 90 degree turn. As a result in additional flexural demands are observed in the base slab and shear demands in the tunnel corner.

10. For the ESWPT analyses performed, the following benchmarking was performed to validate the results of the SASSI models:

The natural frequencies of the FE model used for the SSI interaction analysis performed in SASSI (coarse model) and a more refined FE model (ANSYS) used for the analysis of all static load cases (detailed model) are compared. For this analysis both models have all nodes at the intersection of mat slab and the walls fixed against translation. The meshing of the refined model has 12 elements across the width of each cell, 16 elements across the height and 48 elements across the length. The meshing of the coarse model has 6 elements across each tunnel cell and 8 elements across the height of the walls and 24 elements along the length. The comparisons showed that the frequencies of interest were captured with less than 3% difference.

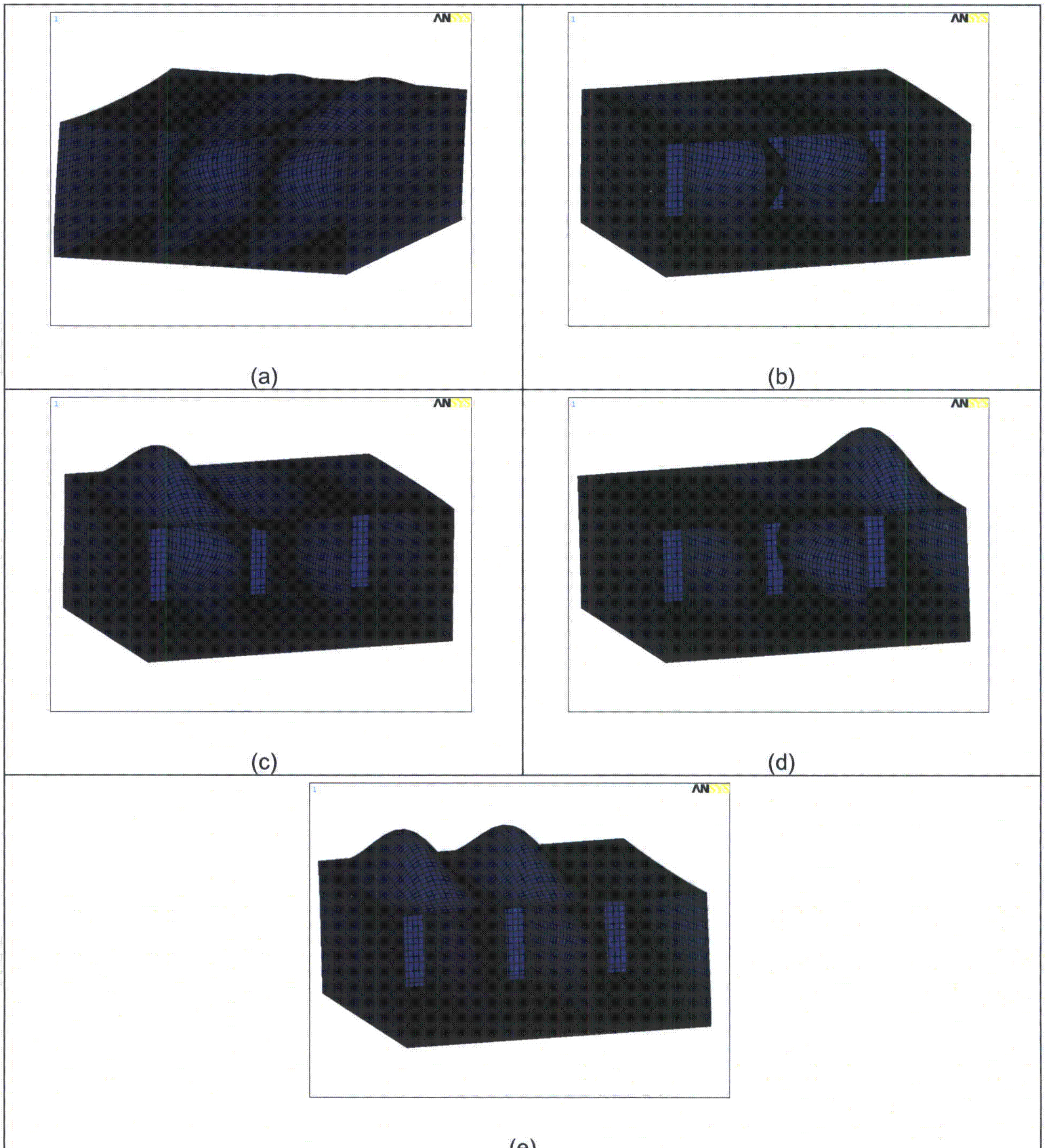
Transfer functions were examined for each analysis to verify that the interpolation was reasonable and that the expected structural responses were observed. Transfer functions, spectra, accelerations, and soil pressures were compared between the various soil profiles used in analyses to verify that the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

Appendix MM – PSFSV

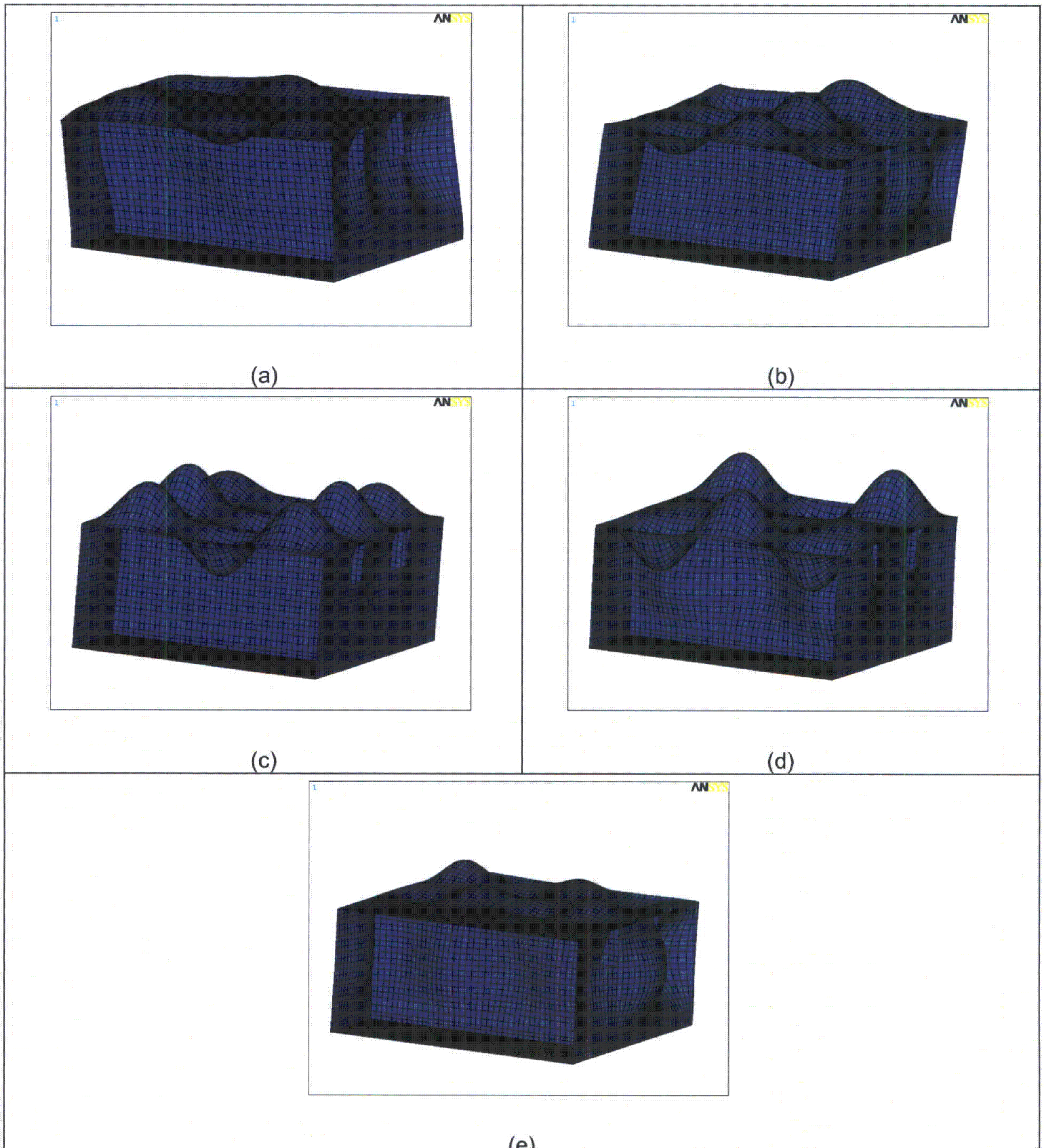
1. The analysis of the PSFSV produced 50 modes below 45 Hz. Table 15 below lists 5 major structural frequencies for each direction of motion selected and organized by highest mass participation. Figures showing the mode shapes of these frequencies follow after Table 15.

Table 15 Major Structural Modes of PSFSV			
Major East-West (X) Direction Modes			
Mode	Frequency (Hz)	Period (sec)	Effective Mass (kip sec^2/ft)
8	17.7	0.057	87.74
2	11.9	0.084	46.65
6	15.5	0.065	26.77
4	14.7	0.068	26.20
7	17.2	0.058	7.21
Major North-South (Y) Direction Modes			
Mode	Frequency (Hz)	Period (sec)	Effective Mass (kip sec^2/ft)
17	24.1	0.042	160.91
18	24.9	0.040	32.76
19	25.0	0.040	4.97
16	23.8	0.042	3.74
27	32.0	0.031	2.01
Major Vertical Modes			
Mode	Frequency (Hz)	Period (sec)	Effective Mass (kip sec^2/ft)
7	17.2	0.058	30.80
8	17.7	0.057	10.76
19	25.0	0.040	7.18
4	14.7	0.068	3.84
14	21.5	0.046	3.75

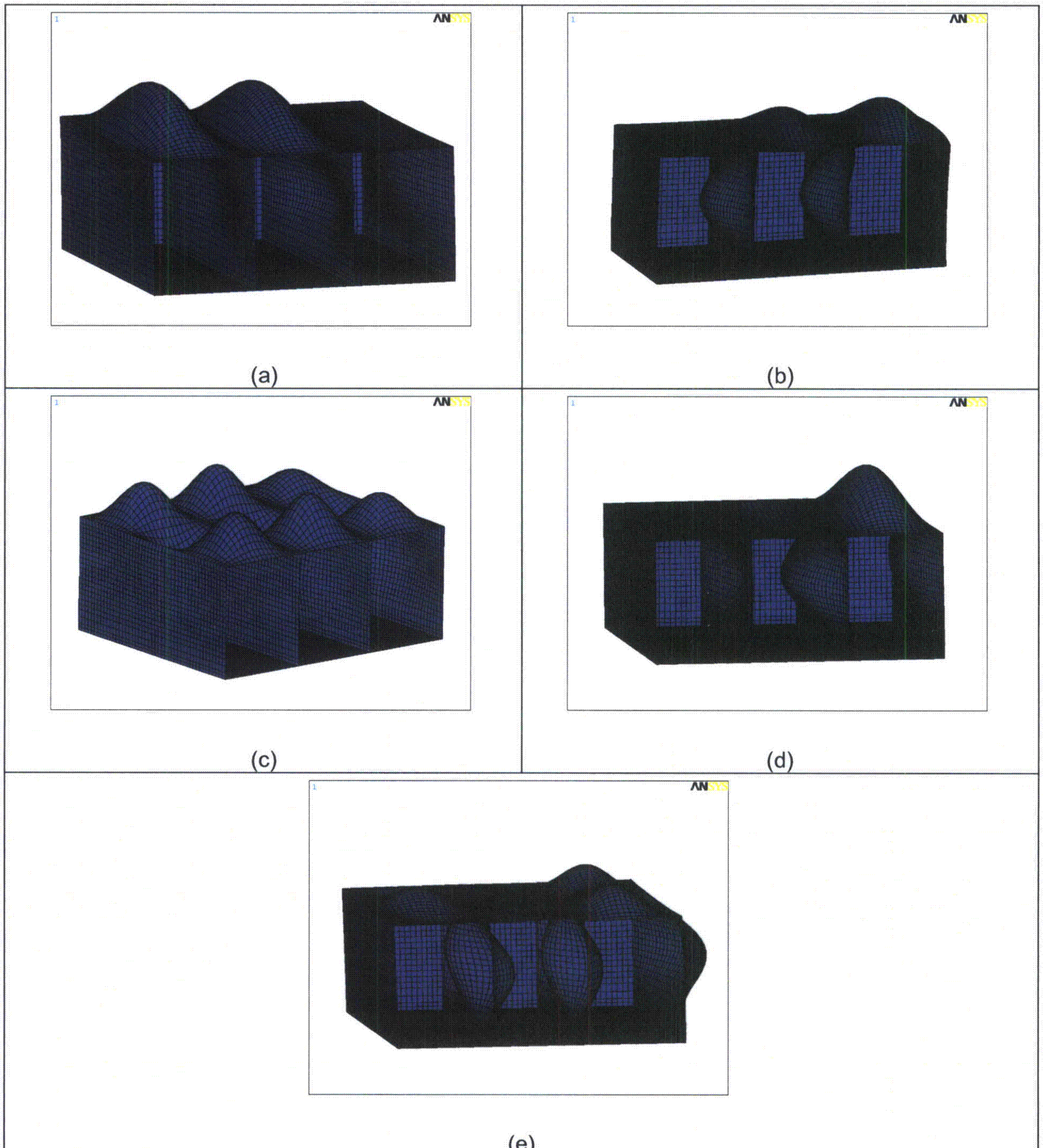
Note: Coordinates (X, Y, Z) given in the table are the local coordinates of the structure.



Major East-West Mode Shapes of PSFSV (a) Mode 8, f = 17.668 Hz, Modal Mass = 87.744 kip-sec^2/ft, (b) Mode 2, f = 11.861 Hz, Modal Mass = 46.6474 kip-sec^2/ft, (c) Mode 6, f = 15.459 Hz, Modal Mass = 26.7655 kip-sec^2/ft, (d) Mode 4, f = 14.71 Hz, Modal Mass = 26.1976 kip-sec^2/ft, (e) Mode 7, f = 17.237 Hz, Modal Mass = 7.20513 kip-sec^2/ft



Major North-South Mode Shapes of PSFSV (a) Mode 17, f = 24.056 Hz, Modal Mass = 160.91 kip-sec^2/ft, (b) Mode 18, f = 24.929 Hz, Modal Mass = 32.7644 kip-sec^2/ft, (c) Mode 19, f = 24.994 Hz, Modal Mass = 4.96764 kip-sec^2/ft, (d) Mode 16, f = 23.799 Hz, Modal Mass = 3.74051 kip-sec^2/ft, (e) Mode 27, f = 31.991 Hz, Modal Mass = 2.01327 kip-sec^2/ft



Major Vertical Mode Shapes of PSFSV (a) Mode 7, f = 17.237 Hz, Modal Mass = 30.7952 kip-sec^2/ft, (b) Mode 8, f = 17.668 Hz, Modal Mass = 10.7574 kip-sec^2/ft, (c) Mode 19, f = 24.994 Hz, Modal Mass = 7.17713 kip-sec^2/ft, (d) Mode 4, f = 14.71 Hz, Modal Mass = 3.83556 kip-sec^2/ft, (e) Mode 14, f = 21.549 Hz, Modal Mass = 3.75472 kip-sec^2/ft

2. The cutoff frequencies were:
   - Lower-bound, non-separated fill: 29.91 Hz
   - Lower-bound, separated fill: 29.91 Hz
   - Best-estimate, non-separated fill: 38.45 Hz
   - Best-estimate, separated fill: 38.45 Hz
   - Upper-bound, non-separated fill: 49.44 Hz
   - Upper-bound, separated fill: 49.44 Hz
   - High-bound, non-separated fill: 50.05 Hz
   - High-bound, separated fill: 50.05 Hz
   - Lower-bound, no fill: 50.05 Hz
   - Fixed-base: 50.05 Hz

3. The frequencies selected are listed in Table 16 below:

Table 16 Frequencies used in SASSI Analysis (Hz)

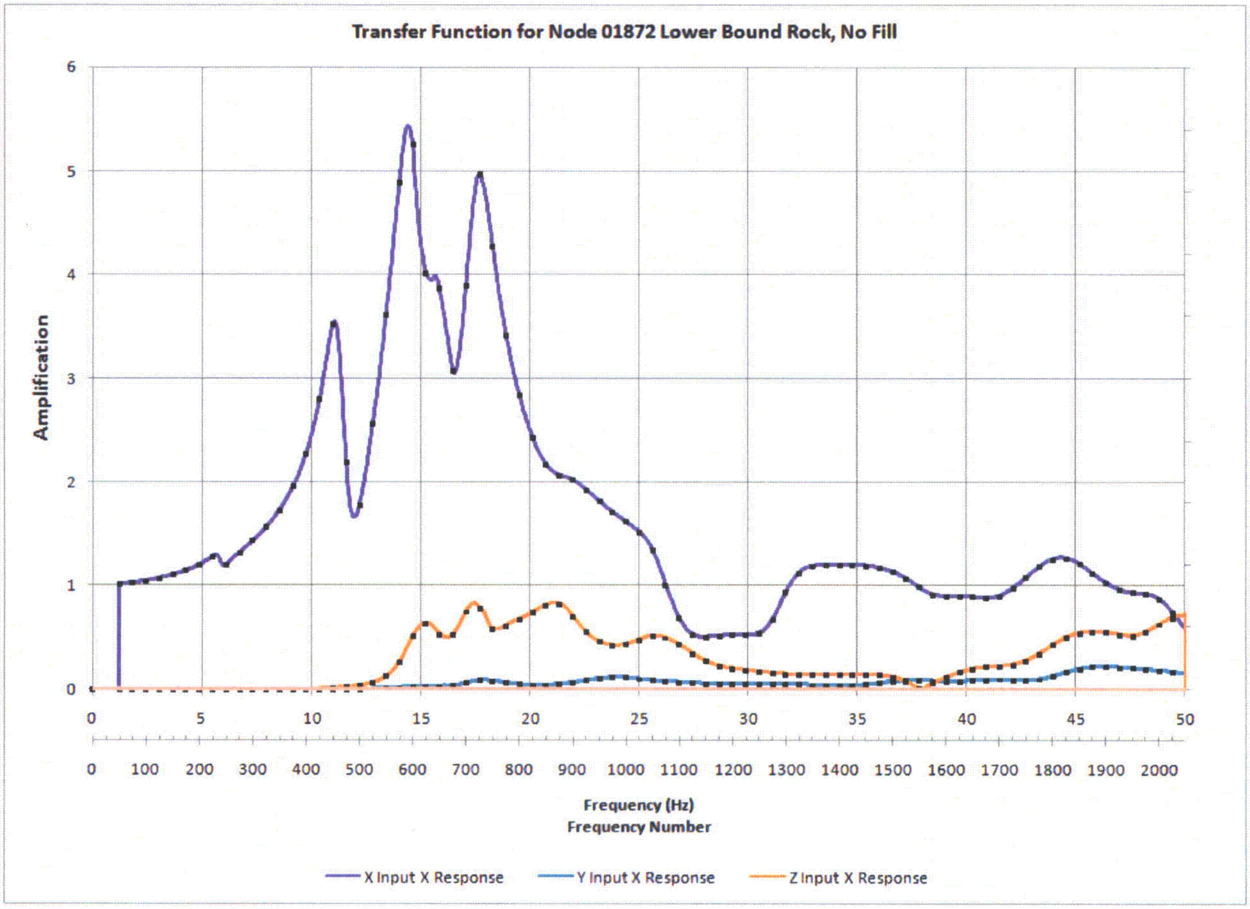
	Non-Separated Fill				Separated Fill					
	Lower Bound	Best Estimate	Upper Bound	High Bound	Lower Bound	Best Estimate	Upper Bound	High Bound	Fixed Base	Lower Bound No Fill
1	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22
2	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83
3	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44
4	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05
5	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66
6	4.27	4.27	4.27	4.27	4.27	4.27	4.27	4.27	4.27	4.27
7	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88
8	5.49	5.49	5.49	5.49	5.49	5.49	5.49	5.49	5.49	5.49
9	6.10	6.10	6.10	6.10	6.10	6.10	6.10	6.10	6.10	6.10
10	6.71	6.71	6.71	6.71	6.71	6.71	6.71	6.71	6.71	6.71
11	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32	7.32
12	7.94	7.94	7.94	7.94	7.94	7.94	7.94	7.94	7.94	7.94
13	8.55	8.55	8.55	8.55	8.55	8.55	8.55	8.55	8.55	8.55
14	9.16	9.16	9.16	9.16	9.16	9.16	9.16	9.16	9.16	9.16
15	9.77	9.77	9.77	9.77	9.77	9.77	9.77	9.77	9.77	9.77
16	10.38	10.38	10.38	10.38	10.38	10.38	10.38	10.38	10.38	10.38
17	10.99	10.99	10.99	10.99	10.99	10.99	10.99	10.99	10.99	10.99
18	11.60	11.60	11.60	11.60	11.60	11.60	11.60	11.60	11.60	11.60
19	12.21	12.21	12.21	12.21	12.21	12.21	12.21	12.21	12.21	12.21
20	12.82	12.82	12.82	12.82	12.82	12.82	12.82	12.82	12.82	12.82
21	13.43	13.43	13.43	13.43	13.43	13.43	13.43	13.43	13.43	13.43
22	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04	14.04
23	14.65	14.65	14.65	14.65	14.65	14.65	14.65	14.65	14.65	14.65

Table 16 Frequencies used in SASSI Analysis (Hz) (continued)

	Non-Separated Fill				Separated Fill				Fixed Base	Lower Bound No Fill
	Lower Bound	Best Estimate	Upper Bound	High Bound	Lower Bound	Best Estimate	Upper Bound	High Bound		
24	15.26	15.26	15.26	15.26	15.26	15.26	15.26	15.26	15.26	15.26
25	15.87	15.87	15.87	15.87	15.87	15.87	15.87	15.87	15.87	15.87
26	16.48	16.48	16.48	16.48	16.48	16.48	16.48	16.48	16.48	16.48
27	17.09	17.09	17.09	17.09	17.09	17.09	17.09	17.09	17.09	17.09
28	17.70	17.70	17.70	17.70	17.70	17.70	17.70	17.70	17.70	17.70
29	18.31	18.31	18.31	18.31	18.31	18.31	18.31	18.31	18.31	18.31
30	18.92	18.92	18.92	18.92	18.92	18.92	18.92	18.92	18.92	18.92
31	19.53	19.53	19.53	19.53	19.53	19.53	19.53	19.53	19.53	19.53
32	20.14	20.14	20.14	20.14	20.14	20.14	20.14	20.14	20.14	20.14
33	20.75	20.75	20.75	20.75	20.75	20.75	20.75	20.75	20.75	20.75
34	21.36	21.36	21.36	21.36	21.36	21.36	21.36	21.36	21.36	21.36
35	21.97	21.97	21.97	21.97	21.97	21.97	21.97	21.97	21.97	21.97
36	22.58	22.58	22.58	22.58	22.58	22.58	22.58	22.58	22.58	22.58
37	23.19	23.19	23.19	23.19	23.19	23.19	23.19	23.19	23.19	23.19
38	23.80	23.80	23.80	23.80	23.80	23.80	23.80	23.80	23.80	23.80
39	24.41	24.41	24.41	24.41	24.41	24.41	24.41	24.41	24.41	24.41
40	25.02	25.02	25.02	25.02	25.02	25.02	25.02	25.02	25.02	25.02
41	25.63	25.63	25.63	25.63	25.63	25.63	25.63	25.63	25.63	25.63
42	26.25	26.25	26.25	26.25	26.25	26.25	26.25	26.25	26.25	26.25
43	26.86	26.86	26.86	26.86	26.86	26.86	26.86	26.86	26.86	26.86
44	27.47	27.47	27.47	27.47	27.47	27.47	27.47	27.47	27.47	27.47
45	28.08	28.08	28.08	28.08	28.08	28.08	28.08	28.08	28.08	28.08
46	28.69	28.69	28.69	28.69	28.69	28.69	28.69	28.69	28.69	28.69
47	29.30	29.30	29.30	29.30	29.30	29.30	29.30	29.30	29.30	29.30
48	29.91	29.91	29.91	29.91	29.91	29.91	29.91	29.91	29.91	29.91
49		30.52	30.52	30.52		30.52	30.52	30.52	30.52	30.52
50		31.13	31.13	31.13		31.13	31.13	31.13	31.13	31.13
51		31.74	31.74	31.74		31.74	31.74	31.74	31.74	31.74
52		32.35	32.35	32.35		32.35	32.35	32.35	32.35	32.35
53		32.96	32.96	32.96		32.96	32.96	32.96	32.96	32.96
54		33.57	33.57	33.57		33.57	33.57	33.57	33.57	33.57
55		34.18	34.18	34.18		34.18	34.18	34.18	34.18	34.18
56		34.79	34.79	34.79		34.79	34.79	34.79	34.79	34.79
57		35.40	35.40	35.40		35.40	35.40	35.40	35.40	35.40
58		36.01	36.01	36.01		36.01	36.01	36.01	36.01	36.01
59		36.62	36.62	36.62		36.62	36.62	36.62	36.62	36.62
60		37.23	37.23	37.23		37.23	37.23	37.23	37.23	37.23
61		37.84	37.84	37.84		37.84	37.84	37.84	37.84	37.84

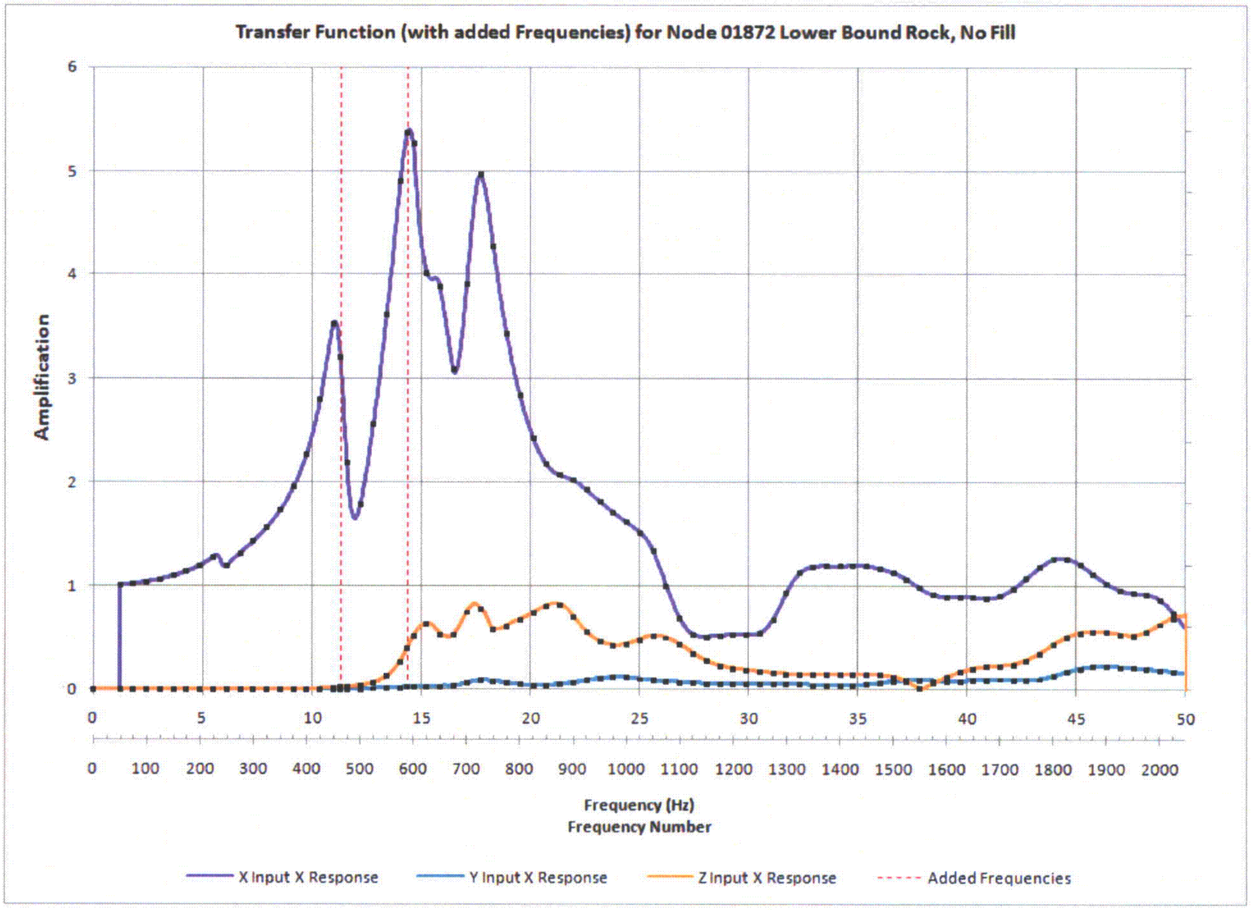
Table 16 Frequencies used in SASSI Analysis (Hz) (continued)										
	Non-Separated Fill				Separated Fill					Lower
	Lower Bound	Best Estimate	Upper Bound	High Bound	Lower Bound	Best Estimate	Upper Bound	High Bound	Fixed Base	Bound No Fill
62		38.45	38.45	38.45		38.45	38.45	38.45	38.45	38.45
63			39.06	39.06			39.06	39.06	39.06	39.06
64			39.67	39.67			39.67	39.67	39.67	39.67
65			40.28	40.28			40.28	40.28	40.28	40.28
66			40.89	40.89			40.89	40.89	40.89	40.89
67			41.50	41.50			41.50	41.50	41.50	41.50
68			42.11	42.11			42.11	42.11	42.11	42.11
69			42.72	42.72			42.72	42.72	42.72	42.72
70			43.33	43.33			43.33	43.33	43.33	43.33
71			43.95	43.95			43.95	43.95	43.95	43.95
72			44.56	44.56			44.56	44.56	44.56	44.56
73			45.17	45.17			45.17	45.17	45.17	45.17
74			45.78	45.78			45.78	45.78	45.78	45.78
75			46.39	46.39			46.39	46.39	46.39	46.39
76			47.00	47.00			47.00	47.00	47.00	47.00
77			47.61	47.61			47.61	47.61	47.61	47.61
78			48.22	48.22			48.22	48.22	48.22	48.22
79			48.83	48.83			48.83	48.83	48.83	48.83
80			49.44	49.44			49.44	49.44	49.44	49.44
81				50.05				50.05	50.05	50.05

4. The SASSI analysis frequencies were selected to cover the range between around 1 Hz and the cutoff frequency. This frequency range includes the SSI frequency and primary structural frequencies. The 1Hz lower limit was shown to be low enough to be outside the range of SSI or structural mode amplification. Initially, the frequencies are selected evenly spaced. Frequencies were added as needed to produce smooth interpolation of the transfer functions and accurately capture peaks. As verification, additional frequencies were added to observe that the results did not change. See Figure 13 and Figure 14 for an example of adding frequencies to verify the transfer function response.



Note 1: Vertical lines at end of transfer functions and data point at origin represent blanks in EXCEL data and do not represent SASSI data.

Figure 13 X-Response Transfer Function for Node 01872 Lower Bound Rock, No Fill



Note 1: Vertical dashed lines show major structural frequencies calculated in the ANSYS design model and vertical dotted lines show the soil frequency.

Note 2: Vertical lines at end of transfer functions and data point at origin represent blanks in EXCEL data and do not represent SASSI data.

Figure 14 X-Response Transfer Function for Node 01872 Lower Bound Rock, No Fill, with Additional Frequencies

5. The response of the PSFSV is significantly influenced by the presence of soil on the side, shifting the frequencies. The analysis was verified by comparing the soil case with no side soil analyzed in SASSI to the structural frequencies calculated by the ANSYS design model. Figures demonstrating this response are provided in Figure 15, Figure 16, and Figure 17 below. Transfer functions and spectra of the results were then examined to observe the change in response with addition of and variation in side soil to ensure that the same major responses were observed and changed appropriately.

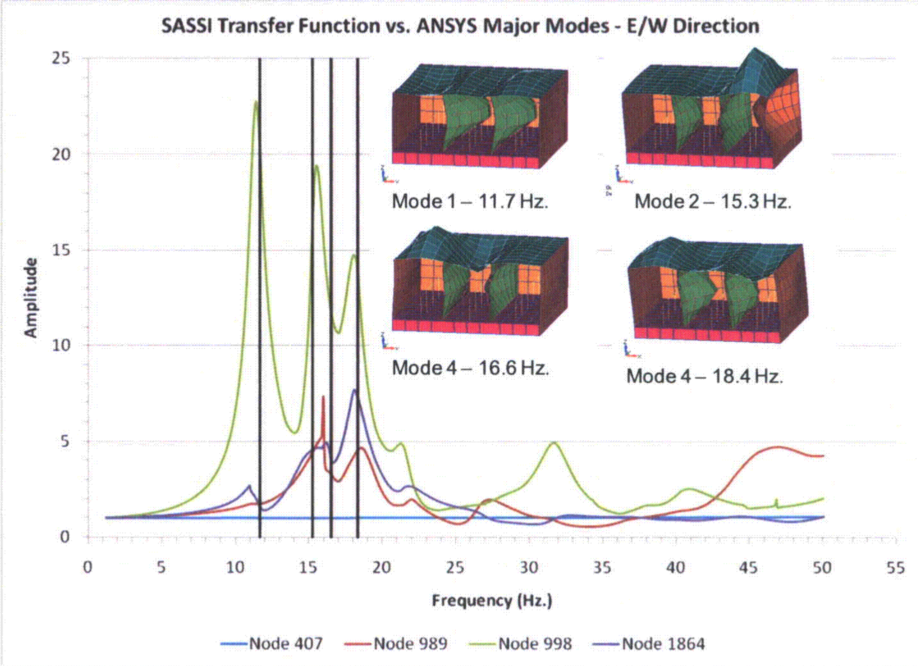


Figure 15 - Verification of East-West Modes PSFSV

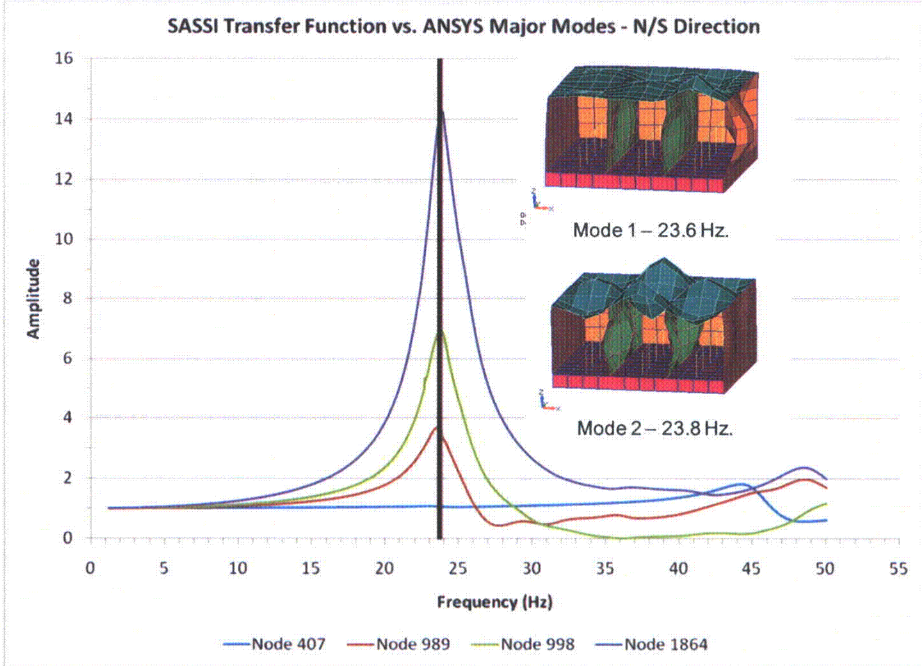


Figure 16 - Verification of North-South Modes PSFSV

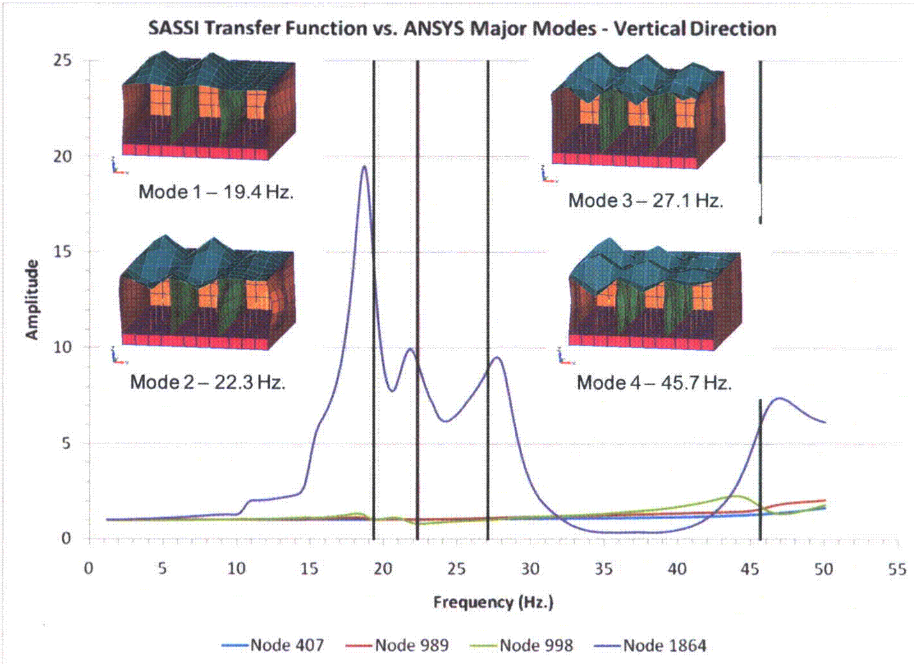


Figure 17 - Verification of Vertical Modes PSFSV

6. The soil layer thicknesses used in the SASSI analyses, and a demonstration that the layer thicknesses comply with the maximum layer thicknesses given by the "1/5 wavelength" guideline is shown in Table 17 and Table 18 below:

Table 17 SASSI Subsurface Properties

Layer	Thickness (ft)	Unit Weight (ksf)	Shear Wave Velocity (ft/s)				Compression Wave Velocity (ft/s)				Damping Ratio			
			Lower Bound	Best Estimate	Upper Bound	High Bound	Lower Bound	Best Estimate	Upper Bound	High Bound	Lower Bound	Best Estimate	Upper Bound	High Bound
1	6.625	0.125	508.9	686.8	917.1	1071.4	1059.3	1429.7	1909.1	2230.2	0.0396	0.0308	0.0238	0.0205
2	5.625	0.125	475.7	689.9	957.5	1142.1	990.3	1436.1	1993.2	2377.4	0.0750	0.0517	0.0369	0.0299
3	7.083	0.125	402.8	633.0	912.4	1100.2	838.5	1317.7	1899.3	2290.1	0.1126	0.0706	0.0478	0.0380
4	7.083	0.125	584.5	851.3	1172.3	1387.4	1216.7	1772.2	2440.2	2888.1	0.0698	0.0452	0.0325	0.0269
5	7.083	0.125	595.5	863.0	1193.7	1413.9	1239.6	1796.4	2484.9	2943.3	0.0730	0.0477	0.0337	0.0280
6	6.500	0.125	578.6	845.1	1181.7	1402.2	1204.3	1759.3	2460.0	2918.9	0.0798	0.0518	0.0365	0.0298
7	16.250	0.155	4425.7	5683.0	7297.4	7297.8	8786.2	11282.3	14487.3	14488.1	0.0260	0.0180	0.0130	0.0130
8	16.250	0.155	4427.5	5685.0	7299.7	7299.7	8789.7	11286.1	14491.7	14491.7	0.0260	0.0180	0.0130	0.0130
9	16.250	0.155	4427.5	5685.0	7299.7	7299.7	8789.7	11286.1	14491.7	14491.7	0.0260	0.0180	0.0130	0.0130
10	16.250	0.155	4427.5	5685.0	7299.7	7299.7	8789.7	11286.1	14491.7	14491.7	0.0260	0.0180	0.0130	0.0130
11	3.000	0.135	2351.6	3019.5	3877.1	3877.1	6331.4	8129.7	10438.8	10438.8	0.0280	0.0200	0.0140	0.0140
12	24.000	0.155	3849.5	4942.9	6346.7	6346.7	8230.7	10568.4	13570.1	13570.1	0.0260	0.0180	0.0130	0.0130
13	34.000	0.155	5358.0	6879.9	8834.0	8834.0	10210.7	13110.9	16834.8	16834.8	0.0260	0.0180	0.0130	0.0130
14	17.000	0.150	3148.0	4042.1	5190.1	5190.1	7155.4	9187.8	11797.2	11797.2	0.0260	0.0180	0.0130	0.0130
15	17.000	0.150	3147.9	4042.0	5190.0	5190.0	7155.3	9187.6	11797.0	11797.0	0.0260	0.0180	0.0130	0.0130
16	14.500	0.130	2383.9	3061.0	3930.5	3930.5	6103.8	7837.4	10063.4	10063.4	0.0280	0.0200	0.0140	0.0140
17	14.500	0.130	2383.9	3061.0	3930.4	3930.4	6103.7	7837.3	10063.3	10063.3	0.0280	0.0200	0.0140	0.0140
18	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
19	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
20	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
21	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
22	16.000	0.135	2562.3	3290.0	4224.4	4224.4	5824.2	7478.3	9602.2	9602.2	0.0280	0.0200	0.0140	0.0140
23	15.500	0.140	2670.5	3429.0	4402.9	4402.9	6288.7	8074.8	10368.2	10368.2	0.0280	0.0200	0.0140	0.0140
24	15.500	0.140	2670.5	3429.0	4402.9	4402.9	6288.7	8074.9	10368.3	10368.3	0.0280	0.0200	0.0140	0.0140
25	15.500	0.140	2670.5	3429.0	4402.9	4402.9	6288.7	8074.9	10368.3	10368.3	0.0280	0.0200	0.0140	0.0140
26	15.500	0.140	2670.5	3429.0	4402.9	4402.9	6288.7	8074.9	10368.3	10368.3	0.0280	0.0200	0.0140	0.0140
27	15.750	0.145	2408.1	3092.0	3970.2	3970.2	5898.6	7573.9	9725.0	9725.0	0.0280	0.0200	0.0140	0.0140
28	15.750	0.145	2408.1	3092.0	3970.2	3970.2	5898.6	7573.8	9725.0	9725.0	0.0280	0.0200	0.0140	0.0140
29	15.750	0.145	2408.1	3092.0	3970.2	3970.2	5898.6	7573.8	9725.0	9725.0	0.0280	0.0200	0.0140	0.0140
30	15.750	0.145	2408.1	3092.0	3970.2	3970.2	5898.6	7573.8	9725.0	9725.0	0.0280	0.0200	0.0140	0.0140
31	25.000	0.150	4319.2	5546.0	7121.1	7121.1	8395.0	10779.4	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
32	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
33	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
34	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
35	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
36	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
37	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
38	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
39	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
40	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
41	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
42	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
43	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
44	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130
45	25.000	0.150	4319.2	5546.0	7121.2	7121.2	8395.0	10779.5	13841.1	13841.1	0.0260	0.0180	0.0130	0.0130

Table 18 Passing Frequency for 5 Points per Wavelength

Layer	Thickness (ft)	Shear Wave Frequncy (Hz) Lower Bound	Best Estimate	Upper Bound	High Bound	Compression Wave Frequency (Hz) Lower Bound	Best Estimate	Upper Bound	High Bound
1	6.625	15.4	20.7	27.7	32.3	32.0	43.2	57.6	67.3
2	5.625	16.9	24.5	34.0	40.6	35.2	51.1	70.9	84.5
3	7.083	11.4	17.9	25.8	31.1	23.7	37.2	53.6	64.7
4	7.083	16.5	24.0	33.1	39.2	34.4	50.0	68.9	81.6
5	7.083	16.8	24.4	33.7	39.9	35.0	50.7	70.2	83.1
6	6.500	17.8	26.0	36.4	43.1	37.1	54.1	75.7	89.8
7	16.250	54.5	69.9	89.8	89.8	108.1	138.9	178.3	178.3
8	16.250	54.5	70.0	89.8	89.8	108.2	138.9	178.4	178.4
9	16.250	54.5	70.0	89.8	89.8	108.2	138.9	178.4	178.4
10	16.250	54.5	70.0	89.8	89.8	108.2	138.9	178.4	178.4
11	3.000	156.8	201.3	258.5	258.5	422.1	542.0	695.9	695.9
12	24.000	32.1	41.2	52.9	52.9	68.6	88.1	113.1	113.1
13	34.000	31.5	40.5	52.0	52.0	60.1	77.1	99.0	99.0
14	17.000	37.0	47.6	61.1	61.1	84.2	108.1	138.8	138.8
15	17.000	37.0	47.6	61.1	61.1	84.2	108.1	138.8	138.8
16	14.500	32.9	42.2	54.2	54.2	84.2	108.1	138.8	138.8
17	14.500	32.9	42.2	54.2	54.2	84.2	108.1	138.8	138.8
18	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
19	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
20	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
21	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
22	16.000	32.0	41.1	52.8	52.8	72.8	93.5	120.0	120.0
23	15.500	34.5	44.2	56.8	56.8	81.1	104.2	133.8	133.8
24	15.500	34.5	44.2	56.8	56.8	81.1	104.2	133.8	133.8
25	15.500	34.5	44.2	56.8	56.8	81.1	104.2	133.8	133.8
26	15.500	34.5	44.2	56.8	56.8	81.1	104.2	133.8	133.8
27	15.750	30.6	39.3	50.4	50.4	74.9	96.2	123.5	123.5
28	15.750	30.6	39.3	50.4	50.4	74.9	96.2	123.5	123.5
29	15.750	30.6	39.3	50.4	50.4	74.9	96.2	123.5	123.5
30	15.750	30.6	39.3	50.4	50.4	74.9	96.2	123.5	123.5
31	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
32	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
33	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
34	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
35	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
36	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
37	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
38	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
39	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
40	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
41	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
42	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
43	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
44	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7
45	25.000	34.6	44.4	57.0	57.0	67.2	86.2	110.7	110.7

7. The location of the lower boundary used in the SASSI is around 809 feet below grade. This depth is more than twice the depth of the base dimension (87' x2 = 174') recommended by SRP 3.7.2.

8. A ten layer half-space is used in the SASSI analysis. The SASSI half-space simulation consists of an additional layers with viscous dashpots added at the base of the half-space. The half-space layer has a thickness of 1.5 Vs/ f where Vs is the shear wave velocity of the half-space and f is the frequency of analysis and it is divided by the selected number of layers in the half-space. The SASSI manual recommends use of a ten layer half-space.

9. A description of critical locations in the various structures under seismic loading is provided below:

   The PSFSV is a simple shear wall structure with nearly unbroken walls on all sides plus two interior shear walls. The walls must resist the out of plane flexure and shear due to transverse accelerations, soil pressures (for exterior walls) and flexure imparted on the wall from flexure in the roof slab. The roof slab resists vertical demands as a continuous three span plate although there is some two way response. Critical locations are therefore centers and edges of roof slabs and walls for flexure and bottom of walls for in-plane shear.

10. For the PSFSV analyses performed, the following benchmarking was performed to validate the results of the SASSI models:

    Comparison of the model with the mesh used for SASSI analyses was compared with the more refined design model. This comparison was performed by calculating eigenvalues and mode shapes for the models with each mesh and comparing the results. The comparisons showed that the two models provided similar dynamic responses.

    Comparison of the SASSI dynamic response to the ANSYS model response was performed. Fixed base eigenvalue analysis was performed in ANSYS. A corresponding fixed base analysis was performed in SASSI by placing the structure at the soil surface and setting the stiffness of the soil layers to high values to represent the fixed base condition. The fixed base ANSYS eigenvalues were then compared to the transfer functions of the SASSI "fixed base" case to verify that the SASSI model was exhibiting the same dynamic response.

    Transfer functions were 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 were compared between the various soil profiles used in analyses to verify that the responses were reasonably similar between these cases except for the expected trends due to soil frequency changes. .

Appendix NN – PCCV, CIS and R/B on Common Basemat

1. Appendix 3H of the US-APWR (Revision 1) provides the description of the Reactor Building (R/B) complex structures that include the Reactor Building (R/B), the Prestressed Concrete Containment Vessel (PCCV), and containment internal structure (CIS). DCD Tables 3.H.3-1, 3.H.3-2 and 3.H.3-3 present the results for natural frequencies obtained from the fixed base modal analyses of the ANSYS lumped mass stick models of the R/B, PCCV and CIS respectively.

2. A cut-off frequency of 50 Hz was used for all of the site-specific SASSI analyses of the R/B, PCCV and CIS that are documented in Calculation SSI-12-05-100-003.

3. Table 5 of Calculation SSI-12-05-100-003 list the frequency of analyses of the SASSI analyses for each of the six (6) site conditions considered, three (3) cases of surface foundation (SLB, SBE and SUB) and four (4) cases of embedded foundation (ELB, EBE, EUB and EHB).

4. Calculation 4DS-CP34-20080048 Rev.1 documents the development and validation of the SASSI model used for site-specific SSI analyses of the R/B complex. A set of SASSI analyses was performed within the scope of this calculation of the R/B complex model to validate the translation of the SASSI model. The initial set of frequencies of analyses used for production runs presented in Calculation SSI-12-05-100-003 was determined based on the transfer function results from the "hard rock" validation SASSI runs. Additional frequencies of analyses

were added as needed to obtain acceptable results for the interpolated transfer functions at the representative lumped mass locations.

5. Figures 45 through 56 of Calculation 4DS-CP34-20080048 Rev.1 present the transfer function results of the "hard rock" SASSI analyses. Appendices A, B and C of Calculation SSI-12-05-100-003 present the transfer function results for response at representative lumped mass locations of the PCCV, CIS and R/B structure, respectively, that were obtained from the SASSI analyses of the 7 site conditions considered. The figures provide graphs of the interpolated transfer functions together with the calculated transfer function amplitudes at the selected frequency analyses.

6. Table 1 in Calculation SSI-12-05-100-003 lists the layering and the dynamic properties of the subgrade that were directly used as input for the analyses of surface foundations. These site profiles are identical to those used for the analyses of the site-specific buildings UHSRS, ESWPT and PSFSV. Table 3 in Calculation SSI-12-05-100-003 presents the layering and dynamic properties of the site profiles used for the analyses of embedded foundation that were developed using the methodology described in Section 6.2 of this calculation. The frequencies of the shear waves passing through 5 points per wavelength are listed in the table in Section 7.1 of Calculation SSI-12-05-100-003 and together with the shear waves are reproduced in the table below :

Elevation (ft)	Layer Thickness (ft)	S-Wave Velocity (fps)				S-Wave Max. Frequency (Hz)			
		ELB	EBE	EUB	EHB	ELB	EBE	EUB	EHB
822	8.89	505	691	930	1091	11.4	15.5	20.9	24.5
813	8.88	428	653	929	1116	9.6	14.7	20.9	25.1
804	8.89	535	799	1114	1324	12.0	18.0	25.1	29.8
795	13.34	587	854	1188	1408	8.8	12.8	17.8	21.1
782	16.25	4427	5685	7300	7300	54.5	70.0	89.8	89.8

7. The location of the lower boundary used in the SASSI analysis is 504 feet below the foundation bottom elevation. This is approximately 1.75 times the effective diameter of the building (288 ft.) which is deemed sufficient to represent the effects of the subgrade on the seismic response of the building.

8. A ten layer half-space is used in the SASSI analysis which is deemed appropriate to model half-space boundaries.

9. As documented in Chapter 3 of the US-APWR, the seismic demands used for the standard design of the R/B complex structural members are obtained from the SSI analysis of generic site profiles using input design motion compatible to the CSDRS specified in Section 3.7.1 of the DCD. The 5% in-structure response spectra at the lumped mass locations for the R/B complex standard design are documented in Appendix 3I of the US-APWR. The comparison between Appendix D of Calculation SSI-12-05-100-003 of the DCD ISRS and the corresponding 5% damping acceleration response spectra obtained from the site-specific SSI analyses demonstrates that the standard design envelopes the site-specific seismic demands by a large margin of safety.

10. Calculation 4DS-CP34-20080048 Rev.1 documents the development and validation of the SASSI model used for site-specific SSI analyses of the R/B complex. The structural model

used for the SASSI analyses consists of three lumped-mass-stick models of the PCCV, CIS and R/B representing the stiffness and mass inertia properties of the building above the ground elevation and a 3-D Finite Element (FE) model represents the building basement and the floor slabs at ground elevation. The lumped mass stick models used for the SSI analyses for the standard design SSI analyses described in Subsection 3.7.2 of the DCD are translated into SASSI and combined together with the FE model of the basement. A set of SASSI analyses was performed of the R/B complex structural model resting on the surface of a "hard rock" half space with high stiffness with the intent of simulating fixed base conditions. The acceleration time histories documented in Subsection 3.7.1 of the DCD were input to the model at the foundation-subgrade interface. The results of these SASSI analyses were compared with the results of the ANSYS fixed base modal and direct integration time history analyses to validate the SASSI model. In Figures 45 through 56 of Calculation 4DS-CP34-20080048 Rev.1 the transfer function results of the "hard rock" SASSI analyses are compared to the results of the ANSYS modal analysis. The figures show that the peaks of the transfer functions occur at frequencies that are very close to the frequencies of the predominant modes calculated by the modal analysis. The comparison of the results for 5% damping ARS at selected locations that are presented in Figures 21 through 28 in Calculation 4DS-CP34-20080048 Rev.1 demonstrates that the response obtained from the SASSI match well the response calculated from the ANSYS direct integration time history analyses. Section 7.5 of Calculation 4DS-CP34-20080048 Rev.1 provides a detailed description of the validation of the SASSI model for the R/B complex structures.

Impact on R-COLA

For appendix 3KK, 3LL, 3MM and 3NN, the FSAR has been revised to contain the following:

- The description of number of modes, number of convective modes and the table of major structural modes,
- A list of the cutoff frequencies,
- The number of frequencies analyzed in SASSI along with a basis for the selection,
- A description of the checking performed to verify that the frequencies selected were appropriate,
- A discussion of the maximum and minimum layer thicknesses and the minimum 1/5 wavelength passing frequency for each soil case,
- A discussion of the soil depth and lower boundary condition, and
- A description of the validation analyses performed to validate the models and results.

See attached marked-up FSAR Draft Revision 1 pages 3KK-1, 3KK-2, 3KK-3, 3KK-7, 3KK-8, 3KK-18, 3LL-1, 3LL-2, 3LL-3, 3LL-4, 3LL-21, 3MM-1, 3MM-2, 3MM-3, 3MM-4, and 3MM-15.

Impact on S-COLA

None.

Impact on DCD

None.

Attachments

SASSI Model of US-APWR Reactor Building, 4DS-CP34-20080048 Rev.1, Mitsubishi Heavy Industries, LTD, September 17, 2008 (Attachment 3 to this letter)

Site Specific SSI Analysis of US-APWR Reactor Building, SSI-12-05-100-003 Rev. C, URS, November 13, 2009 (Attachment 4 to this letter)

3KK MODEL PROPERTIES AND SEISMIC ANALYSIS RESULTS FOR UHSRS

3KK.1 Introduction

This Appendix discusses the seismic analysis of the ultimate heat sink related structures (UHSRSs), including the ultimate heat sink (UHS) Basin and its pump house. The computer program SASSI (Reference 3KK-1) serves as the platform for the soil-structure interaction (SSI) analyses. The three-dimensional (3D) finite element (FE) models of the UHSRS used in the SASSI analysis are generated from FE models with finer mesh patterns initially developed using the ANSYS computer program (Reference 3KK-2). The coarser mesh ~~SA~~SSI model is confirmed by comparing the structural frequencies between the ~~SA~~SSI model mesh and the fine mesh design model. The structural frequencies are calculated from modal analysis performed in ANSYS, and the similar results ensure compatibility between the two models and indicate that the ~~SA~~SSI model is acceptable. RCOL2_03.07.02-16 RCOL2_03.07.02-16

Dynamic analysis is performed in SASSI to obtain seismic responses including in-structure response spectra (ISRS), maximum accelerations, and dynamic soil pressures of the structure that includes SSI effects. Response spectra analyses are performed in ANSYS to obtain seismic ~~design~~ demands used for design (Table 3KK-8 summarizes the analyses performed for calculating seismic demands). The SASSI analyses results for ~~maximum accelerations~~ISRS at the base slab and seismic soil pressures are used to verify the load demands assigned to the ANSYS structural design analysis that are included in the load combinations in accordance with the requirements of Section 3.8. The SASSI analysis ~~and results presented in this Appendix~~ include site-specific features such as the layering of the subgrade, embedment of the UHSRS, flexibility of the basemat and seismic motion scattering. 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 UHSRS. RCOL2_03.07.02-16 RCOL2_03.07.02-16

3KK.2 Model Description and Analysis Approach

The SASSI FE structural model for the UHSRS is shown in Figures 3KK-1. Table 3KK-1 presents the structural element material properties for the SASSI FE model. Detailed descriptions of the UHSRS are contained in Subsection 3.8.4. Figures 3.8-206 through 3.8-211 show detailed dimensions and layout of the UHSRS.

The UHSRS model is developed and analyzed using methods and approaches consistent with ASCE 4 (Reference 3KK-3), and accounting for the site-specific stratigraphy and subgrade conditions described in Chapter 2, as well as the backfill conditions around the embedded UHSRS. The four UHSRS (per unit) are nearly ~~symmetric~~identical with minor variations on backfill layout for the east and west walls. The essential service water pipe tunnel (ESWPT) is present along the RCOL2_03.07.02-16 full length on the south side of the UHSRS. Backfill is present on the north and west sides of UHSRS B and D, and on the north and east sides of UHSRS A and C. ~~Due to symmetry, s~~Soil-structure interaction (SSI) analysis is performed only on UHSRS B/D, and the responses are deemed applicable to the other UHSRS. RCOL2_03.07.02-16

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 UHSRS 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. To account for uncertainty in the site-specific properties, three profiles of subgrade properties are considered, including best estimate (BE), lower bound (LB), and upper bound (UB). For backfill, an additional high bound (HB) profile is also used together with the UB subgrade profile to account for expected uncertainty in the backfill properties.

The following SSI analyses and site profiles are used for calculating seismic responses of UHSRS:

- a surface foundation condition (without the presence of backfill) <u>with the lower bound in-situ soil properties below the base slab (</u>~~for the~~ lower bound case<u>)</u> RCOL2_03.07.02-16

- an embedded foundation without separation of the backfill from the UHSRS exterior walls for the best estimate case

- an embedded foundation with separation of the backfill from the UHSRS exterior walls for all four soil cases, namely; LB, BE, UB, and HB

The backfill separation is modeled by reducing the shear wave velocity by a factor of 10 for the soil elements adjacent to the structure that are determined to be separated. The potential for separation of backfill is determined ~~using an iterative approach that compares~~<u>by comparing</u> the peak envelope soil pressure results for the best estimate (BE) case 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. RCOL2_03.07.02-16

<u>The maximum shear wave passing frequency for all layers below the base slab and concrete fill based on layer thicknesses of 1/5 wavelength, ranges from 30.6 Hz for LB to 50.4 Hz for HB. The passing frequency for the backfill ranges from 14.7 Hz for the LB to 37.2 Hz for the HB.</u> RCOL2_03.07.02-16

<u>The lower boundary used in the SASSI analysis is 759 feet below grade. This depth is more than twice the size of foundation plus embedment (131' x 2 + 47' =</u>

309') recommended by SRP 3.7.2. A ten layer half-space is used below the lower boundary is the SASSI analysis consistent with SASSI manual recommendations. The SASSI half-space simulation consists of additional layers with viscous dashpots added at the base of the half-space. The half-space layer has a thickness of 1.5 Vs/ f where Vs is the shear wave velocity of the half-space and f is the frequency of the analysis and it is divided by the selected number of layers in the half-space. RCOL2_03.07.02-16

The cutoff frequencies for all cases are greater than 37 Hz and a minimum of 57 frequencies are analyzed for SSI analyses. The SASSI analysis frequencies are selected to cover the range between 1 Hz and the cutoff frequency. This frequency range includes the SSI frequency and primary structural frequencies. The 1 Hz lower limit was shown to be low enough to be outside the range of SSI or structural mode amplification. It was 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.

The UHSRS analyses were verified by the following methods:

- Comparison of eigenvalue analysis results between a coarser mesh (used for SASSI SSI analyses) and a finer mesh (used for ANSYS design analyses), the results are presented in Table 3KK-8.

- Review of SASSI transfer functions to verify that interpolation was reasonable and that expected structural responses were observed. All SASSI output results were compares between soil profiles to verify reasonably similar responses between the cases.

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 3KK-4) for structures on sites with low seismic responses where the analyses consider a relatively narrow range of site-specific subgrade conditions. The SASSI analyses produce results including peak accelerations, in-structure response spectra, and seismic soil pressures. All results from SSI analyses represent the envelope of the six soil conditions. The SASSI analyses results are used to produce the final response spectra and provide confirmation of the design spectra and seismic soil pressures used in ANSYS. RCOL2_03.07.02-11

Shell elements are used to model the basemat and brick elements are used for the concrete fill that is present beneath basemat. Beam elements are used for the concrete beams, that support slabs and equipment in the structure, and for the concrete columns in the cooling towers. Beam elements are also used to model the steel members in the UHSRS. Shell elements are used for the reinforced concrete walls and elevated slabs. Walls are modeled using gross section properties at the centerline. All roof slabs and elevated slabs (pump room, fan slab, missile shield protection) are considered as cracked with an out-of-plane

The dynamic horizontal soil pressure of the backfill on the basin walls varied depending on the soil case considered as the soil frequency approached that of the wall. The peak soil pressures varied along the height of the wall from values of approximately 0.5 ksf to almost 2ksf. The dynamic horizontal soil pressure used for design varied linearly from a value of 0.50ksf at the base slab to 1.5ksf at soil grade. The base shear and moment demands on walls, calculated in SASSI calculated lateral dynamic soil pressures and equivalent pressure used for design analysis, were compared and the design pressure profile shown to be conservative. The peak design vertical soil pressure calculated under the base slab is 11.7 ksf, which reduces away from edges. This value excludes the peak corner pressure of 23.0 ksf calculated on a single element, representing less than 0.2 percent of the total base slab area. The average peak vertical seismic pressure calculated under the base slab is 1.6 ksf.

For design of the UHSRS per the loads and load combinations given in Section 3.8.4.3, response spectra analysis is performed in ANSYS to obtain seismic demands. The eigenvalue analysis of the UHS produced more than 400 modes below 40 Hz. The modes include 16 convective fluid modes ranging from 0.16 to 0.66 Hz and the peak sloshing height in any hydrodynamic region is equal to 1.91 ft. The first three structural modes are listed in Table 3KK-9. The response spectra analysis includes sloshing effects on the basins considering 0.5 percent damping, and follows the Lindley-Yow method (Reference 3KK-8) and 10 percent modal combination method. Note that the rigid response coefficient is set to zero for frequencies below the spectral peak acceleration (2.5 Hz for horizontal directions, 3.5 Hz for vertical direction) in accordance with RG 1.92 (Reference 3KK-6). Since the sloshing modes are well separated from all structural modes, the decreased level of damping is accounted for by increasing the spectrum for frequencies below 1.0Hz (all sloshing mode frequencies are below this value and all structural mode frequencies are above this value). The spectrum is increased by a factor of 1.57, which is equal to the ratio of 0.5% damped spectral values to 5 percent damped values for the frequency range in which the sloshing modes act. An equivalent static acceleration equal to the ZPA (0.10g) which accounts for "missing mass" is also applied to the UHSRS, and the results are combined with the Lindley-Yow spectral response using SRSS. The spectra used for this approach were confirmed to be higher than the enveloped base spectra calculated from the SASSI analysis. RCOL2_03.07.02-16

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 percent - 40 percent – 40 percent combination method. The walls' shear forces were increased to account for 5 percent accidental torsion, and total base shear to be resisted by in-plane shear of the walls. Figure 3KK-2 presents the total adjusted wall seismic shear forces used for design.

The model used for response spectra seismic design analysis considered two bounding base slab behaviors; (a) flexible base slab – modeled with slab supported by using soil springs calculated using ASCE 4 (Reference 3KK-3) methodology, and (b) rigid base slab – modeled by fixing the nodes across the base of the structure. The design analysis enveloped the demands from these two cases.

A comparison of the SASSI generated site-specific in-structure response spectra at the base slab to the ANSYS input spectra confirm that the input used for the ANSYS analyses is conservative. A comparison of the SASSI generated soil pressures with the soil pressures used for the seismic soil pressure analyses performed in ANSYS confirms that the applied loading used for design exceeds that calculated in the SASSI analyses. RCOL2_03.07.02-16

The seismic design forces and moments resulting from the design analysis are presented in Table 3KK-5 at key UHSRS locations. The force and moment values represent the enveloped results for the seismic demands for all soil cases considered in the SASSI analyses.

Table 3KK-6 summarizes the resulting maximum displacements for enveloped seismic loading conditions at key UHSRS locations obtained from the seismic analysis.

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

The enveloped broadened in-structure response spectra (ISRS) calculated in SASSI are presented in Figure 3KK-3 for the UHSRS base slab, pump room elevated slab, pump room roof slab, and cooling tower fan support slab 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 3KK-7). The ISRS include the envelope of the 6 site conditions (BE, LB, UB, and HB, ~~with and~~ BE without backfill separation from the structure, and the no-fill surface foundation condition with LB subgrade conditions). All results have been broadened by 15 percent and all valleys removed. ~~It is permitted to perform 15 percent peak clipping of the spectra presented herein in accordance with ASCE 4 (Reference 3KK-3) for spectra with less than 10 percent damping.~~ For the design of seismic category I and II subsystems and components mounted to the UHSRS walls, it is required to account for the effects of out-of-plane wall flexibility. RCOL2_03.07.02-15 RCOL2_03.07.02-15 RCOL2_03.07.02-15

3KK.5 References

3KK-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.

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

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

RCOL2_03.07.02-16

Table 3KK-9
Comparison of Major Structural Modes of UHSRS between ANSYS Design Model and SASSI SSI Model(1)

Mode	Frequency (Hz)		Modal Participation Factor (calculated per ASCE 4-98)		Modal Mass Ratio	
	ANSYS Design Model(2)	SSI Model Mesh(3)	ANSYS Design Model(2)	SSI Model Mesh(3)	ANSYS Design Model(2)	SSI Model Mesh(3)
E-W, Mode 1	6.77	7.08	7.07	7.28	0.251	0.306
E-W, Mode 2	6.55	6.78	2.93	2.48	0.043	0.035
E-W, Mode 3	4.15	4.48	2.89	2.84	0.042	0.047
N-S, Mode 1	7.37	7.62	5.86	5.84	0.172	0.203
N-S, Mode 2	11.49	11.23	2.44	3.55	0.030	0.075
N-S, Mode 3	13.86	14.73	2.33	2.38	0.027	0.033
Vertical, Mode 1	17.37	17.73	2.15	2.00	0.023	0.020
Vertical, Mode 2	10.65	10.67	2.05	1.91	0.021	0.018
Vertical, Mode 3	12.88	16.89	2.04	1.90	0.021	0.018

1. All eigenvalue analyses are performed in ANSYS
2. ANSYS Design Model is the fine mesh model used to calculate demands for design
3. SSI Model Mesh is the identical mesh of the UHSRS used for SSI analysis but eigenvalue analysis is performed in ANSYS

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 and base response spectra 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. Table 3LL-14 summarizes the analyses performed for calculating seismic demands. 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. RCOL2_03.07.02-16 RCOL2_03.07.02-16

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~~SSI 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. RCOL2_03.07.02-16

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 for all four soil property cases 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~~by comparing 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. RCOL2_03.07.02-11 RCOL2_03.07.02-11

The location of the lower boundary used in the SASSI analysis is greater than 710 feet below grade. The depth is greater than the embedment plus twice the depth of the largest base dimensions (i.e. 192' x 2 + 31' = 415' for Tunnel 1) recommended by SRP 3.7.2 A ten layer half-space is used below the lower boundary in the SASSI analysis consistent with SASSI manual recommendations. The SASSI half-space simulation consists of additional layers with viscous dashpots added at the base of the half-space. The half-space layer has a thickness of 1.5 Vs/ f where Vs is the shear wave velocity of the half-space and f is RCOL2_03.07.02-16 the frequency of analysis and it is divided by the selected number of layers in the half-space. RCOL2_03.07.02-16

The maximum shear wave passing frequency for all layers below the base slab and concrete fill, based on layer thicknesses of 1/5 wavelength, ranges from 30.6 Hz for LB to 50.4 Hz for HB. The passing frequency for the backfill ranges from 11.6 Hz for LB to 44.9 Hz for HB. The cutoff frequencies for all cases are greater than 29.3Hz and a minimum of 39 frequencies are analyzed for SSI analyses.

For the ESWPT analyses performed, benchmarking is performed to validate the results of the SASSI models. The natural frequencies of Tunnel Segment 1 are calculated for the FE model used for the SSI interaction analysis performed in SASSI (coarse model) and a more refined FE model (ANSYS) used for the analysis of all static load cases (detailed model) and compared. Tunnel 1 is deemed representative of the coarse and fine mesh models of all tunnel segments. For this analysis both models have all nodes at the intersection of mat slab and the walls fixed against translation. Results show close comparison between the calculated frequencies.

The tunnels are simple structures and responses are significantly influenced by the surrounding soil, producing frequencies of peak response in the embedded SASSI model that do not match the eigenvalue analysis of the fixed base structure without soil which limits the ability to compare transfer functions. Therefore, the response of these structures are checked primarily through model and analysis input file checks and reviews of the transfer functions and other output to make sure that adequate frequencies are used for calculation. The SASSI analysis frequencies are selected to cover the range between around 1 Hz and the cutoff frequency. This frequency range includes the SSI frequency and primary structural frequencies. The 1 Hz lower limit is low enough to be outside the range of SSI or structural mode amplification. It was 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. Initially, the frequencies are selected evenly spaced. Frequencies are added as needed to produce smooth interpolation of the transfer functions and accurately capture peaks. As verification, additional frequencies are added to observe that the results did not change. 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.

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. The SASSI analyses produce results including peak RCOL2_03.07.02-11 accelerations, in-structure response spectra, seismic element demands, and seismic soil pressures. All results from SSI analyses represent the envelope of the soil conditions. The SASSI analysis results are used to produce the final response spectra and provide confirmation of the inputs to the ANSYS design model. RCOL2_03.07.02-11

ANSYS analyses are used to calculate the structural demands of the ESWPT to seismic soil pressure and seismic inertia which are then added to all other design loads discussed in Section 3.8.

The seismic inertia demand of segment 2 are calculated using ANSYS, response spectra analyses with the site specific 5% damped design response spectra. Modal combination is performed in accordance with RG 1.91 Combination Method B. Analysis of the ESWPT produced 40 modes below 50 Hz. Table 3LL-15 lists five major structural frequencies for each direction of motion organized by mass participation. RCOL2_03.07.02-16

The seismic inertia demand of segments 1 and 3 are calculated using an equivalent static lateral load based on the enveloped peak accelerations calculated in SASSI for all soil cases. RCOL2_03.07.02-11

The seismic soil pressure demands are calculated statically in ANSYS. 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 and the enveloped SASSI results.

Demands calculated from the response spectra and soil pressure analyses performed in ANSYS for segment 2 are combined on an absolute basis to produce the maximum demands for each direction of motion and these directions are then combined spatially by 100-40-40 percent combination rule (Eq. 13 of RG 1.92).

Demands calculated from the equivalent static accelerations and soil pressure analyses performed in ANSYS for segments 1 and 3 are combined to produce the maximum demands in each direction. The maximum demands for each direction of motion and these directions are then combined spatially by 100-40-40 percent combination rule (Eq. 13 of RG 1.92).

To confirm the design input and results from the ANSYS model of tunnel segment 2 used for response spectra analysis, the enveloped in-structure response spectra at the base slab calculated in the SASSI analysis are compared to the input spectra. The enveloped soil pressures from SASSI are compared to the soil pressures used as input to the ANSYS model, and the plate stresses from SASSI are compared to those calculated in ANSYS. The comparisons show that the seismic loads used for design exceeded those based on results of the SASSI analysis.

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Table 3LL-15

Major Structural Modes of Tunnel Segment 2 - Adjacent to UHS Structures

Major North-South (X) Direction Modes				
Mode	Frequency (Hz)	Period (sec)	Participation Factor	Effective Mass (kip sec^2/ft)
1	5.478	0.1825484	12.78	163.455
5	15.02	0.0665779	-3.381	11.432
4	13.33	0.0750188	-3.147	9.901
13	26.24	0.0381098	1.397	1.953
40	49.03	0.0203957	-1.381	1.908
Major East-West (Y) Direction Modes				
Mode	Frequency (Hz)	Period (sec)	Participation Factor	Effective Mass (kip sec^2/ft)
6	17.52	0.057078	9.757	95.205
21	31.98	0.03127	-6.261	39.201
10	22.86	0.043745	4.599	21.148
2	7.968	0.125502	3.84	14.746
15	29.7	0.03367	3.495	12.215
Major Vertical Modes				
Mode	Frequency (Hz)	Period (sec)	Participation Factor	Effective Mass (kip sec^2/ft)
13	26.24	0.03811	-11.08	122.688
8	20.9	0.047847	5.715	32.662
9	21.36	0.046816	4.76	22.653
10	22.86	0.043745	3.611	13.042
38	47.69	0.020969	3.353	11.244

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 Table 3MM-8 summarizes the analyses performed for calculating seismic demands. 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. RCOL2_03.07.02-16

3MM.2 Model Description and Analysis Approach

The SASSI 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. RCOL2_03.07.02-16

The PSVSV is a simple shear wall structure with four exterior walls plus two interior shear walls. The walls must resist the out of plane flexure and shear due to transverse accelerations, soil pressures (for exterior walls) and flexure imparted on the wall from flexure in the roof slab. The roof slab resists vertical seismic demands as a continuous three span plate although there is some two-way response. Critical locations are therefore centers and edges of roof slabs and walls for flexure and bottom of walls for in-plane shear. RCOL2_03.07.02-16

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. RCOL2_03.07.02-16

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 <u>or mass</u>, the following element properties are assigned: RCOL2_03.07.02-16

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

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

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

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.

<u>The analysis of the PSFSV produces 50 modes below 45 Hz.</u> 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. RCOL2_03.07.02-16

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~~. An additional case representing a surface foundation condition using lower bound in-situ soil properties beneath the base slab without presence of any backfill is included.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~~by comparing the peak envelope soil pressure results to the at-rest soil pressure for the BE soil case. 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. RCOL2_03.07.02-11 RCOL2_03.07.02-11

The shear wave passing frequency for all layers below the base slab and concrete fill, based on layer thickness of 1/5 wavelength, ranges from 30.6Hz for LB to 50.4Hz for HB. The shear wave passing frequency for the backfill ranges from 11.4Hz for LB to 31.1Hz for HB. RCOL2_03.07.02-16

A ten-layer half-space is used in the SASSI analysis in accordance with the SASSI Manual recommendations. The SASSI half-space simulation consists of additional layers with viscous dashpots added at the base of the half-space. The half-space layer has a thickness of 1.5 Vs/ f where Vs is the shear wave velocity of the half-space and f is the frequency of analysis. The half-space is sub-divided by the selected number of layers in the half-space.

The lower boundary used in the SASSI analysis is 809 feet below grade. The depth is more than the embedment depth plus twice the depth of the largest base dimension (88' x 2 + 40' = 216') recommended by SRP 3.7.2. RCOL2_03.07.02-16

The cutoff frequencies for all cases are greater than 29.9Hz and a minimum of 48 frequencies are analyzed for SSI analyses. The SASSI analysis frequencies were selected to cover the range between around 1 Hz and the cutoff frequency. This frequency range includes the SSI frequency and primary structural frequencies. The 1 Hz lower limit is shown to be low enough to be outside the range of SSI or structural mode amplification. It was 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. Initially, the frequencies are selected evenly spaced. Frequencies are added as needed to produce smooth interpolation of the transfer functions and accurately capture peaks. As verification, additional frequencies were added to observe that the results did not change.

For the PSFSV analyses, benchmarking is performed to validate the results of the SASSI models for verification of both the mesh and the dynamic response. The mesh used for SASSI analyses is justified with respect to with the more refined design model by calculating eigenvalues and mode shapes for the models with each mesh using ANSYS and comparing the results. The comparisons show that the two models provide similar dynamic responses.

To verify the dynamic response, fixed base eigenvalue analysis is performed in ANSYS, and a corresponding fixed base analysis is performed in SASSI by placing the structure at the soil surface and setting the stiffness of the soil layers to high values to represent the fixed base condition. The fixed base ANSYS eigenvalues are compared to the transfer functions of the SASSI "fixed base" case to verify that the SASSI model exhibits the same dynamic response as the ANSYS model.

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

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.

The SASSI analyses produce results including peak accelerations, in-structure response spectra, and seismic soil pressures. All results from SSI analyses RCOL2_03.07.02-11

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Table 3MM-9

Major Structural Modes of PSFSV

Major East-West Direction Modes			
Mode	Frequency (Hz)	Period (sec)	Effective Mass (kip sec^2/ft)
8	17.688	0.0566	87.744
2	11.861	0.08431	46.6474
6	15.459	0.064687	26.7655
4	14.71	0.067981	26.1976
7	17.237	0.058015	7.20513
Major North-South Direction Modes			
Mode	Frequency (Hz)	Period (sec)	Effective Mass (kip sec^2/ft)
17	24.056	0.04157	160.91
18	24.929	0.040114	32.7644
19	24.994	0.04001	4.96764
16	23.799	0.042019	3.74051
27	31.991	0.031259	2.01327
Major Vertical Modes			
Mode	Frequency (Hz)	Period (sec)	Effective Mass (kip sec^2/ft)
7	17.237	0.058015	30.7952
8	17.668	0.0566	10.7574
19	24.994	0.04001	7.17713
4	14.71	0.067981	3.83556
14	21.549	0.046406	3.75472