Appendix 3GG 3-D SSI Analysis of AP1000 at Vogtle Site Using NI15 Model

3-D SSI ANALYSIS OF AP1000 AT VOGTLE SITE USING NI15 MODEL

FOR

VEGP UNITS 3 AND 4

October 2010

Table of Contents

List of Tables

List of Figures

List of Figures (Cont.)

1. Introduction

This report presents the results of the three-dimensional soil-structure interaction (SSI) analysis of the AP1000 plant at the Vogtle site to confirm the applicability of the AP1000 design to the site.

This report supplements the two-dimensional site-specific SSI analysis previously submitted as Appendix 2.5E in the Vogtle Early Site Permit Application.

Site-specific SSI analysis is required since the site specific design response spectra exceed the certified seismic design response spectra (CSDRS) at some limited frequency range and the Vogtle soil profile is significantly different than the AP1000 generic soil profiles in shear wave velocity versus depth and overall soil depth.

Reference 1 describes changes to the AP1000 NI20 SASSI model now identified as NI20r and provides revised AP1000 CSDRS broadened envelope ISRS. This report reflects those changes and consists of updating the Vogtle NI15 SASSI model, rerunning the Vogtle SASSI analyses using the updated Vogtle NI15 SASSI model to generate revised Vogtle ISRS at the six key locations for the Vogtle soil profile (Lower Bound, Best Estimate, and Upper Bound soil cases), and providing a comparison of the revised Vogtle ISRS to the new AP1000 CSDRS broadened envelope ISRS.

2. Methodology

The free-field analyses are performed using the Bechtel Computer Program SHAKE2000. The SSI analyses are performed using the Bechtel Computer Program SASSI2000

3. Vogtle Site Profile

A detailed description of the site geology and soil stratigraphy including the extent and characteristics of the backfill materials is contained in the Early Site Permit Application and is not repeated in this report. For the three-dimensional SSI analysis, the same soil profiles used for the two-dimensional SSI analysis are used. The strain-compatible soil shear-wave velocity and damping profiles for the three soil cases, (upper bound (UB), median (BE) and lower bound (LB)) are shown in Figure 1 and Figure 2. Note that the UB shear-wave velocity profile is combined with the LB damping profile to form the UB SSI soil profile. Likewise, the LB velocity profile is combined with the UB damping profile to form the LB SSI soil profile. The BE shear wave velocity and damping profiles are for the BE SSI soil profile. These profiles are obtained from the group of simulated soil profiles used for development of the soil amplification factors and site specific ground motions by considering the median and one standard deviation of the range of data and incorporating the NUREG-0800 requirement of the minimum soil shear modulus variation of 1.5. For SSI analysis, the rock was modeled at the depth of about 1000 ft corresponding to the approximate depth of the rock at the site.

For comparison purposes, the strain-compatible generic soil profiles used for certified design of AP1000 are compared with the strain-compatible Vogtle UB, BE and LB site-specific soil profiles in Figure 3. As shown, the Vogtle site-specific soil profiles are softer than the lower-bound generic Soft Soil profile in the upper 50 ft. In addition, the Vogtle site-specific soil profiles extend to the depth of about 1000 ft whereas the generic soil profiles are only 120 ft deep overlying a bedrock layer assumed to be a halfspace layer below 120 ft depth.

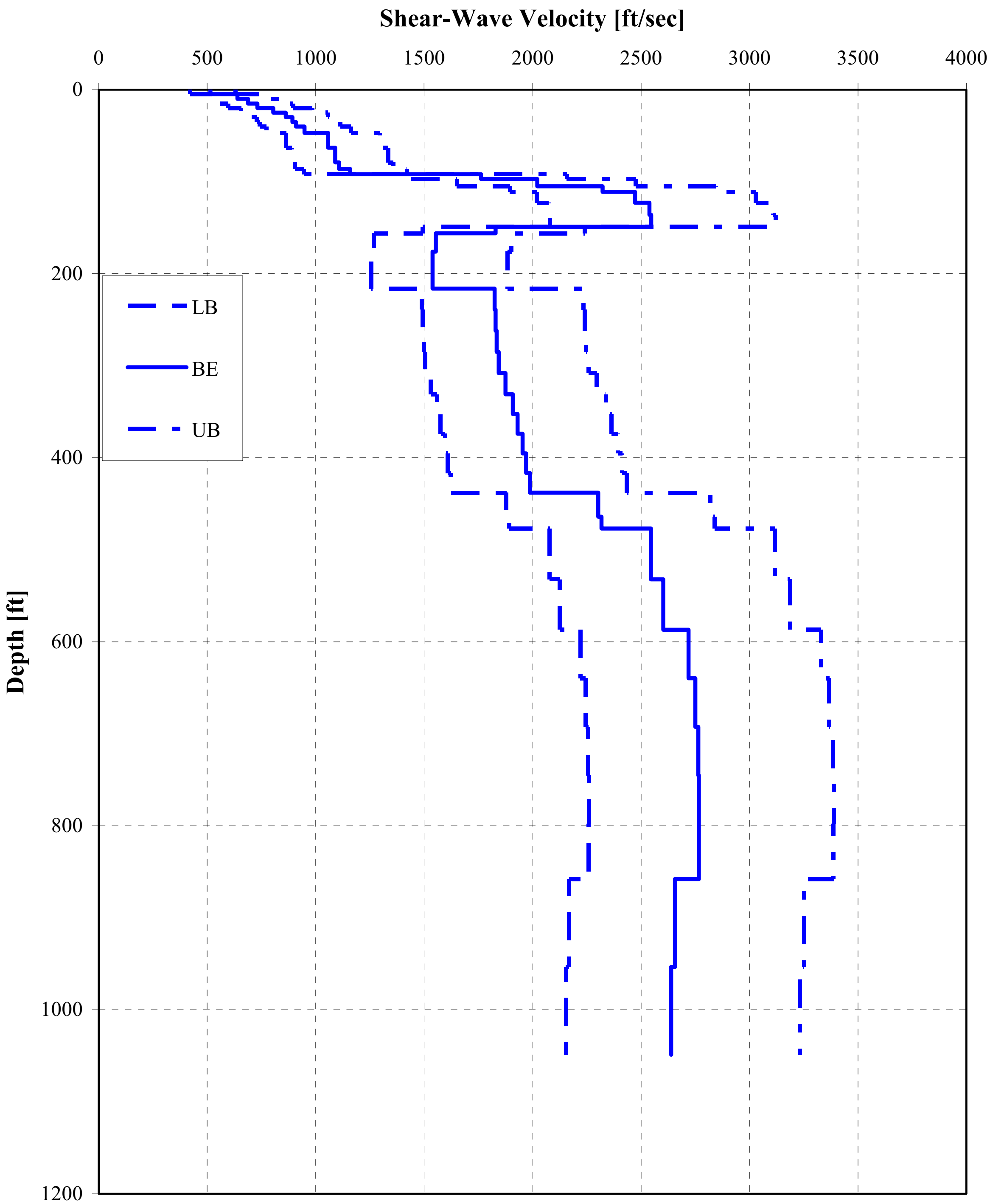

Figure 1 Vogtle Strain-Compatible Soil Shear Wave Velocity Profiles Used in SSI Analysis

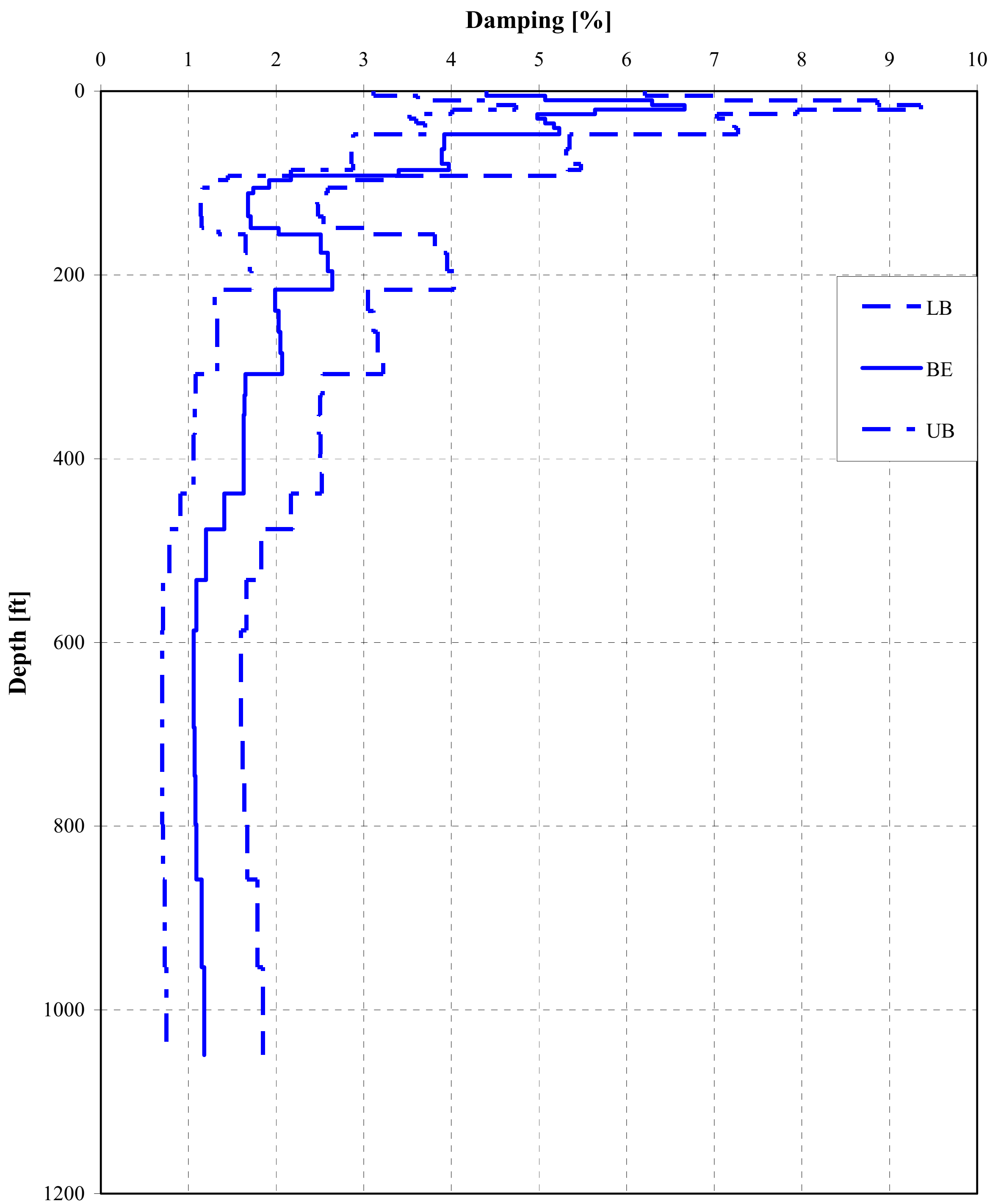

Figure 2 Vogtle Strain-Compatible Soil Damping Profiles Used in SSI Analysis

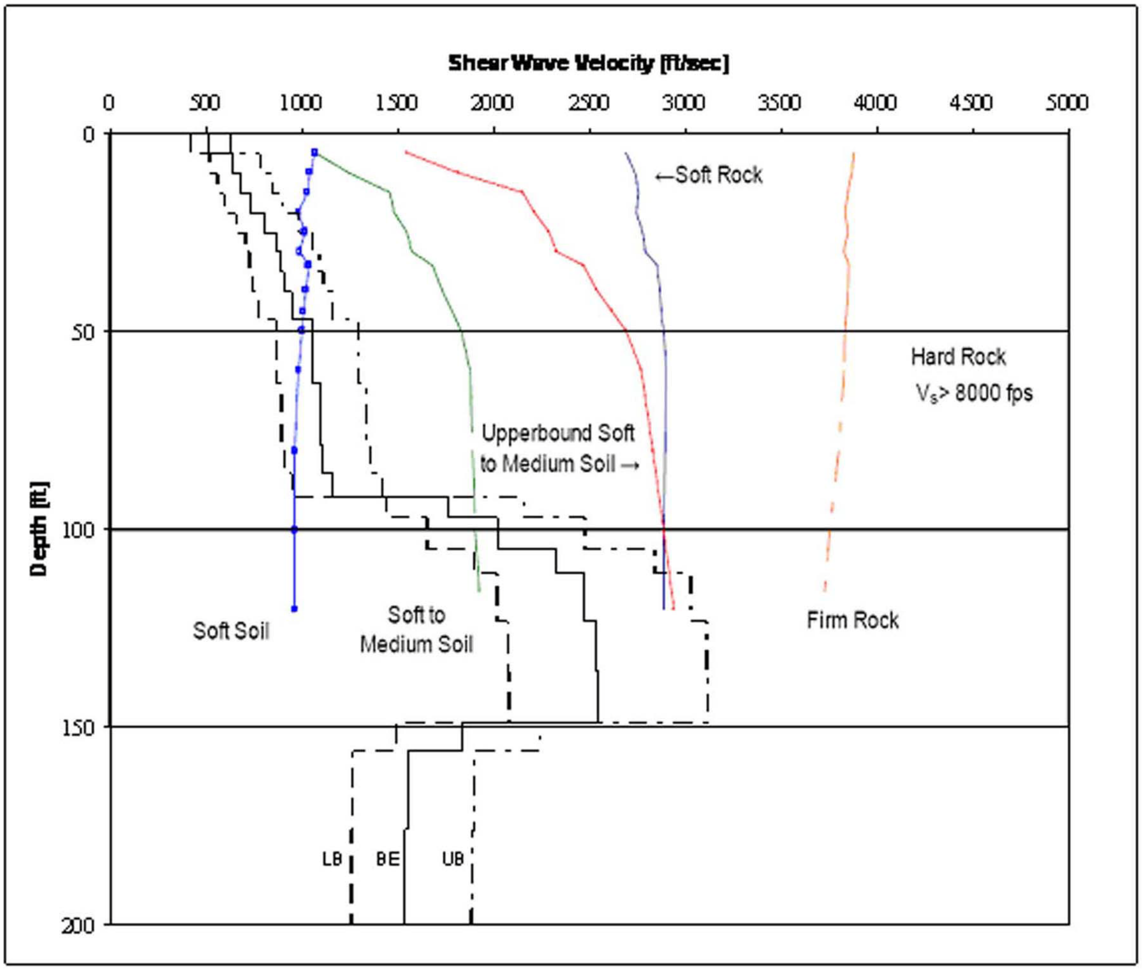

Figure 3 Vogtle Site-Specific and AP1000 Generic Strain-Compatible Soil Profiles

4. Vogtle Site Specific Seismic Motion

As described in the ESP application, the ground motion response spectra (GMRS) at the Vogtle site are defined at the finished grade at the top of the backfill. The foundation input response spectra (FIRS) is at the foundation horizon at the depth of 40 ft below the finished grade. FIRS and GMRS are compared with CSDRS in Figure 4 and Figure 5 for the horizontal and vertical motions, respectively. Note that the FIRS is an outcrop motion at the foundation level obtained from the soil column analysis of the site full soil column extending to the top of the backfill.

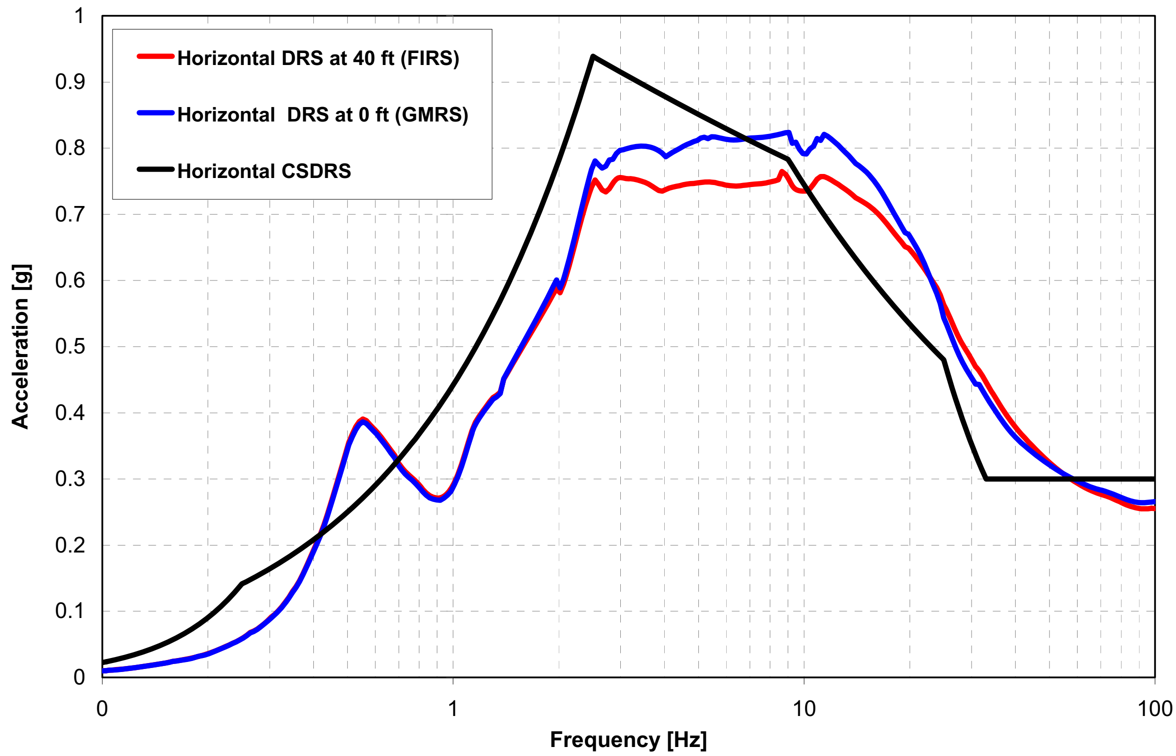

Figure 4 AP1000 CSDRS and Vogtle GMRS and FIRS - Horizontal Motion (5% Damping)

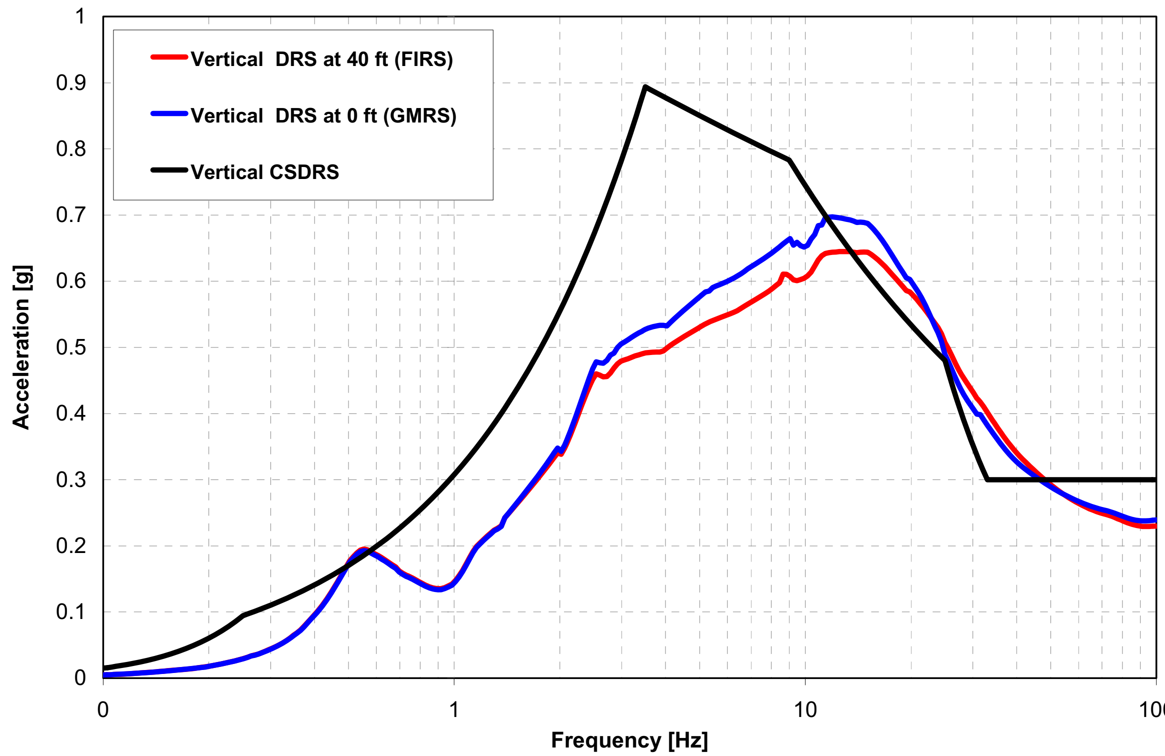

Figure 5 AP1000 CSDRS and Vogtle GMRS and FIRS - Vertical Motion (5% Damping)

As shown in the above figures, both the horizontal and vertical Design Response Spectra (DRS) at both GMRS and FIRS levels exceed the CSDRS at a limited frequency range.

4.1 SSI Input Motion

The development of SSI input motion follows the procedure outlined in the recent NRC position on this subject (ADAMS Accession Numbers ML083580072 and ML083020171). The development of SSI input motion is consistent with the development of FIRS and the required check has been made at the ground surface to evaluate the adequacy of the SSI input motion. Using the three SSI soil profiles defined above, acceleration time histories compatible with the FIRS are generated and applied as outcrop input motion at the depth of 40 ft, and the response motions at the surface are computed using Bechtel Program SHAKE2000. The resulting three spectra are compared with the surface design spectra (GMRS) in Figure 6 through Figure 8 for the horizontal H1, H2 and the Vertical component of the motion, respectively. As shown in these figures, the envelope of the three horizontal SSI input motions (LB, BE and UB) adequately envelops the GMRS in the two horizontal directions (H1 and H2) and no further modification of the horizontal motion is warranted, The vertical motions, however, are slightly less that the vertical GMRS in the frequency range 2.5 to 7 Hz. For this reason the vertical time history associated with the lower bound soil profile analysis was increased uniformly by a factor of 1.11. Figure 9 shows the comparison for the vertical motion confirming the enveloping spectra from the three soil profiles envelop the vertical GMRS at the ground surface.

For SASSI SSI analysis and for each SSI soil profile, the outcrop motions were converted to in-column motions at the depth of 40 ft and the in-column motions are subsequently used in the SSI analysis. For each of the three soil profiles, three in-column time histories are developed resulting in a total of nine incolumn time histories for SSI analysis. As described above, the vertical in-column time history corresponding to the LB soil profile was increased by a factor of 1.11 to meet the enveloping requirement at the surface.

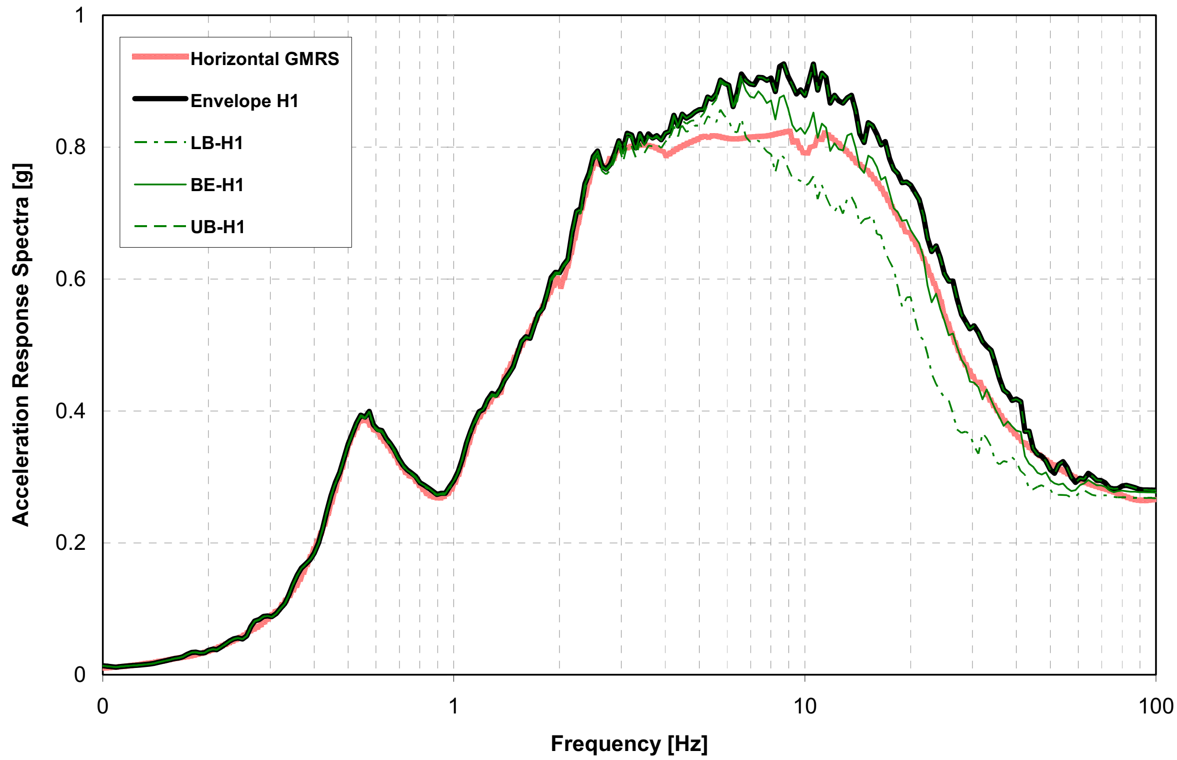

Figure 6 Comparison of H1 Response Motion and GMRS at the Ground Surface Level (5% Damping)

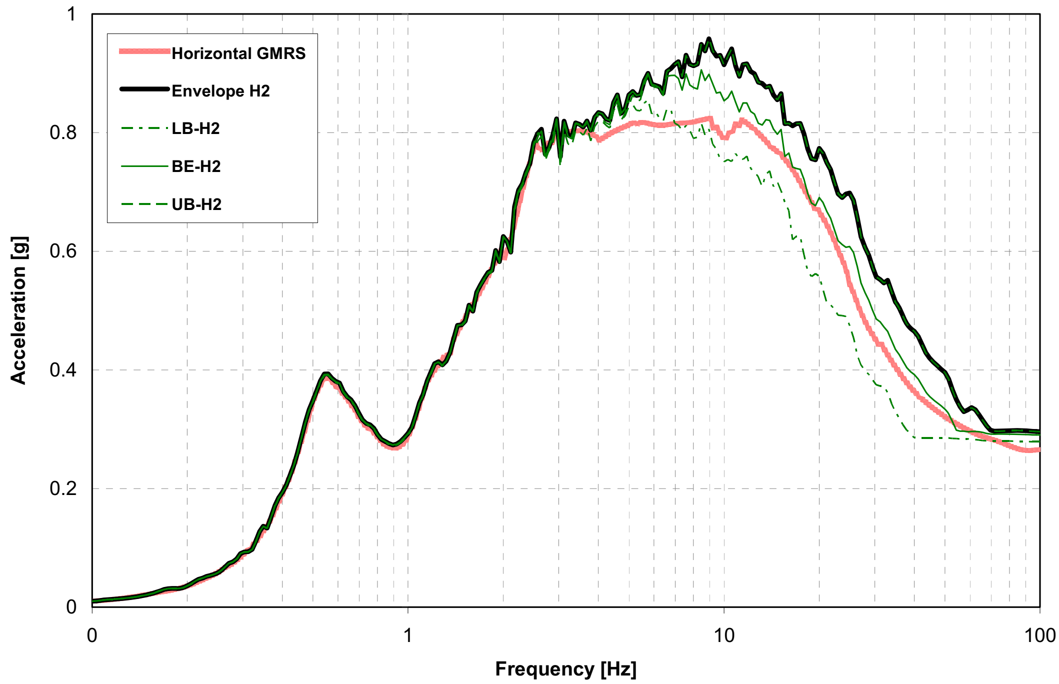

Figure 7 Comparisons of the H2 Response Motions with the GMRS at the Ground Surface Level (5% Damping)

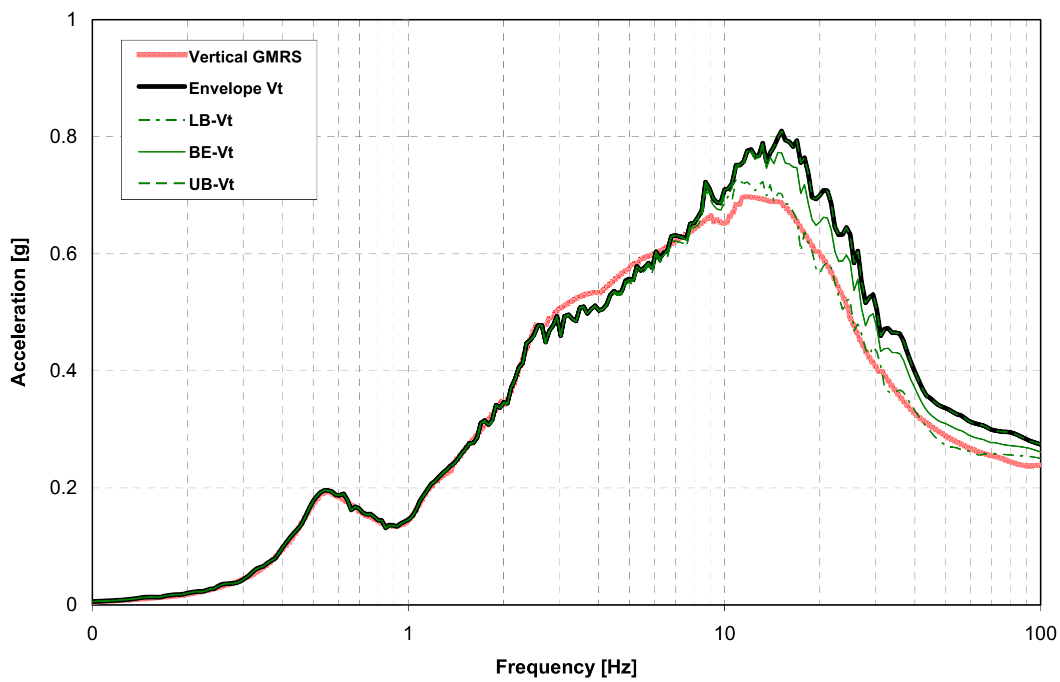

Figure 8 Comparisons of the Vertical Response Motions with the GMRS at the Ground Surface Level (5% Damping)

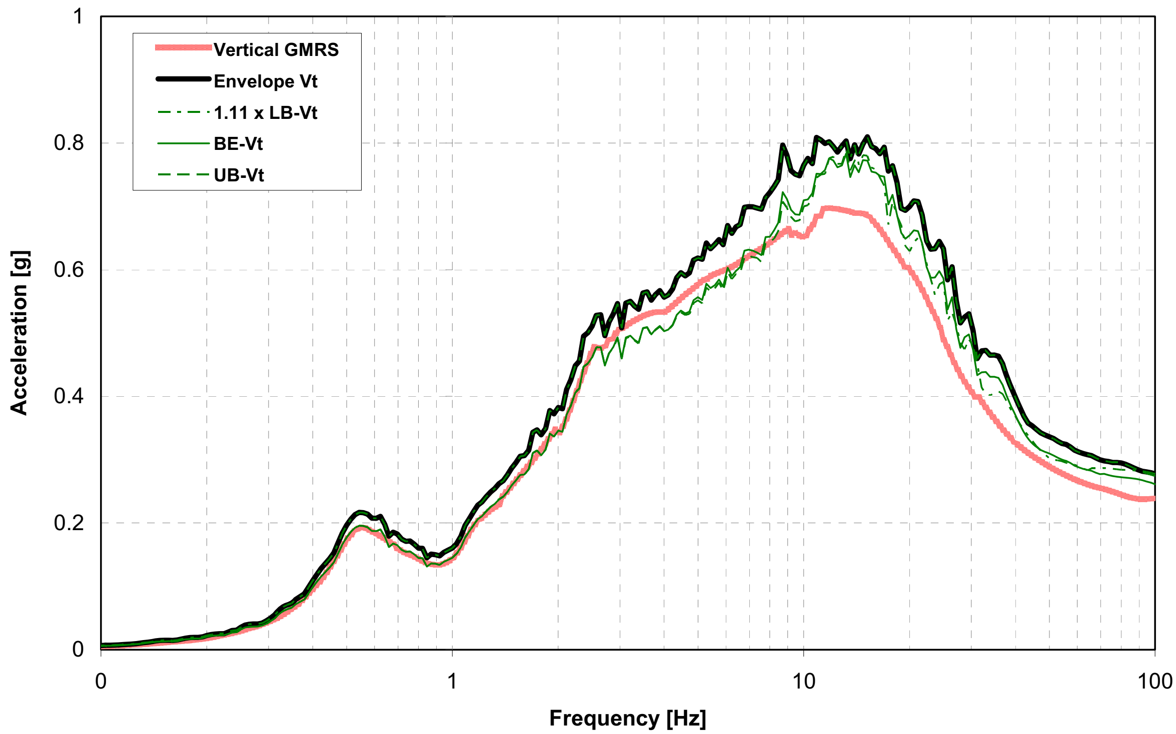

Figure 9 Comparisons of the Modified Vertical Response Motions with the GMRS at the Ground Surface Level (5% Damping)

5. Structural Model

The AP1000 model used for Vogtle site-specific SSI analysis is a three-dimensional finite element model defined as the NI15 model that is developed by Westinghouse. This model was developed specifically for the Vogtle site to incorporate additional refinement in order to capture the Vogtle high frequency exceedance beyond CSDRS as shown in Figure 4 and Figure 5. In addition as shown in Figure 3, the Vogtle soil profile is softer than the generic profiles in the upper 50 ft and significantly deeper with an inverted impedance mismatch below the Blue Bluff marl requiring site specific modeling and analysis to evaluate applicability of the design.

The AP1000 Nuclear Island consists of the Auxiliary and Shield building (ASB), Containment Internal Structure (CIS), Reactor Coolant Loop and Steel Containment Vessel (SCV). The ANSYS NI15 Model, averaging 15' by 15' for solid and shell elements in the ASB, is shown in Figure 10. The structure model has over 6300 nodes and 7500 elements. The embedded part of the NI is modeled with 5 layers of elements for a total embedment depth of 39.5 ft. Solid elements and Beam elements for SCV, CIS including Reactor Coolant Loop, Pressurizer, and polar crane are shown in Figure 11.

The NI15 was verified by Westinghouse by assuring that the mass distribution, the modal behavior and the floor response spectra results were consistent in ANSYS with WEC's most detailed model which is the model used for Hard Rock (NI10). The mass, centroid, and moment of inertia analysis determined the geometric and material properties were consistent with the finite element model NI10. The dynamic behavior of the Nuclear Island building is identified by means of a modal analysis, and a floor response spectra comparison of the two models.

The ANSYS NI15 model is converted into the SASSI NI15 Model where excavated soil elements are added. The SASSI NI15 model is used in the Soil and Structure Interaction (SSI) analysis.

Due to the changes to the AP1000 NI20 SASSI model now identified as NI20r as described in Reference 1, the Vogtle NI15 SASSI model was revised from that described above as follows:

1. The properties of the Shield Building walls and air-inlet were updated to reflect the Shield Building design changes.

2. Modeling corrections to the Westinghouse AP1000 NI20 SASSI, as described in Reference 1, Section 4.2.3 “Corrections to NI20 SASSI Model”, were not required for the Vogtle NI15 SASSI model. These corrections to the SASSI NI20 model were to address modeling concerns with beam to solid element connectivity and improve the stress distribution in the basemat. The Vogtle NI15 SASSI model beam to solid element connectivity already properly modeled the connections between the solid elements and beam elements. Unlike the NI20 SASSI model that modeled the Auxiliary Building portion of the basemat of the Nuclear Island as shell elements, the Vogtle NI15 SASSI model used solid elements for the entire basemat. Therefore, there was no issue with the stress distribution at the basemat interface between the Auxiliary Building and the Containment Internal Structure (CIS).

3. The original NI20 SASSI model was revised to account for stiffness due to out-of-plane flexure where the walls, which are modeled as shell elements, connect to the floors, which are modeled as solid elements. Therefore, the Vogtle NI15 SASSI model was revised by extending the wall shell elements the depth of one solid element to capture the effects of out-of-plane flexural stiffness. This modeling change showed no significant effect on the response since in-plane wall stiffness was the controlling contributor to overall lateral structural stiffness.

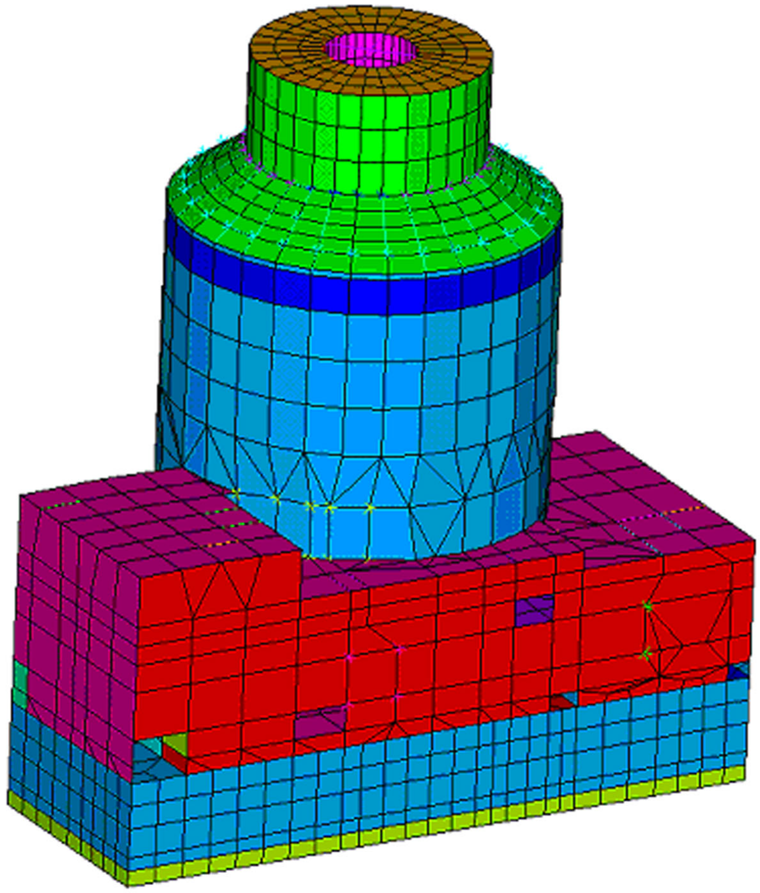

Figure 10 NI15 Finite Element Model

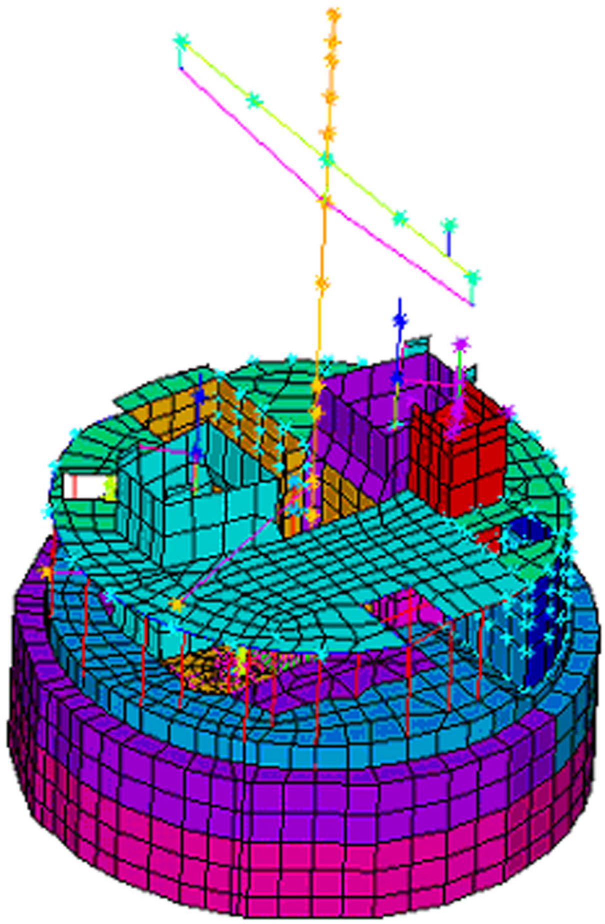

Figure 11 NI15 CIS, RCL, and SCV Elements

6. SSI Analysis and Results

Using the above structural model, the Vogtle site-specific SASSI SSI model of AP1000 was constructed by modeling the soil profile and the soil foundation model for the embedded part of the nuclear island (NI). For all structural members, 4% material damping was used. This damping is considered to be conservative and is representative of the lower bound value for damping compatible to structural response per RG 1.61. For each soil profile, the respective in-column motions were used as input at the depth of the foundation level with excitation in all three (North-South, East-West, and Vertical) directions. The results in terms of in-structure response spectra (ISRS) at 5% damping at the six key locations in the NI (Table 1) are computed. The coupling responses are combined using the SRSS method. The analyses are performed to 30 Hz (15 Hz for LB, 17 Hz for BE, 30 Hz for UB) to cover all frequencies of interest for the given design motion.

Table 1: Key Location for ISRS Comparison with DCD

Node	X* [ft]	Y* [ft]	Z [ft]	Location
10115	1116.5	948.5	116.5	ASB NE Corner at Control Room Floor
11111	929	1000	179.19	ASB Corner of Fuel Building Roof at Shield Building
12052	956.5	1000	327.41	ASB Shield Building Roof Area
10471	1008	1014	134.25	CIS Operating Deck
9007	1000	1000	100	CIS at Reactor Vessel Support Elevation
11224	1000	1000	224	SCV Near Polar Crane

*Note: X=Y=1000 ft at center of ASB and SCV

The results at these six locations are compared with the CSDRS-based design envelops in Figure 12 through Figure 29. In these figures, X denotes plant North, Y denotes plant West and, Z denotes vertical direction.

For a point of reference, the comparisons also include the original AP1000 CSDRS broadened envelope ISRS to aid in understanding the differences in the revised ISRS comparison.

As shown in these figures, the “design envelope” exceeds the site specific response motions basically over the entire range of frequencies and by a large margin. This margin is particularly large at the zero period acceleration level indicating a large margin for seismic member forces. At a very limited frequency range, small exceedances beyond the design envelops are observed. The exceedance at about 0.55 Hz is consistent with the previous two-dimensional SSI results and has no design consequence since there are no structural members at this frequency.

7. Conclusion

The results of the three dimensional SSI analysis of a refined AP1000 NI model at the Vogtle site show a large margin against the design envelops. This study confirms the applicability of the AP1000 design to the Vogtle site.

8. Reference

1. AP1000 Standard Combined License Technical Report: Extension of Nuclear Island Seismic Analyses to Soil Sites; APP-GW-S2R-010, Revision 4, March 2010, Docket No. 52-006, Westinghouse letter dated April 21, 2010 (DCP_NRC_002855).

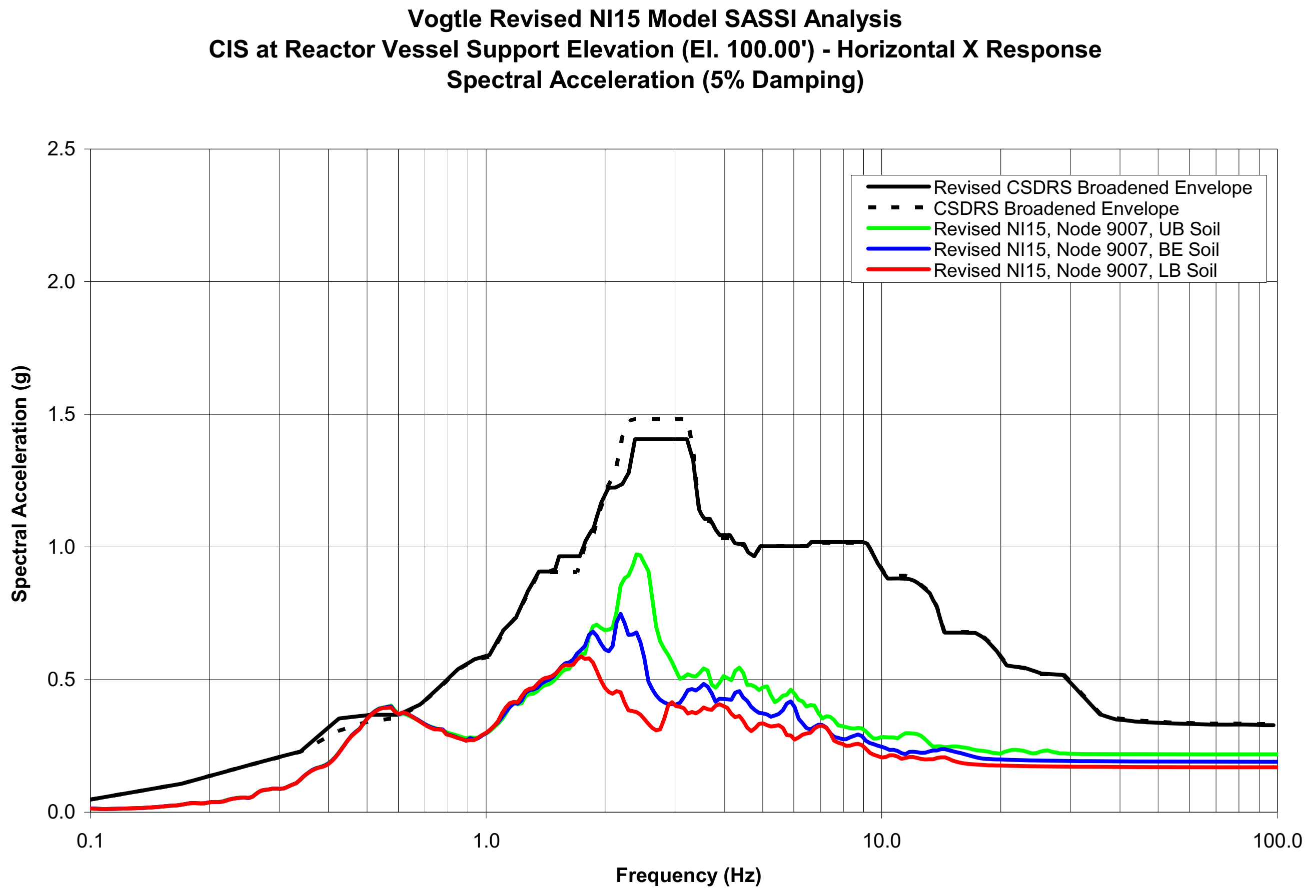

Figure 12 Horizontal X Response Spectra at CIS at Reactor Vessel Support Elevation (El. 100.00 ft, Node 9007)

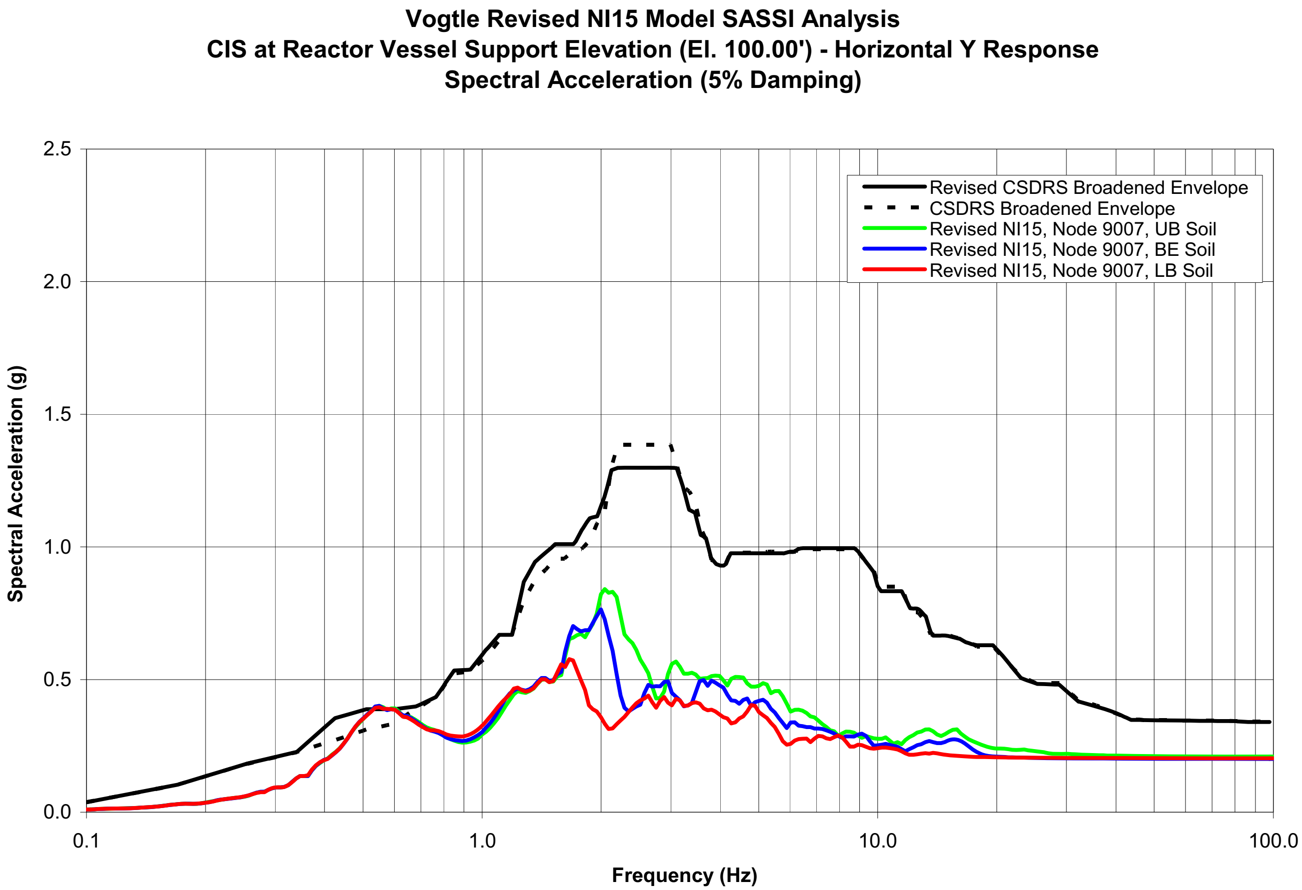

Figure 13 Horizontal Y Response Spectra at CIS at Reactor Vessel Support Elevation (El. 100.00 ft, Node 9007)

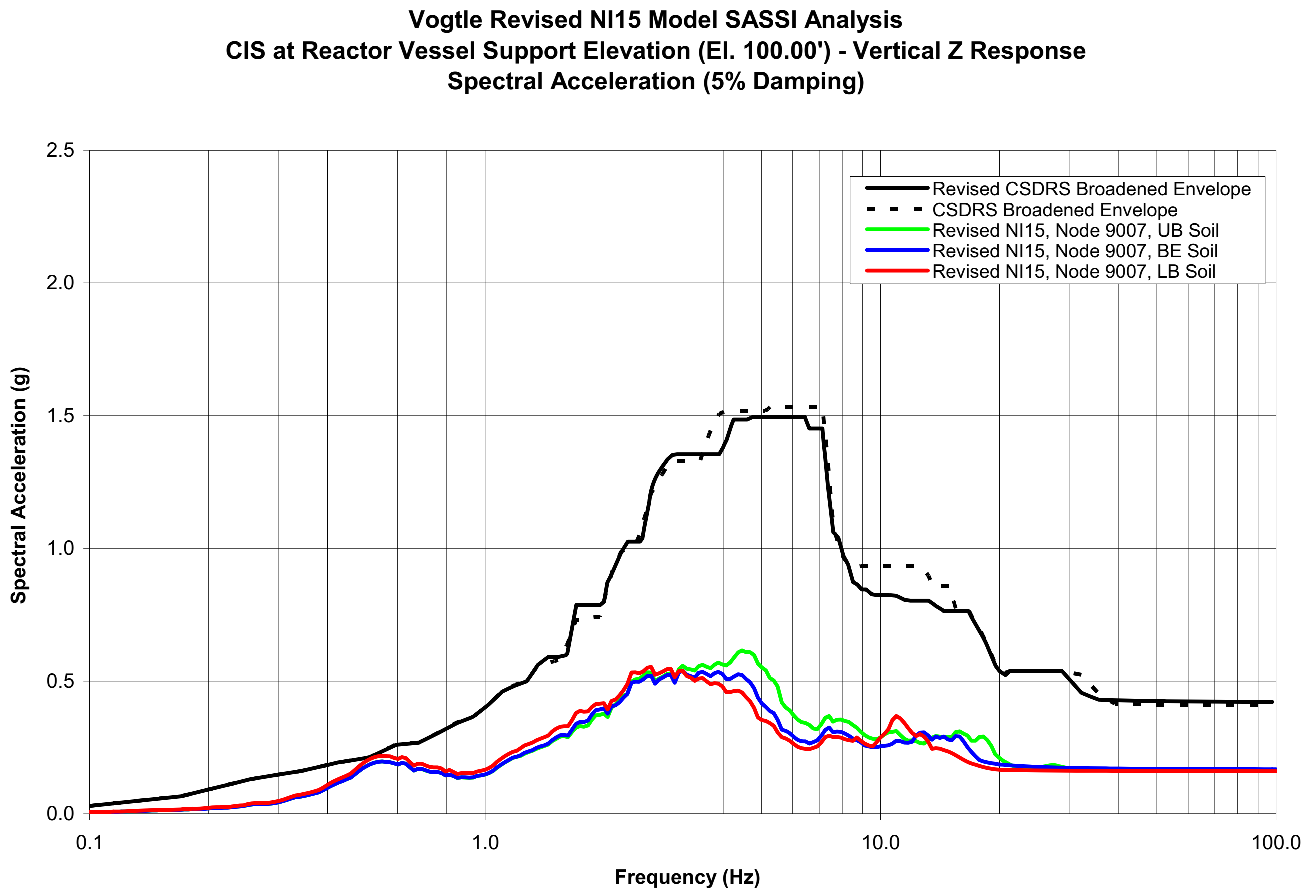

Figure 14 Vertical Z Response Spectra at CIS at Reactor Vessel Support Elevation (El. 100.00 ft, Node 9007)

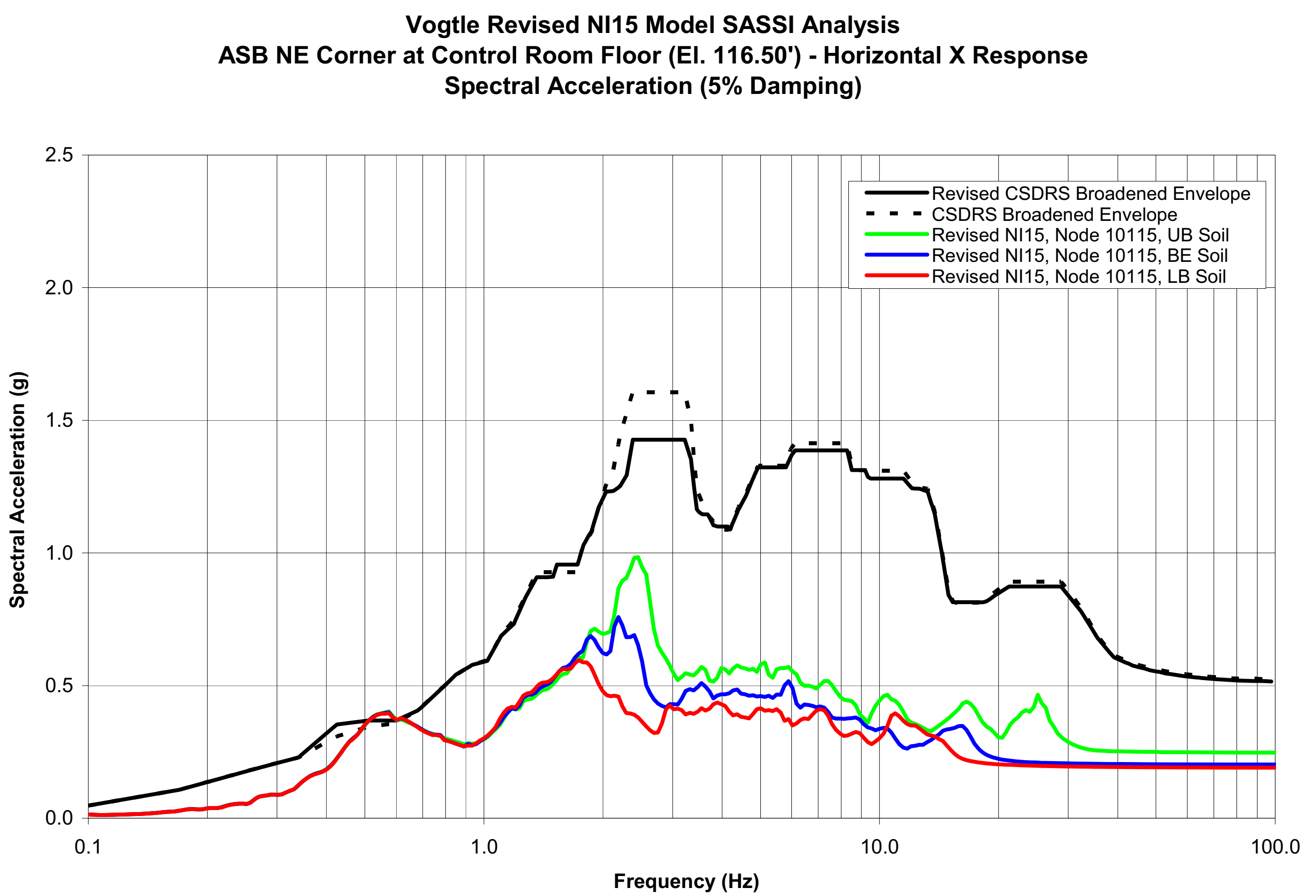

Figure 15 Horizontal X Response Spectra at ASB NE Corner at Control Room Floor (El. 116.50 ft, Node 10115)

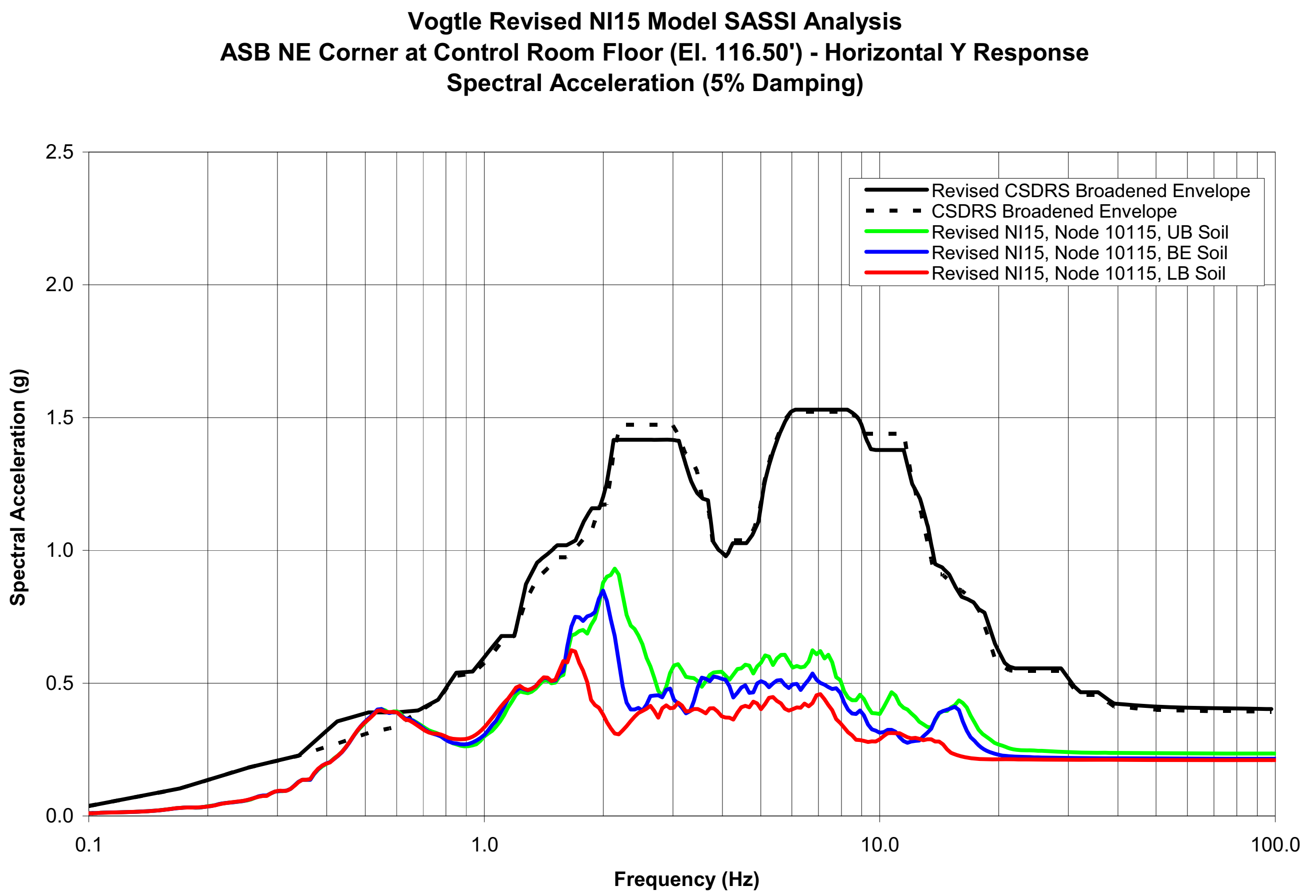

Figure 16 Horizontal Y Response Spectra at ASB NE Corner at Control Room Floor (El. 116.50 ft, Node 10115)

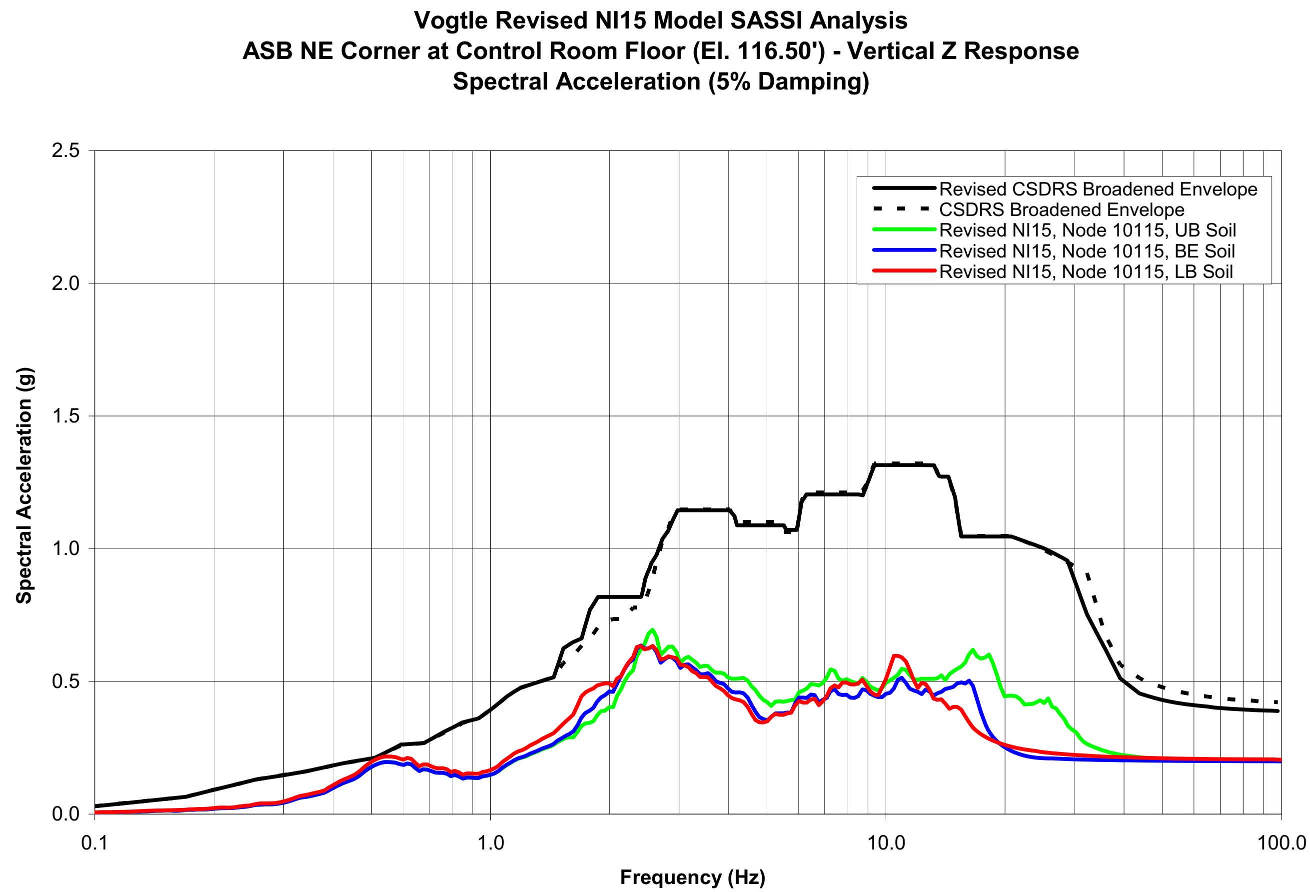

Figure 17 Vertical Z Response Spectra at ASB NE Corner at Control Room Floor (El. 116.50 ft, Node 10115)

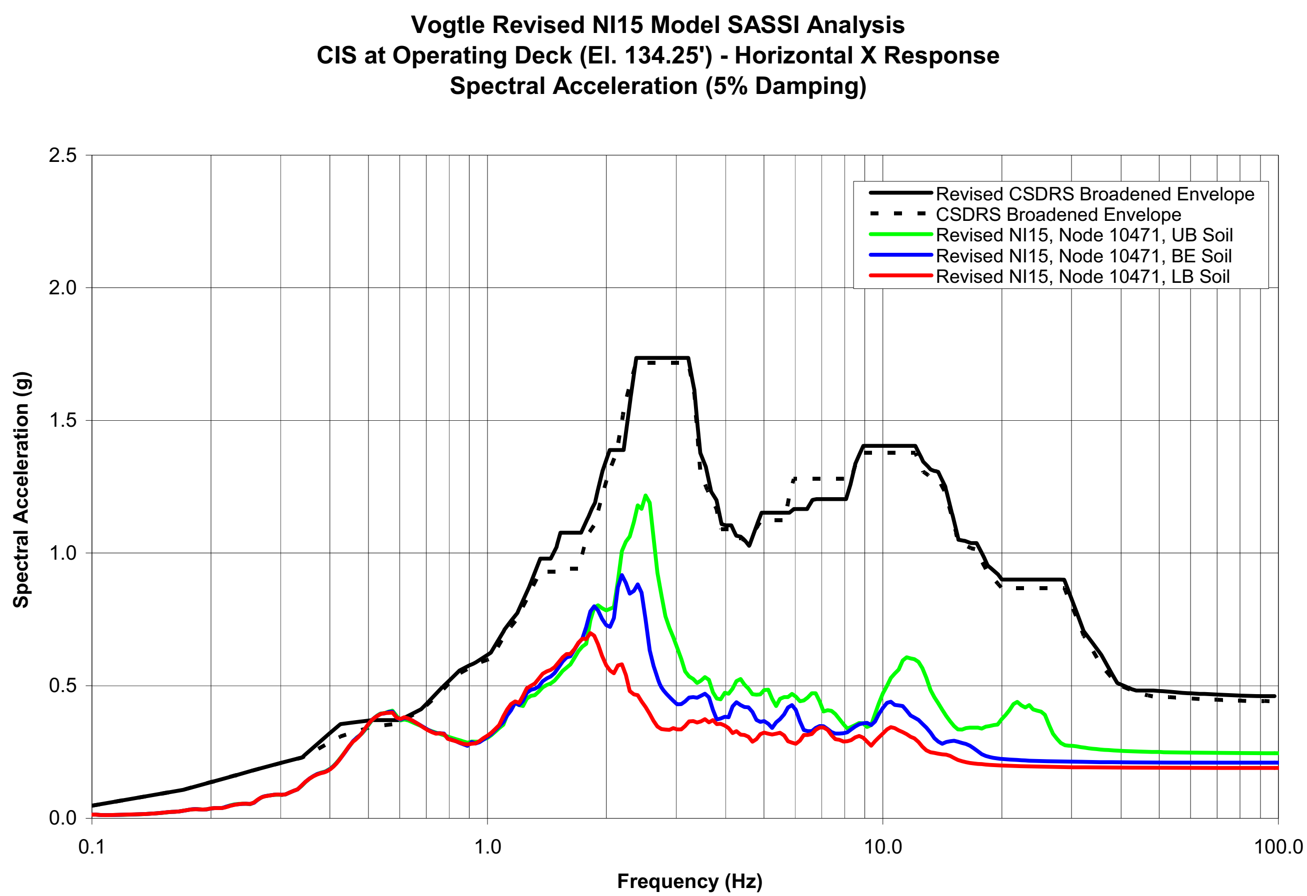

Figure 18 Horizontal X Response Spectra at CIS at Operating Deck (El. 134.25 ft, Node 10471)

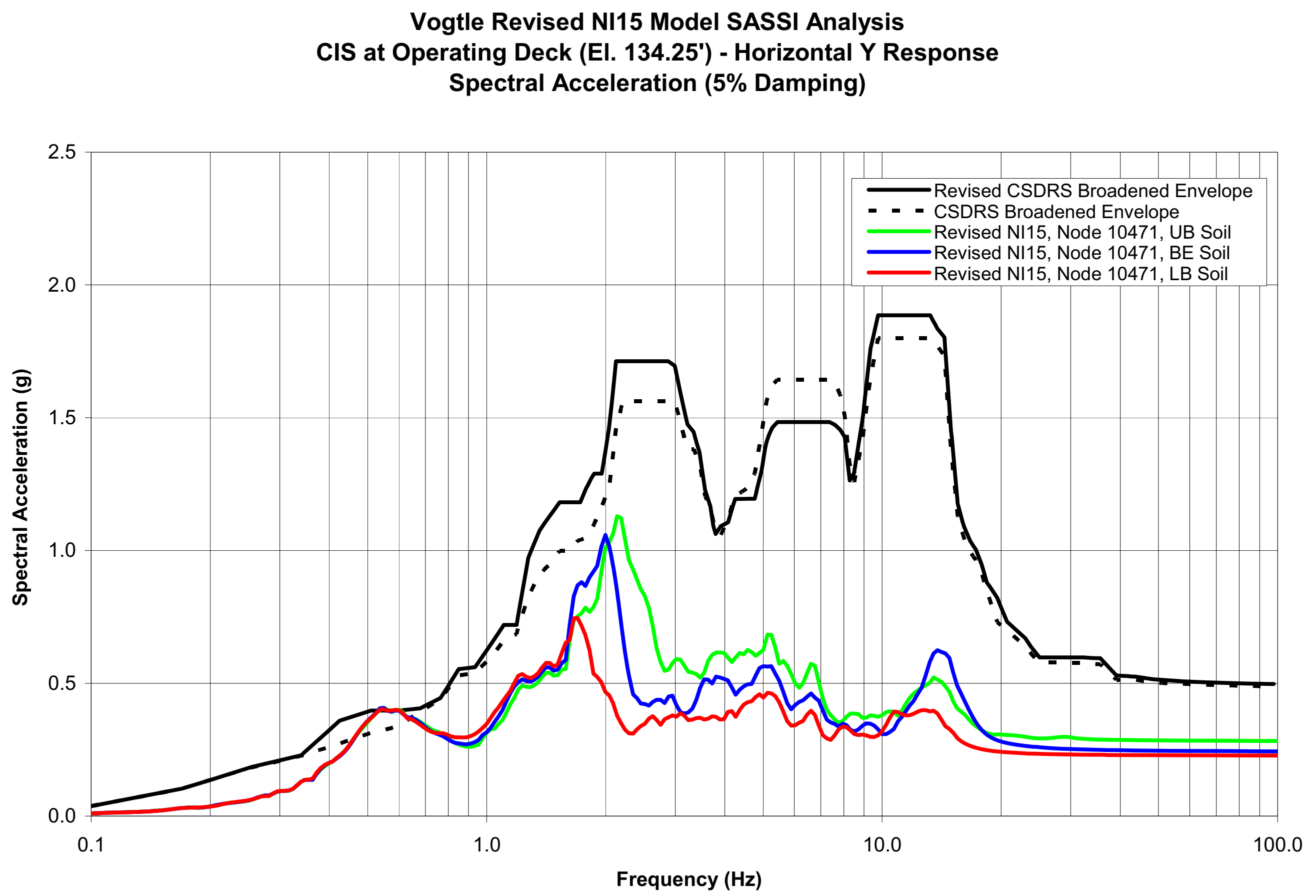

Figure 19 Horizontal Y Response Spectra at CIS at Operating Deck (El. 134.25 ft, Node 10471)

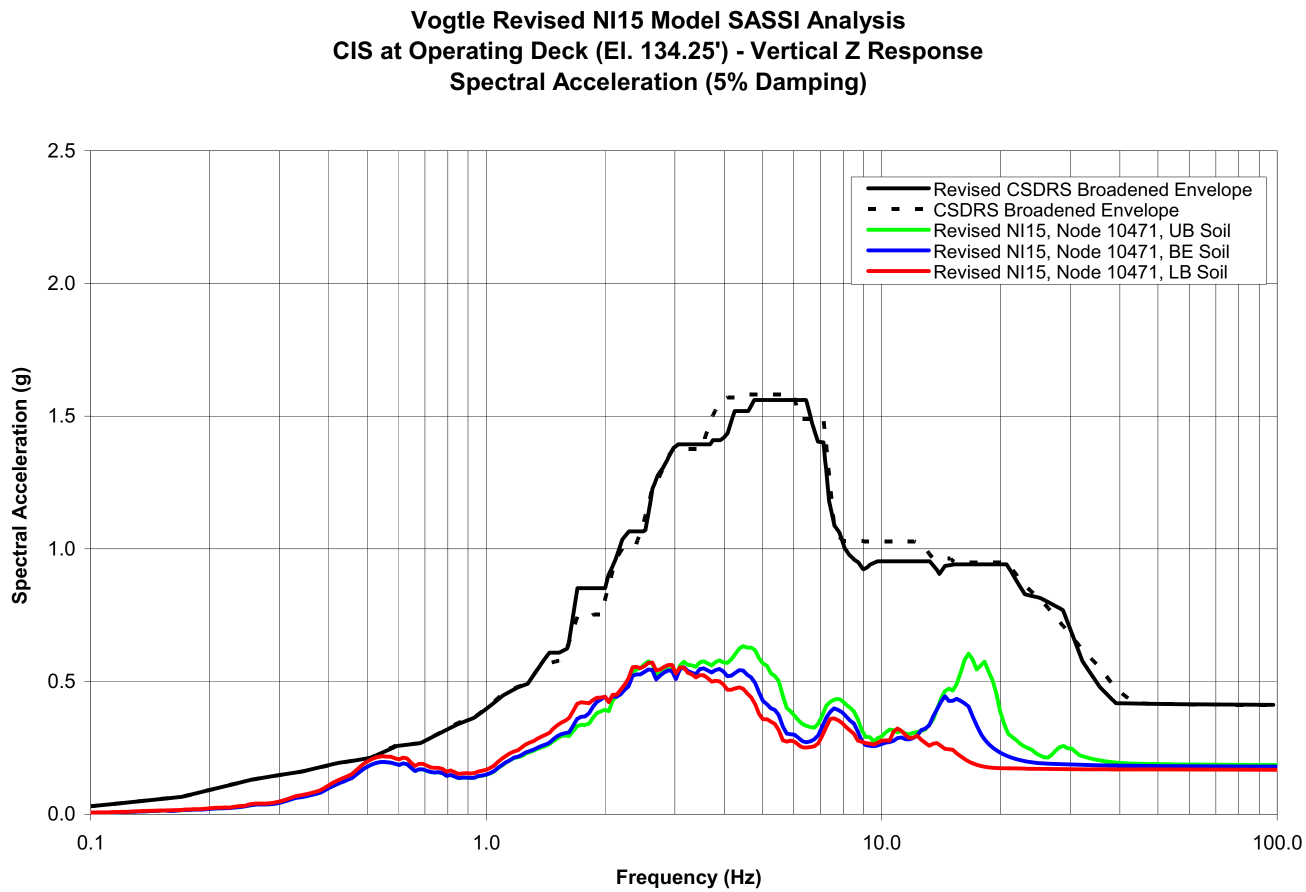

Figure 20 Vertical Z Response Spectra at CIS at Operating Deck (El. 134.25 ft, Node 10471)

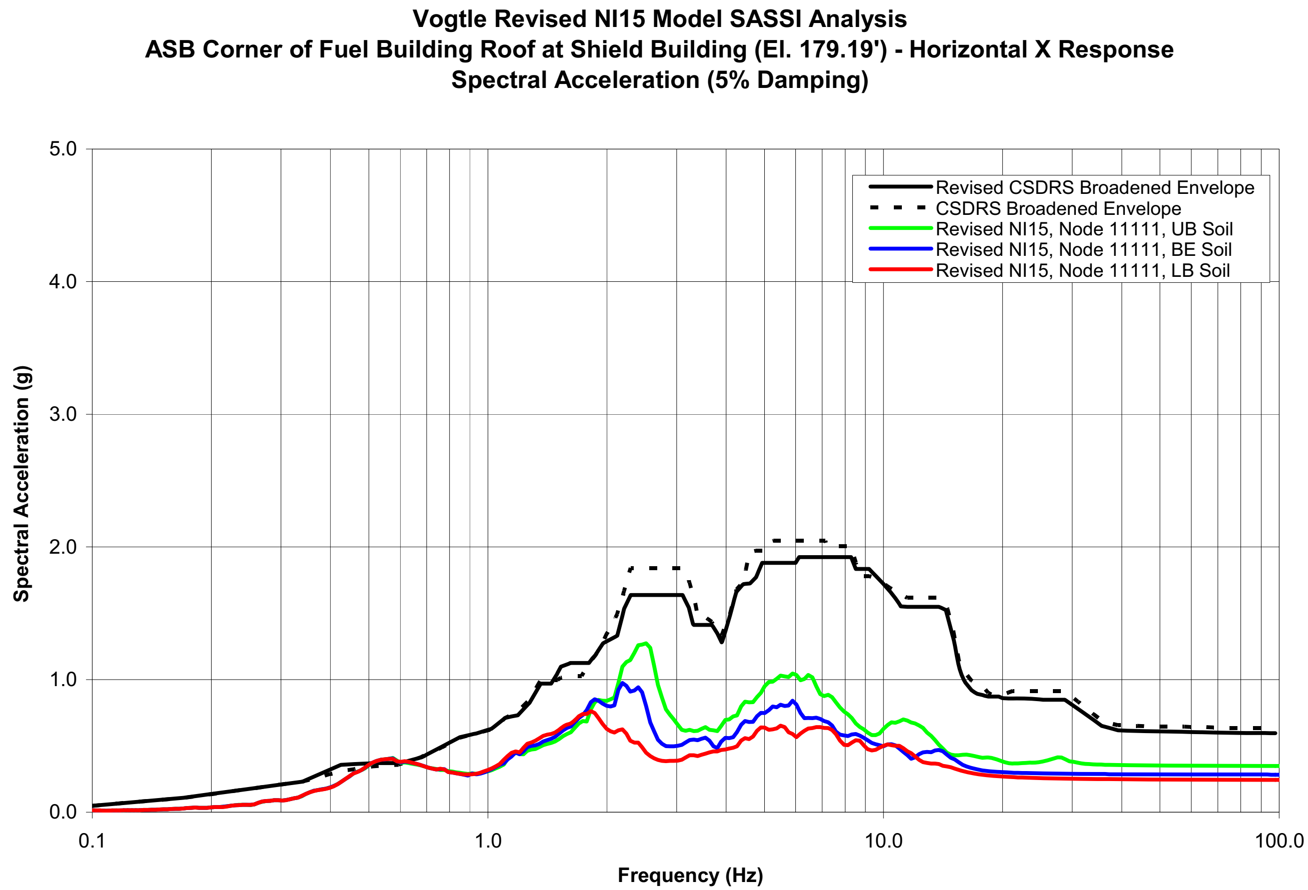

Figure 21 Horizontal X Response Spectra at ASB Corner of Fuel Building Roof at Shield Building (El. 179.19 ft, Node 11111)

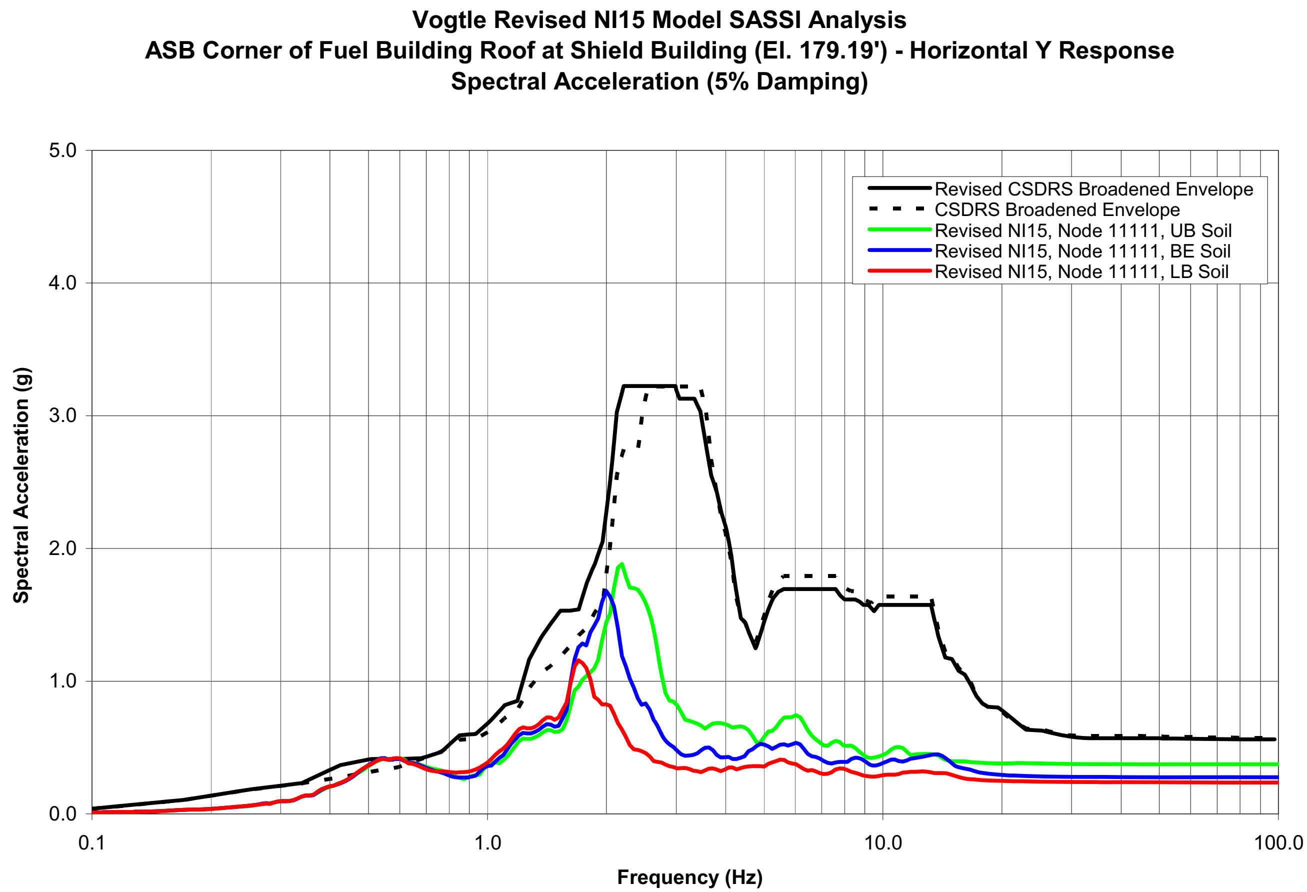

Figure 22 Horizontal Y Response Spectra at ASB Corner of Fuel Building Roof at Shield Building (El. 179.19 ft, Node 11111)

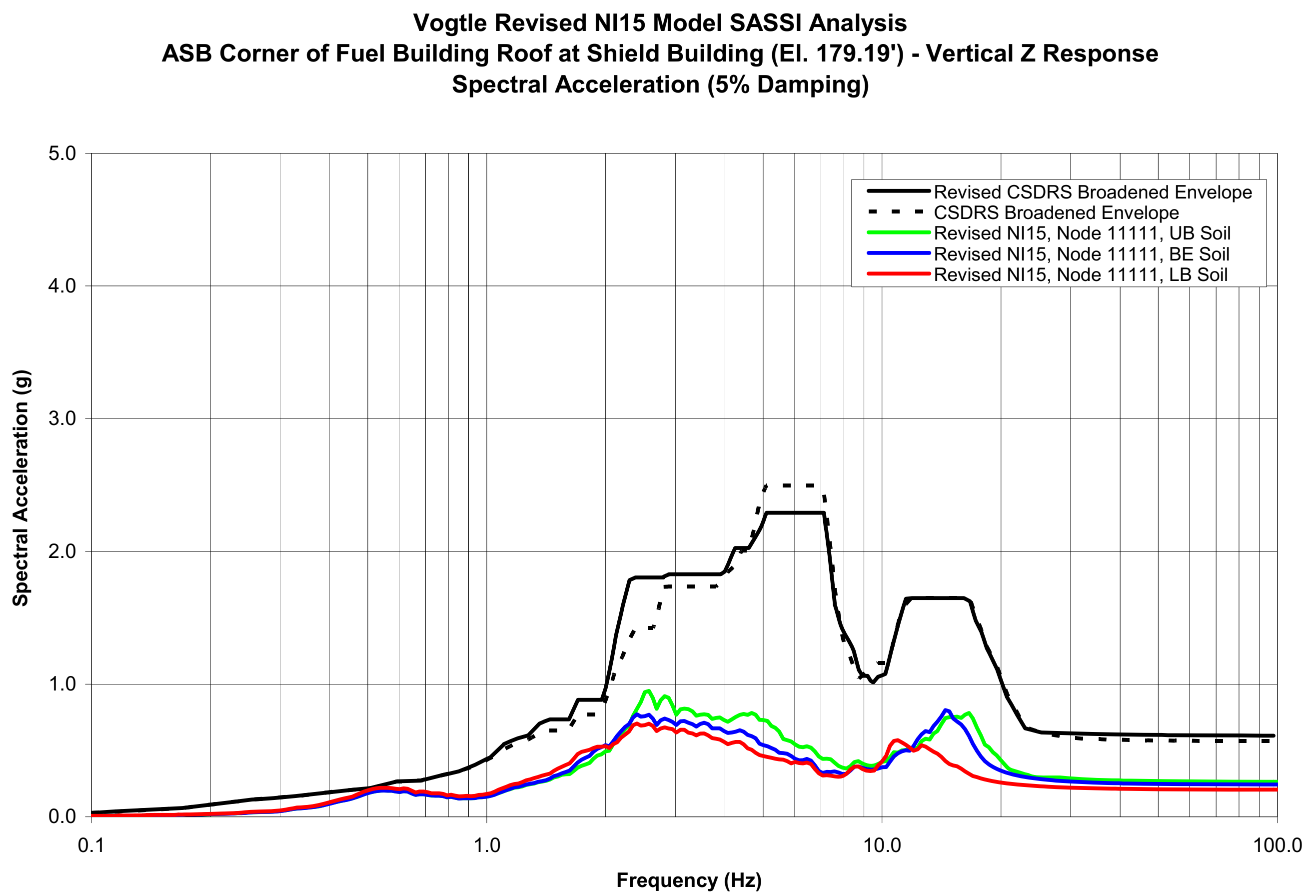

Figure 23 Vertical Z Response Spectra at ASB Corner of Fuel Building Roof at Shield Building (El. 179.19 ft, Node 11111)

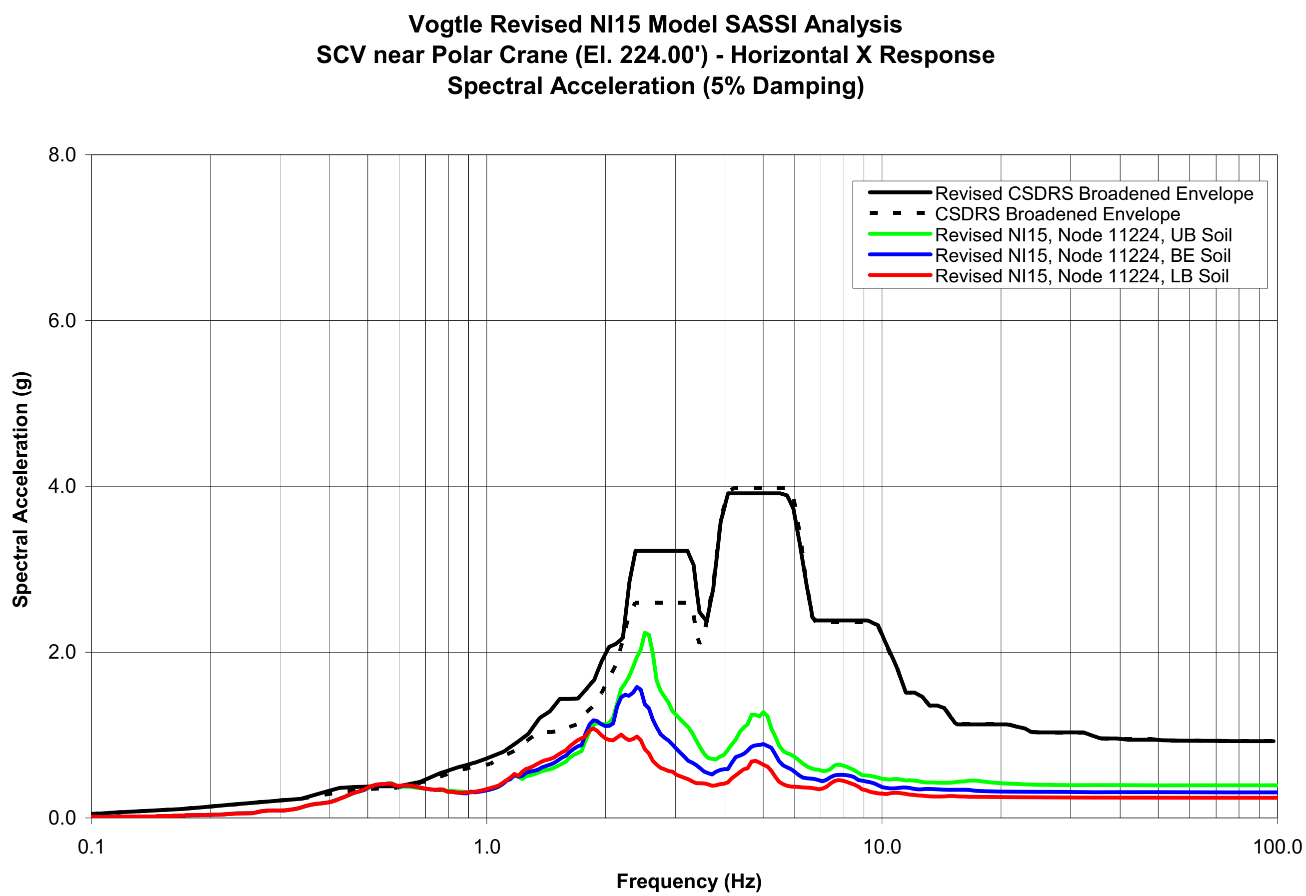

Figure 24 Horizontal X Response Spectra at SCV near Polar Crane (El. 224.00 ft, Node 11224)

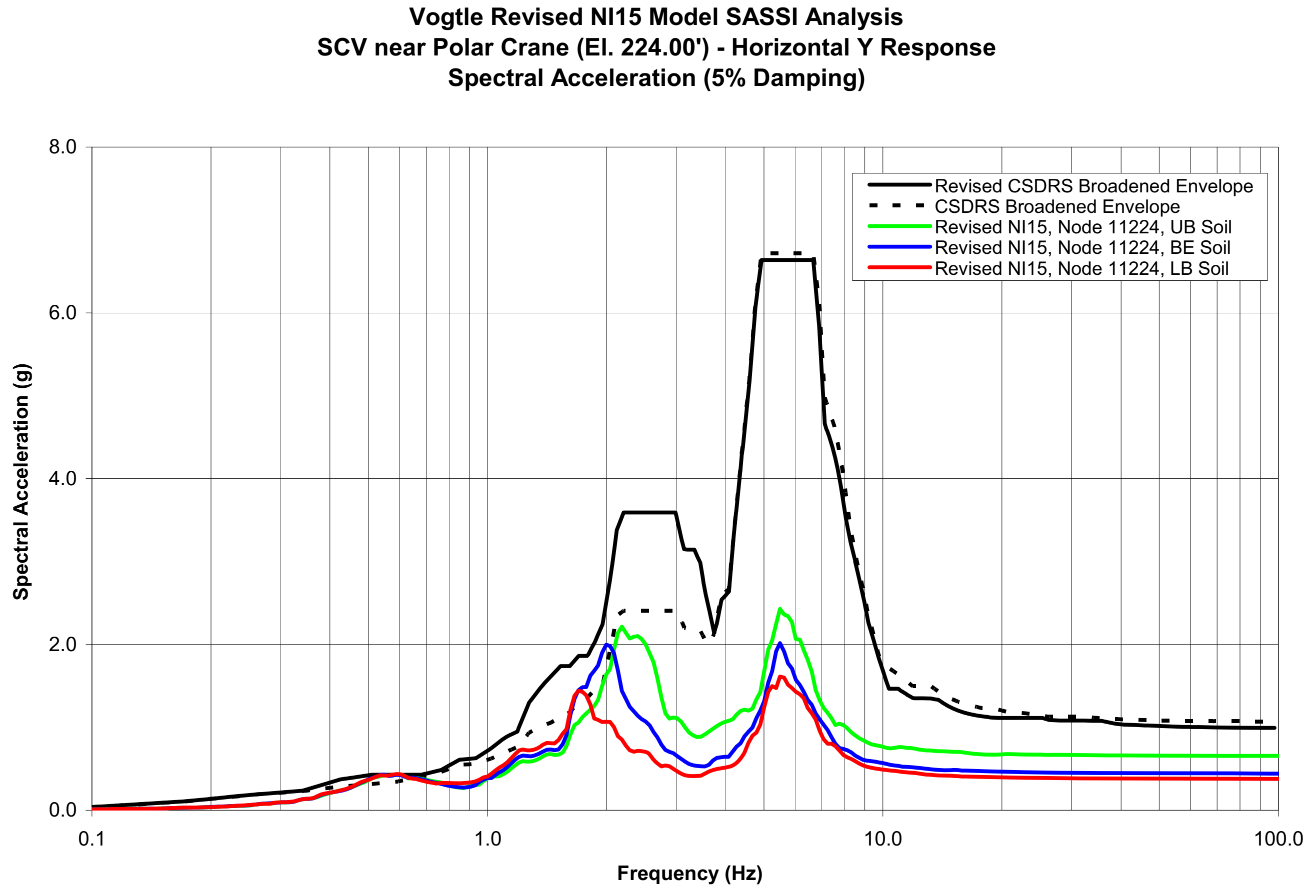

Figure 25 Horizontal Y Response Spectra at SCV near Polar Crane (El. 224.00 ft, Node 11224)

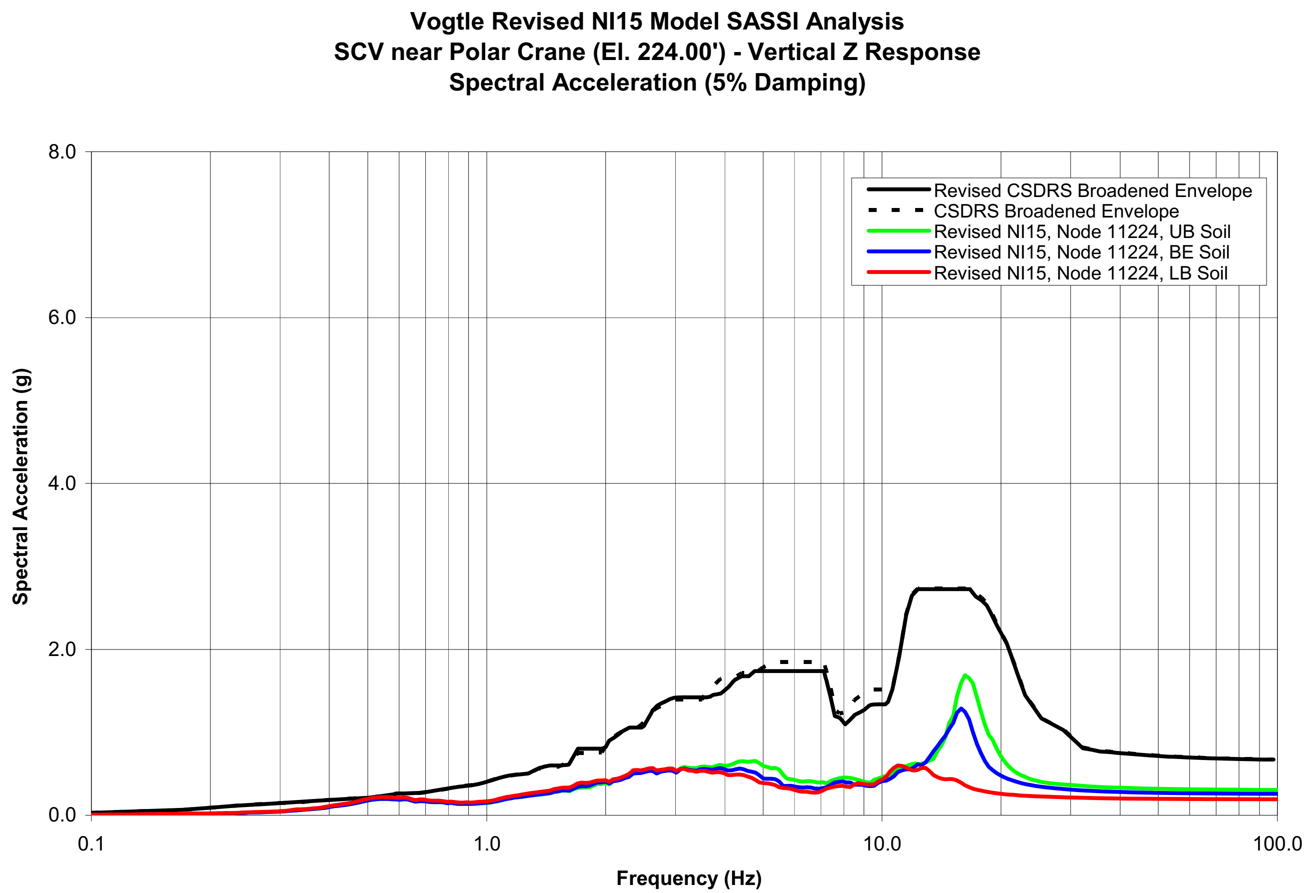

Figure 26 Vertical Z Response Spectra at SCV near Polar Crane (El. 224.00 ft, Node 11224)

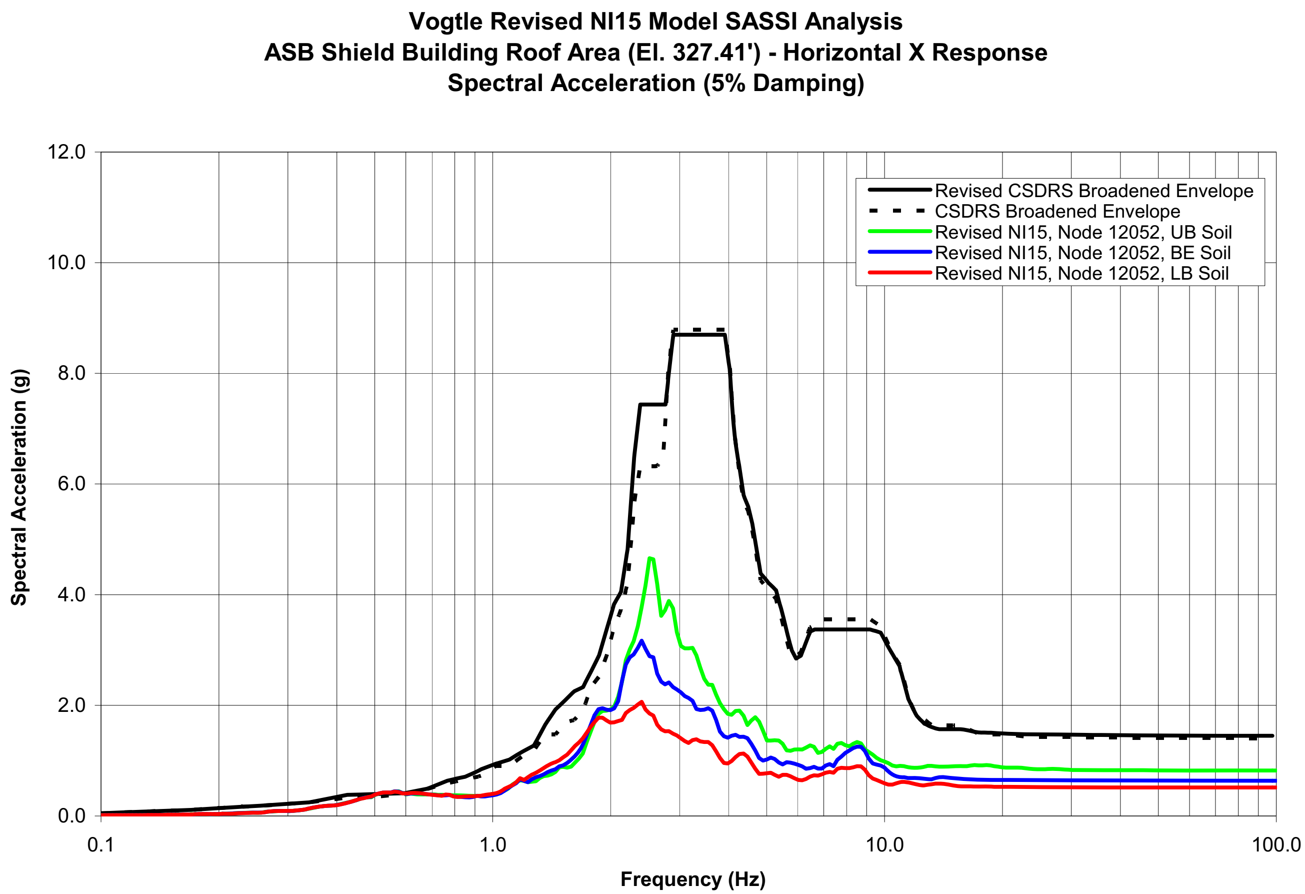

Figure 27 Horizontal X Response Spectra at ASB Shield Building Roof Area (El. 327.41 ft, Node 12052)

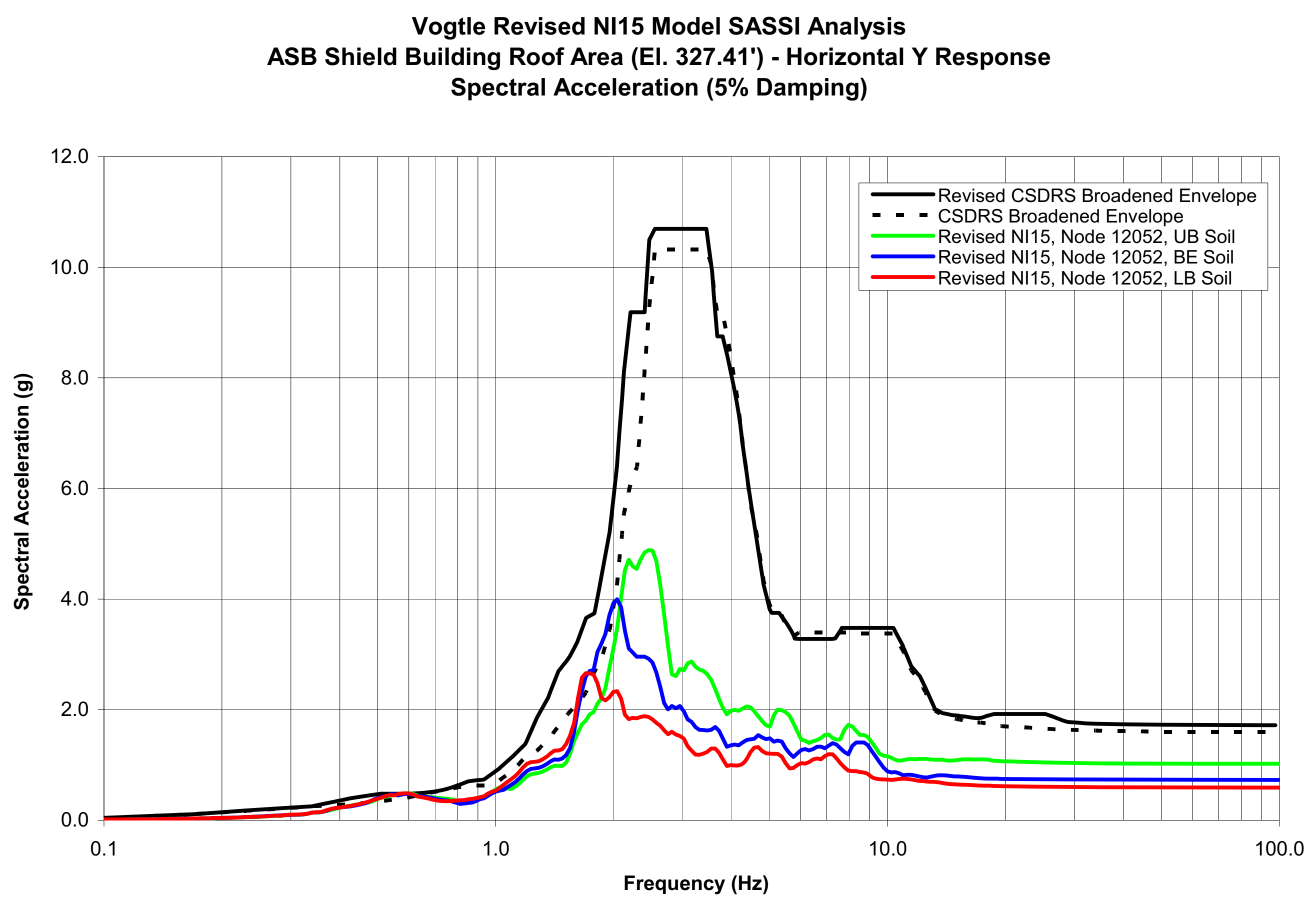

Figure 28 Horizontal Y Response Spectra at ASB Shield Building Roof Area (El. 327.41 ft, Node 12052)

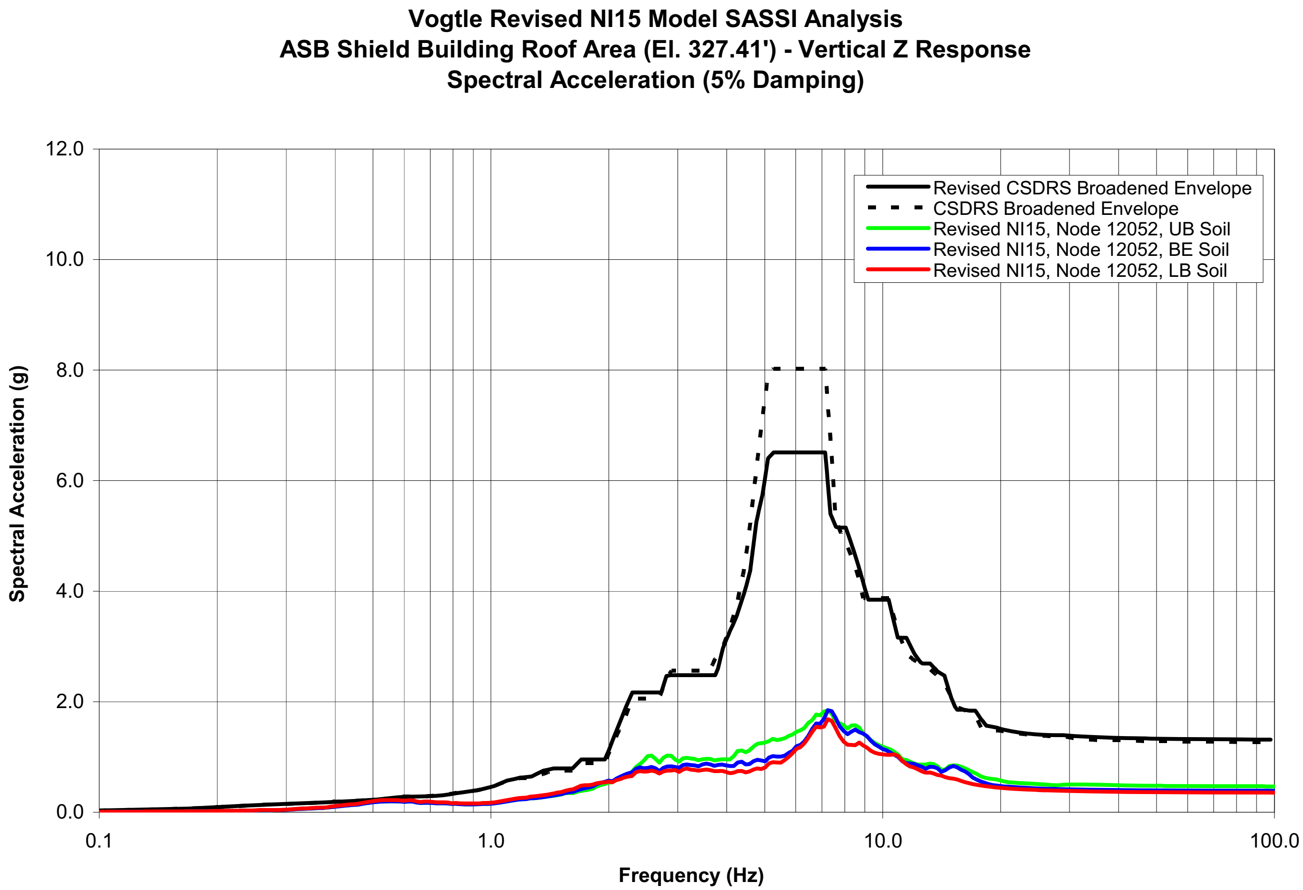

Figure 29 Vertical Z Response Spectra at ASB Shield Building Roof Area (El. 327.41 ft, Node 12052)