Appendix 3G Nuclear Island Seismic Analyses

3G.1 Introduction

This appendix summarizes the seismic analyses of the nuclear island building structures performed to support the AP1000 design certification extension from just hard rock sites, to sites ranging from soft soils to hard rock. The seismic Category I building structures consist of the containment building (the steel containment vessel [SCV] and the containment internal structures [CIS]), the shield building, and the auxiliary building. These structures are founded on a common basemat and are collectively known as the nuclear island or nuclear island structures. Key dimensions of the seismic Category I building structures, such as thickness of the basemat, floor slabs, roofs and walls, are shown in Figures 3.7.1-14 and 3.7.2-12.

Analyses were performed in accordance with the criteria and methods described in Section 3.7. Section 3G.2 describes the development of the finite element models. Section 3G.3 describes the soil structure interaction analyses of a range of site parameters and the selection of the parameters used in the design analyses. Section 3G.4 describes the fixed base and soil structure interaction dynamic analyses and provides typical results from these dynamic analyses. References 3 and 6 provide a summary of dynamic and seismic analysis results (i.e., modal model properties, accelerations, displacements, response spectra) and the nuclear island liftoff analyses. The seismic analyses of the nuclear island are summarized in a seismic analysis summary report. Deviations from the design due to as-procured or as-built conditions are acceptable based on an evaluation consistent with the methods and procedures of Sections 3.7 and 3.8 provided the following acceptance criteria are met:

- The structural design meets the acceptance criteria specified in Section 3.8.
- The seismic floor response spectra (FRS) meet the acceptance criteria specified in Subsection 3.7.5.4.

Depending on the extent of the deviations, the evaluation may range from documentation of an engineering judgment to performance of a revised analysis and design. The results of the evaluation will be documented in an as-built summary report by the Combined License applicant.

Table 3G.1-1 and Figure 3G.1-1 summarize the types of models and analysis methods that are used in the seismic analyses of the nuclear island, as well as the type of results that are obtained and where they are used in the design. Table 3G.1-2 summarizes the dynamic analyses performed and the methods used for combination of modal responses and directional input.

3G.2 Nuclear Island Finite Element Models

The AP1000 nuclear island consists of three distinct seismic Category I structures founded on a common basemat. The three building structures that make up the nuclear island are the coupled auxiliary and shield building (ASB), the SCV, and the CIS. The shield building and the auxiliary building are monolithically constructed with reinforced concrete and, therefore, considered one structure. The nuclear island is embedded approximately 40 feet with the bottom of basemat at elevation 60′-6″ and plant grade located at elevation 100′-0″. The SCV is described in Subsection 3.8.2, the CIS in Subsection 3.8.3, the ASB in Subsection 3.8.4, and the nuclear island basemat in Subsection 3.8.5.

Seismic systems are defined, according to SRP 3.7.2 (Reference 1), Section II.3.a, as the seismic Category I structures that are considered in conjunction with their foundation and supporting media to form a soil-structure interaction model. Fixed base seismic analyses are performed for the nuclear island at a rock site. Soil-structure interaction analyses are performed for soil sites. The analyses generate a set of in-structure responses (design member forces, nodal accelerations, nodal displacements, and floor response spectra), which are used in the design and analysis of seismic Category I structures, components, and seismic subsystems. Concrete structures are modeled with linear elastic uncracked properties. However, the modulus of elasticity is reduced to 80% of the ACI code value to reduce stiffness to simulate cracking.

A seismic response spectrum analysis is performed to develop the seismic design loads for the design of the auxiliary building, shield building, and containment internal structure, and the loads generated include the amplified load due to flexibility and the distribution of this load to the surrounding structures. Equivalent static analyses are used to design the shield building roof and radial roof beams, tension ring, air inlet structure, and PCS tank.

3G.2.1 Individual Building and Equipment Models

3G.2.1.1 Coupled Auxiliary and Shield Building

The finite element shell dynamic model of the coupled ASB is a finite element model using primarily shell elements. The portion of the model up to the elevation of the auxiliary building roof is developed using the solid model features of ANSYS, which allow definition of the geometry and structural properties. The nominal element size in the auxiliary building model is about 9 feet so that each wall has two elements for the wall height of about 18 feet between floors. This mesh size, which is the same as that of the solid model, has sufficient refinement for global seismic behavior. It is combined with a finite element model of the shield building roof and cylinder above the elevation of the auxiliary building roof. This model is shown in Figure 3G.2-1. This finite element shell dynamic model is part of the NI10 model.

Since the water in the passive containment cooling system tank responds at a very low frequency (sloshing) and does not affect building response, the passive containment cooling system tank water mass is reduced to exclude the low frequency water sloshing mass. The wall thickness of the bottom portion of the shield building (elevation 63.5′ to 81.5′) is modeled as one half (1.5′) since the CIS model is connected to this portion and extends out to the mid-radius of the shield building cylindrical wall. Local portions of the ASB floors and walls are modeled with sufficient detail to give the response of the flexible areas.

3G.2.1.2 Containment Internal Structures

The finite element shell model of the containment internal structures is a finite element model using primarily shell elements for the walls and floors and solid elements for the mass concrete. It is developed using the solid model features of ANSYS, which allow definition of the geometry and structural properties. This model is used in both static and dynamic analyses. It models the inner and outer mass concrete basemats embedding the lower portion of the containment vessel, and the concrete structures above the mass concrete inside the containment vessel. The walls and basemat inside containment for this model are shown in Figure 3G.2-2. The basemat (dish) outside the containment vessel is shown in Figure 3G.2-3. This finite element shell dynamic model is part of the NI10 model. Static analyses are also performed on the model to obtain member forces in the walls. This model is also used in the 3D finite element basemat model (see Subsection 3.8.5.4.1).

3G.2.1.3 Containment Vessel

The SCV is a freestanding, cylindrical, steel shell structure with ellipsoidal upper and lower steel domes. The finite element model of the containment vessel is an axisymmetric model fixed at elevation 100′. Static analyses are performed with this model to obtain shell stresses as described in Subsection 3.8.2.4.1.1. The model is also used to develop modal properties (frequencies and mode shapes). The three-dimensional, lumped-mass stick model of the SCV is developed based on the axisymmetric shell model. Figure 3G.2-4 presents the SCV stick model. In the stick model, the properties are calculated as follows:

- Members representing the cylindrical portion are based on the properties of the actual circular cross section of the containment vessel.
- Members representing the bottom head are based on equivalent stiffnesses calculated from the shell of revolution analyses for static 1.0g in vertical and horizontal directions.
- Shear, bending and torsional properties for members representing the top head are based on the average of the properties at the successive nodes, using the actual circular cross section. These are the properties that affect the horizontal modes. Axial properties, which affect the vertical modes, are based on equivalent stiffnesses calculated from the shell of revolution analyses for static 1.0g in the vertical direction.

The equivalent static acceleration analyses of the containment vessel use a finite element shell model with a refined mesh in the area adjacent to the large penetrations. Comparison of this with a time history analysis for the regions immediately surrounding the large penetrations verifies that the loads from equivalent static analysis are conservative to time history using a representative study.

The stick model is combined with the polar crane stick model as shown in Figure 3G.2-4. Modal properties of the containment vessel with and without the polar crane are shown in Table 3G.2-1. It is connected to nodes on the dish model. NI10 node numbers are shown in red and NI20 node numbers are shown in black.

The method used to construct a stick model from the axisymmetric shell model of the containment vessel is verified by comparison of the natural frequencies determined from the stick model and the shell of revolution model as shown in Table 3G.2-2. The shell of revolution vertical model (n = 0 harmonic) has a series of local shell modes of the top head above elevation 265′ between 23 and 30 hertz. These modes are predominantly in a direction normal to the shell surface and cannot be represented by a stick model. These local modes have small contribution to the total response to a vertical earthquake as they are at a high frequency where seismic excitation is small. The only seismic Category I components attached to this portion of the top head are the water distribution weirs of the passive containment cooling system. These weirs are designed such that their fundamental frequencies are outside the 23 to 30 hertz range of the local shell modes.

An evaluation was made of the connection of the bottom of the steel containment vessel stick model to the CIS finite element model. Comparisons were made between the unconstrained fully symmetric, radially constrained fully symmetric, and original asymmetric connectivity models. The response spectra at the elevation of the polar crane girder for the first two models are almost identical, and the third model had only minor differences. Based on this comparison, the unconstrained fully symmetric connectivity model is used.

3G.2.1.4 Polar Crane

The polar crane is supported on a ring girder, which is an integral part of the SCV at elevation 228′-0″, as shown in Figure 3.8.2-1. It is modeled as a multi-degree of freedom system attached to the steel containment shell at elevation 224′ (midpoint of ring girder) as shown in Figure 3G.2-4. The polar crane is modeled using a simplified and detailed model. The simplified model has five masses at the mid-height of the bridge at elevation 236′-6″ and one mass for the trolley, as shown in Figure 3G.2-5A. The polar crane model includes the flexibility of the crane bridge girders and truck assembly. The containment shell's local flexibility is considered when combined with the global model. When fixed at the center of containment, the model shows fundamental frequencies of 4.6 hertz transverse to the bridge, 6.9 hertz vertically, and 9.4 hertz along the bridge. The Detailed

Model of the polar crane consists of 76 nodes is defined having 96 dynamic degrees of freedom. It is used to verify the accuracy of the simplified model. This model is shown in Figure 3G.2-5B.

Nodes 425 to 428 are connected to 48 additional nodes. All 52 of these nodes are used to model the truck stiffnesses. The local SCV stiffness is considered when the detailed model of the polar crane is combined with the SCV model.

1. The elements connecting nodes 433, 431/477, 435, 436, 432/478, and 434 represent the trolley.
2. Nodes 437 to 454 are located on the polar crane bridge girders and cross beams. The end nodes (437, 443, 444, and 450) are used to connect the cross beams to the girders; these nodes are also attached to the trucks (nodes 425 to 428) by rigid links.
3. When the Detailed Model of the polar crane is combined with the SCV model, nodes 508 to 511, 528 to 531, 548 to 551, and 568 to 571 are merged to SCV nodes on the polar crane ring girder.

3G.2.1.5 Major Equipment and Structures Using Stick Models

The major equipment supported by the CIS is represented by stick models connected to the CIS. These stick models are the reactor coolant loop model shown in Figure 3G.2-6, the pressurizer model shown in Figure 3G.2-7, and the core makeup tank model shown in Figure 3G.2-8. The core makeup tank model is used only in the nuclear island fine (NI10) model; the core makeup tank is represented by mass in the nuclear island coarse model (NI20).

3G.2.2 Nuclear Island Dynamic Models

Finite element shell models (3D) of the nuclear island concrete structures are used for the time history seismic analyses. Stick models are coupled to the shell models of the concrete structures for the containment vessel, polar crane, the reactor coolant loop and pressurizer. Two models are used. The fine (NI10) model is used to define the seismic response for the hard rock site. The coarse (NI20) model is used for the soil structure interaction (SSI) analyses. It is similar to the NI10 model with the exception that the mesh size for the ASB and CIS is approximately 20 feet instead of 10 feet. This model is set up in both ANSYS and SASSI. The NI05 model is used to develop amplified seismic response for the envelope of soil profiles presented in Subsection 3.7.1.4 for flexible regions not captured by the coarser NI20 model. The NI05 model is also used in response spectrum analysis of the nuclear island to develop design seismic member forces and moments. The NI10, NI20, and NI05 models are described in the subsections below.

3G.2.2.1 NI10 Model

The large solid-shell finite element model of the AP1000 nuclear island shown in Figure 3G.2-9 combines the ASB solid-shell model described in Subsection 3G.2.1.1, and the CIS solid-shell model described in Subsection 3G.2.1.2. The containment vessel and major equipment that are supported by the CIS are represented by stick models and are connected to the CIS. These stick models are the SCV and the polar crane models, the reactor coolant loop model, core makeup tank models, and the pressurizer model. The stick models are described in Subsections 3G.2.1.3 and 3G.2.1.4. The CIS and attached sticks are shown in Figure 3G.2-10. This AP1000 nuclear island model is referred to as the NI10 or fine model. The ASB portion of this model has a mesh size of approximately 10 feet.

The SCV is connected to the CIS model using constraint equations. The SCV at the bottom of the stick at elevation 100′ (node 130401) is connected to CIS nodes at the same elevation. Figure 3G.2-4 shows the SCV stick model with the constraint equation nodes. The nodes are defined using a cylindrical coordinate system whose origin coincides with the center of containment (node 130401). The CIS vertical displacement is tied rigidly (constrained) to the vertical displacement and RX and RY rotations of node 130401. The CIS tangential displacement is tied rigidly (constrained) to the horizontal displacement and RZ rotation of node 130401.

3G.2.2.2 NI20 Model

The NI20 coarse model has fewer nodes and elements than the NI10 model. It captures the essential features of the nuclear island configuration. The nominal shell and solid element dimension is about 20 feet. It is used in the soil-structure interaction analyses of the nuclear island performed using the program SASSI. The stick models are the same as used for the NI10 model except that the core makeup tank is not included. This model is shown in Figures 3G.2-11 and 3G.2-12. Results of fixed base analyses of the NI20 model were compared to those of the NI10 model to confirm the adequacy of the NI20 model for use in the soil-structure-interaction analyses.

3G.2.2.3 Nuclear Island Stick Model

The nuclear island lumped-mass stick model consists of the stick models of the individual buildings interconnected by rigid links. Each individual stick model is developed to match the modal properties of the finite element models described in Subsections 3G.2.1.1 and 3G.2.1.2 above. Modal analyses and seismic time history analyses were performed using this model for the hard rock design certification.

The nuclear island lumped-mass stick model has been replaced in the design analyses described in this appendix by the NI10 and NI20 finite element shell dynamic models of the nuclear island described in Subsections 3G.2.2.1 and 3G.2.2.2 above. A 2D stick model is used in the soil sensitivity analyses described in Section 3G.3.

3G.2.2.4 NI05 Model

The NI05 solid-shell finite element model of the AP1000 nuclear island is shown in Figures 3G.2-13 to 3G.2-15. The NI05 model is used for response spectrum analysis of the nuclear island auxiliary and shield building structures. The NI05 model is also used for the mode superposition time history analysis of the nuclear island for the amplified response at flexible floors. The NI05 model is used for the static analysis of the nuclear island for the basemat design. The NI05 model is a refined version of the NI10 model where the auxiliary and shield building mesh size is reduced from approximately 10 feet by 10 feet tetrahedral mesh to approximately 5 feet by 5 feet. The major equipment stick models supported by the CIS are the same as used for the NI10 model. The steel containment vessel stick model and connections are also the same as the NI10 model. The only difference between the NI05 CIS and NI10 CIS is the basemat (bowl) and dish region as shown in Figure 3G.2-15. The model is validated by a comparison of the mass participation by frequency of the fundamental modes to those of the NI10 model.

3G.2.2.5 Seismic Stability Model

The sliding stability of the nuclear island basemat is evaluated using a non-linear 2D East-West (EW) stick model of the nuclear island structures using the ANSYS program. Three concentric sticks represent ASB, CIS, and SCV, respectively. The reactor coolant loop is included as mass only. The basemat is modeled as a rigid beam, which is free in translation along the EW and vertical directions. The nuclear island combined sticks are attached to the rigid basemat at the nuclear island mass center.

Each node of the rigid basemat is connected with two spring elements in the horizontal and vertical directions, respectively. The spring elements only model the foundation media (rock or soil) damping, not stiffness. A layer of contact elements is added along the rigid basemat bottom to simulate the friction forces between basemat bottom and foundation media as well as foundation media stiffnesses. The friction coefficient between the basemat bottom and the soil media is set at 0.55. Figure 3G.2-19 shows the schematic of this non-linear 2D EW nuclear island stick model. The contact elements are free to uplift when the upward force (normal force) is larger than the associated dead load component. When the tangential force is larger than the friction force, sliding occurs.

3G.2.3 Static Models

Member forces in the ASB are obtained from analyses of a model that is more refined than the finite element model described in Subsection 3G.2.1.1. This model is developed by meshing one area of the solid model with four finite elements. The nominal element size in this auxiliary building model is about 4.5 feet so that each wall has four elements for the wall height of about 18 feet between floors. This finite element shell model is referred to as the NI05 model. This refinement is used to calculate the design member forces and moments using response spectra analysis of the nuclear island models with seismic input enveloping all soil conditions. The finite element shell model of the containment internal structures described in Subsection 3G.2.1.2, which includes the basemat within the shield building and the containment vessel stick model, is also included.

Finite element solid/shell models were used for the equivalent static seismic analysis. For the detailed design of the shield building roof, a finite element model of one quadrant of the roof is used as described in Subsection 3G.2.3.1. For the detailed design of the steel containment vessel, a shell mesh finite element model with a much finer mesh in the areas surrounding the major penetrations is used as described in Subsection 3G.2.3.2. For the static analysis of the containment vessel, an axisymmetric model is used as described in Subsection 3G.2.3.3. The nuclear island basemat is evaluated using the NI05 finite element model described in Subsection 3G.2.2.4.

3G.2.3.1 Quadrant Model of Shield Building Roof

The one quadrant model of the shield building roof is shown in Figure 3G.2-16. The model is constructed with solid and shell elements and contains structures from the exposed shield wall through the top of the shield building roof. The quadrant model is used for the equivalent static analysis of the shield building roof. The results from the more detailed analysis are used in the design of the shield building roof and radial roof beams, tension ring, air inlet structure, and PCS tank.

3G.2.3.2 Containment Vessel 3D Finite Element Model

The 3D finite element model of the steel containment vessel is shown in Figure 3G.2-17. The finite element model for the steel containment vessel is used for the stress analysis of the large penetrations (personnel locks and equipment hatches) of the containment vessel.

3G.2.3.3 Containment Vessel Axisymmetric Model

The axisymmetric finite element model of the steel containment vessel is shown in Figure 3G.2-18. The axisymmetric model is a two-dimensional model with added mass for the stiffeners, crane girder, equipment hatches, and air locks.

3G.3 2D SASSI Analyses

This section describes the soil structure interaction analyses performed using 2D models in SASSI to select the design soil cases for the AP1000. The AP1000 footprint, or interface to the soil medium, is identical to the AP600. The AP1000 containment and shield building are 25′ 6″ and 20′ 6″ (Reference 4) respectively taller than AP600. Results and conclusions from the AP600 soil studies (Reference 2) are considered in establishing the design soil profiles for the AP1000.

Analyses were performed using 2D stick models of the AP1000 for horizontal seismic input with and without adjacent structures. The soil profiles included a hard rock site, a firm rock site, a soft rock site, a soft-to-medium soil site, an upper bound soft-to-medium site, and a soft soil site. Analyses were also performed without adjacent structures for a hard rock site, a firm rock site, a soft rock site, a soft-to-medium soil site, an upper bound soft-to-medium site, and a soft soil site. The soil damping and degradation curves are described in Subsection 3.7.1.4. The soil profiles selected for the AP1000 use the same parameters on depth to bedrock, depth to water table, and variation of shear wave velocity with depth as those used in the AP600 design analyses. The Poisson's ratio is 0.25 for rock sites (hard and firm rock) and 0.35 for soil sites (soft-to-medium soil, and upper bound soft-to-medium soil). For all the soil profiles defined, the base rock has been taken to be at 120 feet below grade level. The soil profiles are shown in Figure 3G.3-1. The shear wave velocity profiles and related governing parameters are as follows:

- For the hard rock site, an upper bound case for rock sites using a shear wave velocity of 8000 feet per second.
- For the firm rock site, a shear wave velocity of 3500 feet per second to a depth of 120 feet, and base rock at the depth of 120 feet.
- For the soft rock site, a shear wave velocity of 2400 feet per second at the ground surface, increasing linearly to 3200 feet per second at a depth of 240 feet, and base rock at the depth of 120 feet.
- For the upper bound soft-to-medium soil site, a shear wave velocity of 1414 feet per second at ground surface, increasing parabolically to 3394 feet per second at 240 feet, base rock at the depth of 120 feet, and ground water at grade level. The initial soil shear modulus profile is twice that of the soft-to-medium soil site.
- For the soft-to-medium soil site, a shear wave velocity of 1000 feet per second at ground surface, increasing parabolically to 2400 feet per second at 240 feet, base rock at the depth of 120 feet, and ground water is assumed at grade level.
- For the soft soil site, a shear wave velocity of 1000 feet per second at ground surface, increasing linearly to 1200 feet per second at 240 feet, base rock at the depth of 120 feet, and ground water is assumed at grade level.

The analyses with and without adjacent structures demonstrated that the effect of adjacent buildings on the nuclear island response is small. Based on this, the 3D SASSI analyses of the AP1000 nuclear island can be performed without adjacent buildings similar to those performed for the AP600.

The maximum acceleration values obtained from the AP1000 analyses without adjacent structures are given in Table 3G.3-1. The soil cases giving the maximum response are shown in bold. Floor response spectra associated with nodes 41, 120, 310, 411, and 535 for the six AP1000 soil cases are shown in Figures 3G.3-2 to 3G.3-11.

Based on review of the above results, five soil conditions were selected for 3D SASSI analyses in addition to the hard rock condition evaluated in the existing AP1000 Design Certification. Thus, the following five soil and rock cases identified in Subsection 3.7.1.4 are considered: hard rock, firm rock, soft rock, soft-to-medium soil, upper bound soft-to-medium, and soft soil.

3G.4 Nuclear Island Dynamic Analyses

3G.4.1 ANSYS Fixed Base Analysis

The NI10 model described in Subsection 3G.2.2.1 was analyzed by time history modal superposition. To perform the time history analysis of this large model, the ANSYS superelement (substructuring) techniques were applied. Substructuring is a procedure that condenses a group of finite elements into one element represented as a matrix. The reasons for substructuring are to reduce computer time of subsequent evaluations. Two sets of analyses were performed. To obtain the time history response of the ASB, the ASB finite element model was merged with the superelement of the CIS and its major components. To obtain the time history response of the CIS, the CIS finite element model was merged with the superelement of the ASB.

Deflection time history responses were obtained at selected representative locations. These locations included major wall and floor intersections and nodes at the cardinal orientations at key elevations of the shield building. Nodes were also selected at mid-span on flexible walls and floors. Typical locations are shown for the ASB at elevation 135′ on Figures 3G.4-1 and 3G.4-2. Figure 3G.4-1 shows the “rigid” locations, and Figure 3G.4-2 shows the “flexible” locations.

ANSYS is used to calculate the maximum relative deflection to the nuclear island for the envelope case that considers all of the soil and hard rock site cases. Synthesized displacement time histories are developed using the envelope seismic response spectra from the six site conditions (hard rock, firm rock, soft rock, upper-bound-soft-to-medium, soft-to-medium, and soft soil). Seismic response spectra at nine locations are used (four edge locations, one center location, and four corner locations). It is not necessary to adjust for drift since relative deflections to the basemat are calculated and the drift would be subtracted from the results.

3G.4.2 3D SASSI Analyses

The computer program SASSI 2000 is used to perform Soil-Structure Interaction analysis with the NI20 Coarse Finite Element Model. The SASSI Soil-Structure Interaction analyses are performed for the five soil conditions established from the AP1000 2D SASSI analyses. These soil conditions are firm rock, soft rock, soft-to-medium soil, upper bound soft-to-medium, and soft soil. The model includes a surrounding layer of excavated soil and the existing soil media as shown in Figures 3G.4-3 and 3G.4-4. Acceleration time histories and floor response spectra are obtained. Adjacent structures have a negligible effect on the nuclear island structures and, thus, are not considered in the 3D SASSI analyses.

Westinghouse has adopted the approach that calculates displacements internally within the ACS SASSI program based on an analytical complex frequency domain approach that uses inverse Fast-Fourier Transforms (FFT) to compute relative displacement histories instead of double numerical integration in the time domain that computes absolute displacement time histories from absolute acceleration time histories.

The relative displacement time history is calculated using ACS SASSI RELDISP module. The complex acceleration transfer functions (TF) are computed for reference and all selected output nodes. The relative acceleration transfer function is calculated by subtracting the reference node TF from the output node TF. The relative displacement transfer function is obtained by dividing the circular frequency square (ω^2) for each frequency data point. The relative displacement time history is obtained by taking the inverse FFT.

Relative displacements are calculated between adjacent buildings and the nuclear island using soft springs between the buildings. The spring stiffness is very small so that it does not affect the dynamic response. These calculations are performed using 2D models and SASSI 2000. The relative deflection is calculated using the maximum compressive spring force and the stiffness value.

In these analyses, the three components of ground motions (N-S, E-W, and vertical direction) are input separately. Each design acceleration time history (N-S, E-W, and vertical) is applied separately, and the time history responses are calculated at the required nodes. The resulting co-linear time history responses at a node due to the three earthquake components are then combined algebraically.

3G.4.3 Seismic Analysis

3G.4.3.1 Response Spectrum Analysis

The response spectrum methodology used in the AP1000 design employs the Complete Quadratic Combination (CQC, Section 1.1 of Reference 5) grouping method for closely spaced modes with the Der Kiureghian Correlation Coefficient (Section 1.1.3 of Reference 5) used for correlation between modes. The Lindley-Yow (Section 1.3.2, Reference 5) spectra analysis methodology is employed for modes with both periodic and rigid response components. The modal analysis performed to develop composite modal participation is used to develop input for the response spectrum analysis. Modes ranging from 0 to 33 Hz or higher are considered. For modes above the cutoff frequency, the Lindley-Yow is used. The Static ZPA Method (Section 1.4.2, Reference 5) is employed for the residual rigid response component for each mode as outlined in NRC Regulatory Guide 1.92 (Reference 5). The complete solution is developed via Combination Method B (Section 1.5.2, Reference 5). The combined effects, considering three spatial components of an earthquake (N-S, E-W, and Vertical), are combined by square root sum of the squares method (Section 2.1, Reference 5).

In Subsection 3.7.2.6, “Three Components of Earthquake Motion,” the combination of three components of earthquake motion is discussed.

3G.4.3.2 Absolute Accelerations

The seismic analyses results, which include the new shield building configuration described in Section 3.8, are given in Reference 3.

3G.4.3.3 Seismic Response Spectra

The AP1000 plant floor response spectra for the six key locations are provided in Figure 3G.4-5X to 3G.4-10Z. The key locations are defined in Table 3G.4-1. The design seismic response spectra are conservatively adjusted in the low frequency range in anticipation of future sites having a slightly higher response at the lower frequency.

The in-structure response spectra at six key locations, as defined below, are used if a site-specific 3D dynamic analysis evaluation as outlined in Subsection 2.5.2 is required. The site is acceptable if the floor response spectra from the site-specific evaluation do not exceed the AP1000 spectra for each of the locations identified below or the exceedances are justified.

[*FRS Location*	*Figure Numbers*
Containment internal structures at elevation of reactor vessel support	*Figure 3G.4-5X* to *3G.4-5Z*
Containment operating floor	*Figure 3G.4-6X* to *3G.4-6Z*
Auxiliary building NE corner at elevation 116'-6"	*Figure 3G.4-7X* to *3G.4-7Z*
Shield building at fuel building roof	*Figure 3G.4-8X* to *3G.4-8Z*

*NRC Staff approval is required prior to implementing a change in this information.

Shield building roof	*Figure 3G.4-9X to 3G.4-9Z*
Steel containment vessel at polar crane support	*Figure 3G.4-10X to 3G.4-10Z*]*

Note:
See Table 3G.4-1 for locations of six key locations.

3G.4.3.4 Bearing Pressure Demand

Bearing pressure demand was calculated using both 2D and 3D analyses. Both linear and non-linear analyses are performed with the 2D nuclear island model. The maximum bearing pressures calculated include the effect of dead, live, and seismic loading.

The 2D model was used to evaluate the effect of liftoff on the bearing pressure. Since the largest bearing pressure will result from the east-west seismic excitation because of the smaller width of the basemat in this direction, liftoff was evaluated using an east-west stick model of the nuclear island structures, supported on a rigid basemat with non-linear springs. Direct integration time history analyses were performed. The bearing pressures calculated from these analyses are summarized in Table 3G.4-2. The pressures are at the edge of the basemat. Results are given for the three cases that result in the highest bearing pressure (hard rock [HR], upper bound soft to medium [UBSM] soil, and soft to medium [SM] soil). The linear results show maximum bearing pressures on the west side of 31 to 33 ksf. Liftoff increases the subgrade pressure close to the west edge by 4 percent to 6 percent with insignificant effect beneath most of the basemat.

The SASSI soil-structure interaction analyses are performed based on the nuclear island 3D SASSI model for the hard rock and five soil conditions established from the AP1000 2D SASSI analyses. The SASSI model of the nuclear island is based on the NI20 finite element model. The bearing pressures from the 3D SASSI analyses have been obtained by combining the time history results from the north-south, east-west, and vertical earthquakes. The maximum soil-bearing pressure demand is obtained from the hard rock (HR) case equal to 35 ksf. It is noted that a maximum localized peak is obtained on the west edge of 38 ksf; a limit of 35 ksf for maximum bearing seismic demand is obtained by averaging the soil pressure over 335 ft^2 of the west edge of the shield building where the maximum stress occurs.

3G.5 References

1. NUREG-800, Review of Safety Analysis Reports for Nuclear Power Plants, Section 3.7.2, Seismic System Analysis, Revision 2.

2. GW-GL-700, AP600 Design Control Document, Appendices 2A and 2B, Revision 4.

3. APP-GW-S2R-010, “Extension of Nuclear Island Seismic Analyses to Soil Sites,” Westinghouse Electric Company LLC.

4. APP-GW-GLN-112, “Structural Verification for Enhanced Shield Building,” Westinghouse Electric Company LLC.

5. U.S. NRC Regulatory 1.92, Revision 2, “Combining Modal Responses and Spatial Components in Seismic Analysis.”

6. APP-GW-GLR-044, “Nuclear Island Basemat and Foundation,” Westinghouse Electric Company LLC.

*NRC Staff approval is required prior to implementing a change in this information.

Table 3G.1-1 (Sheet 1 of 4)
Summary of Models and Analysis Methods

Model	Analysis Method	Program	Type of Dynamic Response/Purpose
3D (ASB) solid-shell model	-	ANSYS	Creates the finite element mesh for the ASB finite element model.
3D (CIS) solid-shell model	-	ANSYS	Creates the finite element mesh for the CIS finite element model.
3D finite element model including shield building roof (ASB10)	-	ANSYS	ASB portion of NI10.
3D finite element model including dish below containment vessel	Response spectrum analysis	ANSYS	CIS portion of NI10.
3D finite element shell model of nuclear island [NI10] (coupled auxiliary and shield building shell model, containment internal structures, steel containment vessel, polar crane, RCL, pressurizer, and CMTs)	Mode superposition time history analysis	ANSYS	Performed for hard rock profile for ASB with CIS as superelement and for CIS with ASB as superelement. To develop time histories for generating plant design floor response spectra for nuclear island structures. To obtain maximum absolute nodal accelerations (ZPA) to be used in equivalent static analyses. To obtain maximum displacements relative to basemat.
3D finite element coarse shell model of auxiliary and shield building and containment internal structures [NI20] (including steel containment vessel, polar crane, RCL, and pressurizer)	Mode superposition time history analysis	ANSYS	Performed for hard rock profile for comparisons against more detailed NI10 model.

Table 3G.1-1 (Sheet 2 of 4)
Summary of Models and Analysis Methods

Model	Analysis Method	Program	Type of Dynamic Response/Purpose
Finite element lumped-mass stick model of nuclear island	Time history analysis	SASSI	Performed 2D parametric soil studies to help establish the bounding generic soil conditions and to develop adjustment factors to reflect all generic site conditions for seismic stability evaluation.
Finite element lumped-mass stick model of nuclear island	Direct integration time history analysis	ANSYS	Performed 2D linear and non-linear seismic analyses to evaluate effect of liftoff on Floor Response Spectra and bearing.
3D finite element coarse shell model of auxiliary and shield building and containment internal structures [NI20] (including steel containment vessel, polar crane, RCL, and pressurizer)	Time history analysis Complex frequency response analysis	SASSI	Performed for the five soil profiles of firm rock, soft rock, upper bound soft-to-medium soil, soft-to-medium soil, and soft soil. To develop time histories for generating plant design floor response spectra for nuclear island structures. To obtain maximum absolute nodal accelerations (ZPA) to be used in equivalent static analyses. To obtain maximum displacements relative to basemat. To obtain SSE bearing pressures for all generic soil cases. To obtain maximum member forces and moments in selected elements for comparison to equivalent static results.
3D shell model of auxiliary and shield building and containment internal structures [NI20] (including steel containment vessel)	Mode superposition time history analysis	ANSYS	Performed to develop loads for seismic stability evaluation.

Table 3G.1-1 (Sheet 3 of 4)
Summary of Models and Analysis Methods

Model	Analysis Method	Program	Type of Dynamic Response/Purpose
3D shell of revolution model of steel containment vessel	Modal analysis; equivalent static analysis using accelerations from time history analyses	ANSYS	To obtain dynamic properties. To obtain SSE stresses for the containment vessel.
3D lumped-mass stick model of the SCV	-	ANSYS	Used in the NI10 and NI20 models.
3D lumped-mass stick model of the RCL	-	ANSYS	Used in the NI10 and NI20 models.
3D lumped-mass stick model of the pressurizer	-	ANSYS	Used in the NI10 and NI20 models.
3D lumped-mass stick model of the CMT	-	ANSYS	Used in the NI10 model.
3D lumped mass detailed model of the polar crane	Modal analysis	ANSYS	To obtain dynamic properties. Used with 3D finite element shell model of the containment vessel.
3D lumped mass simplified (single beam) model of the polar crane	-	ANSYS	Used in the NI10 and NI20 models.
3D finite element shell model of containment vessel	Mode superposition time history analysis Equivalent static analysis	ANSYS	Used with detailed polar crane model to obtain acceleration response of equipment hatch and airlocks. To obtain shell stresses in vicinity of the large penetrations of the containment vessel.

Table 3G.1-1 (Sheet 4 of 4)
Summary of Models and Analysis Methods

Model	Analysis Method	Program	Type of Dynamic Response/Purpose
3D finite element refined shell model of nuclear island (NI05)	Equivalent static non-linear analysis using accelerations from time history analyses Mode superposition time history analysis for the wall and floor flexibility using synthetic time histories developed to match spectral envelopes applied at the base Response spectrum analysis with seismic input enveloping all soils cases	ANSYS	To obtain SSE member forces for the nuclear island basemat. To obtain floor and wall flexibility response characteristics. To obtain maximum displacements relative to basemat. To obtain SSE member forces for the auxiliary and shield building and the containment internal structures.
3D finite element coarse shell model of auxiliary and shield building and containment internal structures [NI20] (including steel containment vessel, polar crane, RCL, and pressurizer)	Mode superposition time history analysis with seismic input enveloping all soil cases	ANSYS	To obtain total basemat reactions for comparison to reactions in equivalent static linear analyses using NI05 model.
Quadrant model of shield building roof (See subsection 3.8.4.4.1 for information on use of the quadrant model.)	Equivalent static analysis The PCS tank is designed using the maximum accelerations at the applicable elevation resulting from time history dynamic analyses of the nuclear island. The tension ring and air inlet use maximum accelerations that are increased based on results of response spectrum analysis.	ANSYS	To obtain member forces for shield building roof and radial roof beams, air inlet structure, tension ring, and PCS tank.

Table 3G.1-2
Summary of Dynamic Analyses and Combination Techniques

Model	Analysis Method	Program	Three Components Combination	Modal Combination
3D finite element, fixed base models, coupled auxiliary and shield building shell model, with superelement of containment internal structures (NI10 and NI20)	Mode superposition time history analysis	ANSYS	Algebraic Sum	n/a
3D finite element nuclear island model (NI20)	Complex frequency response analysis	SASSI	Algebraic Sum	n/a
3D finite element, fixed base models, coupled auxiliary and shield building and containment internal structures including shield building roof (NI05)	Response spectrum analysis	ANSYS	SRSS or 100%, 40%, 40%	Lindley-Yow
3D finite element model of the nuclear island basemat (NI05)	Equivalent static analysis using nodal accelerations from shell model	ANSYS	100%, 40%, 40%	n/a
3D shell of revolution model of steel containment vessel	Equivalent static analysis using nodal accelerations from 3D stick model	ANSYS	SRSS or 100%, 40%, 40%	n/a
PCS valve room and miscellaneous steel frame structures, miscellaneous flexible walls, and floors	Response spectrum analysis	ANSYS	SRSS or 100%, 40%, 40%	Grouping or Lindley-Yow
2D stick model analyses with liftoff	Direct integration time history	ANSYS	Algebraic Sum	n/a

Table 3G.2-1 (Sheet 1 of 2)
Steel Containment
Vessel Lumped-Mass Stick Model (Without Polar Crane) Modal Properties

Mode	Frequency	Effective Mass		
		X Direction	Y Direction	Z Direction
1	6.28	3.51	159.81	0.01
2	6.28	160.01	3.51	0.00
3	12.87	0.03	0.00	0.00
4	16.89	0.00	0.01	173.42
5	18.87	0.29	40.91	0.00
6	18.89	40.77	0.29	0.00
7	28.13	0.00	0.00	28.45
8	31.67	0.09	2.81	0.00
9	31.80	3.05	0.09	0.00
10	37.66	1.28	0.02	0.00
11	38.34	0.04	4.98	0.02
12	38.73	3.41	0.02	0.00
13	47.37	0.00	0.00	5.26
14	53.48	4.76	0.66	0.00
15	53.53	0.64	4.84	0.00
16	59.55	0.00	0.03	3.78
17	62.60	0.15	0.00	0.05
18	63.10	0.00	0.05	6.98
19	63.23	0.00	0.00	0.04
20	65.80	0.03	0.66	0.05
Sum of Effective Masses		218.06	218.69	218.05

Notes:
1. Fixed at Elevation 100′.
2. The total mass of the containment vessel is 229.16 kip-sec^2/ft.

Table 3G.2-1 (Sheet 2 of 2)
Steel Containment Vessel Lumped-Mass Stick Model (With Polar Crane)
Modal Properties

Mode	Frequency	Effective Mass		
		X Direction	Y Direction	Z Direction
1	4.20	0.00	78.15	0.00
2	4.98	149.97	0.00	0.17
3	6.44	6.80	0.01	23.59
4	6.47	0.00	112.05	0.00
5	8.00	35.09	0.00	1.19
6	8.61	0.00	4.06	0.00
7	12.58	0.03	0.18	0.00
8	16.00	0.06	0.08	0.22
9	16.09	5.16	0.00	146.06
10	17.21	24.58	0.00	36.27
11	18.86	0.00	40.88	0.00
12	20.64	13.30	0.00	0.71
13	23.74	0.00	0.40	0.00
14	27.04	0.13	0.00	15.64
15	29.62	2.88	0.00	3.61
16	30.21	0.00	0.07	0.00
17	31.62	0.00	2.92	0.01
18	32.85	0.58	0.00	0.38
19	34.02	0.28	0.01	4.87
20	36.97	0.20	1.61	0.00
Sum of Effective Masses		239.04	240.42	232.72

Notes:
1. Fixed at Elevation 100′.
2. The total mass of the containment vessel with the polar crane is 261.02 kip-sec^2/ft.

Table 3G.2-2 Comparison of Frequencies for Containment Vessel Seismic Model

Mode No.	Vertical Model		Horizontal Model	
	Shell of Revolution Model	Stick Model	Shell of Revolution Model	Stick Model
1	16.51 hertz	16.97 hertz	6.20 hertz	6.31 hertz
2	23.26 hertz	28.20 hertz	18.58 hertz	18.96 hertz

Note:
1. Fixed at elevation 100′.

Table 3G.3-1
AP1000 ZPA for 2D SASSI Cases

	North-South		**Hard Rock ZPA [g]**	**Firm Rock ZPA [g]**	**Soft Rock ZPA [g]**	**UBSM ZPA [g]**	**SM ZPA [g]**	**Soft Soil ZPA [g]**
	Node	**El. feet**						
ASB	21	81.5	0.326	0.326	0.345	**0.358**	0.306	0.249
	41	99	0.348	0.327	0.347	**0.361**	0.308	0.227
	120	179.6	**0.571**	0.501	0.469	0.498	0.529	0.247
	150	242.5	0.803	0.795	0.816	**0.819**	0.787	0.29
	310	333.1	1.449	1.561	**1.567**	1.524	1.226	0.453
SCV	407	138.6	0.405	**0.424**	0.408	0.387	0.407	0.232
	411	200	0.82	**0.916**	0.672	0.541	0.484	0.263
	417	281.9	1.396	**1.465**	1.031	0.723	0.598	0.372
CIS	535	134.3	**0.548**	0.45	0.347	0.368	0.355	0.229
	538	169	**1.517**	0.874	0.45	0.441	0.397	0.317
	East-West		**Hard Rock ZPA [g]**	**Firm Rock ZPA [g]**	**Soft Rock ZPA [g]**	**UBSM ZPA [g]**	**SM ZPA [g]**	**Soft Soil ZPA [g]**
	Node	**El. feet**						
ASB	21	81.5	0.309	0.318	0.359	**0.376**	0.311	0.235
	41	99	0.318	0.336	0.367	**0.385**	0.317	0.237
	120	179.6	**0.607**	0.561	0.546	0.549	0.605	0.295
	150	242.5	0.84	0.823	0.854	0.912	**0.962**	0.557
	310	333.1	1.449	1.536	1.624	**1.74**	1.506	0.891
SCV	407	138.6	0.528	0.529	**0.535**	0.513	0.38	0.247
	411	200	0.817	**0.95**	0.816	0.741	0.515	0.429
	417	281.9	1.251	**1.503**	1.136	0.985	0.716	0.675
CIS	535	134.3	**0.52**	0.404	0.391	0.404	0.365	0.259
	538	169	**1.679**	1.052	0.755	0.553	0.526	0.441

Table 3G.4-1
Key Nodes at Location

Location	General Area	Elevation (feet)
CIS at Reactor Vessel Support Elevation	SCV Center	100.00
CIS at Operating Deck	SG West Compartment, NE	134.25
ASB NE Corner at Control Room Floor	NE Corner	116.50
ASB Corner of Fuel Building Roof at Shield Building	NW Corner of Fuel Bldg	179.19
ASB Shield Building Roof Area	South Side of Shield Bldg	327.41
SCV Near Polar Crane	SCV Stick Model	224.00

Table 3G.4-2
Maximum Bearing Pressure from 2D Time History Analyses

Soil Case	Analysis	East Edge (ksf)	West Edge (ksf)
Hard Rock	Linear	17.18	32.77
	Liftoff	17.38	34.85
Upper-bound Soft to Medium	Linear	19.46	31.69
	Liftoff	18.42	33.51
Soft to Medium	Linear	15.84	30.82
	Liftoff	17.06	32.18

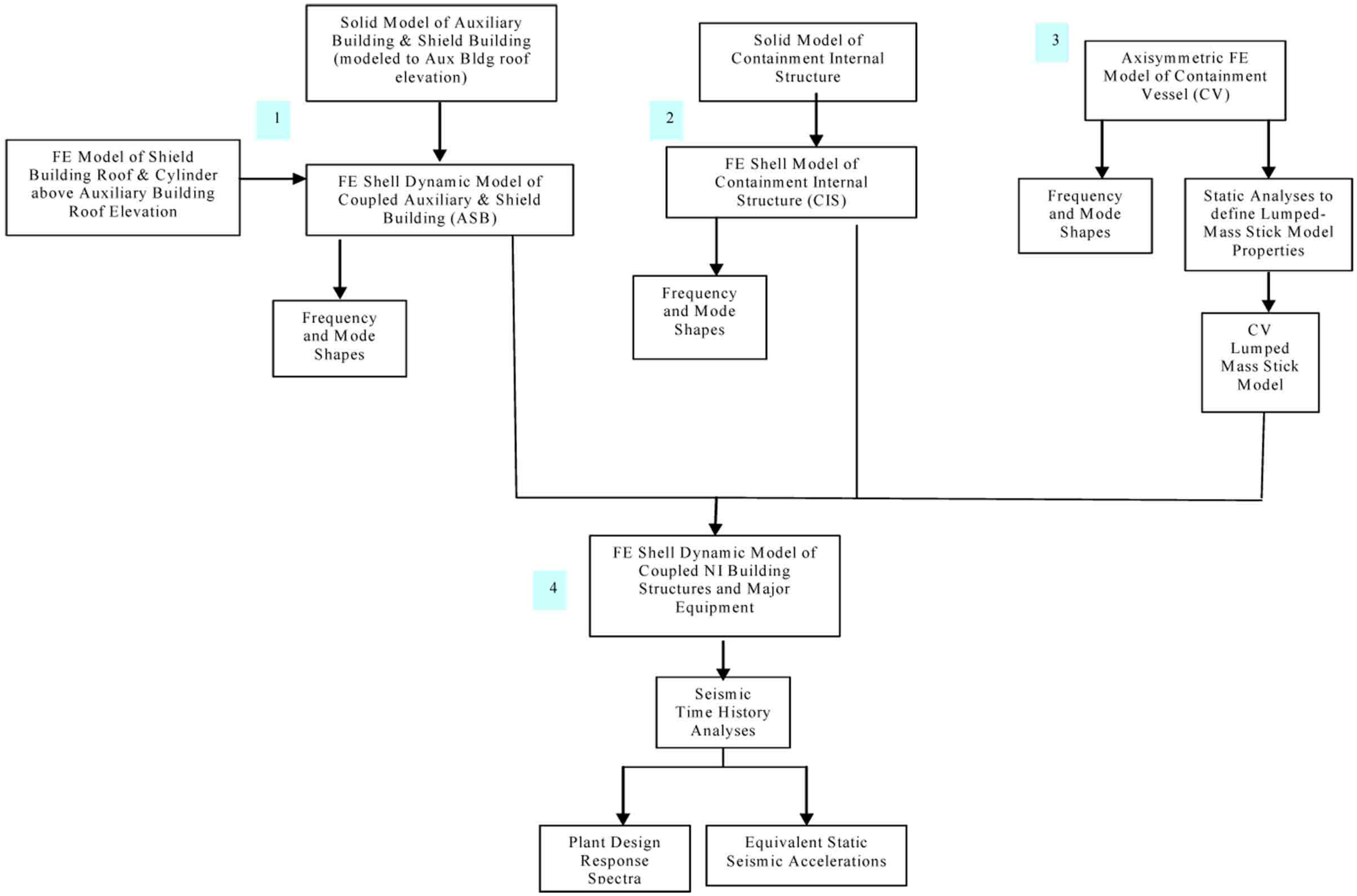


Figure 3G.1-1
Nuclear Island Seismic Analysis Models

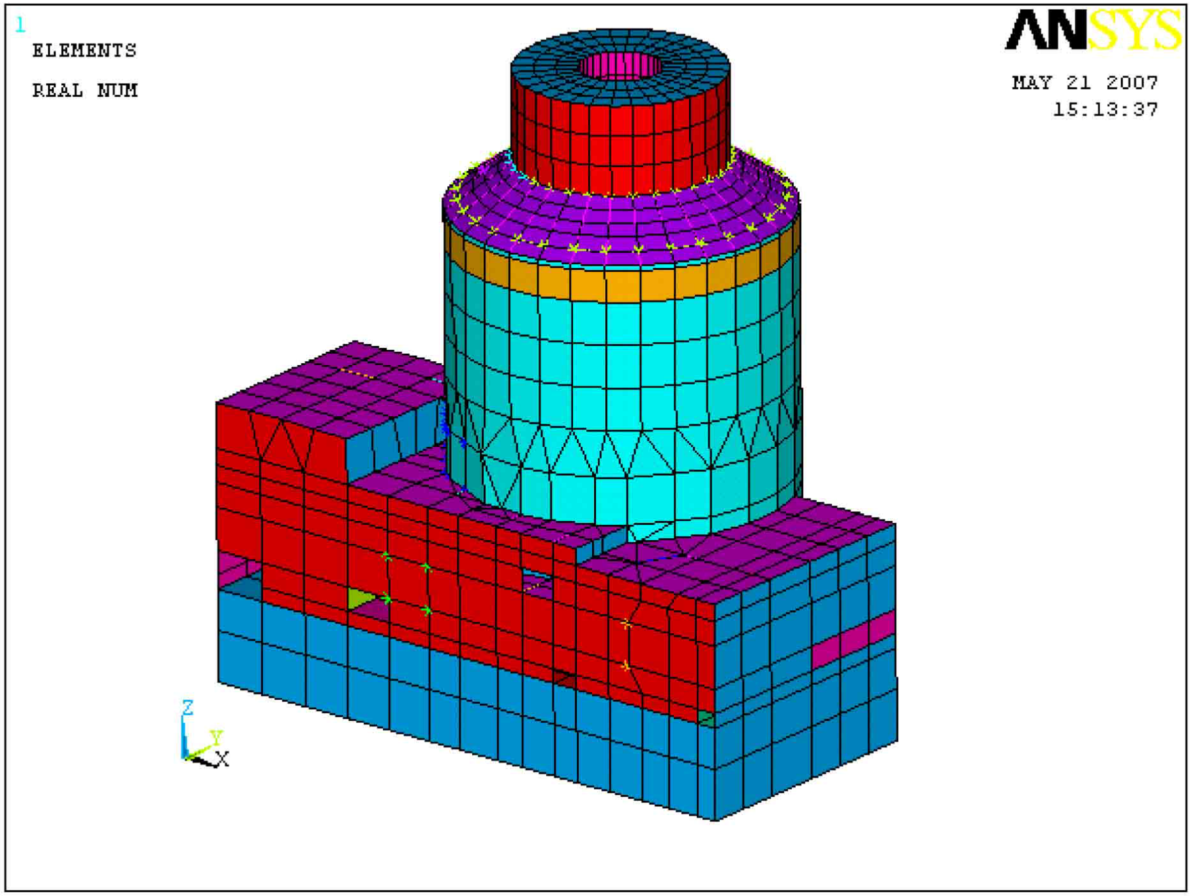
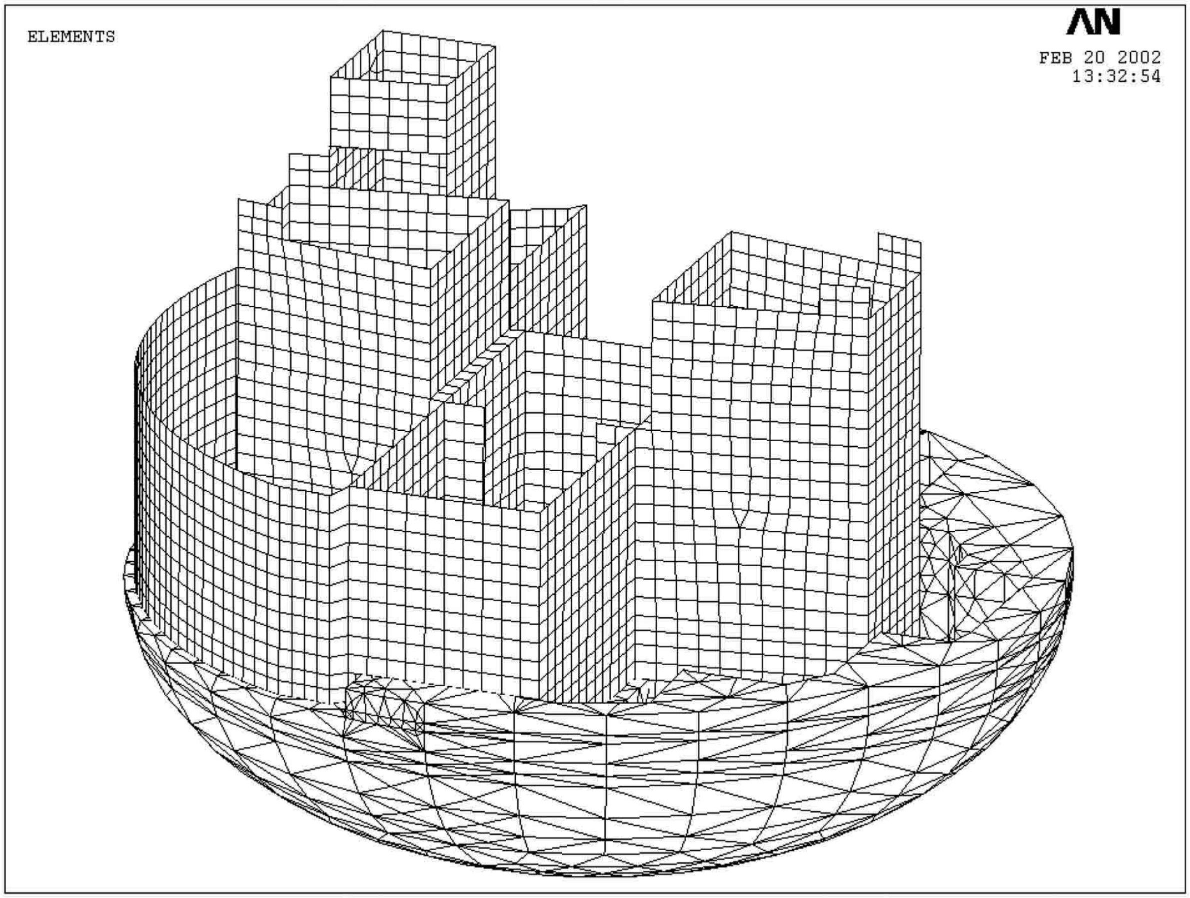


Figure 3G.2-1
3D Finite Element Model of
Coupled Shield and Auxiliary Building



Note: This figure shows the finite element model of walls and basemat inside containment.
Floors are not shown.

Figure 3G.2-2
3D Finite Element Model of
Containment Internal Structures

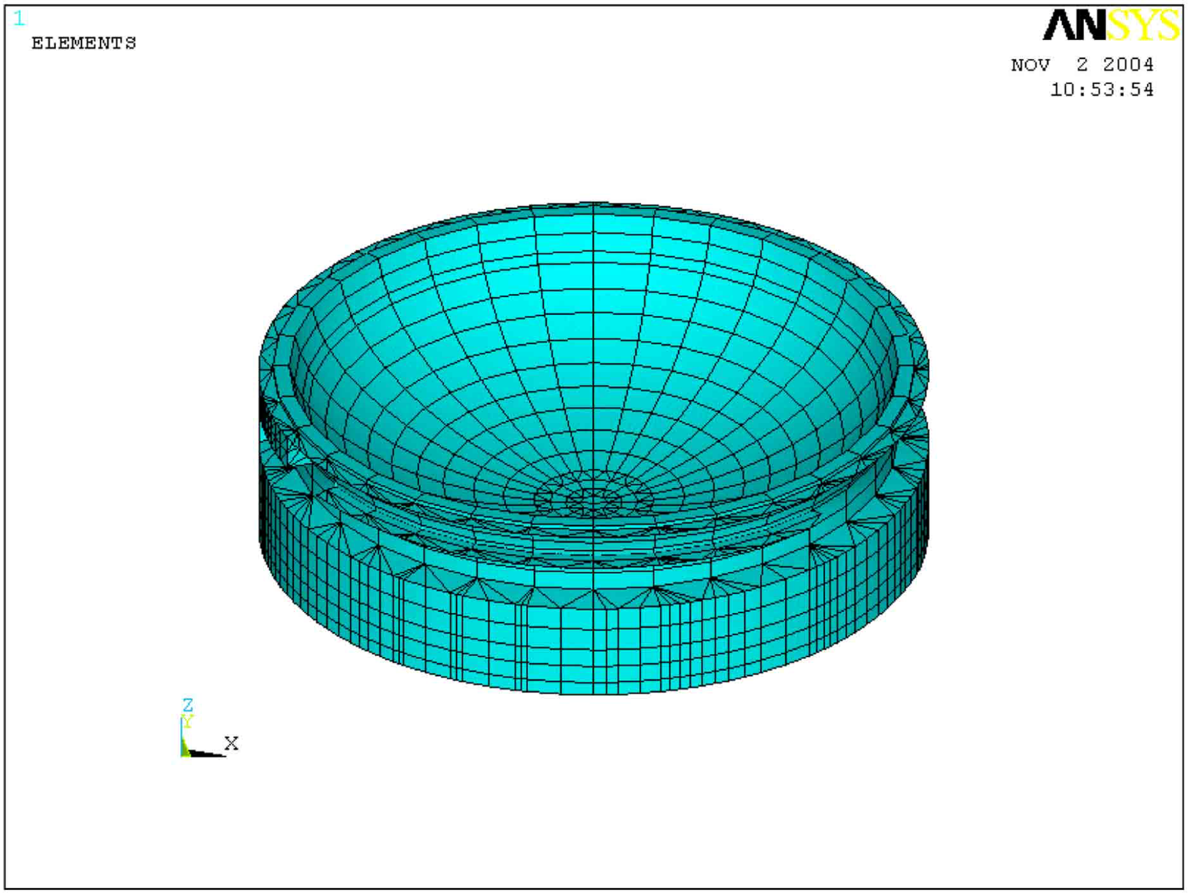


Figure 3G.2-3
3D Finite Element Model of
Containment Outer Basemat (Dish)

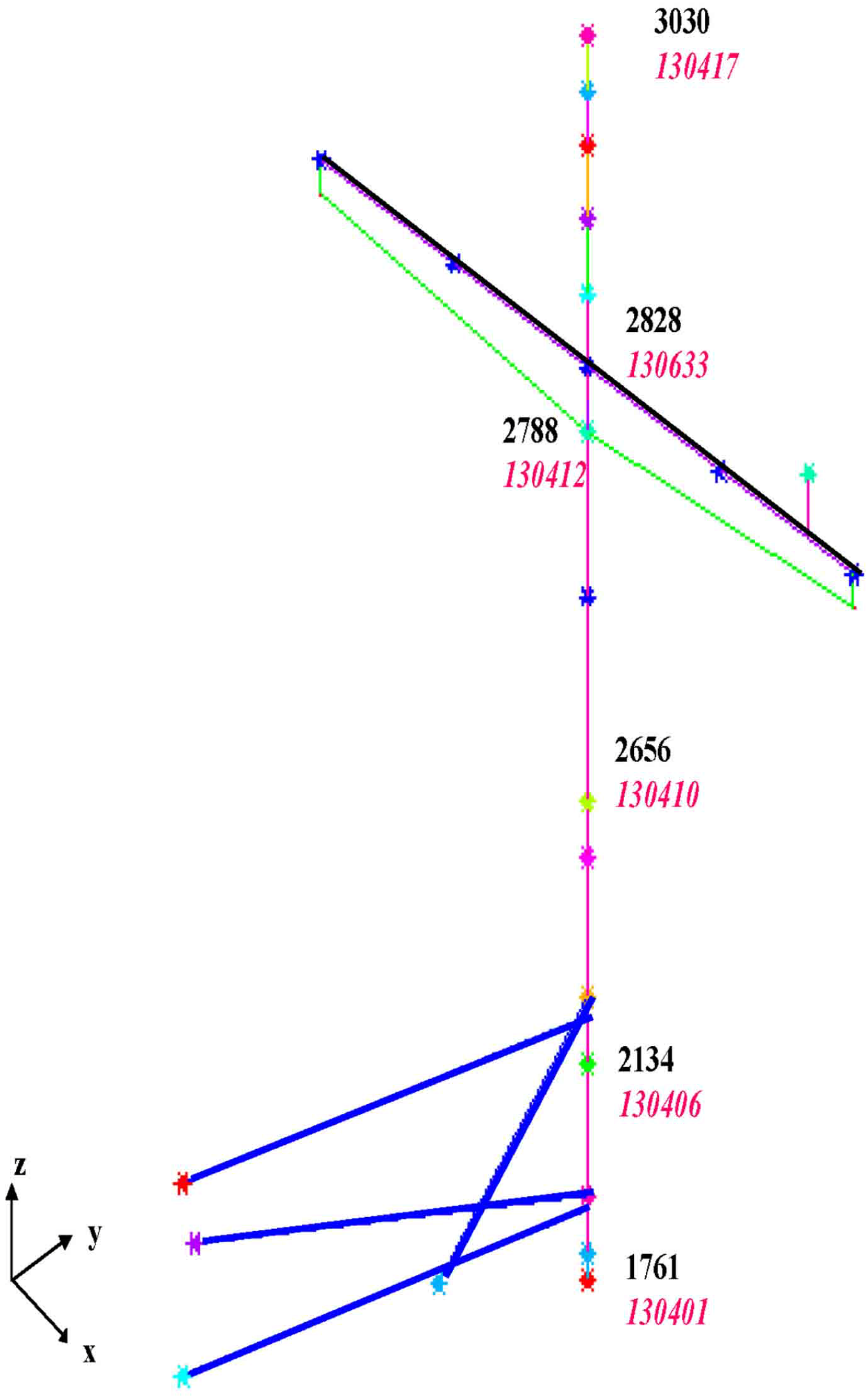
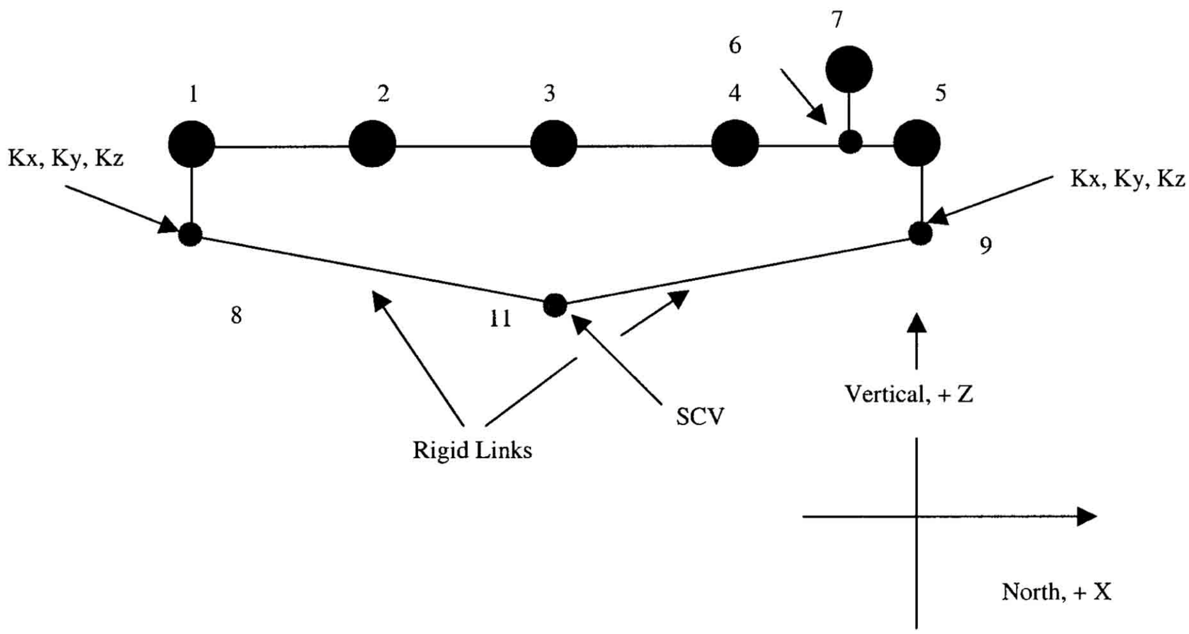


Figure 3G.2-4
Steel Containment Vessel and Polar Crane Models



Local SCV Stiffness are Kx, Ky, Kz

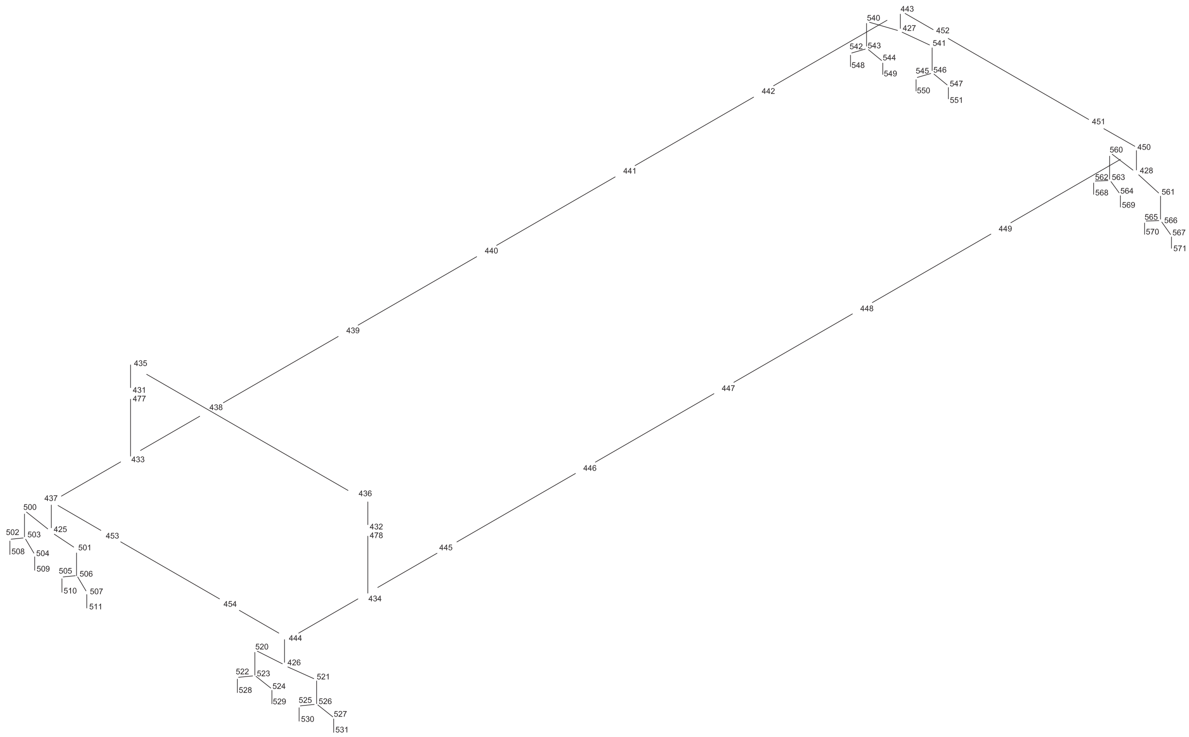
Dynamic Degrees of Freedom

- Masses at nodes 1, 2, 3, 4, 5, and 7
- All Mass nodes have DOFs in X, Y, and Z directions

Comments:

1. Cross Beams between girders are represented by rotation spring constants Kxx and Kzz
2. Cross Beam rotational spring constant Kyy is negligible compared to girder stiffness

Figure 3G.2-5A
Polar Crane Model Simplified Model



NOTES:

1. Nodes 431 and 477 on the trolley frame are coincident and are fully coupled. Likewise, 432 and 478, also on the trolley frame are coincident and are fully coupled nodes.

Figure 3G.2-5B
Polar Crane Model Detailed Model

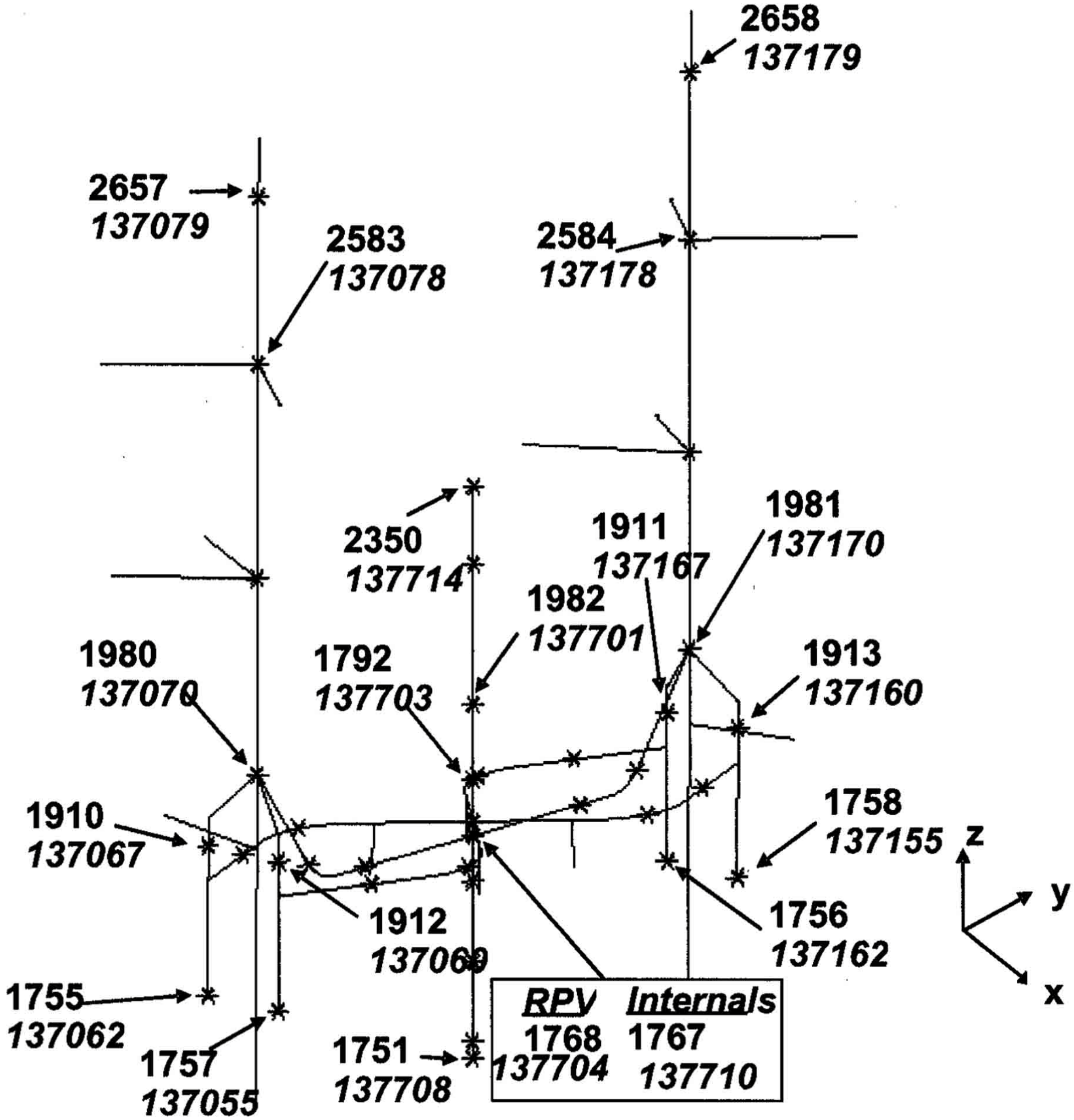


Figure 3G.2-6
Reactor Coolant Loop
Lumped-Mass Stick Model

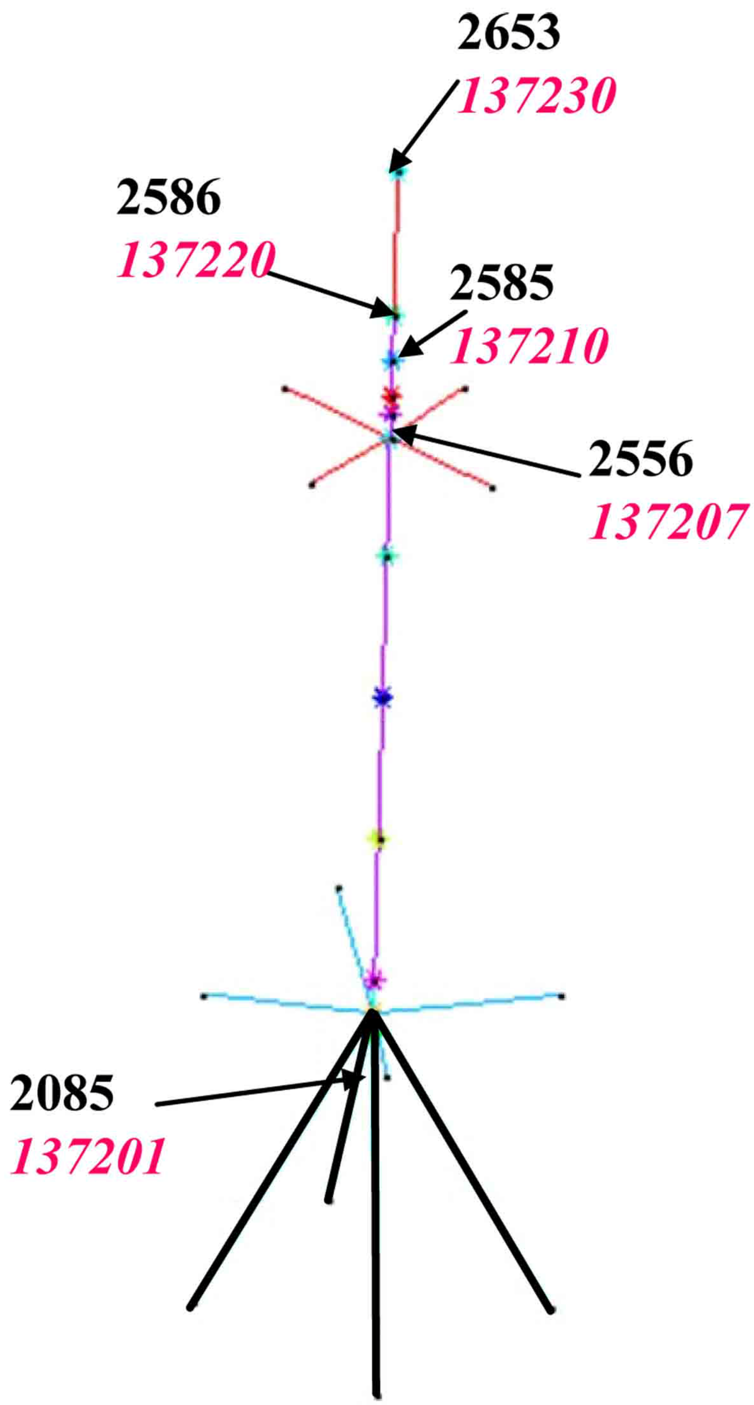


Figure 3G.2-7
Pressurizer Model

Figure 3G.2-8
Core Makeup Tank Models

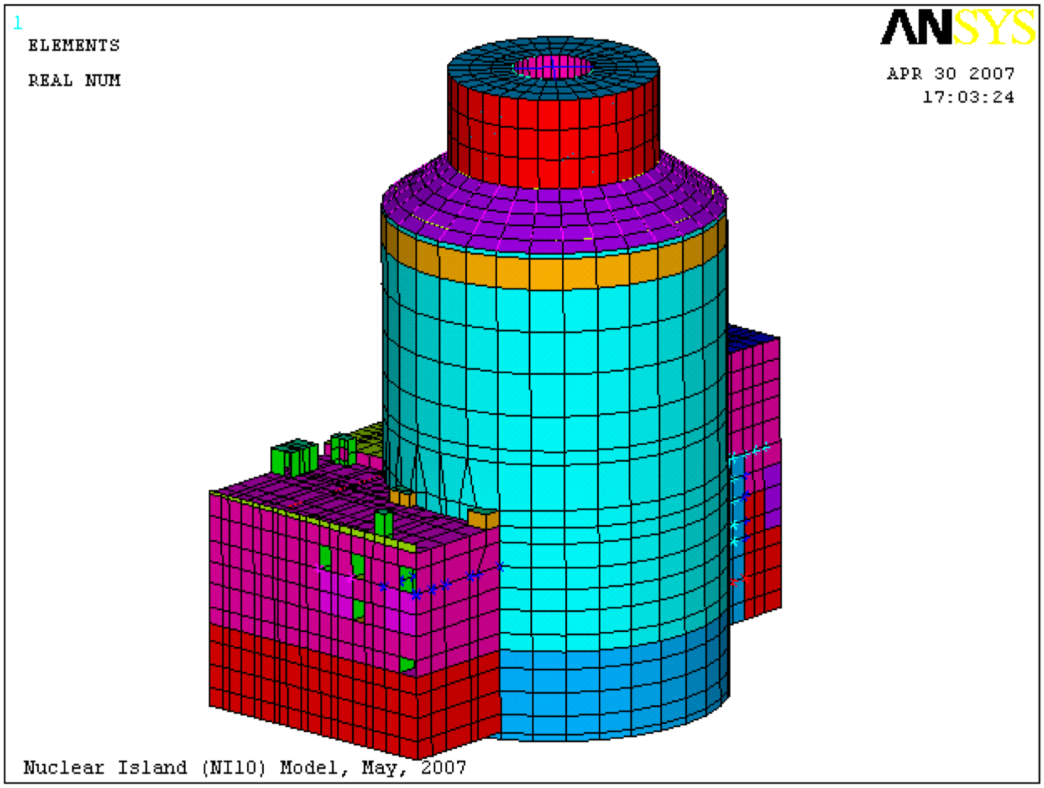


Figure 3G.2-9
AP1000 Nuclear Island Solid-Shell Model (NI10)

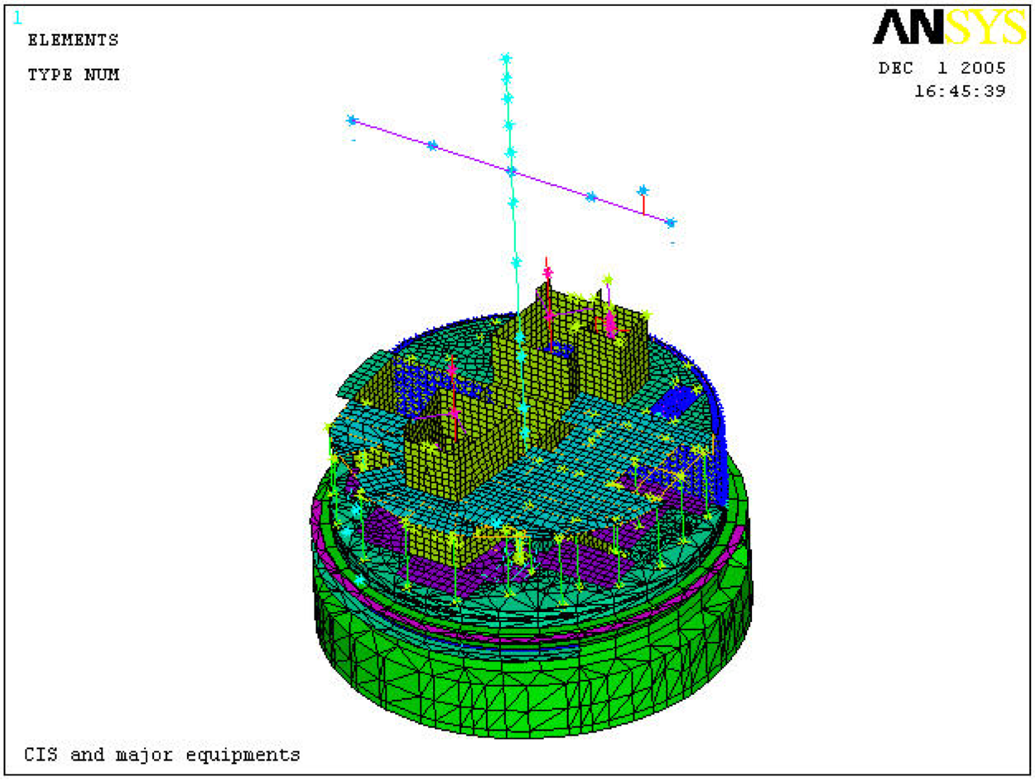
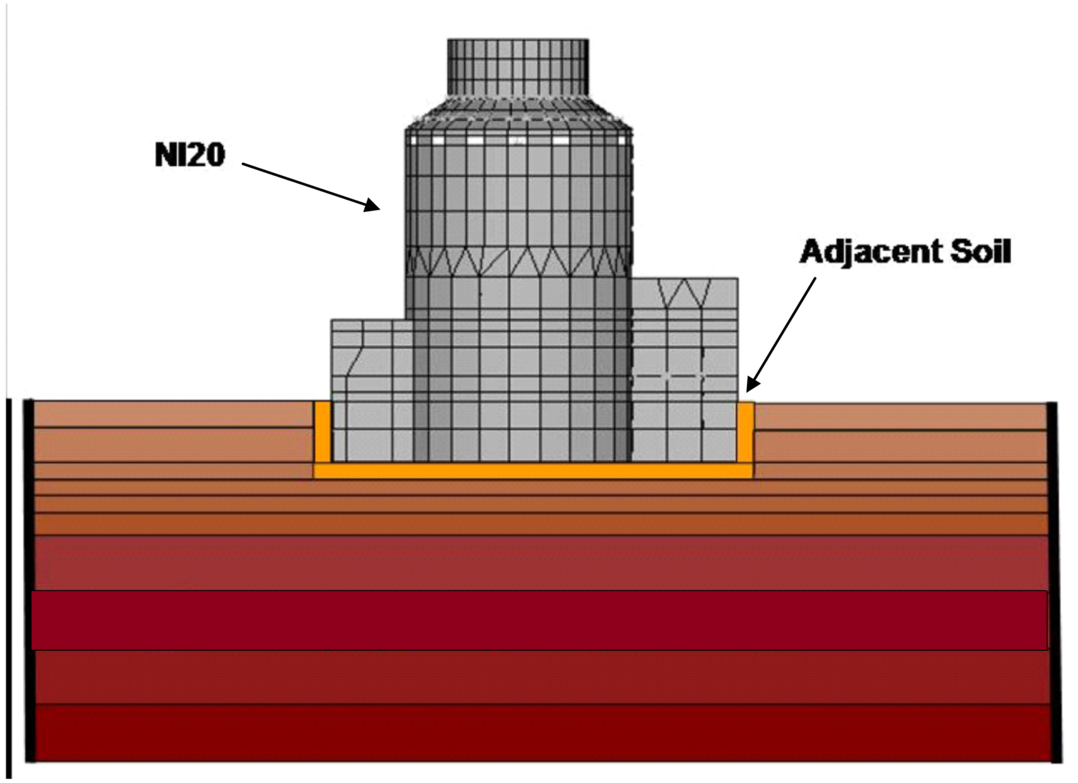


Figure 3G.2-10
Containment Internal Structure with the SCV, PC, Reactor Coolant Loop, and Pressurizer



Note: The adjacent soil elements are part of the structural portion of SASSI and have the same material properties as the soil. These elements are used to obtain soil lateral and bearing soil pressures.

Figure 3G.2-11
Soil Structure Interaction Model – NI20 Looking East

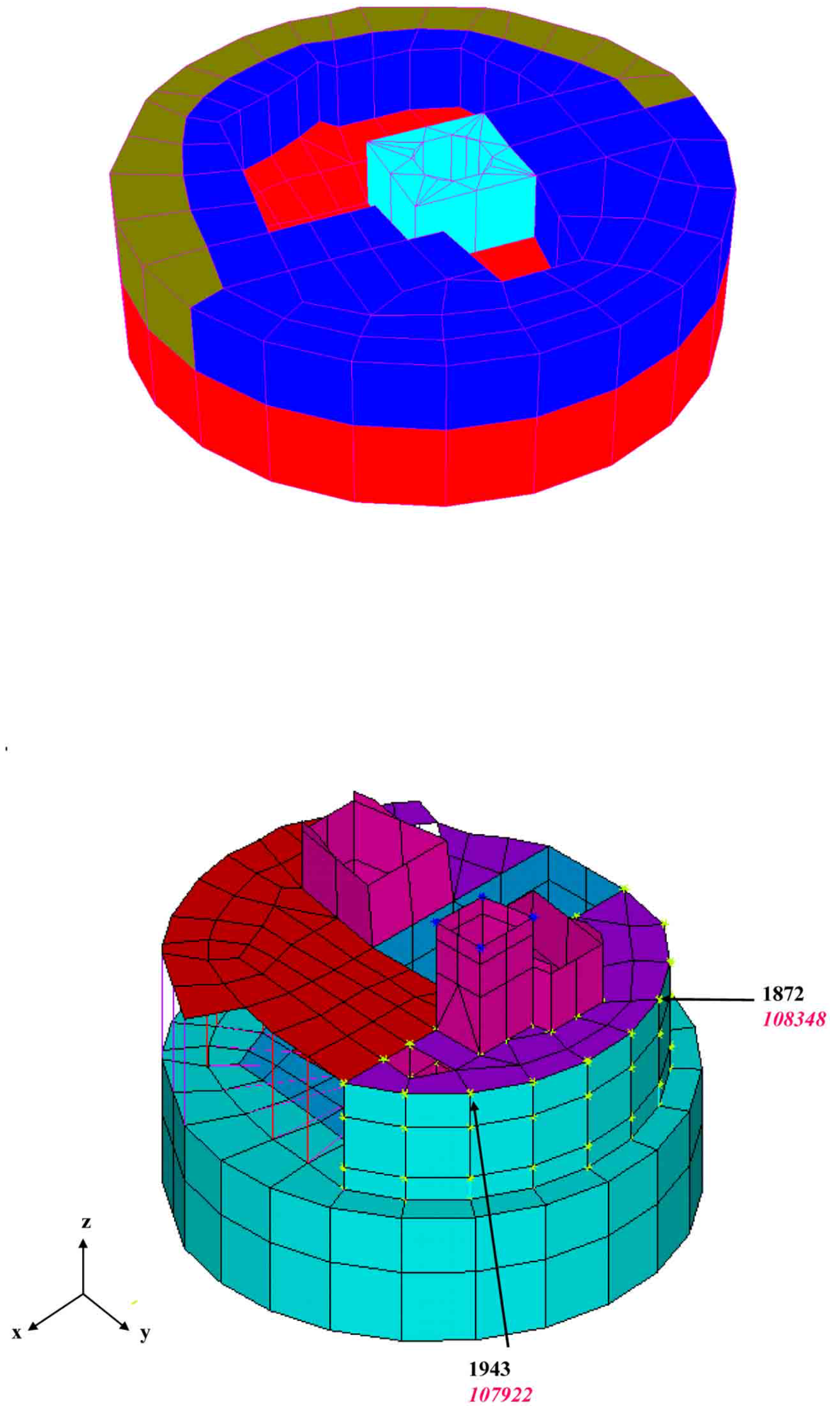


Figure 3G.2-12
Coarse Model of Containment Internal Structures

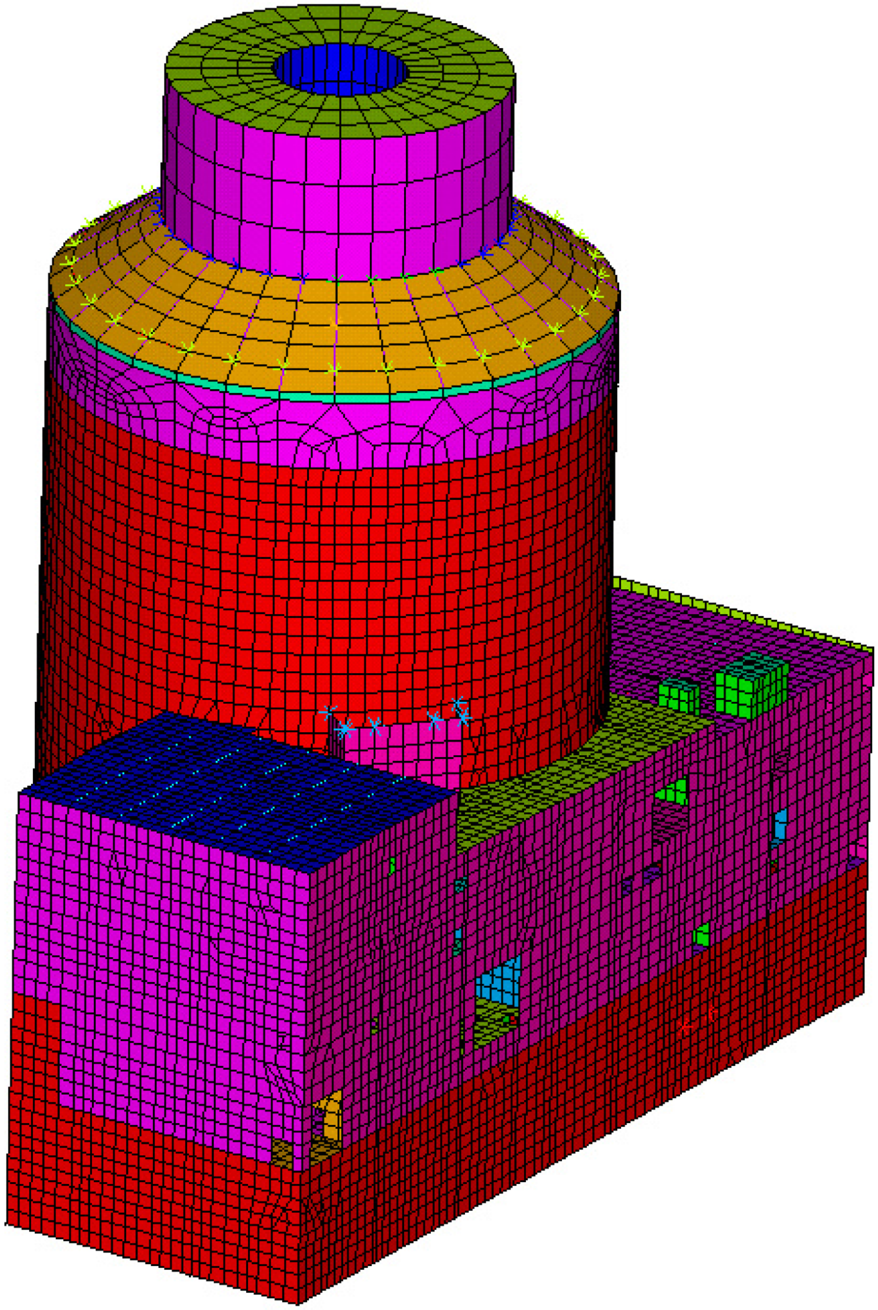


Figure 3G.2-13
Fine Mesh (NI05) Model of Auxiliary and Shield Building

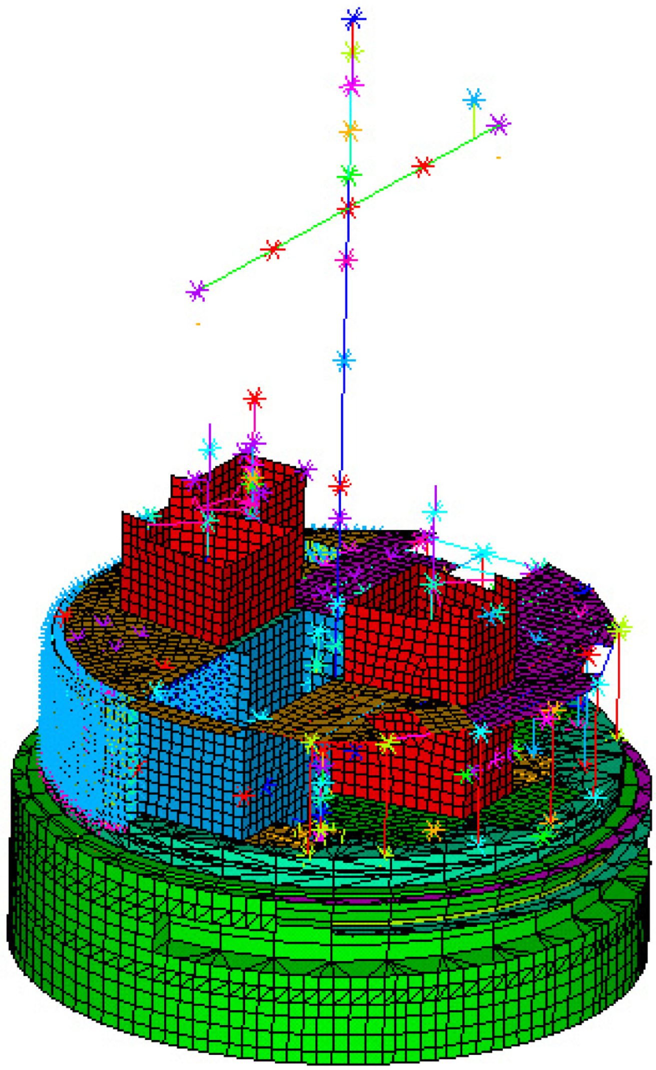


Figure 3G.2-14
NI05 Model of Containment Internal Structures

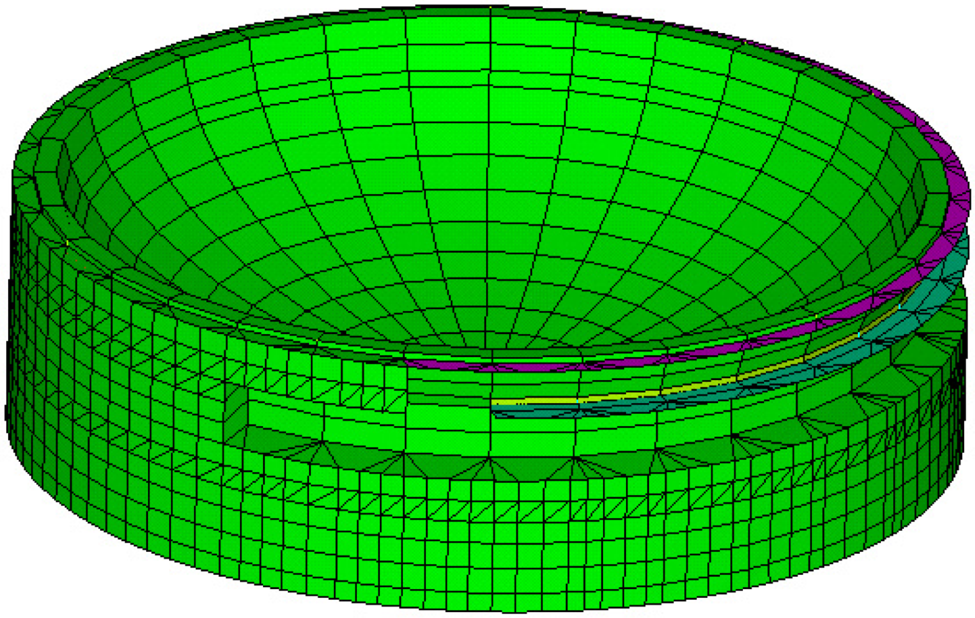


Figure 3G.2-15
3D NI05 Refined Mesh Model of Outer Containment Basemat (Dish)

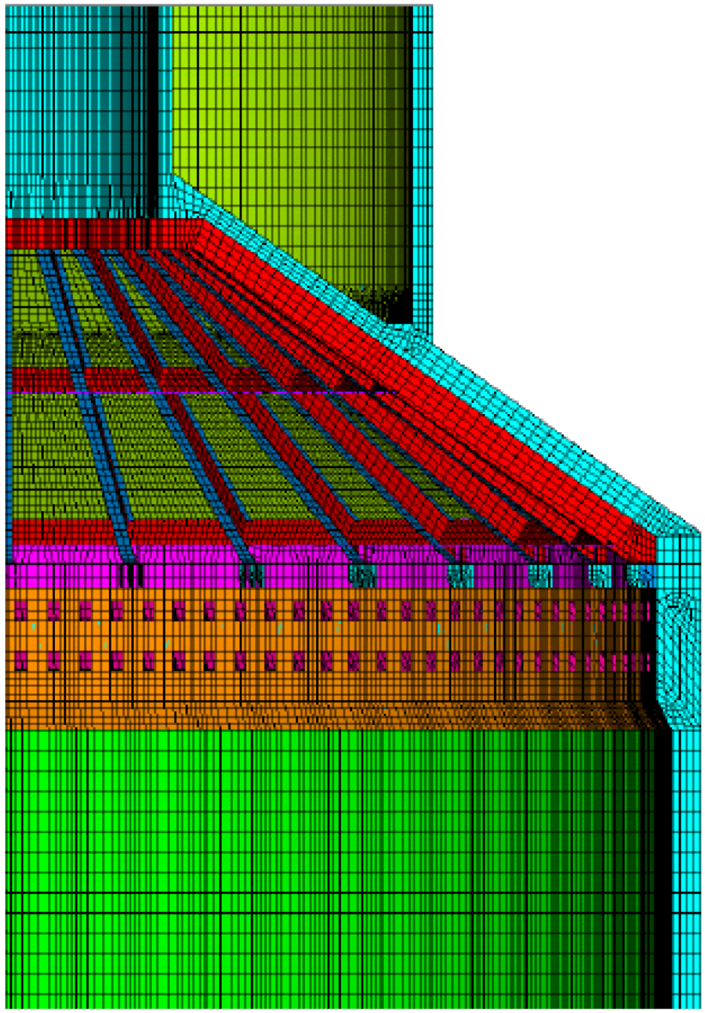
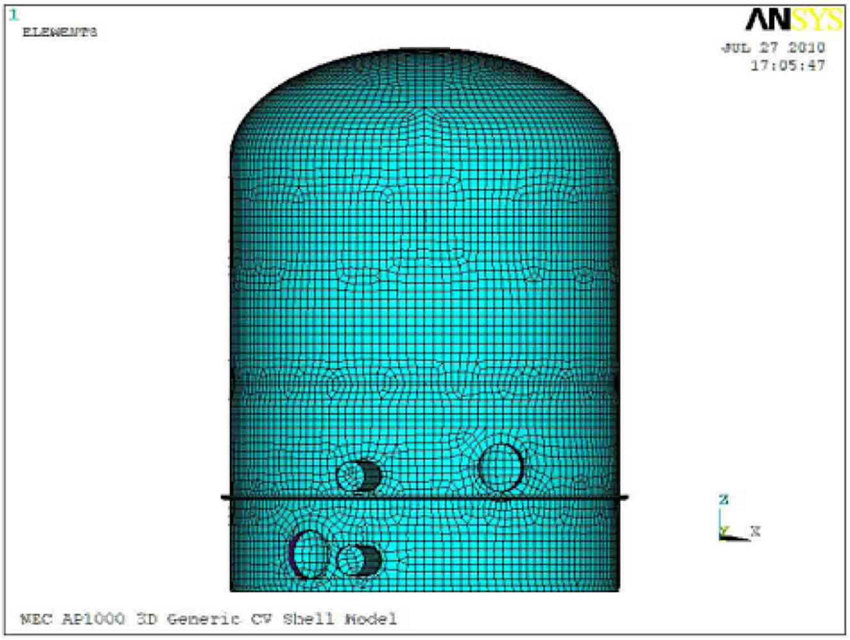
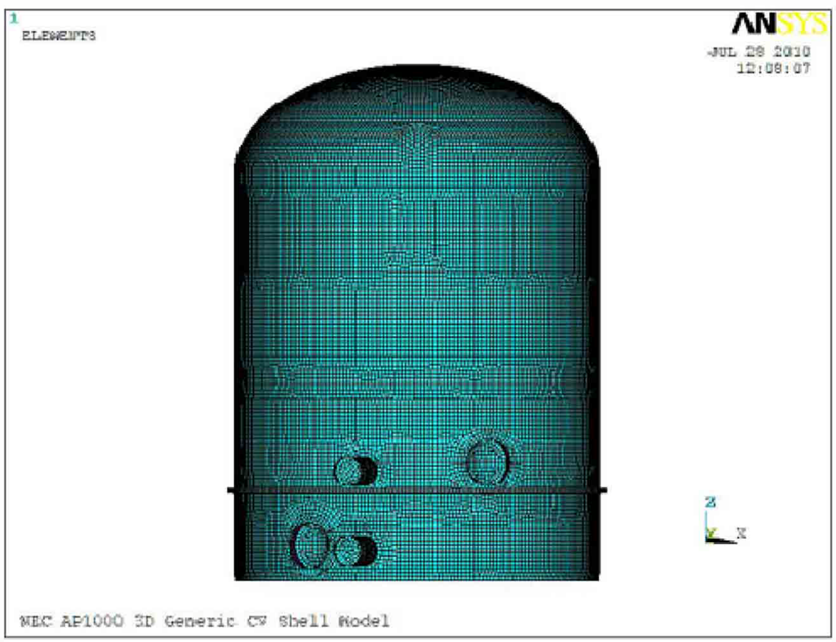


Figure 3G.2-16
Quadrant Model of Shield Building Roof



Mesh Size 37″ x 37″



Mesh Size 18″ x 18″

Figure 3G.2-17
Detailed 3D Finite Element Model of Containment Vessel Including Large Penetrations

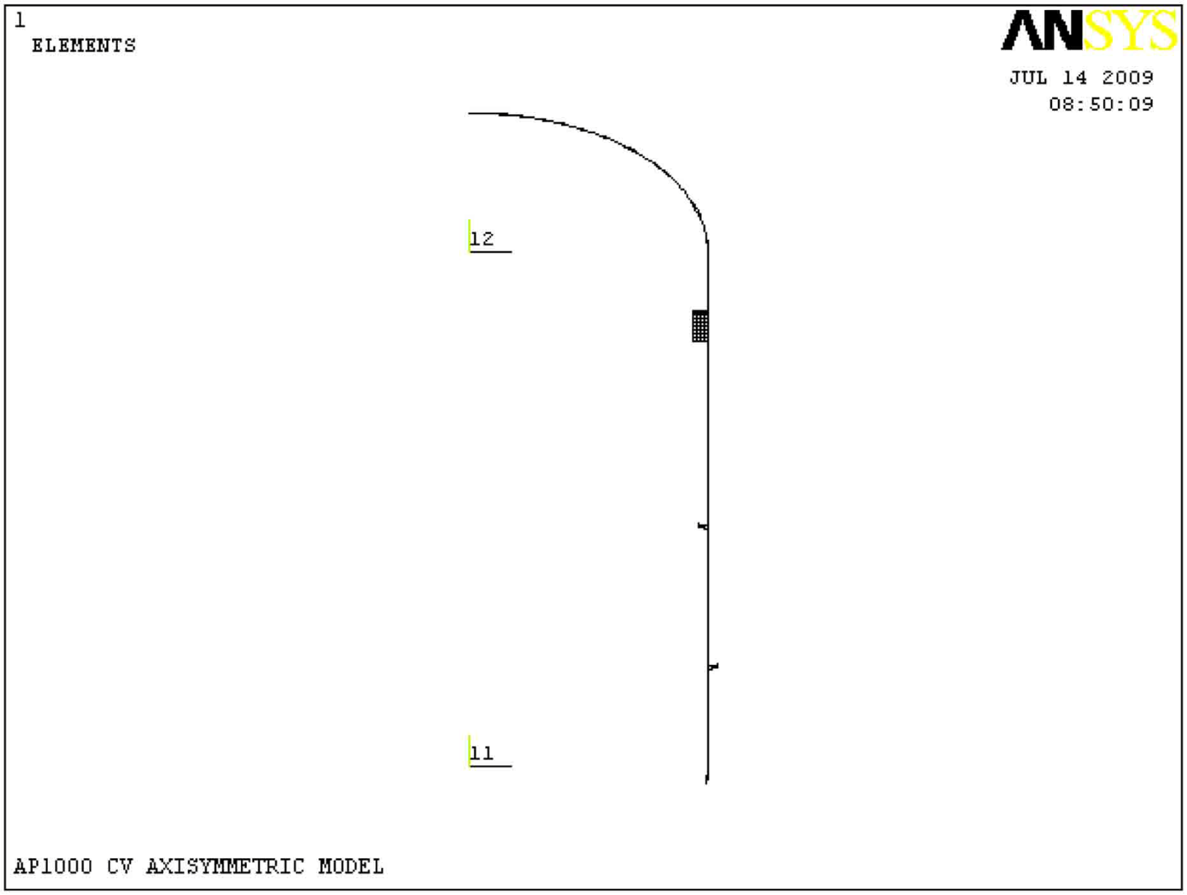


Figure 3G.2-18
Axisymmetric Model of Containment Vessel

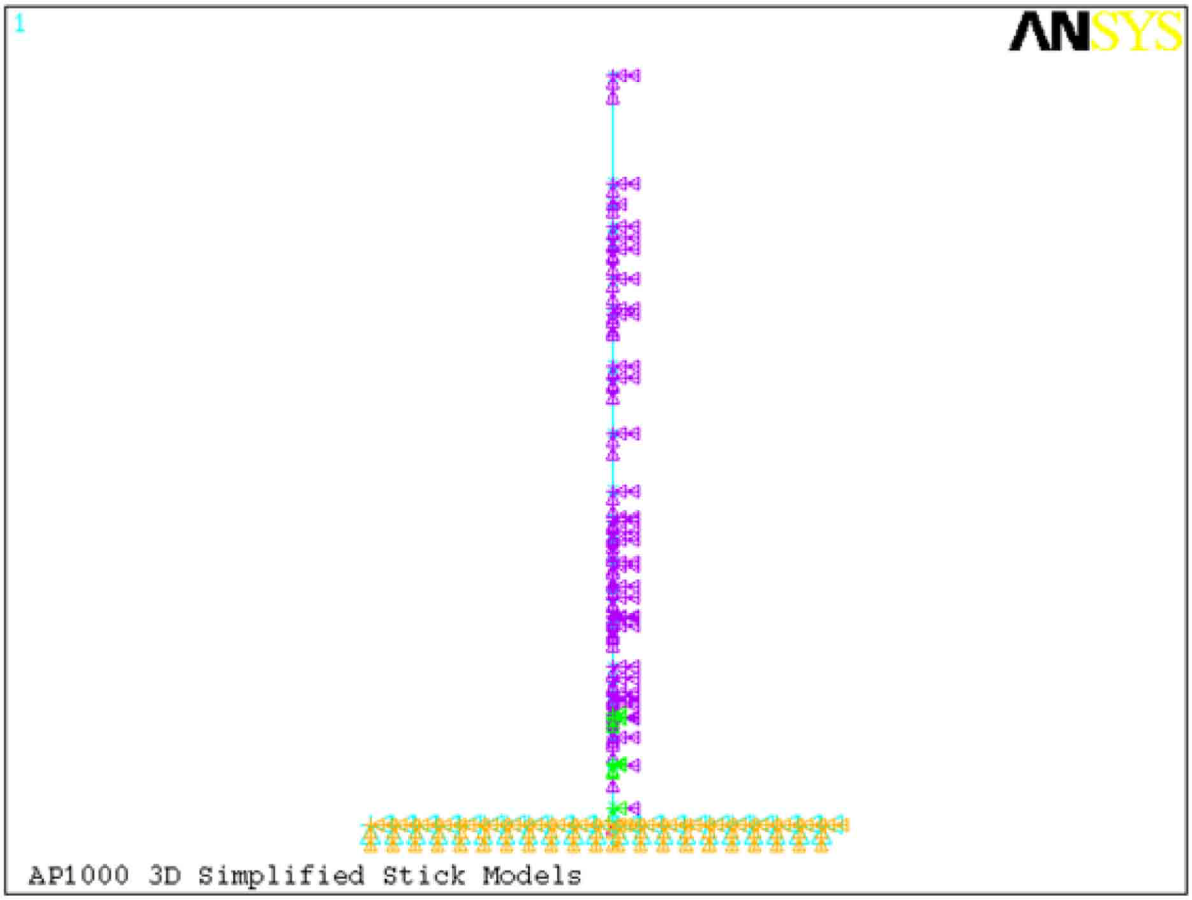
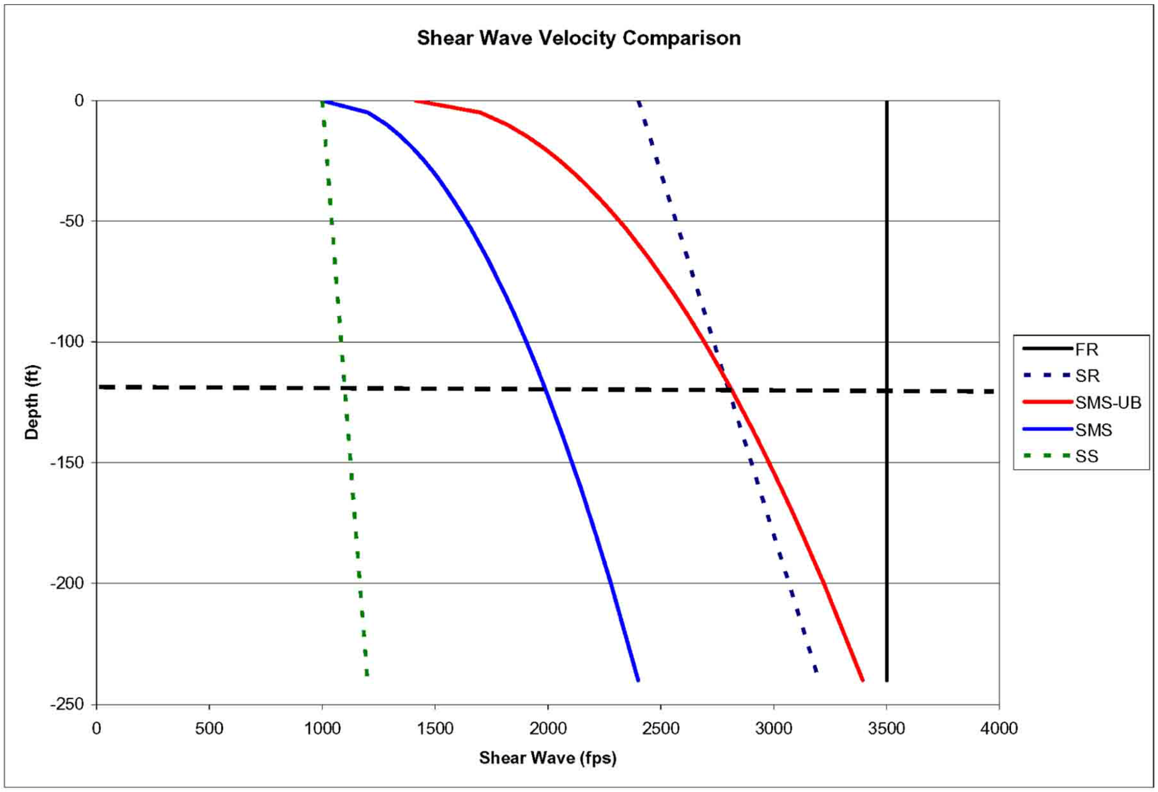


Figure 3G.2-19
Schematic of Non-linear 2D East-West Nuclear Island Stick Model Used for Stability Evaluation that Addresses Sliding and Overturning



Note: Fixed base analyses were performed for hard rock sites. These analyses are applicable for shear wave velocity greater than 8000 feet per second.

Figure 3G.3-1
Generic Soil Profiles

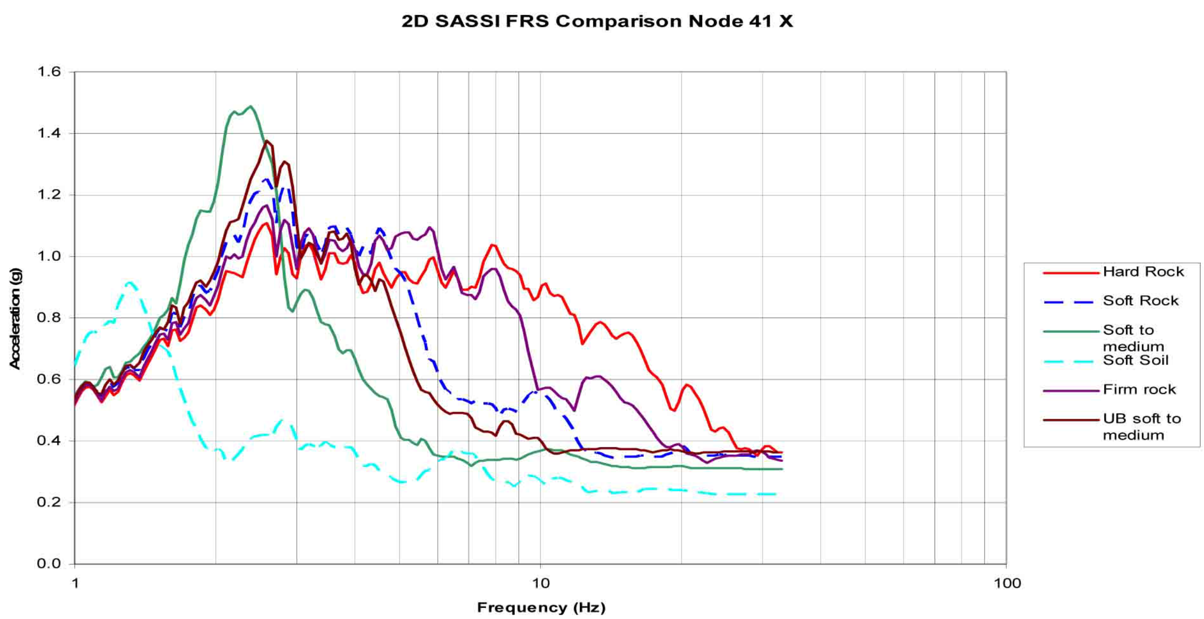


Figure 3G.3-2
2D SASSI FRS – Node 41 X (ASB El. 99′)

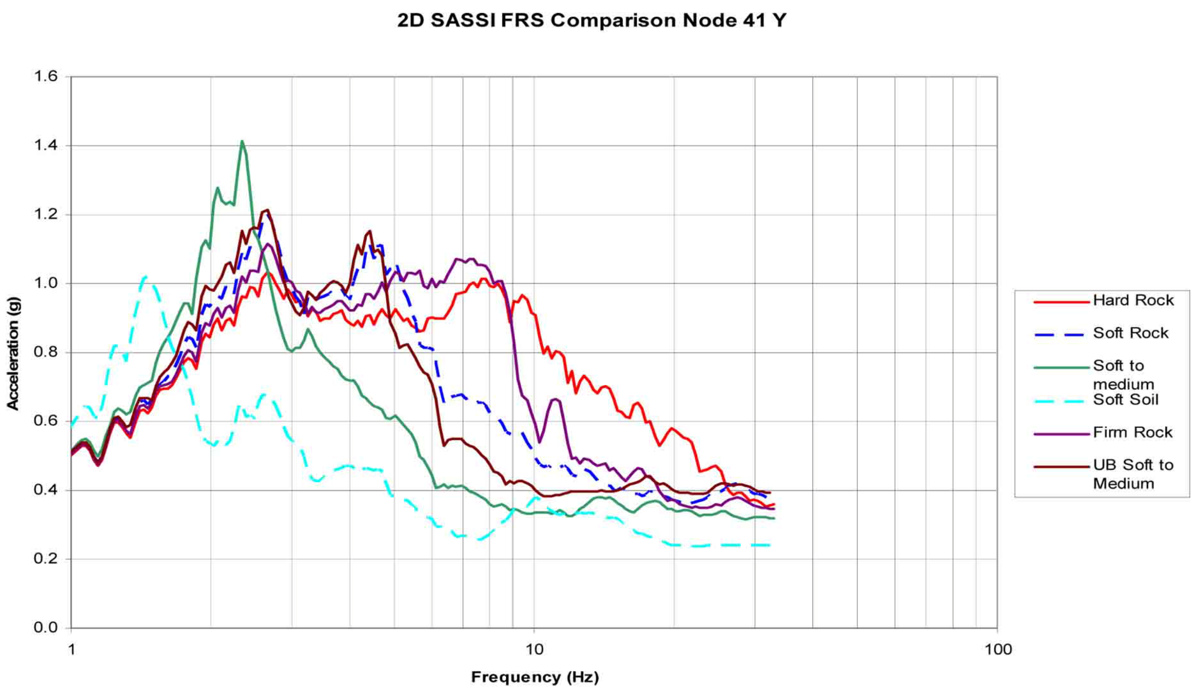


Figure 3G.3-3
2D SASSI FRS – Node 41 Y (ASB El. 99′)

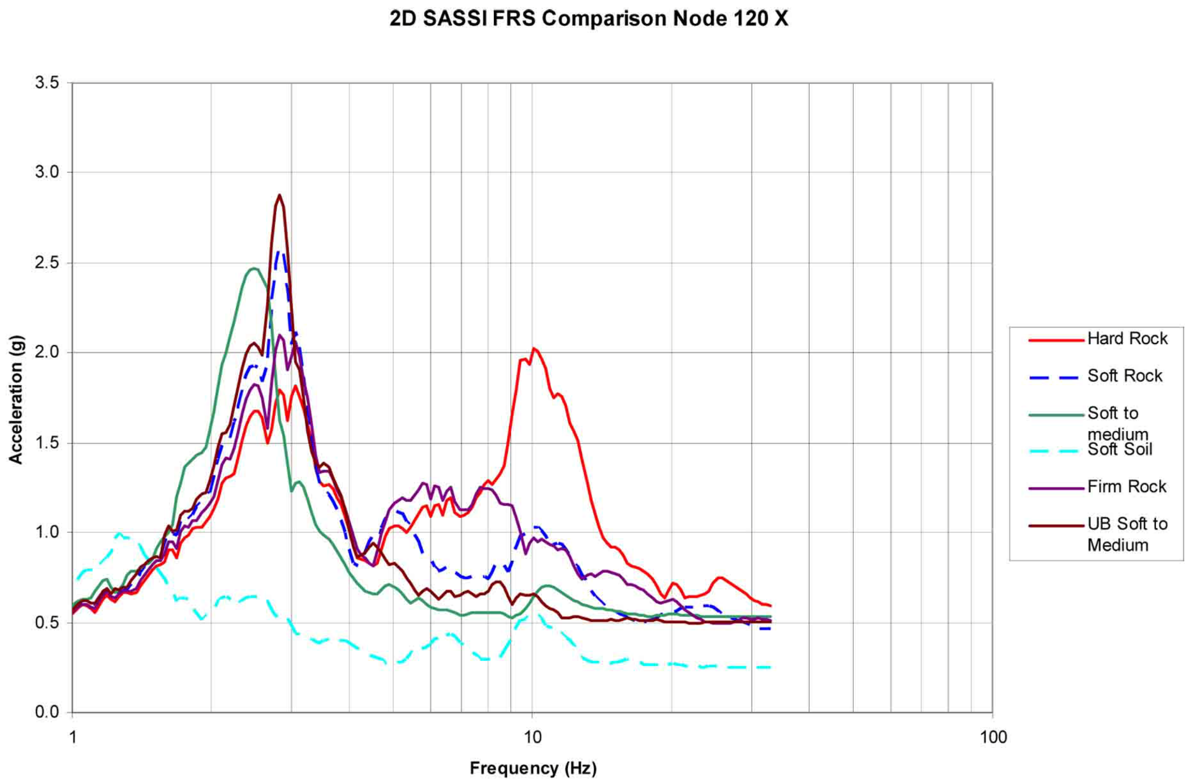


Figure 3G.3-4
2D SASSI FRS – Node 120 X (ASB El. 179.6′)

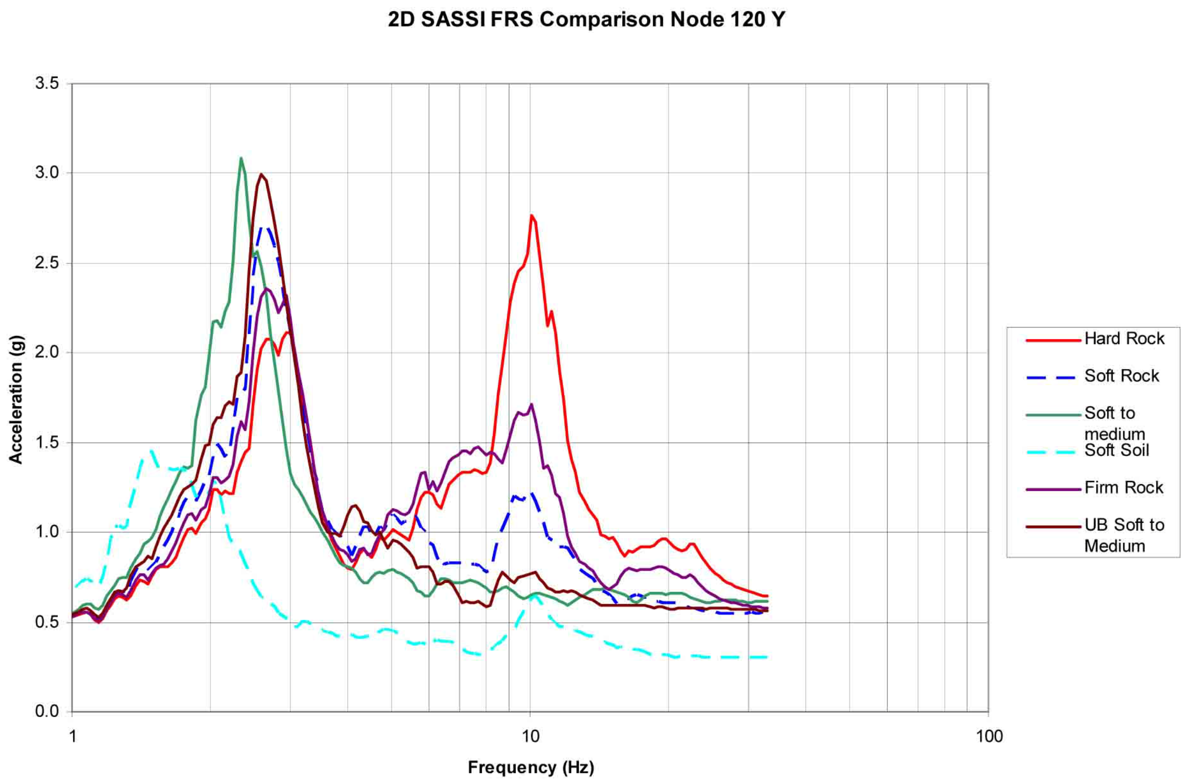


Figure 3G.3-5
2D SASSI FRS – Node 120 Y (ASB El. 179.6′)

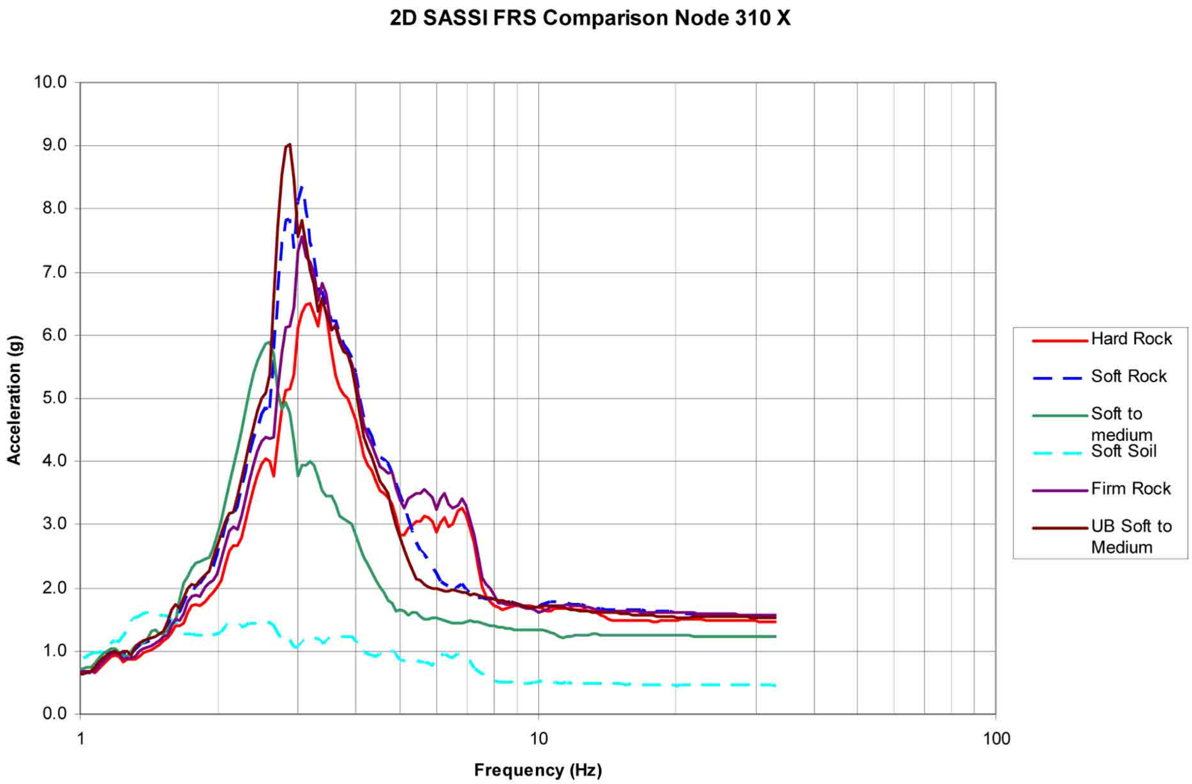


Figure 3G.3-6
2D SASSI FRS – Node 310 X (ASB El. 333.2′)

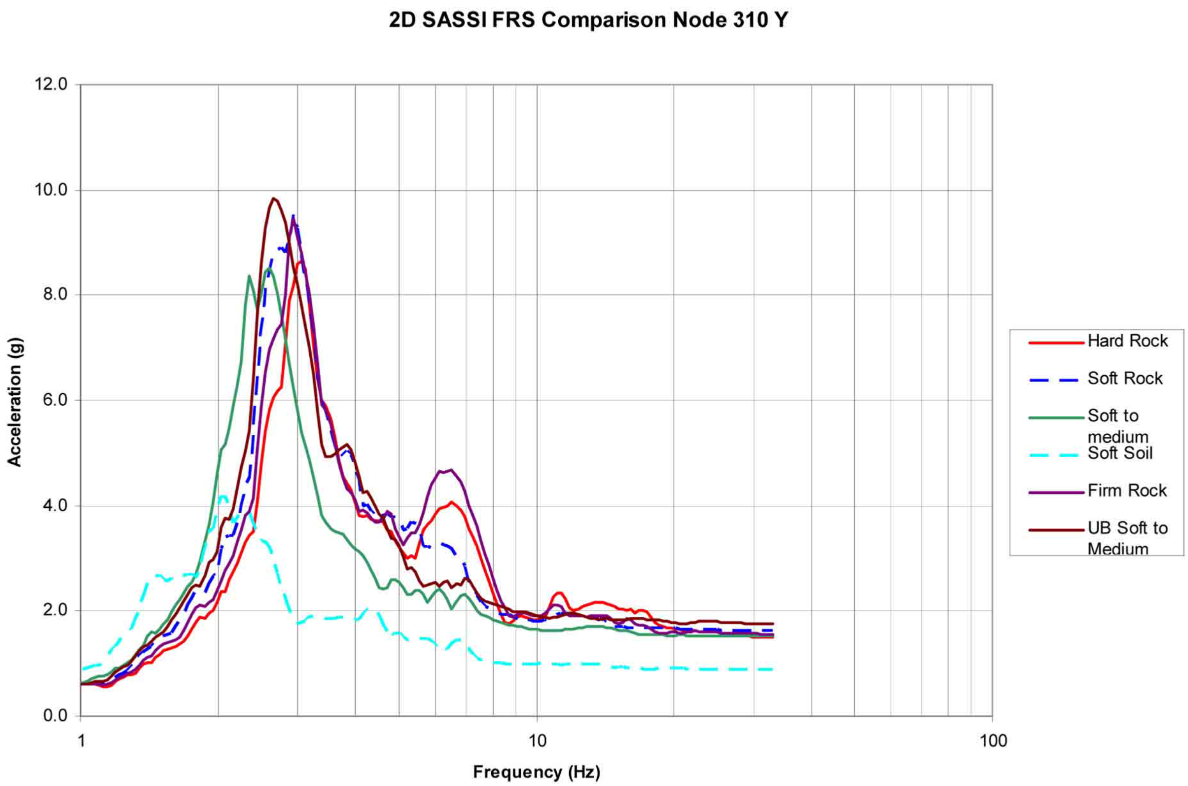


Figure 3G.3-7
2D SASSI FRS – Node 310 Y (ASB El. 333.2′)

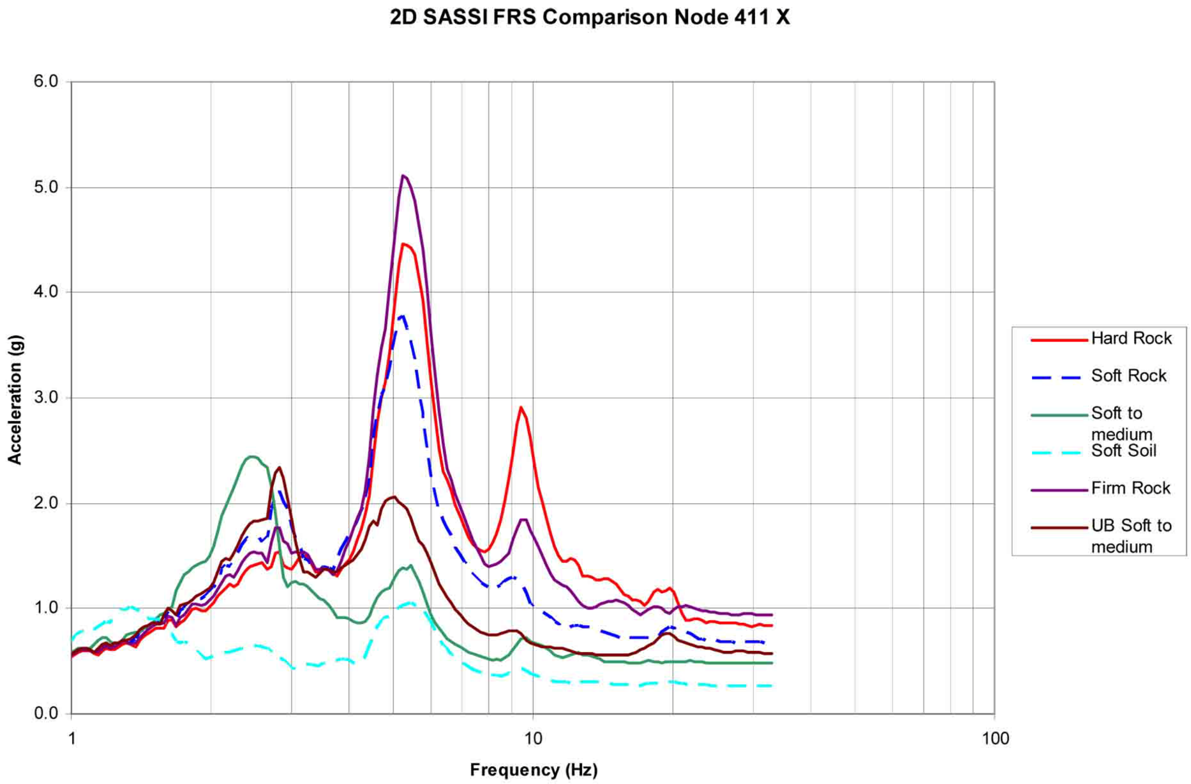


Figure 3G.3-8
2D SASSI FRS – Node 411 X (SCV El. 200.0′)

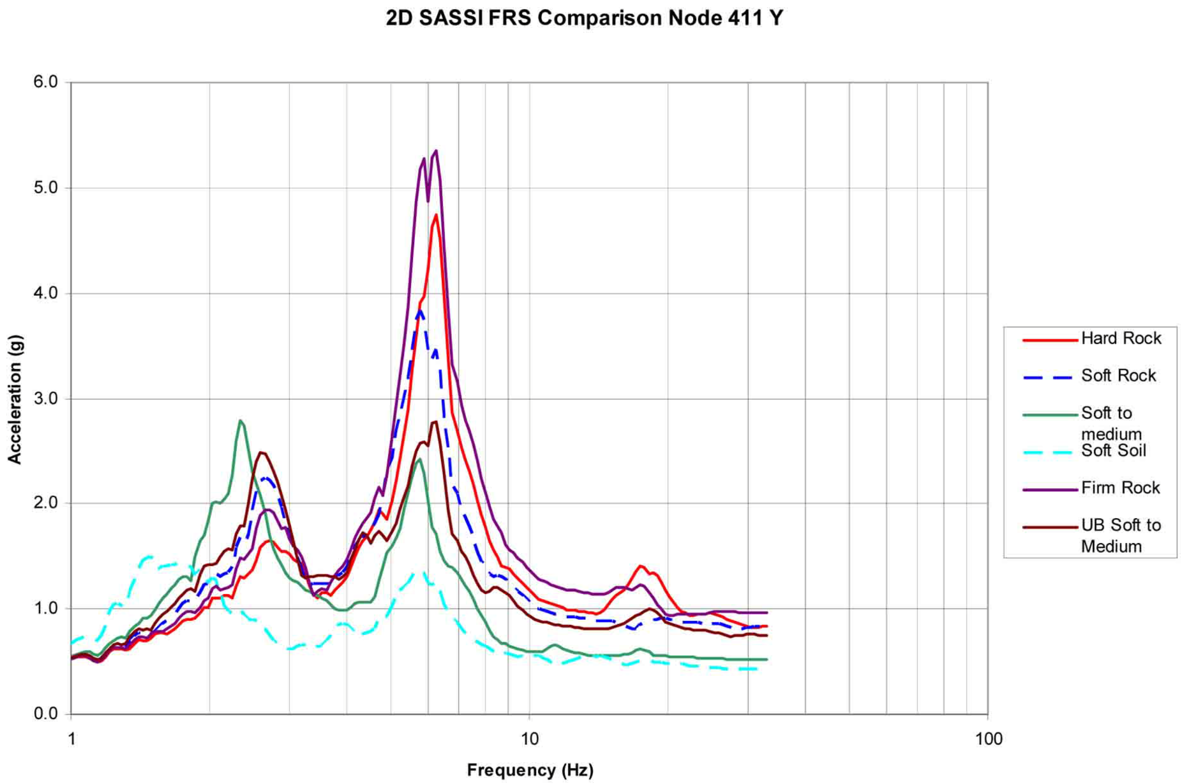


Figure 3G.3-9
2D SASSI FRS – Node 411 Y (SCV El. 200.0′)

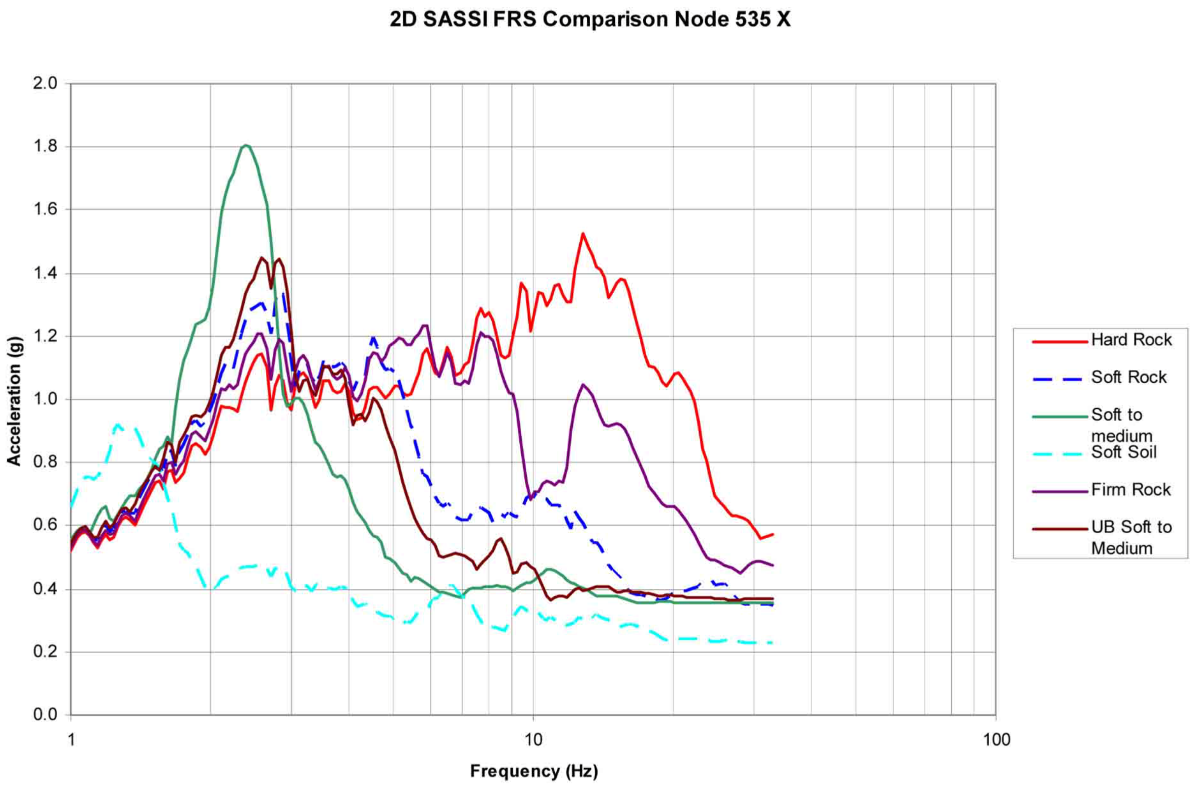


Figure 3G.3-10
2D SASSI FRS – Node 535 X (CIS El. 134.3′)

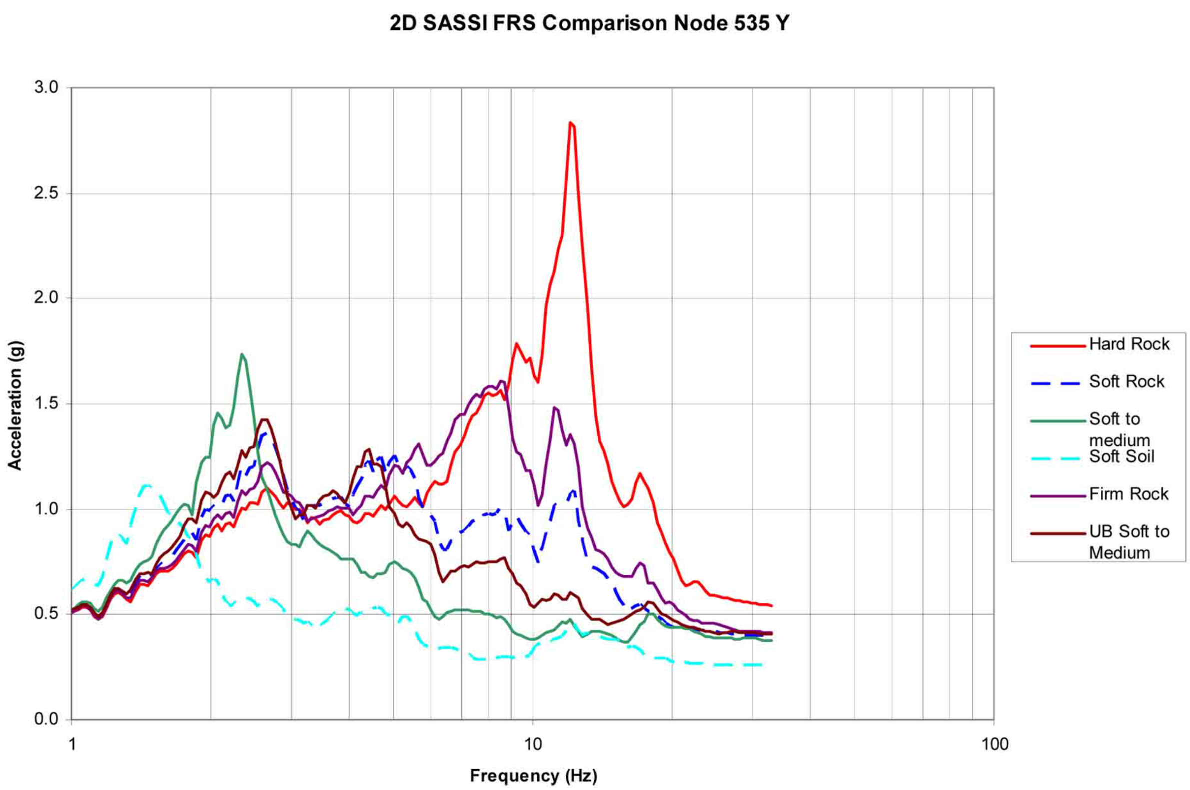


Figure 3G.3-11
2D SASSI FRS – Node 535 Y (CIS El. 134.3′)

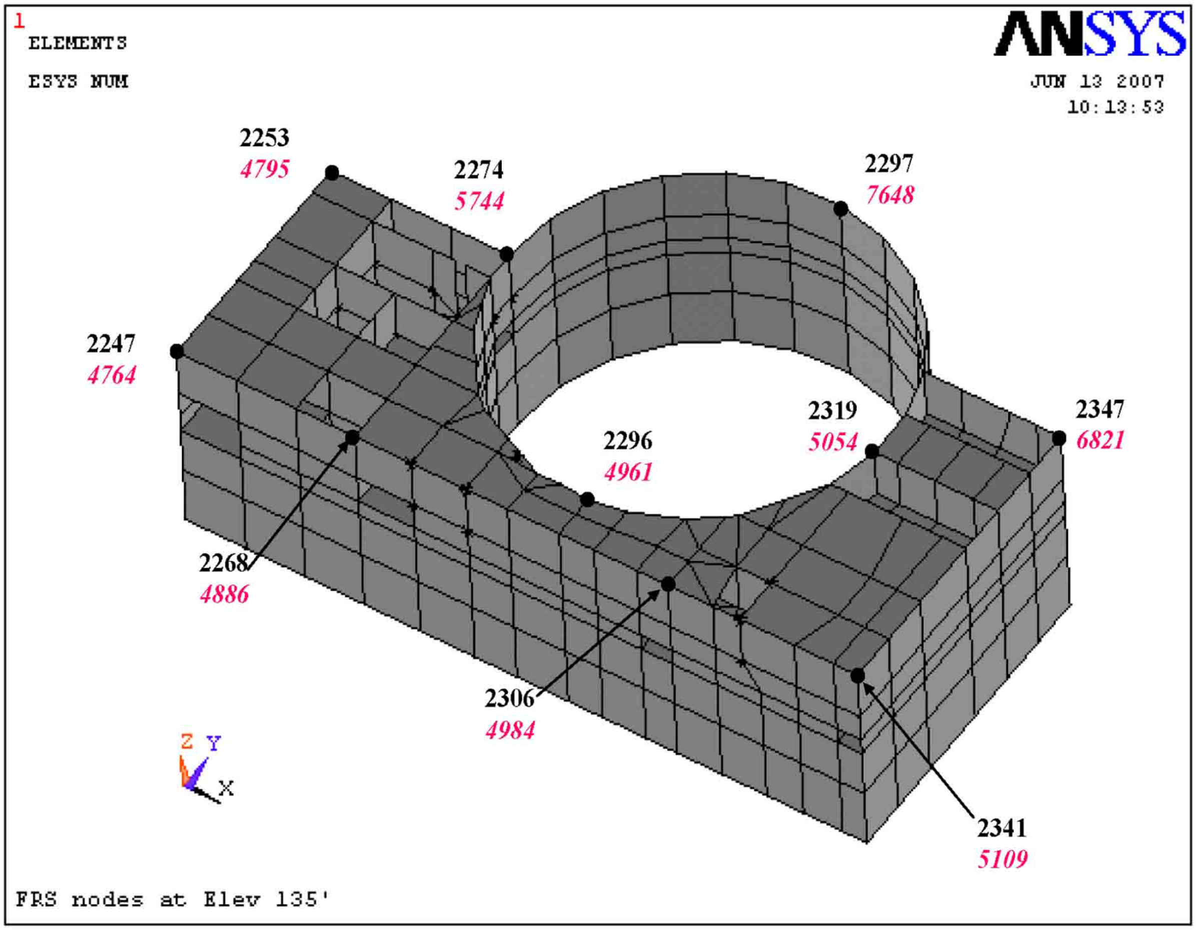


Figure 3G.4-1
Auxiliary Shield Building "Rigid" Nodes at El. 135′

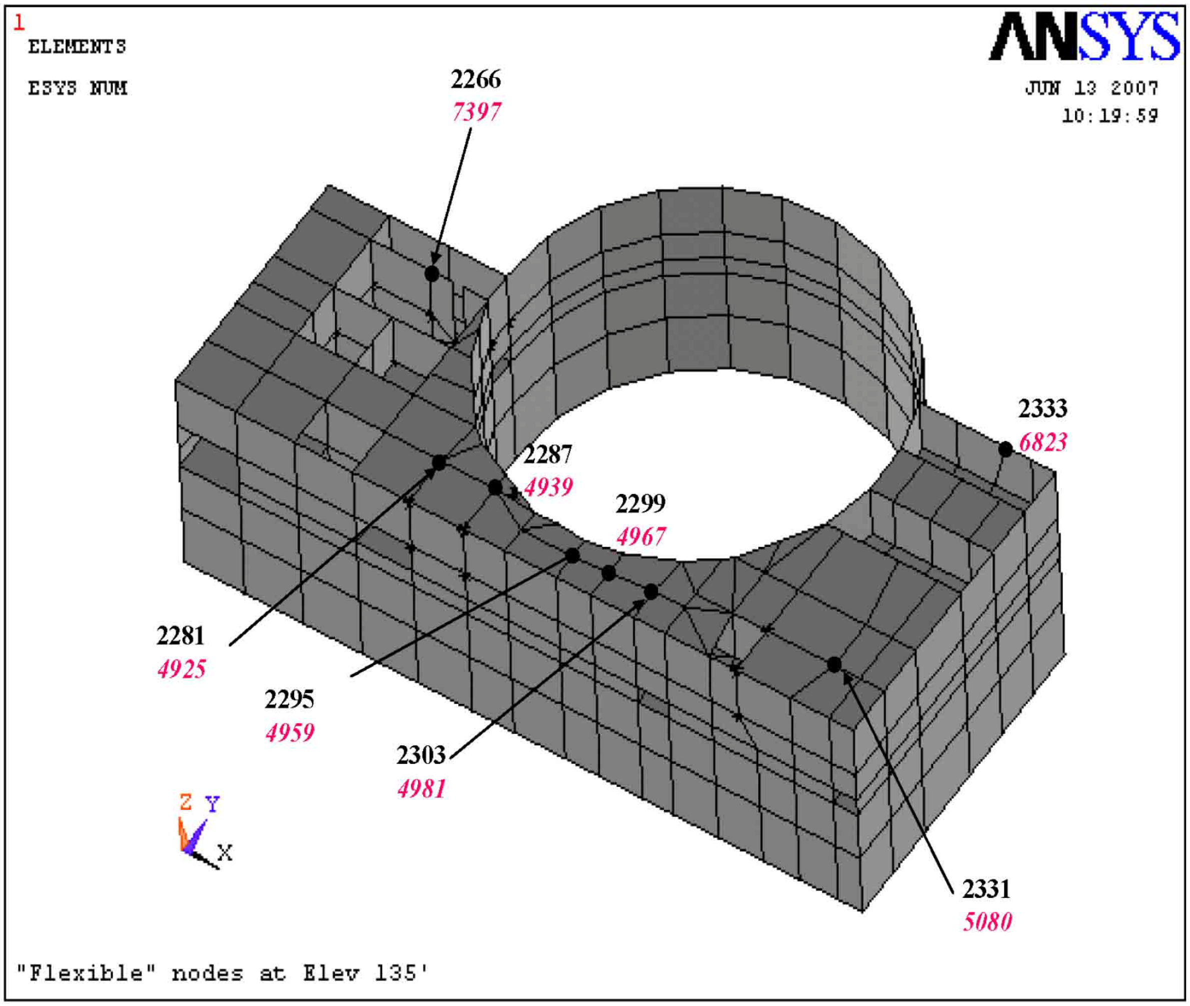


Figure 3G.4-2
Auxiliary Shield Building "Flexible" Nodes at El. 135′

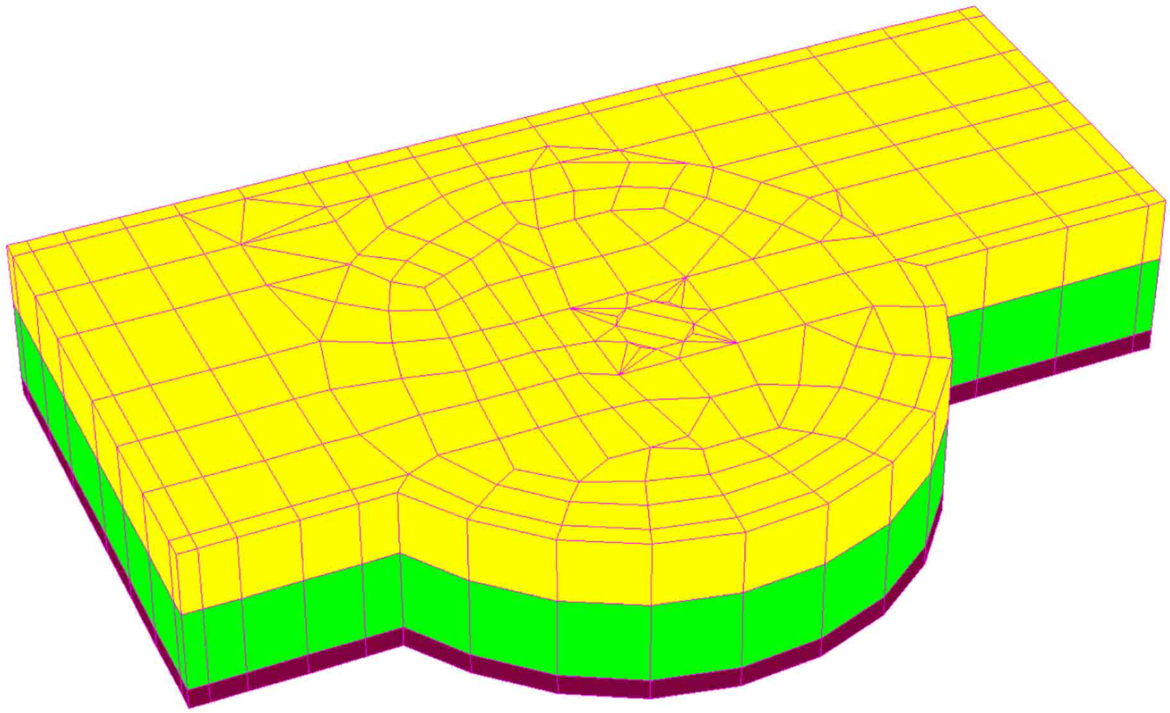


Figure 3G.4-3
Excavated Soil

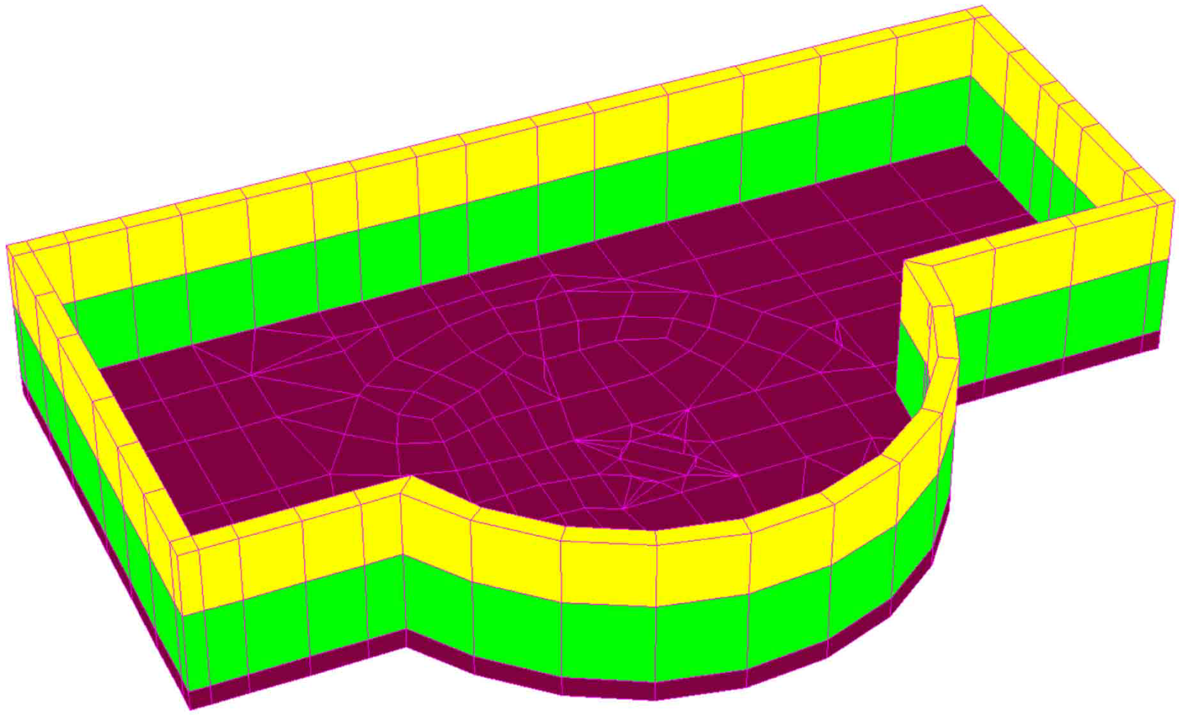
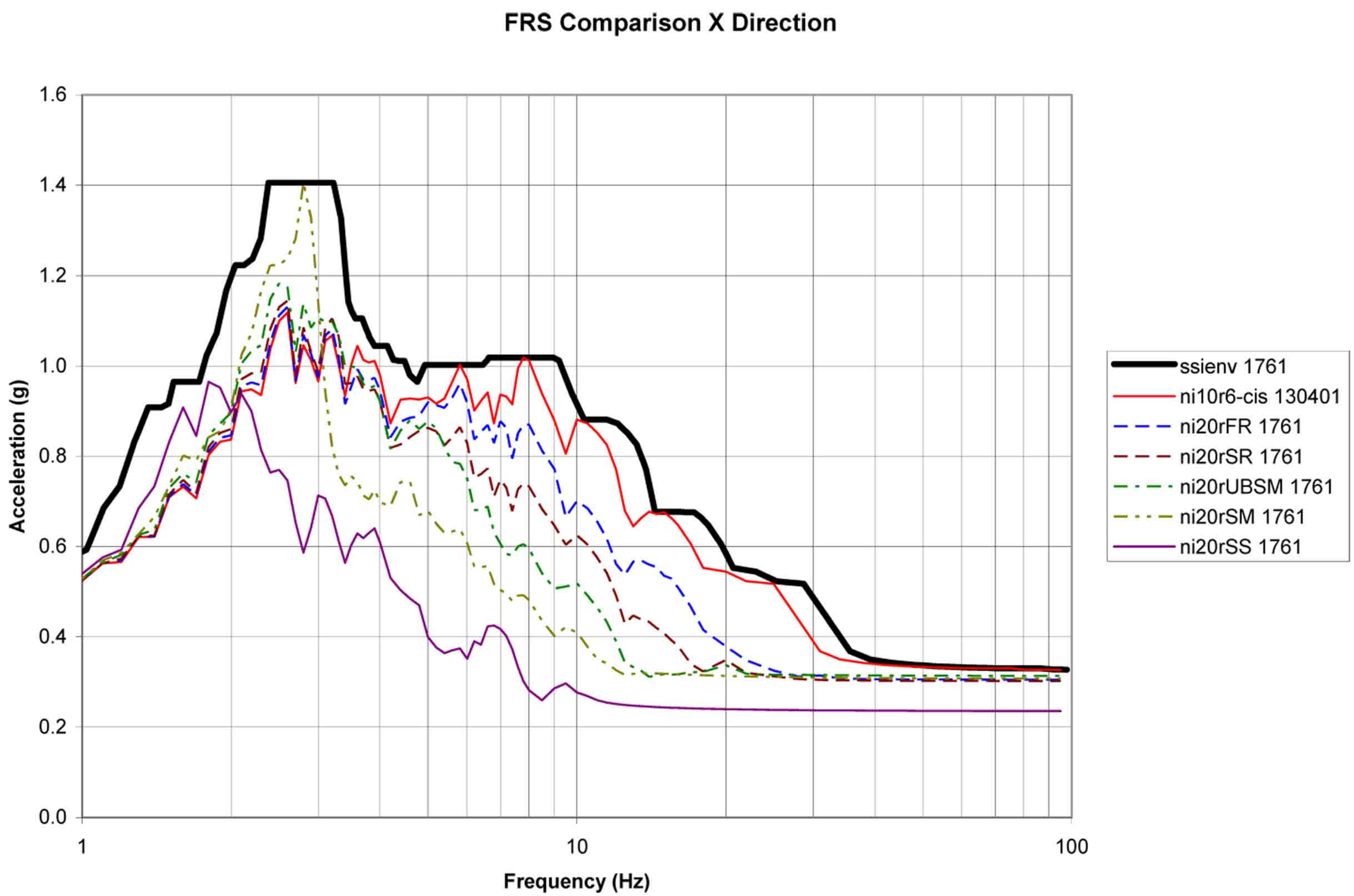
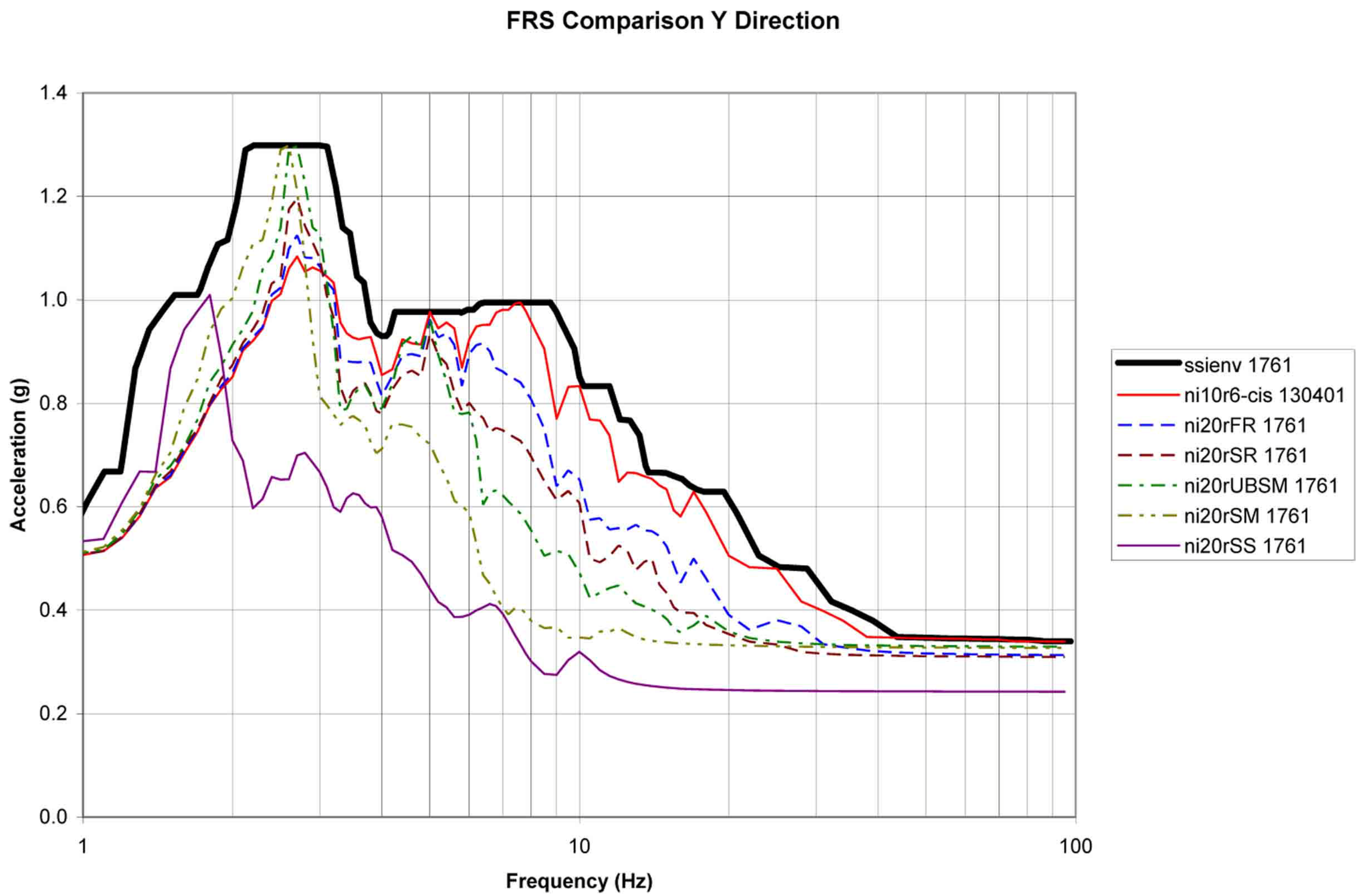


Figure 3G.4-4
Additional Elements for Soil Pressure Calculations



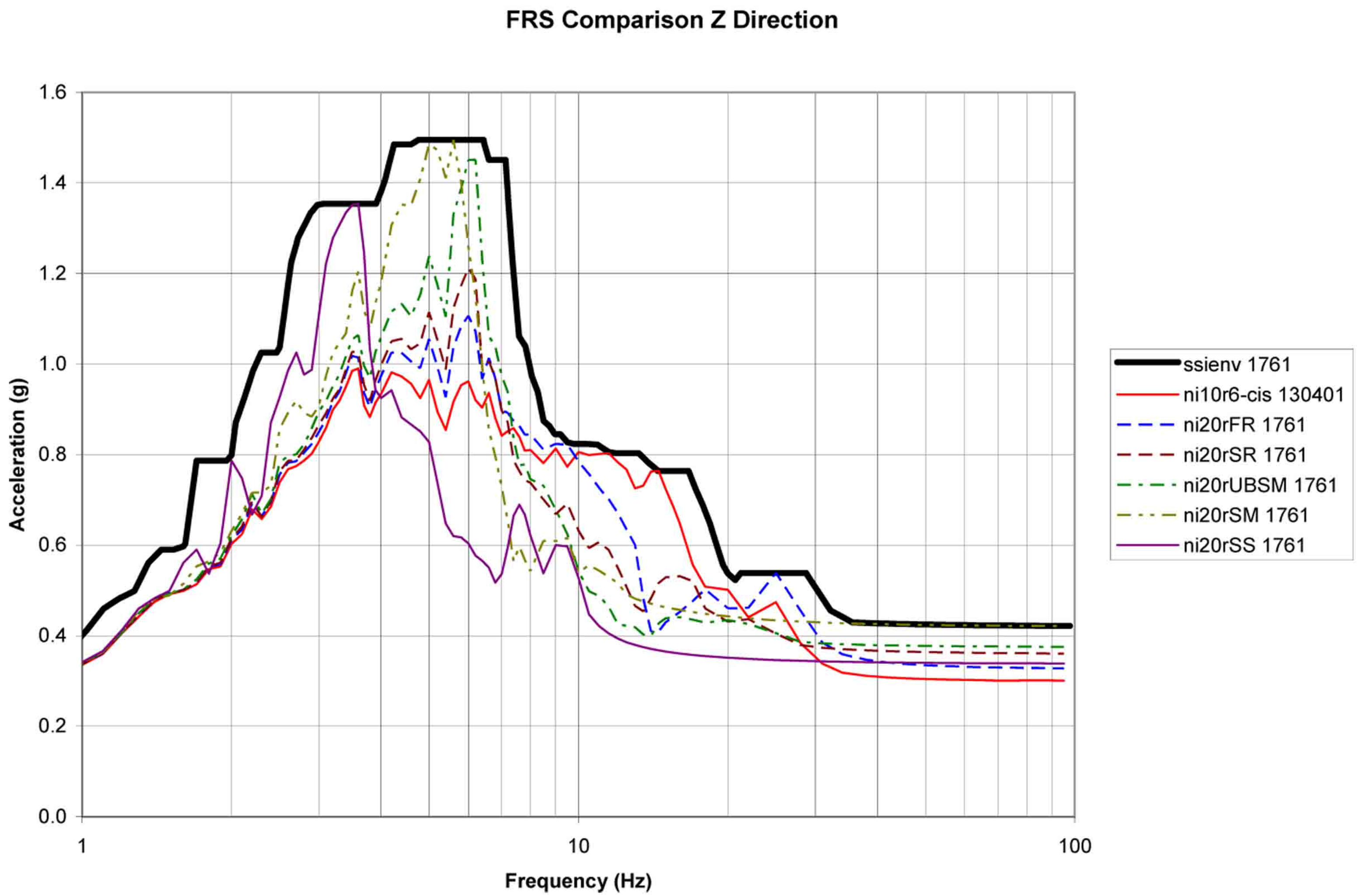
[*Figure 3G.4-5X*
X Direction FRS for Node 130401 (NI10) or 1761 (NI20)
CIS at Reactor Vessel Support Elevation of 100'*]

*NRC Staff approval is required prior to implementing a change in this information.



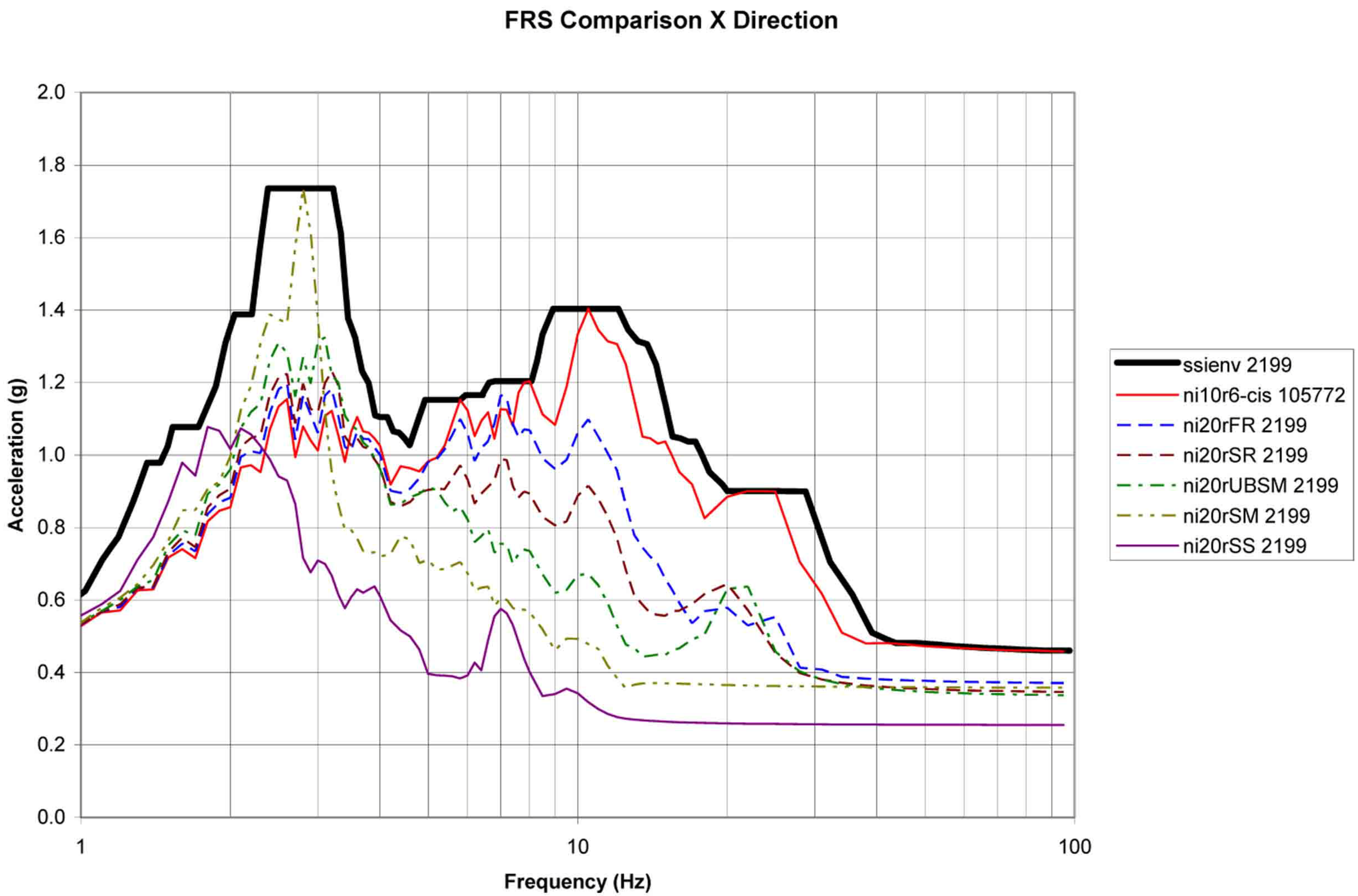
[*Figure 3G.4-5Y*
Y Direction FRS for Node 130401 (NI10) or 1761 (NI20)
CIS at Reactor Vessel Support Elevation of 100'**]***

*NRC Staff approval is required prior to implementing a change in this information.



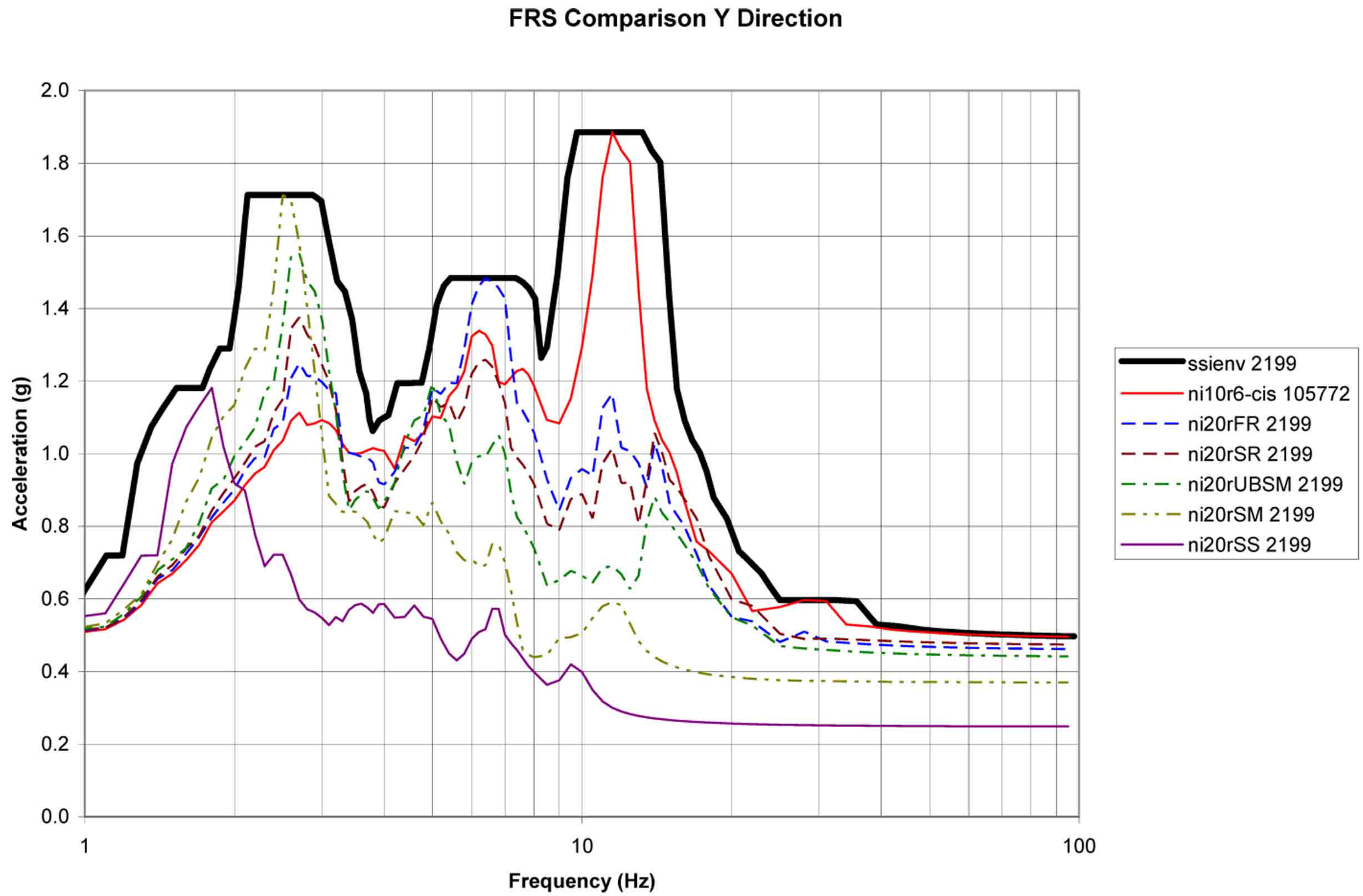
[Figure 3G.4-5Z
Z Direction FRS for Node 130401 (NI10) or 1761 (NI20)
CIS at Reactor Vessel Support Elevation of 100']*

*NRC Staff approval is required prior to implementing a change in this information.



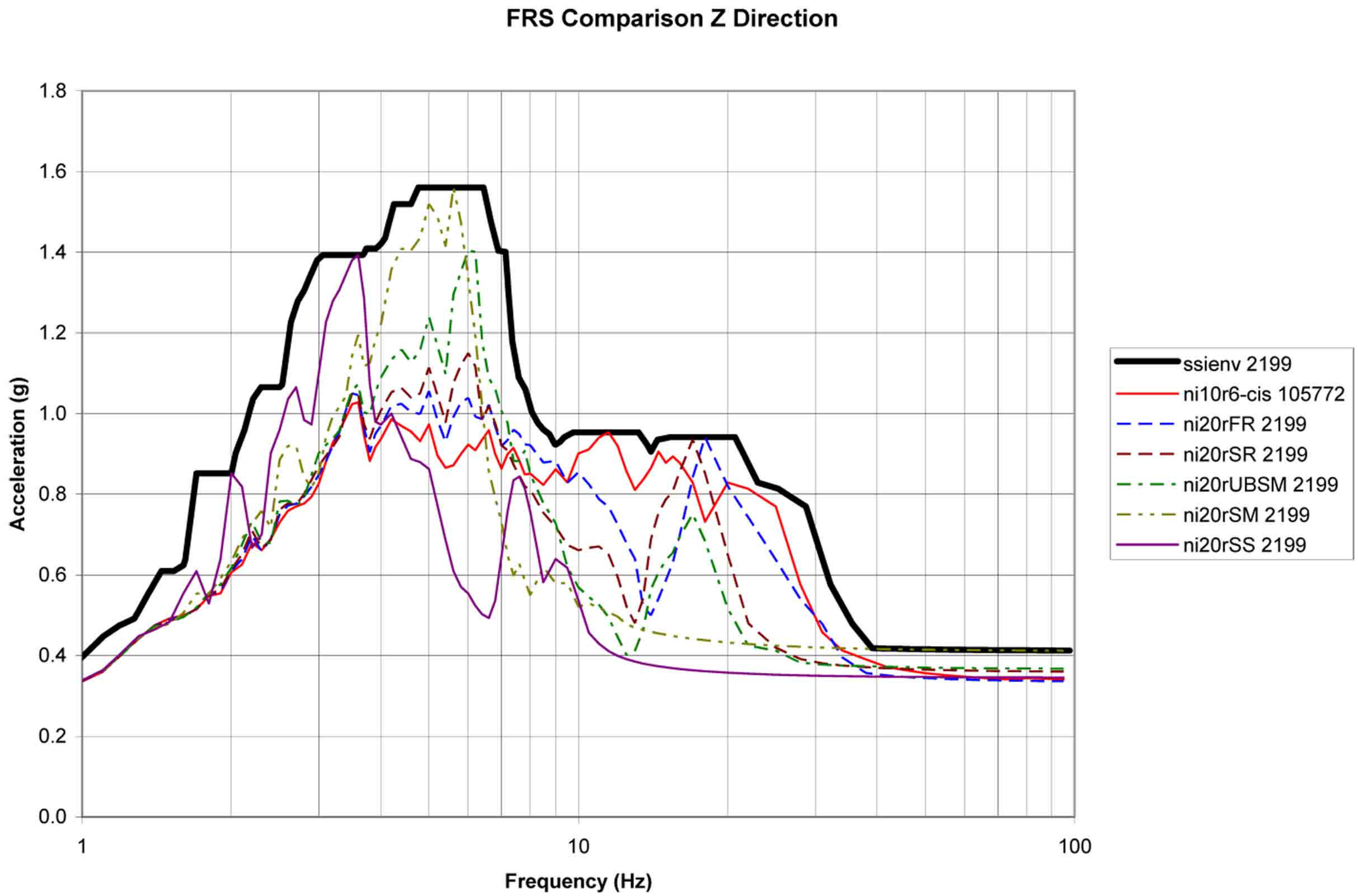
[*Figure 3G.4-6X*
X Direction FRS for Node 105772 (NI10) or 2199 (NI20)
CIS at Operating Deck Elevation 134.25]*

*NRC Staff approval is required prior to implementing a change in this information.



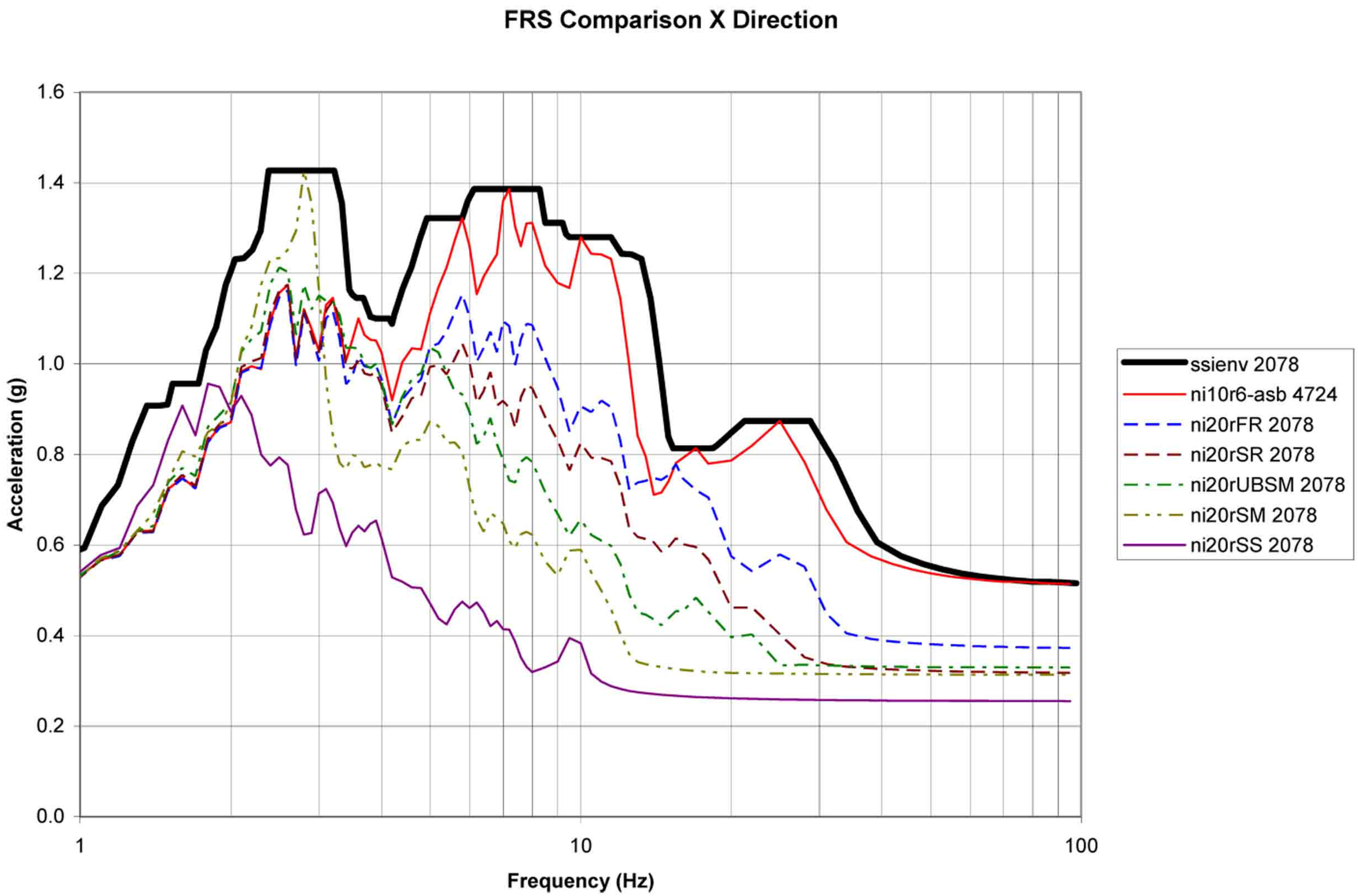
[*Figure 3G.4-6Y*
Y Direction FRS for Node 105772 (NI10) or 2199 (NI20)
CIS at Operating Deck Elevation 134.25]*

*NRC Staff approval is required prior to implementing a change in this information.



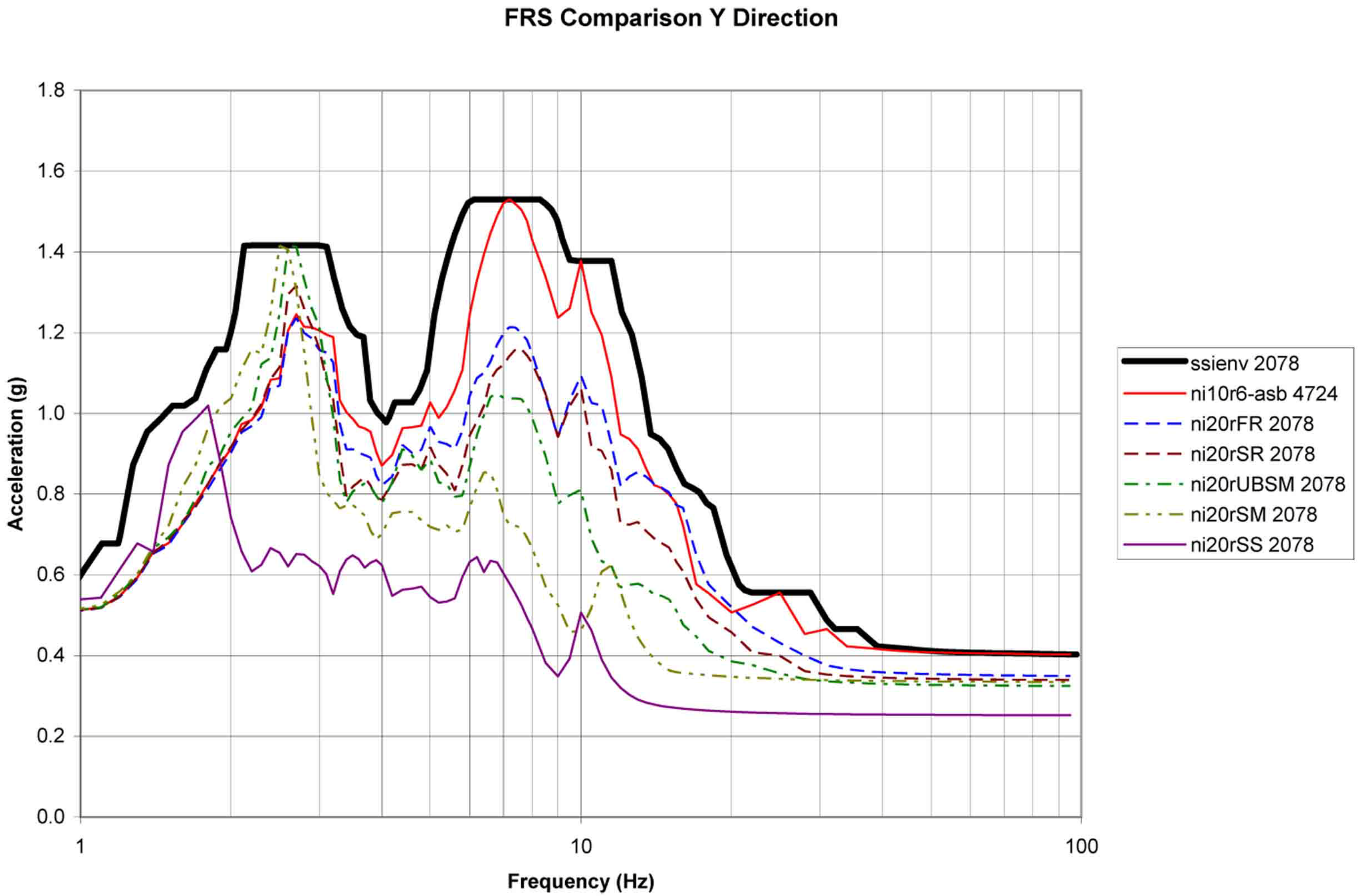
[*Figure 3G.4-6Z*
Z Direction FRS for Node 105772 (NI10) or 2199 (NI20)
CIS at Operating Deck Elevation 134.25']*

*NRC Staff approval is required prior to implementing a change in this information.



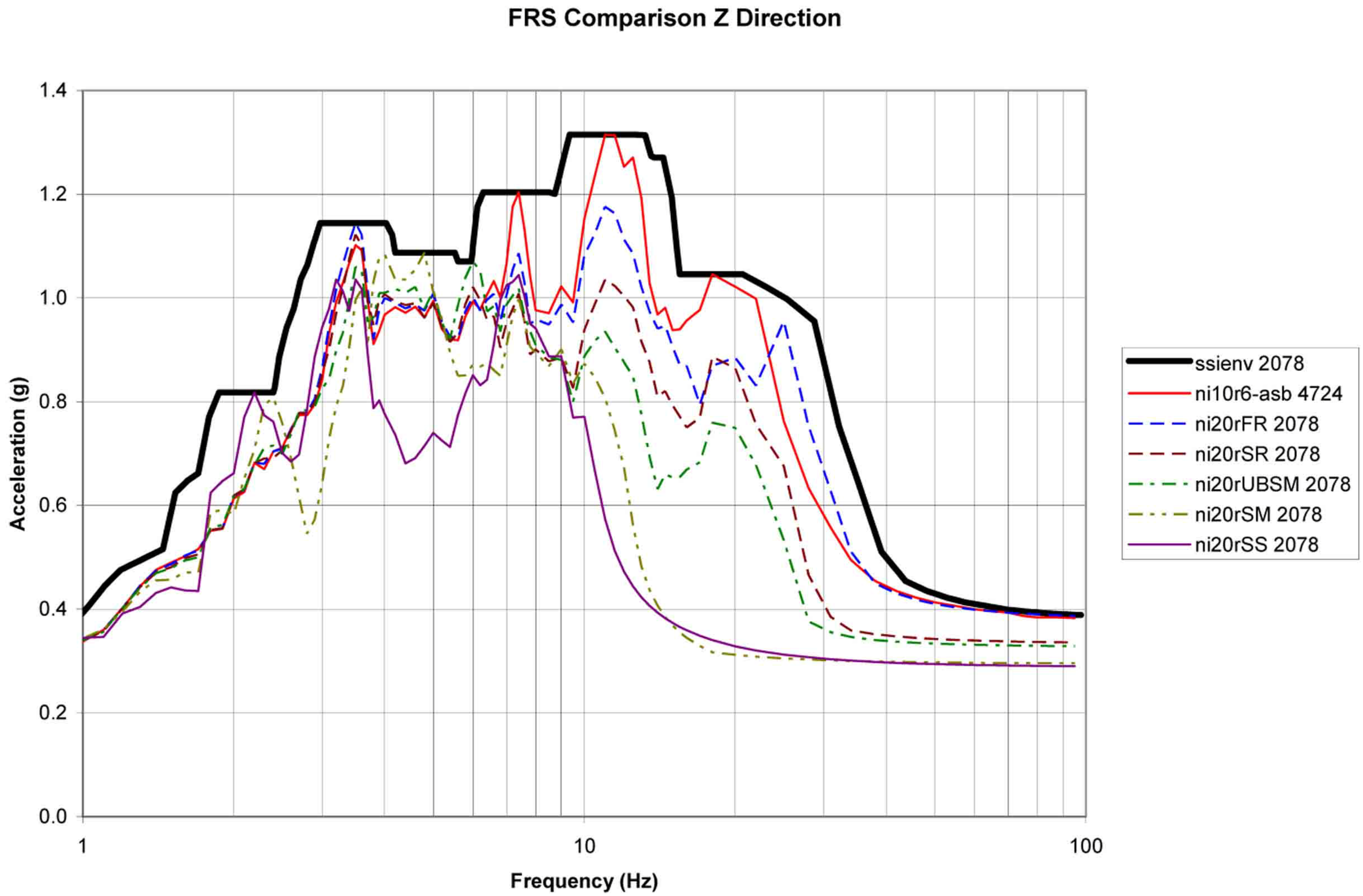
[*Figure 3G.4-7X*
X Direction FRS for Node 4724 (NI10) or 2078 (NI20)
ASB Control Room Side Elevation 116.50'*]

*NRC Staff approval is required prior to implementing a change in this information.



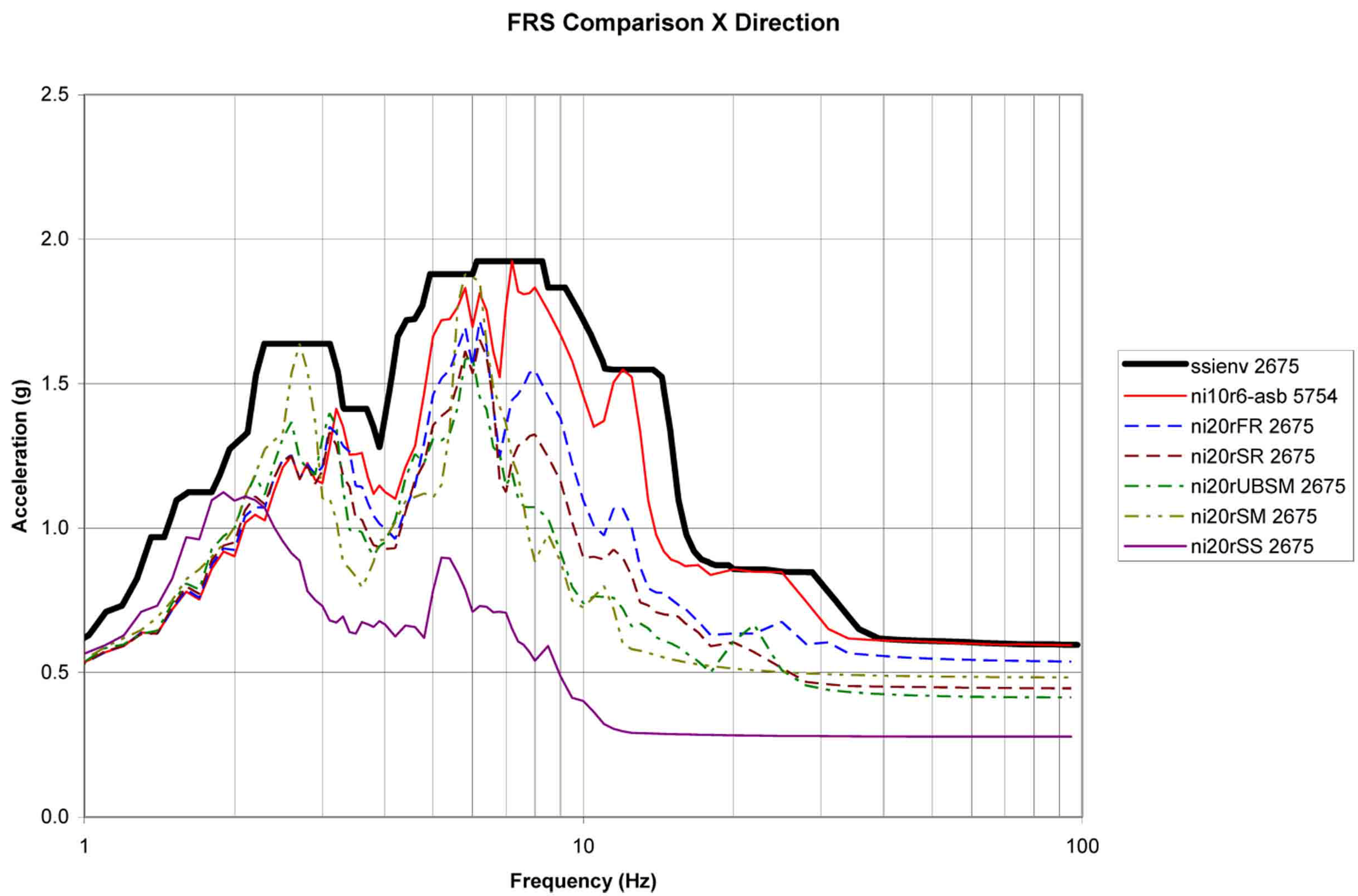
[*Figure 3G.4-7Y*
Y Direction FRS for Node 4724 (NI10) or 2078 (NI20)
ASB Control Room Side Elevation 116.50']*

*NRC Staff approval is required prior to implementing a change in this information.



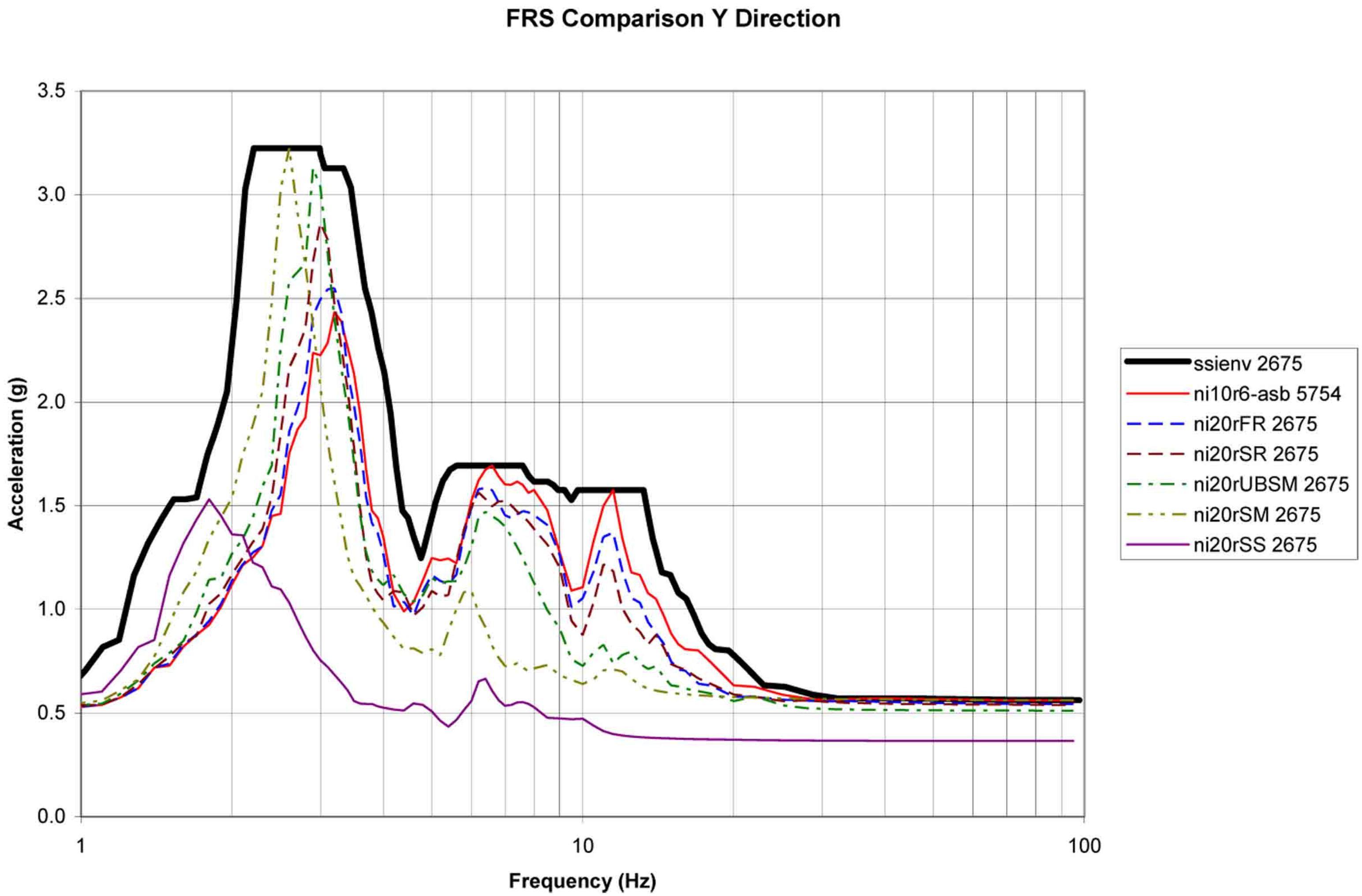
[*Figure 3G.4-7Z*
Z Direction FRS for Node 4724 (NI10) or 2078 (NI20)
ASB Control Room Side Elevation 116.50']*

*NRC Staff approval is required prior to implementing a change in this information.



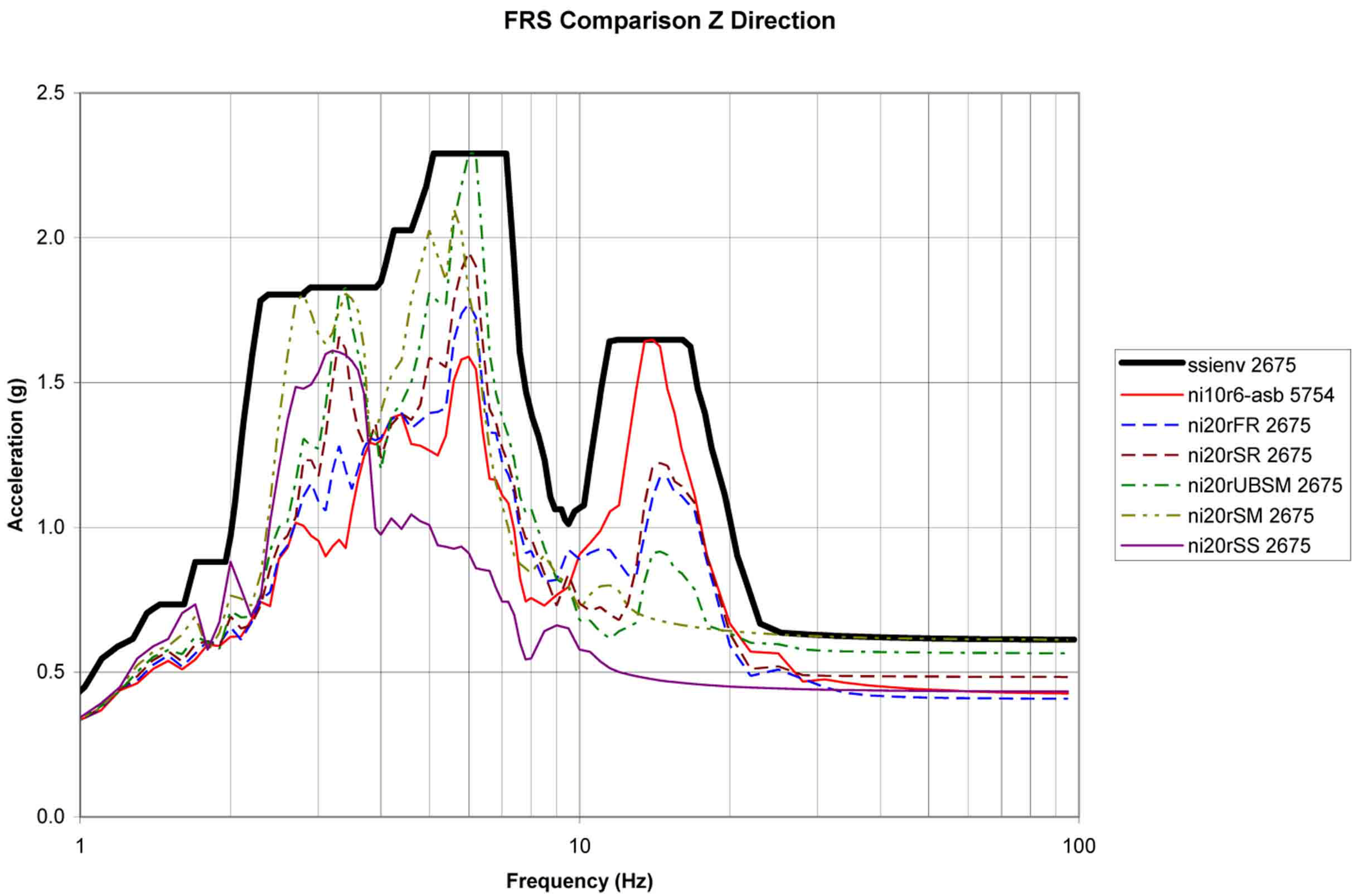
[*Figure 3G.4-8X*
X Direction FRS for Node 5754 (NI10) or 2675 (NI20)
ASB Fuel Building Roof Elevation 179.19]*

*NRC Staff approval is required prior to implementing a change in this information.



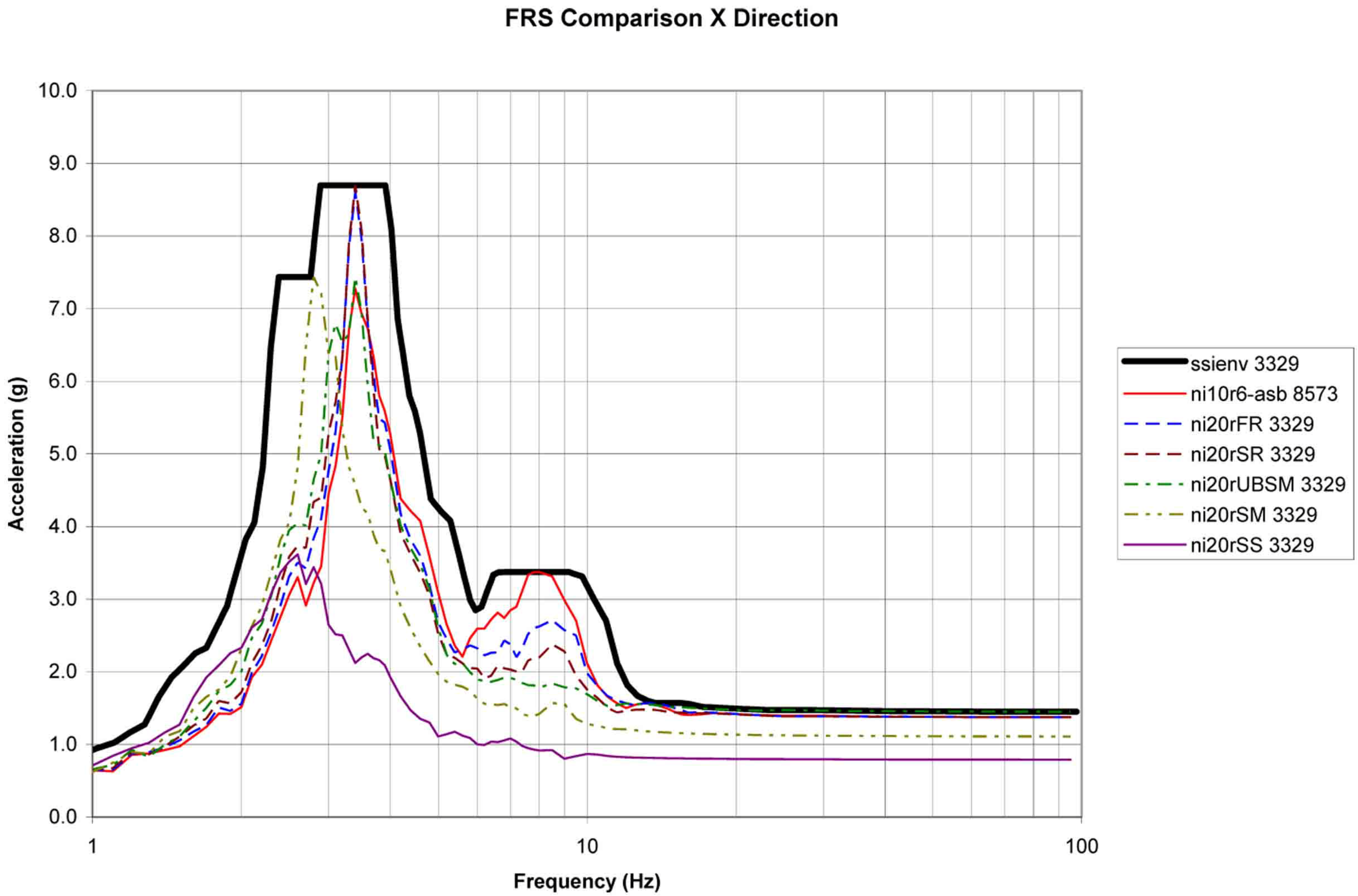
[*Figure 3G.4-8Y*
Y Direction FRS for Node 5754 (NI10) or 2675 (NI20)
ASB Fuel Building Roof Elevation 179.19]*

*NRC Staff approval is required prior to implementing a change in this information.



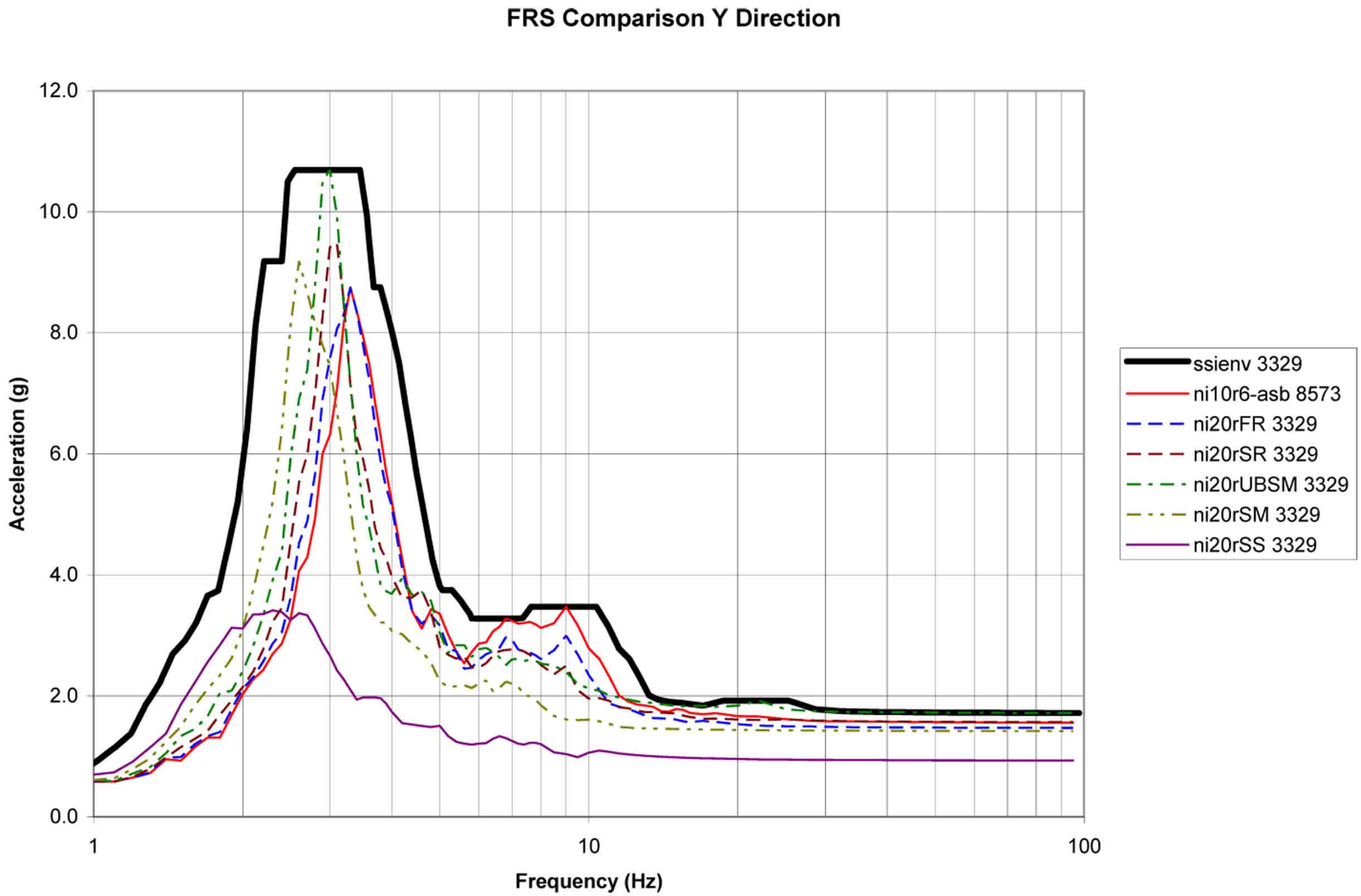
[*Figure 3G.4-8Z*
Z Direction FRS for Node 5754 (NI10) or 2675 (NI20)
ASB Fuel Building Roof Elevation 179.19*]

*NRC Staff approval is required prior to implementing a change in this information.



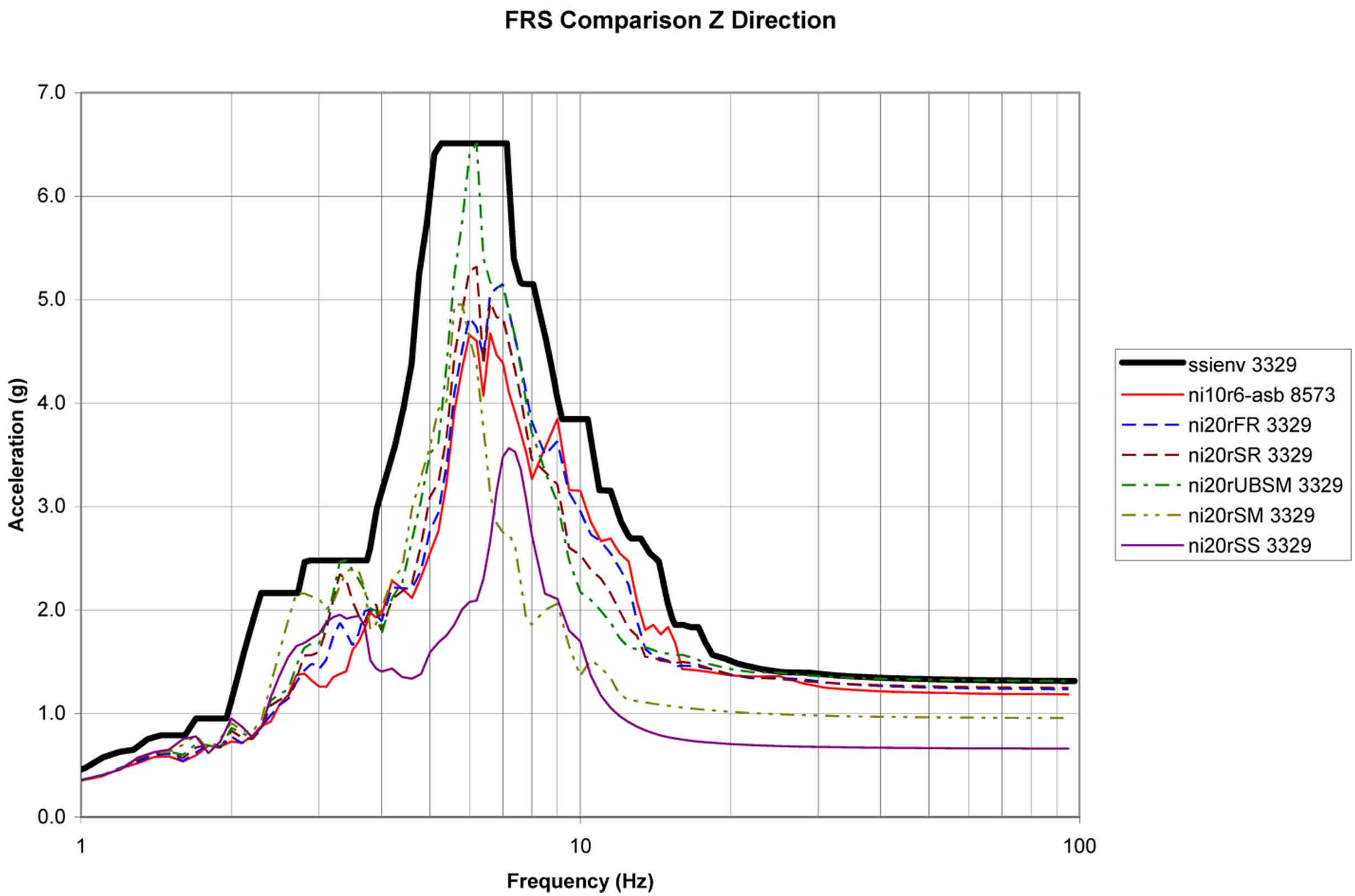
[*Figure 3G.4-9X*
X Direction FRS for Node 8573 (NI10) or 3329 (NI20)
ASB Shield Building Roof Elevation 327.41']*

*NRC Staff approval is required prior to implementing a change in this information.



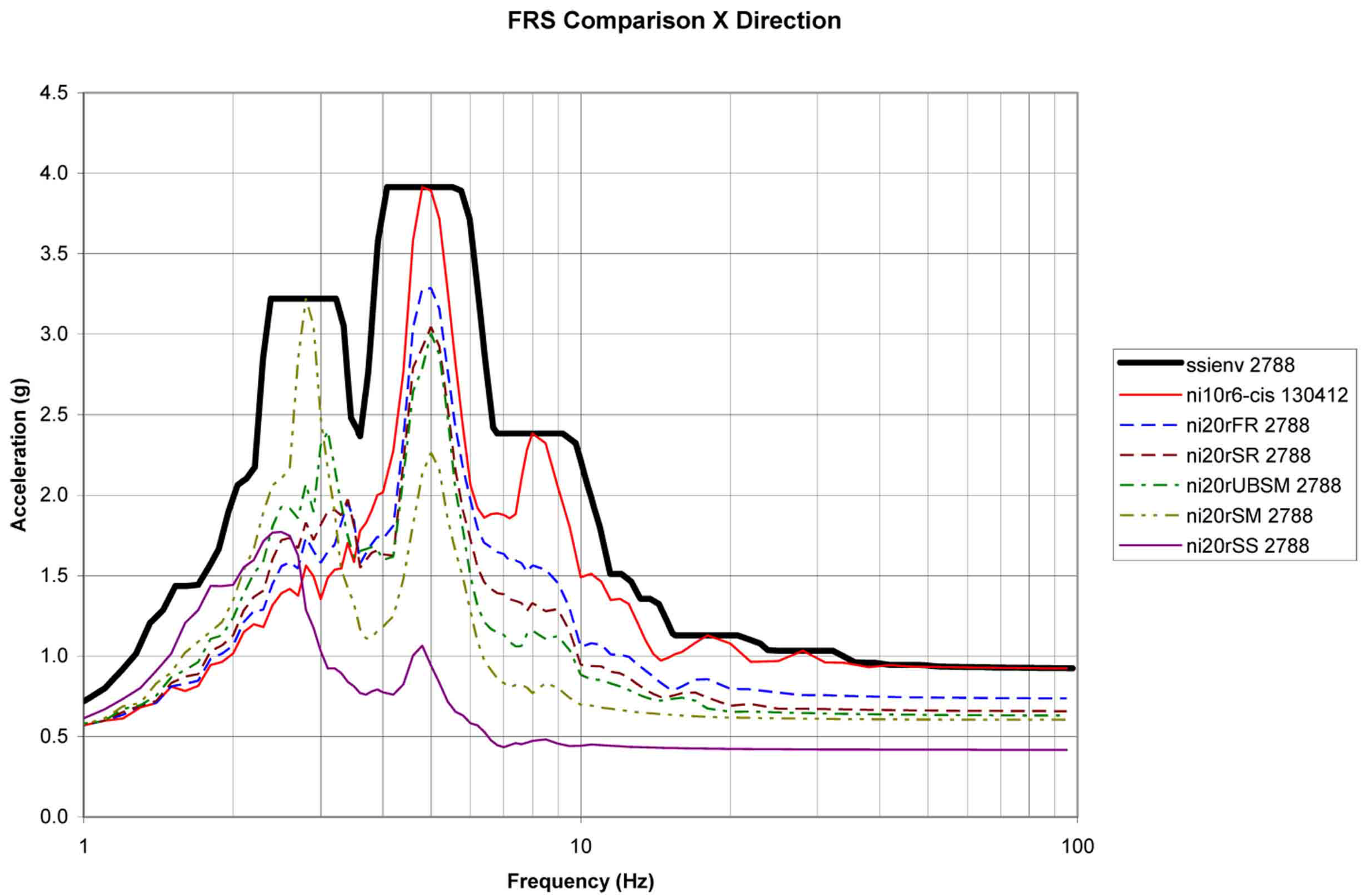
[*Figure 3G.4-9Y*
Y Direction FRS for Node 8573 (NI10) or 3329 (NI20)
ASB Shield Building Roof Elevation 327.41']*

*NRC Staff approval is required prior to implementing a change in this information.



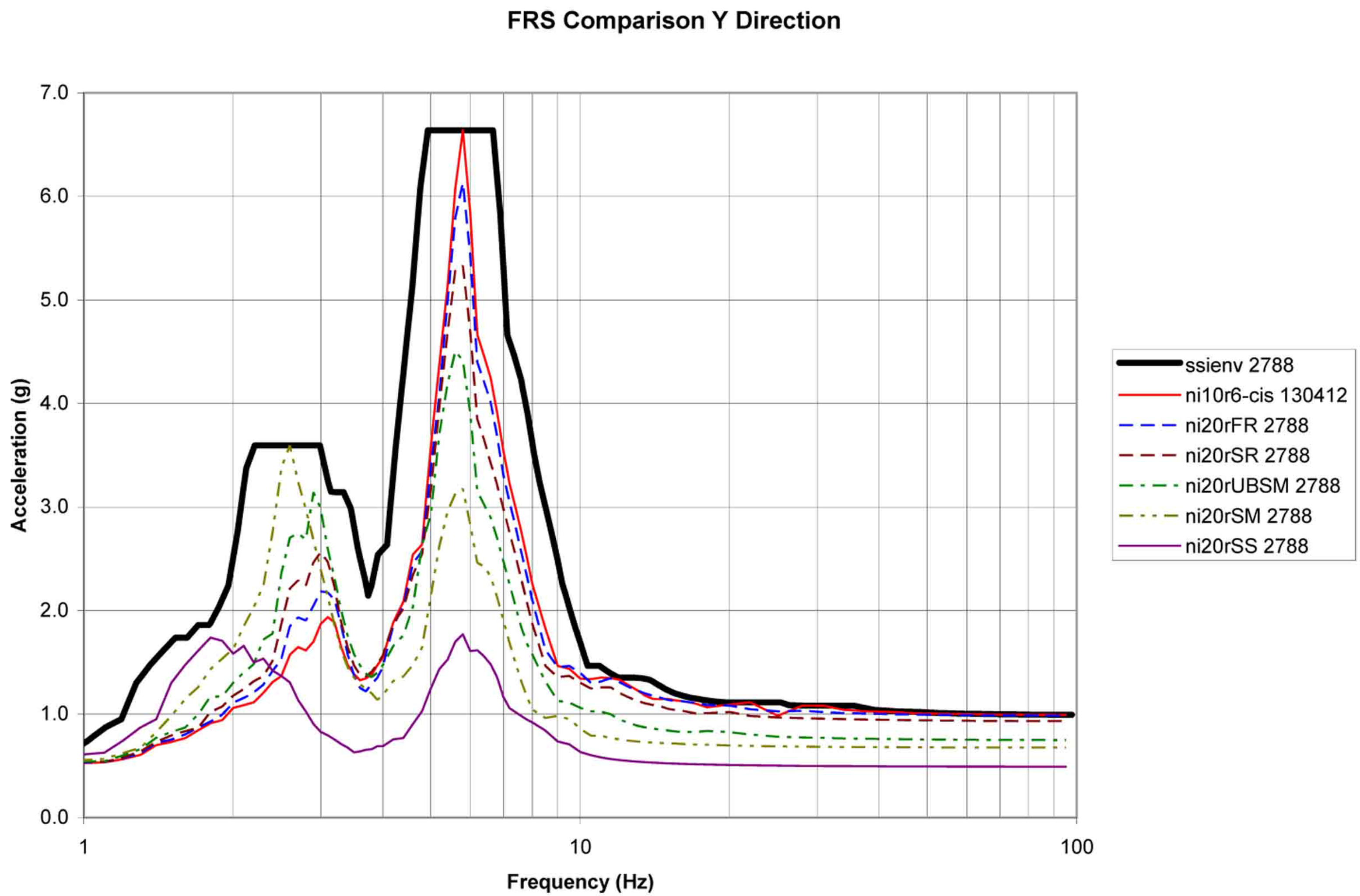
[*Figure 3G.4-9Z*
Z Direction FRS for Node 8573 (NI10) or 3329 (NI20)
ASB Shield Building Roof Elevation 327.41']*

*NRC Staff approval is required prior to implementing a change in this information.



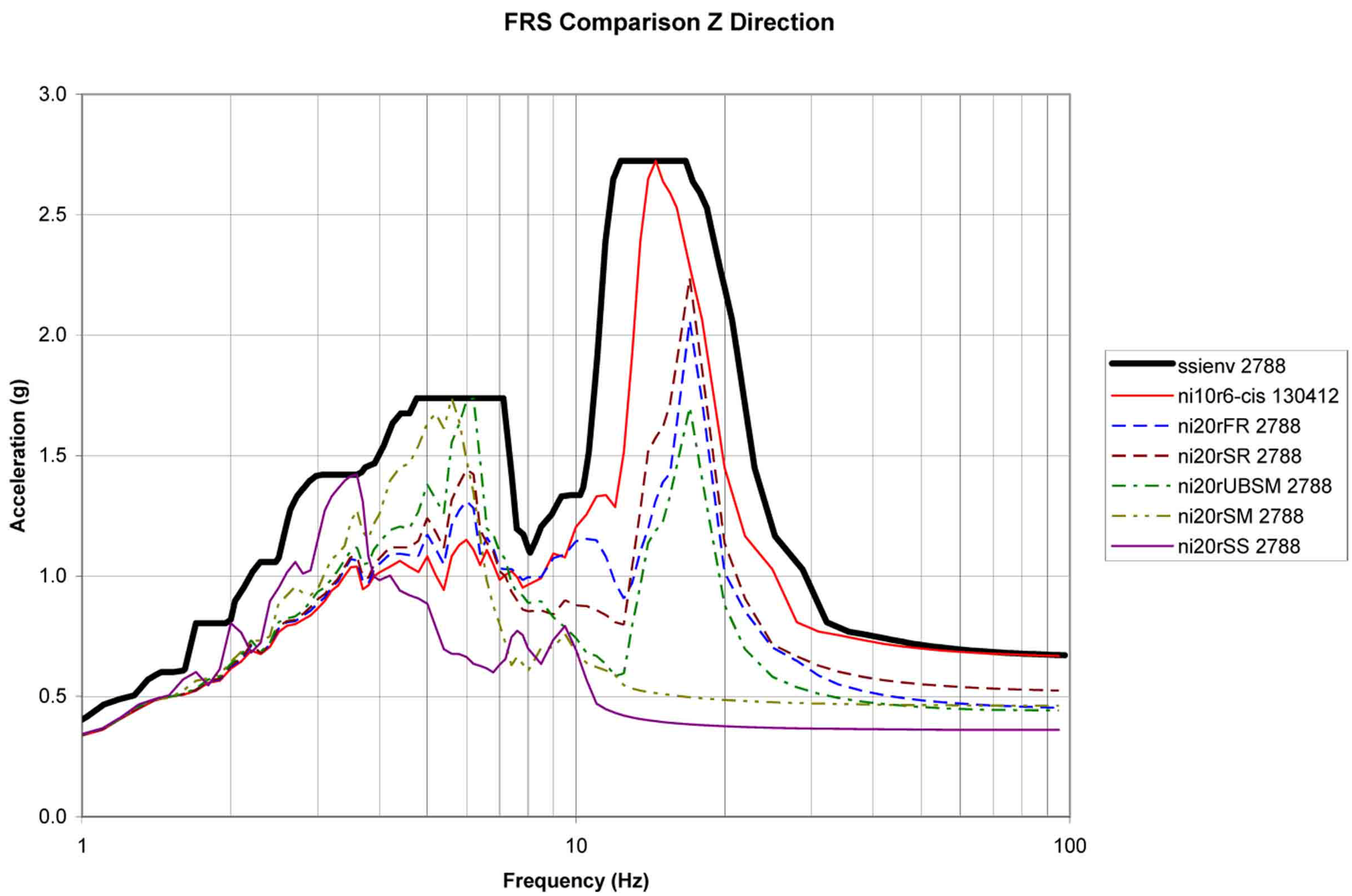
[*Figure 3G.4-10X*
X Direction FRS for Node 130412 (NI10) or 2788 (NI20)
SCV Near Polar Crane Elevation 224.00']*

*NRC Staff approval is required prior to implementing a change in this information.



[*Figure 3G.4-10Y*
Y Direction FRS for Node 130412 (NI10) or 2788 (NI20)
SCV Near Polar Crane Elevation 224.00']*

*NRC Staff approval is required prior to implementing a change in this information.



[*Figure 3G.4-10Z*
Z Direction FRS for Node 130412 (NI10) or 2788 (NI20)
SCV Near Polar Crane Elevation 224.00']*

*NRC Staff approval is required prior to implementing a change in this information.

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

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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.

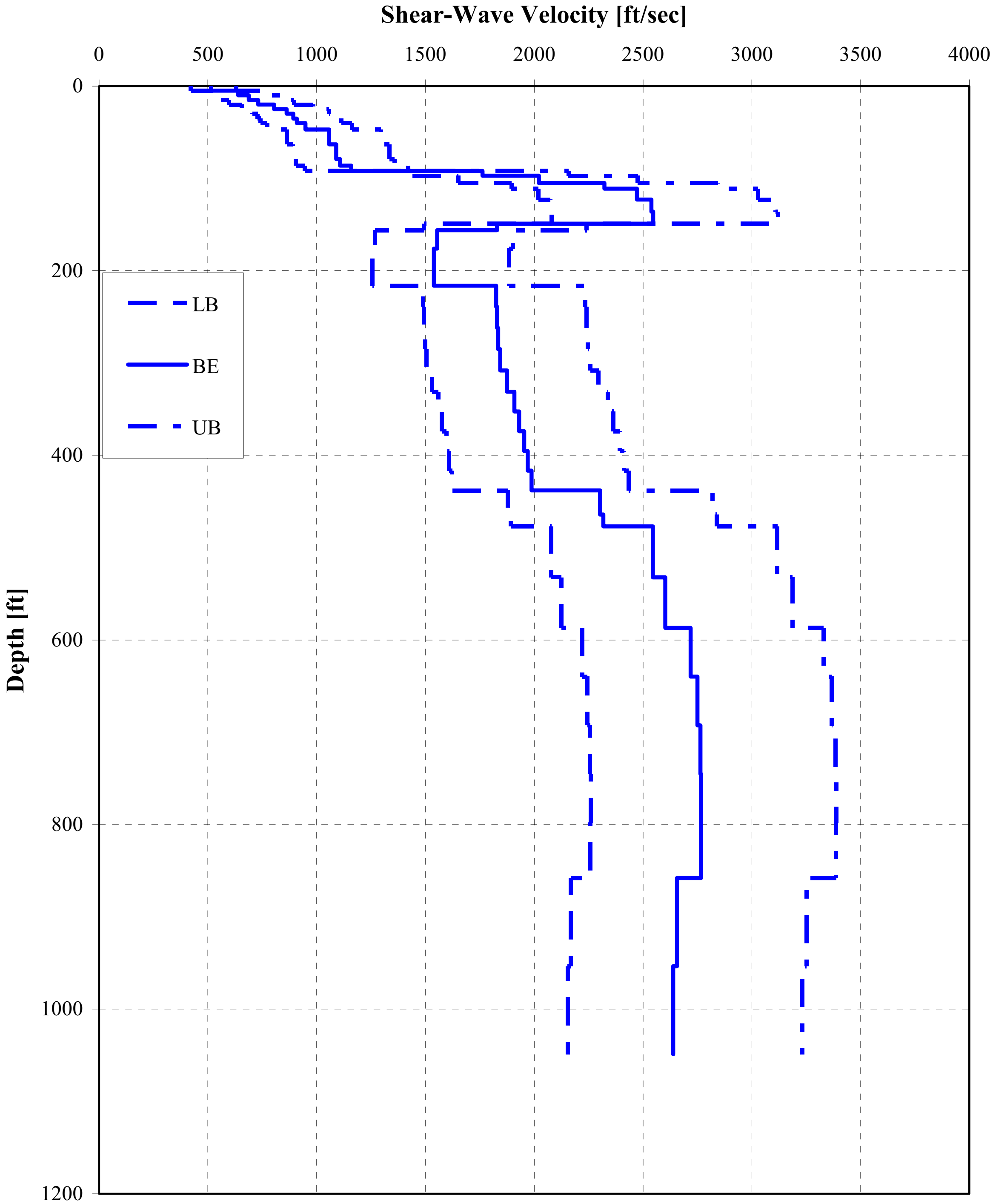

Figure 1 Vogtle Strain-Compatible Soil Shear Wave Velocity Profiles Used in SSI Analysis

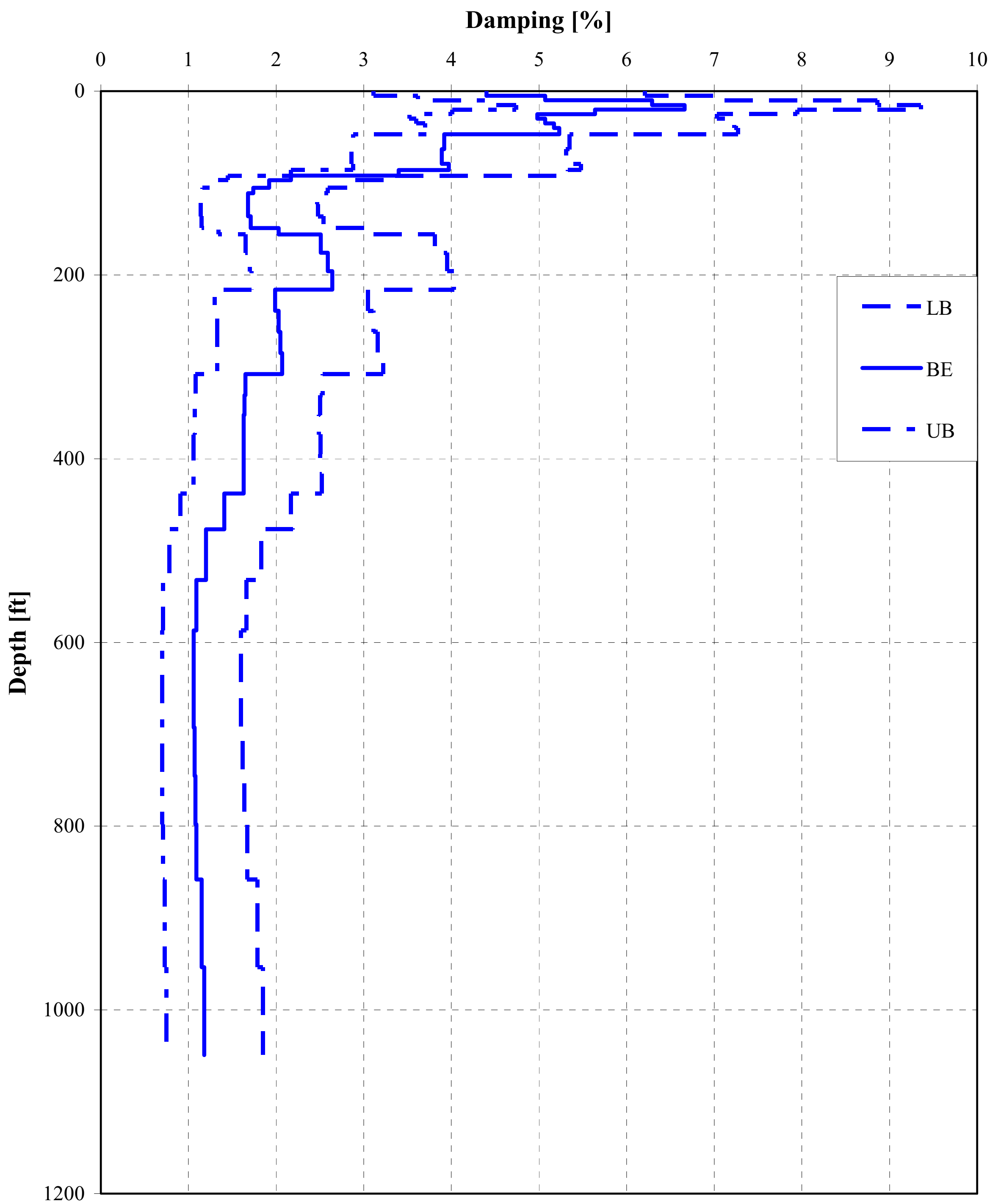

Figure 2 Vogtle Strain-Compatible Soil Damping Profiles Used in SSI Analysis

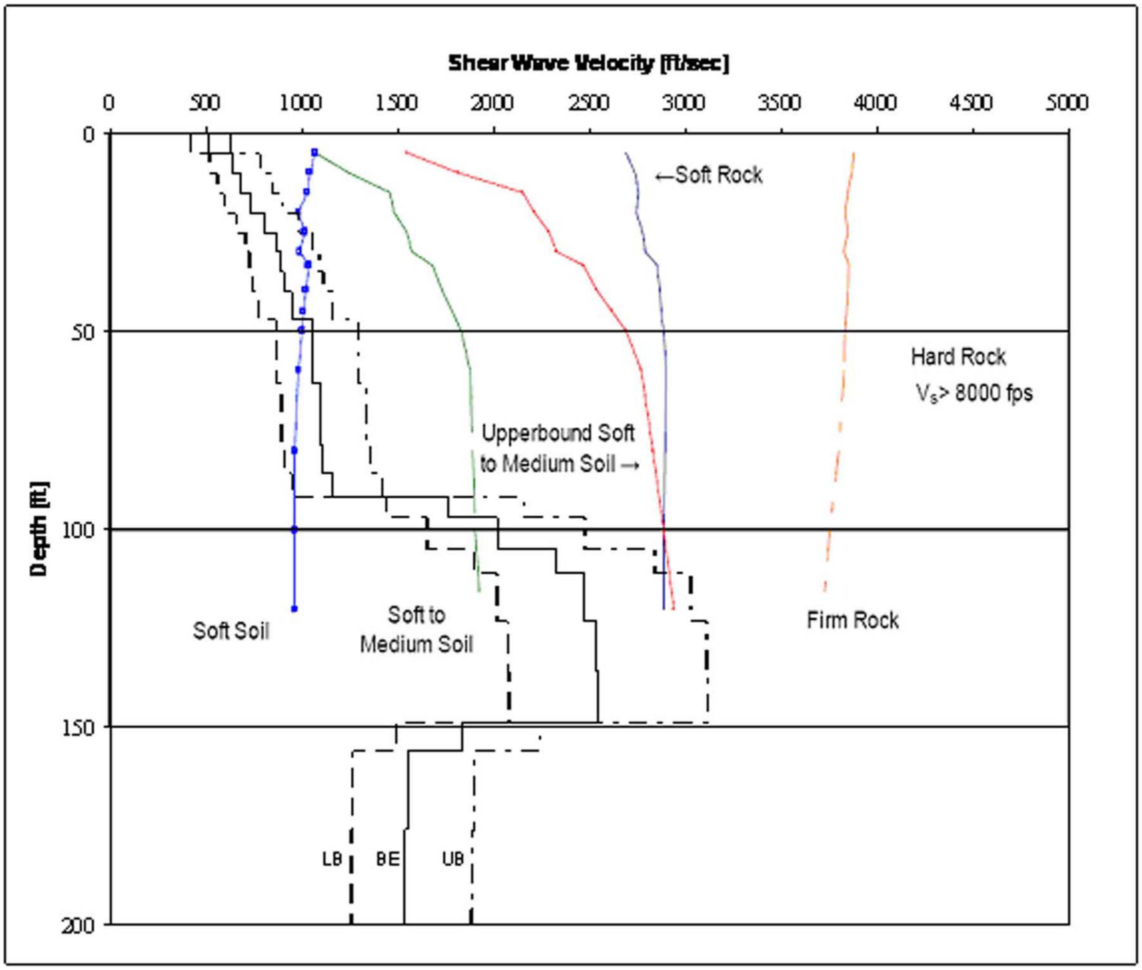

Figure 3 Vogtle Site-Specific and AP1000 Generic Strain-Compatible Soil Profiles

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.

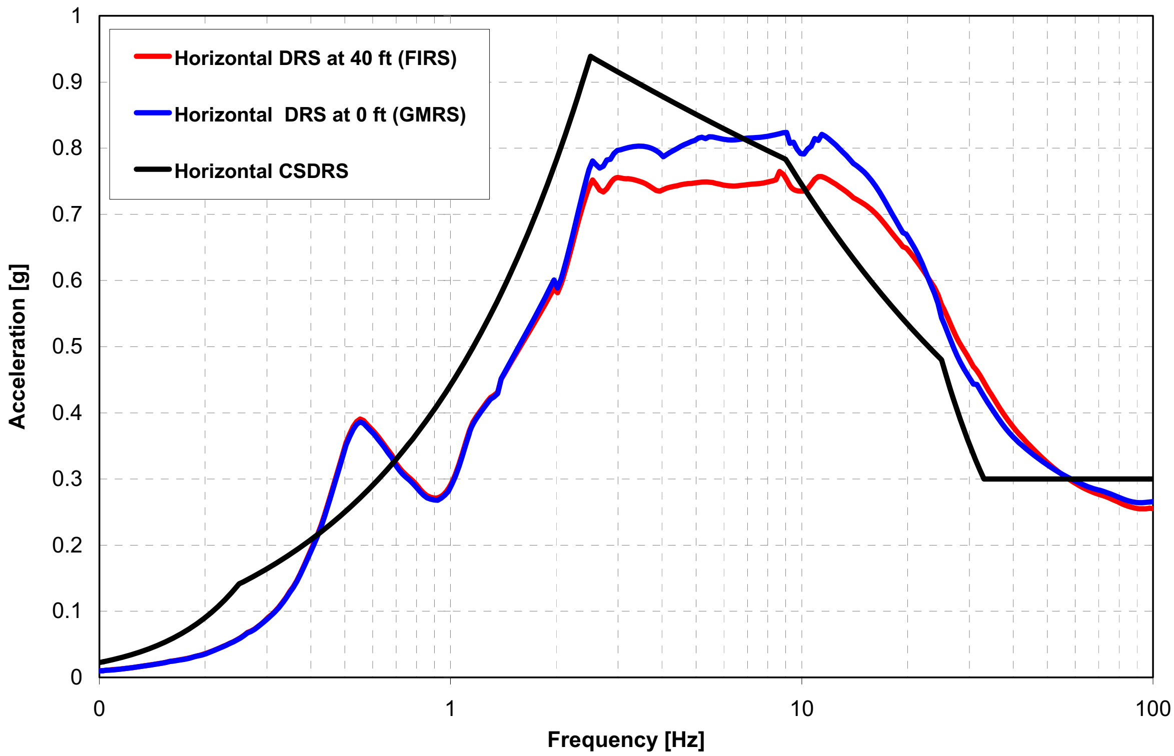

Figure 4 AP1000 CSDRS and Vogtle GMRS and FIRS - Horizontal Motion (5% Damping)

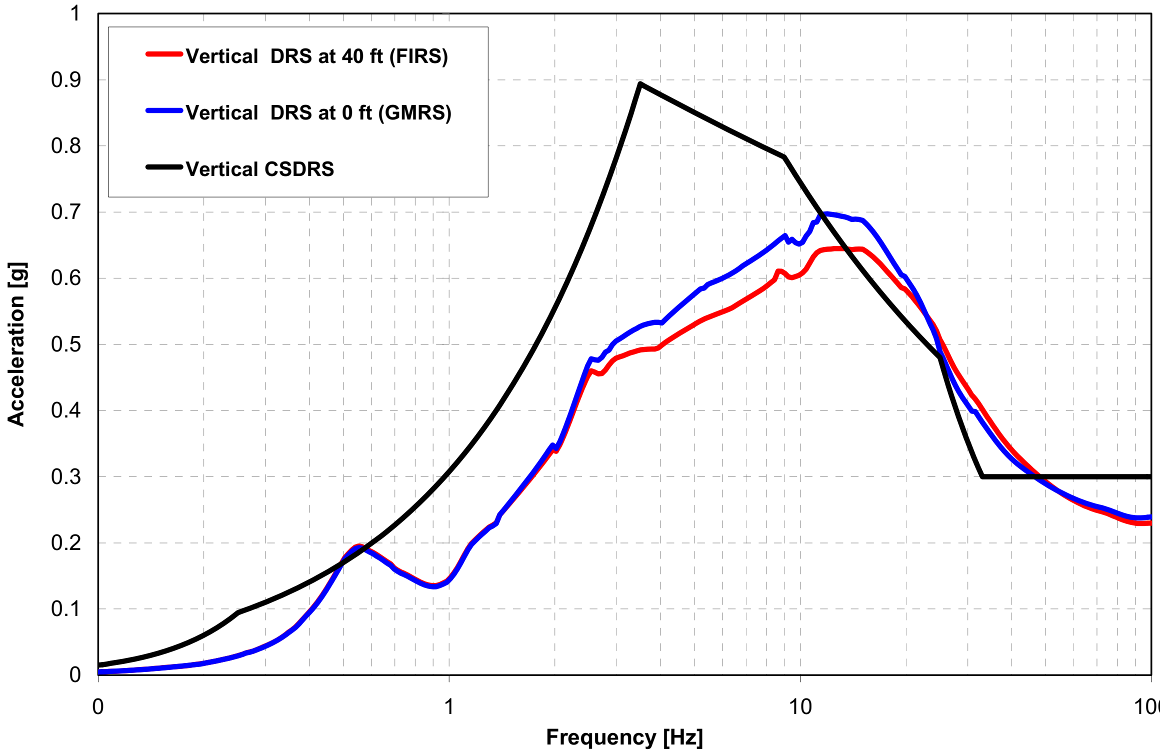

Figure 5 AP1000 CSDRS and Vogtle GMRS and FIRS - Vertical Motion (5% Damping)

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.

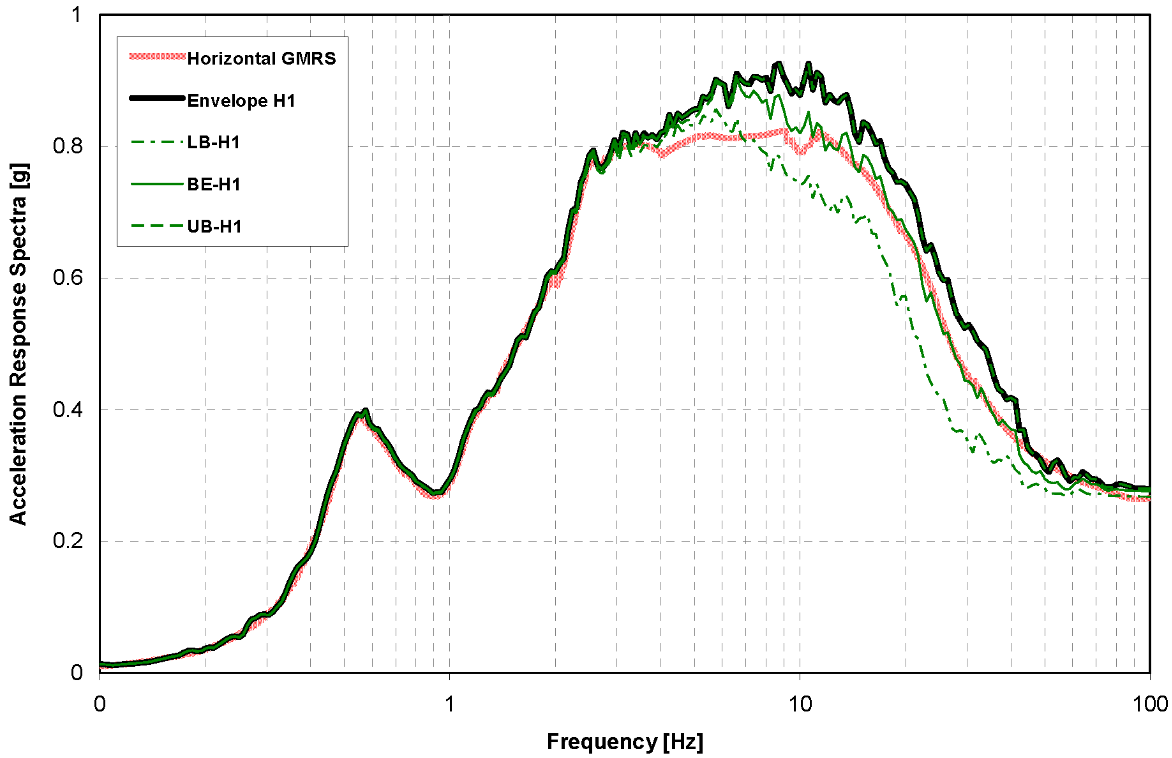

Figure 6 Comparison of H1 Response Motion and GMRS at the Ground Surface Level (5% Damping)

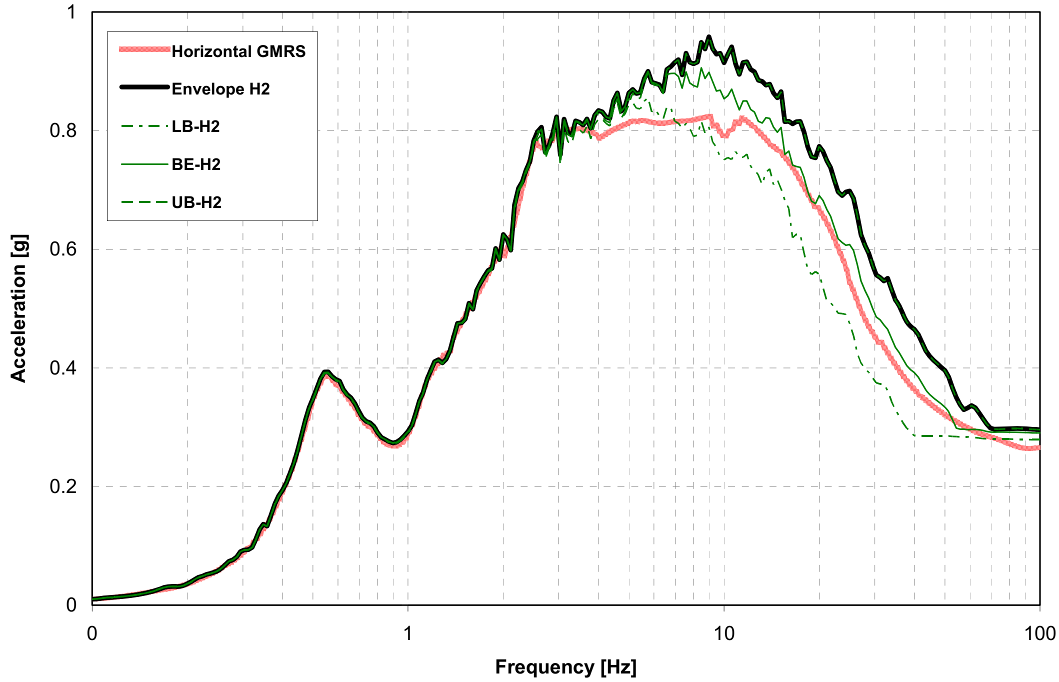

Figure 7 Comparisons of the H2 Response Motions with the GMRS at the Ground Surface Level (5% Damping)

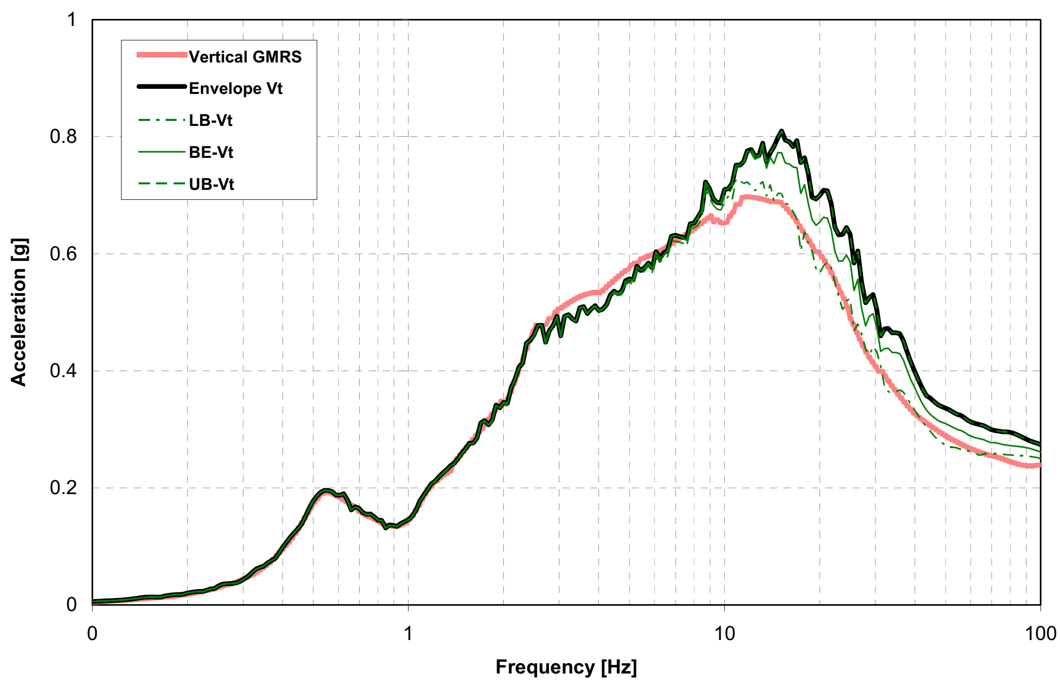

Figure 8 Comparisons of the Vertical Response Motions with the GMRS at the Ground Surface Level (5% Damping)

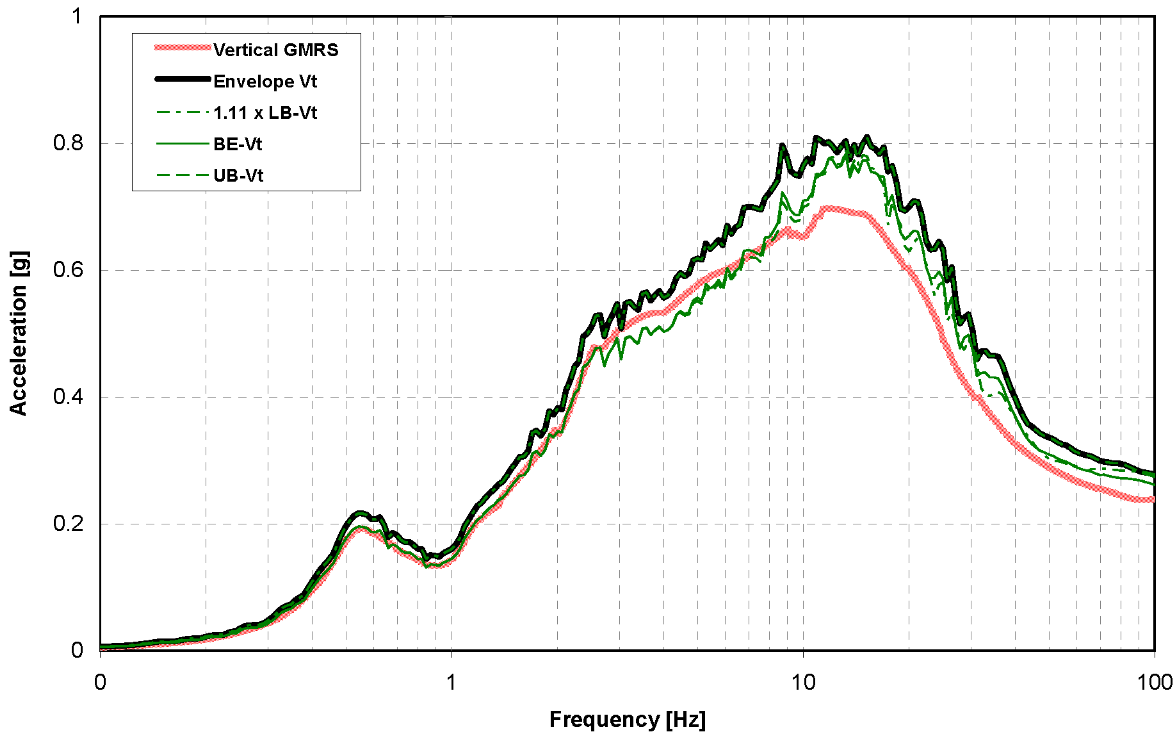

Figure 9 Comparisons of the Modified Vertical Response Motions with the GMRS at the Ground Surface Level (5% Damping)

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.

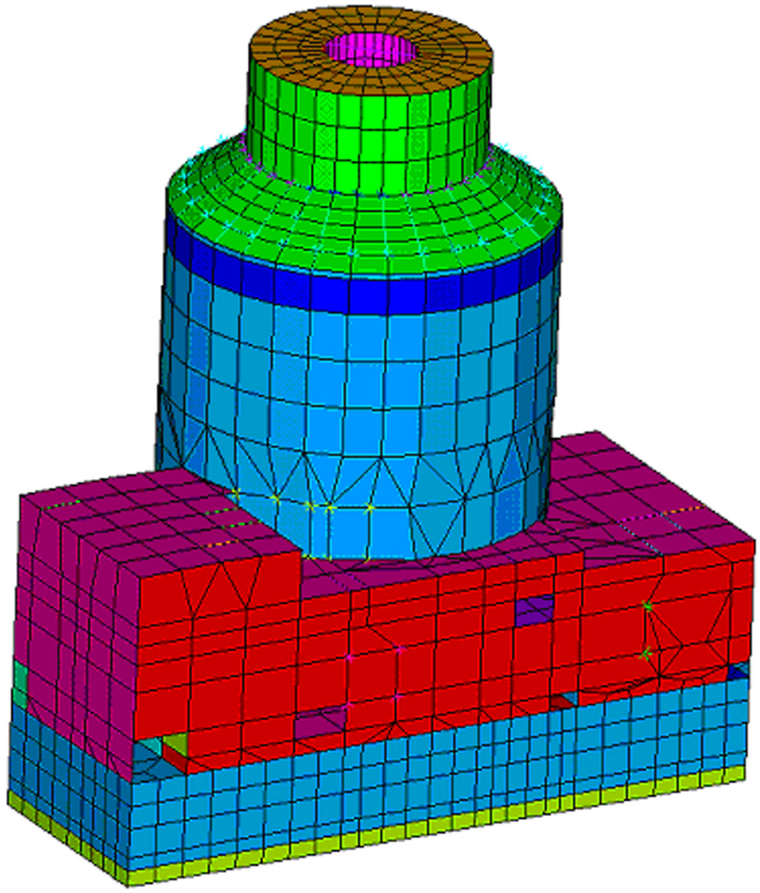

Figure 10   NI15 Finite Element Model

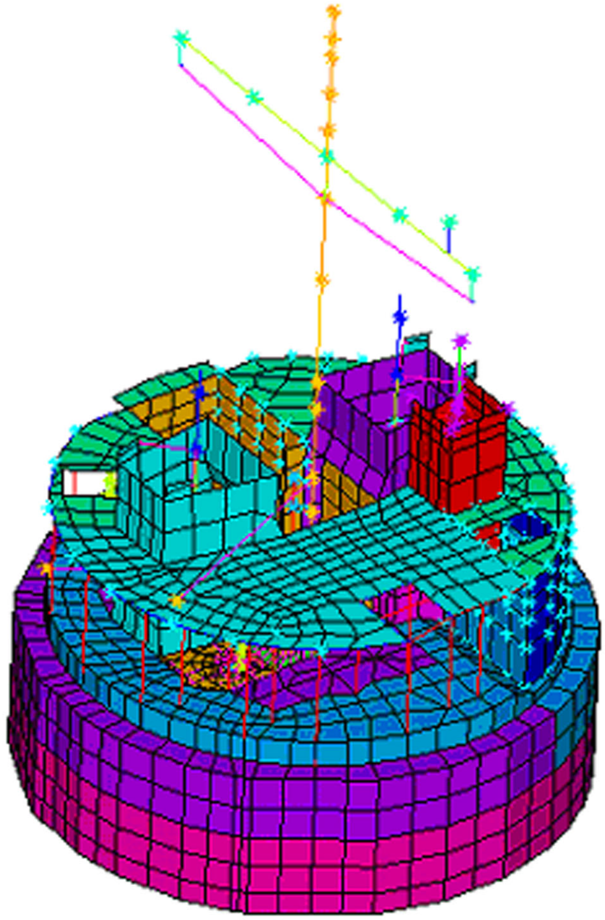

Figure 11 NI15 CIS, RCL, and SCV Elements

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).

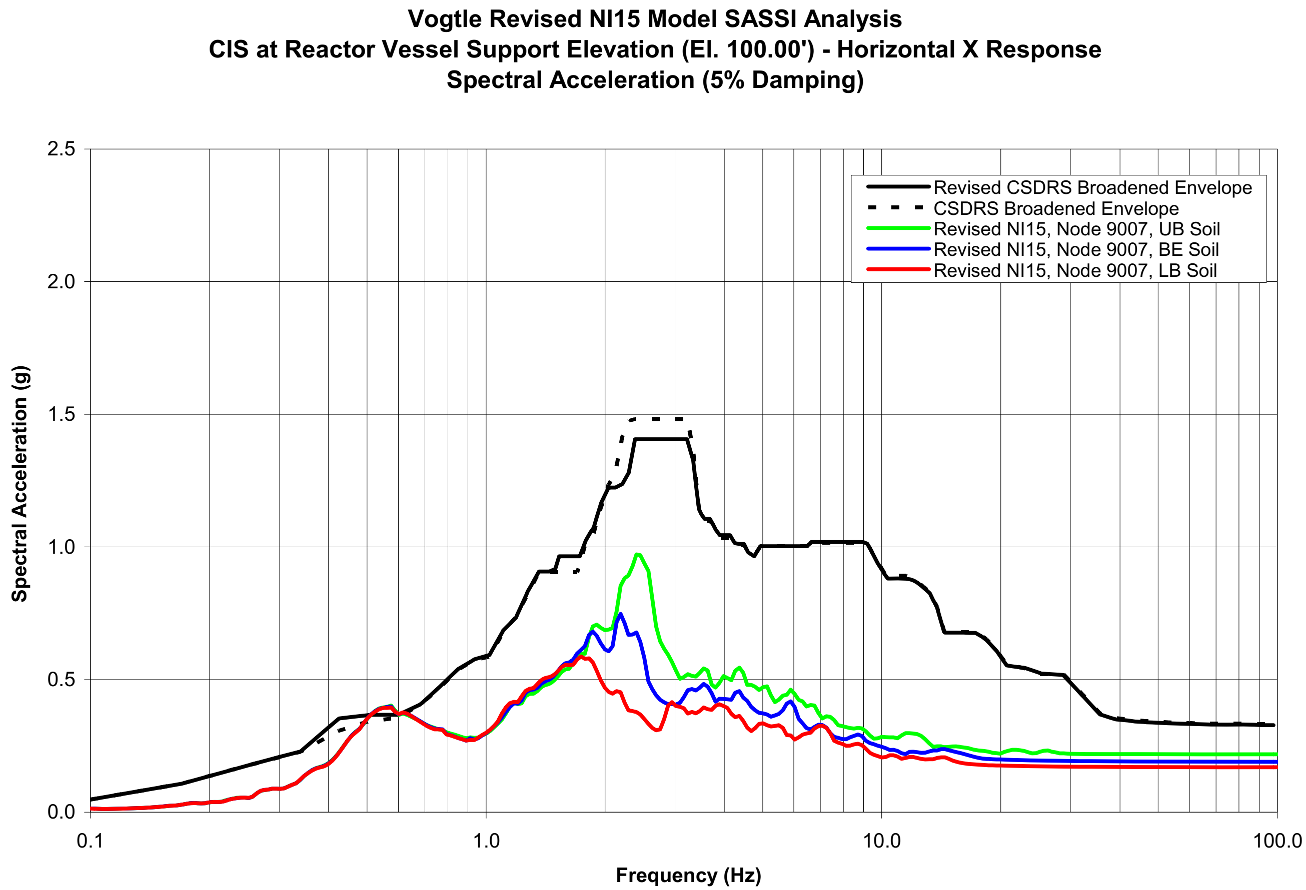

Figure 12 Horizontal X Response Spectra at CIS at Reactor Vessel Support Elevation (El. 100.00 ft, Node 9007)

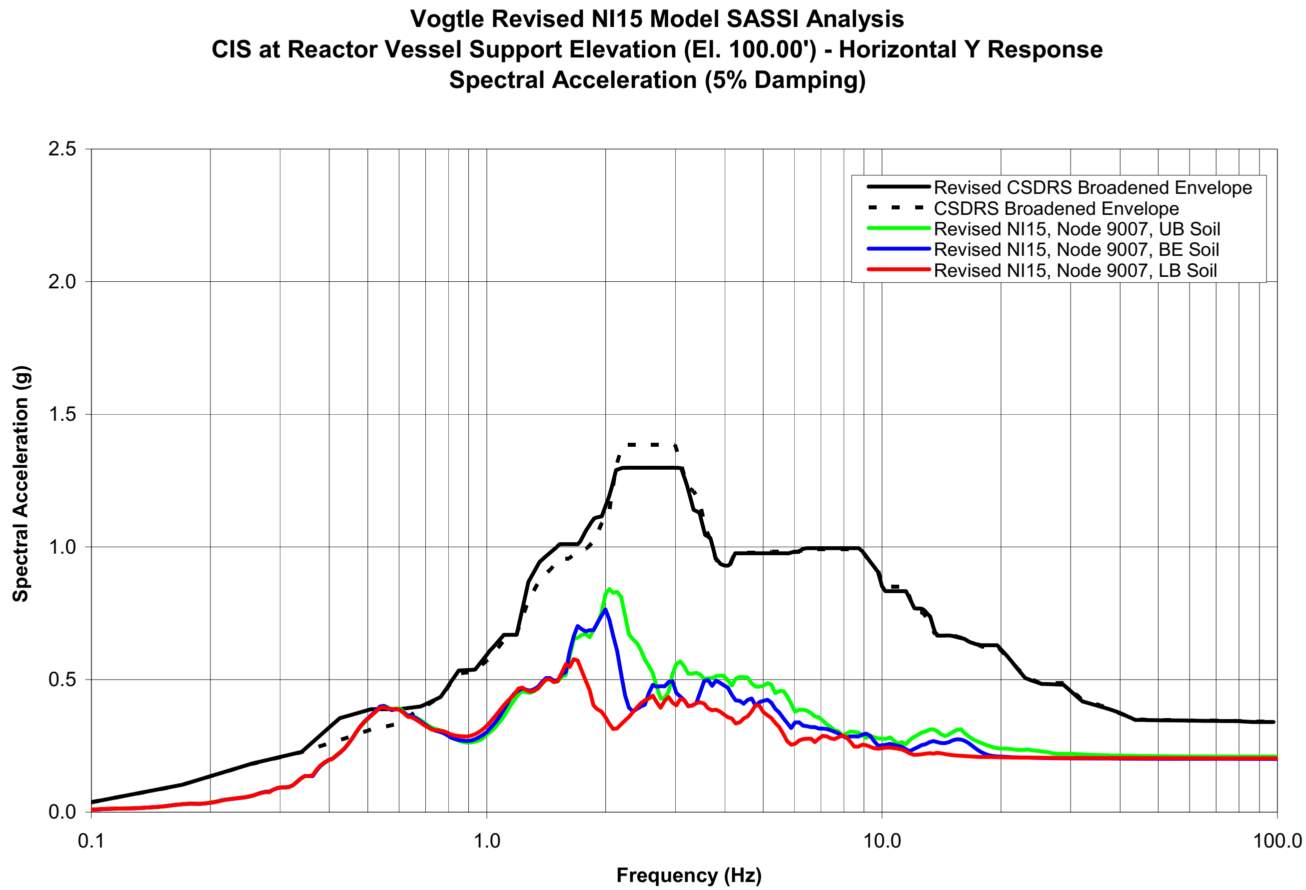

Figure 13 Horizontal Y Response Spectra at CIS at Reactor Vessel Support Elevation (El. 100.00 ft, Node 9007)

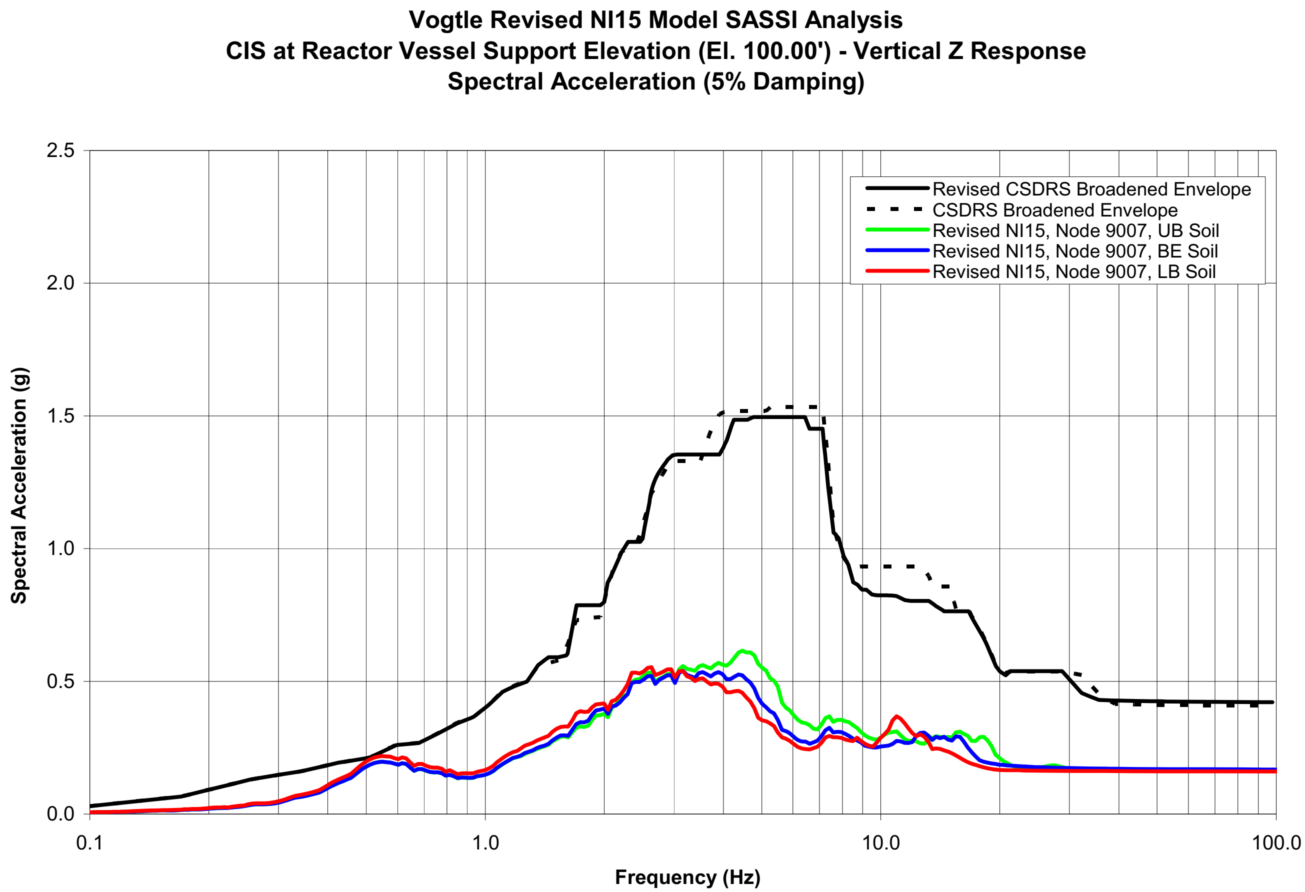

Figure 14 Vertical Z Response Spectra at CIS at Reactor Vessel Support Elevation (El. 100.00 ft, Node 9007)

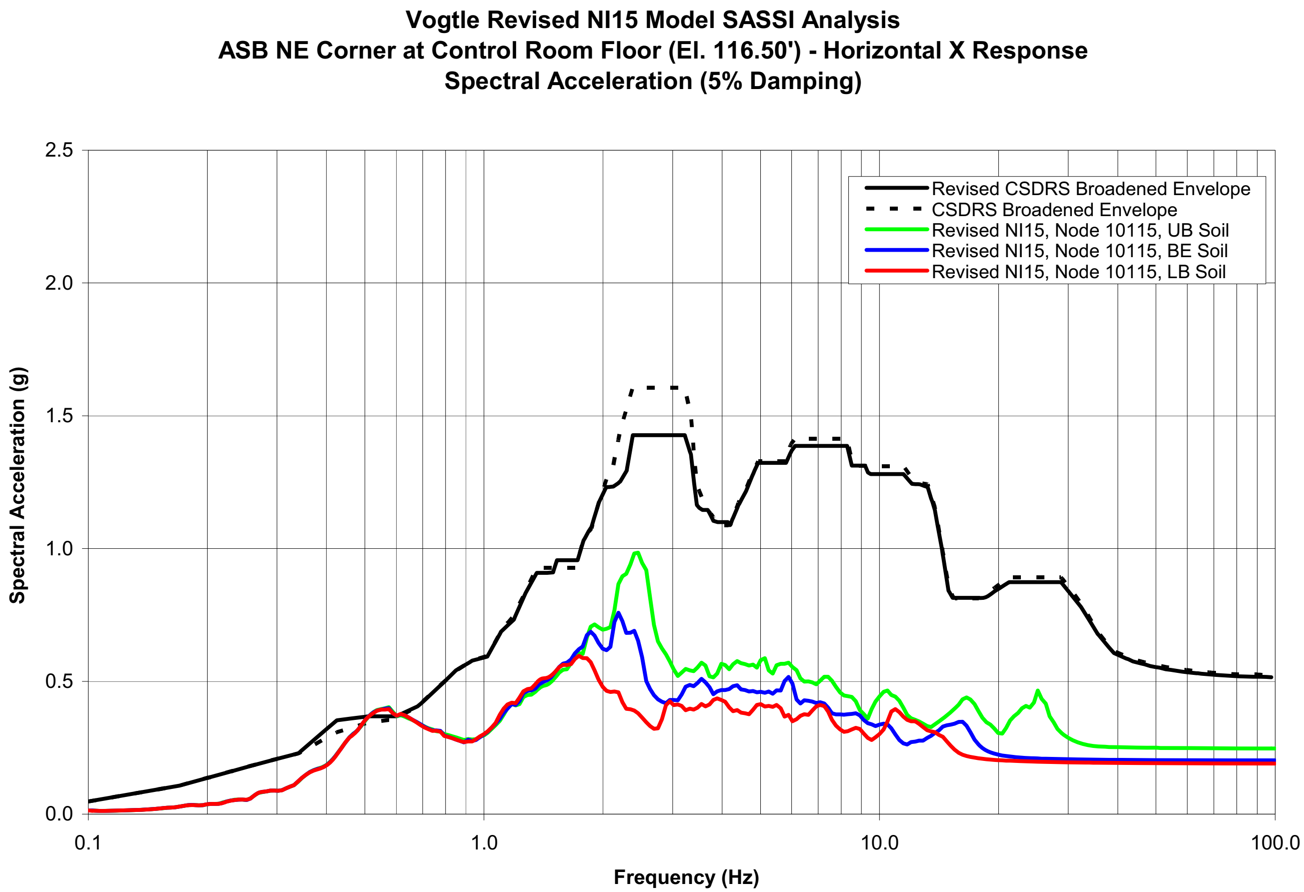

Figure 15 Horizontal X Response Spectra at ASB NE Corner at Control Room Floor (El. 116.50 ft, Node 10115)

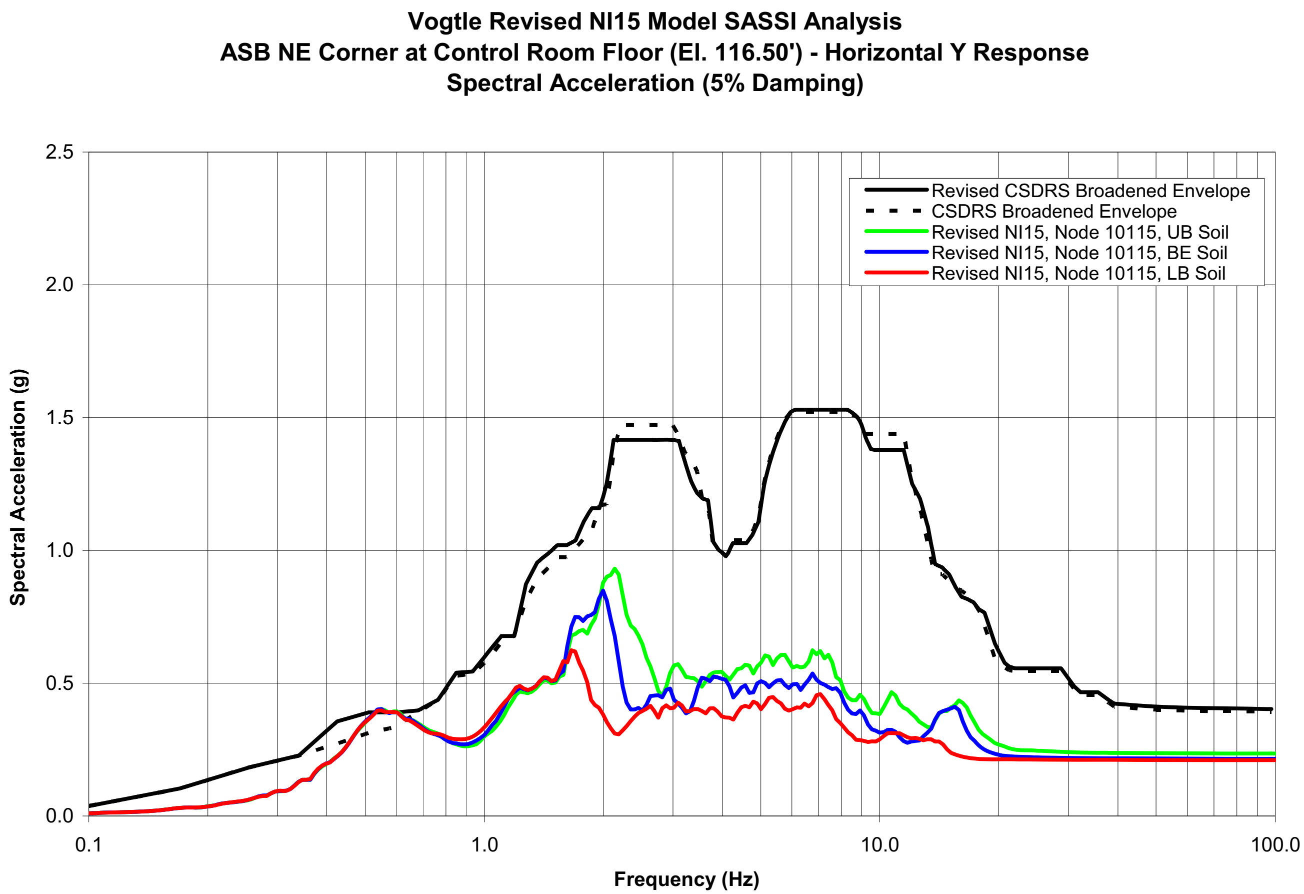

Figure 16 Horizontal Y Response Spectra at ASB NE Corner at Control Room Floor (El. 116.50 ft, Node 10115)

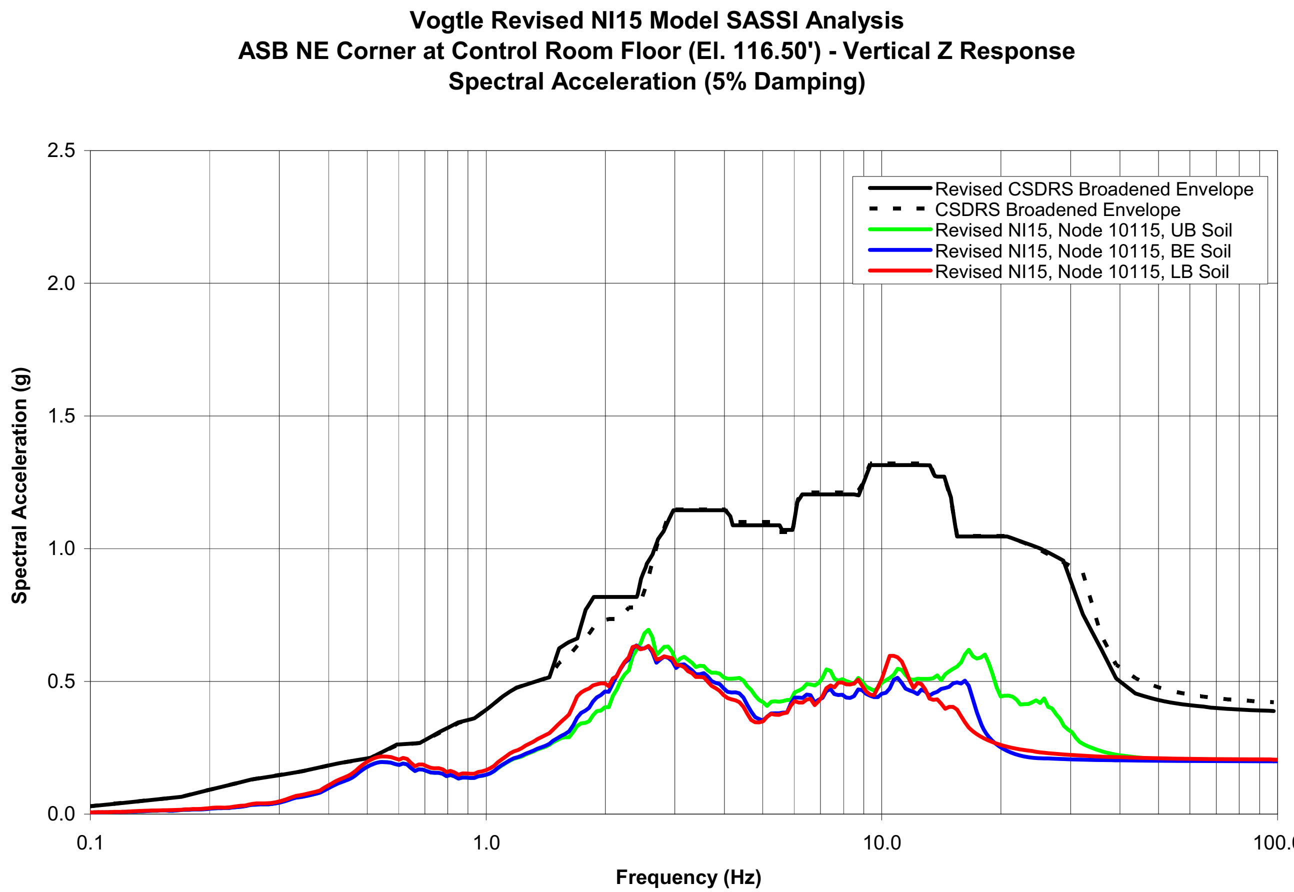

Figure 17 Vertical Z Response Spectra at ASB NE Corner at Control Room Floor (El. 116.50 ft, Node 10115)

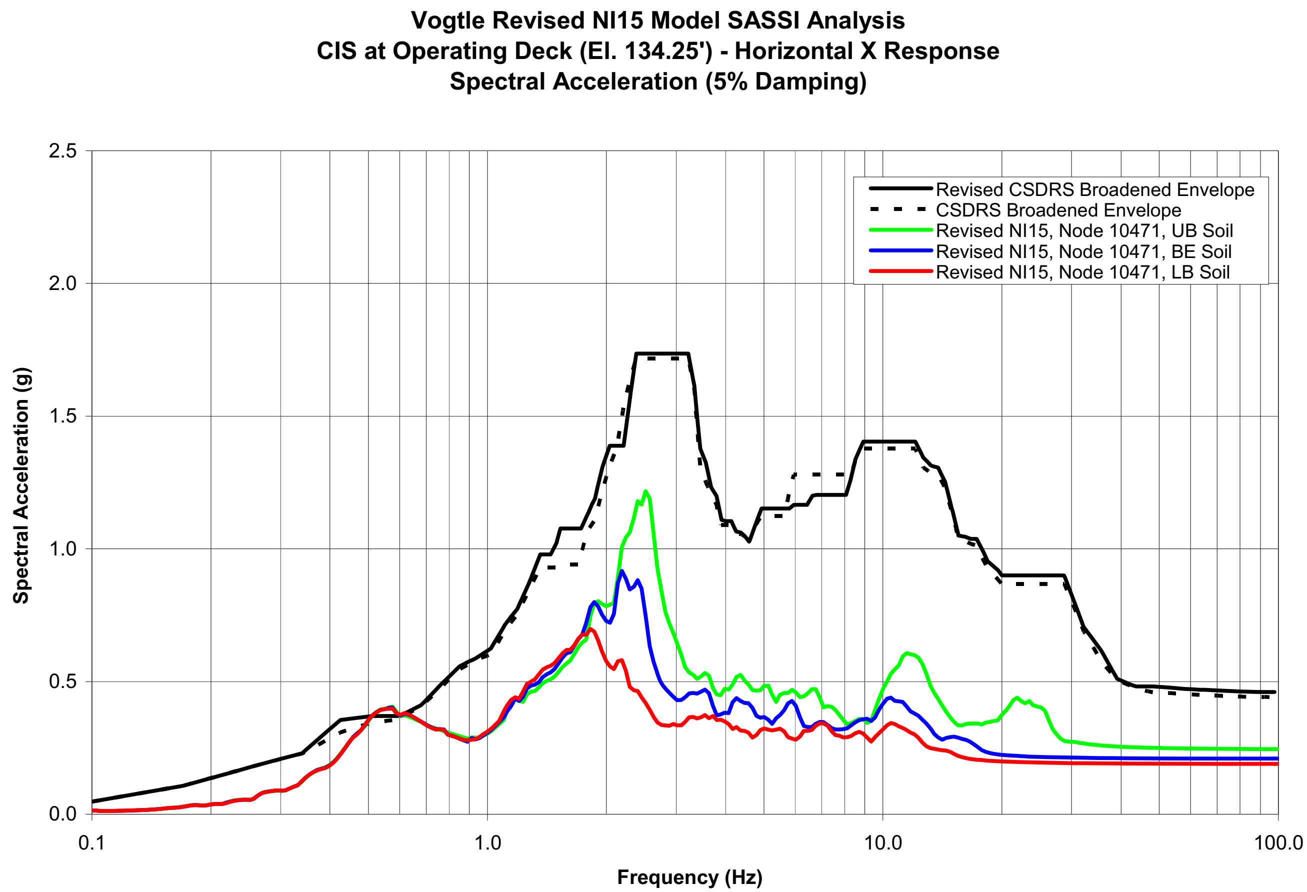

Figure 18 Horizontal X Response Spectra at CIS at Operating Deck (El. 134.25 ft, Node 10471)

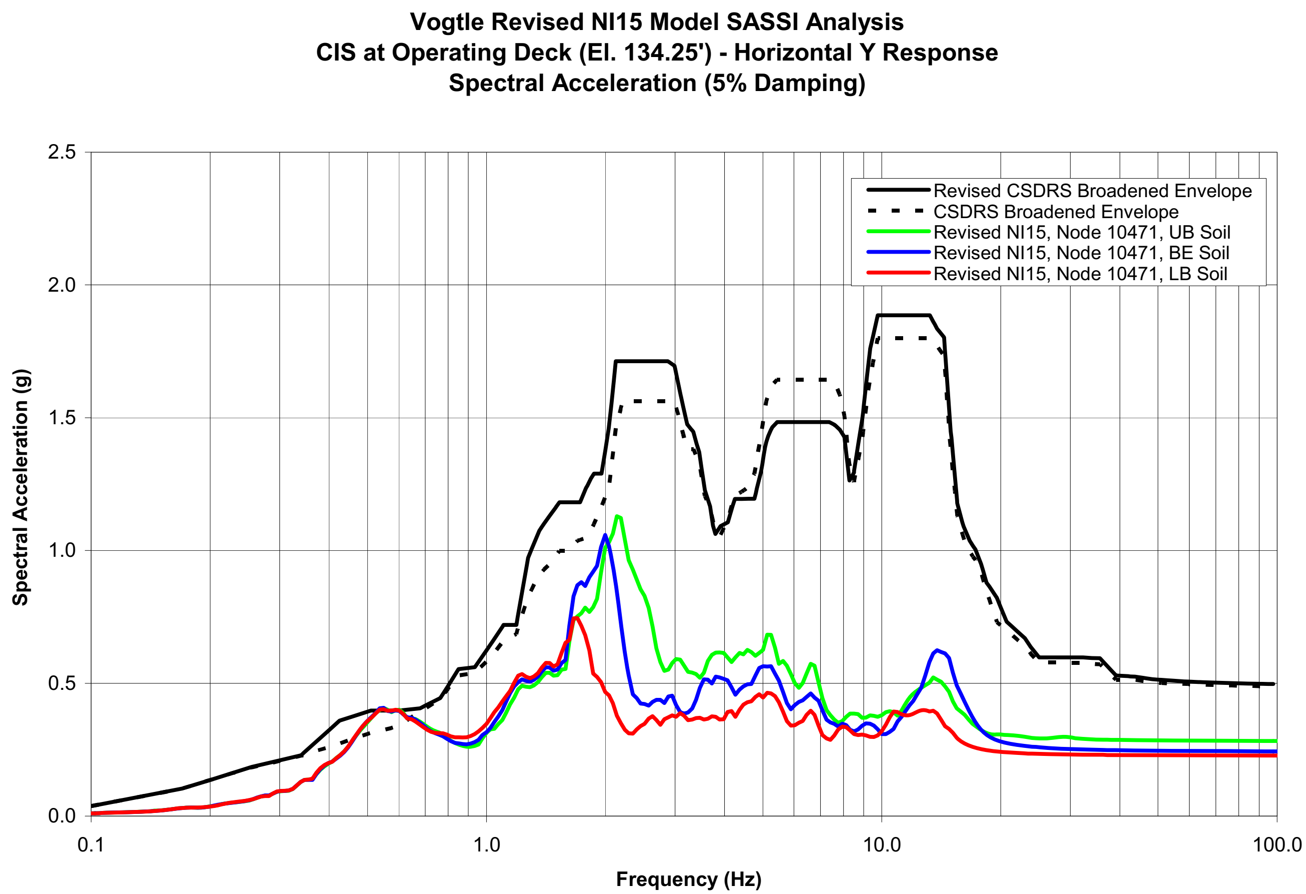

Figure 19 Horizontal Y Response Spectra at CIS at Operating Deck (El. 134.25 ft, Node 10471)

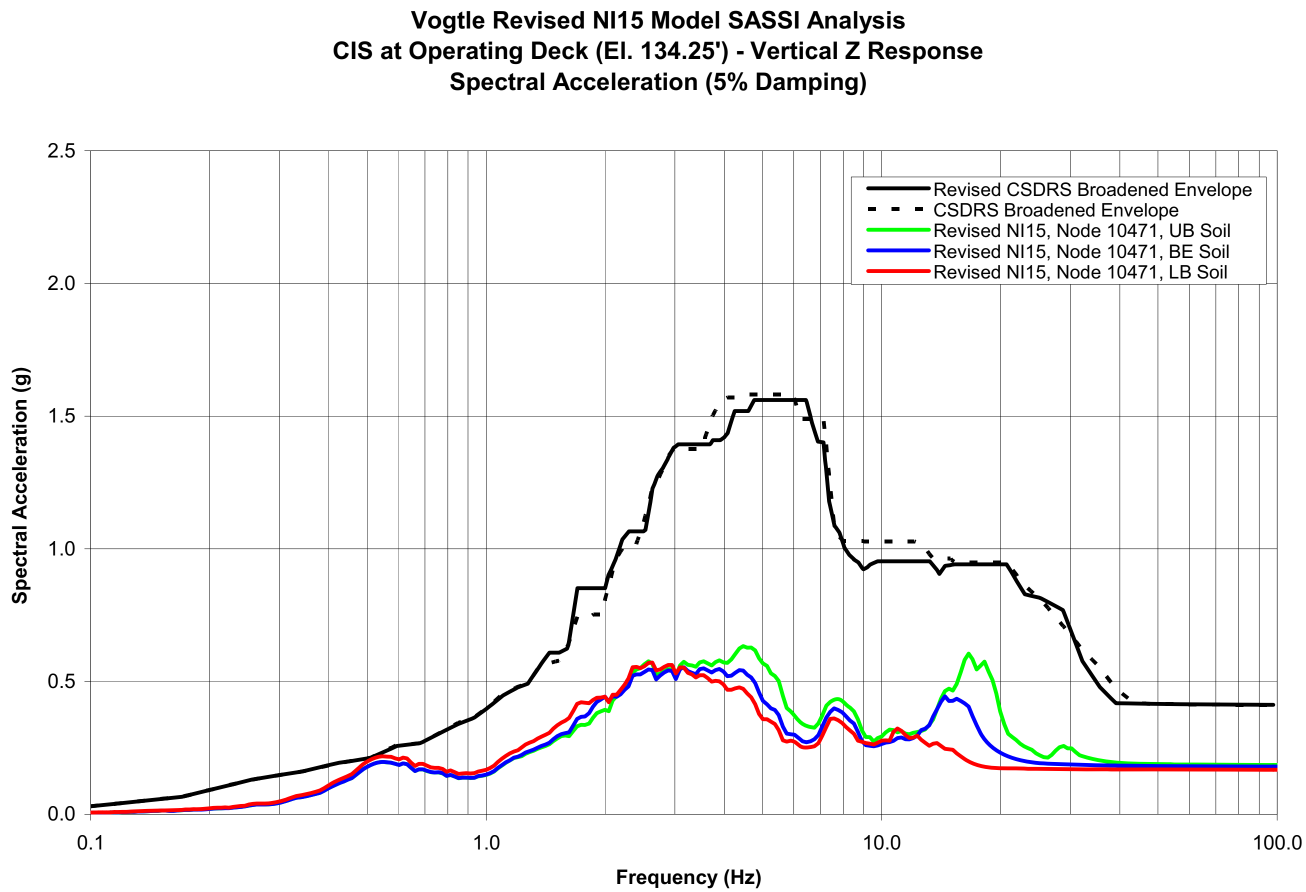

Figure 20 Vertical Z Response Spectra at CIS at Operating Deck (El. 134.25 ft, Node 10471)

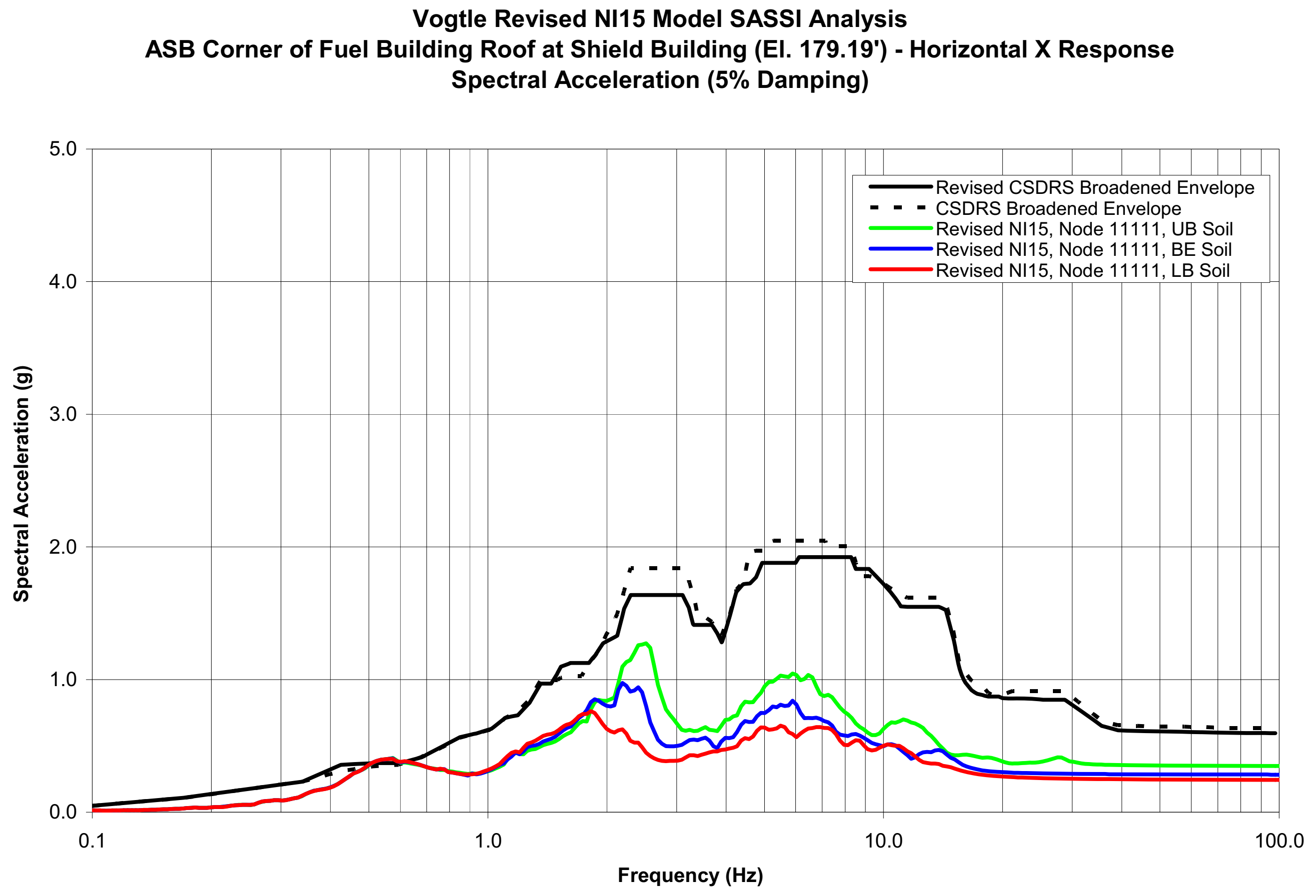

Figure 21 Horizontal X Response Spectra at ASB Corner of Fuel Building Roof at Shield Building (El. 179.19 ft, Node 11111)

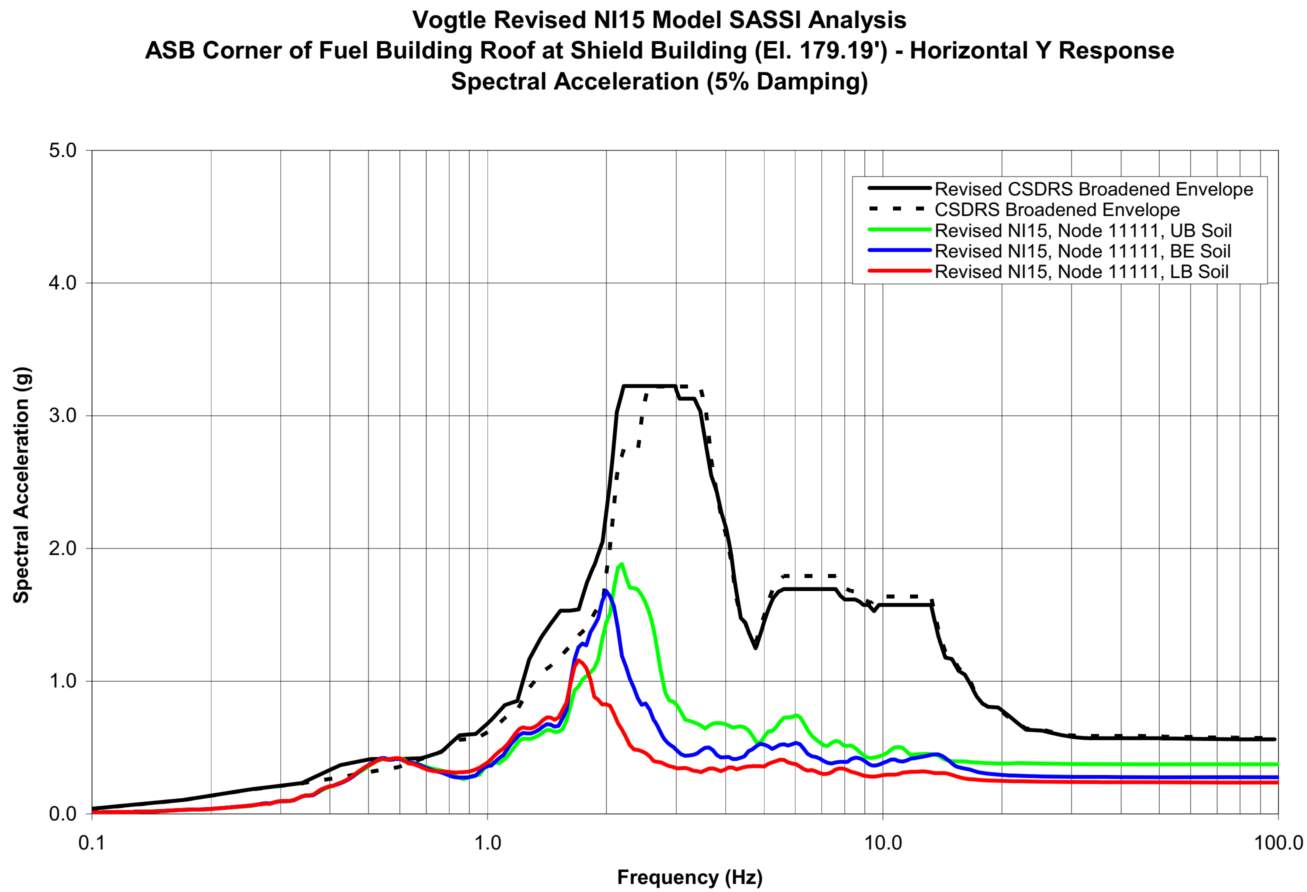

Figure 22 Horizontal Y Response Spectra at ASB Corner of Fuel Building Roof at Shield Building (El. 179.19 ft, Node 11111)

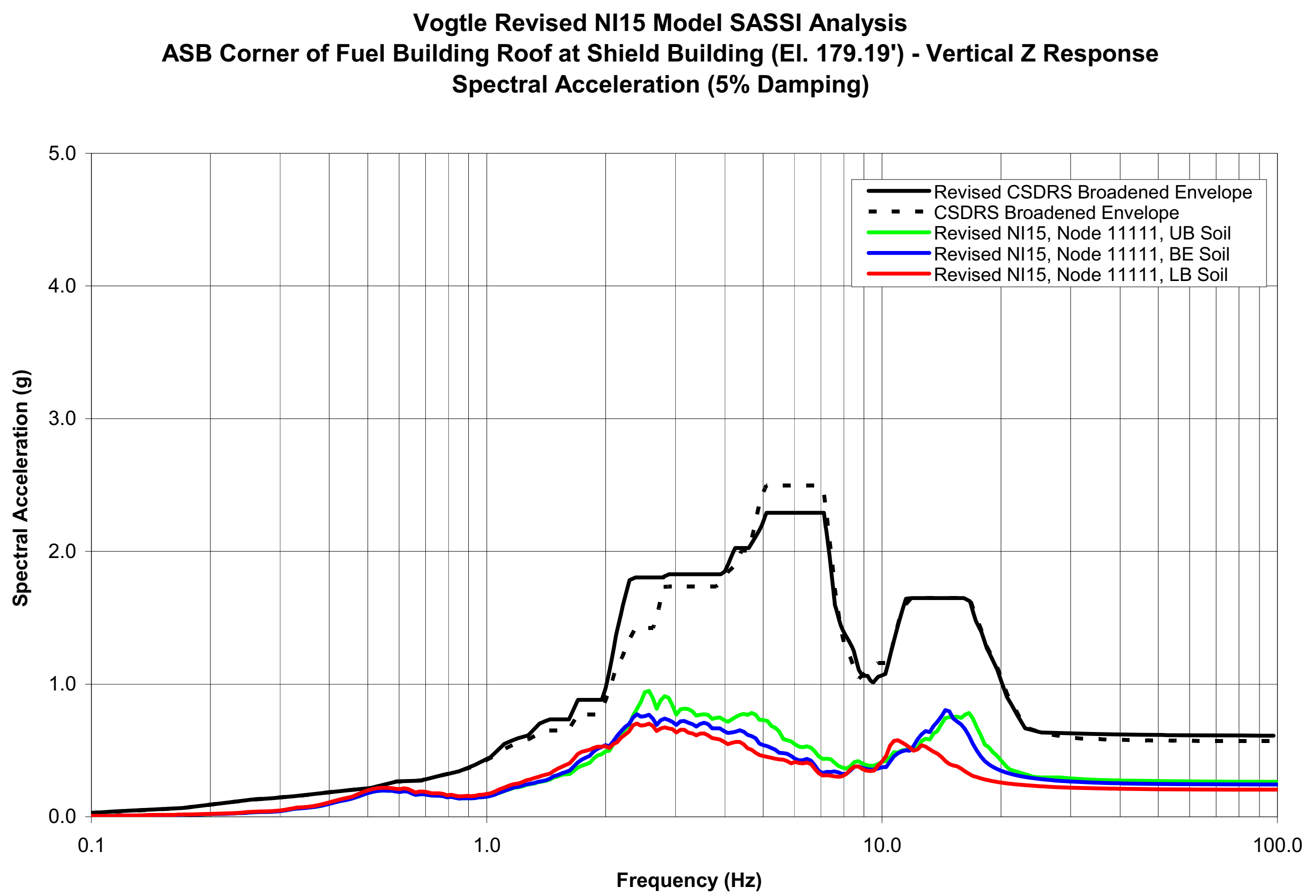

Figure 23 Vertical Z Response Spectra at ASB Corner of Fuel Building Roof at Shield Building (El. 179.19 ft, Node 11111)

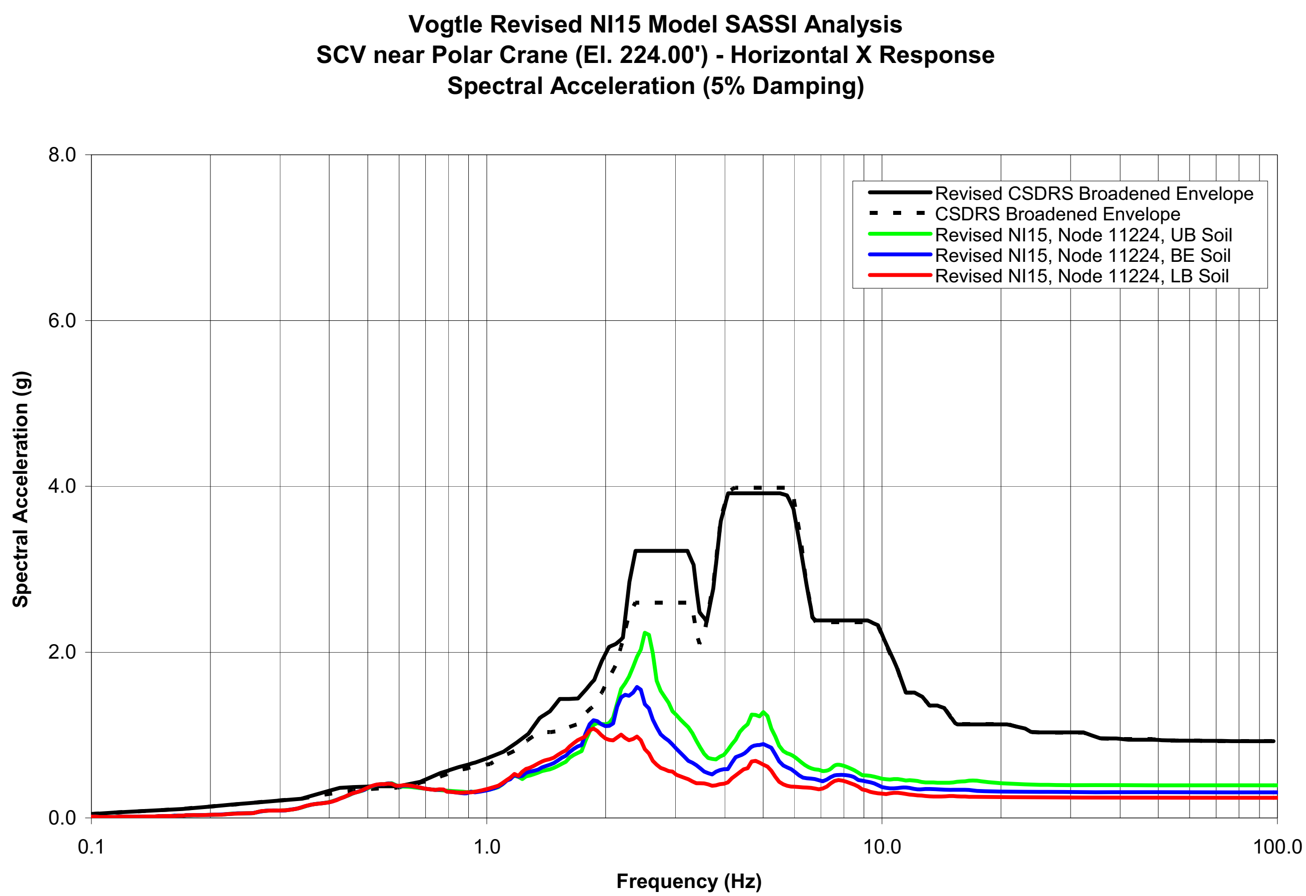

Figure 24 Horizontal X Response Spectra at SCV near Polar Crane (El. 224.00 ft, Node 11224)

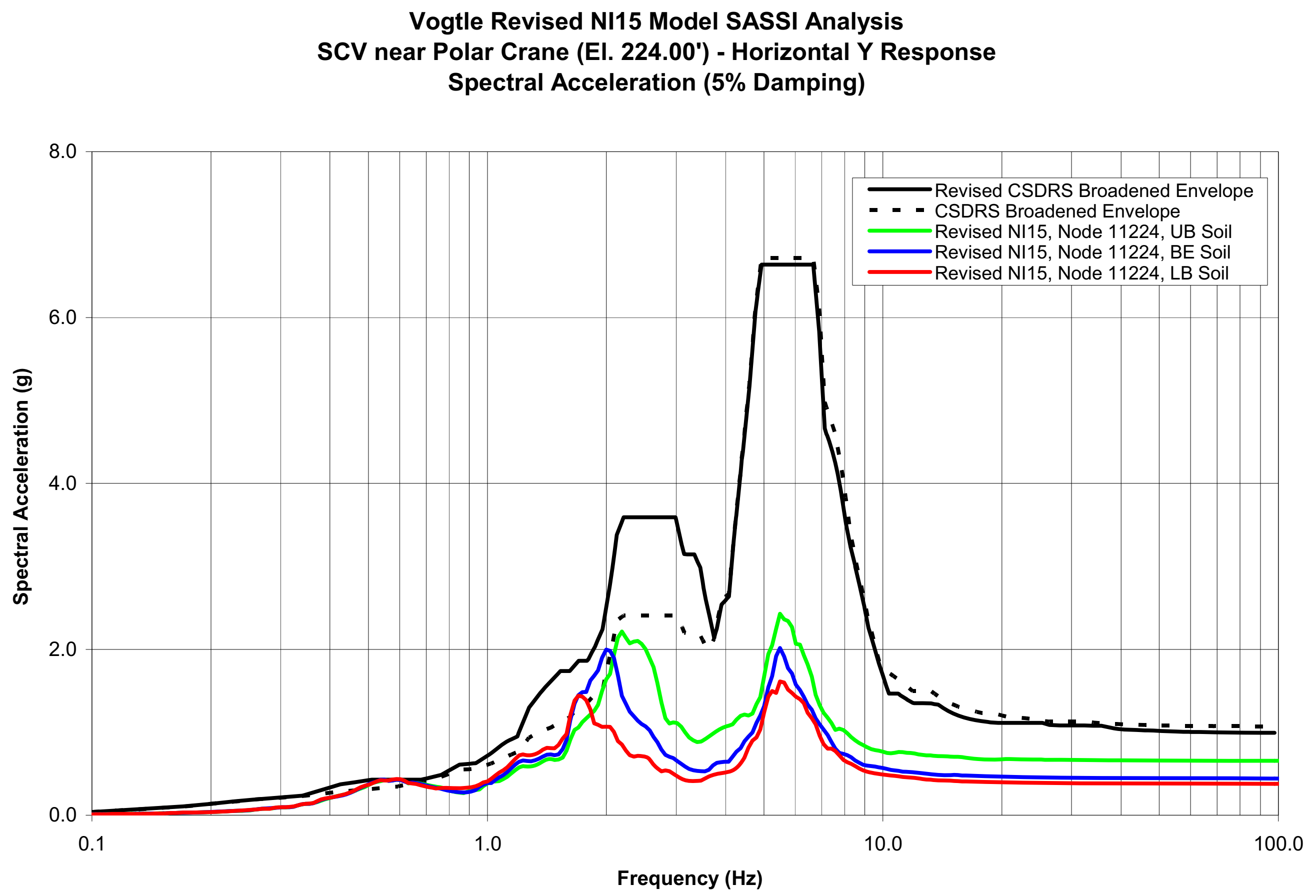

Figure 25 Horizontal Y Response Spectra at SCV near Polar Crane (El. 224.00 ft, Node 11224)

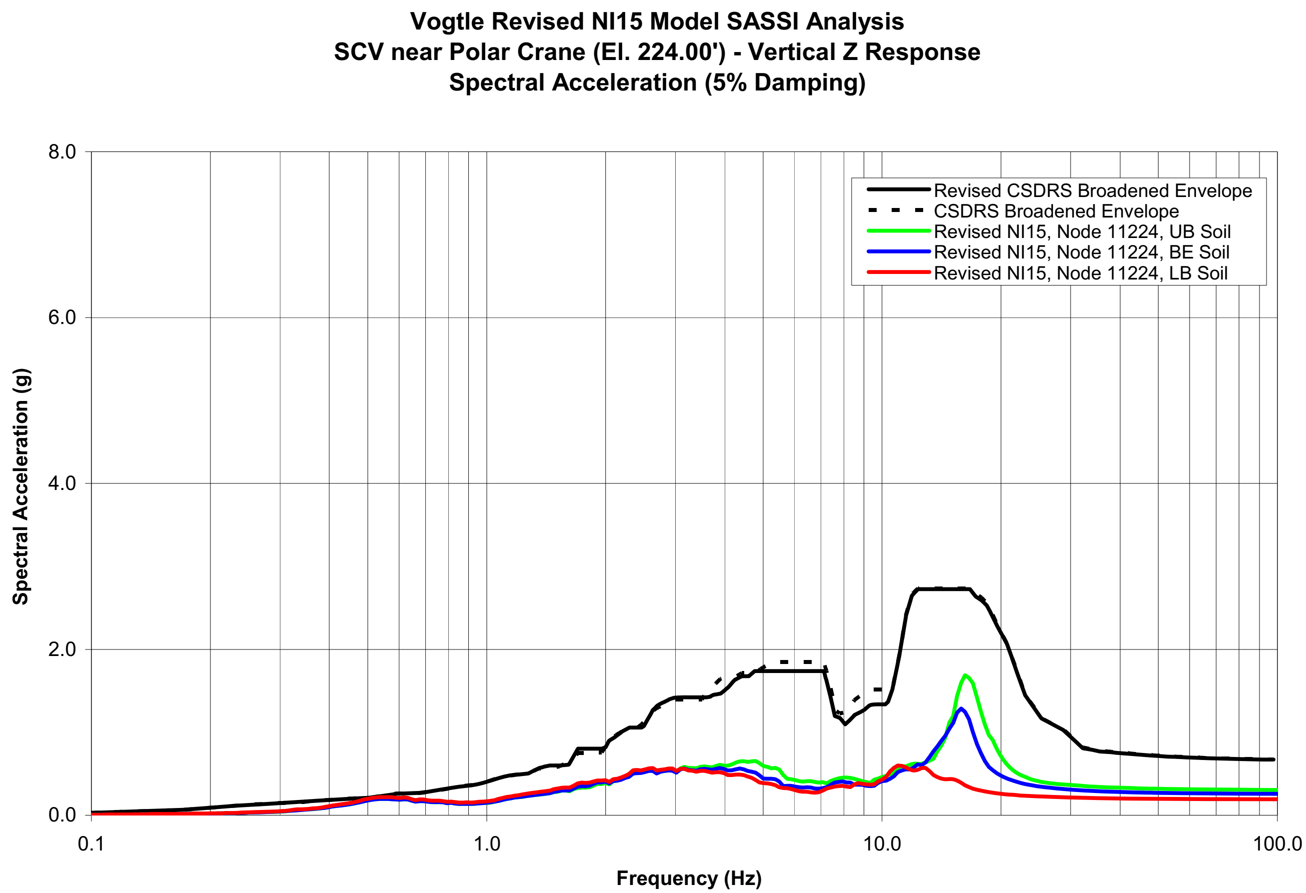

Figure 26 Vertical Z Response Spectra at SCV near Polar Crane (El. 224.00 ft, Node 11224)

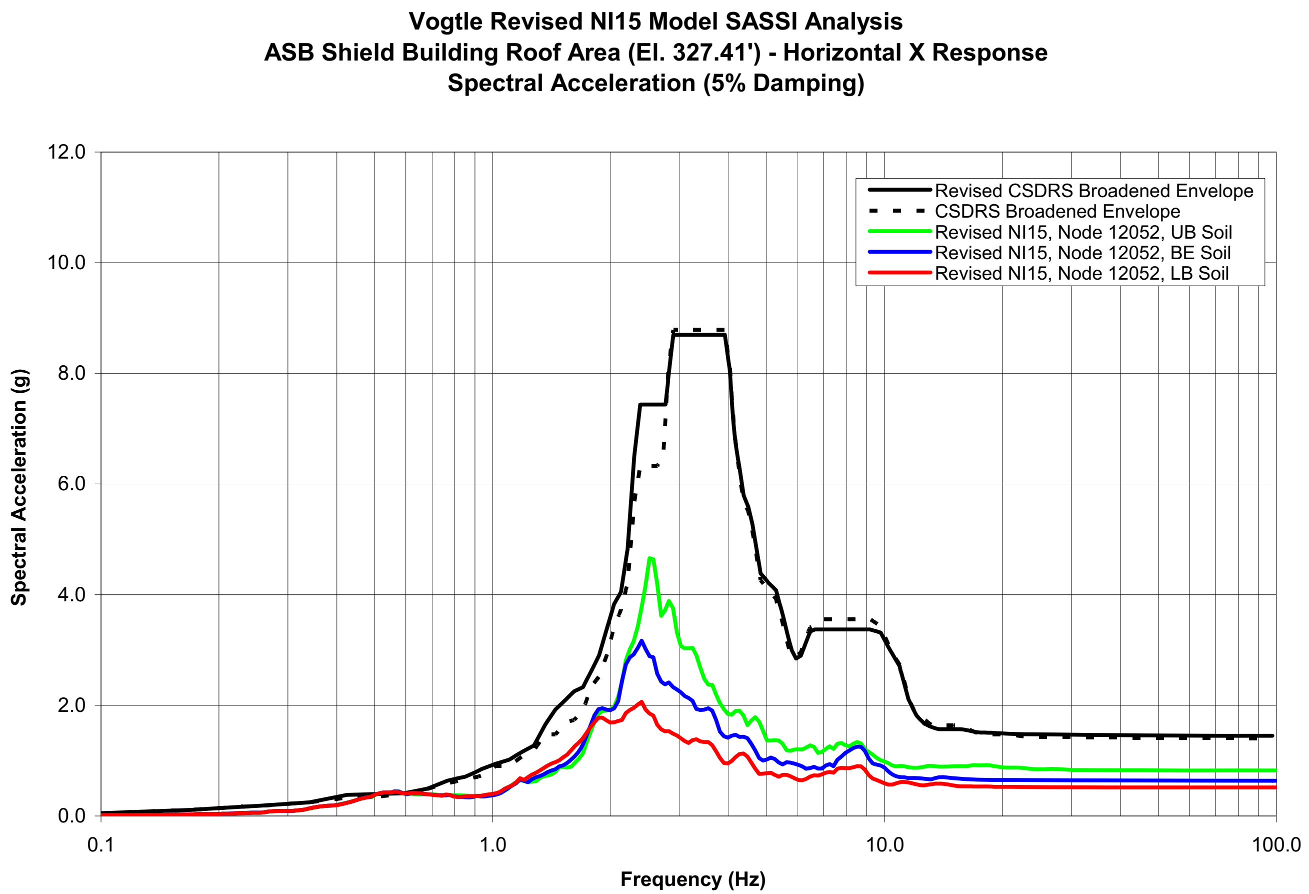

Figure 27 Horizontal X Response Spectra at ASB Shield Building Roof Area (El. 327.41 ft, Node 12052)

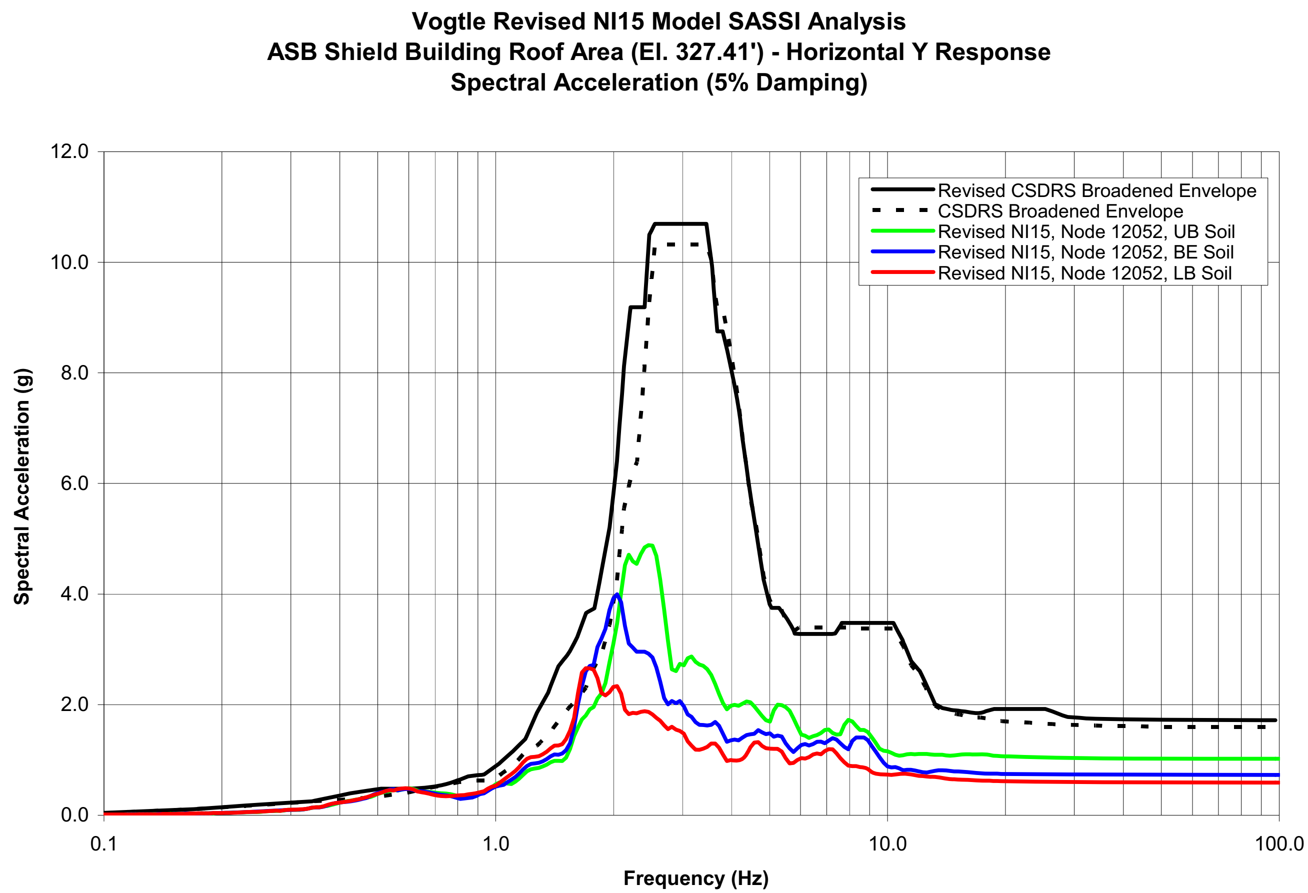

Figure 28 Horizontal Y Response Spectra at ASB Shield Building Roof Area (El. 327.41 ft, Node 12052)

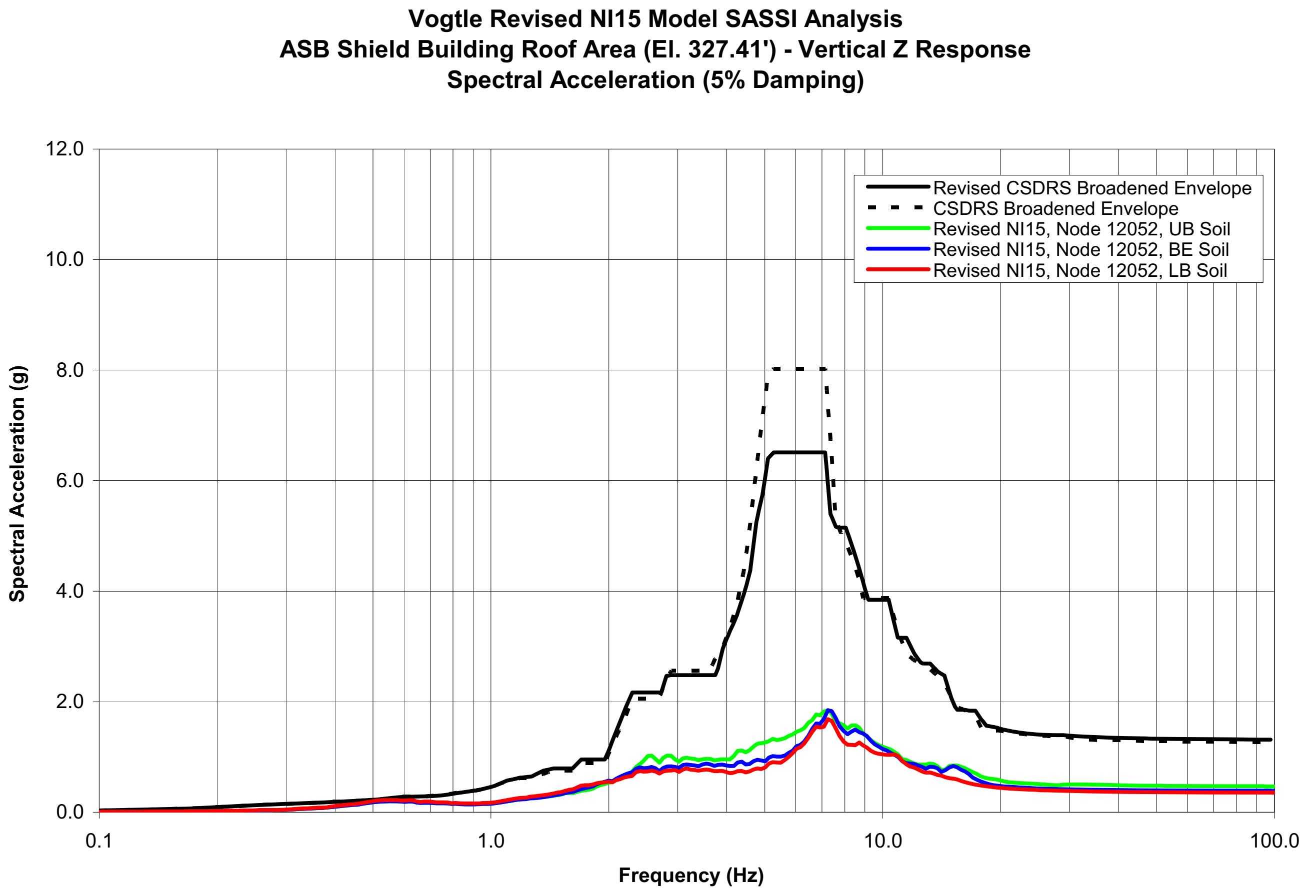

Figure 29 Vertical Z Response Spectra at ASB Shield Building Roof Area (El. 327.41 ft, Node 12052)