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Your ref: Project Number 740
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September 14, 2007

Subject: AP1000 COL Standard Technical Report Submittal of APP-GW-S2R-010, Revision 1, (TR 3)

In support of Combined License application pre-application activities, Westinghouse is submitting Revision 1 of AP1000 Standard Combined License Technical Report Number 3. The purpose of Technical Report 3 is to describe the seismic analyses that have been performed to extend applicability of the AP1000 to soil sites. This revision to Technical Report 3 incorporates changes based on the latest spectra and an enhanced shield building design and also incorporates changes made in response to NRC Requests for Additional Information (RAI). The TR also includes DCD markups in support of Rev. 16 as well as post-Rev. 16 markups based on the RAI responses.

This report is submitted as part of the NuStart Bellefonte COL Project (NRC Project Number 740). The information included in this report is generic and is expected to apply to all COL applications referencing the AP1000 Design Certification.

The purpose for submittal of this report was explained in a March 8, 2006 letter from NuStart to the NRC.

Pursuant to 10 CFR 50.30(b), APP-GW-S2R-010, Revision 1, "Extension of Nuclear Island Seismic Analysis to Soil Sites" Technical Report Number 3, is submitted as Enclosure 1 under the attached Oath of Affirmation. Revision 0 of Technical Report 3 was submitted June 14, 2006 under Westinghouse letter DCP/NRC1751.

It is expected that when the NRC review of Technical Report Number 3 is complete, the changes to the AP1000 DCD identified in Technical Report 3 will be considered approved generically for COL applicants referencing the AP1000 Design Certification.

Questions or requests for additional information related to content and preparation of this report should be directed to Westinghouse. Please send copies of such questions or requests to the prospective applicants for combined licenses referencing the AP1000 Design Certification. A representative for each applicant is included on the cc: list of this letter.

Westinghouse requests the NRC to provide a schedule for review of the technical report within two weeks of its submittal.

D063
D079
NRO

Very truly yours,

Mont D Bartley FOR

A. Sterdis, Manager
Licensing and Customer Interface
Regulatory Affairs and Standardization

/Attachment

1. "Oath of Affirmation," dated September 14, 2007

/Enclosure

1. APP-GW-S2R-010, Revision 1, "Extension of Nuclear Island Seismic Analysis to Soil Sites," Technical Report Number 3

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ATTACHMENT 1

"Oath of Affirmation"

ATTACHMENT 1

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

In the Matter of:)

NuStart Bellefonte COL Project)

NRC Project Number 740)

APPLICATION FOR REVIEW OF
"AP1000 GENERAL COMBINED LICENSE INFORMATION"
FOR COL APPLICATION PRE-APPLICATION REVIEW

W. E. Cummins, being duly sworn, states that he is Vice President, Regulatory Affairs & Standardization, for Westinghouse Electric Company; that he is authorized on the part of said company to sign and file with the Nuclear Regulatory Commission this document; that all statements made and matters set forth therein are true and correct to the best of his knowledge, information and belief.

W. E. Cummins
Vice President
Regulatory Affairs & Standardization

Subscribed and sworn to
before me this 14th day
of September 2007.

COMMONWEALTH OF PENNSYLVANIA
Notarial Seal
Patricia S. Aston, Notary Public
Murrysville Boro, Westmoreland County
My Commission Expires July 11, 2011
Member, Pennsylvania Association of Notaries

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ENCLOSURE 1

APP-GW-S2R-010, Revision 1

"Extension of Nuclear Island Seismic Analysis to Soil Sites"

Technical Report 3

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APP-GW-S2R-010
Revision 1

September 2007

AP1000 Standard Combined License Technical Report

Extension of Nuclear Island Seismic Analyses to Soil Sites

Revision 1

Westinghouse Electric Company LLC
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1.0 Introduction

This report describes the seismic analyses that have been performed to extend applicability of the AP1000 to soil sites. The AP1000 and the AP600 have the same footprint but the profile of AP1000 is taller than the AP600. The increased height of the AP1000 changes its seismic response and its interaction with the soil and also increases the soil bearing demand.

This report describes the seismic methodology, criteria, modeling and analysis for the Nuclear Island Category I Building Structures. These building structures are the auxiliary building, shield building, containment building, and foundation with basemat. Described in this seismic summary report are the following:

- Seismic Analysis methodology
- Description of the Category I Nuclear Island building structures
- Nuclear Island Building Dynamic Models
- Requirements for Site Seismic Characteristics
- Seismic Response
- Response spectrum analysis for Building Design
- Effect of Basemat Lift Off

The AP600 Design Certification covers a wide range of soil and rock sites. The current AP1000 Design Certification is limited to hard rock sites. Additional analyses have been performed to permit application of the AP1000 to the same wide range of soil sites as those certified for the AP600. The AP1000 seismic analyses for the hard rock Design Certification analyses used two distinct nuclear island hard rock models. A detailed finite element model was used to develop the lumped mass stick properties of the nuclear island stick model. The detailed finite element model was also used to develop vertical response spectra. The dynamic analyses that are being performed to support the licensing activities to extend the AP1000 Design Certification to soil sites as well as the rock sites rely to a greater extent on shell models and less on stick models. The dynamic modeling that is used is discussed in this report. Analyses using these models are also performed for a hard rock site and results are compared against those using stick models in the current AP1000 Design Certification.

Many of the AP600 parametric soil studies used to determine the critical soil profiles for the AP600 are also applicable to the AP1000. They are used in combination with parametric cases for the AP1000 to select the generic soil profiles for the AP1000 seismic analyses. Soil structure interaction analyses are described. These analyses use shell models of the concrete structures.

This document addresses seismic response spectra, soil sites, dynamic models, minor structural changes that are significant, seismic results and their impact on seismic design loads for the building structures. Note that in the modeling X is north, Y is west, and Z is vertical.

The site seismic characteristics are discussed in this report, along with interface parameters that the proposed site should meet to demonstrate acceptability for siting the AP1000. Also presented is a more extensive set of analyses that the Combined License applicant may perform to show acceptability if the site geoscience parameters are outside the interface parameters.

A separate report addresses reconciliation of the building and basemat designs for soil sites.

1.1 Acronyms

ASB = Auxiliary and Shield building
CIS = Containment Internal Structures
CMT = Core Make up Tank
DCD = Design Control document
EL (El.) = Elevation
EQ = Equivalent Static Acceleration Profile
EW = East West
FEM = Finite Element Model
FR = Firm rock
FRS = Floor response spectra (spectrum)
FSER = Final Safety Evaluation report
KSF = Kips per square foot
MAX = Maximum
MDOF = Master Degrees of Freedom
NE = North East
NW = North West
NI = Nuclear Island
NS = North South
PC = Polar Crane
PCCS = Passive Containment Cooling System
PSD = Power spectral density
PZR = Pressurizer
RCL = Reactor Coolant Loop
RG = Regulatory Guide
RLE = Review level earthquake
RPV = reactor pressure vessel
SB = Shield Building
SE = South East
SG = Steam Generator
SCV = Steel Containment Vessel
SM (SMS) = Soft to medium
SS = Soft soil
SSE = Safe shut down earthquake
SSI = Soil structure interaction
SR = Soft rock
SW = South West
UB = Upper bound
UBSM = Upper bound soft to medium
US = Upper support
VT = Vertical
ZPA = Zero period acceleration

2.0 Seismic Input

The peak ground acceleration of the safe shutdown earthquake has been established as 0.30g for the AP1000 design. The vertical peak ground acceleration is conservatively assumed to equal the horizontal value of 0.30g. Seismic response spectra are specified as shown in DCD Figures 3.7.1-1 and 3.7.1-2 and reproduced in Figures 2.1-1 and 2.1-2. These response spectra are based on Regulatory Guide (RG) 1.60 (Reference 3) with an additional control point specified at 25 Hz. The spectral amplitude at 25 Hz is 30 percent higher than the Regulatory Guide 1.60 spectral amplitude.

A "single" set of three mutually orthogonal, statistically independent, synthetic acceleration time histories is used as the input in the dynamic analysis of seismic Category I structures. The design time histories include a total time duration equal to 20 seconds and a corresponding stationary phase, strong motion duration greater than 6 seconds. These time histories envelop the design response spectra and satisfy power spectral density (PSD) requirements.

This same seismic input is being used for the AP1000 seismic analyses for the different soil sites.

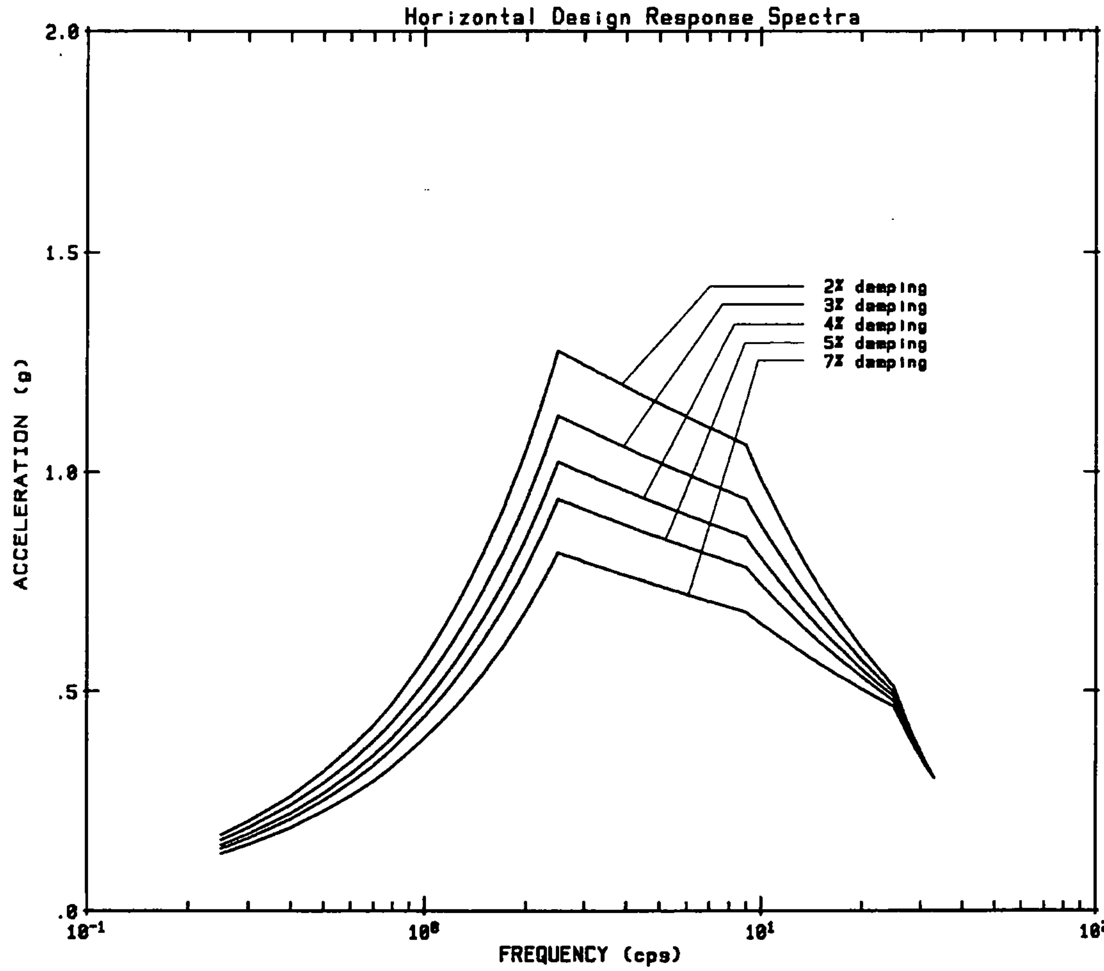


Figure 2.1-1 – AP1000 Horizontal Design Response Spectra for Safe Shutdown Earthquake

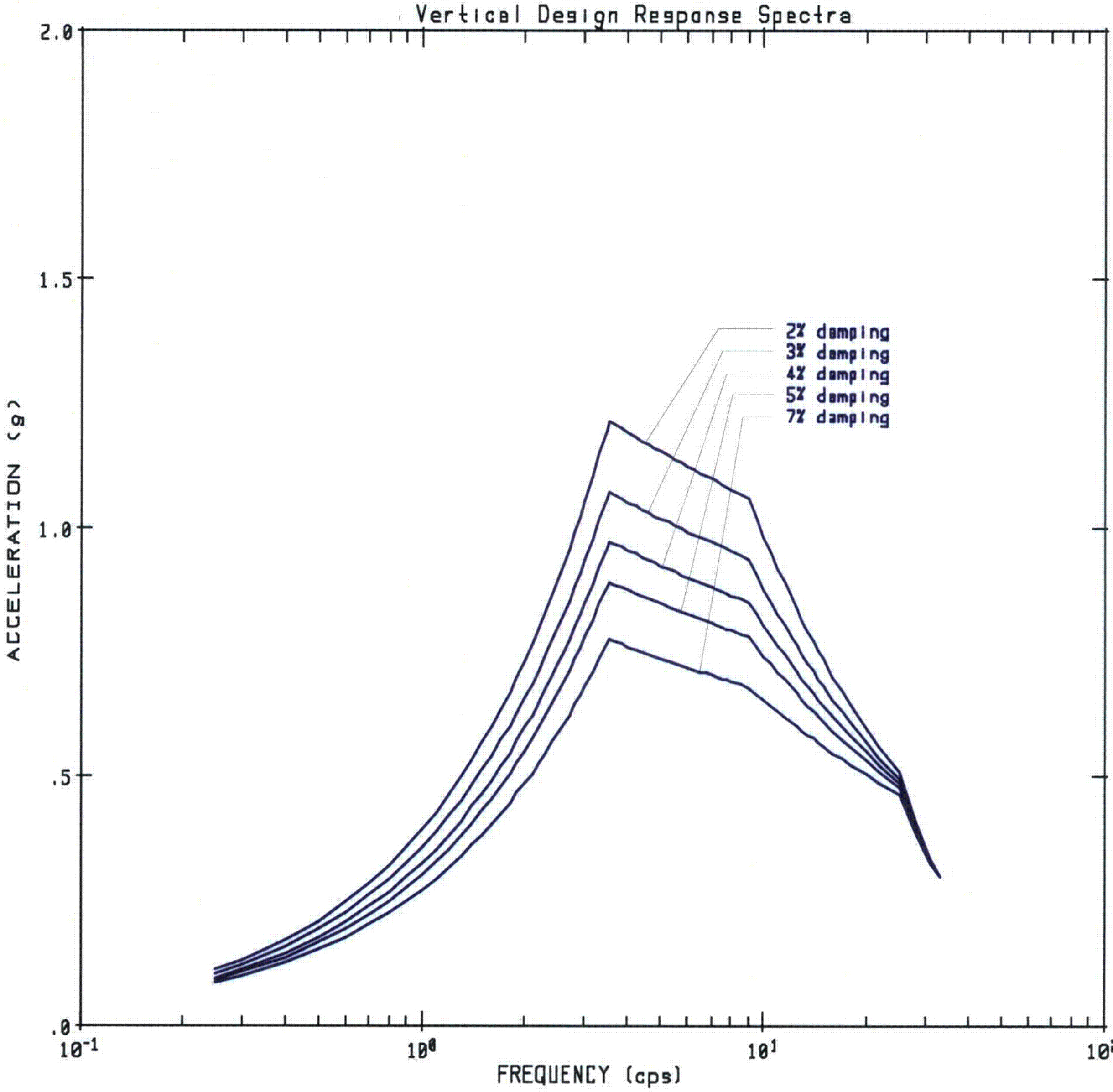


Figure 2.1-2 – AP1000 Vertical Design Response Spectra Safe Shutdown Earthquake

3.0 *Nuclear Island Building Design Description*

The AP1000 nuclear island (NI) consists of three distinct Seismic Category I structures. The three building structures that make up the nuclear island are the coupled auxiliary and shield building (ASB), the steel containment vessel (SCV), and the containment internal structures (CIS). Note that the shield building and the auxiliary building are monolithically constructed with reinforced concrete and therefore considered one structure.

The nuclear island structures, including the SCV, the CIS, and the ASB are founded on a common basemat. The nuclear island is embedded approximately forty feet with the bottom of basemat at Elevation 60'-6" and plant grade located at elevation 100'-0".

The steel containment vessel is a freestanding cylindrical steel structure with elliptical upper and lower heads. It is surrounded by the reinforced concrete shield building. The inside diameter and height are equal to 130' and 215' 4", respectively. The top of containment is at Elevation 281' 10". The design pressure of the containment vessel is 59 psig and the containment cylindrical shell thickness is 1-3/4". The polar crane is supported on the steel containment vessel with the top of the crane rail at Elevation 226' 6 1/4".

The containment internal structures are designed using reinforced concrete and structural steel. At the lower elevations conventional concrete and reinforcing steel are used, except that permanent steel forms are used in some areas in lieu of removable forms based on constructability considerations. Walls and floors are steel structural modules. These modules are structural elements built up with welded structural shapes and plates. Concrete is used where required for shielding, but reinforcing steel in the form of bars is not normally used.

The shield building is a cylindrical reinforced concrete structure which includes the open annulus area surrounding the containment vessel. It has a conical roof structure which supports the containment air cooling diffuser and the Passive Containment Cooling System (PCCS) water storage tank. It's outside diameter and wall thickness is equal to 145 feet and 3 feet, respectively. The shield building is designed to provide radiation shielding and to protect the containment vessel and reactor coolant system from effects of tornadoes and tornado generated missiles.

The auxiliary building is a reinforced concrete structure. Structural modules, similar to those used in the containment internal structures, are used in the southern portion of the auxiliary building. It essentially wraps approximately 50 percent of the circumference of the shield building. The floor slabs and the structural walls of the auxiliary building are structurally connected to the cylindrical section of the shield building. The auxiliary building includes the fuel handling area located south of the shield building. A 150 ton bridge crane is provided in the fuel handling area for spent fuel cask handling.

Key dimensions, such as the foundation size and thickness of the basemat, floor slabs, roofs and walls, of the seismic Category I building structures are shown in DCD Figures 3.7.1-14 and 3.7.2-12. Design changes have been incorporated partly to reduce regions of high seismic response as described in the pressurizer change technical report (Reference 5). The significant changes are to the pressurizer compartment and shield slab bracing. A new 2100 ft^3 pressurizer is used. It has a smaller length from outside surface of lower head to outside surface of upper head. The change in length is from 607.11" to 502.88". This change was made to reduce the seismic response of the pressurizer compartment. The elevation at the top of the pressurizer compartment wall changes from El. 169'-0" to El. 160'-0". Appendix A provides drawings showing the changes to the pressurizer compartment and the piping elements attached to the top of the pressurizer.

Additional structural changes are reflected in the models used for the soil and hard rock cases along with modeling improvements. These are summarized below:

- A design change was made in the spent fuel pool area to permit heavier fuel racks. Masses reflecting the racks and spent fuel were updated. In addition, the water in the fuel pits was modeled as lumped masses instead of solid elements.
- The shield building roof slab bracing was modified from tie rods to cross bracing to improve the seismic response.
- The dish model was modified to incorporate changes in the annulus configuration included in existing DCD figures. The annulus tunnel on the west side was deleted and replaced by concrete. In addition nodes and elements were modified in the lower shield building and upper CIS basemat to be compatible with the revised Dish model.
- The core makeup tanks were added as stick models.
- Floors in the CIS model were refined to provide better member force results for use in design.
- Polar Crane Model – Changes made to the model weight (3% reduction), updated SCV local stiffness, and inclusion of polar crane truck stiffness.
- The shield building roof was lowered 5'

The shield building cylindrical wall and roof design is made more robust. Modifications are made to strengthen the shield building cylindrical wall. A 3' (outside face to inside face) wall thickness is maintained; however two 0.5" steel plate on the inside and outside face of the cylindrical wall are added. Shear studs and L-Channel stiffeners are added to stiffen the wall and join the plates and concrete sections. The shield building roof is modified to use 32 W36x393 steel beams in place of previous 4' x 1' pre-cast concrete beams. The shield building roof is modified by increased roof thickness, from 2' to 3' at the exposed locations. A 0.5" steel plate is included on the inside face of the concrete (between concrete and steel beams) to further strengthen the roof. Passive Cooling System Air Inlet are also designed as CA module-type walls. Two 0.5" steel plates enclose 4.5' of concrete. The number of inlets is enhanced to two or three rows of 16" x 16" square tubes, two rows for locations directly below beams and three rows at other locations. The tubes are angled downward. The overall height of the shield building and roof is lowered 5' (top of shield building is at 329'). The concrete compressive strength for the shield building, the exposed shield building, and the shield building roof is increased from 4000 psi to 6000 psi.

4.0 Dynamic Models

Seismic systems are defined, according to SRP 3.7.2 (Reference 6), 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. 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.

It is noted that Concrete structures are modeled with linear elastic uncracked properties. However, the modulus of elasticity is reduced to 80% of its value to reduce stiffness to reflect the observed behavior of concrete when stresses do not result in significant cracking as recommended in Table 6.5 of FEMA 356.

The lumped mass stick model of the nuclear island was used in the analyses on hard rock described in the DCD. This provided good representation of the important modes of the structure and seismic interaction between the nuclear island structures. The stick models were carefully prepared so that the responses at lumped mass nodes simulated the structural response as well as possible. The development of stick model properties was aided by the use of shell and/or solid models. It is now possible to develop acceleration response spectra for complex structures, such as the AP1000 nuclear island, directly from large solid-shell models. Therefore, the AP1000 design analyses are now using the shell models. This change in modeling methodology does not change the conclusions of adequacy on the hard rock site based on review of the analyses and design using stick models. The comparisons of the stick model against the shell models with two levels of refinement show that all three models give similar results. Hence, stick and shell models provide results that are comparable and adequate for design. The decision to move away from the use of the combined stick model is predicated on the use of the shell model for soil-structure-interaction analyses, and to reflect the improvement in technology where the use of the shell models are reflective of the state of the art.

4.1 Overview of Models

Two finite element shell models (3D of the entire nuclear island concrete structures are used. The NI10 model is a fine model and the NI20 model is a coarse model used for soil structure interaction. Sections 4.2, 4.2.2, and 4.2.2 describe these models.

4.2 Nuclear Island Shell Models Descriptions and Comparison Response

Finite element shell models (3-D) 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 and the reactor coolant loop. Two models are used. The fine (NI10) model is used to define the seismic response for the hard rock site. This NI10 and NI20 models are updated to reflect the robust shield building design as described in section 3.0. The coarse (NI20) model is used for the soil structure interaction (SSI) analyses and is set up in both ANSYS and SASSI.

Soil structure interaction analyses use the NI20 coarse finite element model of the nuclear island. This model is similar to the NI10 model with the exception that the mesh size for the ASB and CIS is approximately 20' instead of 10'. The NI10 and NI20 models are described in Sections 4.2.1 and 4.2.2. The nodes associated with each model are shown in the figures in Section 4.2.3; node numbers are the same in both the ANSYS and SASSI NI20 models. Appendix C provides comparisons between the floor response spectra generated from the coarse (NI20) and fine (NI10) models. Also shown in this appendix is a comparison of NI20 ANSYS and NI20 SASSI.

4.2.1 NI10 Model Description

The large solid-shell finite element model of the AP1000 nuclear island shown in Figure 4.2.1-1 combines the auxiliary and shield building (ASB) solid-shell model, and the containment internal structure (CIS) solid-shell model together with the containment vessel and major equipment

(Figure 4.2.1-4). 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 Steel Containment Vessel (SCV) and the polar crane models, the reactor coolant loop (RCL) model, core make-up tank (CMT) models, and the pressurizer (PZR) model. The stick models are described in Section 4.3. 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 finite element model database is an ANSYS solid model of the ASB below the auxiliary building roof. It creates a finite element mesh by setting one element for each area of the solid model. A finite element model of the shield building above the auxiliary building roof is then added. Since the water in the PCCS tank responds at a very low frequency (sloshing) and does not affect building response, the PCCS 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 reduced to 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 are re-meshed to obtain more precise dynamic analysis results for flexible areas.

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 superelements (ASB & CIS) have been prepared. The superelement finite models that have been developed as part of the dynamic analysis of the nuclear island structures are shown in Figure 4.2.1-5 and 4.2.1-6.

To obtain the time history response of the ASB, the ASB finite element model is merged with the superelement of the CIS and its major components. The CIS has superelement 1200 Master Degrees Of Freedom (MDOF). Figure 4.2.1-5 shows the ASB in conjunction with the CIS superelement model.

To obtain the time history response of the CIS, the CIS finite element model is merged with a superelement of the ASB. The ASB superelement has 1200 MDOFs. Figure 4.2.1-6 shows the CIS in conjunction with the ASB superelement model.

The SCV was connected to the CIS model using constraint equations. The SCV node 130401 at elevation 100' was connected to CIS nodes at the same elevation. Figure 4.2.1-2 shows the nodes where constraint equations are applied and Figure 4.2.1-3 shows the SCV stick model with the constraint equation nodes. The nodes are defined using a cylindrical coordinate system whose origin coincides with the location of 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.

4.2.2 NI20 Model Description

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 are performed using the program SASSI. The stick models are the same as used for the NI10 model except that the CMT is not included. This model is shown in Figure 4.2.2-1.

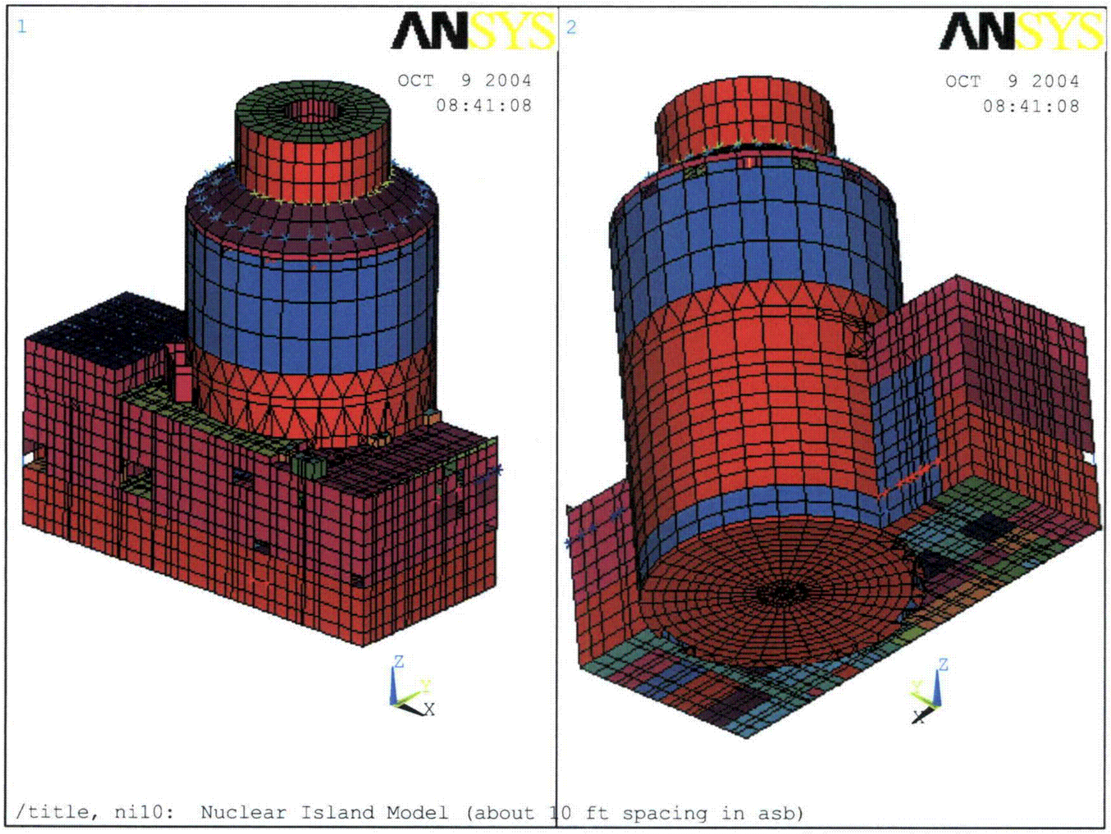


Figure 4.2.1-1 - AP1000 Nuclear Island solid-shell model

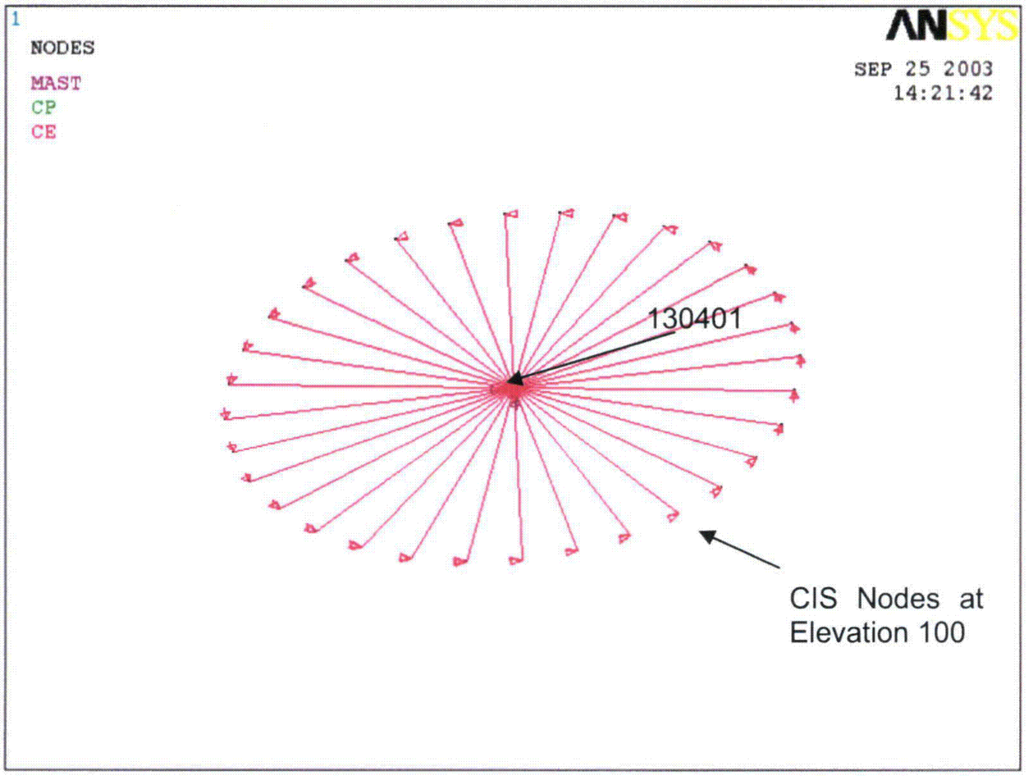


Figure 4.2.1-2 - SCV Connections to CIS

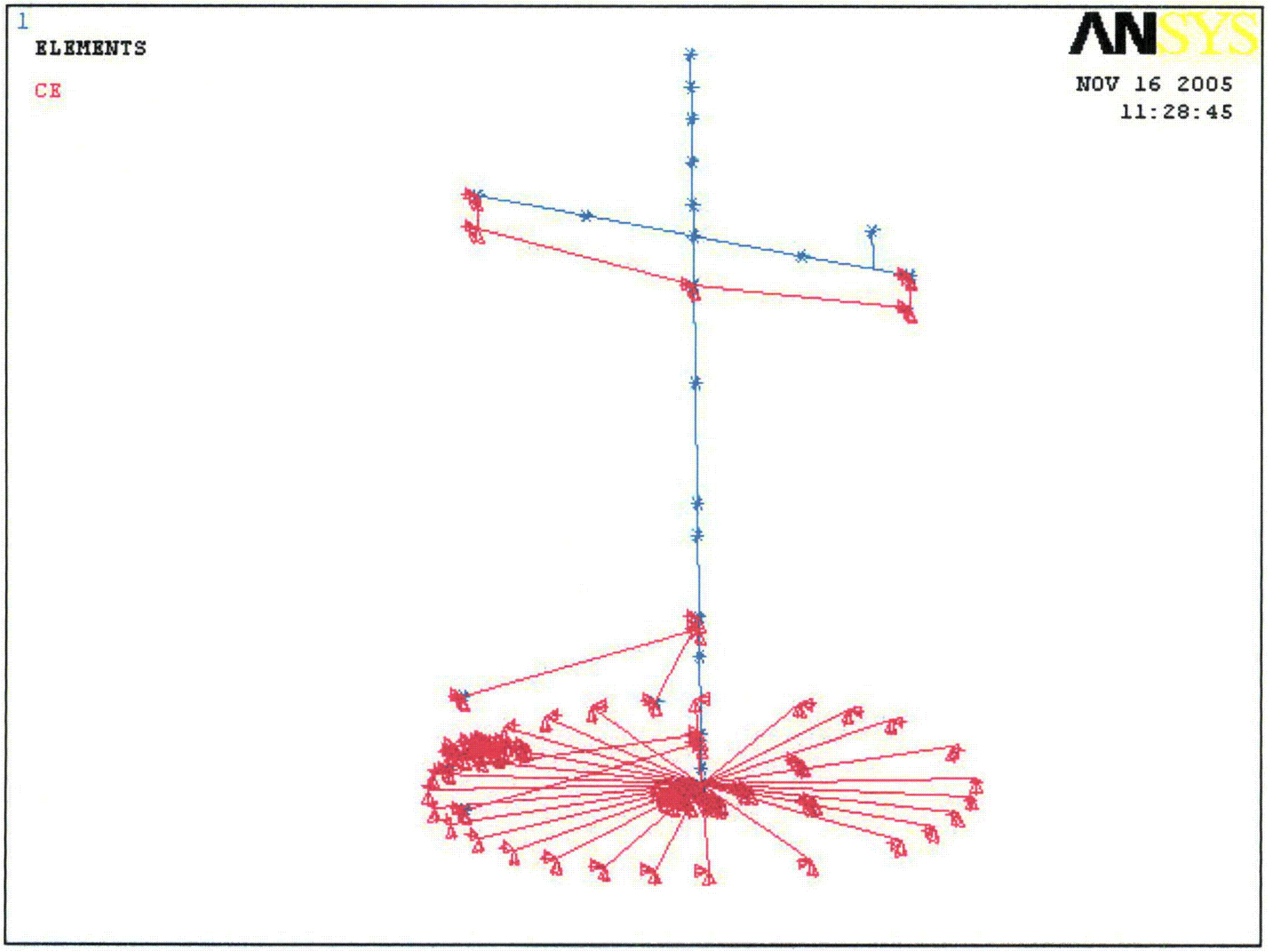


Figure 4.2.1-3 - Polar Crane and Steel Containment Vessel Nodes

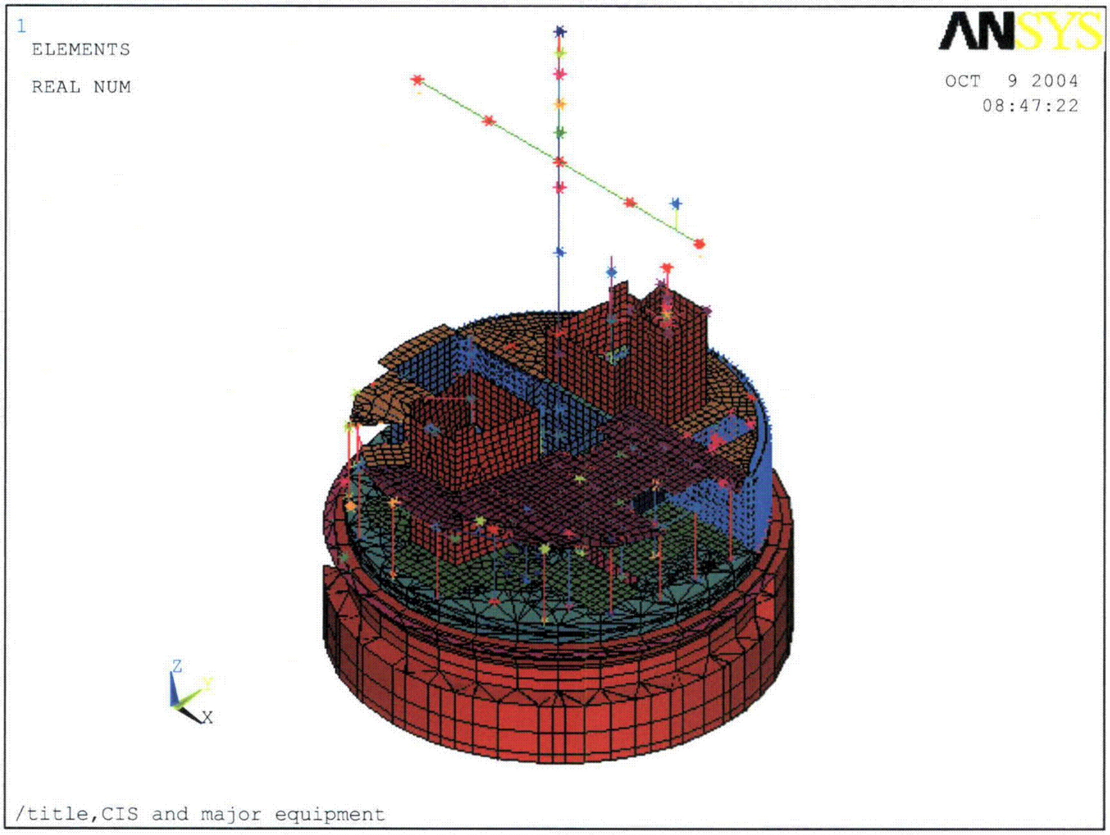


Figure 4.2.1-4 - CIS with the SCV, PC, RCL and PZR

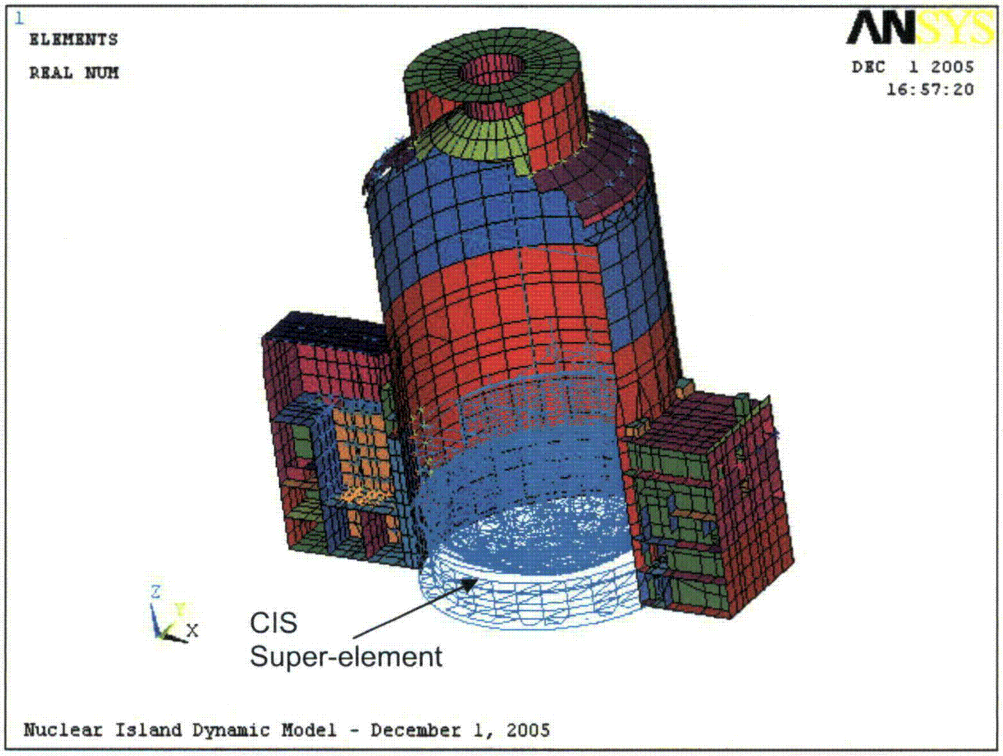


Figure 4.2.1-5 - ni10-asb model, ASB FEM with CIS and major equipment as Super-element

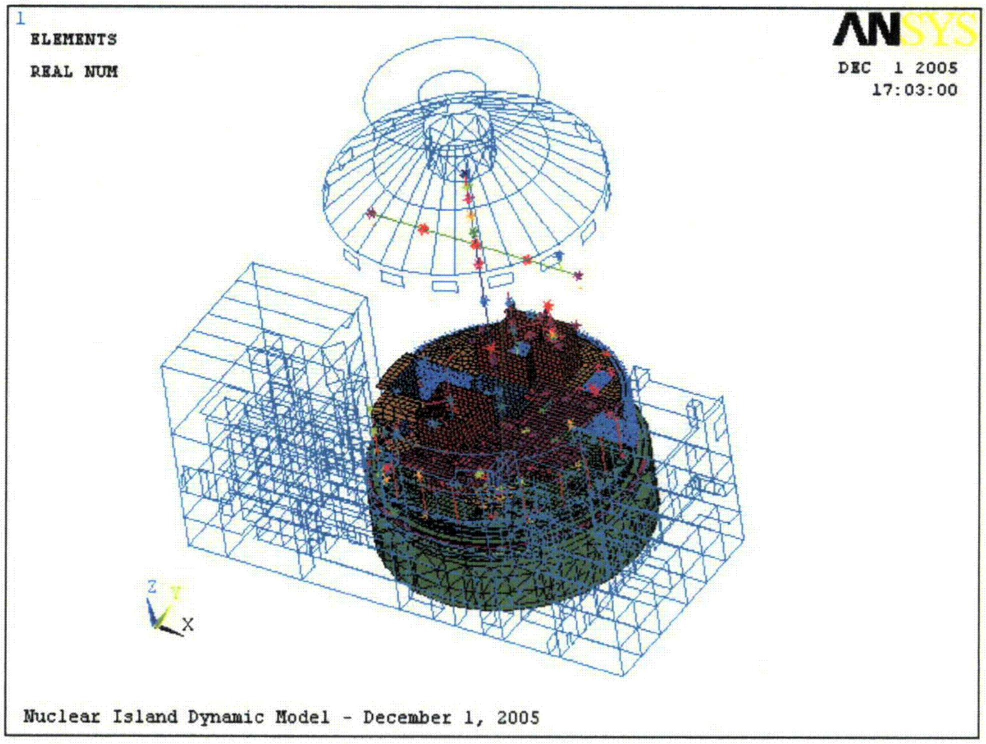
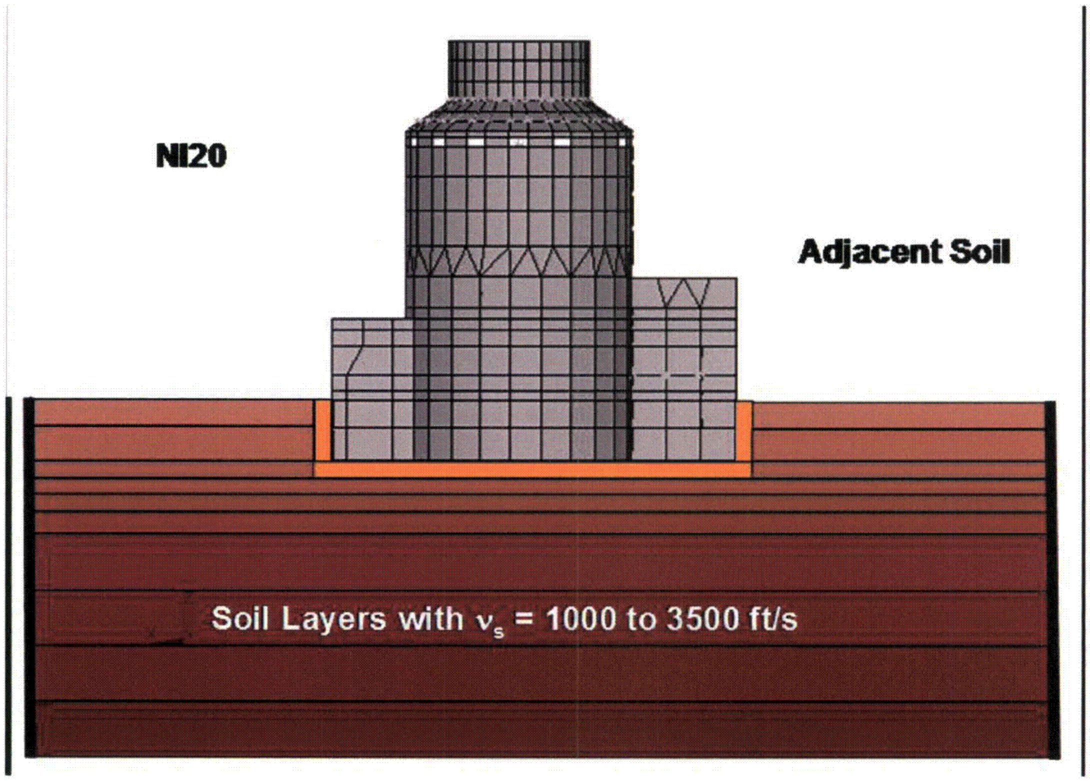


Figure 4.2.1-6 - ni10-cis model, CIS and major equipment FEM with ASB as Super-element



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 4.2.2-1 - Soil Structure Interaction Model – NI20 Looking East

4.2.3 NI10 and NI20 Model Nodes

Figures 4.2.3-1 to 4.2.3-12 show the NI20 model of the ASB. Locations and numbers of nodes are identified on these figures where floor response spectra are calculated. Corresponding node numbers on the NI10 model are shown in red and those on the NI20 model are shown in black.

Figures 4.2.3-13 to 4.2.3-16 show the nodes associated with the Containment Internal Structures. Both nodes for the NI10 (shown in red) and NI20 are shown.

Node numbers on the containment vessel and major equipment are discussed in Section 4.3.

The node plant coordinates are given in Tables 4.2.3-1 to 4.2.3-4 for the ASB, CIS, and SCV. Note that X is north, Y is west, and Z is vertical.

Seismic response spectra are developed at the locations of the nodes. These response spectra are grouped and enveloped to define the seismic design response spectra. The nodes associated with a specific elevation and building structure (i.e., ASB and CIS) are grouped. For the ASB where the floor at the elevation of interest is rigid (i.e. frequency $\geq$ 33 hertz), it is only necessary to envelop the response spectra at edge points and interior nodes at the shield wall to obtain the largest seismic response spectra because of rigid motion. The edge nodes reflect the largest rocking and translational response of the auxiliary building, and the response spectra associated with the nodes on the shield wall will reflect the shield wall dynamic response. It is not necessary to include any nodes between the shield wall and auxiliary building edge since the floor is rigid, and the response cannot be worse than those enveloped. The edge nodes chosen are shown in Figure 4.2.3-1 where the response spectra at the edge and shield wall nodes are enveloped. If the floor is flexible, then response spectra for these interior nodes associated with this flexible area are enveloped. Interior nodes representing flexible areas are shown in Figure 4.2.3-2 where the seismic response spectra associated with nodes 4548 (2030), 4570 (2038), and 4556 (2034) are enveloped.

If equipment or a structure is supported at more than one elevation, then the analysts of such equipment will define the seismic input as an envelope of multiple groups based on the support locations. Therefore, if the equipment or structure is supported on rigid and flexible floor areas the response spectra (horizontal and vertical directions) used by the analysts will be the envelope of the rigid and flexible areas that include inside and outside nodes.

Appendix B provides tables showing the grouping for the ASB and the CIS. There is no grouping for the SCV since it is represented by a stick model.

The equivalent static accelerations associated with the nodes that are used in the building design are discussed in subsection 6.5.

Comparison of the NI10 and NI20 responses is given in Appendix C.

Table 4.2.3-1 – ASB Nodes (EL. 99' to 163')

FRS name	Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
			Auxiliary and Shield Building			
ASB99	1676	2391	1070.5	992	100	SBC north
	1585	2376	1005.2	929.2	100	SBC east
	1688	2406	929	1000	100	SBC south
	1750	2595	1005.4	1070.8	100	SBC west
	1564	4084	862.5	913	100	ASB SE 1I
	1685	4115	862.5	1000	100	ASB SW 1N
	1574	4233	1045.8	913	100	ASB 7.3I
	1579	4380	1116.5	913	100	ASB NE 11I
	1719	4399	1116.5	1027.5	100	ASB NW 11Q
	1567	6614	929	913	100	ASB 4I
ASB 116.5 C. ROOM	2063	4681	1093	930.5	116.5	
	2055	4632	1072.6	913	116.5	
	2076	4718	1116.5	913	116.5	
	2057	4623	1072.6	948.5	116.5	
	2078	4724	1116.5	948.5	116.5	
ASB 34-116	2030	4548	1005.2	922.3	116.5	ASB 7I (flexible node)
	2034	4556	1018.2	923	116.5	ASB 7I (flexible node)
	2038	4570	1034.2	924.5	116.5	ASB 7I (flexible node)
ASB135	2319	5054	1070.5	992	134.9	SBC north
	2296	4961	1005.2	929.2	134.9	SBC east
	2274	5744	929	1000	134.9	SBC south
	2297	7648	1005.4	1070.9	134.9	SBC west
	2347	6821	1116.5	1027.5	134.9	ASB NW
	2247	4764	862.5	913	134.9	ASB SE
	2253	4795	862.5	1000	134.9	ASB SW
	2268	4886	929	913	134.9	ASB 4I
	2306	4984	1045.8	913	134.9	ASB 7.3I
	2341	5109	1116.5	913	134.9	ASB NE
ASB34-135	2295	4959	1005.2	922.3	134.9	ASB 7I (flexible node)
	2299	4967	1018.2	923	134.9	ASB 7I (flexible node)
	2303	4981	1034.2	924.5	134.9	ASB 7I (flexible node)
ASB4-135	2281	4925	950	931	134.9	ASB 4I (flexible node)
	2287	4939	970.4	931	134.9	ASB 4I (flexible node)

Table 4.2.3-2 – ASB Nodes (EL. 163' to 333')

FRS Name	Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
			Auxiliary and Shield Building			
ASB160	2505	5538	1070.5	992	152.6	SBC north
	2627	5487	1005.2	929.19	159.9	SBC east
	2637	5510	1045.8	913	159.9	ASB 7.3I
	2640	5515	1045.8	945.71	159.9	SBC 7.3
	2528	5351	1116.5	913	152.6	ASB NE
	2534	5370	1116.5	1027.5	152.6	ASB NW
	2600	6955	929	913	159.9	ASB 4I
ASB34-160	2626	5485	1005.2	922.3	159.9	ASB 7-7.2I (flexible node)
	2630	5494	1018.2	923	159.9	ASB 7-7.2I (flexible node)
	2634	5507	1034.2	924.5	159.9	ASB 7-7.2I (flexible node)
ASB180	2722	6153	1070.5	992	180.1	SBC north
	2710	6054	1005.2	929.2	180.1	SBC east
	2675	5754	929	1000	179.2	SBC south
	2711	7719	1005.4	1070.9	180.1	SBC west
	2668	5574	862.5	1000	179.2	ASB SW
	2662	5543	862.5	913	179.2	•ASB SE
	2669	5703	929	913	179.2	ASB 4I
ASB56-180	2695	5628	895.8	942.8	179.9	ASB 2 (flexible node)
	2697	5633	895.8	971.2	179.9	ASB 2 (flexible node)
ASB230	2823	8049	1069.6	986.1	236.3	SBC north
	2809	8035	1000	929	236.3	SBC east
	2794	8050	929	1000	236.3	SBC south
	2810	8066	1000	1071	236.3	SBC west
ASB267	2900	8116	1071	1000	267.8	SBC north
	2884	8100	1000	929	267.8	SBC east
	2869	8115	929	1000	267.8	SBC south
	2885	8131	1000	1071	267.8	SBC west
ASB289	3103	8317	1043.5	1000	289.2	SBR north
	3087	8301	1000	956.5	289.2	SBR east
	3072	8316	956.5	1000	289.2	SBR south
	3088	8332	1000	1043.5	289.2	SBR west
	3067	8296	1000	1000	289.1	
ASB327	3360	8574	1043.5	1000	327.4	SBR north
	3344	8558	1000	956.5	327.4	SBR east
	3329	8573	956.5	1000	327.4	SBR south
	3345	8589	1000	1043.5	327.4	SBR west

Table 4.2.3-3 – CIS Nodes

FRS name	Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
			Containment Internal Structures			
CIS99	1688	2406	929	1000	100	SBC south
	1761	130401	1000	1000	100	CV stick
	1676	2392	1070.5	992	100	SBC east
	1750	2595	1005.4	1070.8	100	SBC west
	1585	2376	1005.2	929.2	100	SBC north
CIS134	2217	106962	1022.8	1040.8	134.3	Pressurizer
	2216	106958	1022.8	1024.2	134.3	Pressurizer
	2184	106805	1002.1	1046.2	134.3	SG west
	2199	105772	1008	1014	134.3	SG west
	2162	105773	978	1014	134.3	SG west
	2170	106819	982.9	1046.2	134.3	SG west
	2197	105805	1008	986	134.3	SG east
	2183	107241	1002.1	953.8	134.3	SG east
	2169	107252	982.9	953.8	134.3	SG east
	2159	105806	978	986	134.3	SG east
	2244	105852	1057	1024.2	134.3	IRWST North
	2138	105955	942.5	1014	134.3	RC south
	2136	106300	942.5	986	134.3	RC south
	2181	111745	994.2	930.1	134.3	East
CIS153	2546	106806	1002.1	1046.2	153	SG west
	2552	105868	1007.6	1016.2	153	SG west
	2536	105875	978.34	1016.2	153	SG west
	2540	106760	982.9	1046.2	153	SG west
	2547	106899	1003.1	1040.8	153	PZR
	2550	106428	1006	1024.8	153	PZR
	2560	106166	1022.8	1024.2	153	PZR
	2562	106160	1022.8	1040.8	153	PZR
	2551	105975	1007.6	983.8	153	SG east
	2545	107235	1002.1	953.8	153	SG east
	2539	107256	982.9	953.8	153	SG east
	2535	105982	978.3	983.8	153	SG east
CIS160	2646	106216	1003.1	1040.8	160	
	2652	106163	1022.8	1040.8	160	
	2650	106174	1022.8	1024.2	160	
	2647	106204	1006	1024.8	160	
IRWST	2154	110671	971.5	1055.8	134.3	
	2229	110701	1036.7	1050.9	134.3	

FRS name	Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
	Containment Internal Structures					
134cisWEST	2170	106819	982.9	1046.2	134.3	SG west
	2184	106805	1002.1	1046.2	134.3	SG west
	2162	105773	979.3	1014.0	134.3	SG west
	2199	105772	996.7	1014.0	106.3	SG west
	2216	106958	1022.8	1024.2	134.3	Pressurizer
	2217	106962	1022.8	1040.8	134.3	Pressurizer
134cisEAST	2169	107252	982.9	953.8	134.3	SG east
	2159	105806	978	986	134.3	SG east
	2183	107241	1002.1	953.8	134.3	SG east
	2197	105805	1008	986	134.3	SG east
153cisWEST	2540	106760	982.9	1046.2	153	SG west
	2546	106806	1002.1	1046.2	153	SG west
	2536	105875	978.3	1016.2	153	SG west
	2552	105868	1007.6	1016.2	153	SG west
	2560	106166	1022.8	1024.2	153	PZR
	2562	106160	1022.8	1040.8	153	PZR
	2547	106899	1003.1	1040.8	153	PZR
	2550	106428	1006	1024.8	153	PZR
153cisEAST	2551	105975	1007.6	983.8	153	SG east
	2545	107235	1002.1	953.8	153	SG east
	2539	107256	982.9	953.8	153	SG east
	2535	105982	978.3	983.8	153	SG east

Table 4.2.3-4 – Steel Containment Vessel

FRS name	Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
	Steel Containment Vessel and Polar Crane					
SCV132	2134	130406	1000	1000	131.7	Lower stiffener
SCV170	2656	130410	1000	1000	169.93	mid
SCV224	2788	130412	1000	1000	224	PC
SCV241	2828	130633	1000	1000	236.5	PC
SCV282	3030	130417	1000	1000	281.9	Top of SCV

Table 4.2.3-5 – Reactor Coolant Loop FRS Nodes

FRS name	Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
	Reactor Coolant Loop					
RCL Cold Legs	1774	137047	982.3	987.6	102.7	
	1775	137147	982.3	1012.5	102.7	
	1809	137036	1002.7	987.6	102.7	
	1810	137136	1002.7	1012.5	102.7	
	1805	137038	1000.2	977	102.7	
	1778	137049	984.8	977	102.7	
	1806	137138	1000.2	1023	102.7	
	1779	137149	984.8	1023	102.7	
RCL Hot Legs	1772	137187	992.5	1014.9	101.3	
	1812	137189	992.5	1022.7	103.11	
	1763	137087	992.5	985.1	101.3	
	1811	137089	992.5	977.3	103.1	
	Major Equipment Location					
RPV078	1751	137708	992.5	1000	78.3	
RPVINTB	1767	137710	992.5	1000	101.3	
RPV137	2350	137714	992.5	1000	137.3	
RPV	1768	137704	992.5	1000	101.3	
	1792	137703	992.5	1000	102.7	
RCP	1755	137062	988.3	968.1	90.9	
RCP	1756	137162	988.3	1031.9	90.9	
RCP	1757	137055	996.7	968.1	90.9	
RCP	1758	137155	996.7	1031.9	90.9	
RCPNOZ	1910	137067	988.3	968.1	106.3	
RCPNOZ	1911	137167	988.3	1031.9	106.3	
RCPNOZ	1912	137060	996.7	968.1	106.3	
RCPNOZ	1913	137160	996.7	1031.9	106.3	
SG Bottom	1980	137070	992.5	970	114	
SG Bottom	1981	137170	992.5	1030	114	
RPV Dome	1982	137701	992.5	1000	114.9	
SG Feed	2583	137078	992.5	970	156.4	
Water	2584	137178	992.5	1030	156.4	
SG Main	2657	137079	992.5	970	173.6	
Steam	2658	137179	992.5	1030	173.6	

FRS name	Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
Table 6-6		RCL Support Locations				
	2568	106767	981.9	1039.5	156.4	
SG Top Support	2573	106901	1003.1	1040.8	156.35	
	2575	107231	1003.3	960.5	156.35	
	2566	107338	981.9	960.5	156.35	
	1933	108940	980.5	970	107.2	
	2167	109009	981.64	1037.8	134.25	
SG Interm. RPV Support	2163	109015	979.25	1022.2	134.25	
	2186	109192	981.64	962.17	134.25	
	2195	109198	979.25	977.83	134.25	
	1947	109496	1005.1	1030	107.17	
RPV&SG Supports	1519	118089	992.5	1030	82.5	
	1436	118131	992.5	970	82.5	
	1559	117529	986	1006.5	100	
	1560	117527	999	1006.5	100	
	1554	117528	999	993.5	100	
	1553	117530	986	993.5	100	

Table 4.2.3-6 – Pressurizer FRS Nodes

FRS name	Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
			Pressurizer			
PZR Bot	2085	137201	1014	1032.5	120.5	
PZR Top	2556	137207	1014	1032.5	153.0	
	2653	137210	1014	1032.5	161.9	
	2655	137220	1014	1032.5	167.3	ADS123
	2659	137230	1014	1032.5	178.0	ADS123

Table 4.2.3-7 – Core Make-up Tank

FRS name	Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
			Core Make-up Tank			
CMT	Not modeled for soil condition.	147201	954.5	973.17	106.71	
		147207	954.5	973.17	128.23	
		147301	1016	968.29	106.71	
		147307	1016	968.29	128.23	

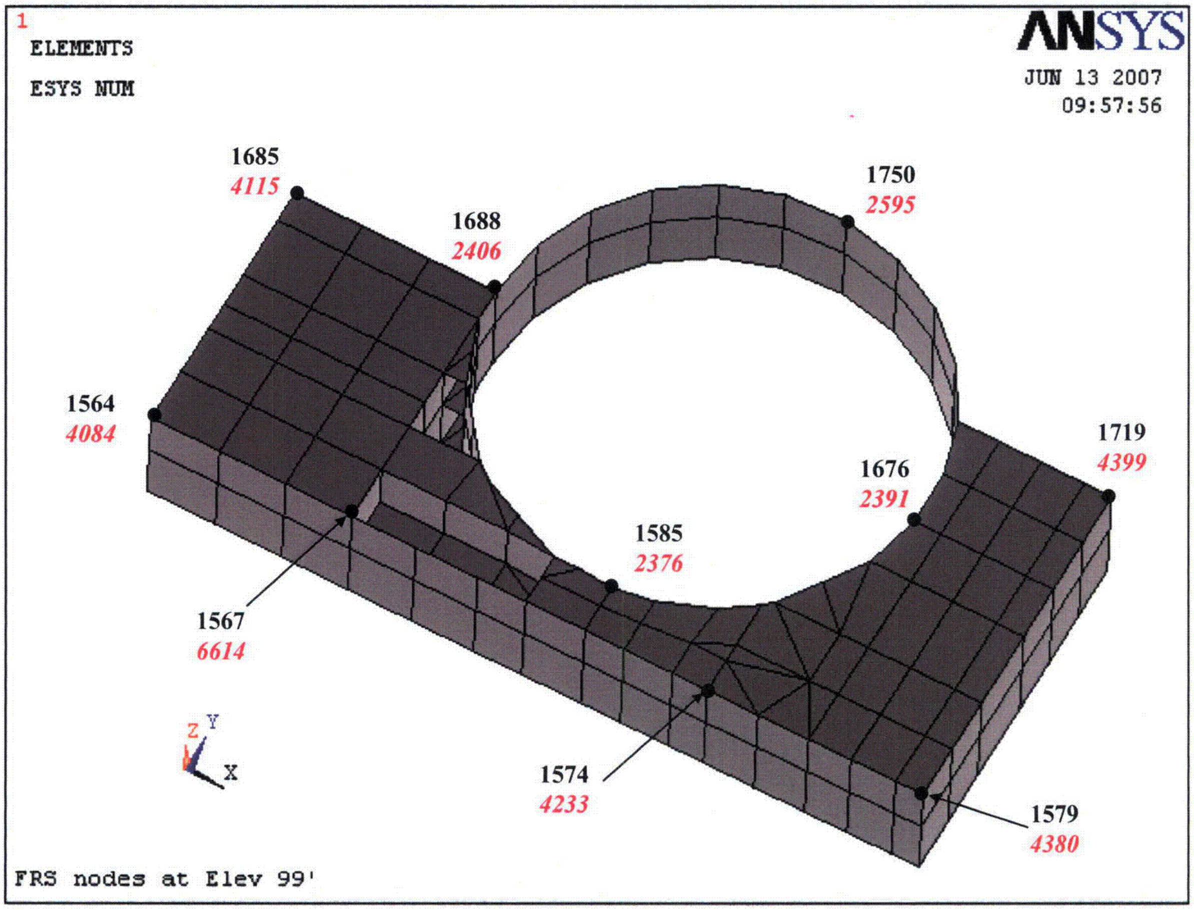


Figure 4.2.3-1 – ASB Nodes at or below El. 100'

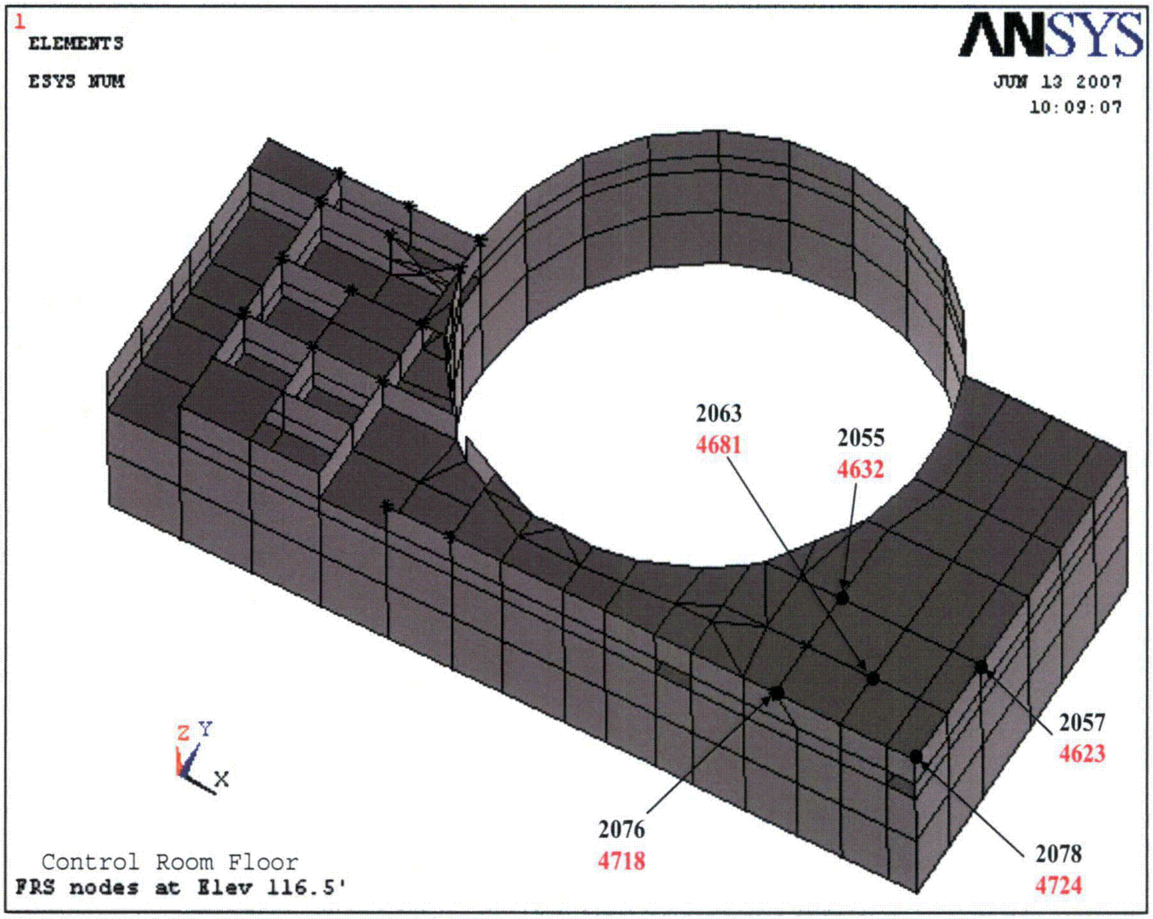


Figure 4.2.3-2 – ASB Nodes at or below El. 116.5' Control Room Floor

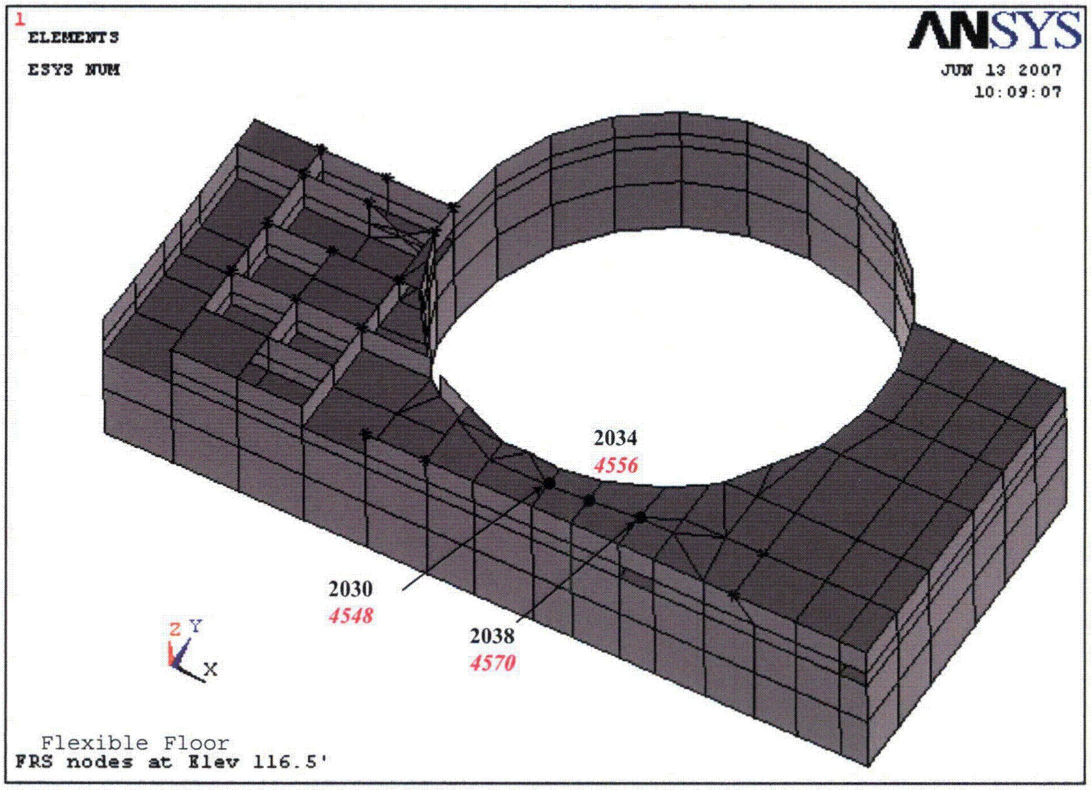


Figure 4.2.3-3 - FRS nodes at Elevation 116.5'

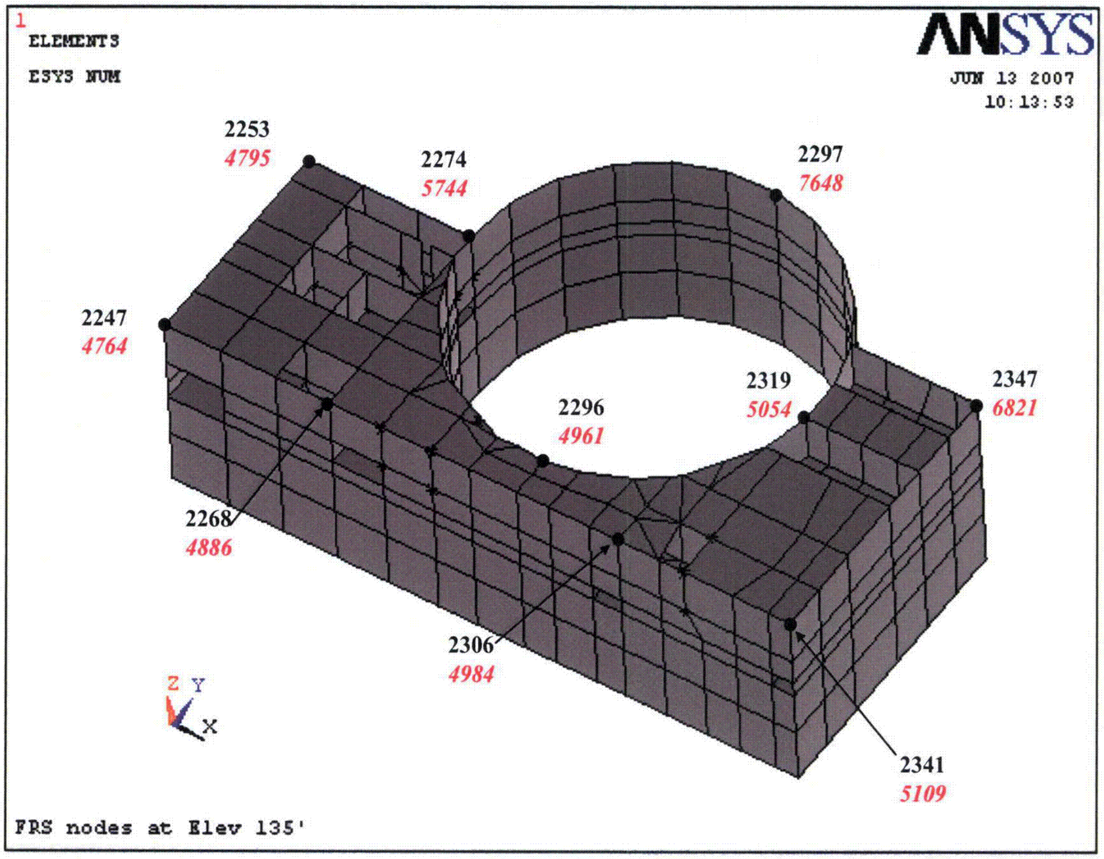


Figure 4.2.3-4 - FRS nodes at Elevation 135'

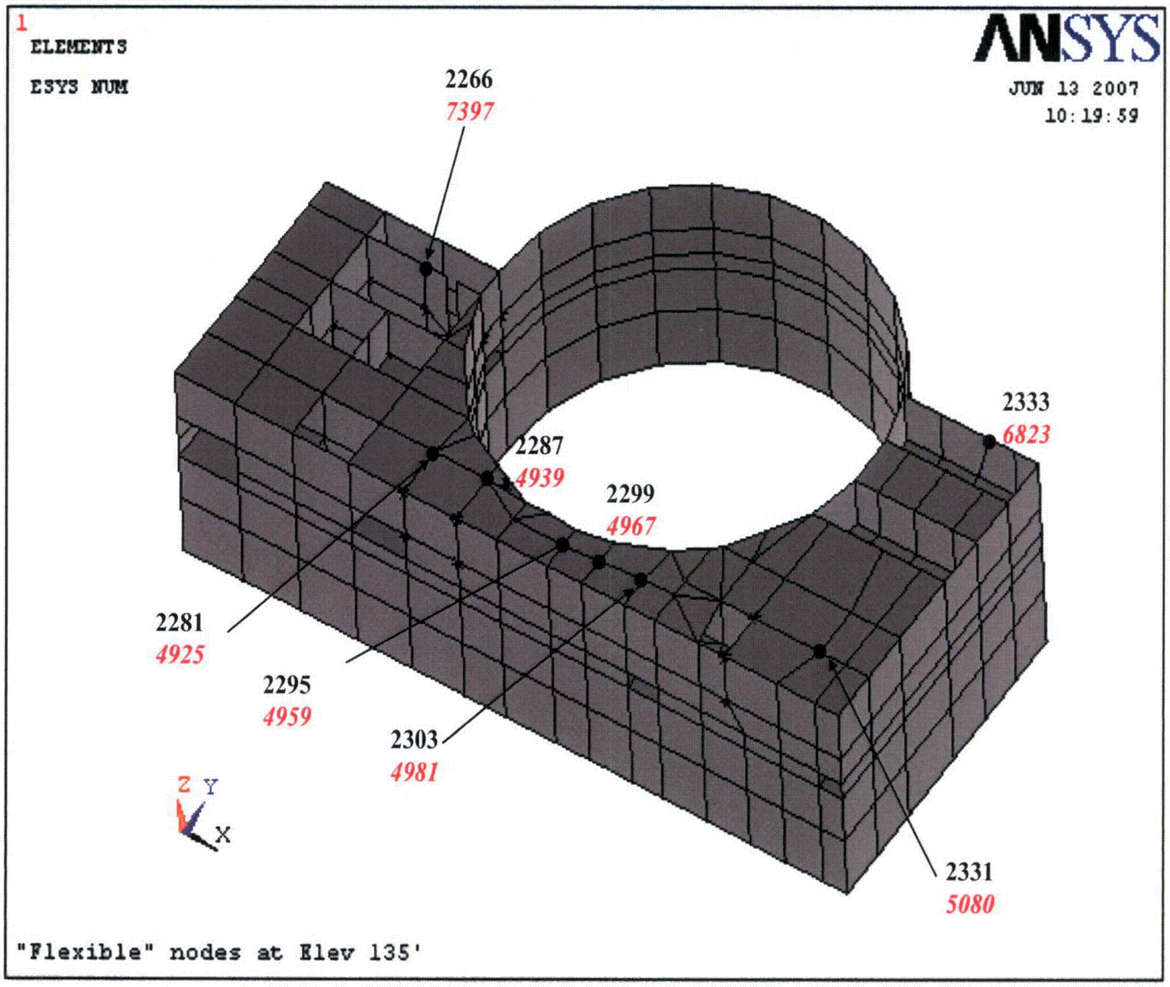


Figure 4.2.3-5 - "Flexible" nodes at Elevation 135'

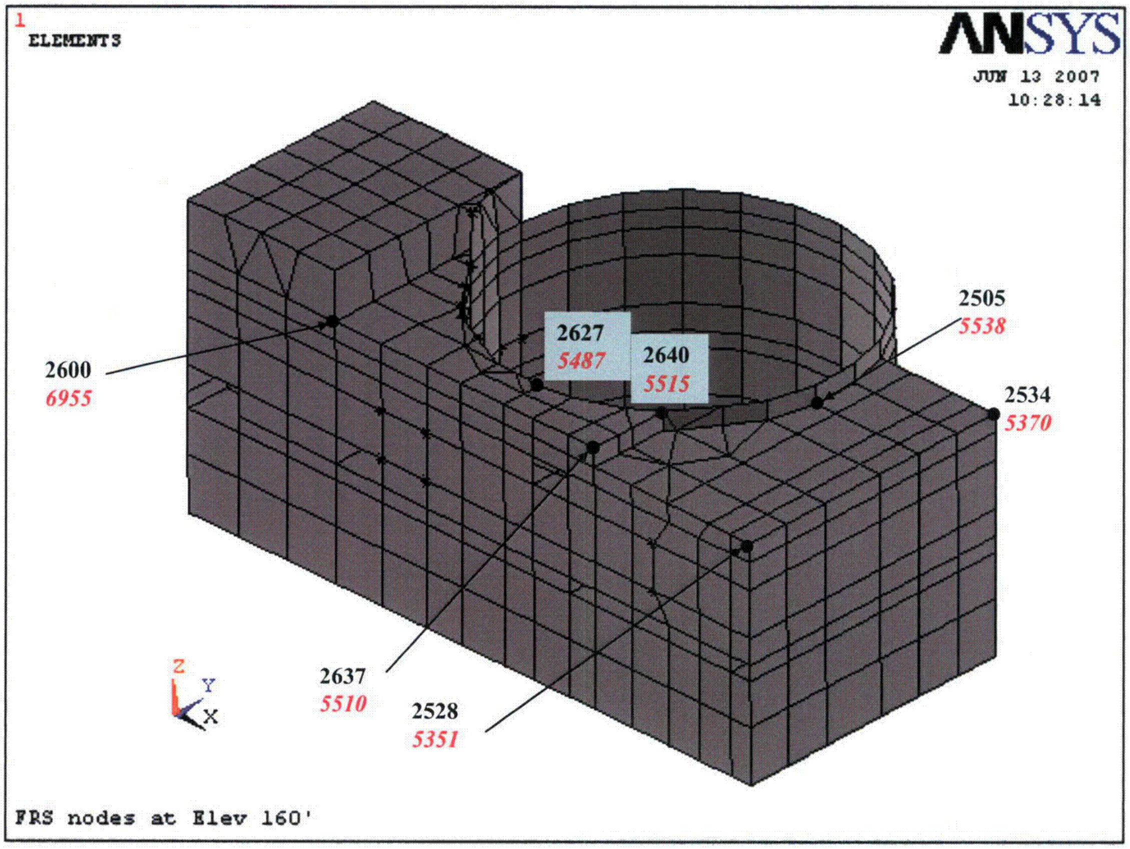


Figure 4.2.3-6 - Nodes at Elevation 160'

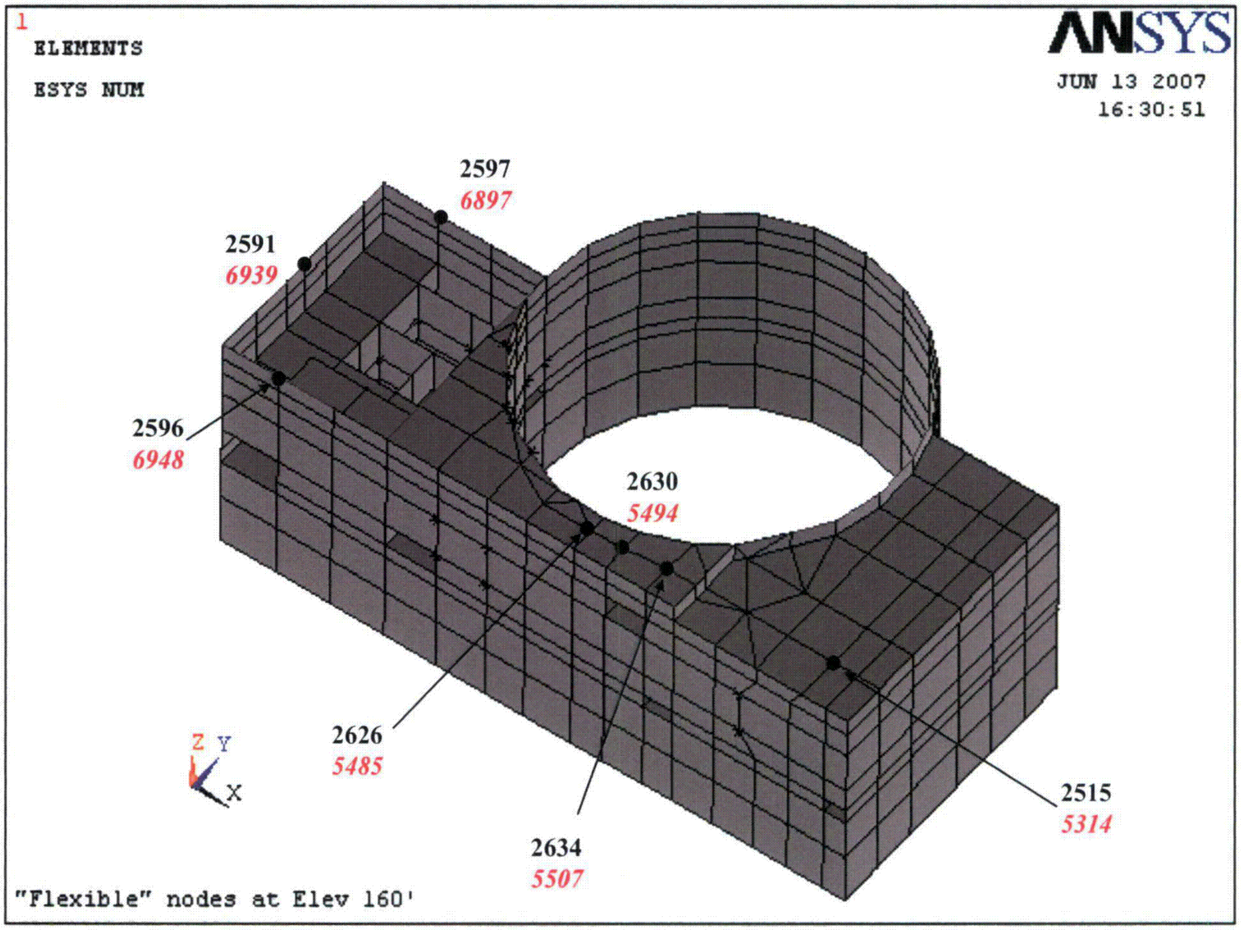


Figure 4.2.3-7 - "Flexible" nodes at Elevation 160'

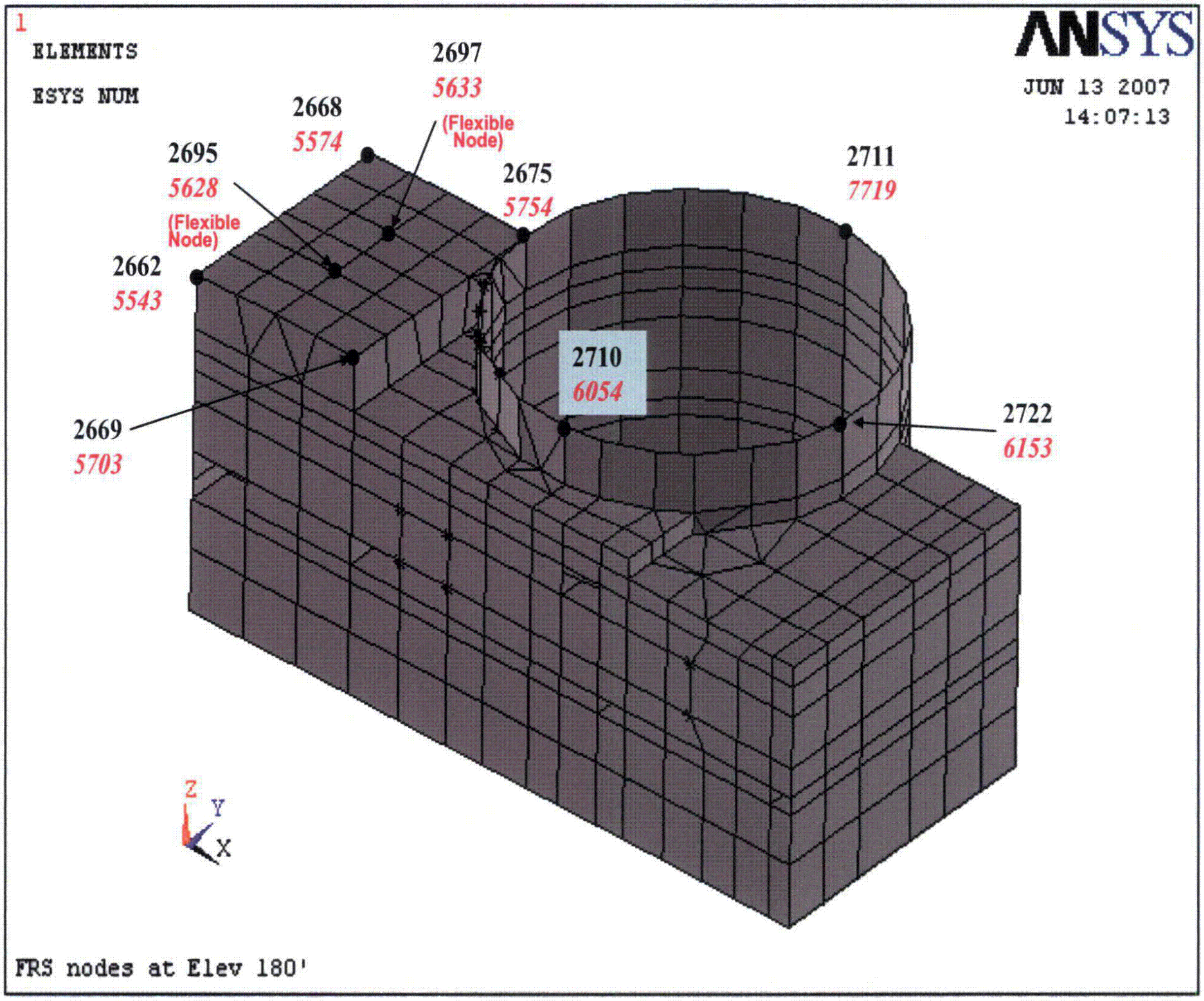


Figure 4.2.3-8 - FRS nodes at Elevation 180'

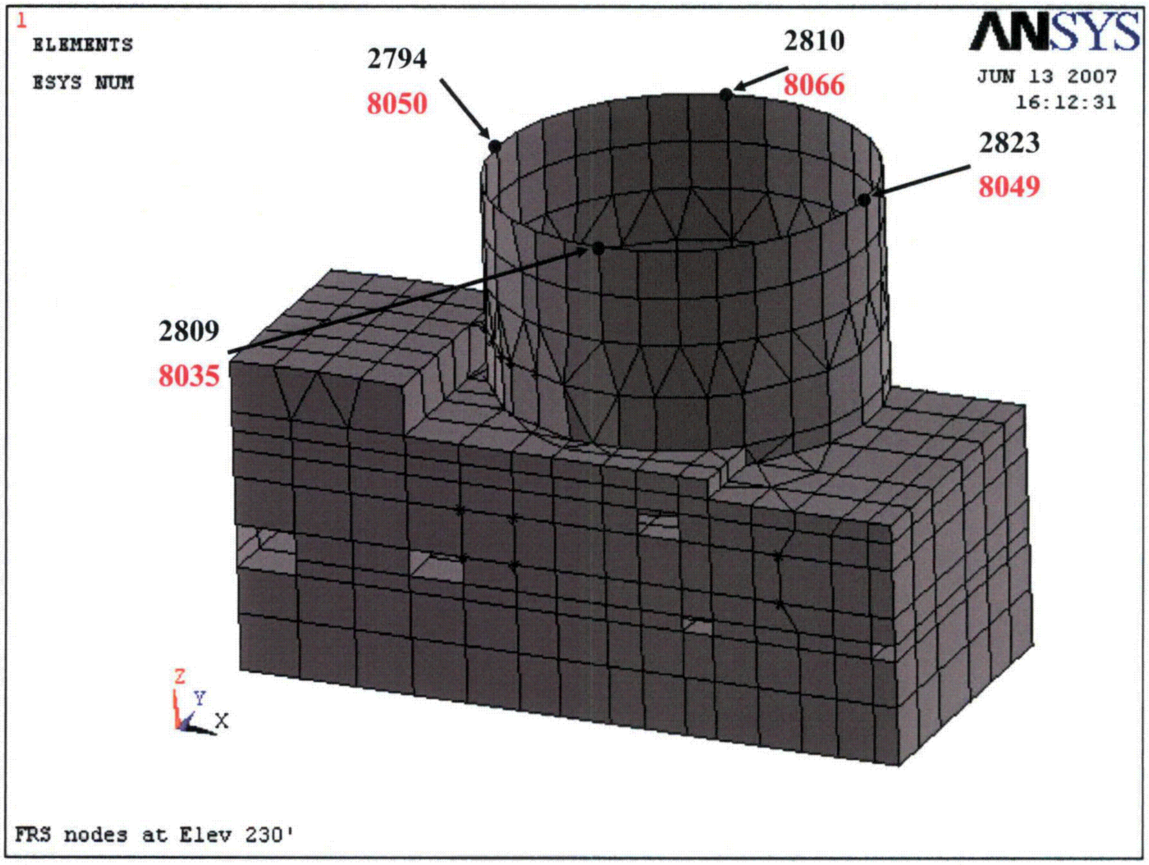
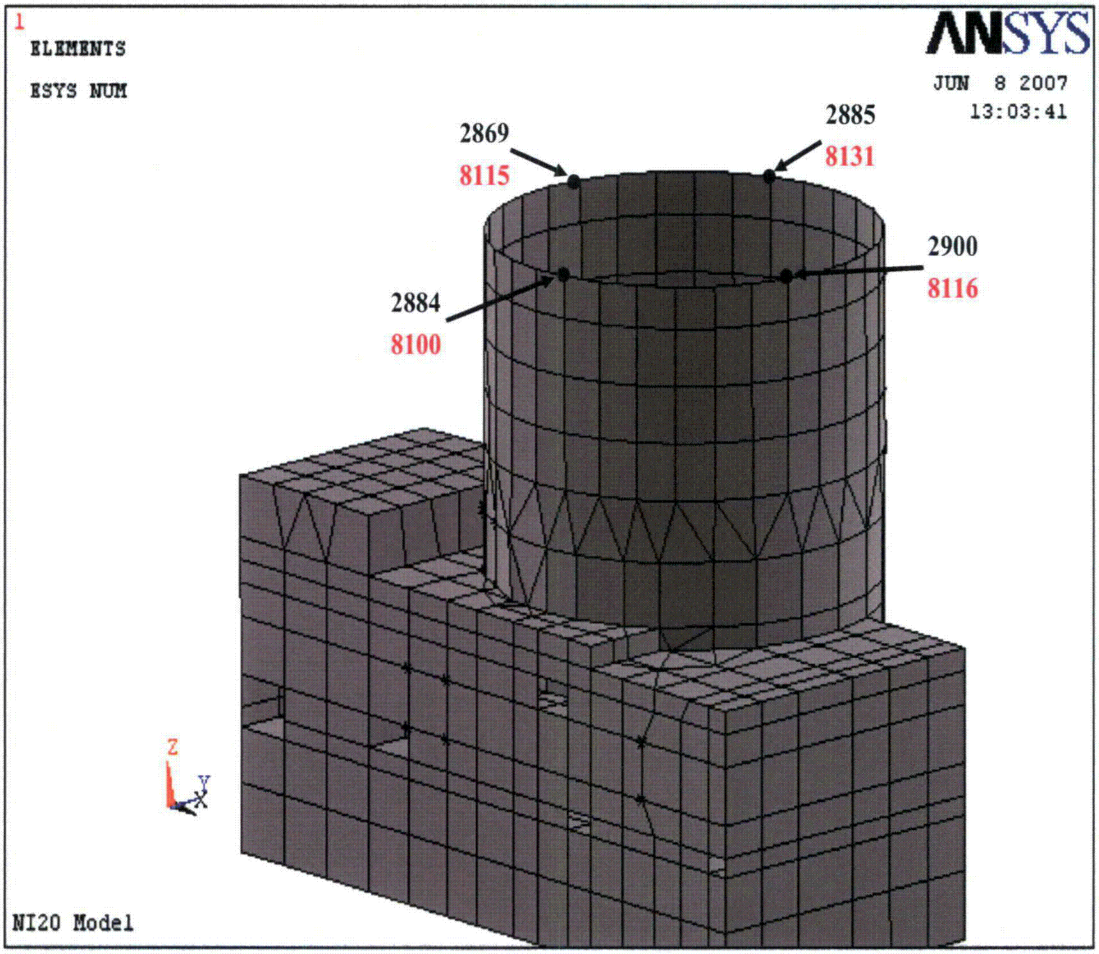
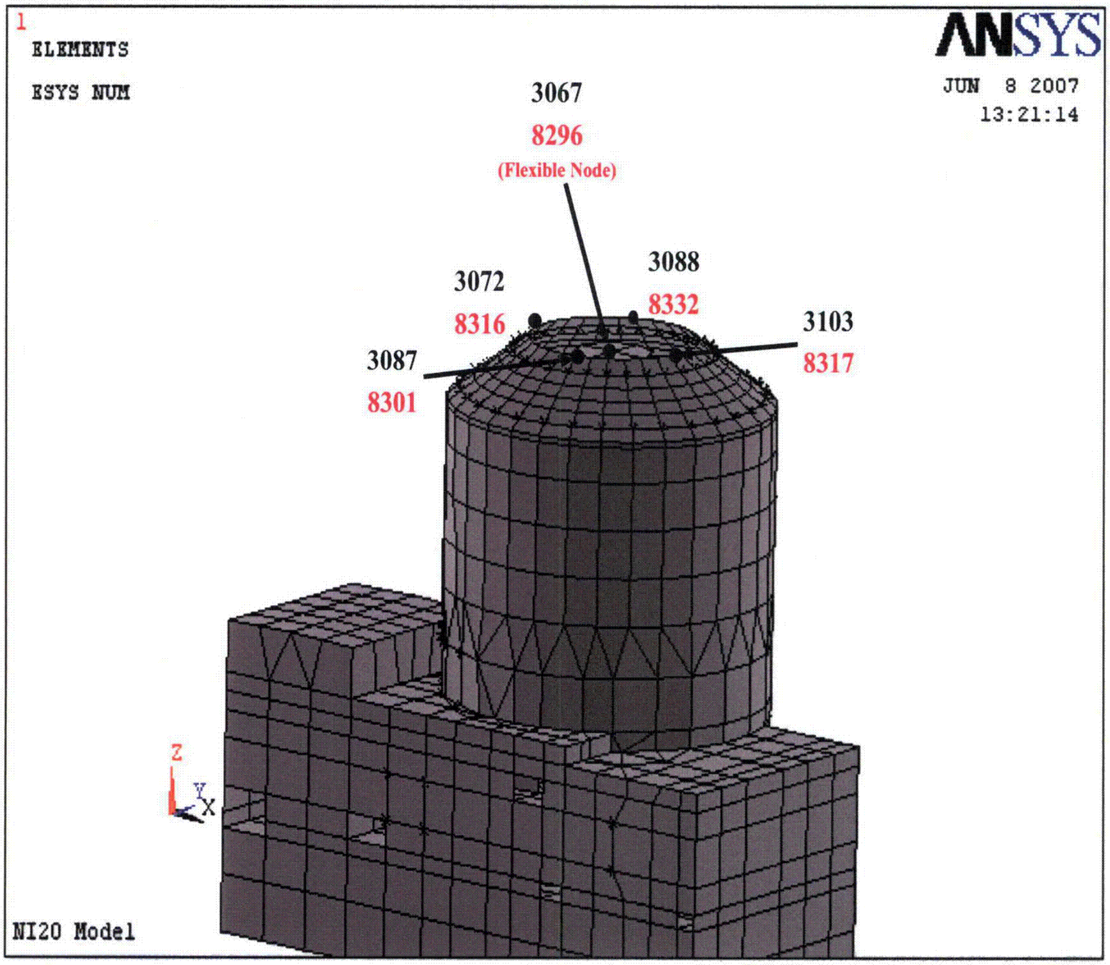


Figure 4.2.3-9 - FRS nodes at Elevation 230'



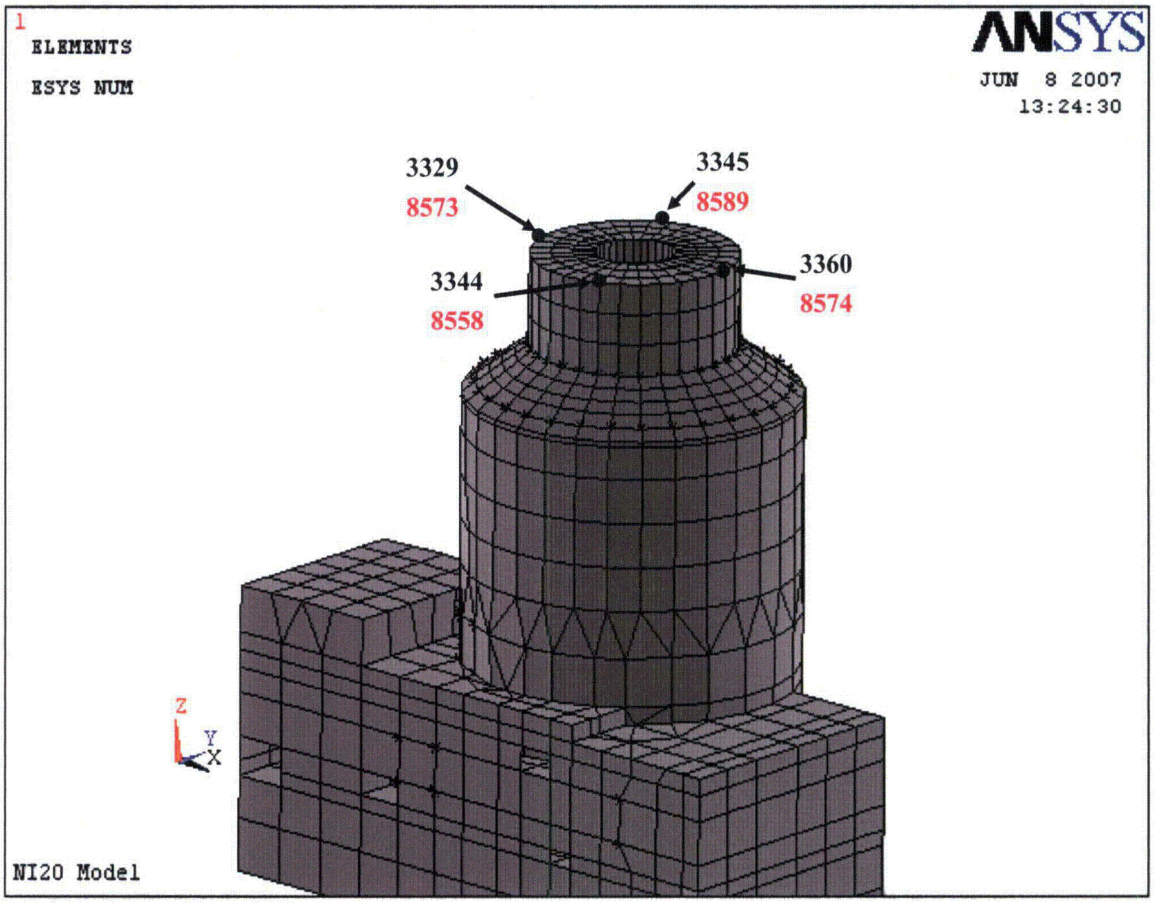
FRS Nodes at Elev. 267.8'

Figure 4.2.3-10 - FRS nodes at Elevation 267.8'



FRS Nodes at Elev. 289.2'

Figure 4.2.3-11 - FRS nodes at Elevation 289.2'



FRS Nodes at Elev. 327.4'

Figure 4.2.3-12 - FRS nodes at Elevation 327.4'

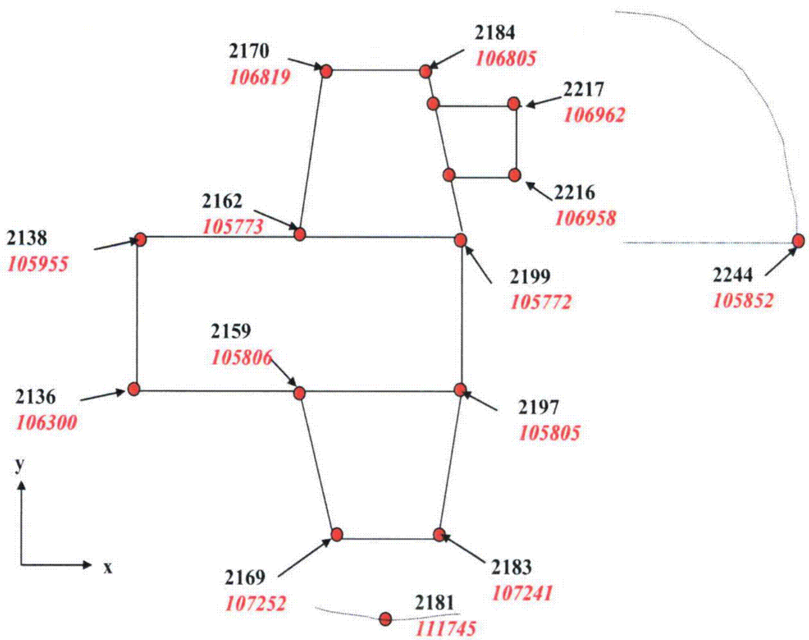


Figure 4.2.3-13 – CIS Nodes at Elevation 134.25'

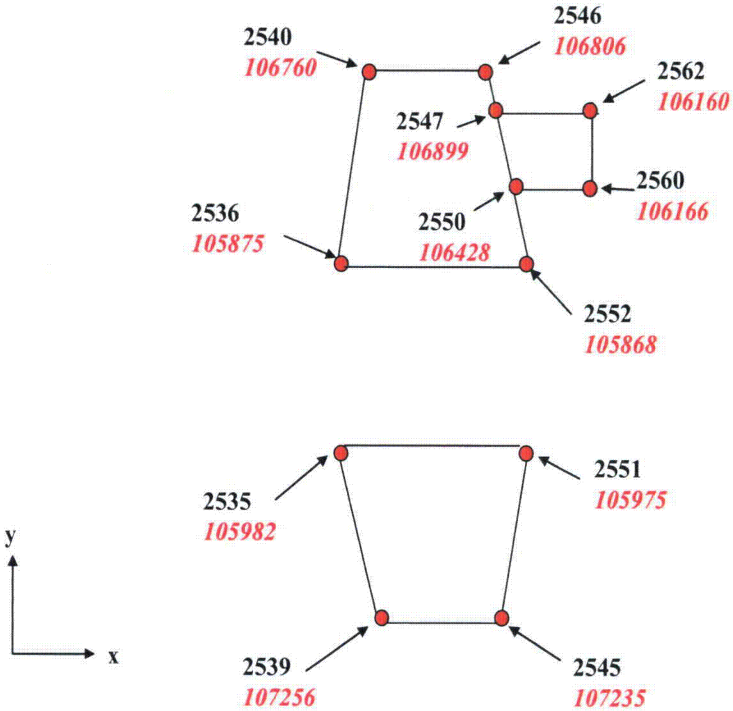


Figure 4.2.3-14 – CIS Nodes at Elevation 153'

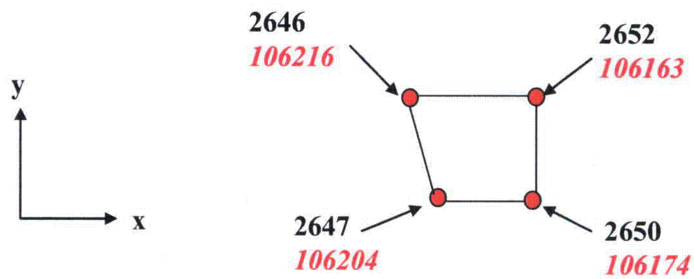
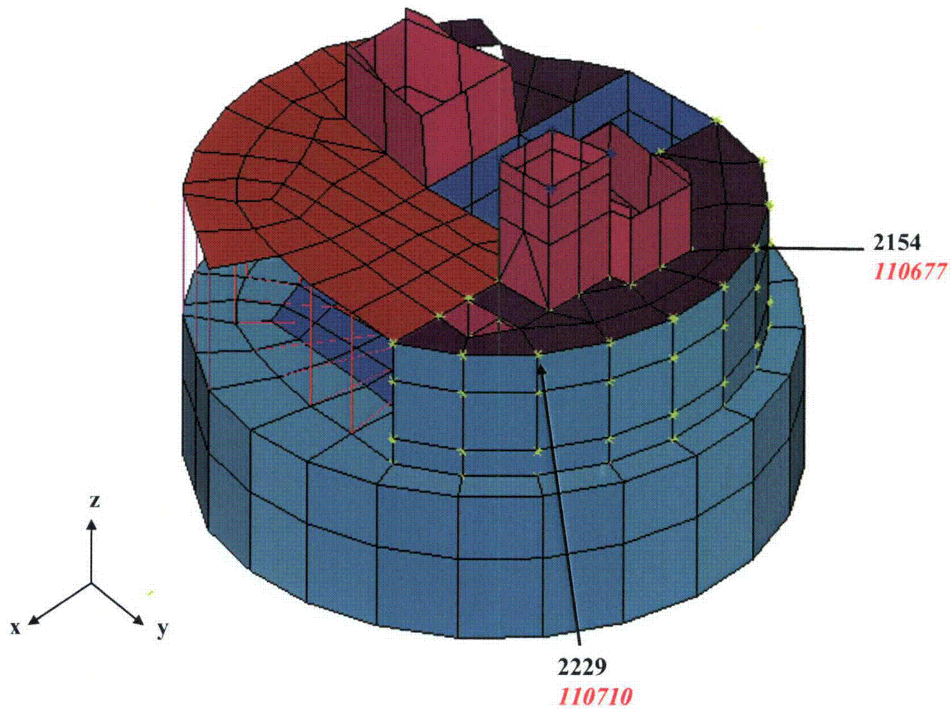


Figure 4.2.3-15 – CIS Nodes at Elevation 160'



Critical nodes at isometric view

Figure 4.2.3-16 – CIS Nodes at or near the top of the IRWST Wall

4.2.4 Types of Models and Analysis Methods

Table 4.2.4-1 summarizes 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 4.2.4-1- 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 To obtain SSE member forces for the containment internal structures.
3D finite element shell model of nuclear island [NI10](coupled auxiliary/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. To obtain maximum member forces and moments in selected elements for comparison to equivalent static results.
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

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 loads for overturning and stability evaluation.
Finite element lumped mass stick model of nuclear island	Time history analysis	SASSI	Performed 2D linear and non-linear seismic analyses to evaluate effect of lift off 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	SASSI	Performed for the three soil profiles of firm rock, upper bound soft to medium soil, and soft to medium 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 maximum member forces and moments in selected elements for comparison to equivalent static results.
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		ANYSYS	Used in the NI10 and NI20 models

Model	Analysis Method	Program	Type of Dynamic Response/Purpose
3D finite element shell model of containment vessel [1]	Mode superposition time history analysis static analysis; response spectrum 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
Static and Response Spectrum analyses			
3D finite element refined shell model of nuclear island (NI05)	Equivalent static non-linear analysis using accelerations from time history analyses; response spectrum analysis	ANSYS	To obtain SSE member forces for the nuclear island basemat

Note: 1) The 3D finite element shell model of the containment vessel is described in report APP-GW-GLR-005, "Containment Vessel Design Adjacent to Large Penetrations."

4.3 Major Equipment and Structures using Stick Models

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 Steel Containment Vessel (SCV) and the polar crane (PC) models, the reactor coolant loop (RCL) model, the core make-up tank (CMT) model and the pressurizer (PZR) model. The core make-up tank is only modeled in the nuclear island fine (NI10) model. These models are shown in Figures 4.3-1 to 4.3-6. NI10 nodes are shown in red, and NI20 nodes are shown in black.

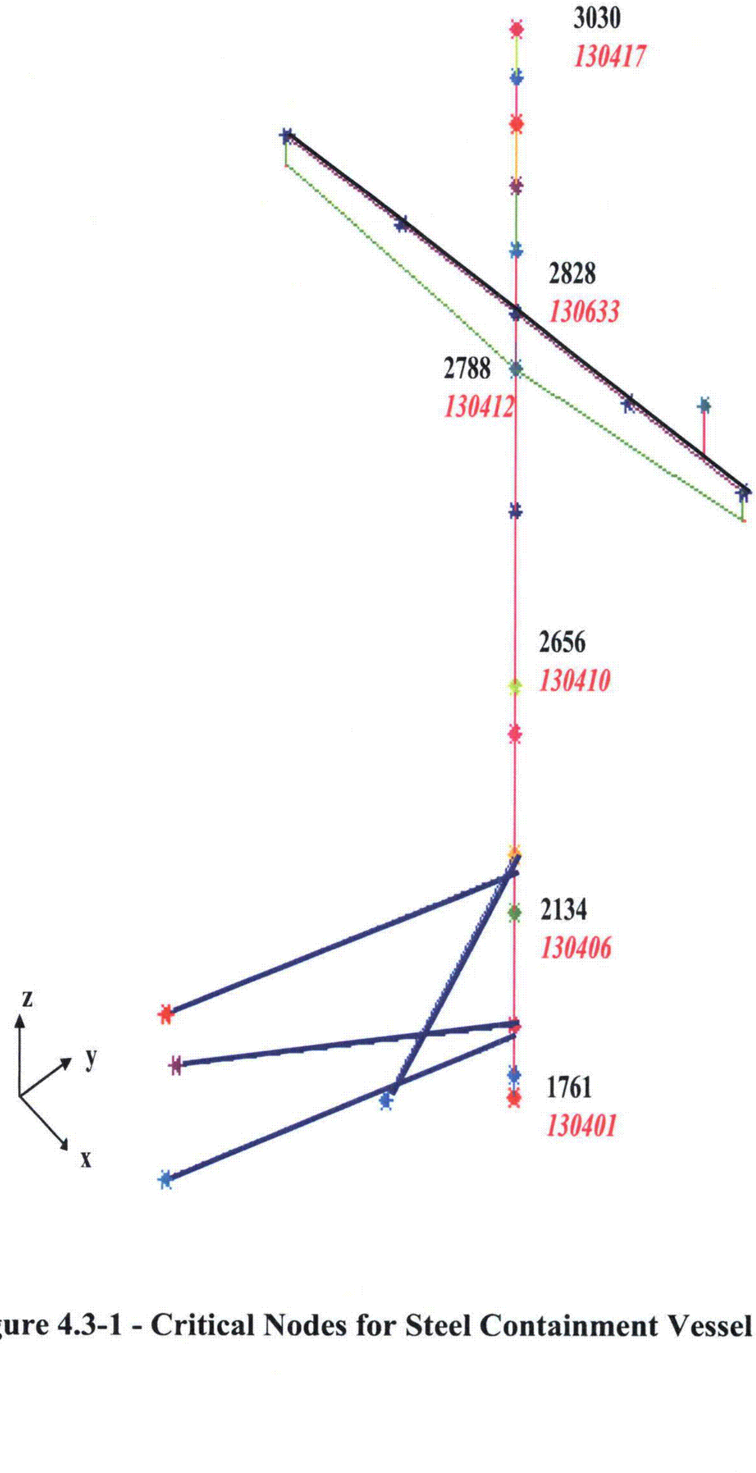


Figure 4.3-1 - Critical Nodes for Steel Containment Vessel and Polar Crane

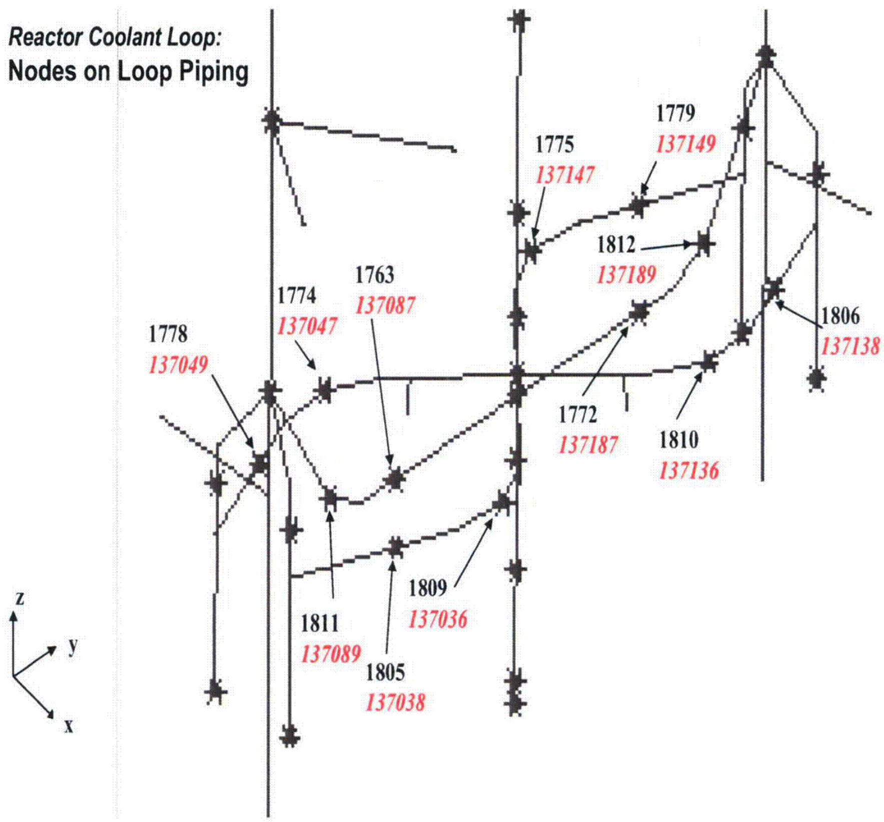


Figure 4.3-2 - Reactor Coolant Loop Nodes on Loop Piping

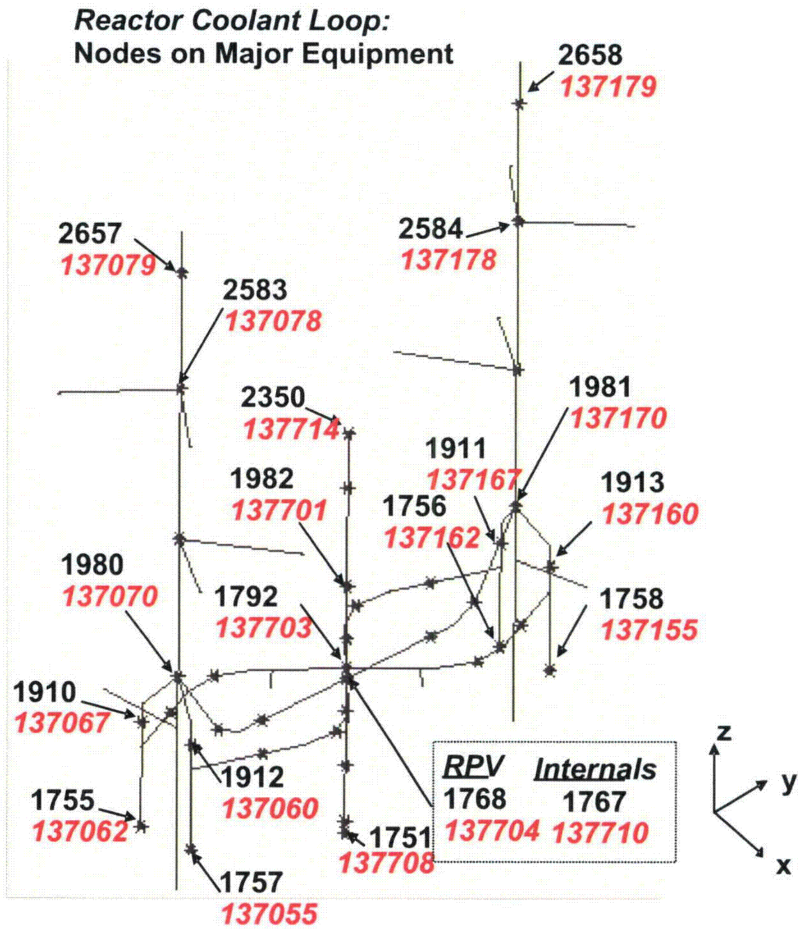


Figure 4.3-3 - Reactor Coolant Loop: Nodes on Major Equipment

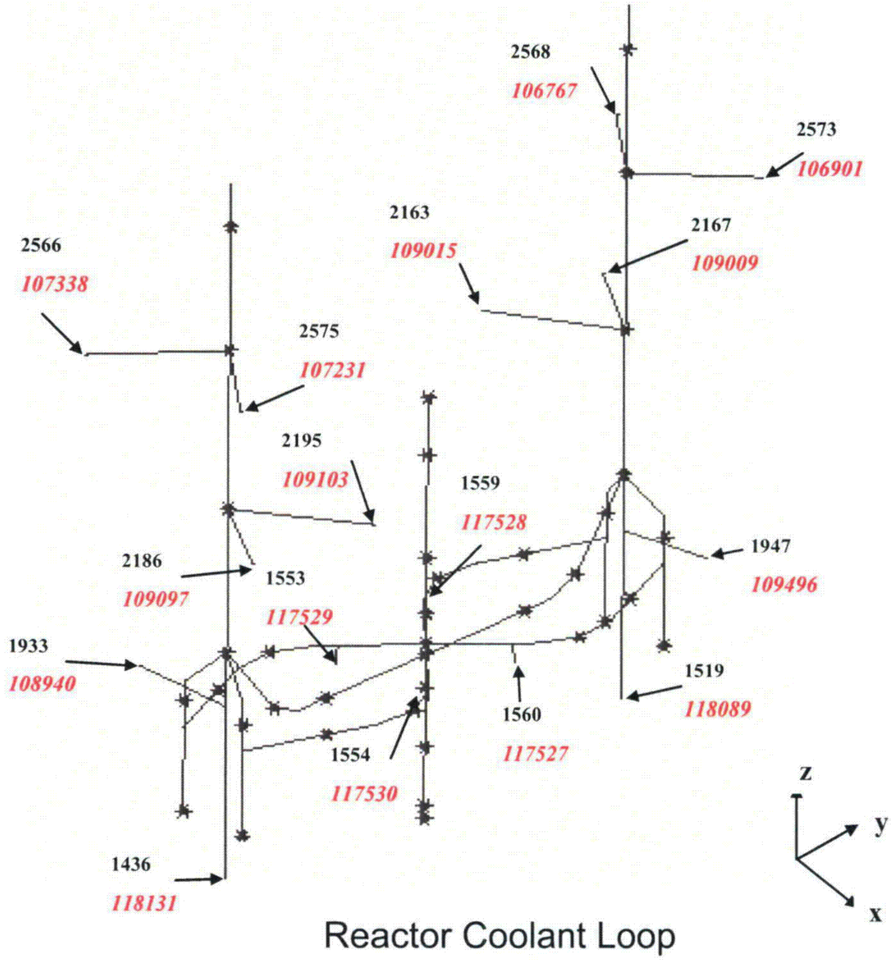


Figure 4.3-4 – Reactor Coolant Loop: Nodes at Support Locations

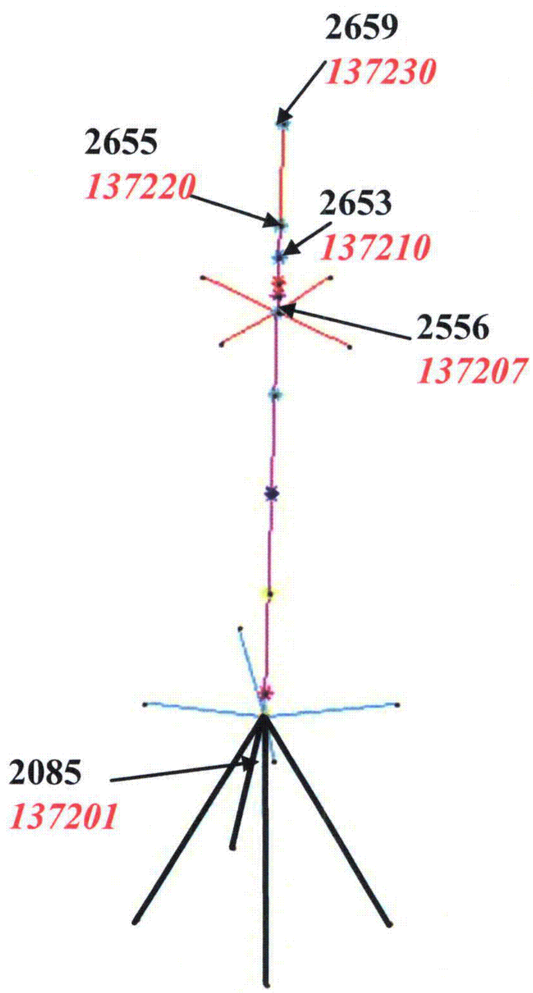


Figure 4.3-5 – Pressurizer Nodes

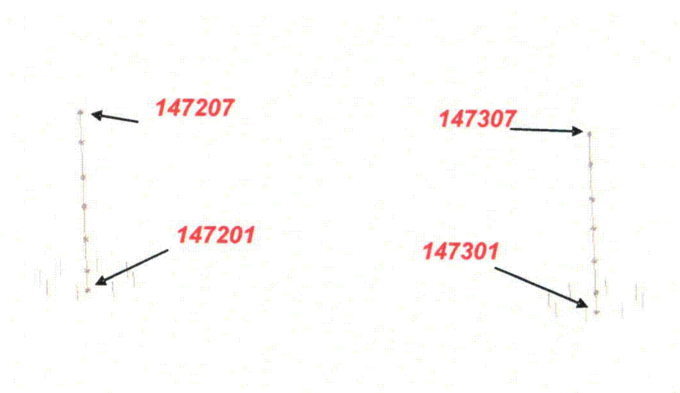


Figure 4.3-6 – Core Make-Up Tank

4.4 Soil Cases and SSI Analyses

4.4.1 2D SASSI Analyses and Parameter Studies

This section describes the parametric 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 20' 6" taller than AP600. Results and conclusions from the AP600 soil studies are summarized since the behavior of the AP1000 is expected to be similar and results from AP600 provide guidance in the selection of the generic cases for the AP1000. Five soil and hard rock cases are selected as follows: hard rock; firm rock; soft rock; upper bound soft to medium soil, soft to medium soil, and soft soil. These are the same as the cases analyzed for the AP600 except that the soft soil case is added and the soft rock case (v_s =2500 feet per second) for the AP600 has been replaced by firm rock (v_s = 3500 feet per second) since the 2D SASSI parametric analyses show that the firm rock case is more significant than on AP600 due to the additional height of the shield building.

4.4.1.1 AP600 Soil Studies

The AP600 studies are summarized below. They are described in Appendices 2A and 2B of the AP600 DCD (Reference 7).

A survey of 22 commercial nuclear power plants in the United States was conducted to identify the subsurface soil profiles and the range of soil properties at these plants as part of the AP600 design certification. The survey included nuclear power plants sites both east and west of the Rocky Mountains. Based on this survey five generic soil profiles (soft soil, soft to medium soil, soft rock and step profile in Figure 4.4.1-1 plus hard rock) were established ranging from soft soil to hard rock. Using these soil profiles, 2D soil-structure interaction analyses were performed to determine site geotechnical variables which induced the highest nuclear seismic response during an earthquake.

The series of parametric studies performed using 2D SASSI models for AP600 certification is shown in Table 4.4.1-1A. Note that for AP1000, 2D SASSI parametric studies were performed and they are shown in Table 4.4.1-1B. These SASSI models consisted of 2D lumped mass stick models coupled with a 2D model of the foundation. The conclusions made based on these parametric studies for the AP600 configuration are given below.

Soil properties were specified to a depth of 240 feet below grade. Analyses were performed for various depths to base rock. In each case, the soil properties above the base rock were those of the soil and the base rock was assumed to have shear wave velocity of 8000 feet per second. The analyses performed for a depth to base rock of 240 feet are described in Table 4.4.1-1A as a deep soil site and results would also be representative of deeper soil sites. Soil sites were found to control the AP600 nuclear island response at frequencies below about 4 hertz for horizontal response and 8 hertz for vertical response while the hard rock site controls the response at higher frequencies. The studies of depth to base rock showed that the response was not very sensitive to the depth. The depth-to-base rock of 120 ft generally gave the higher response for each of the soil profiles and was therefore specified for the 3D SASSI design cases. The shallower depth models gave a higher building response at high frequencies, but these responses were lower than those for hard rock. The deeper models had greater radiation damping reducing the overall response. The dominant AP1000 building mode shapes are similar to the AP600 and the frequencies are lower. Since the response of the AP600 was relatively insensitive to depth and the dominant modes of the AP600 and AP1000 are similar, using a depth-to-base rock of 120 ft is appropriate for the AP1000.

The soil properties associated with the lower and upper bound sandy soils (soft-to-medium soil profile) bound the range of properties associated with clays with plasticity indices from 10 to 70 as shown in Figure 2B-13 of the AP600 DCD. SSI analyses were performed for clay profiles and concluded that the responses for clay profiles were bounded by those for the design soil profiles.

The effect of depth to water table was studied for the soft-to-medium soil case with the depth to base rock of 120 feet. Cases were analyzed for water table at grade, for water table at the foundation level (40 foot depth) and for a dry site. For cases where the water table was below grade, the Poisson's ratio for soil above the water table was also varied from 0.25 to 0.35. These studies showed that the change of water table elevations had insignificant effect on the horizontal results. Comparison of the vertical responses showed that the water table at the grade level controlled the responses in the frequency range of 2 to 8 hertz. The increase in response was mainly due to an increase in foundation effective motion, which results from an increase in the P-wave velocity in conjunction with the SSI frequency for this case. Thus, the water table was specified at grade for the 3D SASSI design cases. Since the mass of the AP1000 is similar to that of the AP600 the vertical SSI frequency and response are similar. Thus, the specification of the water table at grade is appropriate for the AP1000 soil sites.

The change in degradation curves between the 1970 Idriss and Seed and 1990 Seed degradation curves was not significant. The AP1000 uses the EPRI 93 degradation curves. These degradation curves have been used in AP1000 2D SASSI parametric analyses and do not significantly affect the SSI response, and thus should not result in a change in the selection of the generic soil profiles.

Analyses were also performed for a layered soil profile with step-wise change in shear wave velocity. The step-wise layered soil profile had a layered profile with shear wave velocity of 1000 feet per second to a 40-foot depth, 1800 feet per second between 40-foot and 80-foot depth, and 4300 feet per second for depth greater than 80 feet. The response for this profile is enveloped by the soft rock, soft-to-medium, and rigid base response. In addition the cases previously described in the depth to base rock studies showed that the sharp contrast in shear wave velocity (layering) was enveloped by the design cases with depth to base rock at 120 feet. Based on this study and the studies of depth to base rock, the step-wise layered soil profile was not included as a design case for AP600 nor need it be included for AP1000.

Analyses including adjacent buildings showed that the effect of the adjacent buildings on the nuclear island response was small. Based on this, the 3D SASSI analysis of the nuclear island can be performed without adjacent buildings. The nuclear island does affect the response of the adjacent buildings and the results of the 2D SASSI analyses are used for design of the adjacent buildings for both the AP600 and AP1000.

SASSI analyses for hard rock sites were compared to fixed base results. A fixed base analysis is adequate for sites in excess of 8000 fps.

4.4.1.2 AP1000 site studies and selection of soil cases

2D SASSI analyses for the AP1000 configuration have been performed using soil profiles previously evaluated in the AP600 analyses. The analyses used the 2D stick models previously used and reviewed in the AP1000 hard rock lift off analyses.

Analyses were performed with and without adjacent structures for the four soil cases previously analyzed for the AP600. The soil damping and degradation curves used the EPRI recommended curves which represent more recent soils data and differ slightly for those used for the AP600. The Poisson's ratio is 0.25 for rock sites and 0.35 for soft sites. The four design soil profiles included a hard rock site (HR), a soft rock site (SR), and a soft-to-medium soil site (SMS) and a soft soil site (SS) as shown in Figure 4.4.1-1. For all the soil profiles defined, the base rock has been taken to be at 120 feet below grade level. This base rock elevation is based on AP600 parametric studies which showed it to give the most conservative results. Thus, for the AP1000 2D and 3D SSI analyses, although some of the parabolic soil profiles are defined using a depth of 240 feet, the actual soil profile defined in SASSI (base rock) goes only to elevation 120 feet. The shear wave velocity profiles and related governing parameters of the four sites considered are the following:

- For the hard rock site, an upper bound case for rock sites using a shear wave velocity of 8000 feet per second.

- 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 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 strain-dependent shear modulus curves for the foundation materials, together with the corresponding damping curves are taken from References 10 and 11 and are shown in Figures 4.4.1-6 and 4.4.1-7 for rock material and soil material respectively. The different curves for soil in Figure 4.4.1-7 apply to the range of depth within a soil column below grade. The strain-dependent soil material damping is limited to 15 percent of critical damping. The strain-dependent properties used in the SSI analyses for the safe shutdown earthquake are shown in Table 4.4.1-3 for the firm rock, upper bound soft-to-medium soil, soft-to-medium soil, and soft soil properties.

Analyses were also performed without adjacent structures for firm rock and the upper bound soft to medium sites previously analyzed for the AP600. These profiles are shown in Figure 4.4.1-1 (FR and SMS-UB)

- 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 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.

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.

The maximum acceleration values obtained from the AP1000 analyses without adjacent structures are given in Table 4.4.1-2. The soil cases giving the maximum response are highlighted. The elevation and location of the nodes referenced in Table 4.4.1-2 is given below.

Node	Elevation (ft)	Location
21	81.5	ASB
41	99.0	ASB
120	179.6	ASB
150	242.5	ASB
310	333.2	ASB
535	134.3	CIS
538	169.0	CIS
407	138.6	SCV
411	200.0	SCV
417	281.9	SCV

Maximum member forces from the 2D SASSI analyses are shown in Figures 4.4.1-2 to 4.4.1-5. These figures also show member forces for an equivalent static acceleration profile (EQ) based on the maximum acceleration values obtained from 2D ANSYS time history modal analyses of the same stick model on hard rock as described in Section 7.1 of the report. These 2D ANSYS analyses used the same model as the 2D SASSI analyses. Floor response spectra from the 2D SASSI analyses associated with nodes 41, 120, 310, 411 and 535 for the six AP1000 soil cases are shown in Appendix D, Figures D-1 to D-10.

Based on review of the above results, three soil conditions were selected for 3D SASSI analyses in addition to the hard rock condition evaluated in the existing AP1000 Design Certification. Thus, four soil and rock cases are considered as follows: hard rock; firm rock; upper bound soft to medium soil and soft to medium soil. These are the same as the cases analyzed for the AP600 with the exception that the soft rock case (v_s = 2500 feet per second) for the AP600 has been replaced by firm rock (v_s = 3500 feet per second) since the 2D SASSI parametric analyses show that the firm rock case is more significant than on the AP600 due to the additional height of the shield building. The shear wave velocity profiles and related governing parameters are the following:

- For the hard rock site, an upper bound case using fixed base seismic analysis. This is applicable for rock sites with shear wave velocity greater than 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-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 at grade level.

- 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.

Table 4.4.1-1A - AP600 2D SSI Cases

Shear Wave Velocity Profile	Depth to Base Rock (ft)	Depth to Water Table (ft)	SSI Case (X-shaking)	SSI Case (Y-shaking)	SSI Case (Z-shaking)	Notes
Hard Rock	---	---	✓	✓	✓	Rigid Base
	---	---	---	✓	---	$V_s = 20000$
	---	---	✓	✓	---	$V_s = 8000$
Firm Rock	120	deep	---	✓	---	$V_s = 3500$
Soft Rock	deep	deep	✓	✓	✓	
	120	deep	✓	✓	✓	
Soft-to-Medium Soil	deep	deep	✓	✓	✓	
	120	0	✓	---	✓	
		40	✓	---	✓	
		deep	✓	✓	✓	
	40	deep	✓	---	✓	
	120	0	*	*	---	
	120	deep	*	---	---	$\nu = 0.35$
	120	deep	*	---	---	$\nu = 0.25$
	120	0	---	*	---	Parabolic Soil Profile
	80	0	---	*	---	
	60	0	---	*	---	
	50	0	---	*	---	
	40	0	---	*	---	
	120	0	---	*	---	Parabolic, Lower Bound
Upper Bound Soft-to-Medium Soil	120	0	---	*	---	Parabolic, Lower Bound
Soft Soil	deep	deep	✓	✓	✓	
	120	deep	✓	✓	✓	
		40	✓	---	✓	
		0	✓	---	✓	
	120	0	*	*	---	
	50	0	---	*	---	
	120	0	*	---	---	Lower Bound
Step-Wise Layered Soil	deep	deep	✓	✓	✓	layered site study

Legend:

✓ Seed and Idris 1970 soil/rock degradation curves

* Idris 1990 soil degradation curves

Table 4.4.1-1B – AP1000 2D SSI Cases

Shear Wave Velocity Profile	Depth to Base Rock (ft)	Depth to Water Table (ft)	SSI Case			Notes
			(X-shaking)	(Y-shaking)	(Z-shaking)	
Hard Rock	---	---	✓	✓	---	
Firm Rock	120	deep	✓	✓	---	
Soft Rock	120	deep	✓	✓	---	
Upper Bound Soft-to-Medium Soil	120	0	☒	☒	---	
Soft-to-Medium Soil	120	0	☒	☒	---	
Soft Soil	120	0	☒	☒	---	

Legend:
✓ Seed and Idris 1970 rock degradation curves
☒ EPRI soil degradation curves

Table 4.4.1-2 – AP1000 ZPA for 2D SASSI Cases

	North-South		Hard Rock	Firm Rock	Soft Rock	UBSM	SM	Soft soil
	node	El. feet	ZPA [g]	ZPA [g]	ZPA [g]	ZPA [g]	ZPA [g]	ZPA [g]
ASB	21	81.5	0.326	0.326	0.345	0.358	0.306	0.249
	41	99.0	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	0.290
	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	0.820	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	0.450	0.347	0.368	0.355	0.229
	538	169.0	1.517	0.874	0.450	0.441	0.397	0.317

	East-West		Hard Rock	Firm Rock	Soft Rock	UBSM	SM	Soft soil
	node	El. feet	ZPA [g]	ZPA [g]	ZPA [g]	ZPA [g]	ZPA [g]	ZPA [g]
ASB	21	81.5	0.309	0.318	0.359	0.376	0.311	0.235
	41	99.0	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	0.840	0.823	0.854	0.912	0.962	0.557
	310	333.1	1.449	1.536	1.624	1.740	1.506	0.891
SCV	407	138.6	0.528	0.529	0.535	0.513	0.380	0.247
	411	200.0	0.817	0.950	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	0.520	0.404	0.391	0.404	0.365	0.259
	538	169.0	1.679	1.052	0.755	0.553	0.526	0.441

Table 4.4.1-3 – Strain Compatible Soil Properties

(Sheet 1 of 4) Strain Compatible Soil Properties								
Depth to Bottom of Layer (ft)	**Thickness of Layer (ft)**	**Layer Number**	**Total Unit Weight (kcf)**	**Initial G (ksf)**	**Initial Vs (fps)**	**Final G (ksf)**	**Final Vs (fps)**	**Damping**
Firm Rock								
0.0								
5.0	5.0	1	0.15	57422	3500	57030	3499	0.015
10.0	5.0	2	0.15	57422	3500	56579	3485	0.016
15.0	5.0	3	0.15	56963	3486	55961	3466	0.014
20.0	5.0	4	0.15	56963	3486	55731	3459	0.015
25.0	5.0	5	0.15	56442	3470	54894	3433	0.016
30.0	5.0	6	0.15	56442	3470	55260	3444	0.014
33.5	3.5	7	0.15	55922	3454	54564	3422	0.015
39.5	6.0	8	0.15	55922	3454	54395	3417	0.015
45.0	5.5	9	0.15	55406	3438	53708	3395	0.016
60.0	15.0	10	0.15	55406	3438	53462	3388	0.017
70.0	10.0	11	0.15	54763	3418	52285	3350	0.018
80.0	10.0	12	0.15	54763	3418	51561	3327	0.020
90.0	10.0	13	0.15	53647	3383	49794	3269	0.021
100.0	10.0	14	0.15	53647	3383	49236	3251	0.022
Bedrock			0.15	300000	8000	298137	8000	0.000

(Sheet 2 of 4)

Strain Compatible Soil Properties

Depth to Bottom of Layer (ft)	Thickness of Layer (ft)	Layer Number	Total Unit Weight (kcf)	Initial G (ksf)	Initial Vs (fps)	Final G (ksf)	Final Vs (fps)	Damping
Soft Rock								
0								
10	10.0	1	0.15	27214	2417	27050	2402	0.007
20.0	10.0	2	0.15	27962	2450	27533	2424	0.009
30.0	10.0	3	0.15	28720	2483	28162	2451	0.009
40.0	10.0	4	0.15	29512	2517	28865	2481	0.010
60.0	20.0	5	0.15	30696	2567	29940	2527	0.010
80.0	20.0	6	0.15	32295	2633	31422	2589	0.011
120.0	40.0	7	0.15	34795	2733	33772	2684	0.011
160.0	40.0	8	0.15	38290	2867	37094	2813	0.011
200.0	40.0	9	0.15	41925	3000	40584	2942	0.011
240.0	40.0	10	0.15	45725	3133	44259	3073	0.011
Base	-	11	0.15	47702	3200	-	-	0.011

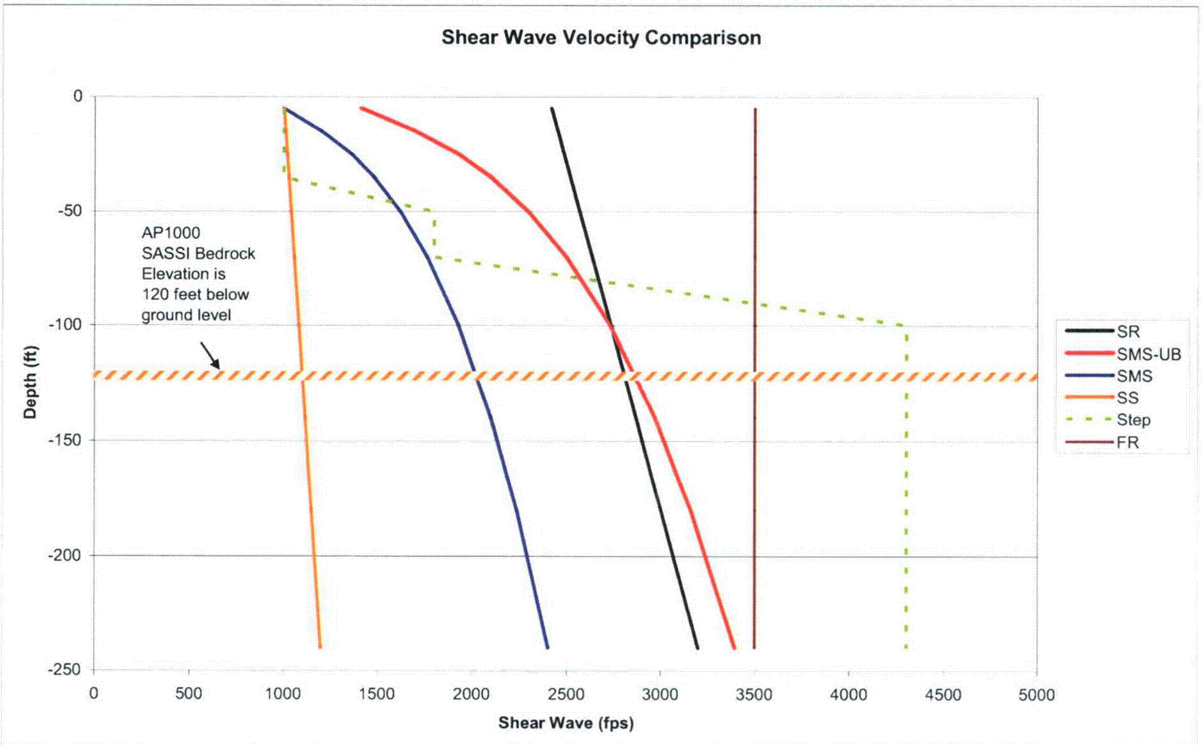
(Sheet 3 of 4) Strain Compatible Soil Properties								
Depth to Bottom of Layer (ft)	Thickness of Layer (ft)	Layer Number	Total Unit Weight (kcf)	Initial G (ksf)	Initial Vs (fps)	Final G (ksf)	Final Vs (fps)	Damping
Upper Bound Soft-to-Medium Soil								
0								
5	5.0	1	0.11	6440	1373	6272	1355	0.018
10.0	5.0	2	0.11	6440	1373	5894	1313	0.027
15.0	5.0	3	0.11	8626	1589	7741	1505	0.030
20.0	5.0	4	0.11	8626	1589	7310	1463	0.037
25.0	5.0	5	0.11	11415	1828	10323	1738	0.026
30.0	5.0	6	0.11	11415	1828	10071	1717	0.029
33.5	3.5	7	0.11	13231	1968	11683	1849	0.029
39.5	6.0	8	0.11	13231	1968	11478	1833	0.031
45.0	5.5	9	0.11	15659	2141	14303	2046	0.023
52.5	7.5	10	0.11	16012	2165	14444	2056	0.025
60.0	7.5	11	0.11	16012	2165	14228	2041	0.026
66.0	6.0	12	0.11	18850	2349	16841	2220	0.026
73.0	7.0	13	0.11	18850	2349	16665	2209	0.027
80.0	7.0	14	0.11	18850	2349	16495	2197	0.028
90.0	10.0	15	0.11	22179	2548	19544	2392	0.027
100.0	10.0	16	0.11	22179	2548	19326	2379	0.028
120.0	10.0	17	0.11	22179	2548	19024	2360	0.030
130.0	10.0	18	0.11	22179	2548	18698	2340	0.032
Base			0.15	298137	8000	298137	8000	0.000

(Sheet 4 of 4)

Strain Compatible Soil Properties

Depth to Bottom of Layer (ft)	Thickness of Layer (ft)	Layer Number	Total Unit Weight (kcf)	Initial G (ksf)	Initial Vs (fps)	Final G (ksf)	Final Vs (fps)	Damping
Soft-to-Medium Soil								
0								
10	10.0	1	0.11	3617	1029	3074	946	0.032
20.0	10.0	2	0.11	4044	1088	2989	933	0.056
30.0	10.0	3	0.11	4486	1146	2859	912	0.077
40.0	10.0	4	0.11	4952	1204	2843	909	0.089
60.0	20.0	5	0.11	5702	1292	2977	931	0.100
80.0	20.0	6	0.11	6772	1408	3453	1002	0.102
120.0	40.0	7	0.11	8560	1583	4764	1177	0.093
160.0	40.0	8	0.12	12304	1817	7343	1399	0.085
200.0	40.0	9	0.12	15661	2050	9277	1573	0.086
240.0	40.0	10	0.12	19424	2283	11490	1750	0.086
Base	-	11	0.12	21466	2400	-	-	0.093

Soft Soil								
0								
10	10.0	1	0.11	3444	1004	2925	922	0.033
20	10.0	2	0.11	3506	1013	2472	848	0.063
30	10.0	3	0.11	3561	1021	2044	771	0.089
40	10.0	4	0.11	3617	1029	1750	713	0.108
60	20.0	5	0.11	3709	1042	1484	657	0.128
80	20.0	6	0.11	3824	1058	1530	667	0.130
120	40.0	7	0.11	4007	1083	1603	683	0.136
160	40.0	8	0.11	4262	1117	1705	704	0.150
200	40.0	9	0.11	4518	1150	1807	725	0.150
240	40.0	10	0.11	4781	1183	1912	746	0.150
Base		11	0.11	6708	1200			0.150



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 4.4.1-1 Generic Soil Profiles

HR:	Hard Rock	*Table 37, Ref 1*
SR:	Soft Rock	*Table 37, Ref 1*
SM:	Soft-to-medium Soil	*Table 38, Ref 1*
SS:	Soft Soil	*Table 38, Ref 1*
FR:	Firm Rock	*Table 10, Ref 8*
UB:	Upper Bound SM	*Table 10, Ref 8*
Eq:	Equivalent Static	*NISASSIstatic*

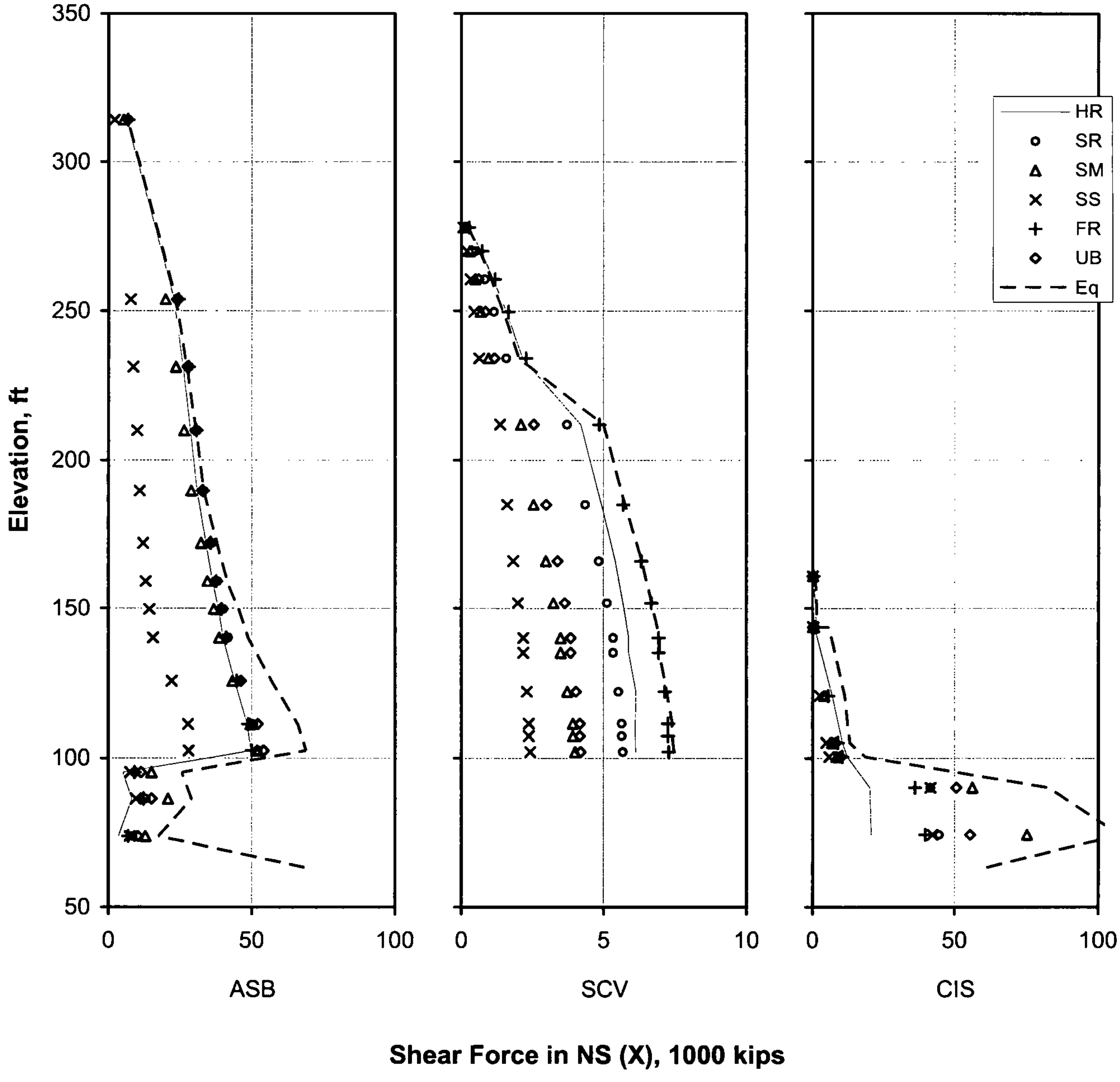


Figure 4.4.1-2 - 2D SASSI NS Shear Force

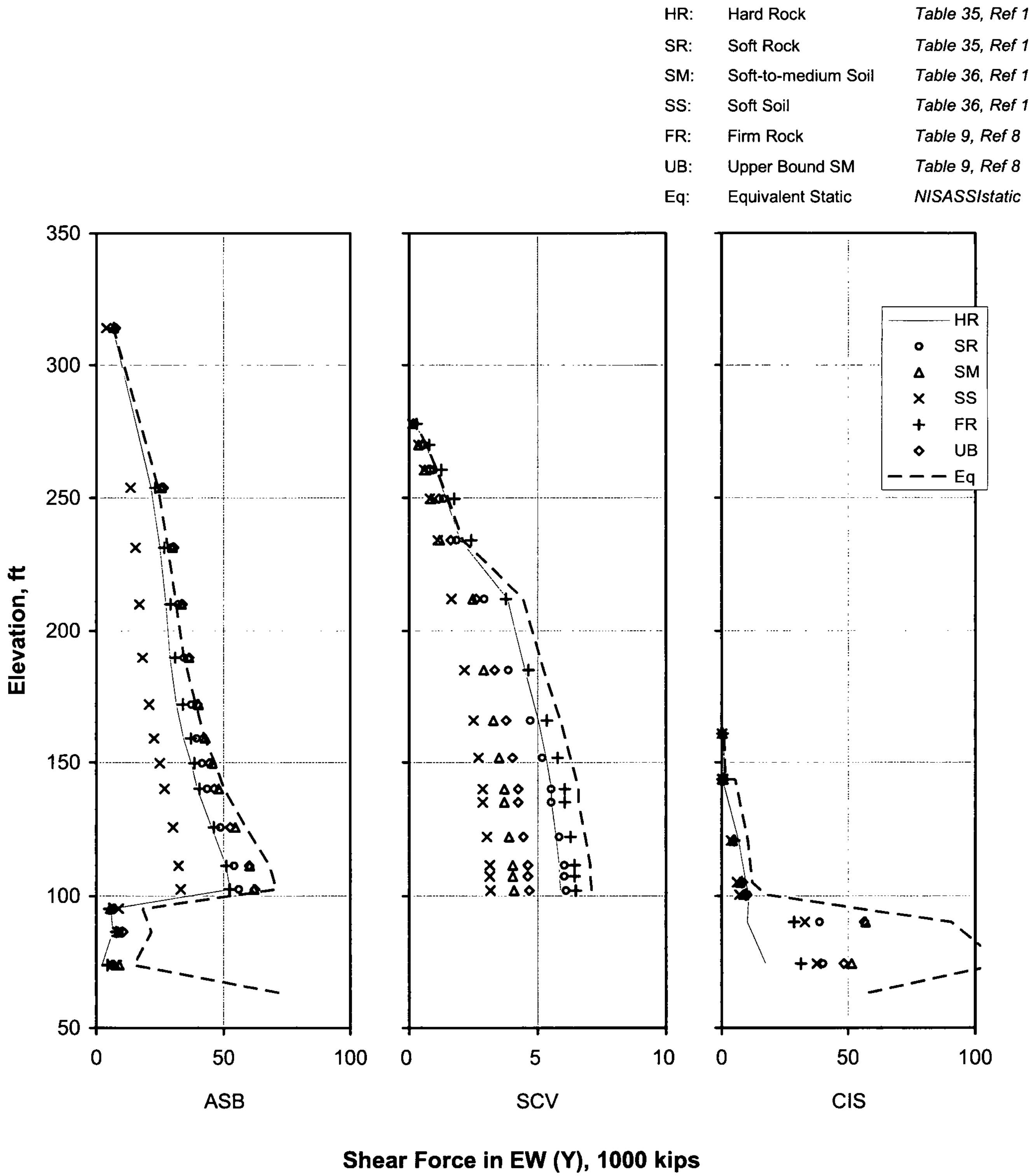


Figure 4.4.1-3 - 2D SASSI EW Shear Force

HR:	Hard Rock	*Table 37, Ref 1*
SR:	Soft Rock	*Table 37, Ref 1*
SM:	Soft-to-medium Soil	*Table 38, Ref 1*
SS:	Soft Soil	*Table 38, Ref 1*
FR:	Firm Rock	*Table 10, Ref 8*
UB:	Upper Bound SM	*Table 10, Ref 8*
Eq:	Equivalent Static	*NISASSIstatic*

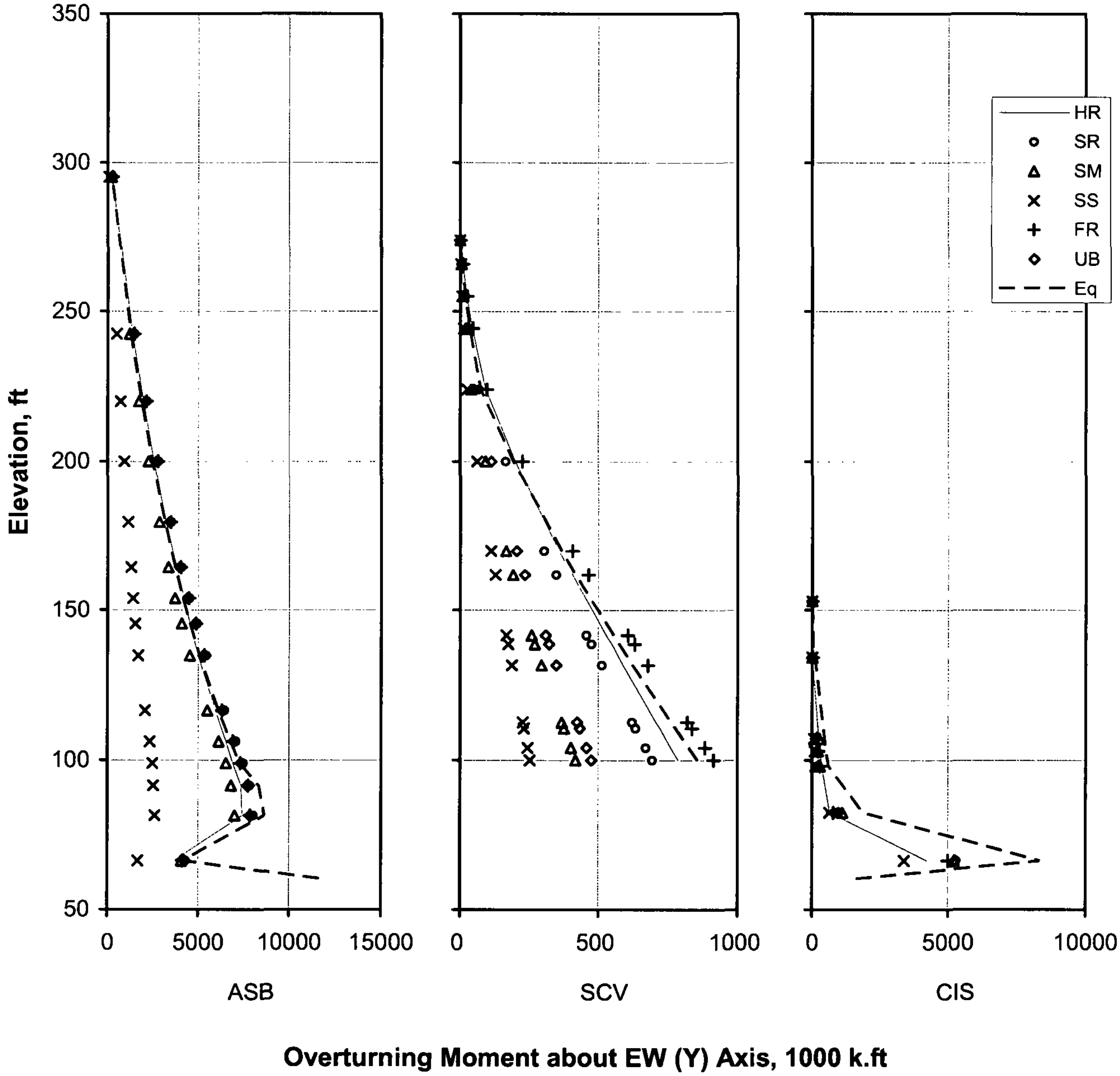


Figure 4.4.1-4 - 2D SASSI EW Overturning Moment

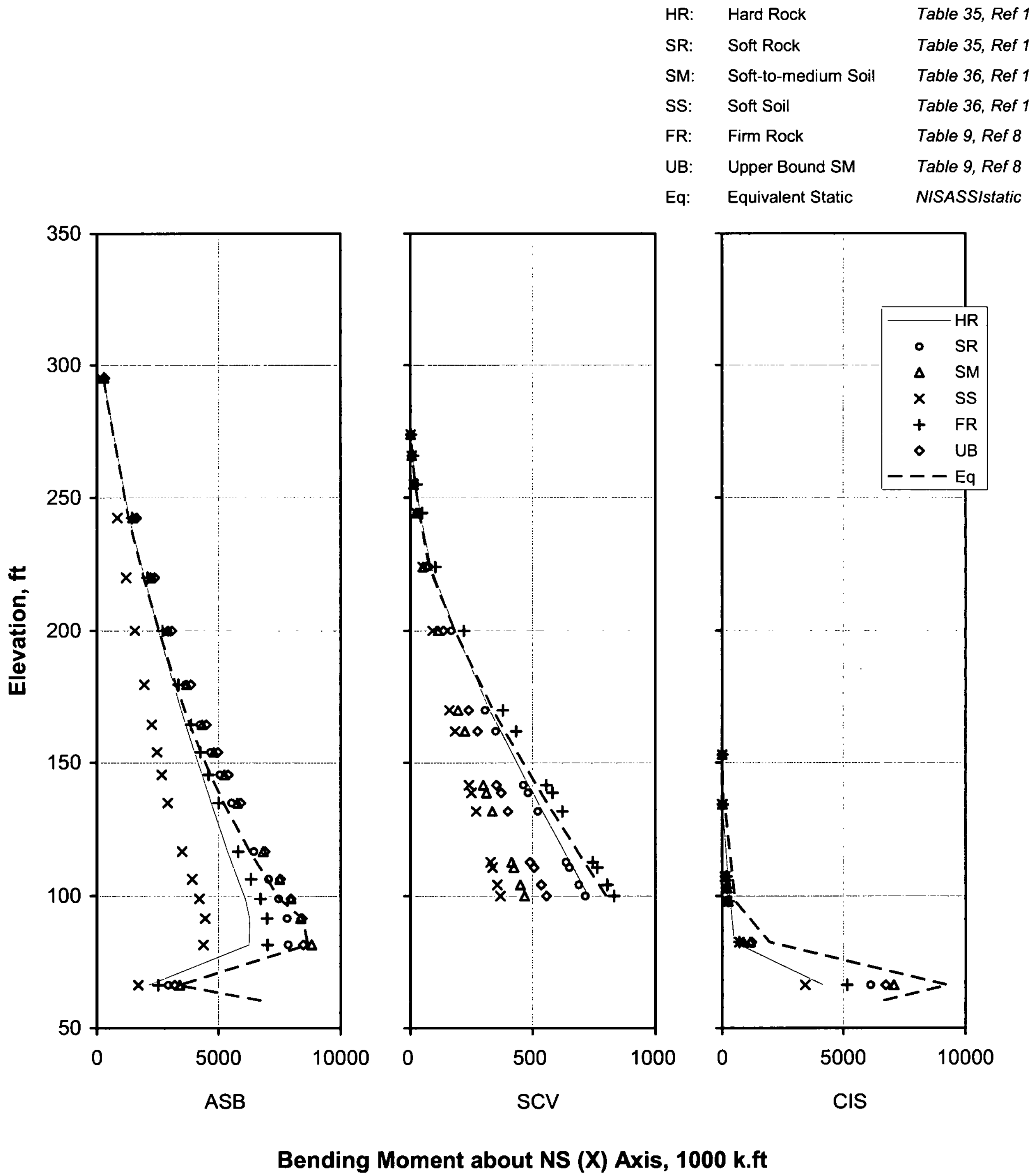


Figure 4.4.1-5 - 2D SASSI NS Bending Moment

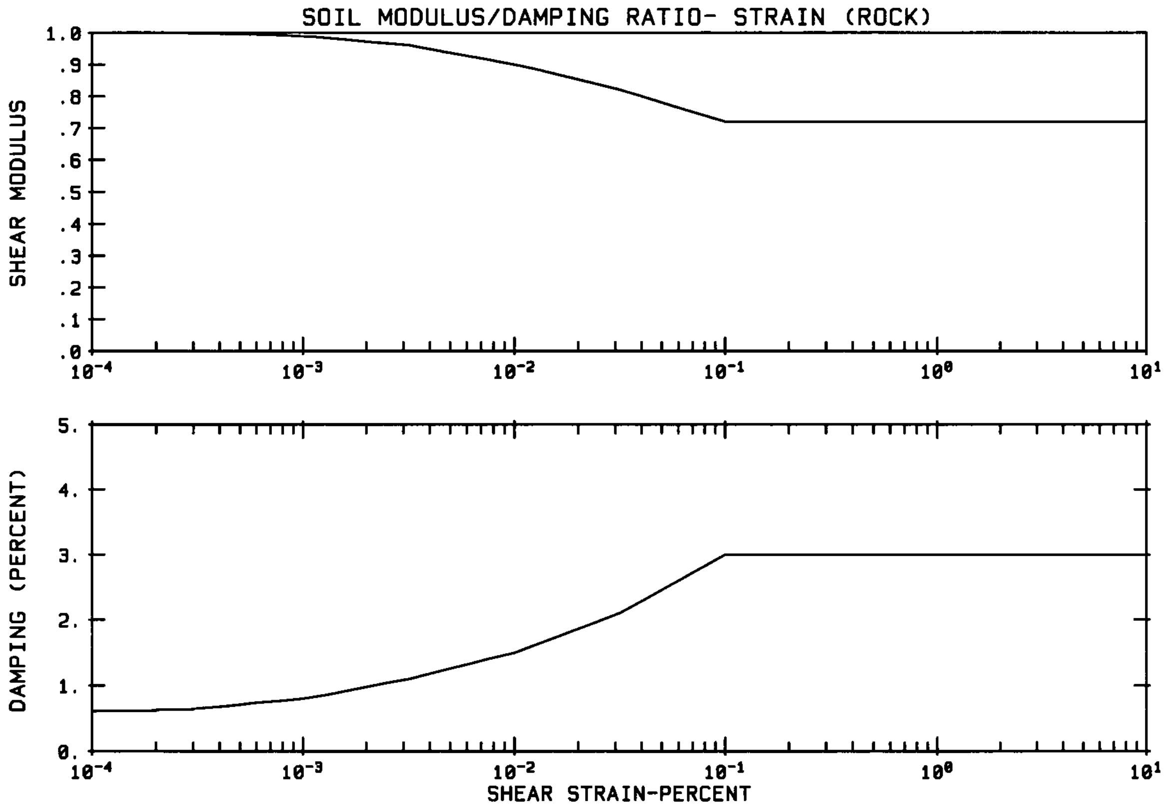


Figure 4.4.1-6 - Strain Dependent Properties of Rock Material

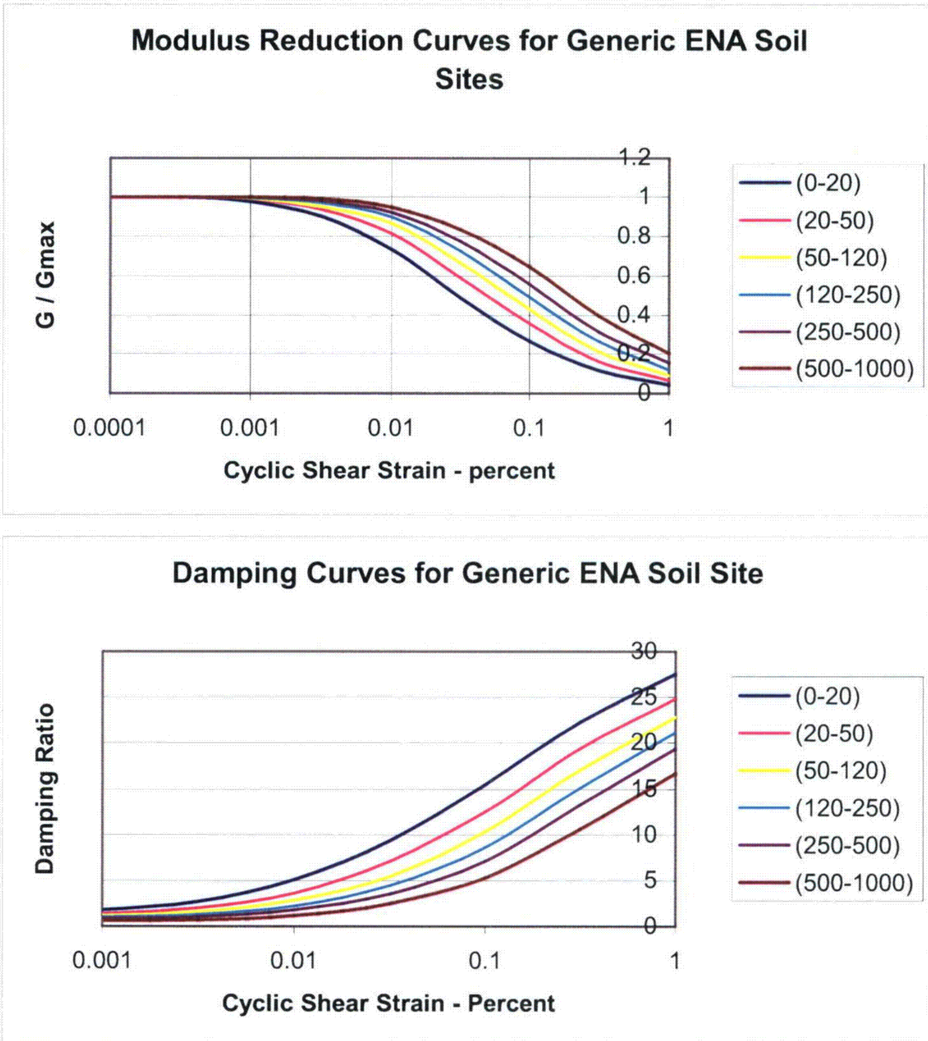


Figure 4.4.1-7 - Strain Dependent Properties of Soil Material

4.4.2 3D SASSI Analyses

The SASSI Soil-Structure Interaction analyses are performed based on the Nuclear Island 3D SASSI-Model for the three soil conditions established from the AP1000 2D SASSI analyses. These soil conditions are firm rock, upper bound soft-to-medium soil, and soft-to-medium soil. The model includes a surrounding layer of excavated soil and the existing soil media. 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.

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, & 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.

The computer program SASSI2000 is used to perform Soil-Structure Interaction analysis. The SASSI Model of Nuclear Island is based on the NI20 Coarse Finite Element.

The solid part of the containment internal structures is represented with two rows of solid elements as shown in Figure 4.4.2-1. The beam elements modeled in the ANSYS NI20 Coarse Model are transferred to the SASSI model. The NI SASSI model beam elements are shown in Figure 4.4.2-2.

All slabs and walls of AP1000 are represented by three dimensional shell elements. Spring elements are used to represent the RCL primary component supports.

Shown in Figure 4.4.2-3 are the soil elements that represent the excavated soil in the 3D SASSI model. The excavated soil element geometry represents the volume of the structure below elevation 100' that have been displaced by the nuclear island structural elements and the additional adjacent soil elements used for soil pressure evaluations. Interaction nodes on the boundary of additional soil elements are used for soil pressure evaluations. These nodes are shown in Figure 4.4.2-4.

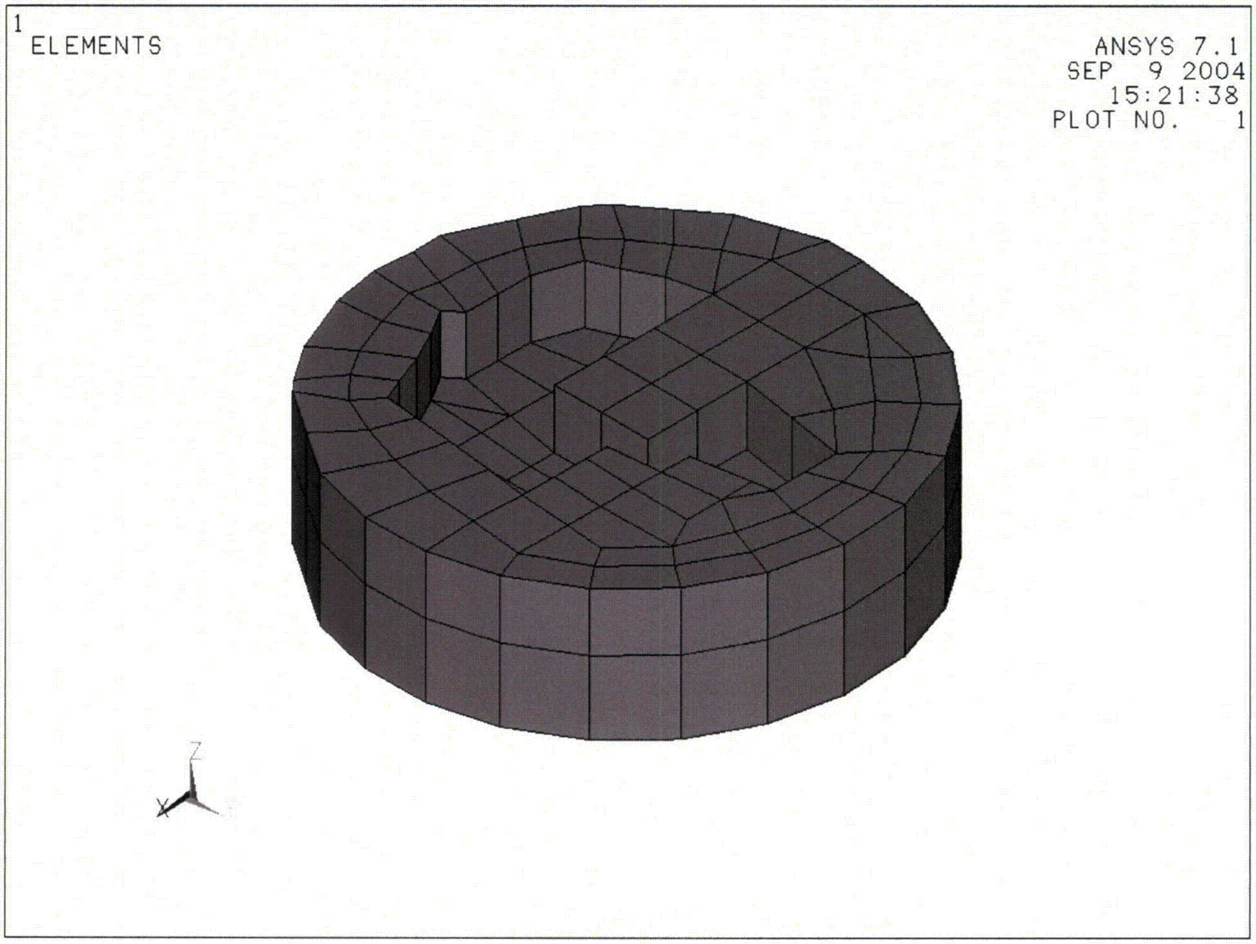


Figure 4.4.2-1- NI 3-D SASSI Model Solid Elements

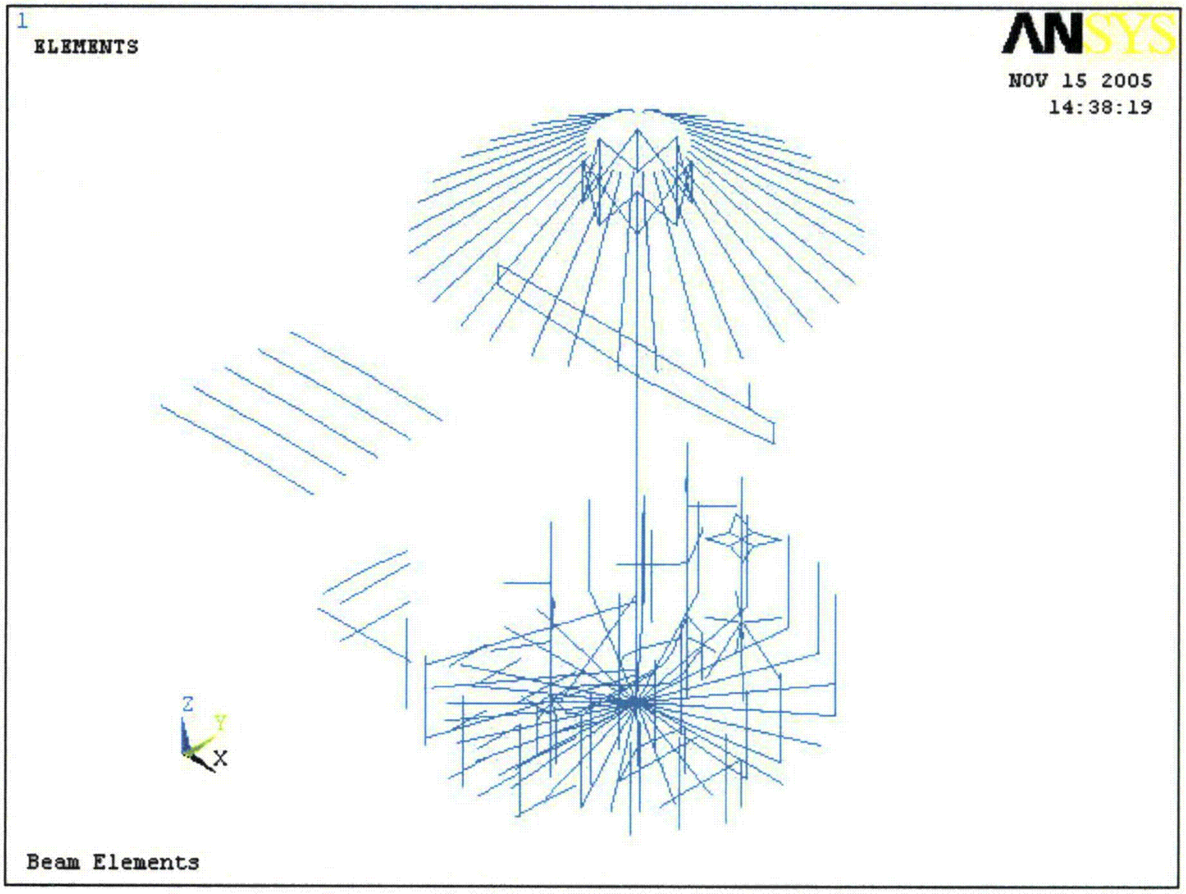


Figure 4.4.2-2 - NI 3-D SASSI Model Beam Elements

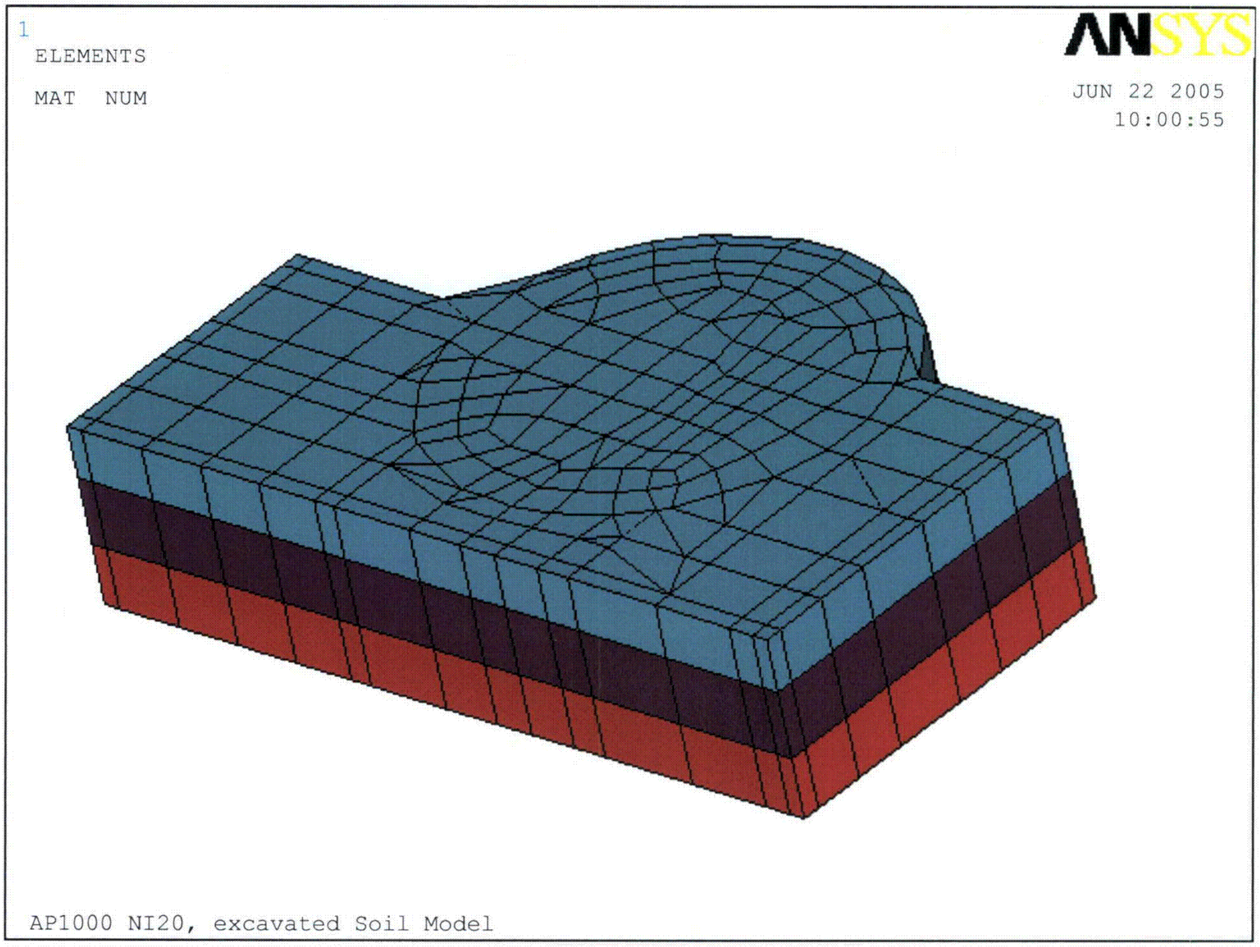


Figure 4.4.2-3 - Excavated Soil

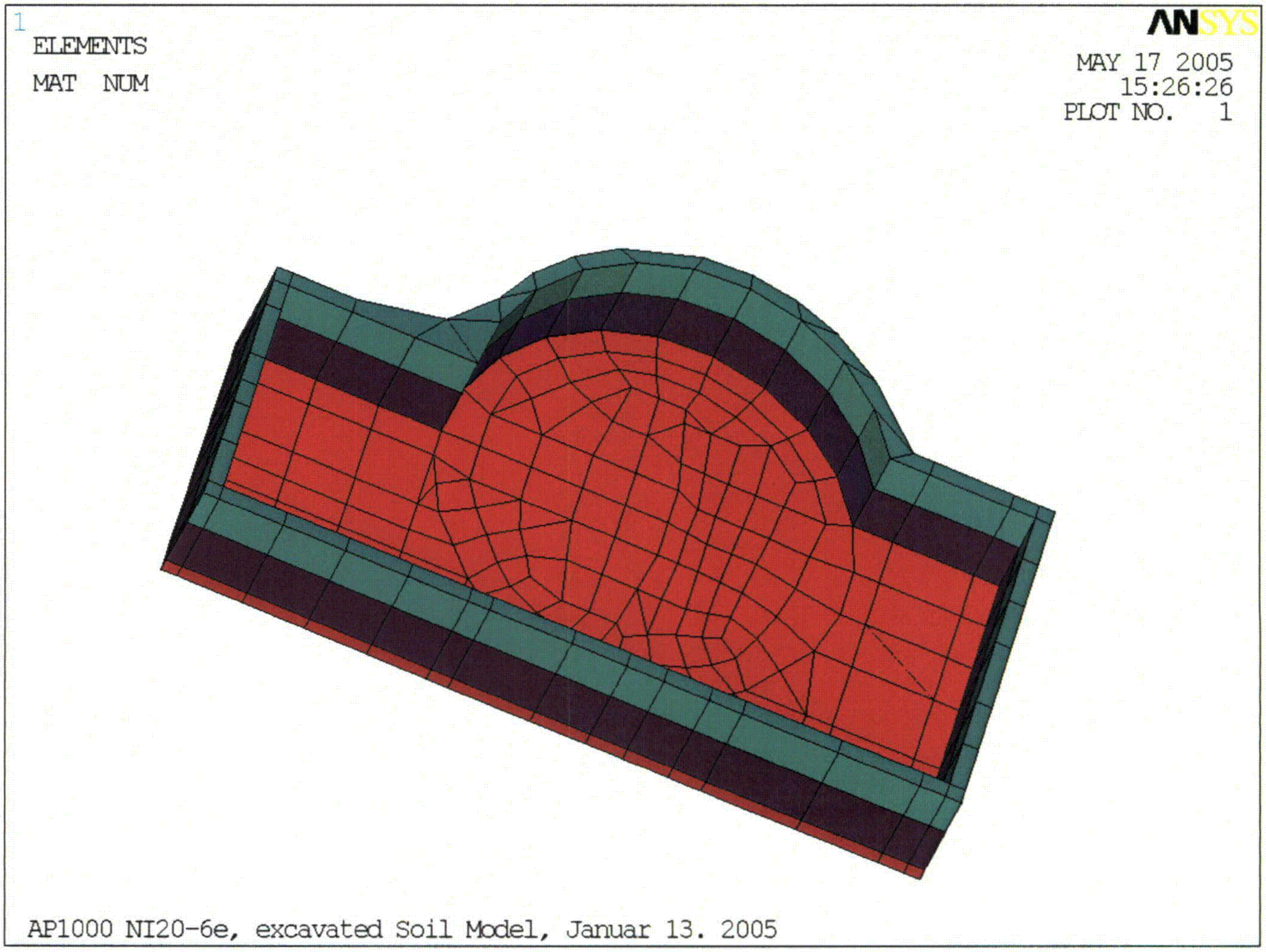


Figure 4.4.2-4 - Additional Elements for Soil Pressure Calculations

4.4.3 Interface Seismic Response

If the site-specific spectra exceed the AP1000 design spectra, or if soil conditions are outside the range evaluated for AP1000 design certification, a site-specific evaluation can be performed as described in section 5.0.

The site is acceptable for construction of the AP1000 if the floor response spectra from the site-specific evaluation do not exceed the AP1000 spectra given for the following six key locations:

- CIS at Reactor Vessel Support Elevation
- CIS at Operating Deck
- ASB North East Corner at Control Room Floor
- ASB Corner of Fuel Building Roof at Shield Building
- ASB Shield Building Roof Area

- SCV Near Polar Crane

The node points in the models are given in Table 4.4.3-1 and the AP1000 spectra provided in Figures 3G.4-5X to 3G.4-10Z (Appendix E, “Post Revision 16 DCD Appendix 3G.”). The spectra are broadened as defined in the AP1000 DCD subsection 3.7.2.5.

Table 4.4.3-1 – Key Nodes at Location

Location	NI10 Node	NI20 Node	General Area	Elevation (feet)
CIS at Reactor Vessel Support Elevation	130401	1761	SCV Center	100.00
CIS at Operating Deck	105772	2199	SG West compartment, NE	134.25
ASB NE Corner at Control Room Floor	4724	2078	NE Corner	116.50
ASB Corner of Fuel Building Roof at Shield Building	5754	2675	NW Corner of Fuel Bldg	179.19
ASB Shield Building Roof Area	8573	3329	South side of Shield Bldg	327.41
SCV Near Polar Crane	130412	2788	SCV Stick Model	224.00

5.0 *Site requirements for AP1000*

This section describes the procedure an applicant would follow to show that their site falls under the analyses used for the AP1000 DCD. It should be noted that the AP1000 design is fairly robust and if the applicant does not meet the conditions outline below, the applicant can still perform site specific evaluations to show that the site is adequate for the AP1000 design. The seismic parameters are described in DCD Chapter 2. Sections of the DCD Chapter 2 are revised to read as follows: (These changes have been incorporated in DCD Rev. 16)

DCD Table 2-1 Site Parameters

Seismic		
	SSE	0.30g peak ground acceleration [c]
Soil		
	Shear Wave Velocity	Greater than or equal to 1,000 ft/sec based on low-strain best-estimate soil properties over the footprint of the nuclear island at its excavation depth
	Lateral Variability	Soils supporting the nuclear island should not have extreme variations in subgrade stiffness Case 1: For a layer with a low strain shear wave velocity greater than or equal to 2500 feet per second, the layer should have approximately uniform thickness, should have a dip not greater than 20 degrees, and should have less than 20 percent variation in the shear wave velocity from the average velocity in any layer. Case 2: For a layer with a low strain shear wave velocity less than 2500 feet per second, the layer should have approximately uniform thickness, should have a dip not greater than 20 degrees, and should have less than 10 percent variation in the shear wave velocity from the average velocity in any layer.

Notes:

(c) With ground response spectra as given in Figures 3.7.1-1 and 3.7.1-2. Seismic input is defined at finished grade except for sites where the nuclear island is founded on rock.

DCD Subsection 2.5.2 Vibratory Ground Motion

The AP1000 is designed for a safe shutdown earthquake (SSE) defined by a peak ground acceleration (PGA) of 0.30g and the design response spectra specified in subsection 3.7.1.1, and Figures 3.7.1-1 and 3.7.1-2. The AP1000 design response spectra were developed using the Regulatory Guide 1.60 response spectra as the base and modified to include additional high frequency amplification at a control point at 25 Hz. The peak ground accelerations in the two horizontal and the vertical directions are equal.

The AP1000 is also evaluated for safe shutdown earthquake (SSE) defined by a peak ground acceleration (PGA) of 0.30g and the design response spectra specified in Appendix 3I, and Figures 3I.1-1 and 3I.1-2. These design response spectra are applicable to certain east coast rock sites.

DCD Subsection 2.5.2.1 Combined License Seismic and Tectonic Characteristics Information

The Combined License applicants referencing the AP1000 certified design will address the following site-specific information related to the vibratory ground motion aspects of the site and region:

- Seismicity
- Geologic and tectonic characteristics of site and region
- Correlation of earthquake activity with seismic sources
- Probabilistic seismic hazard analysis and controlling earthquakes
- Seismic wave transmission characteristics of the site
- SSE ground motion

The site-specific ground motion response spectra (GMRS) are determined in the free-field on the ground surface. For sites with soil layers that will be completely excavated to expose competent material, the GMRS is specified on an outcrop or a hypothetical outcrop that will exist after excavation. Motions at this hypothetical outcrop are developed as a free-surface motion, not as an in-column motion. Competent material may be defined as in-situ material having a shear wave velocity equal to or greater than 1000 fps. The Combined License applicant must demonstrate that the proposed site meets the following requirements:

1. The free field peak ground acceleration at the finished grade level is less than or equal to a 0.30g SSE.

2. The site-specific ground motion response spectra (GMRS) at the finished grade level in the free-field are less than or equal to AP1000 certified seismic design response spectra (CSDRS) given in Figures 3.7.1-1 and 3.7.1-2.

3. In lieu of (1) and (2) above, for a site where the nuclear island is founded on hard rock with shear wave velocity greater than 8,000 feet per second and there are thin layers of soft material overlying the rock, the site specific ground motion may be defined at the foundation level as the foundation input response spectrum (FIRS) and shown to be less than or equal to CSDRS given in Figures 3.7.1-1 and 3.7.1-2.

4. Foundation material layers are approximately horizontal (dip less than 20 degrees), and the median estimate of the low strain shear wave velocity of the soil below the foundation of the nuclear island is greater than or equal to 1000 feet per second.

5. Foundation material layers are approximately horizontal (dip less than 20 degrees), and the median estimate of the low strain shear wave velocity of the

soil below the foundation of the nuclear island is greater than or equal to 1000 feet per second.

6. For sites where the nuclear island is founded on soil, the median estimate of the strain-compatible soil shear modulus and hysteric damping is compared to the values used in the AP1000 generic analyses shown in Table 3.7.1-4 and Figure 3.7.1-17. Properties of soil layers within a depth of 120 feet below finished grade are compared to those in the generic soil site analyses (soft soil, soft-to-medium soil and upper bound soft-to-medium soil).

7. In lieu of (1) to (6) above, a site-specific evaluation can be performed as described in subsection 2.5.2.3.

Where features of the site are not clearly within the parameters specified for the AP1000, site-specific soil structure interaction analyses may be performed using the 2D SASSI models described in Appendix 3G for variations in site conditions that can be adequately represented in these models. Results should be compared to the results of the 2D SASSI analyses described in Appendix 3G. Such analyses may be used to demonstrate that local features, such as soil degradation properties or backfill, are well within the bounds established by the design cases. If the results are not clearly enveloped, then a 3D SASSI analysis may be required.

2.5.2.2 Site Specific Seismic Structures

The AP1000 includes all seismic Category I structures, systems and components in the scope of the design certification.

<u>DCD Subsection 2.5.2.3 Sites with Geoscience Parameters Outside the Certified Design</u>

If the site-specific spectra at foundation level exceed the response spectra in Figures 3.7.1-1 and 3.7.1-2 at any frequency, or if soil conditions are outside the range evaluated for AP1000 design certification, a site-specific evaluation can be performed. This evaluation will consist of a site-specific dynamic analysis and generation of in-structure response spectra to be compared with the floor response spectra of the certified design at 5-percent damping. The site design response spectra at the foundation level in the free-field given in Figures 3.7.1-1 and 3.7.1-2 were used to develop the floor response spectra. They were applied at foundation level for the hard rock site and at finished grade level for the soil sites. The site is acceptable for construction of the AP1000 if the floor response spectra from the site-specific evaluation do not exceed the AP1000 spectra for each of the locations identified below:

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
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

Site-specific soil structure interaction analyses are performed using the 3D SASSI models described in Appendix 3G. The site-specific soil structure interaction analyses would use the site-specific soil conditions (including variation in soil properties in accordance with Standard Review Plan 3.7.2). The three components of the site-specific ground motion time history must satisfy the regulatory requirements for statistical independence and enveloping of the site design spectra at 5% damping. Floor response spectra determined from the site-specific analyses should be compared against the design basis of the AP1000 described above. These evaluations and comparisons will be provided and reviewed as part of the Combined License application.

If the site-specific spectra at foundation level at a rock site exceed the response spectra in Figures 3I.1-1 and 3I.1-2 at any frequency, a site-specific evaluation can be performed similar to that described in Appendix 3I.

6.0 Seismic Results

6.1 Comparison of Response Spectra to Hard Rock Stick Spectra

Shown in Figures 6.1-1 to 6.1-6 are the grouped spectra obtained using the shell model that contain the key interface nodes associated with the ASB at elevation 135', 180' and 333', CIS at elevation 99' and 135', and SCV at elevation 224'. These response spectra are for the hard rock (HR) site condition. They are compared to those obtained from the stick model for the HR case. It is noted that this comparison is made without the robust shield building design because the seismic analyses using the stick model did not have the strengthened shield building.

As seen from these spectra it can be concluded that:

- Using the stick model very conservative horizontal (X and Y) seismic response spectra are obtained.

- Using the shell model allows the development of design response spectra that reflect the seismic response across an elevation (floor) that is more realistic.

- Using the shell model more realistic vertical seismic response spectra are developed.

These conclusions represent some of the factors that contributed to moving away from the stick models and using the shell dynamic models.

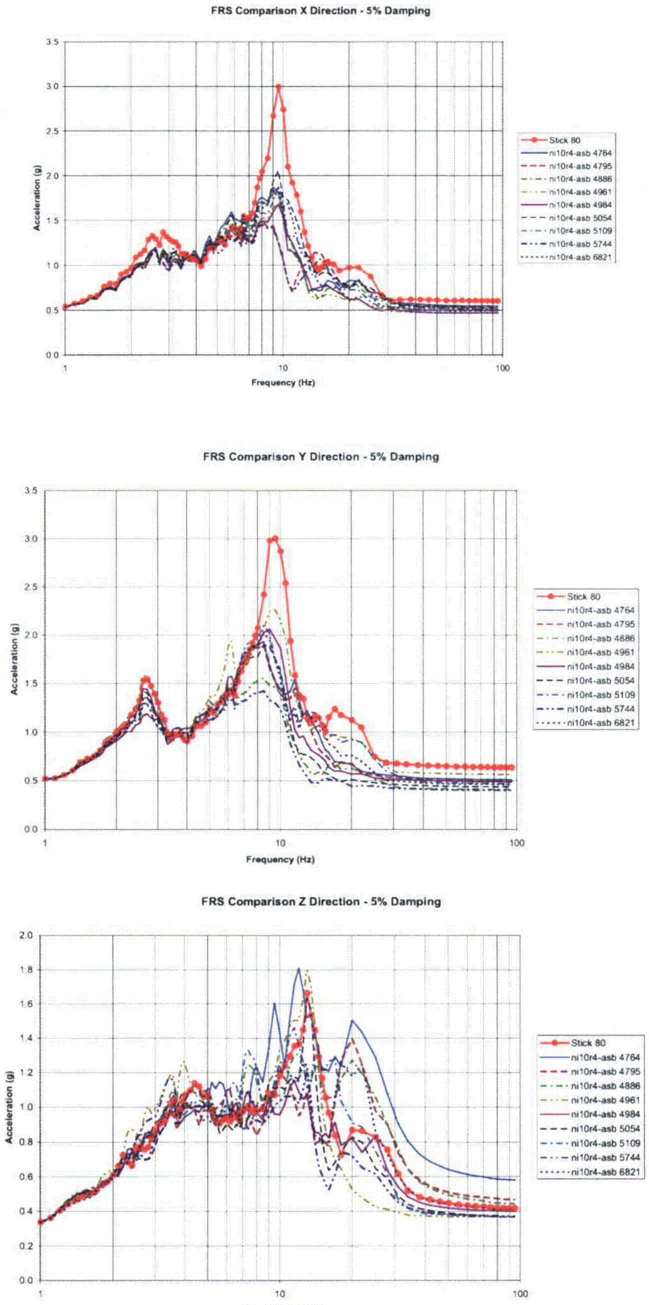


Figure 6.1- 1 - Auxiliary Building at Elevation 135 feet

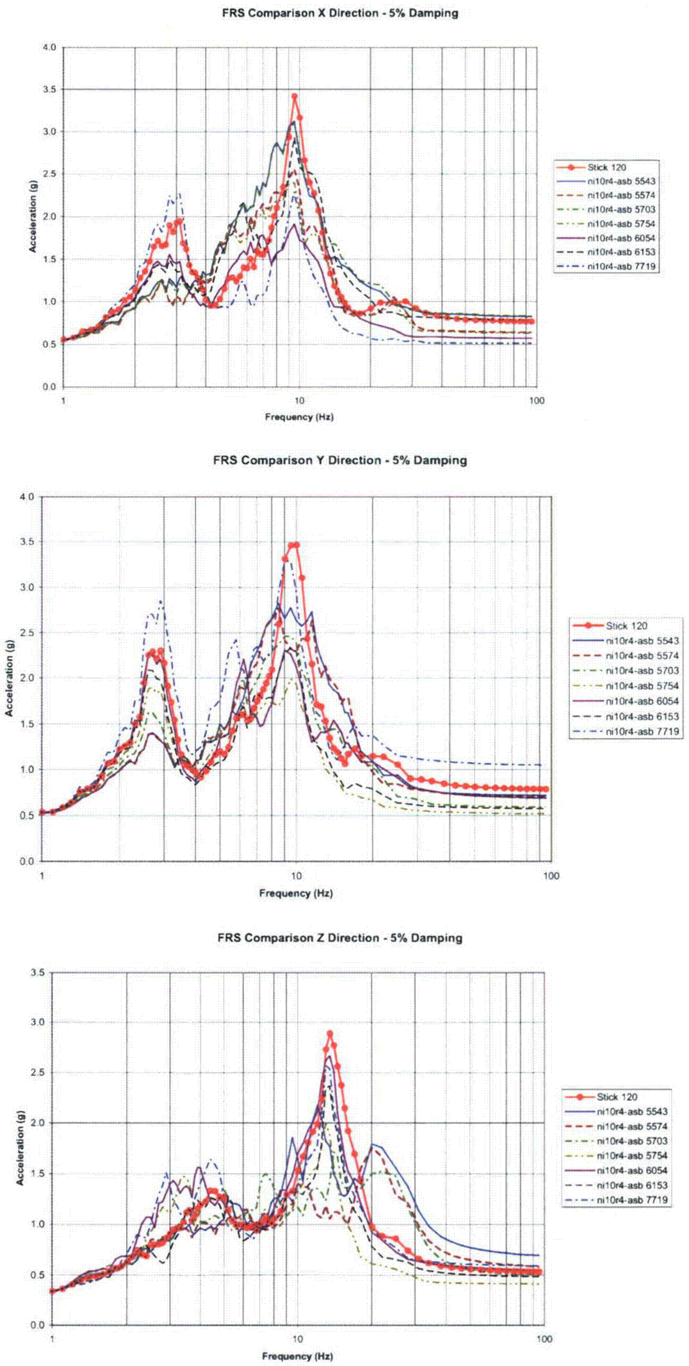
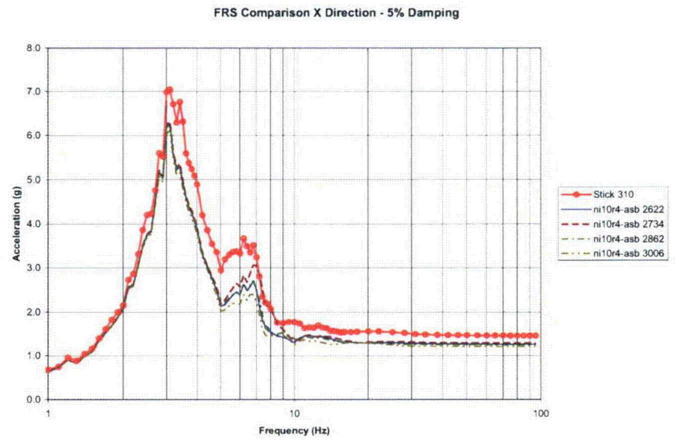
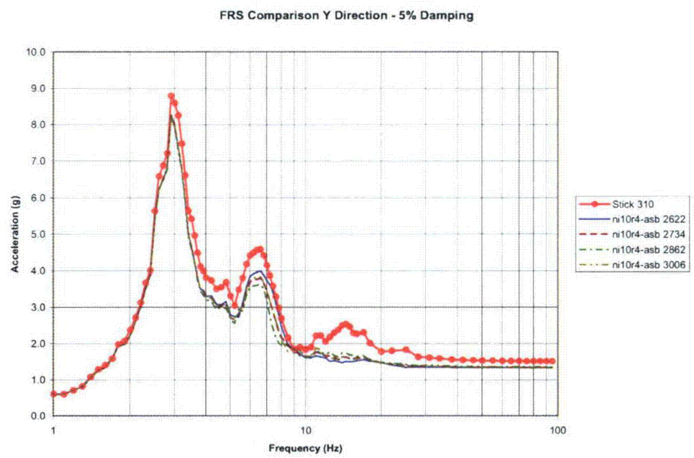


Figure 6.1- 2 - Auxiliary and Shield Building at Elevation 180 feet





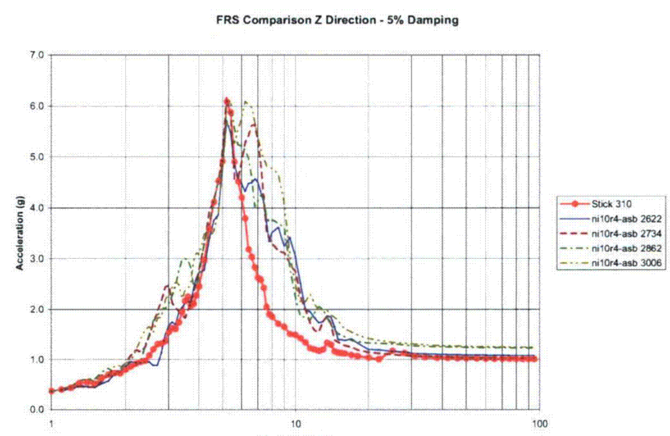


Figure 6.1- 3 - Shield Building at Elevation 333 feet

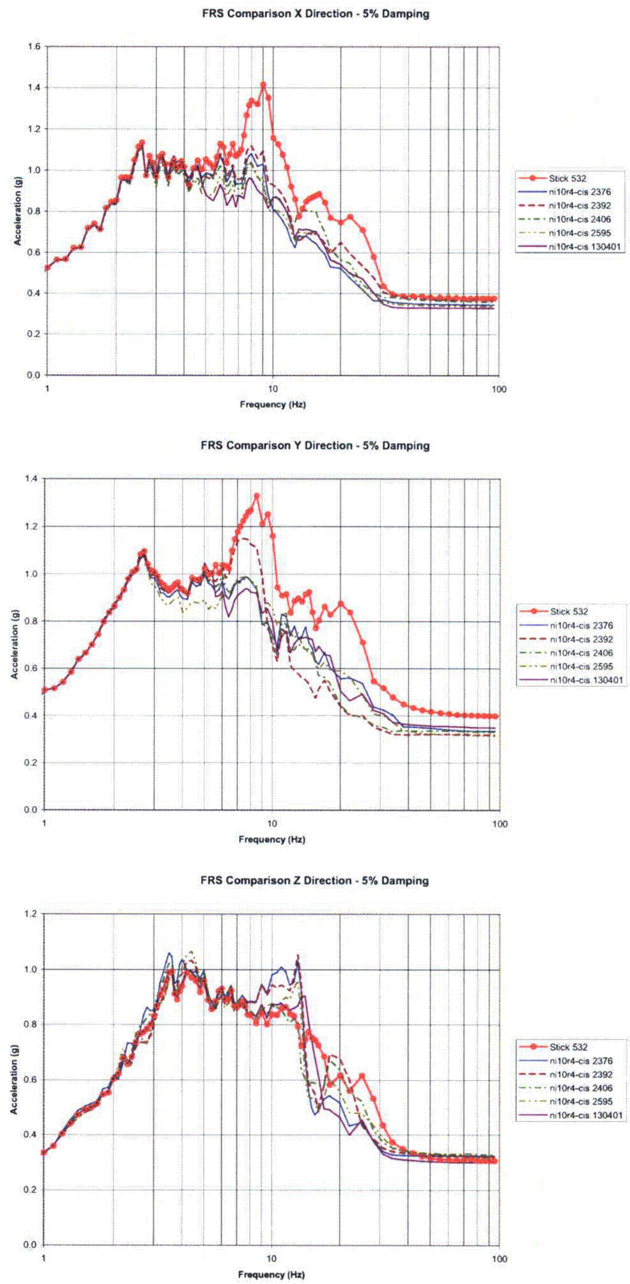


Figure 6.1-4 - CIS at Elevation 99 feet

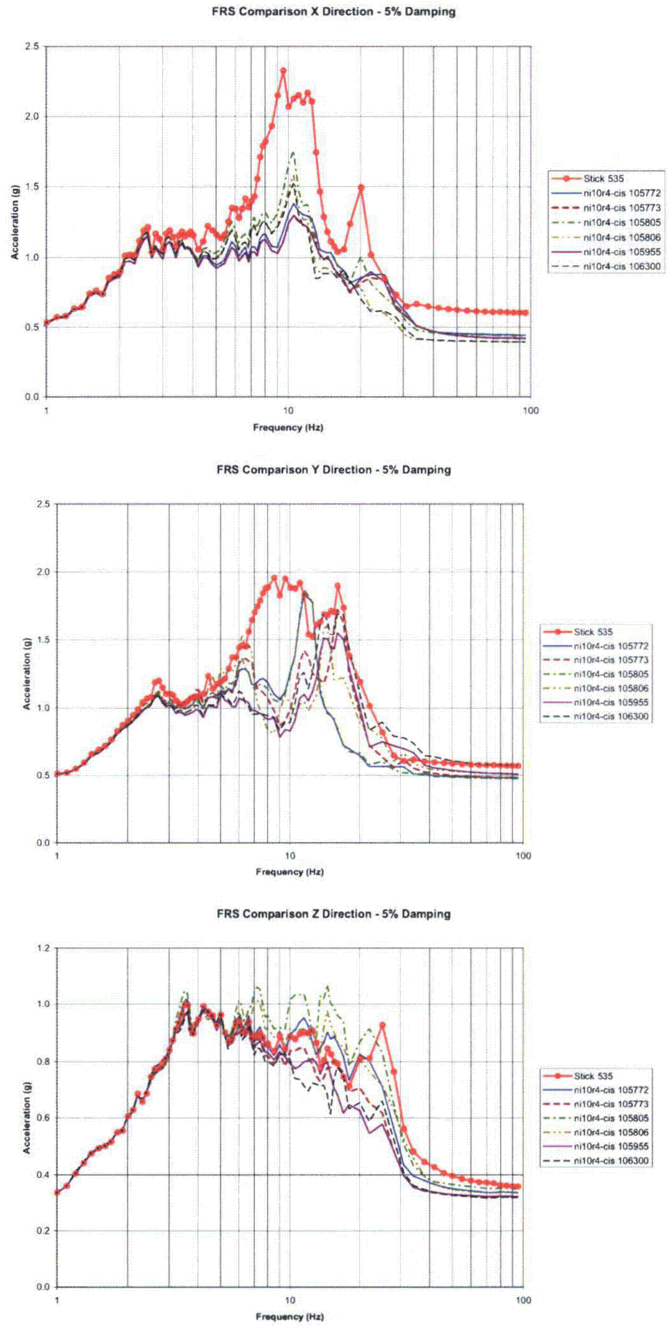


Figure 6.1- 5 - CIS at Elevation 135 feet

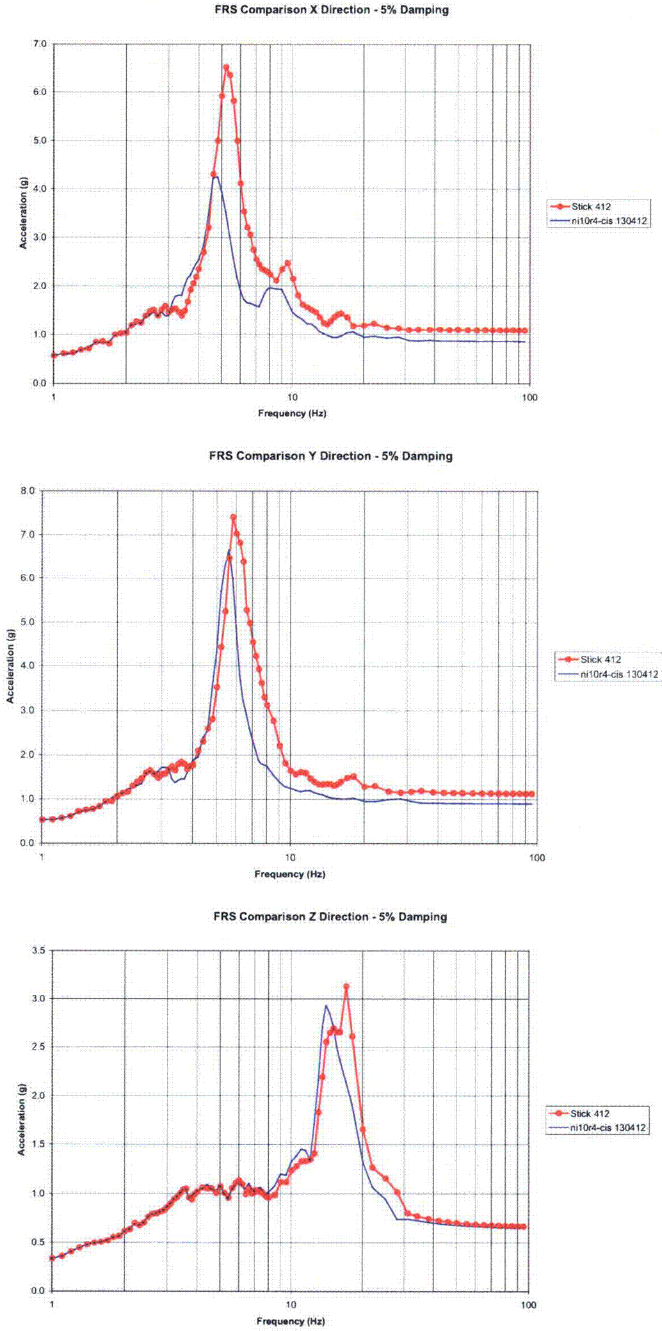
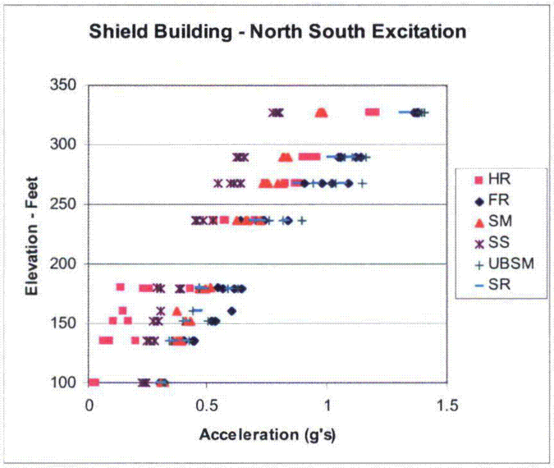


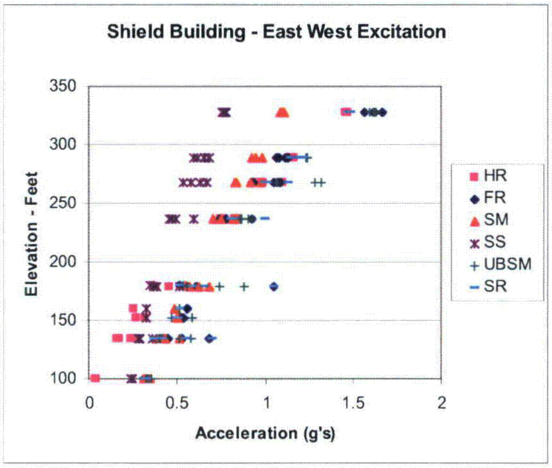
Figure 6.1-6 - SCV at Polar Crane Elevation 224 feet

6.2 Seismic Accelerations

The seismic acceleration obtained from the time history analyses of the hard rock and soil cases (firm rock, soft rock, upper bound soft to medium, soft to medium, soft soil) are given in Figures 6.2-1 to 6.2-4. The accelerations are given for:

- Shield Building
- Steel Containment vessel
- NW Corner of Pressurizer Component
- East SG Component SE Corner





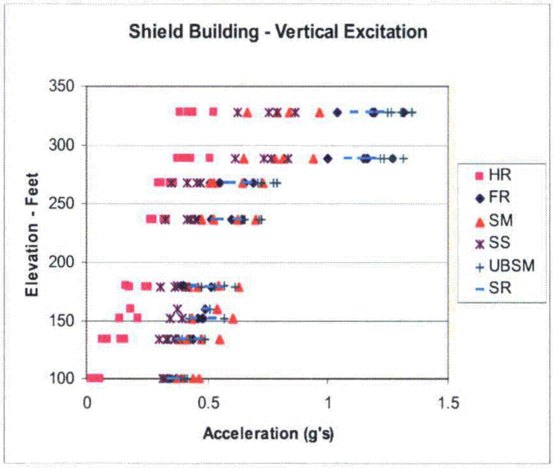
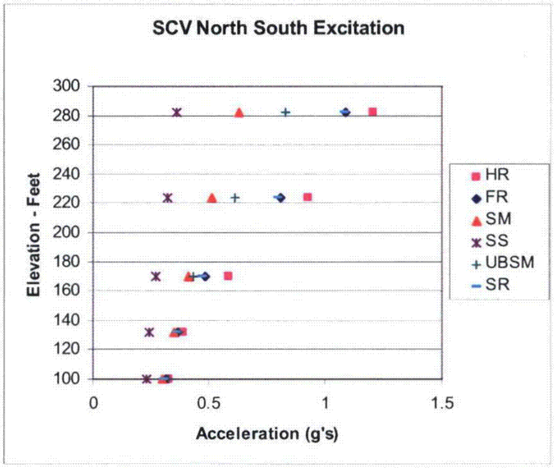
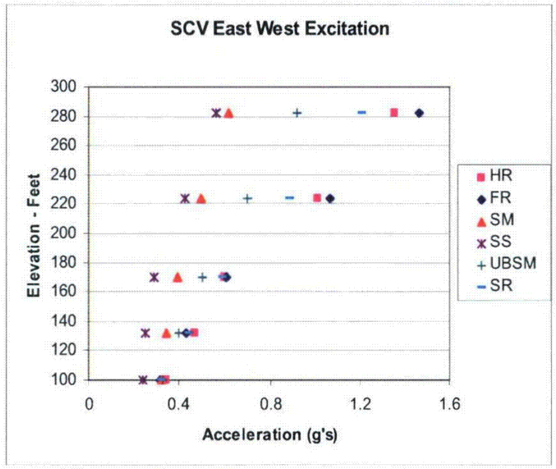


Figure 6.2-1 - Acceleration Plots of Shield Building





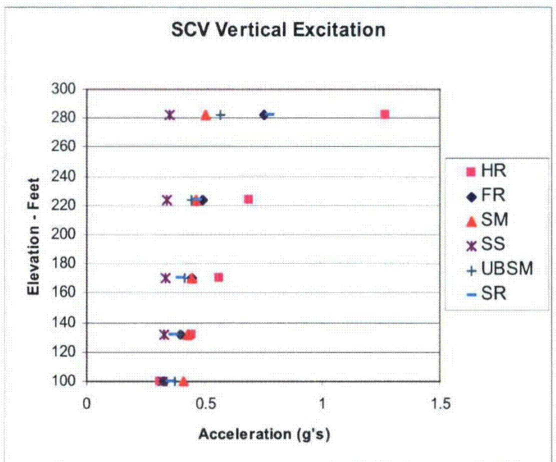


Figure 6.2-2 – Acceleration Plots of SCV

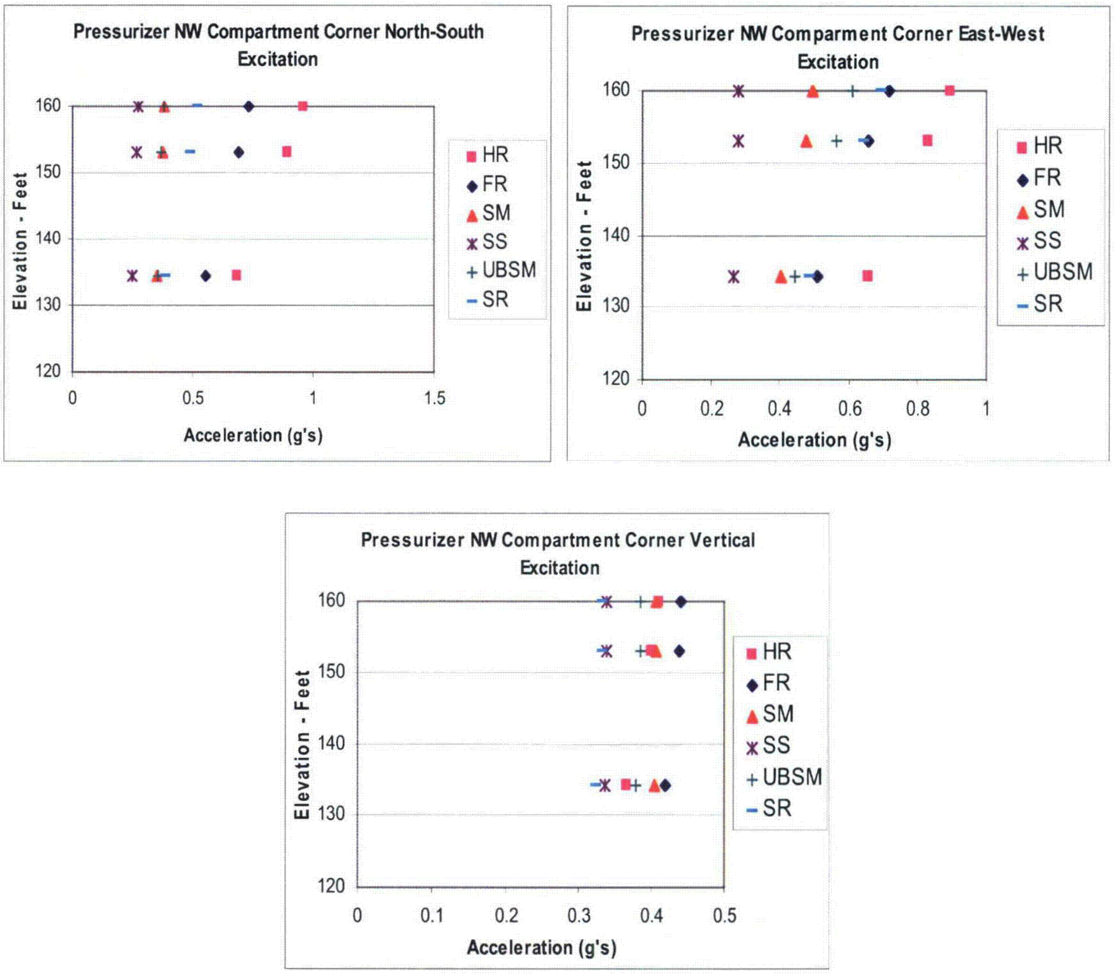


Figure 6.2-3 – Acceleration Plots of Pressurizer Compartment NW Corner

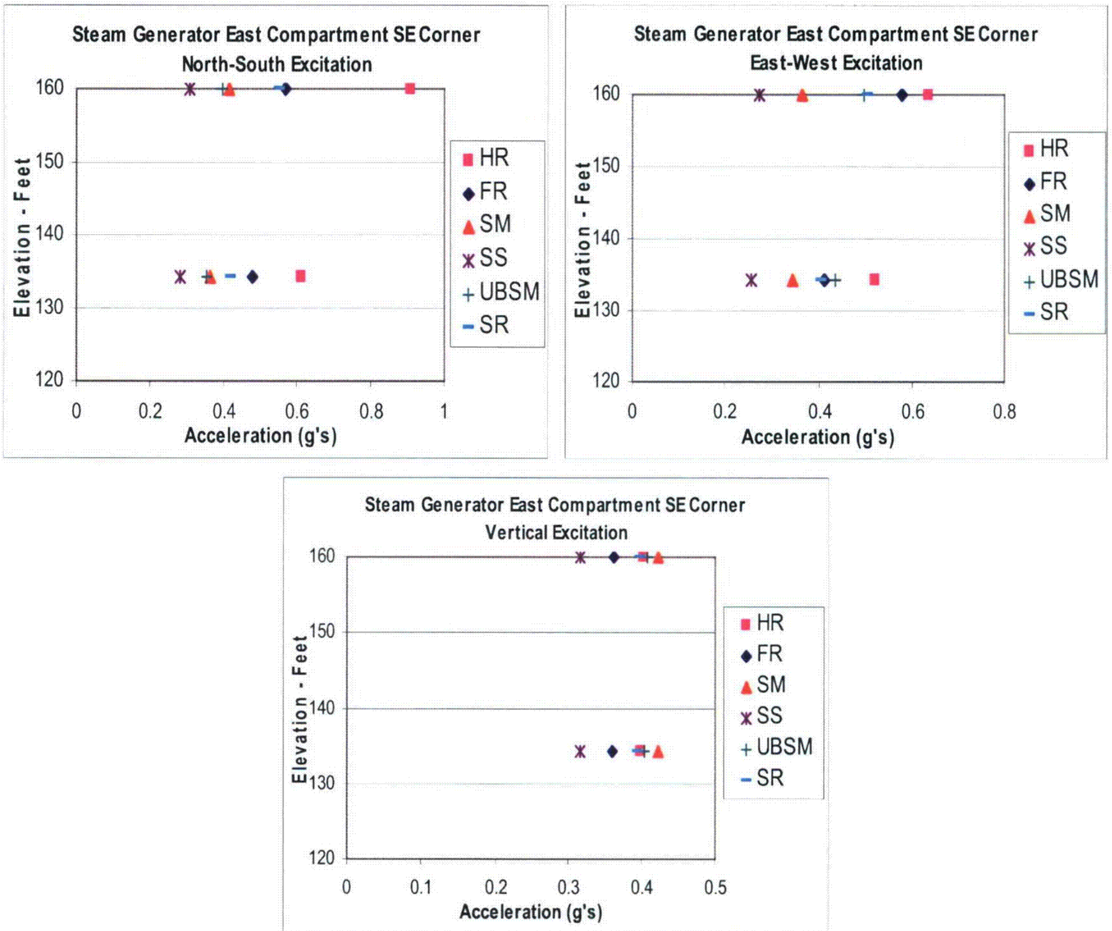


Figure 6.2-4 – Acceleration Plots of East SG Compartment SE Corner

6.3 Maximum Seismic Displacements

Deflections have been developed using the model with the robust shield building design. These displacements for the soil and hard rock cases have been obtained relative to the translation of a reference node at the bottom of the foundation and near the center of the basemat. Coordinates of this reference node are x= 993.00 ft, y= 986.00 ft and z= 60.50ft. The deflections have been revised to remove drift. The absolute displacement time histories are calculated from the nodal time histories accelerations. When the relative displacements are plotted there is a constant slope as shown in Figure 6.3-1. To correct this drift, the slope of the relative displacement multiplied by the time is subtracted from the relative displacement of each time step. Presented in Figure 6.3-2 is the drift corrected relative displacement.

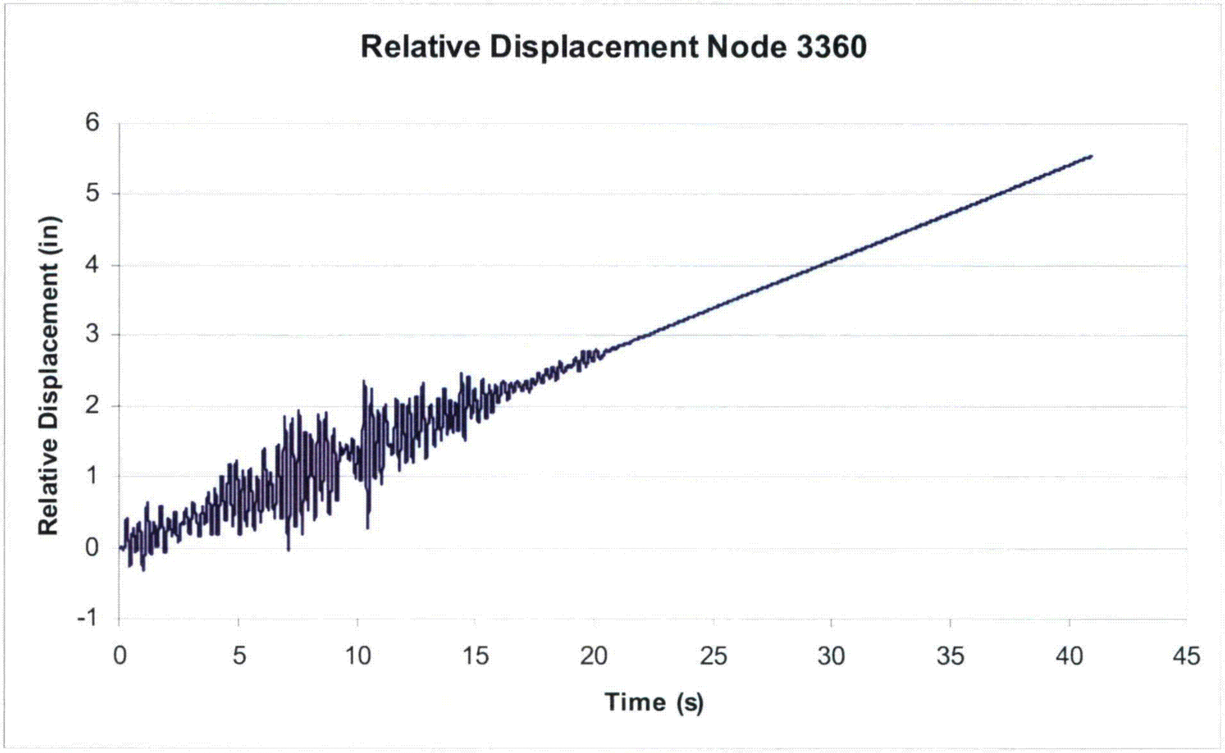


Figure 6.3-1 - Relative Displacement of Node 3360, top of Shield Building

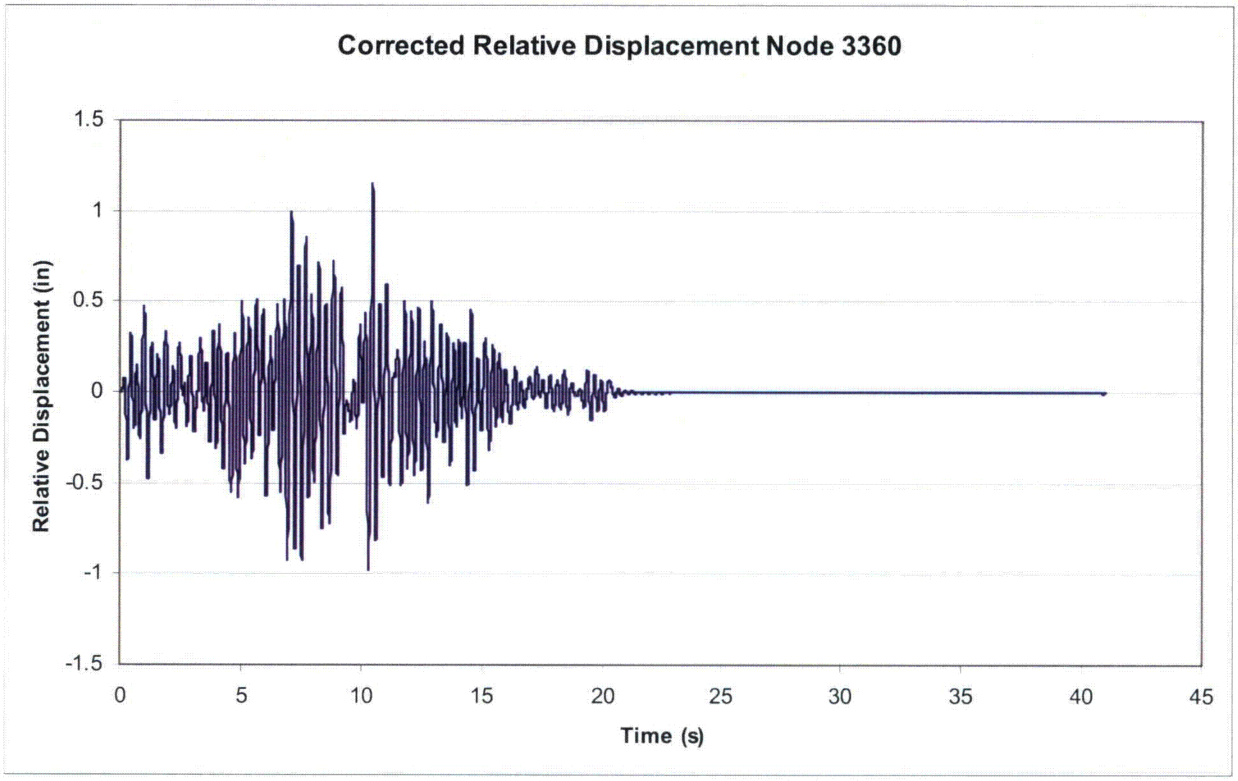
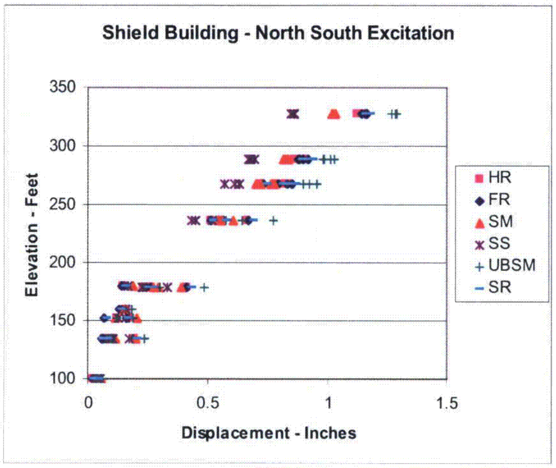
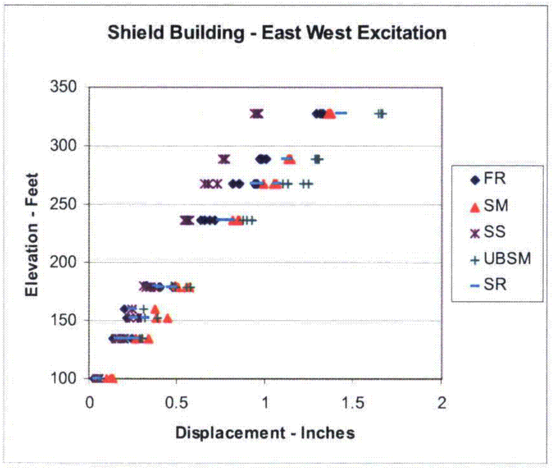


Figure 6.3-2 - Corrected Relative Displacement of Node 3360, top of Shield Building

Figures 6.3-3 and 6.3-4 show the maximum deflection plots for the shield building and steel containment vessel for each of the soil cases (firm rock, FR; soft to medium, SM; soft soil, SS; Upper bound soft to medium, UBSM; and soft rock, SR) and hard rock site (HR). Figures 6.4-5 and 6.4-6 show deflections for the NW corner of the pressurizer compartment and the SE corner of the East steam generator compartment.





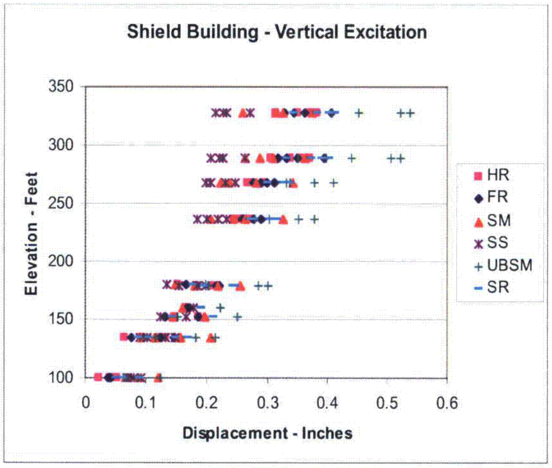


Figure 6.3-3 – Deflection Plots of Shield Building

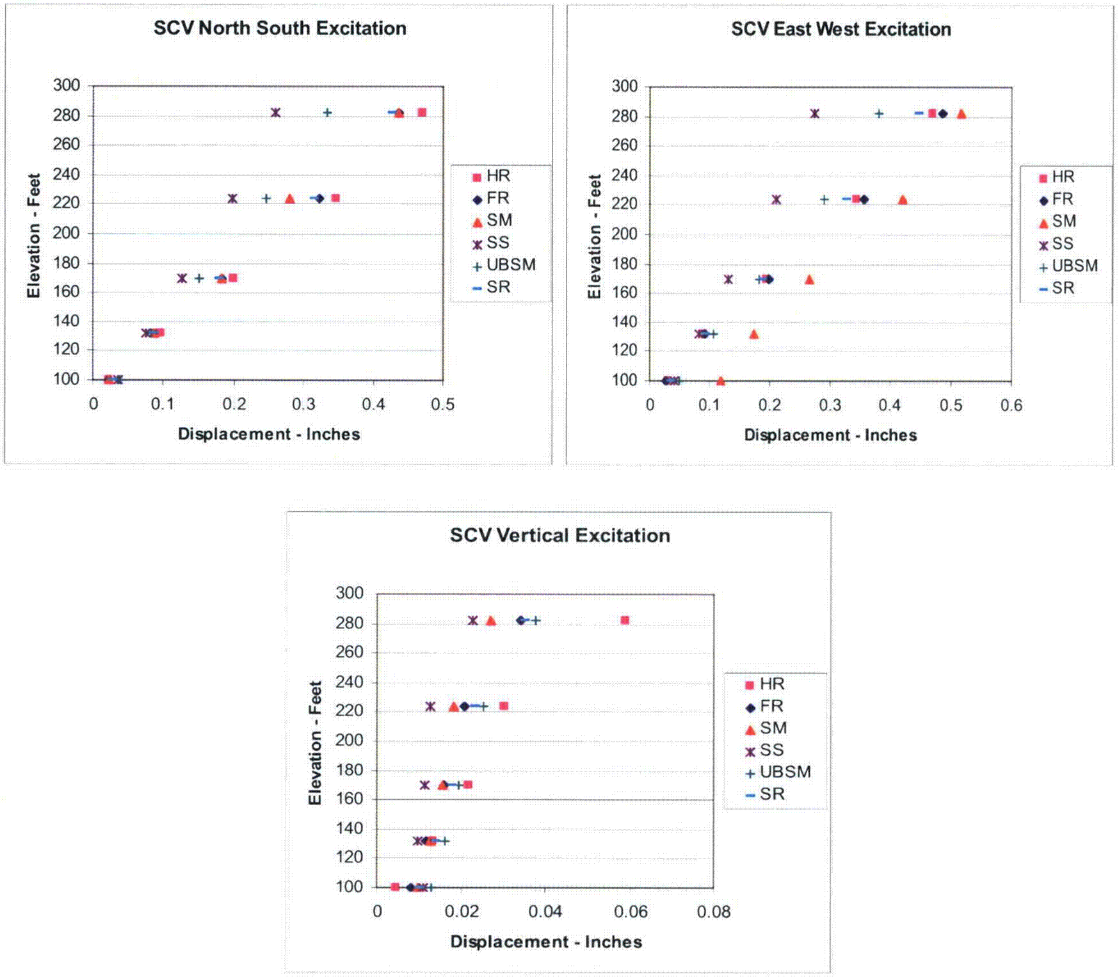


Figure 6.3-4 – Deflection Plots of SCV

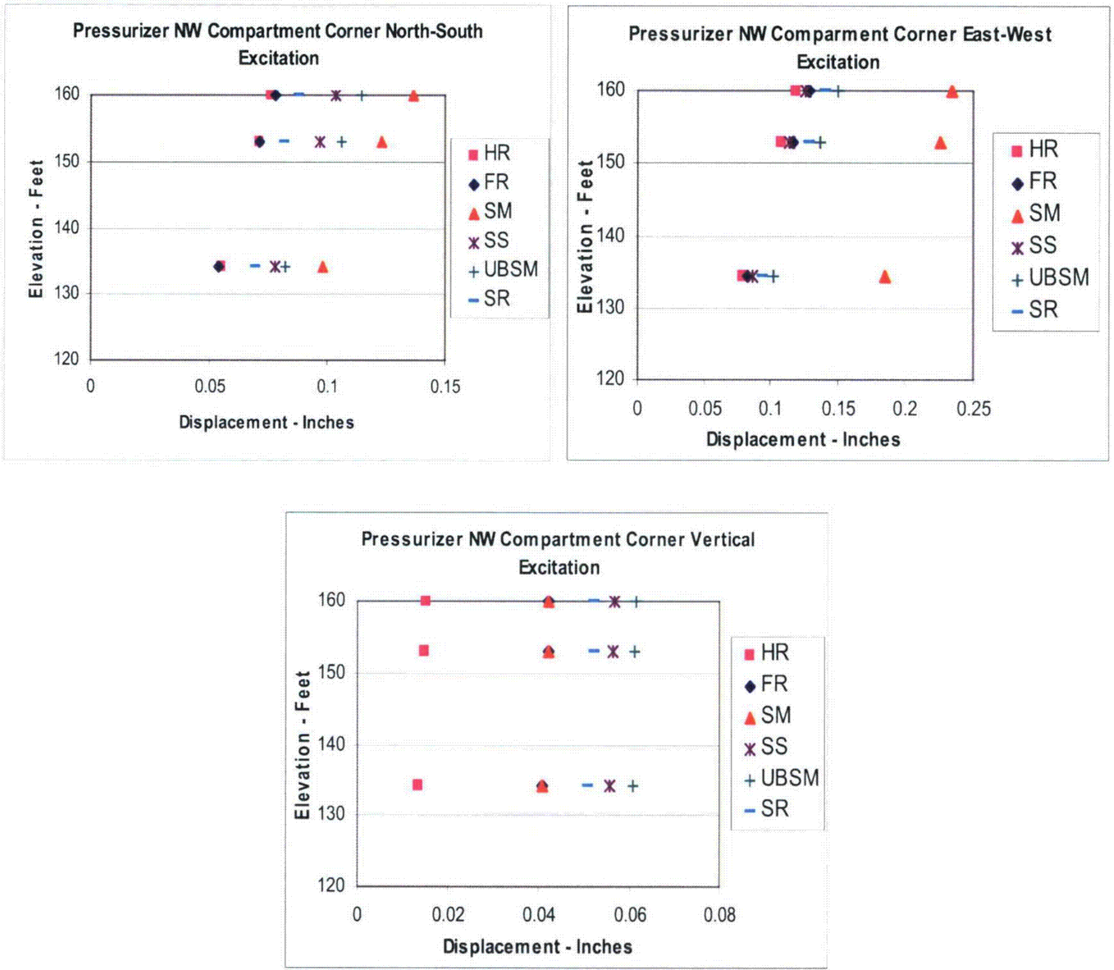


Figure 6.3-5 – Deflection Plots of Pressurizer Compartment NW Corner

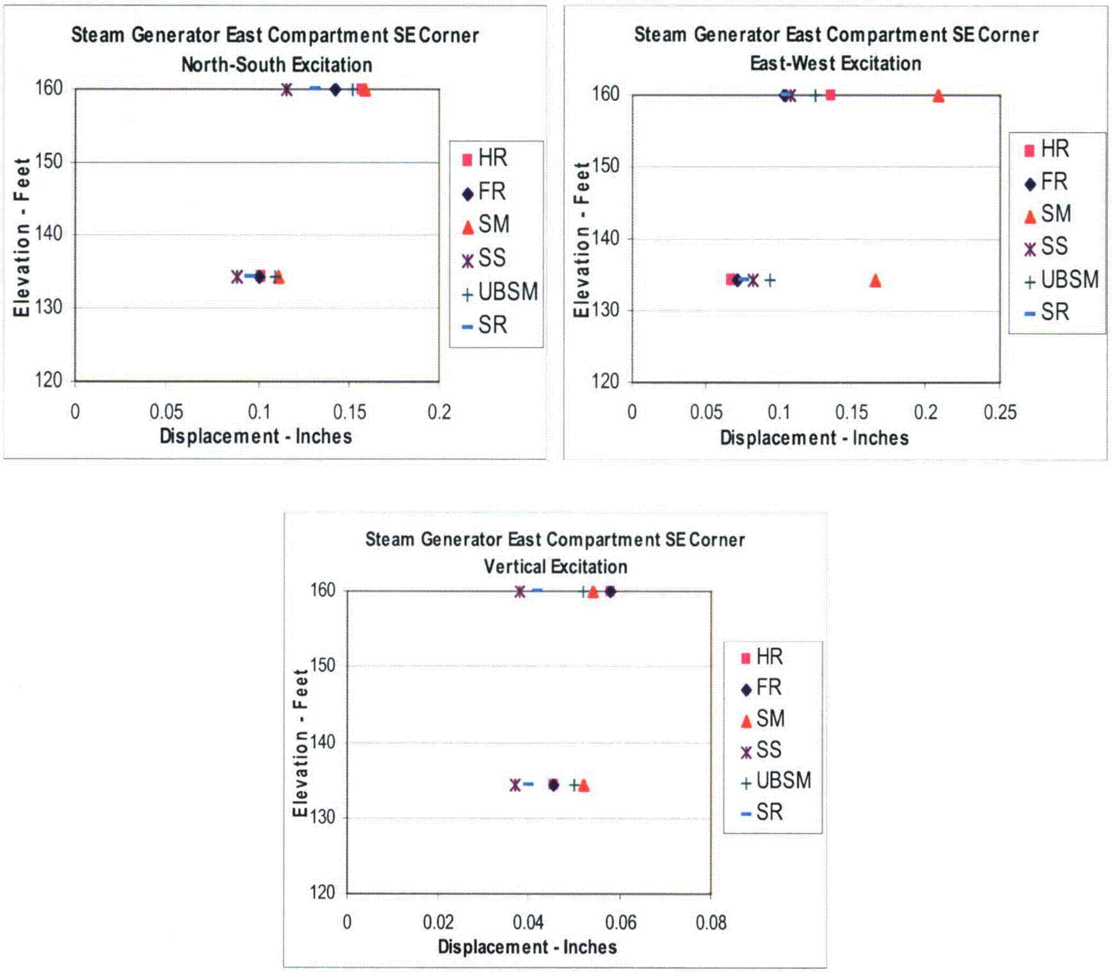


Figure 6.3-6 – Deflection Plots of East SG Compartment SE Corner

6.4 Response Spectrum Analysis

The input spectra are envelopes of the design ground motion spectra (Figures 2.1-1 and 2.1-2) which are applicable for hard rock, and of the basemat response spectra for 5 soil types (Firm Rock, Soft Rock, Upper Bound Soft to Medium, Soft to Medium and Soft Soil) obtained from SASSI analyses. The soil input spectra is the envelope of the center, edge, and corner nodes of the ASB basemat at elevation 60.5'. The nodes enveloped are shown in Figure 6.4-1. The input spectra are applied at the Nuclear Island basemat.

Composite modal damping is calculated for each mode of the building model. The spectra input in the response spectrum analyses are interpolated from the spectra at variable damping based on the composite modal damping at each frequency. The design spectrum for the AP1000 Auxiliary and Shield Building varies between 5% to 7% of critical damping in both horizontal and vertical directions. The design spectra based on composite modal damping are shown in Figures 6.4-2 through 6.4-4.

The response spectrum methodology used in the AP1000 design employs the Complete Quadratic Combination (CQC, Section 1.1 of Reference 12) grouping method for closely spaced modes with the Der Kiureghian Correlation Coefficient (Section 1.1.3 of Reference 12) used for correlation between modes. The Lindley-Yow (Section 1.3.2, Reference 12) 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 12) is employed for the residual rigid response component for each mode as outlined in NRC Reg. Guide 1.92 (Reference 12). The complete solution is developed via Combination Method B (Section 1.5.2, Reference 12). 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 12).

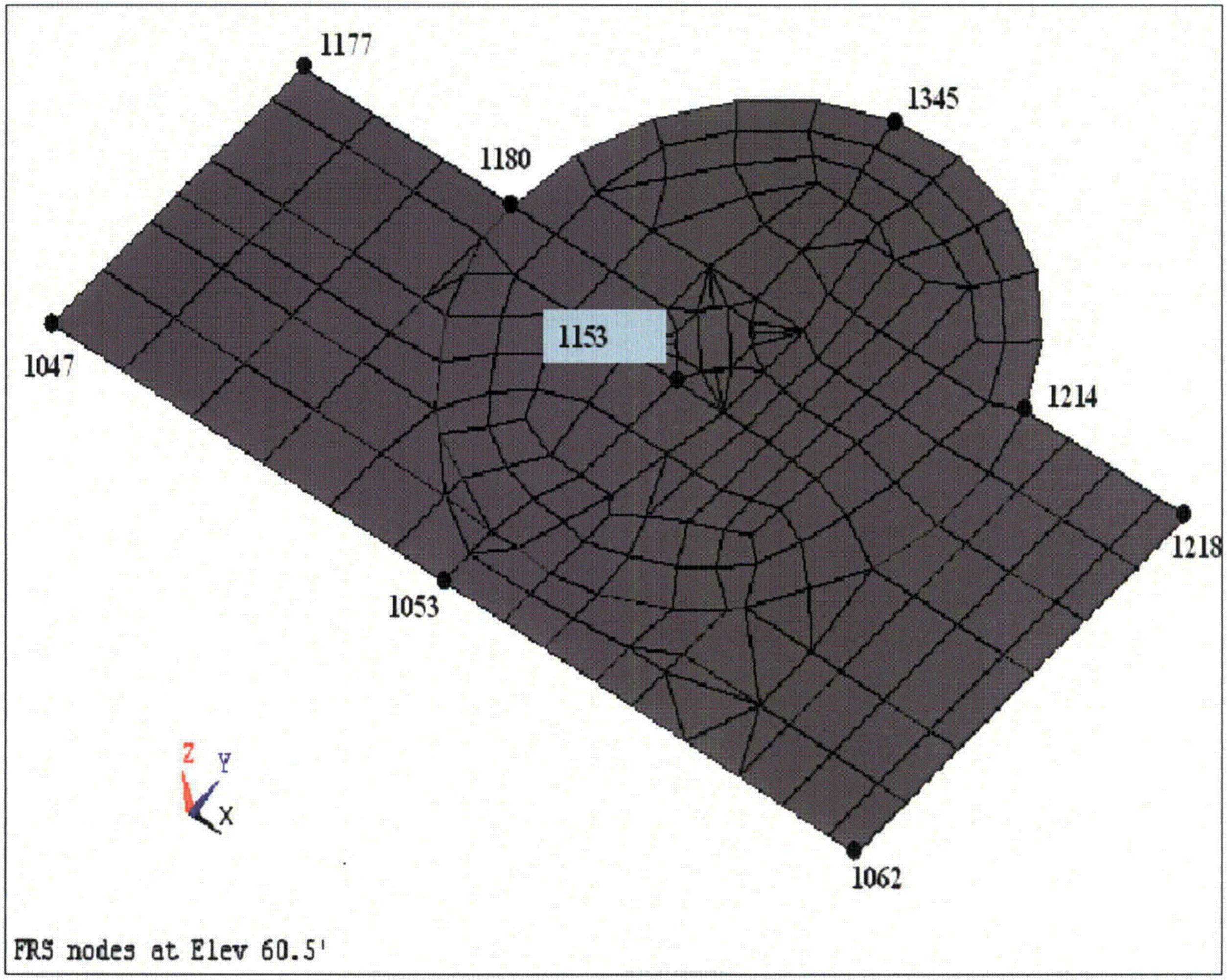


Figure 6.4-1– Nodes Enveloped for AP1000 Basemat Spectral Input

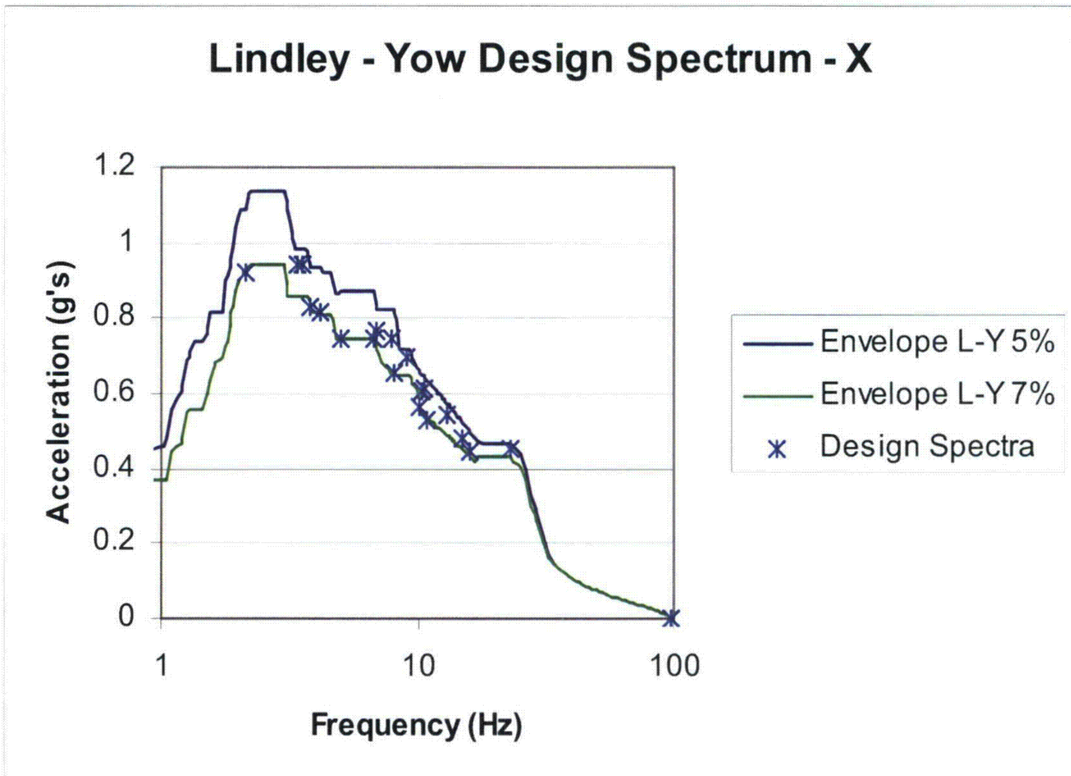


Figure 6.4-2– AP1000 North-South Direction Design Response Spectra

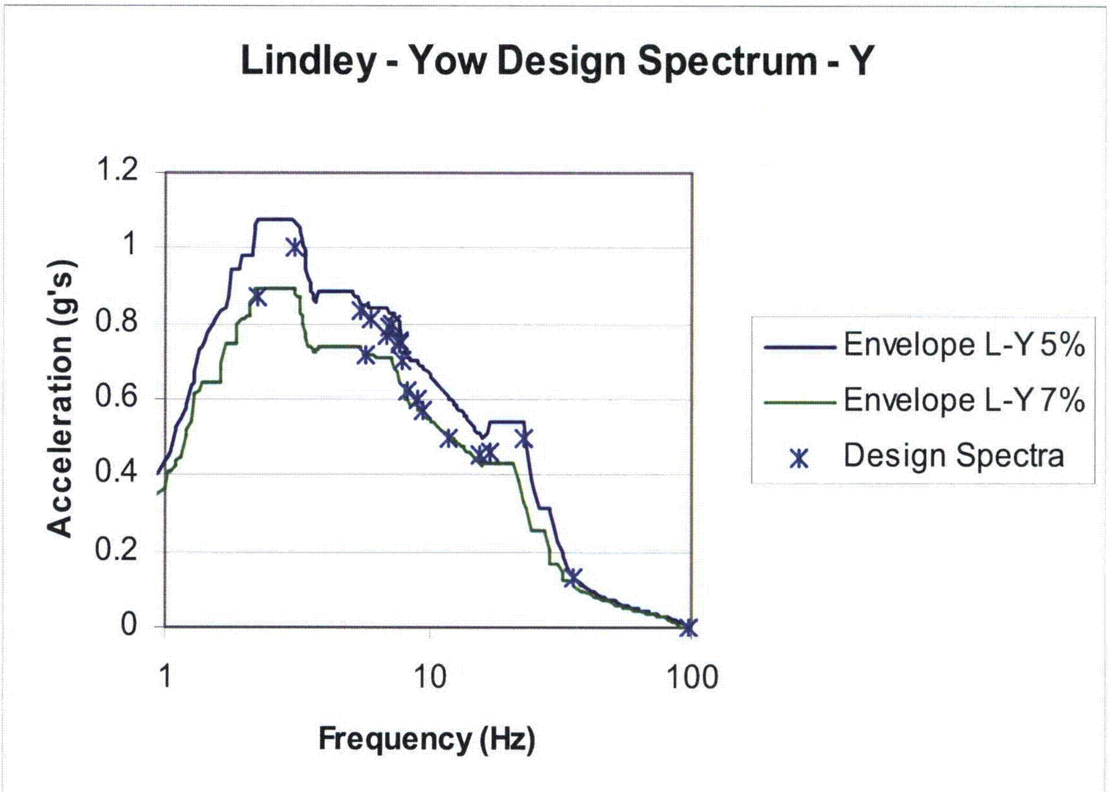


Figure 6.4-3 - AP1000 East-West Direction Design Response Spectra

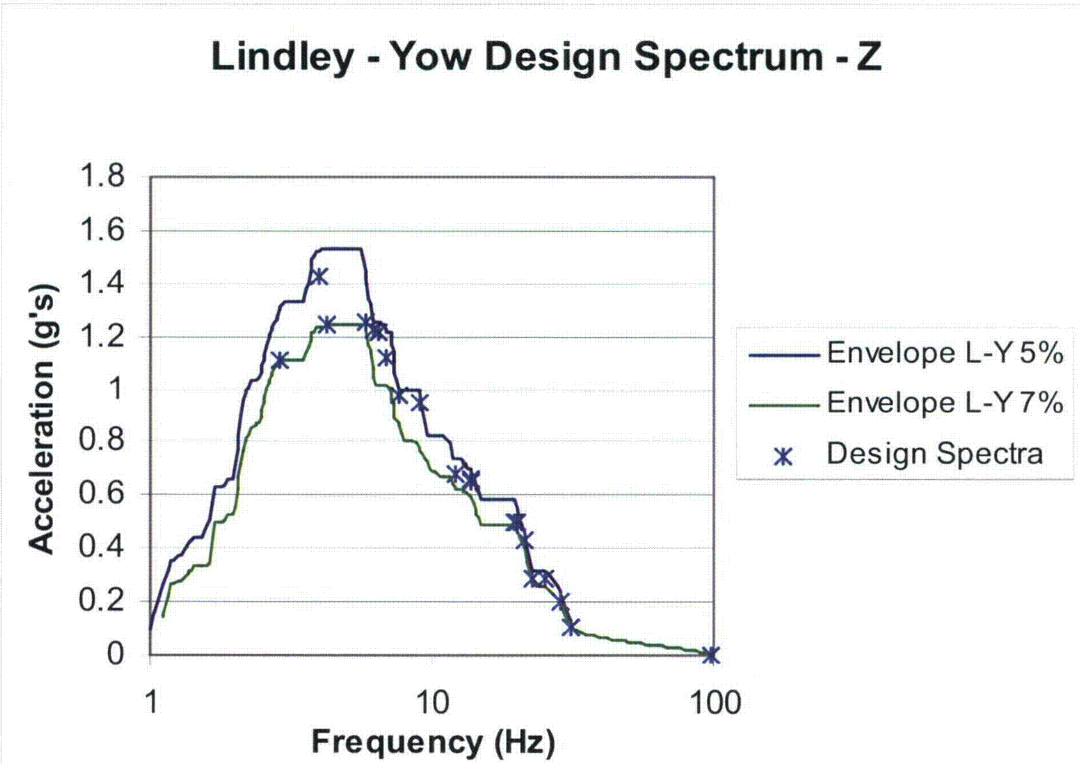


Figure 6.4-4 - AP1000 Vertical Direction Design Response Spectra

6.5 Equivalent Static Analyses

Equivalent static accelerations are applied to building models to obtain stresses and member forces for the design of the containment vessel and the nuclear island basemat. The accelerations applied in these analyses are the maximum accelerations obtained from time history analyses of the nuclear island. These accelerations are from previous iterations of the nuclear island seismic analyses but are consistent with those from the most recent analyses shown in Section 6.2. Use of the accelerations for the containment vessel is justified in Reference 13 by comparison of the member forces in the stick model obtained from equivalent static analyses against those obtained form the nuclear island time history seismic analyses. Use of the accelerations for the nuclear island basemat is justified in Reference 14 by comparison of the basemat reactions obtained from equivalent static analyses against those obtained from the nuclear island time history seismic analyses for hard rock and comparisons of hard rock and soil dynamic results.

7.0 Nuclear Island Liftoff Analyses

7.1 Hard rock site

The effect of liftoff during the safe shutdown earthquake of 0.3g on a hard rock site was described in the response to DSER Open Item 3.7.2.3-1 (Reference 4). The effect of liftoff during the review level earthquake of 0.5g on a hard rock site was described in the response to DSER Open Item 19A.2-8 (Reference 9).

Lift off was evaluated using an East-West lumped-mass stick model of the nuclear island structures supported on a rigid basemat with nonlinear springs. This model is shown in Figure 7.1-1. The liftoff analysis model consists of the following two elements:

1. The nuclear island (NI) combined stick model (ASB, CIS and SCV). The three sticks are concentric and the reactor coolant loop is included as mass only.
2. The rigid basemat model with horizontal and vertical rock springs

Analyses at the safe shutdown earthquake (SSE) level were performed on a model with an equivalent rectangular basemat of 140.0' × 234.5'. Analyses at the review level earthquake (RLE) level were performed initially with the same rectangular basemat. Later analyses used the actual footprint of the basemat. The overall width is 161' whereas the equivalent rectangle only had a width of 140'. Both have the same overturning resistance in linear analyses where soil springs take tension. Both models have the same eccentricity between the center of mass of the nuclear island and the centroid of the basemat.

Hard rock with a shear wave velocity of 8000 feet per second is modeled as horizontal and vertical spring elements with viscous damping at each node of the rigid beam. The NI combined stick is attached to the rigid basemat at the NI gravity center, which is about 9 feet from the center of the rigid basemat. In north-south direction, the stick is fixed at the bottom (EL. 60.5'). The stiffness properties of the ASB and CIS in the NI combined stick model are reduced by a factor of 0.8 to consider the effect of cracking as recommended in Table 6-5 of FEMA 356.

Time history analyses are run by direct integration for dead load plus safe shutdown earthquake for two cases:

"*rocks_di*" with linear rock springs able to take both tension and compression

"*Liftoff*" with non-linear rock springs where the vertical springs act in compression only and the horizontal springs are active when the vertical spring is closed and inactive when the vertical spring lifts off.

Damping is included as mass and stiffness proportional damping matching the modal damping specified for each structure at frequencies of 3 and 25 Hertz.

The response to DSER Open Item 3.7.2.3.-1(Reference 4) tabulates the maximum member forces and moments for these two cases. The results show that the liftoff has insignificant effect on the SSE response

Floor response spectra

The responses to DSER Open Items 3.7.2.3-1 (Reference 4) and 19A.2-8 (Reference 9) show the floor response spectra in the horizontal and vertical directions at representative elevations of the auxiliary and shield building. Typical results are shown in Figures 7.1-2 and 7.1-3 for the SSE and RLE spectra at elevation 116.5' in the ASB. The SSE figure also shows results with the soil springs reduced to 50% of the hard rock spring. The results show that the liftoff and rock stiffness have insignificant effect on the SSE response and a small increase at high frequencies for the RLE.

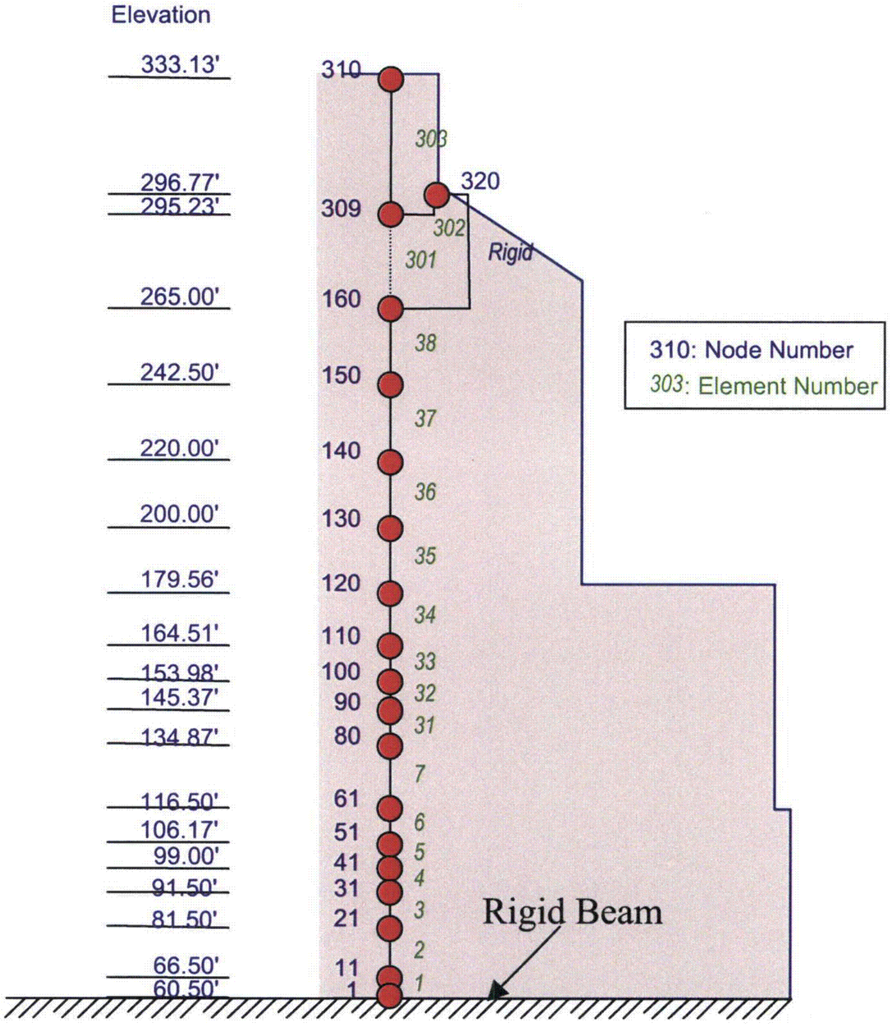
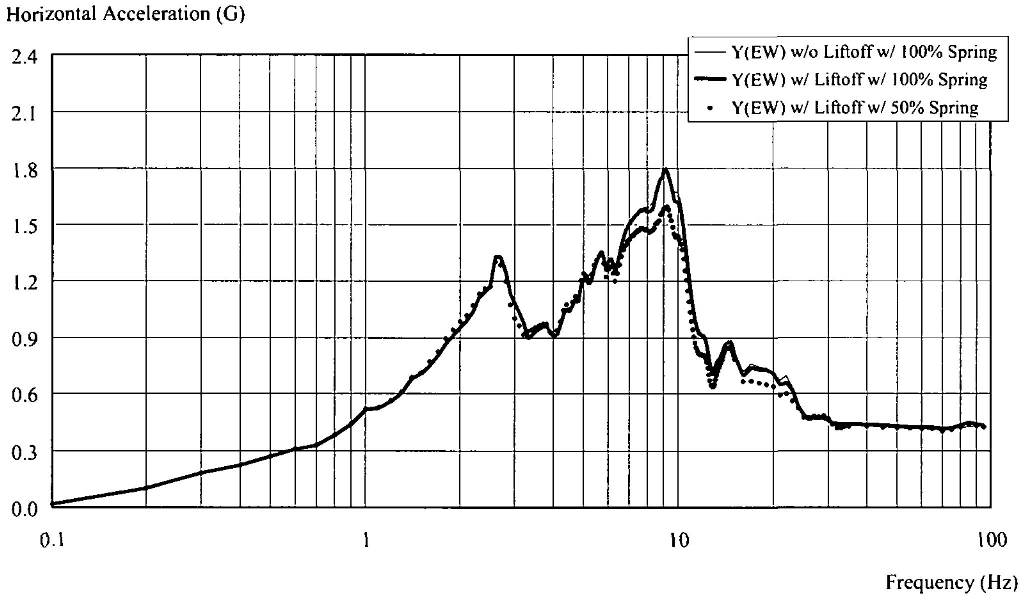


Figure 7.1-1 - ASB Stick portion of NI combined model



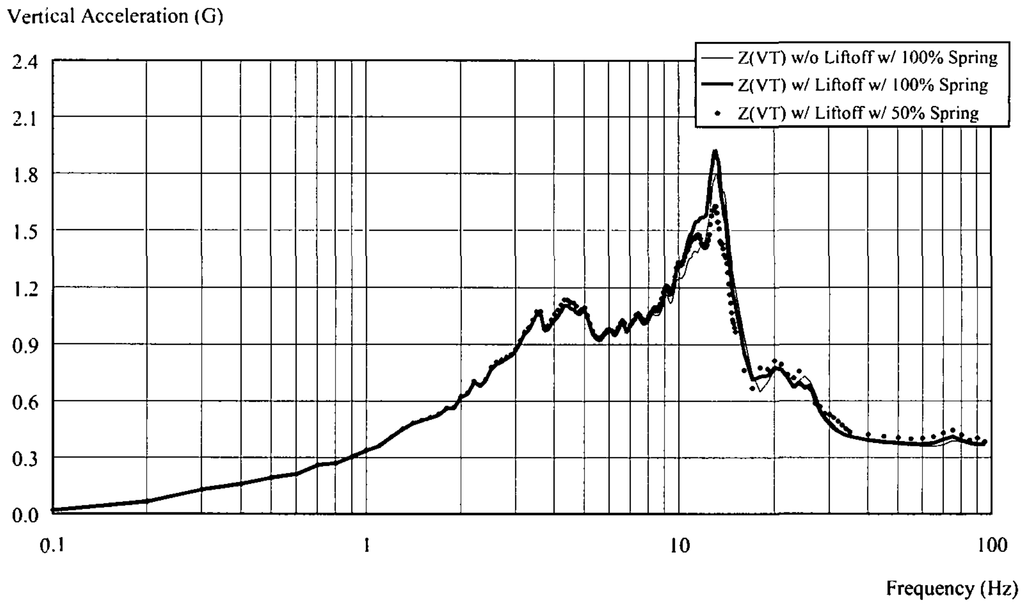


Figure 7.1-2 - SSE Floor Response Spectra at 5 % Damping – Node 61 (EL. 116.50')

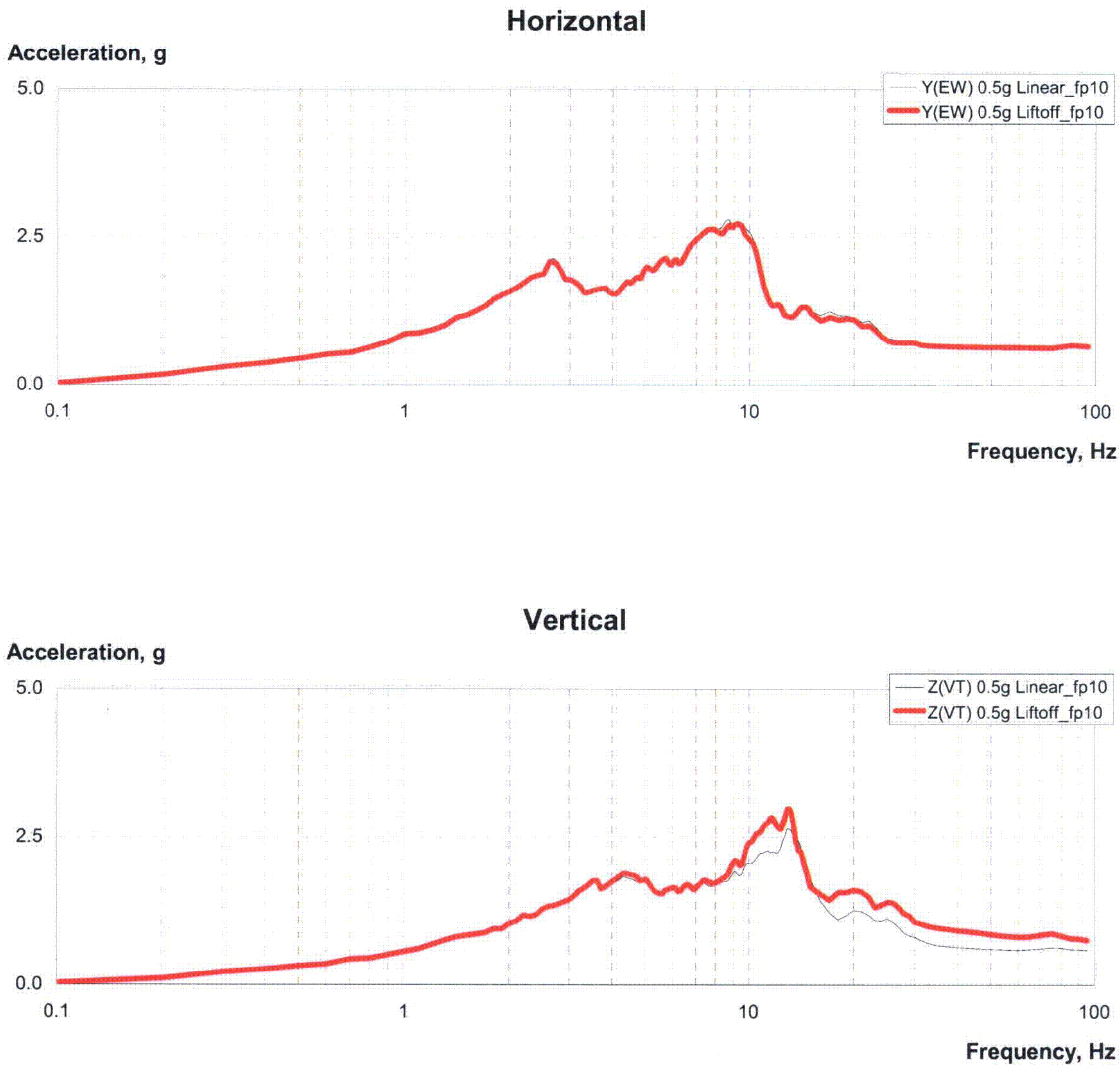


Figure 7.1-3 - RLE Floor Response Spectra of ASB Node at EL. 116.50'

7.2 Soil sites

The effect of liftoff during the safe shutdown earthquake of 0.3g and the review level earthquake of 0.5g was evaluated using the same approach described in section 7.1 for the hard rock site. The analyses used the East-West lumped-mass stick model of the nuclear island structures supported on a rigid basemat with nonlinear springs. The H2 (East-West components) and vertical components of the time histories were used to generate liftoff response in the 2D analyses. They were applied simultaneously. The actual footprint of the basemat was used in the analyses of the East-West model (see Figure 7.2-3).

Table 7-1 summarizes the properties of soil springs and dampers used in this calculation. The stiffness of the soil springs in the vertical direction in the ANSYS models were calculated for elastic layers of finite depth by means of the Steinbrenner approximation. This same approach was used for calculation of the soil springs in the AP600 nuclear island basemat analyses. The depth to bedrock was 120 feet. The stiffness of soil springs in the horizontal direction was calculated from that in the vertical direction assuming that the ratio of horizontal and vertical stiffness for the layered site has the same relationship as for a semi-infinite medium.

Damping was modeled in the ANSYS analyses using Rayleigh damping to match modal damping at 3 and 25 hertz. The value of modal damping shown in Table 7.1 was selected to match member forces from the corresponding 2D SASSI analyses described in section 4.4.1. The soil damping is low (2%) for the soft rock case, 5% for the soft to medium soil case and increases to 30% for the soft soil case.

FRS comparisons of the ASB stick were performed to check the adequacy of the calculated soil spring properties. The peaks match reasonably for all cases. However, the 2D ANSYS results are significantly higher in the high frequency range compared with the 2D SASSI results. The calculated soil spring stiffness and damping are considered adequate because the results of the 2D ANSYS analyses match the peaks of FRS and member forces/moments reasonably to the 2D SASSI analyses.

Linear analyses of the ANSYS models showed that the soft-to-medium soil case gave the maximum base shear force and overturning moment. Hence, a non-linear lift off analysis was performed for the soft-to-medium soil case. Linear and non-linear (liftoff) analyses were performed for the SSE input of 0.3g and the RLE (review level earthquake) input of 0.5g. The linear analysis uses linear soil springs, and the non-linear (liftoff) analysis uses non-linear soil springs that are inactive when a basemat node is higher than its initial location without loads.

Basemat Displacements

Figure 7.2-1 shows the time history of uplift displacements at the basemat edges. Maximum uplift at the east edge occurs at the time around 5 seconds for both linear and non-linear (liftoff) analyses. Maximum lift off is 0.31 inches. This is higher compared with the hard rock case result of 0.07 inches described in section 7.1. The increase ratio is about equal to the inverse of the soil spring stiffness (1000 versus 6267 kcf).

Floor Response Spectra

Figure 7.2-1 compares the SSE FRS between linear and non-linear (liftoff) analyses. The lift off effect on FRS is similar with those for the hard rock case; it is visible but insignificant. Figure 7.2-2 compares RLE FRS between linear and non-linear (liftoff) analyses. The liftoff effect on FRS is similar with those for the hard rock case; it is insignificant in the horizontal direction and visible in the vertical direction at high frequency range.

Table 7-2-1 - ANSYS Soil Spring Property

	Assumption of Soil Conditions				
	Soil Material Property		ANSYS Soil Spring Property		
	Density pcf	Poisson's Ratio	Stiffness kcf		Damping %
			Vertical	East-West	
Soft-to-medium Soil	110	0.35	1000	814	5

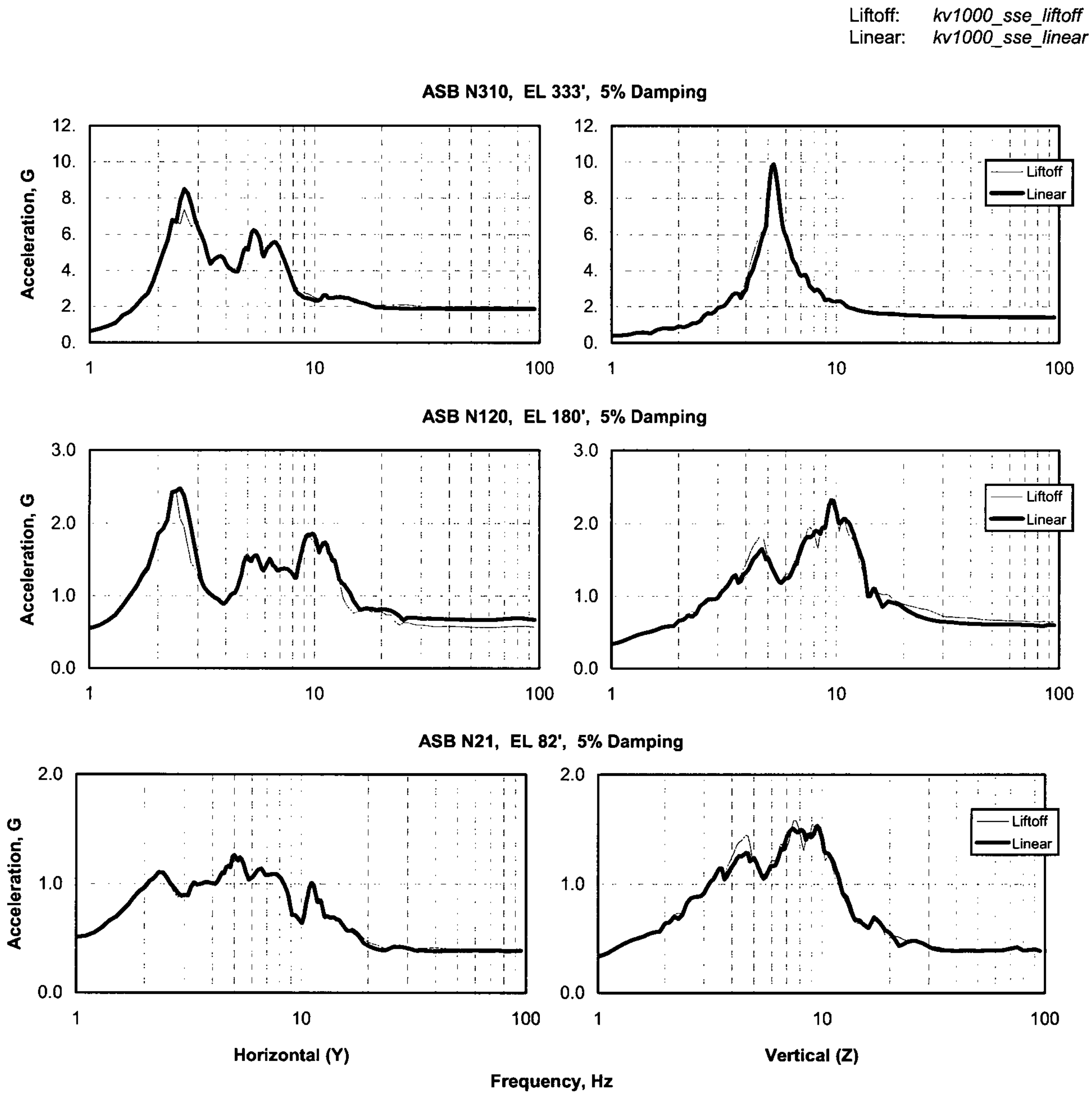


Figure 7.2-1 - ANSYS Lift Off Effects on FRS (SSE) Soft to medium Soil

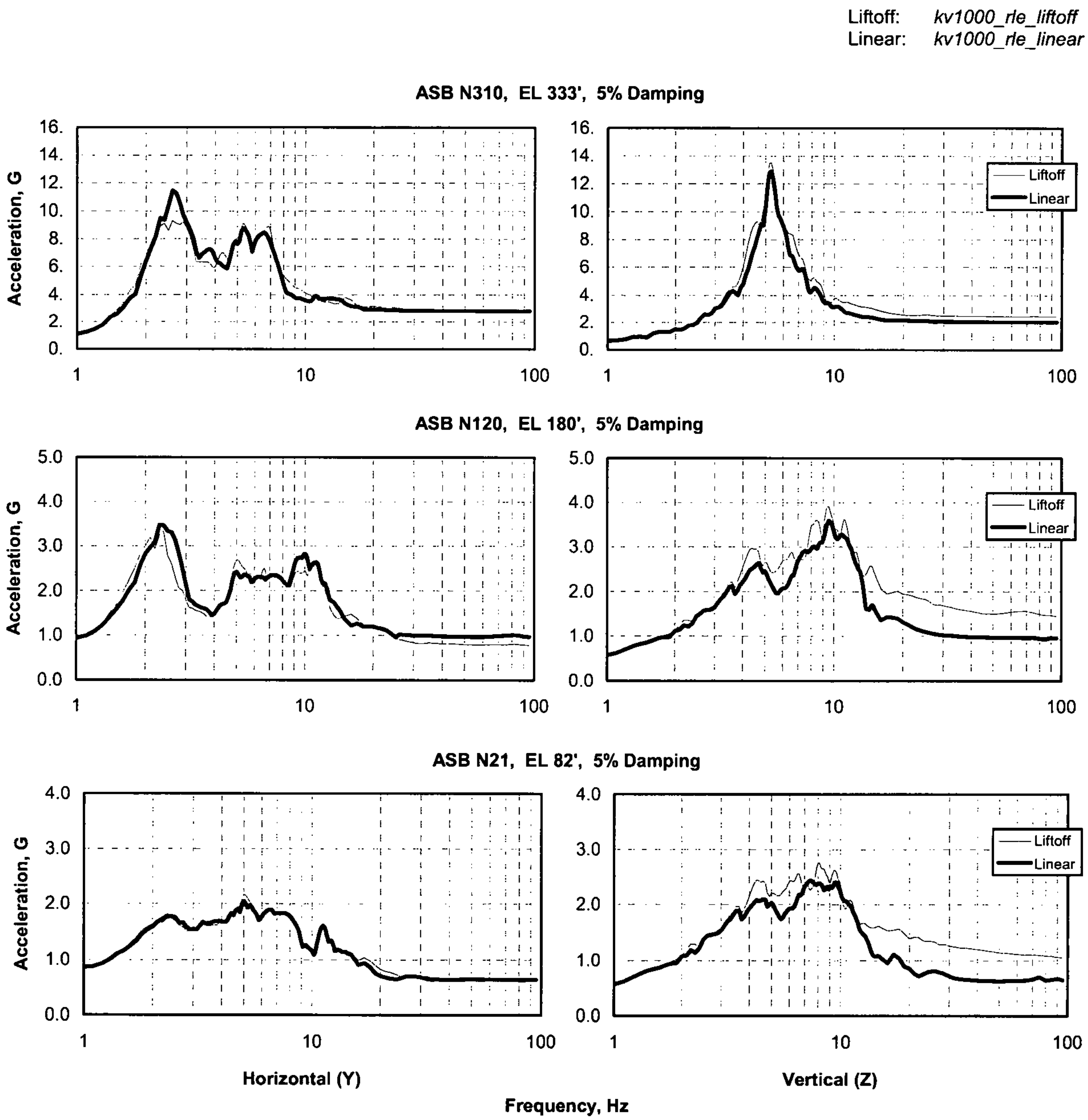
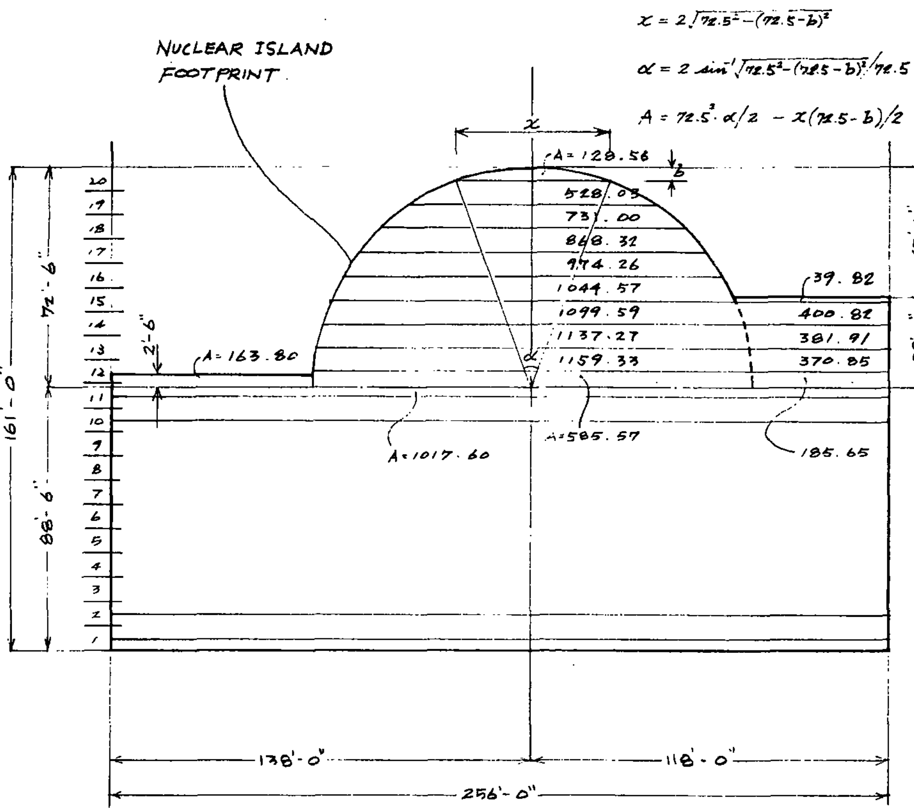


Figure 7.2-2 - ANSYS Lift off Effects on FRS (RLE) Soft to Medium soil



NODE	Y (ft)	AREA (ft²)
621	1072.50	128.6
620	1064.45	528.0
619	1056.40	731.0
618	1048.35	868.3
617	1040.30	974.3
616	1032.25	1084.4
615	1024.20	1500.4
614	1016.15	1519.2
613	1008.10	1530.2
612	1000.05	1952.6
611	992.00	2060.8
610	983.95	"
609	975.90	"
608	967.85	"
607	959.80	"
606	951.75	"
605	943.70	"
604	935.65	"
603	927.60	"
602	919.55	2060.8
601	911.50	1030.4

Σ AREA 32455.4

Σ Y × AREA 31726957.8

ΣAY/ΣA = 977.6

EQUAL WITH EQUIVALENT RECTANGULAR CENTER. OK

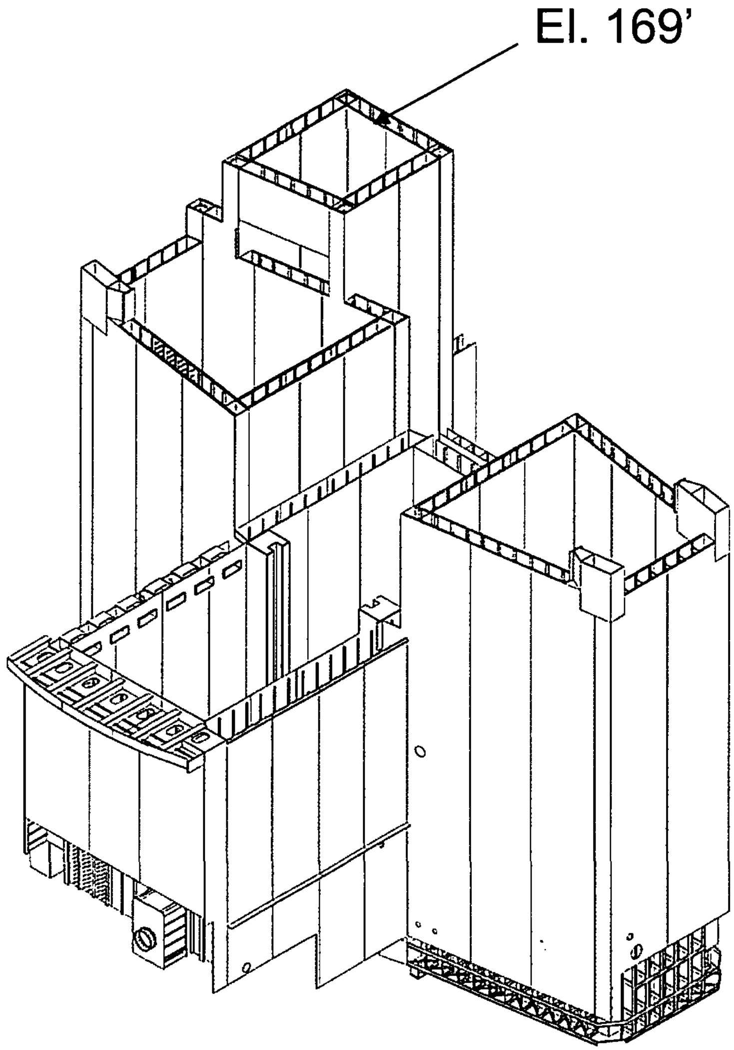
Figure 7.2-3 - Modeling of Actual Footprint in East-West Model

8.0 References

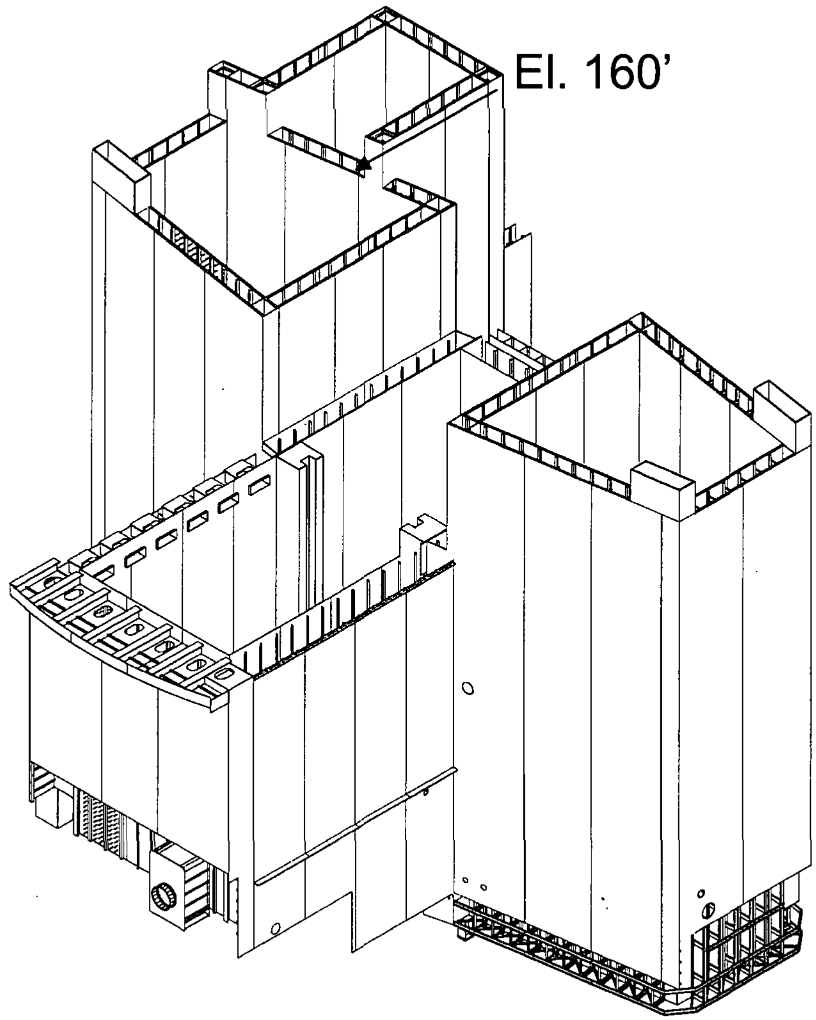
1. APP-GW-GL-700, AP1000 Design Control Document, Section 3.7, Revision 15.
2. NUREG 1793, NRC "Final Safety Evaluation Report for AP1000 Design," September 2004.
3. Regulatory Guide 1.60, Design Response Spectra for Seismic Design of Nuclear Power Plants, Rev. 1.
4. DSER Open Item 3.7.2.3-1, Rev. 1, Transmitted in DCP/NRC 1625, September 11, 2003.
5. APP-GW-GLR-016, AP1000 Pressurizer Design.
6. NUREG-800, Review of Safety Analysis Reports for Nuclear Power Plants, Section 3.7.2, Seismic System Analysis, Rev. 2.
7. GW-GL-700, AP600 Design Control Document, Appendices 2A and 2B, Revision 4.
8. Not Used.
9. DSER Open Item 19A.2-8, Transmitted in DCP/NRC 1599, June 24, 2003.
10. H.B. Seed, and I.M. Idriss, "Soil Moduli and Damping Factors for Dynamic Response Analysis," Report No. EERC-70-14, Earthquake Engineering Research Center, University of California, Berkeley, 1970.
11. EPRI TR-102293, "Guidelines for Determining Design Basis Ground Motions, 1993.
12. U.S. NRC Regulatory Guide 1.92, Rev. 2, "Combining Modal Responses and Spatial Components in Seismic Analysis."
13. APP-GW-GLR-005, "Containment Vessel Design Adjacent to Large Penetrations," Rev 1.
14. APP-GW-GLR-044, "Nuclear Island Basemat and Foundation," Rev. 0.

Appendix A – Pressurizer Compartment Sketches

In this appendix are shown the changes to the pressurizer compartment (Reference 5). As shown the compartment walls are not as high.



Old



New

Appendix B – Response Spectra Node Grouping

This appendix provides tables showing the grouping of the nodes used to develop the seismic design response spectra for the auxiliary and shield building (ASB) and the containment internal structure (CIS). The grouping is based on elevation and location within the Nuclear Island. Grouping was made for the ASB and CIS that included the steam generator (SG) and pressurizer compartments. See Section 4.2.3 for the figures that show the location of the nodes.

Response Spectra groups listed below are intended for equipment and piping systems whose supports extend over large areas. Smaller groups of spectra can be used for equipment or piping that are supported in a limited area.

Table B-1 – ASB Nodes for FRS Envelopes (EL 99' to 163')

FRS name	Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
			Auxiliary and Shield Building			
ASB99	1676	2391	1070.5	992	100	SBC north
	1585	2376	1005.2	929.2	100	SBC east
	1688	2406	929	1000	100	SBC south
	1750	2595	1005.4	1070.8	100	SBC west
	1564	4084	862.5	913	100	ASB SE 1I
	1685	4115	862.5	1000	100	ASB SW 1N
	1574	4233	1045.8	913	100	ASB 7.3I
	1579	4380	1116.5	913	100	ASB NE 11I
	1719	4399	1116.5	1027.5	100	ASB NW 11Q
	1567	6614	929	913	100	ASB 4I
ASB 116.5 C. ROOM	2063	4681	1093	930.5	116.5	
	2055	4632	1072.6	913	116.5	
	2076	4718	1116.5	913	116.5	
	2057	4623	1072.6	948.5	116.5	
	2078	4724	1116.5	948.5	116.5	
ASB 34-116	2030	4548	1005.2	922.3	116.5	ASB 7I (flexible node)
	2034	4556	1018.2	923	116.5	ASB 7I (flexible node)
	2038	4570	1034.2	924.5	116.5	ASB 7I (flexible node)
ASB135	2319	5054	1070.5	992	134.9	SBC north
	2296	4961	1005.2	929.2	134.9	SBC east
	2274	5744	929	1000	134.9	SBC south
	2297	7648	1005.4	1070.9	134.9	SBC west
	2347	6821	1116.5	1027.5	134.9	ASB NW
	2247	4764	862.5	913	134.9	ASB SE
	2253	4795	862.5	1000	134.9	ASB SW
	2268	4886	929	913	134.9	ASB 4I
	2306	4984	1045.8	913	134.9	ASB 7.3I
	2341	5109	1116.5	913	134.9	ASB NE
ASB34-135	2295	4959	1005.2	922.3	134.9	ASB 7I (flexible node)
	2299	4967	1018.2	923	134.9	ASB 7I (flexible node)
	2303	4981	1034.2	924.5	134.9	ASB 7I (flexible node)
ASB4-135	2281	4925	950	931	134.9	ASB 4I (flexible node)
	2287	4939	970.4	931	134.9	ASB 4I (flexible node)

Table B-2 – ASB Nodes for FRS Envelopes (EL 163' to 327')

FRS Name	Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
	Auxiliary and Shield Building					
ASB160	2505	5538	1070.5	992	152.6	SBC north
	2627	5487	1005.2	929.19	159.9	SBC east
	2637	5510	1045.8	913	159.9	ASB 7.3I
	2640	5515	1045.8	945.71	159.9	SBC 7.3
	2528	5351	1116.5	913	152.6	ASB NE
	2534	5370	1116.5	1027.5	152.6	ASB NW
	2600	6955	929	913	159.9	ASB 4I
ASB34-160	2626	5485	1005.2	922.3	159.9	ASB 7-7.2I (flexible node)
	2630	5494	1018.2	923	159.9	ASB 7-7.2I (flexible node)
	2634	5507	1034.2	924.5	159.9	ASB 7-7.2I (flexible node)
ASB180	2722	6153	1070.5	992	180.1	SBC north
	2710	6054	1005.2	929.2	180.1	SBC east
	2675	5754	929	1000	179.2	SBC south
	2711	7719	1005.4	1070.9	180.1	SBC west
	2668	5574	862.5	1000	179.2	ASB SW
	2662	5543	862.5	913	179.2	ASB SE
	2669	5703	929	913	179.2	ASB 4I
ASB56-180	2695	5628	895.8	942.8	179.9	ASB 2 (flexible node)
	2697	5633	895.8	971.2	179.9	ASB 2 (flexible node)
ASB230	2823	8049	1069.6	986.1	236.3	SBC north
	2809	8035	1000	929	236.3	SBC east
	2794	8050	929	1000	236.3	SBC south
	2810	8066	1000	1071	236.3	SBC west
ASB267	2900	8116	1071	1000	267.8	SBC north
	2884	8100	1000	929	267.8	SBC east
	2869	8115	929	1000	267.8	SBC south
	2885	8131	1000	1071	267.8	SBC west
ASB289	3103	8317	1043.5	1000	289.2	SBR north
	3087	8301	1000	956.5	289.2	SBR east
	3072	8316	956.5	1000	289.2	SBR south
	3088	8332	1000	1043.5	289.2	SBR west
	3067	8296	1000	1000	289.1	
ASB327	3360	8574	1043.5	1000	327.4	SBR north
	3344	8558	1000	956.5	327.4	SBR east

	3329	8573	956.5	1000	327.4	SBR south
	3345	8589	1000	1043.5	327.4	SBR west

Table B-3 – CIS Grouping for Enveloping all Node FRS on Elevation

FRS name	Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
			Containment Internal Structures			
CIS99	1688	2406	929	1000	100	SBC south
	1761	130401	1000	1000	100	CV stick
	1676	2392	1070.5	992	100	SBC east
	1750	2595	1005.4	1070.8	100	SBC west
	1585	2376	1005.2	929.2	100	SBC north
CIS134	2217	106962	1022.8	1040.8	134.3	Pressurizer
	2216	106958	1022.8	1024.2	134.3	Pressurizer
	2184	106805	1002.1	1046.2	134.3	SG west
	2199	105772	1008	1014	134.3	SG west
	2162	105773	978	1014	134.3	SG west
	2170	106819	982.9	1046.2	134.3	SG west
	2197	105805	1008	986	134.3	SG east
	2183	107241	1002.1	953.8	134.3	SG east
	2169	107252	982.9	953.8	134.3	SG east
	2159	105806	978	986	134.3	SG east
	2244	105852	1057	1024.2	134.3	IRWST North
	2138	105955	942.5	1014	134.3	RC south
	2136	106300	942.5	986	134.3	RC south
	2181	111745	994.2	930.1	134.3	East
CIS153	2546	106806	1002.1	1046.2	153	SG west
	2552	105868	1007.6	1016.2	153	SG west
	2536	105875	978.34	1016.2	153	SG west
	2540	106760	982.9	1046.2	153	SG west
	2547	106899	1003.1	1040.8	153	PZR
	2550	106428	1006	1024.8	153	PZR
	2560	106166	1022.8	1024.2	153	PZR
	2562	106160	1022.8	1040.8	153	PZR
	2551	105975	1007.6	983.8	153	SG east
	2545	107235	1002.1	953.8	153	SG east
	2539	107256	982.9	953.8	153	SG east
	2535	105982	978.3	983.8	153	SG east
CIS160	2646	106216	1003.1	1040.8	160	
	2652	106163	1022.8	1040.8	160	
	2650	106174	1022.8	1024.2	160	
	2647	106204	1006	1024.8	160	

FRS name	Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
IRWST	2154	110671	971.5	1055.8	134.3	
	2229	110701	1036.7	1050.9	134.3	

Table B-3 – CIS Grouping for Enveloping all Node FRS on Elevation (cont.)

FRS name	Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
	Containment Internal Structures					
134cisWEST	2170	106819	982.9	1046.2	134.3	SG west
	2184	106805	1002.1	1046.2	134.3	SG west
	2162	105773	979.3	1014.0	134.3	SG west
	2199	105772	996.7	1014.0	134.3	SG west
	2216	106958	1022.8	1024.2	134.3	Pressurizer
	2217	106962	1022.8	1040.8	134.3	Pressurizer
134cisEAST	2169	107252	982.9	953.8	134.3	SG east
	2159	105806	978	986	134.3	SG east
	2183	107241	1002.1	953.8	134.3	SG east
	2197	105805	1008	986	134.3	SG east
153cisWEST	2540	106760	982.9	1046.2	153	SG west
	2546	106806	1002.1	1046.2	153	SG west
	2536	105875	978.3	1016.2	153	SG west
	2552	105868	1007.6	1016.2	153	SG west
	2560	106166	1022.8	1024.2	153	PZR
	2562	106160	1022.8	1040.8	153	PZR
	2547	106899	1003.1	1040.8	153	PZR
	2550	106428	1006	1024.8	153	PZR
153cisEAST	2551	105975	1007.6	983.8	153	SG east
	2545	107235	1002.1	953.8	153	SG east
	2539	107256	982.9	953.8	153	SG east
	2535	105982	978.3	983.8	153	SG east

Table B-4 – Steel Containment Vessel

FRS name	Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
	Steel Containment Vessel and Polar Crane					
SCV132	2134	130406	1000	1000	131.7	Lower stiffener
SCV170	2656	130410	1000	1000	169.93	mid
SCV224	2788	130412	1000	1000	224	PC
SCV241	2828	130633	1000	1000	236.5	PC
SCV282	3030	130417	1000	1000	281.9	Top of SCV

Table B-5 – Reactor Coolant Loop FRS Nodes

FRS name	Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
	Reactor Coolant Loop					
RCL Cold Legs	1774	137047	982.3	987.6	102.7	
	1775	137147	982.3	1012.5	102.7	
	1809	137036	1002.7	987.6	102.7	
	1810	137136	1002.7	1012.5	102.7	
	1805	137038	1000.2	977	102.7	
	1778	137049	984.8	977	102.7	
	1806	137138	1000.2	1023	102.7	
	1779	137149	984.8	1023	102.7	
RCL Hot Legs	1772	137187	992.5	1014.9	101.3	
	1812	137189	992.5	1022.7	103.11	
	1763	137087	992.5	985.1	101.3	
	1811	137089	992.5	977.3	103.1	

FRS name	Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
	RCL Support Locations					
	2568	106767	981.9	1039.5	156.4	
SG Top Support	2573	106901	1003.1	1040.8	156.35	
	2575	107231	1003.3	960.5	156.35	
	2566	107338	981.9	960.5	156.35	
	1933	108940	980.5	970	107.2	
	2167	109009	981.64	1037.8	134.25	
SG Interm. RPV Support	2163	109015	979.25	1022.2	134.25	
	2186	109192	981.64	962.17	134.25	
	2195	109198	979.25	977.83	134.25	
	1947	109496	1005.1	1030	107.17	
RPV&SG Supports	1519	118089	992.5	1030	82.5	
	1436	118131	992.5	970	82.5	
	1559	117529	986	1006.5	100	
	1560	117527	999	1006.5	100	
	1554	117528	999	993.5	100	
	1553	117530	986	993.5	100	

Table B-6 – Pressurizer FRS Nodes

FRS name	Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
			Pressurizer			
PZR Bot	2085	137201	1014	1032.5	120.5	
PZR Top	2556	137207	1014	1032.5	153.0	
	2653	137210	1014	1032.5	161.9	
	2655	137220	1014	1032.5	167.3	ADS123
	2659	137230	1014	1032.5	178.0	ADS123

Table B-7 – Core Make-Up Tank

FRS name	Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
			Core Make-up Tank			
CMT	Not modeled for soil condition.	147201	954.5	973.17	106.71	
		147207	954.5	973.17	128.23	
		147301	1016	968.29	106.71	
		147307	1016	968.29	128.23	

Appendix C - Comparison of NI10 and NI20 Responses

In this Appendix the fine (NI10) and coarse (NI20) model seismic responses are compared. Seismic response spectra were developed for both models using a fixed base (hard rock) case. Also in this section the NI10 and NI20 ANSYS model is compared to the SASSI analysis results.

Figures C-1 to C-6 compare response spectra for ANSYS analyses of the NI10 and NI20 as well as the excavated SASSI model at the interface seismic response key nodes (see Section 4.4.3). These locations are given in Table C-1. Also shown in this table are the figures where the comparison spectra are given. The finite element models give comparable results below 10 hertz. However, the results from the coarse model are not as good at high frequencies (above about 15 hertz). Therefore, the hard rock FRS were generated from the fine NI10 model, and the coarse NI20 model was used for the soil site analyses where frequencies of interest are below 10 hertz.

A time history analysis for the Nuclear Island SASSI Surface Structure Model and the embedded structure model is carried out with the seismic input in three orthogonal directions. The acceleration response spectra for 5% damping are generated at the interface locations identified in Table C-1. The nodes chosen for "Sassi Surface Model" in figures C-1 to C-6 compare the Nuclear Island SASSI Surface Structure Model results with the Nuclear Island ANSYS Coarse Model (NI20) and Fine Model (ni10) results for hard rock conditions.

As seen from the comparison (see Figures C-1 to C-6), for the horizontal response, the SASSI and ANSYS results for NI20 are very similar to about 15 Hz horizontal and about 10 Hz vertical. At the higher frequencies, SASSI calculates higher accelerations. The NI20 model uses solid elements for the mass of concrete below grade inside the shield building. Other parts of the model use shell elements. The difference in ANSYS and SASSI results is most noticeable at the three lowest elevations where the response is most affected by the solid elements below grade. This behavior was investigated in a study comparing the SASSI and ANSYS responses using a reduced model with only the solid elements in the NI20 model. One reason for this conservatism in the SASSI results is the different formulation in the solid elements. Another difference is due to the different way the two computer programs calculate the dynamic response. ANSYS performs the dynamic response in the time domain. SASSI converts the time history input (time domain) to the frequency domain, solves the response in the frequency domain, and then converts the output back to the time domain.

SASSI also needs to specify key frequencies to perform its transfer function calculations. For such a large model, resting on a very stiff soil (hard rock), SASSI gives conservative results at high frequencies. The significant responses for soil cases occur at less than 10 Hz. Therefore, the SASSI Model is adequate for the AP1000 Soil-Structure Interaction analyses to be performed.

In a few cases it is found that the soil cases analyzed in SASSI using the NI20 model give higher results than the hard rock case using the NI10 model for frequencies above 10 Hz (see for example Figure 4.4.3-9). The reason for this is two-fold: mesh size and SASSI approximation. The NI20 SASSI model is a much coarser model than the NI10, at higher frequencies it cannot capture the local behavior as well as the NI10 and this causes some of the response to be higher. SASSI uses a limited number of transfer functions to obtain the dynamic response. This limited number (up to 100 frequencies) is an adequate approach when the medium that you are considering is soil, where only a few significant modes need to be captured to obtain the building response. At higher frequencies in shell models, many modes (or transfer frequencies) are required to obtain the building response. Although these cases are due to conservatism in the SASSI results at high frequency, the SASSI results are used in developing the broadened envelope design response spectra.

Table C-1 – Key Nodes at Location

Location	NI10 Node	NI20 Sassi	Figure ANSYS & SASSI FRS Comparaison	General Area	Elevation (feet)
CIS at Reactor Vessel Support Elevation	130401	1761	C-1	RPV Center	100.00
CIS at Operating Deck	105772	2199	C-2	SG West compartment, NE	134.25
ASB NE Corner at Control Room Floor	4724	2078	C-3	NE Corner	116.5
ASB Corner of Fuel Building Roof at Shield Building	5744	2675	C-4	NW Corner of Fuel Bldg	179.19
ASB Shield Building Roof Area	8573	3329	C-5	South side of Shield Bldg	327.41
SCV Near Polar Crane	130412	2788	C-6	SCV Stick Model	224.00

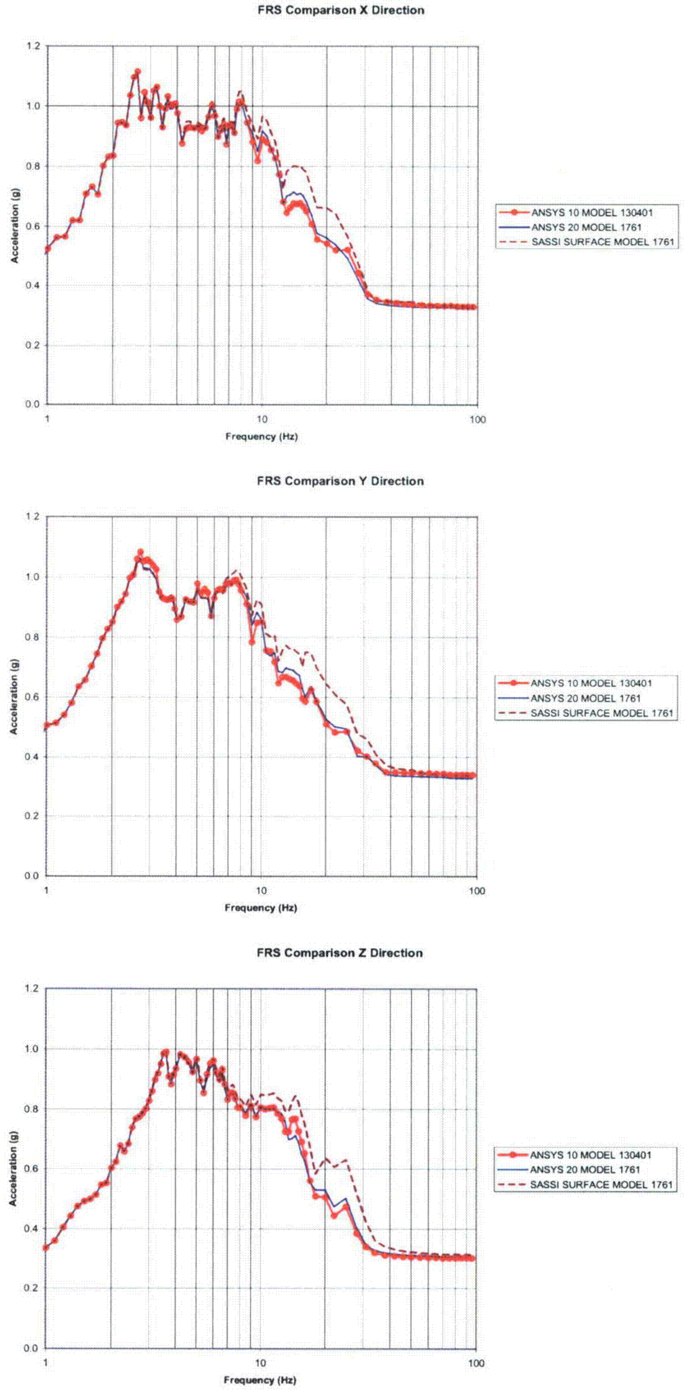


Figure C-1 – FRS Comparison at Base of SCV on CIS at RPV Center

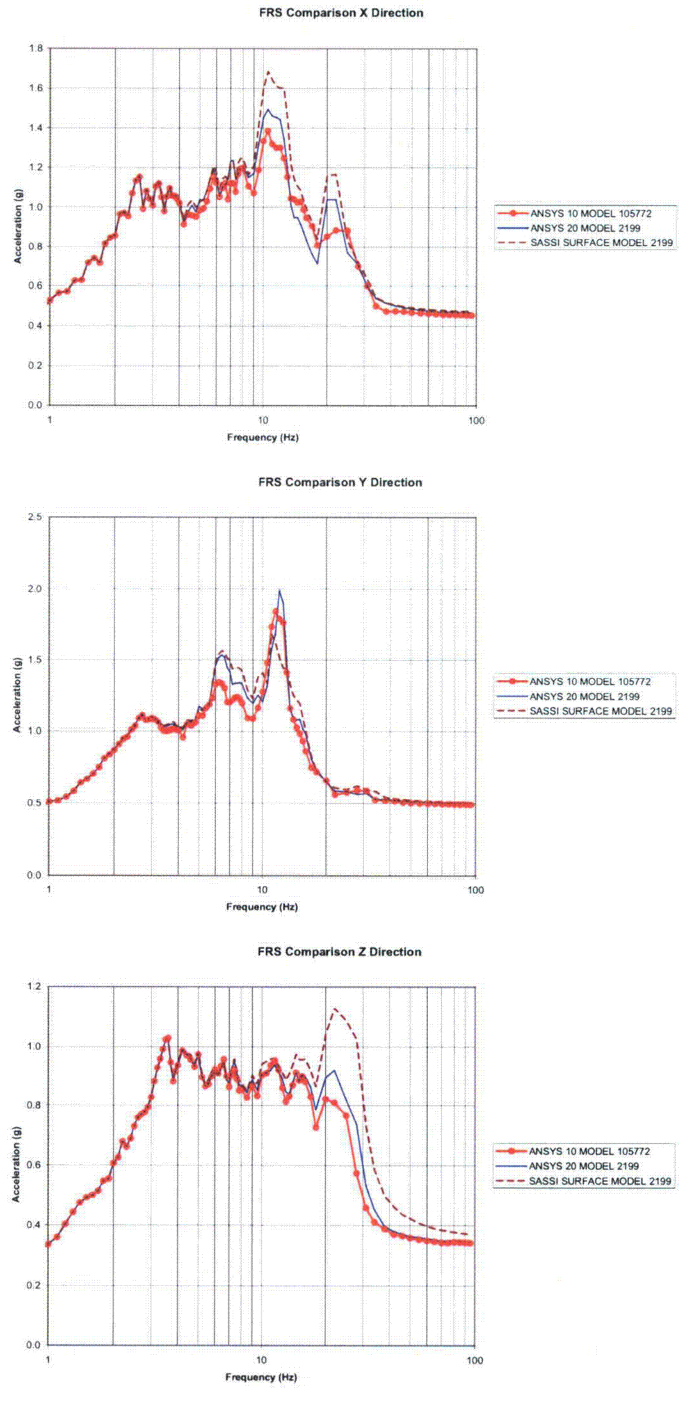


Figure C-2 – FRS Comparison at NE Corner of SG West Compartment, El. 134'

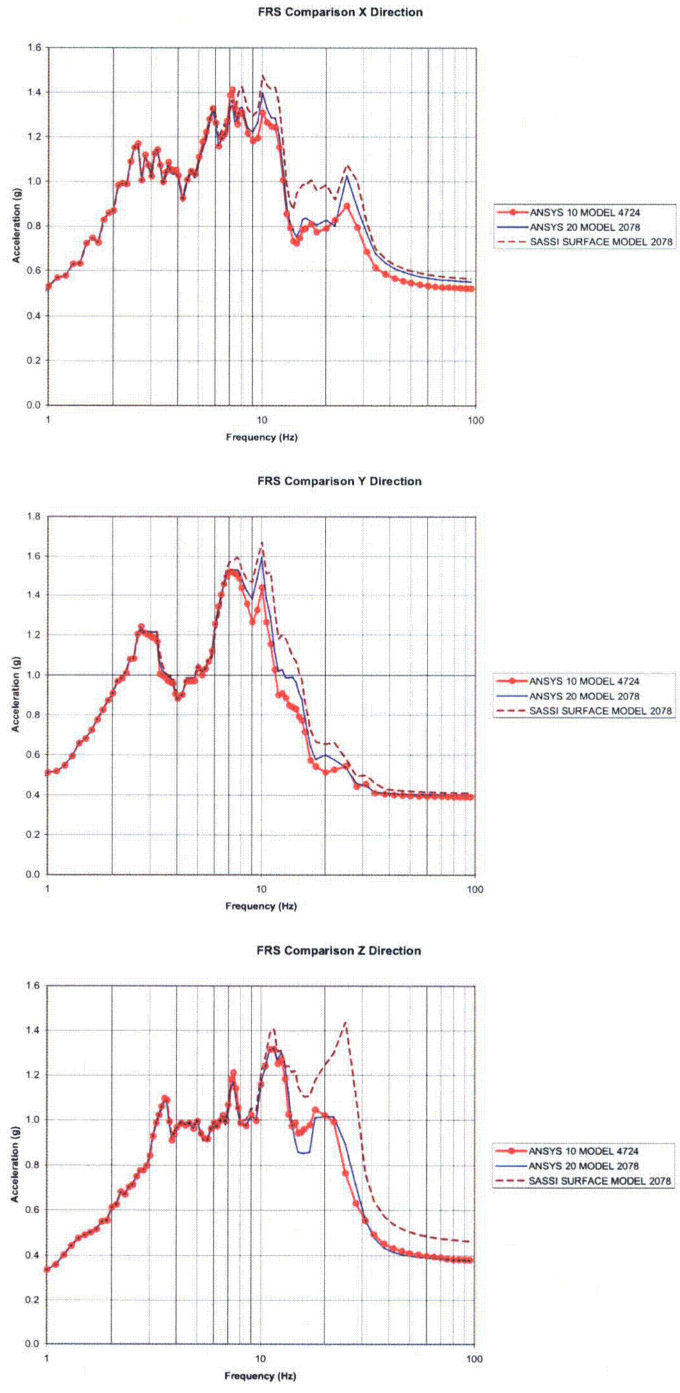


Figure C-3 – FRS Comparison at NE Corner of Control Room Floor

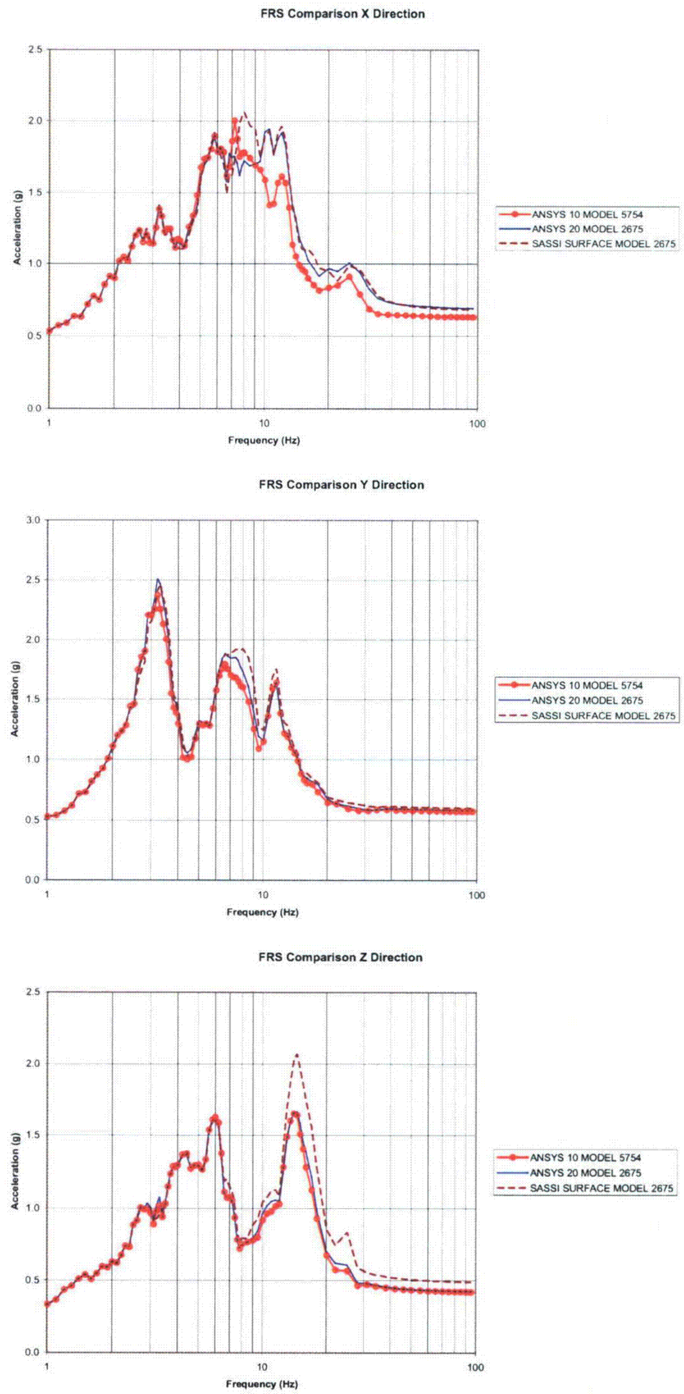


Figure C-4 – FRS Comparison at NW Corner of Fuel Building Roof

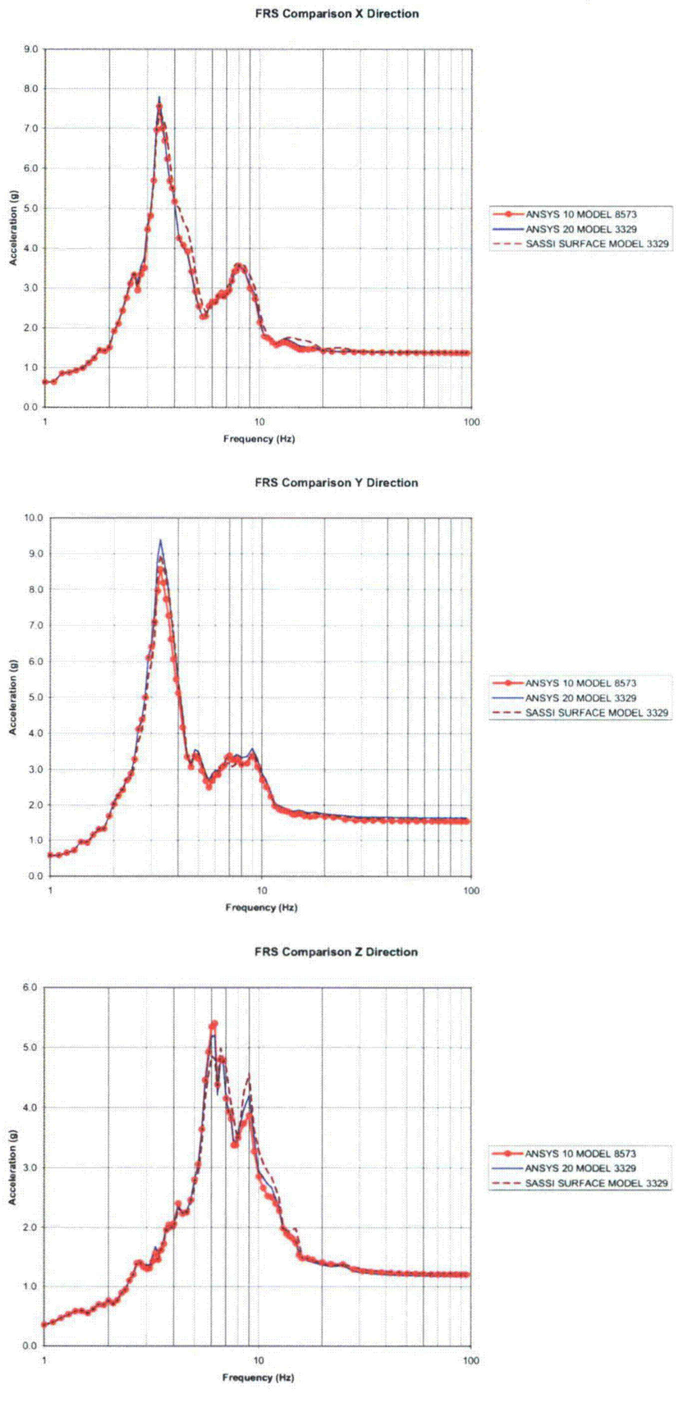


Figure C-5 – FRS Comparison at South Side of Shield Building at El. 327.41'

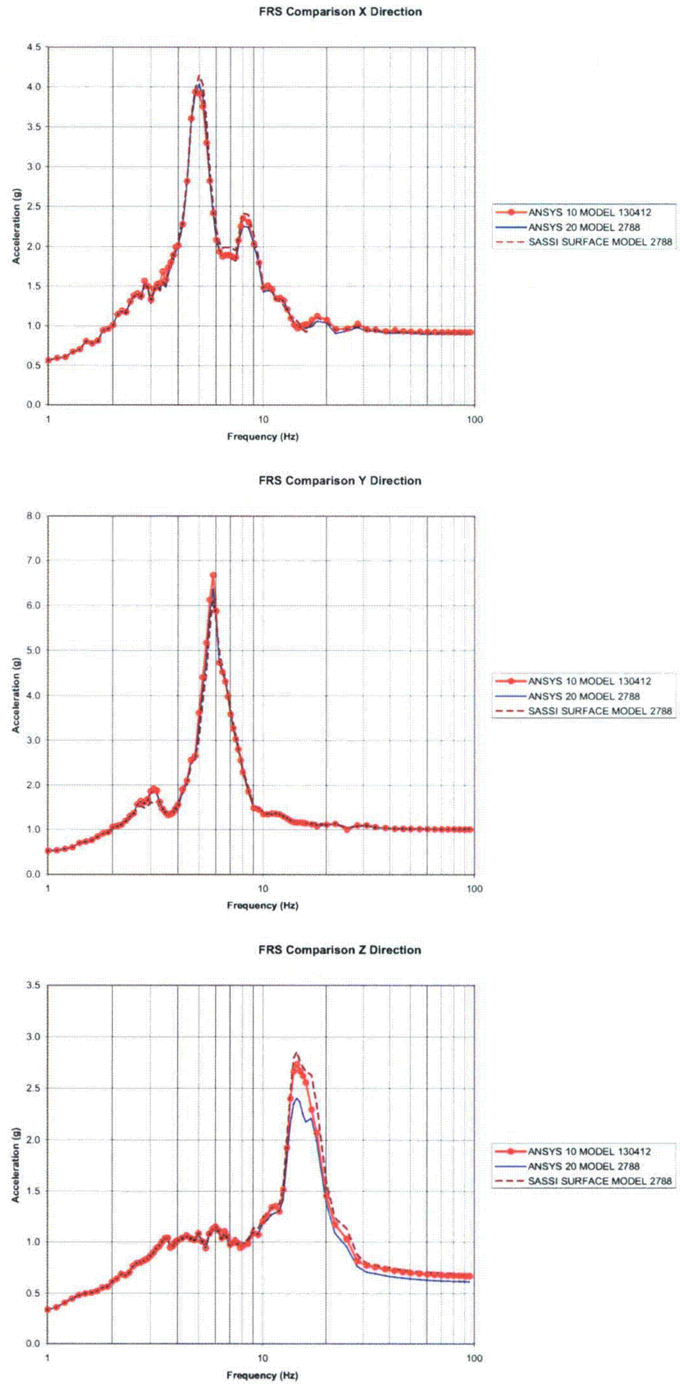


Figure C-6 – FRS Comparison on SCV near Polar Crane, El. 224'

Appendix D - Response Spectra for Six AP1000 soil cases

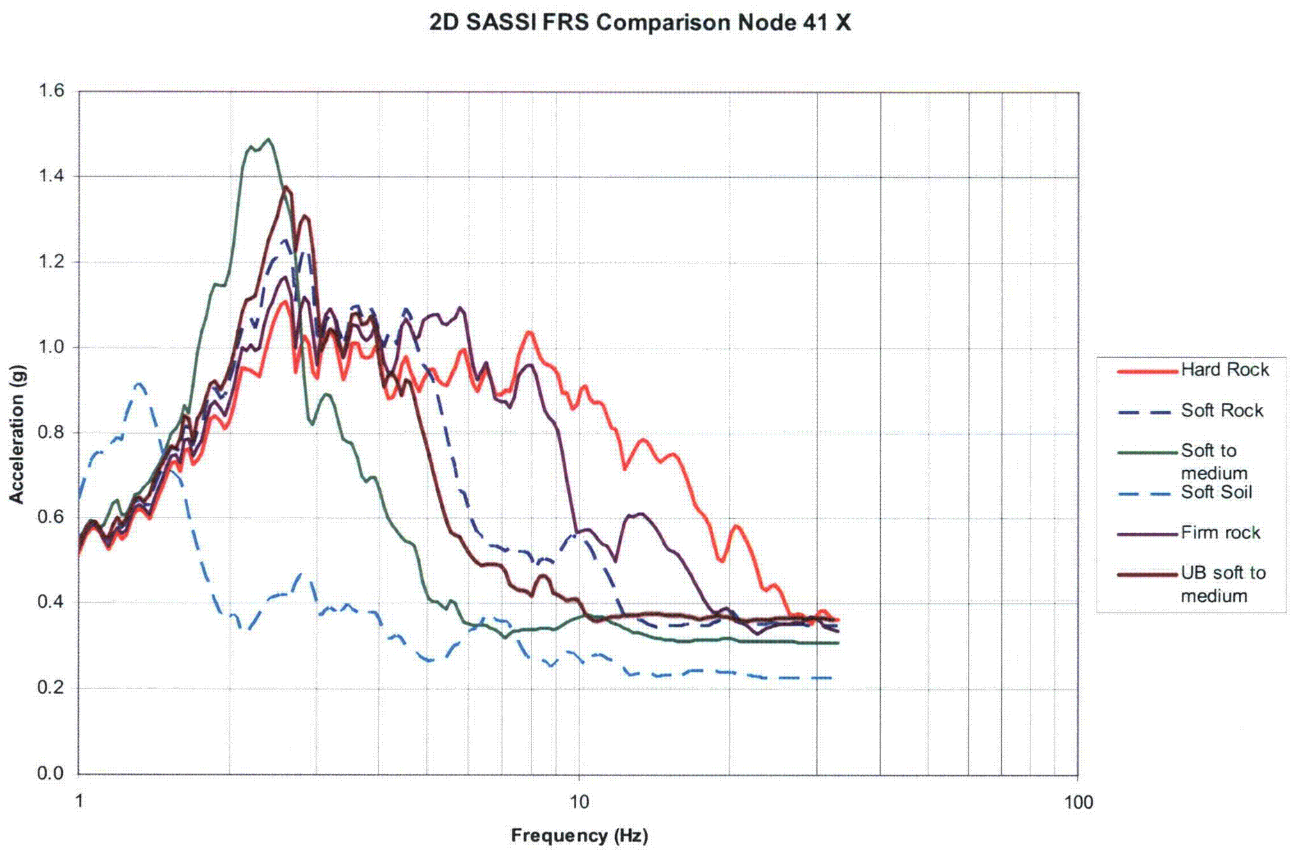


Figure D-1 - 2D SASSI FRS Comparison Node 41 X (ASB El. 99')

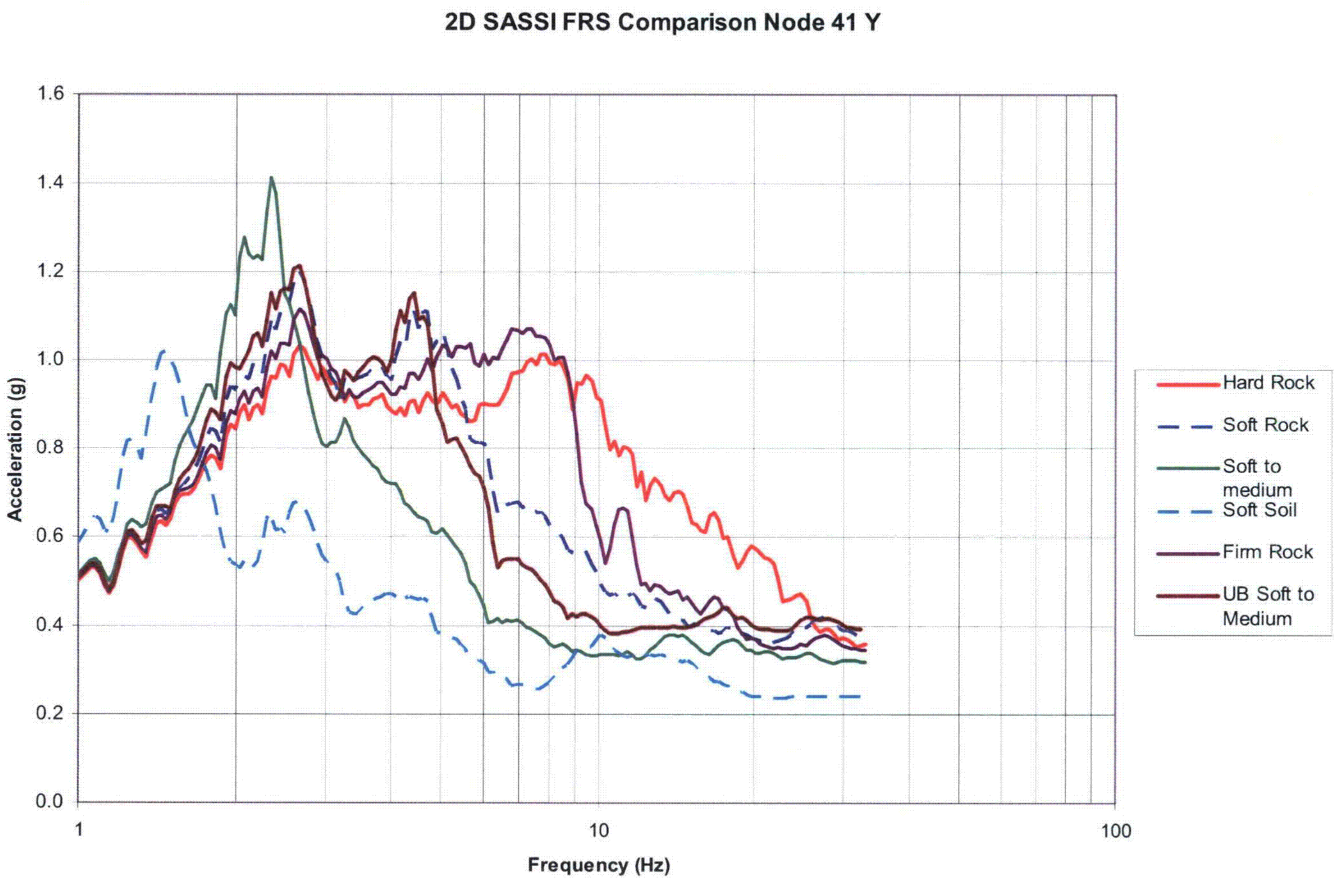


Figure D-2 - 2D SASSI FRS Comparison Node 41Y (ASB El. 99')

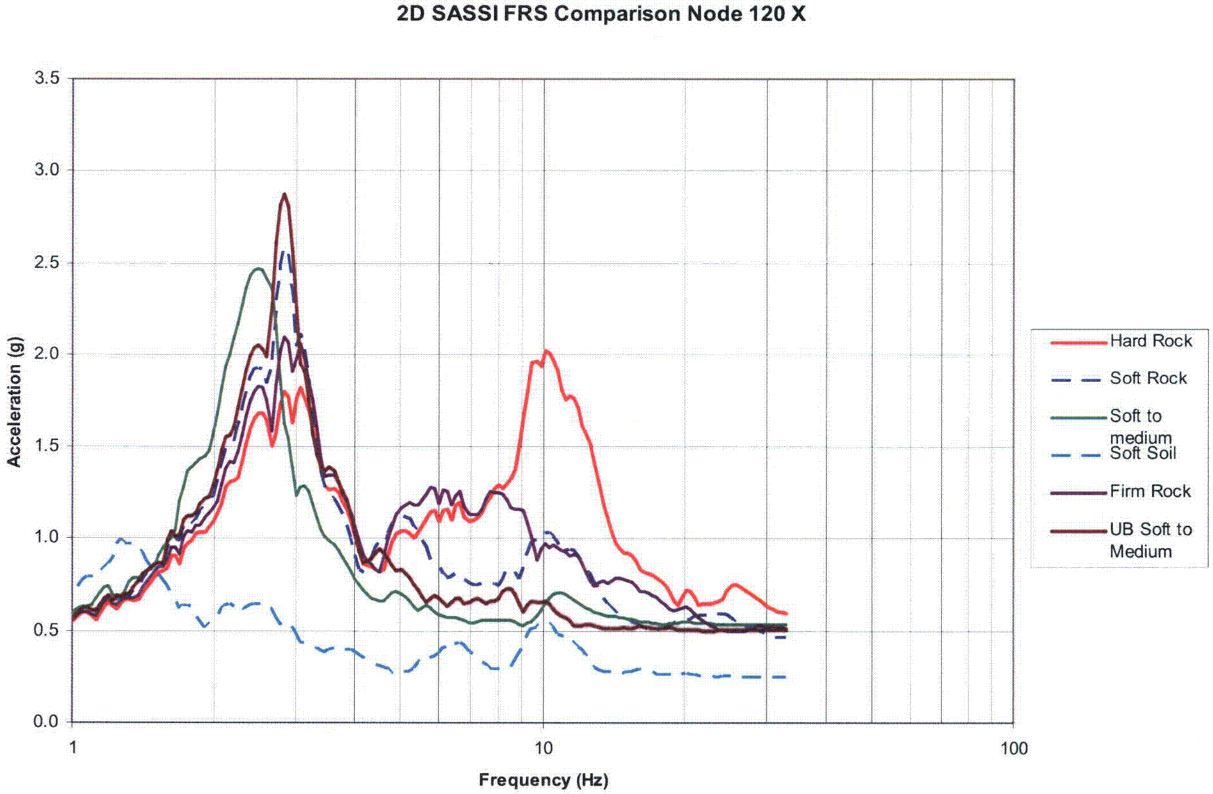


Figure D-3 - 2D SASSI FRS Comparison Node 120 X (ASB El. 179.6')

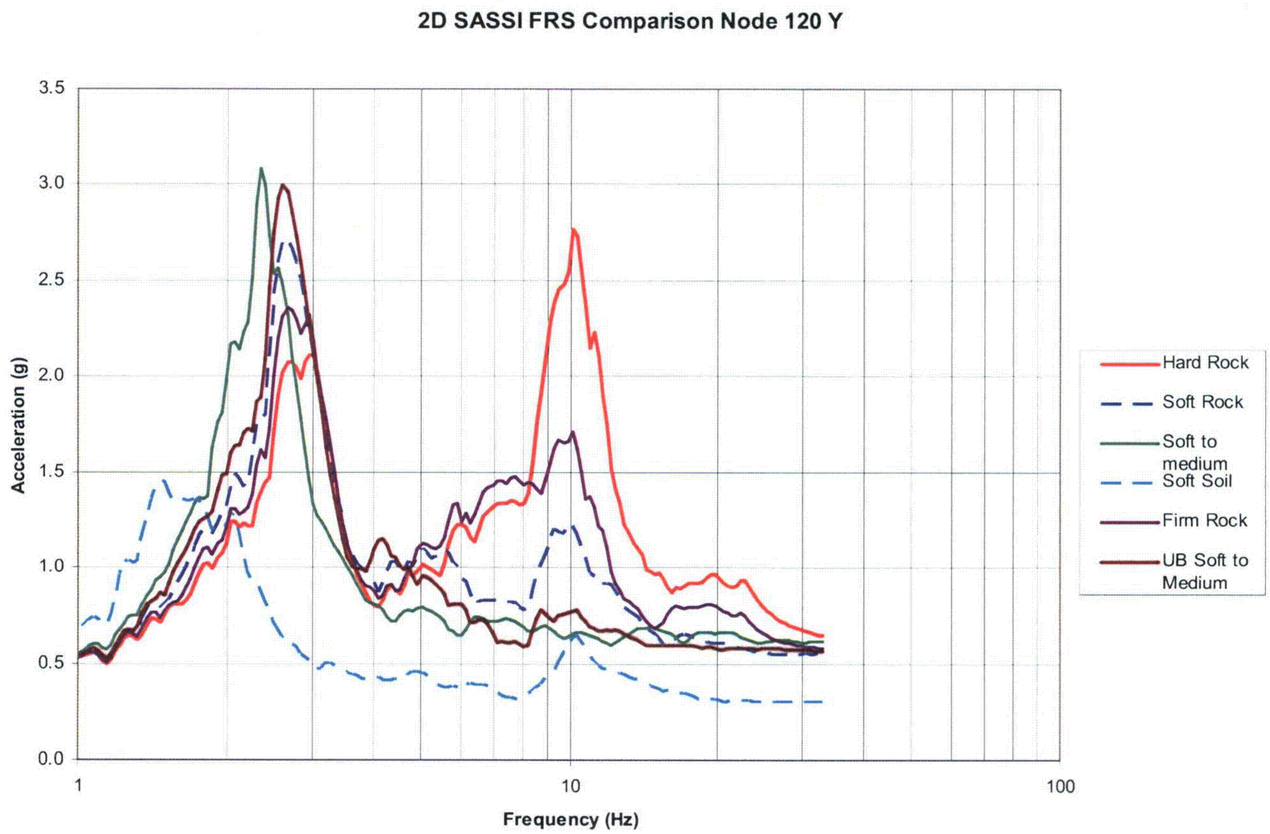


Figure D-4 - 2D SASSI FRS Comparison Node 120 Y (ASB El. 179.6')

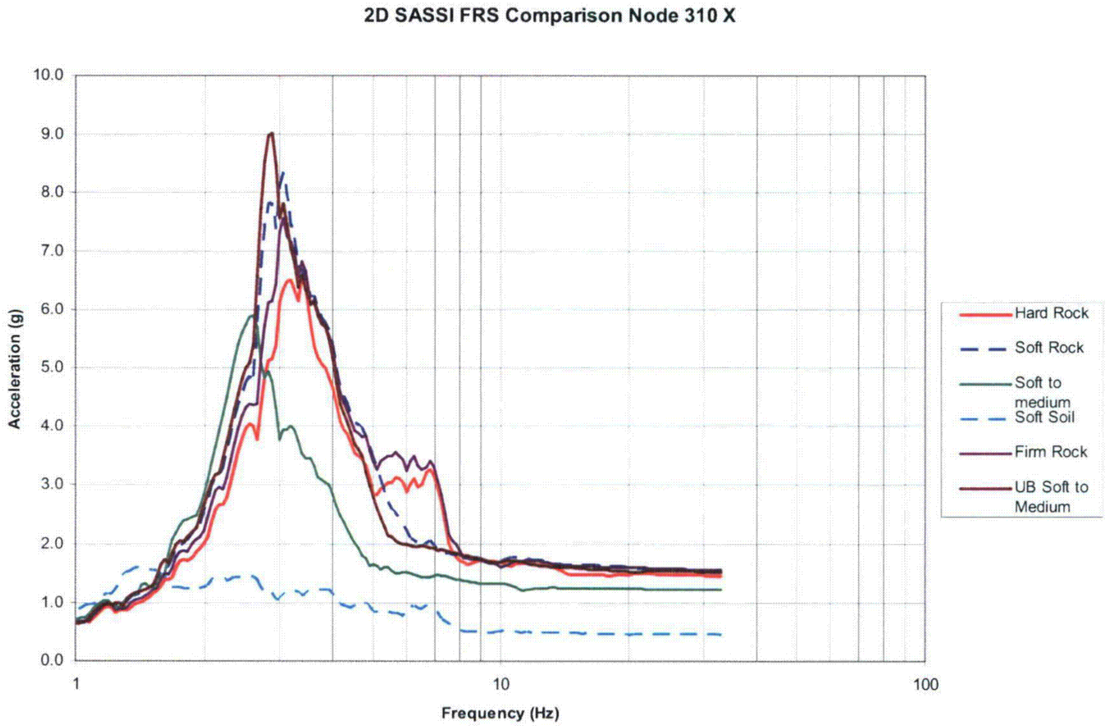


Figure D-5 - 2D SASSI FRS Comparison Node 310 X (ASB El. 333.2')

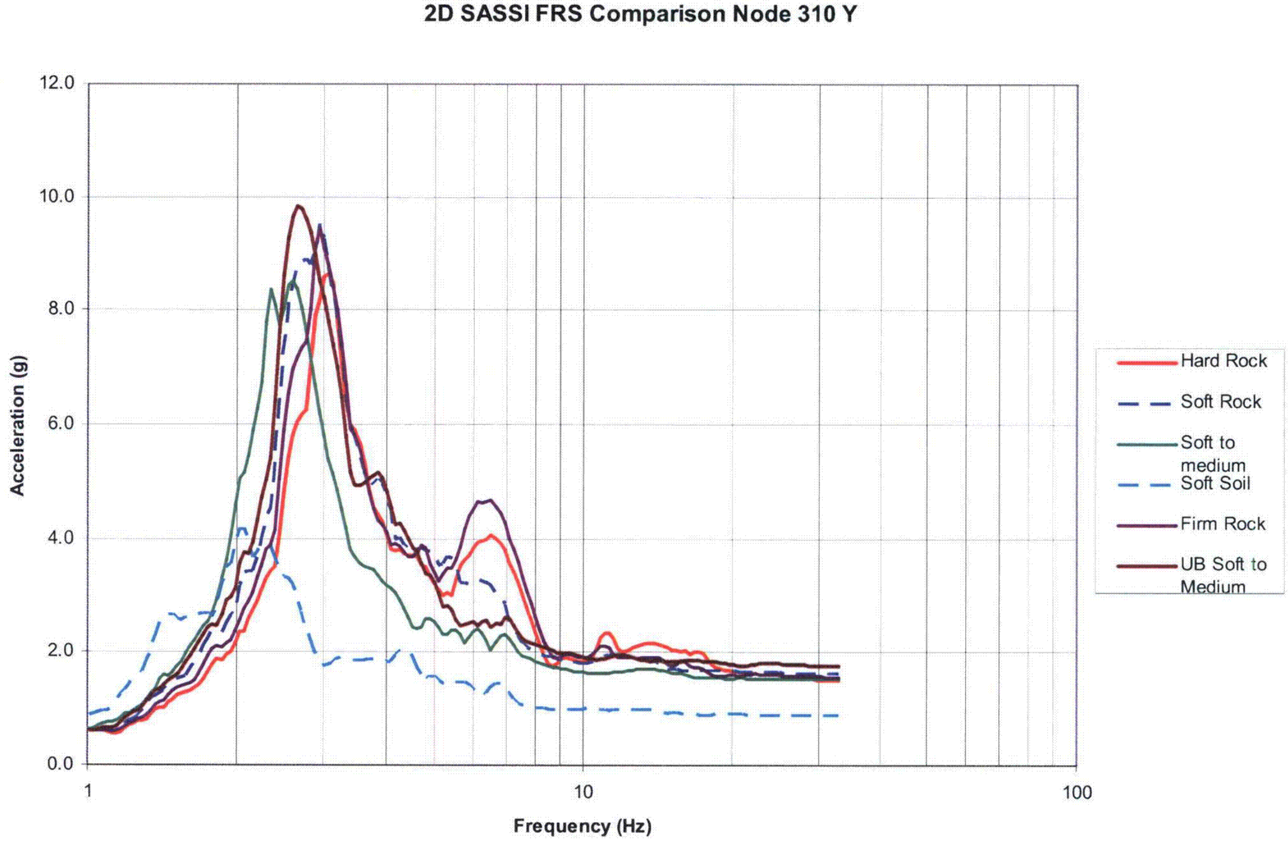


Figure D-6 - 2D SASSI FRS Comparison Node 310 Y (ASB El. 333.2')

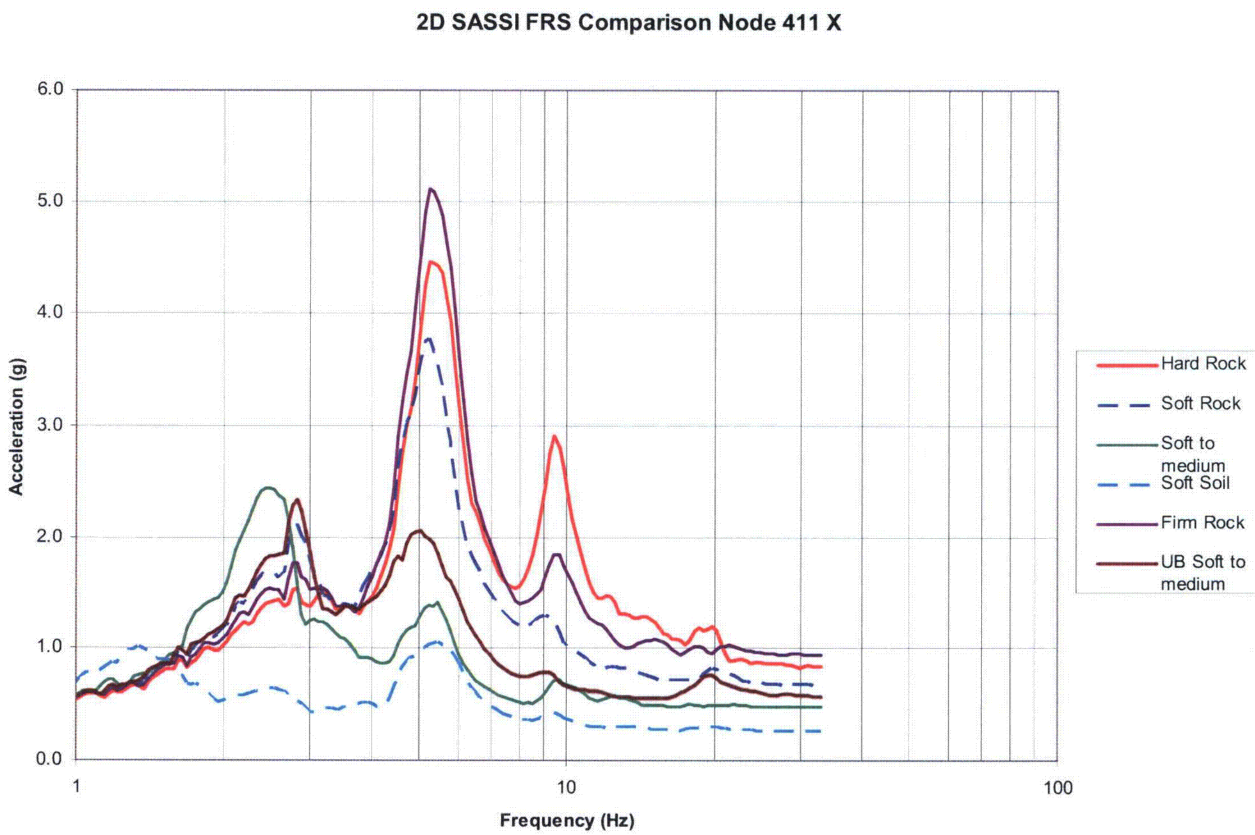


Figure D-7- 2D SASSI FRS Comparison Node 411 X (SCV El. 200.0')

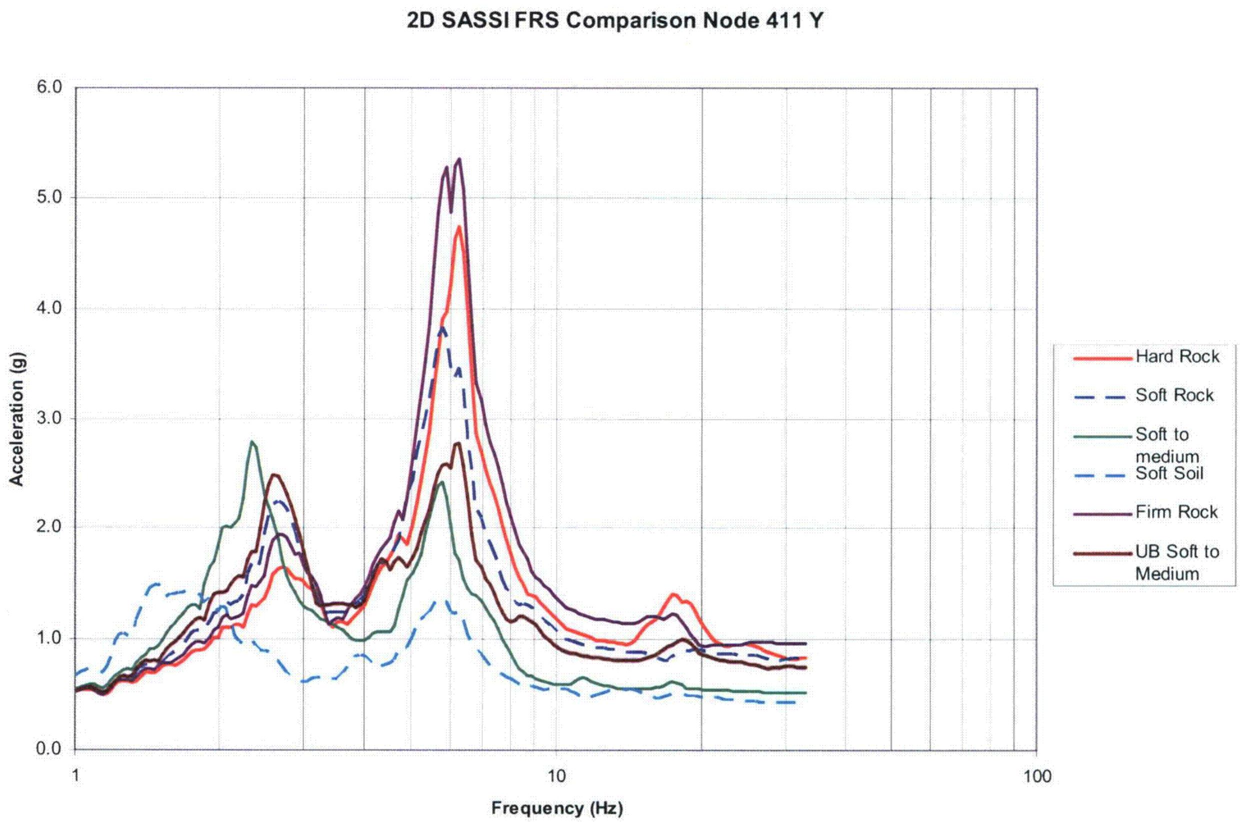


Figure D-8 - 2D SASSI FRS Comparison Node 411 Y (SCV El. 200.0')

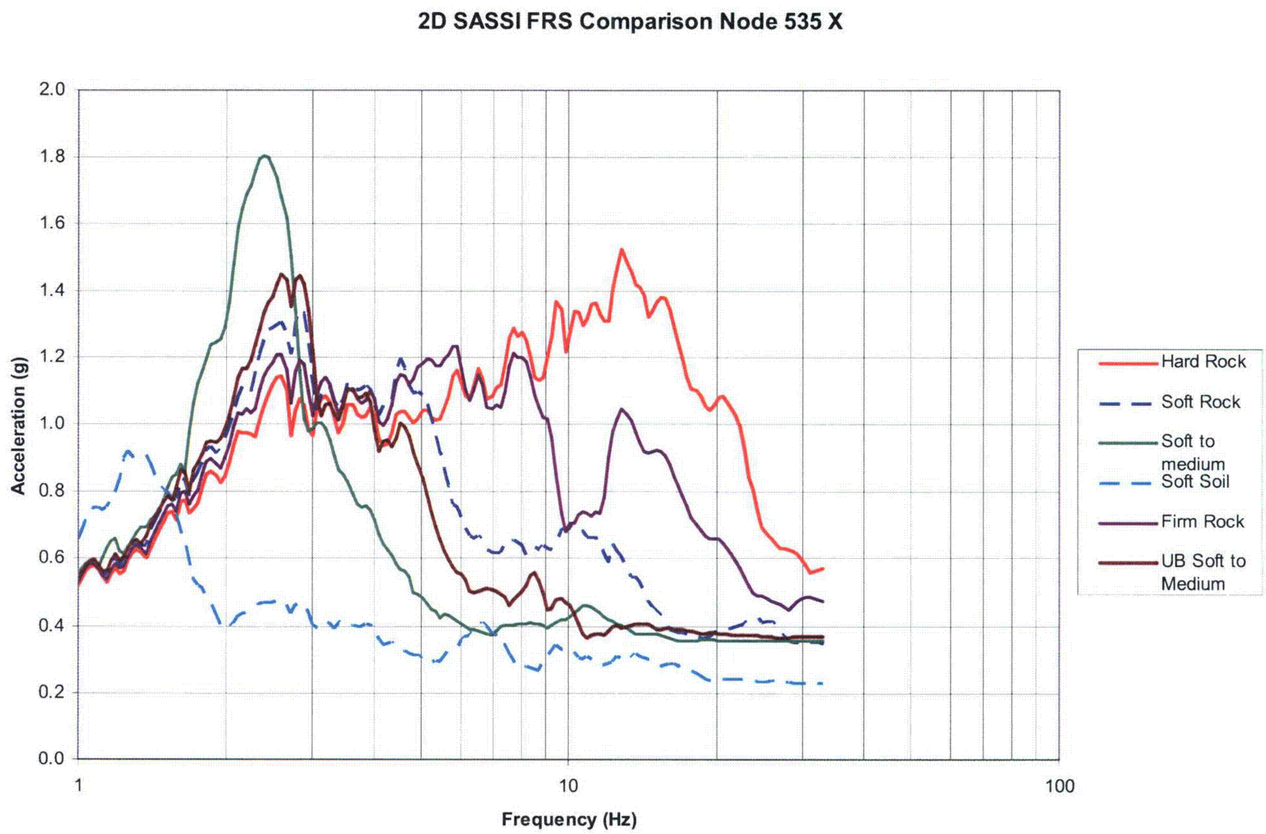


Figure D-9 - 2D SASSI FRS Comparison Node 535 X (CIS El. 134.3')

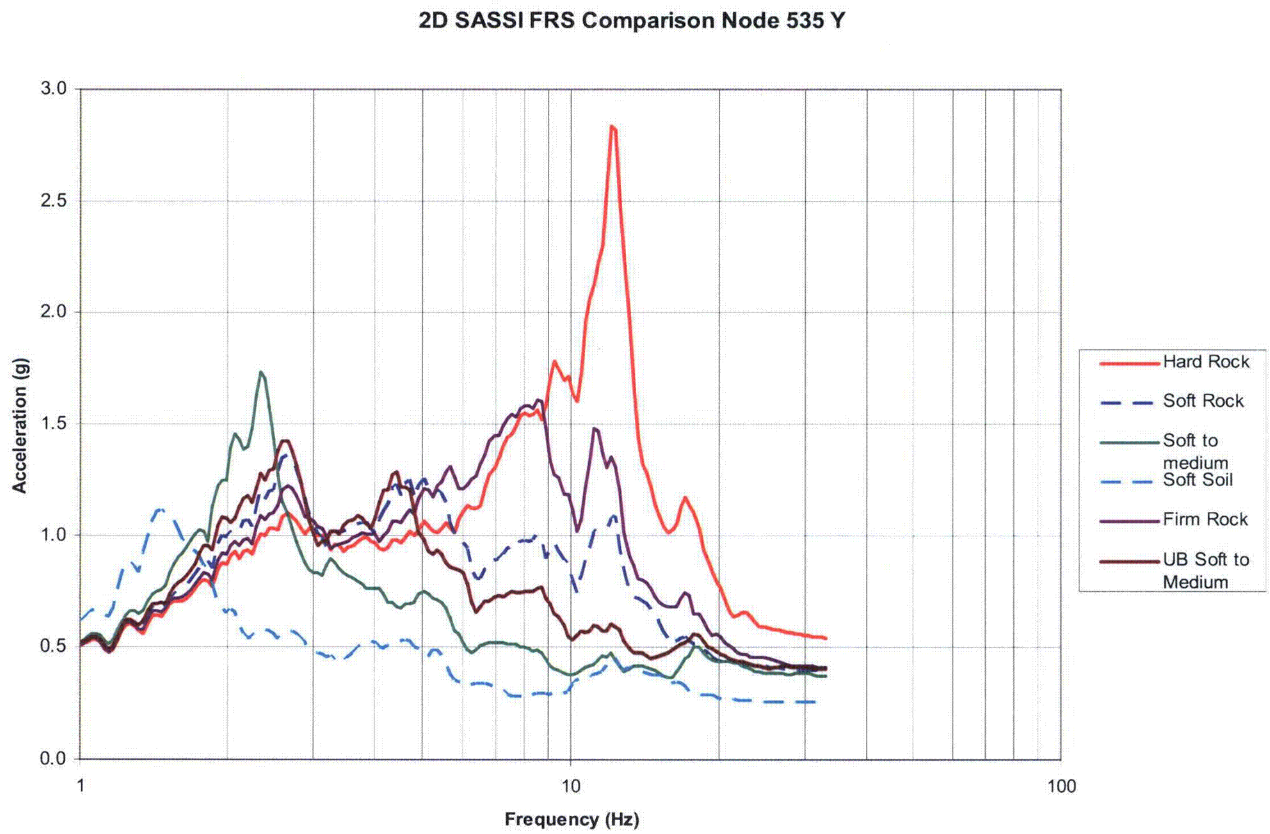


Figure D-10 - 2D SASSI FRS Comparison Node 535 Y (CIS El. 134.3')

Appendix E – Post Revision 16 DCD Appendix 3G

Provided in this appendix is AP1000 DCD Post Revision 16 Appendix 3G, Nuclear Island Analysis.

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. In Reference 3 are provided 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 CSV 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.

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 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.

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 233′-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, and the containment shell's local flexibility. When fixed at the center of containment, the model shows fundamental frequencies of 3.3 hertz transverse to the bridge, 7.0 hertz vertically, and 6.4 hertz along the bridge. The Detailed Model of the polar crane consists of 28 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 1 to 4 represent the Trucks with elevation at top of rails (TOR). There are four nodes that are coincident with nodes 1 to 4 and used to add the local SCV stiffnesses (nodes 465 to 468, not shown in Figure).

1. Nodes 9 to 12 represent the trolley. The trolley is connected to the centerline of the polar crane girders at nodes 9 and 10.

2. Nodes 13 to 26 are located on the polar crane girders. The end nodes (13, 19, 20 and 26) are used to connect the cross beams to the girders; these nodes are also attached to the trucks (nodes 1 to 4) by rigid links.

3. Node 470 is at the center of containment at the top of rail elevation. Nodes 465 to 468 are attached to node 470 using rigid links.

4. Node 29, not shown in Figure, is located on the SCV. It is attached to 470 by a rigid link.

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 NI10 and NI20 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 are 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 subsection 3G.3.

3G.2.3 Static Models

The models of the containment internal structures and containment vessel described in subsections 3G.2.1.2 and 3G.2.1.3 are also used in equivalent static analyses to provide design member forces in each structure. A separate GTSTRUDL model as shown in Figure 3.8.4-3 is used for static analyses of the shield building roof.

Member forces in the ASB are obtained from static 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 the equivalent static accelerations obtained from the time history analyses of the nuclear island models. The finite element shell model of the containment internal structures described in subsections 3G.2.1.2, which includes the basemat within the shield building and the containment vessel stick model, is also included.

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 for four soil profiles previously evaluated for the AP600. The soil profiles included a hard rock site, a firm rock site, a soft rock site, a soft-to-medium soil site, and a soft soil site. Analyses were also performed without adjacent structures for firm rock and the upper bound soft-to-medium sites previously analyzed for the AP600. 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, three 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 four soil and rock cases identified in subsection 3.7.1.4 are considered: hard rock, firm rock, upper bound soft-to-medium soil, and soft-to-medium soil.

3G.4 Nuclear Island Dynamic Analyses

3G.4.1 ANSYS Fixed Base Analysis

The NI10 model described in subsection 3G.3.2.2.1 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.

3G.4.2 3D SASSI Analyses

The computer program SASSI2000 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 three soil conditions established from the AP1000 2D SASSI analyses. These soil conditions are firm rock, upper bound soft-to-medium soil, and soft-to-medium 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.

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 Dynamic Results

3G.4.3-1 Absolute Accelerations

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

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," Revision 1, Westinghouse Electric Company LLC.

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

Table 3G.1-1 (Sheet 1 of 3)

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 To obtain SSE member forces for the containment internal structures.
3D finite element shell model of nuclear island [NI10](coupled auxiliary/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. To obtain maximum member forces and moments in selected elements for comparison to equivalent static results.
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 2)

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 loads for overturning and stability evaluation.
Finite element lumped mass stick model of nuclear island	Time history analysis	SASSI	Performed 2D linear and non-linear seismic analyses to evaluate effect of lift off 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	SASSI	Performed for the three soil profiles of firm rock, upper bound soft to medium soil, and soft to medium 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 maximum member forces and moments in selected elements for comparison to equivalent static results.
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

Table 3G.1-1 (Sheet 3 of 3) **SUMMARY OF MODELS AND ANALYSIS METHODS**			
3D lumped mass simplified (single beam) model of the polar crane		ANYSYS	Used in the NI10 and NI20 models
3D finite element shell model of containment vessel [(1)]	Mode superposition time history analysis static analysis; response spectrum 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
Static and Response Spectrum analyses			
3D finite element refined shell model of nuclear island (NI05)	Equivalent static non-linear analysis using accelerations from time history analyses; response spectrum analysis	ANSYS	To obtain SSE member forces for the nuclear island basemat

Table 3G.1-2

SUMMARY OF DYNAMIC ANALYSES AND COMBINATION TECHNIQUES

Model	Analysis Method	Program	Three Components Combination	Modal Combination
3D lumped-mass stick, fixed base models	Mode superposition time history analysis	ANSYS	Algebraic Sum	n/a
3D finite element, fixed base models, coupled ASB shell model, with superelement of containment internal structures	Mode superposition time history analysis	ANSYS	Algebraic Sum	n/a
3D finite element, fixed base models, coupled ASB and containment internal structures	Equivalent static analysis using nodal accelerations from 3D stick model	ANSYS	SRSS or 100%, 40%, 40%	n/a
3D finite element model of the nuclear island basemat	Equivalent static analysis using nodal accelerations from 3D stick model	ANSYS	100%, 40%, 40%	n/a
3D shell of revolution model of SCV	Equivalent static analysis using nodal accelerations from 3D stick model	ANSYS	SRSS or 100%, 40%	n/a
3D finite element model of the shield building roof	Equivalent static analysis using nodal accelerations from 3D stick model	ANSYS GT STRUDL	SRSS	n/a
PCS valve room and miscellaneous steel frame structures, miscellaneous flexible walls, and floors	Response spectrum analysis	ANSYS	SRSS	Grouping

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	6.309	2.380	159.153	0.005
2	6.311	159.290	2.382	0.000
3	12.942	0.018	0.000	0.000
4	16.970	0.000	0.006	171.030
5	18.960	0.102	40.263	0.002
6	18.970	40.161	0.102	0.000
7	28.201	0.000	0.000	28.073
8	31.898	0.054	2.636	0.000
9	31.999	2.789	0.057	0.000
10	37.990	0.909	0.007	0.000
11	38.634	0.022	4.846	0.009
12	38.877	3.758	0.014	0.000
13	47.387	0.000	0.000	5.066
14	54.039	4.649	0.633	0.000
15	54.065	0.624	4.693	0.002
16	60.628	0.002	0.042	3.389
17	62.734	0.147	0.001	0.018
18	63.180	0.000	0.050	7.069
19	63.613	0.002	0.001	0.003
20	65.994	0.022	0.659	0.041
Sum of Effective Masses		214.929	215.545	214.706

Notes:
1. Fixed at Elevation 100′.
2. The total mass of the containment vessel is 225.697 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	3.619	0.000	41.959	0.000
2	5.387	175.274	0.000	0.175
3	6.192	0.000	148.385	0.005
4	6.415	3.321	0.000	24.074
5	9.422	0.002	1.017	0.000
6	9.674	10.510	0.000	0.532
7	12.811	0.015	0.001	0.000
8	15.757	0.004	0.320	0.010
9	16.367	3.103	0.003	159.153
10	17.495	28.537	0.001	19.546
11	18.944	0.000	40.053	0.001
12	21.043	10.724	0.000	0.426
13	22.102	0.000	0.005	0.000
14	27.340	0.054	0.000	18.661
15	30.387	2.978	0.001	1.559
16	31.577	0.002	3.526	0.004
17	35.033	0.194	0.006	3.895
18	35.535	0.211	0.027	0.399
19	35.646	0.000	1.451	0.019
20	37.599	0.325	0.426	0.007
Sum of Effective Masses		235.254	237.181	228.465

Notes:

1. Fixed at Elevation 100′.
2. The total mass of the containment vessel with the polar crane is 255.85 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

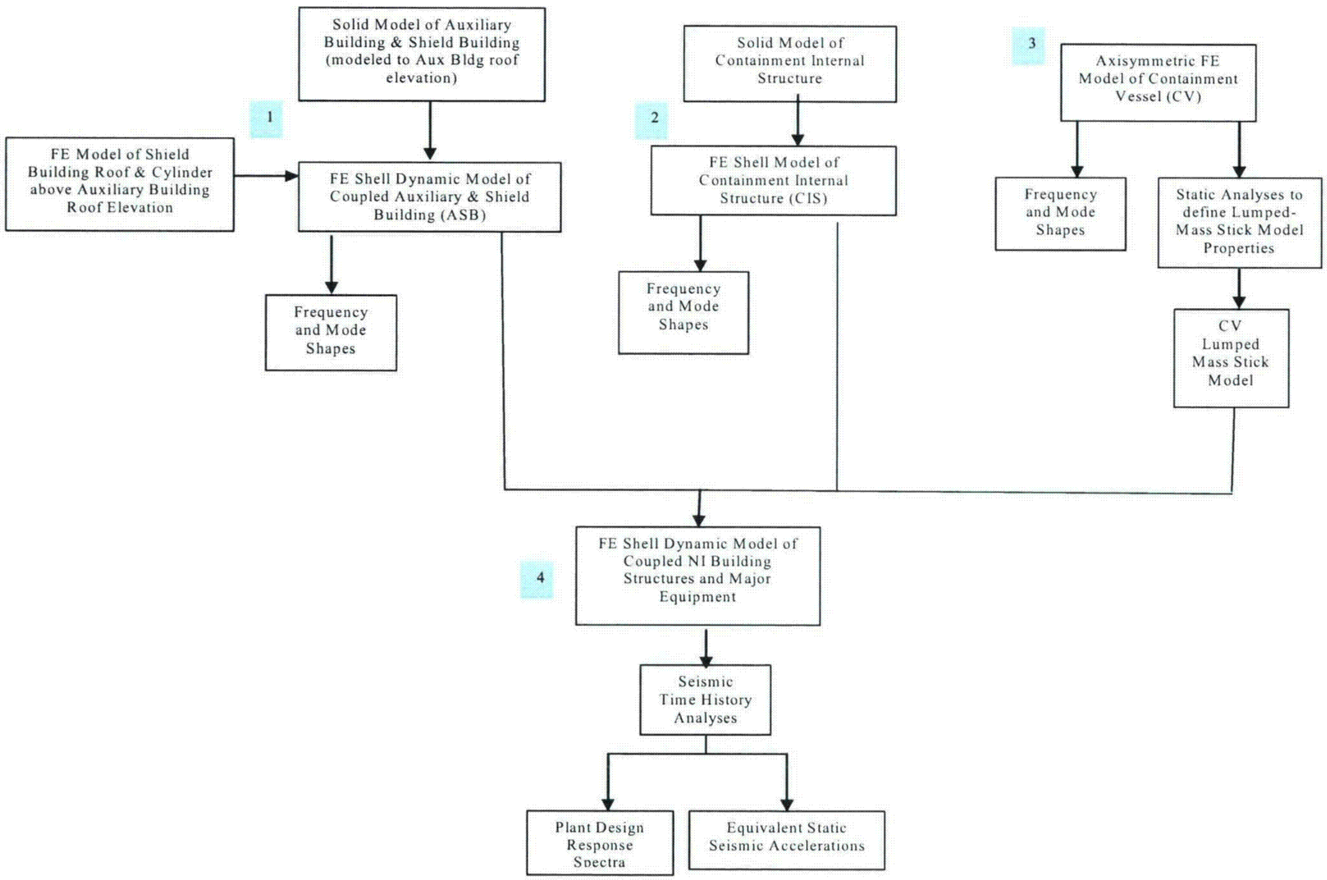


Figure 3G.1-1

Nuclear Island Seismic Analysis Models

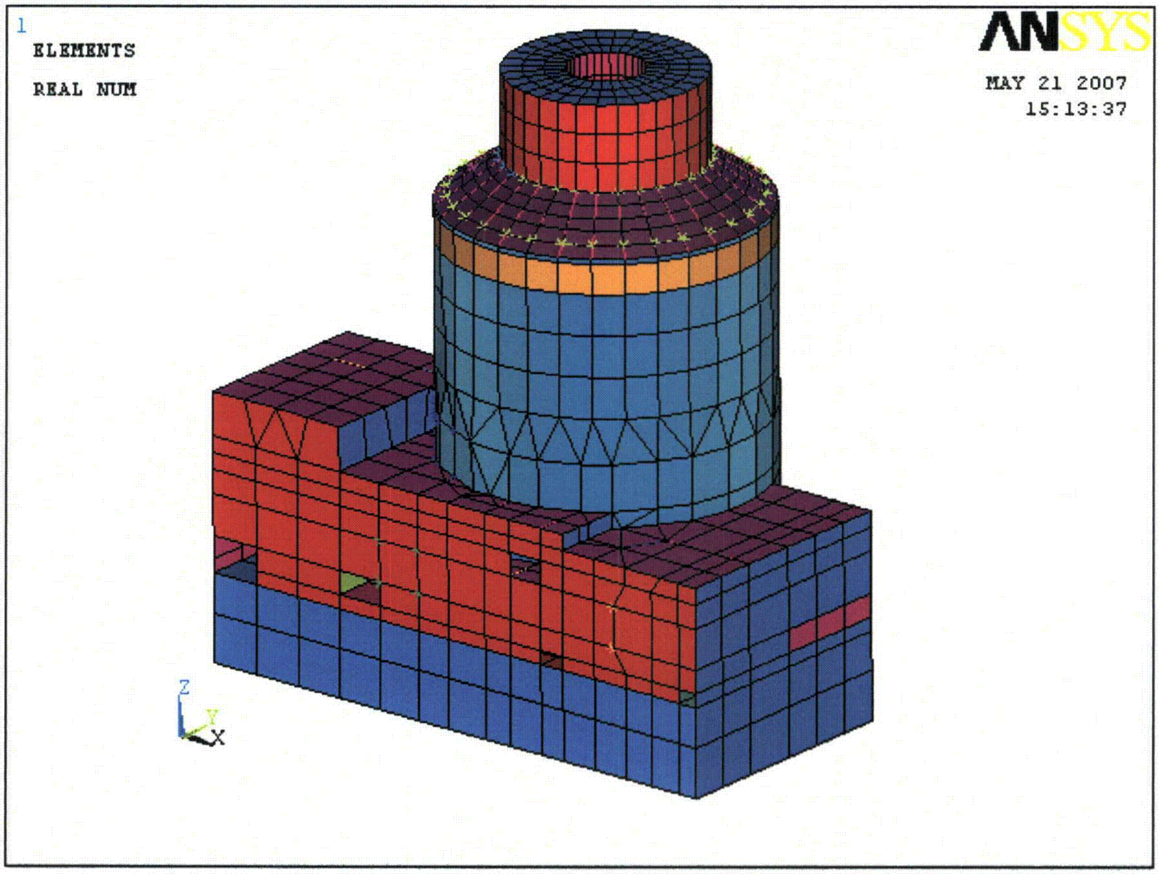
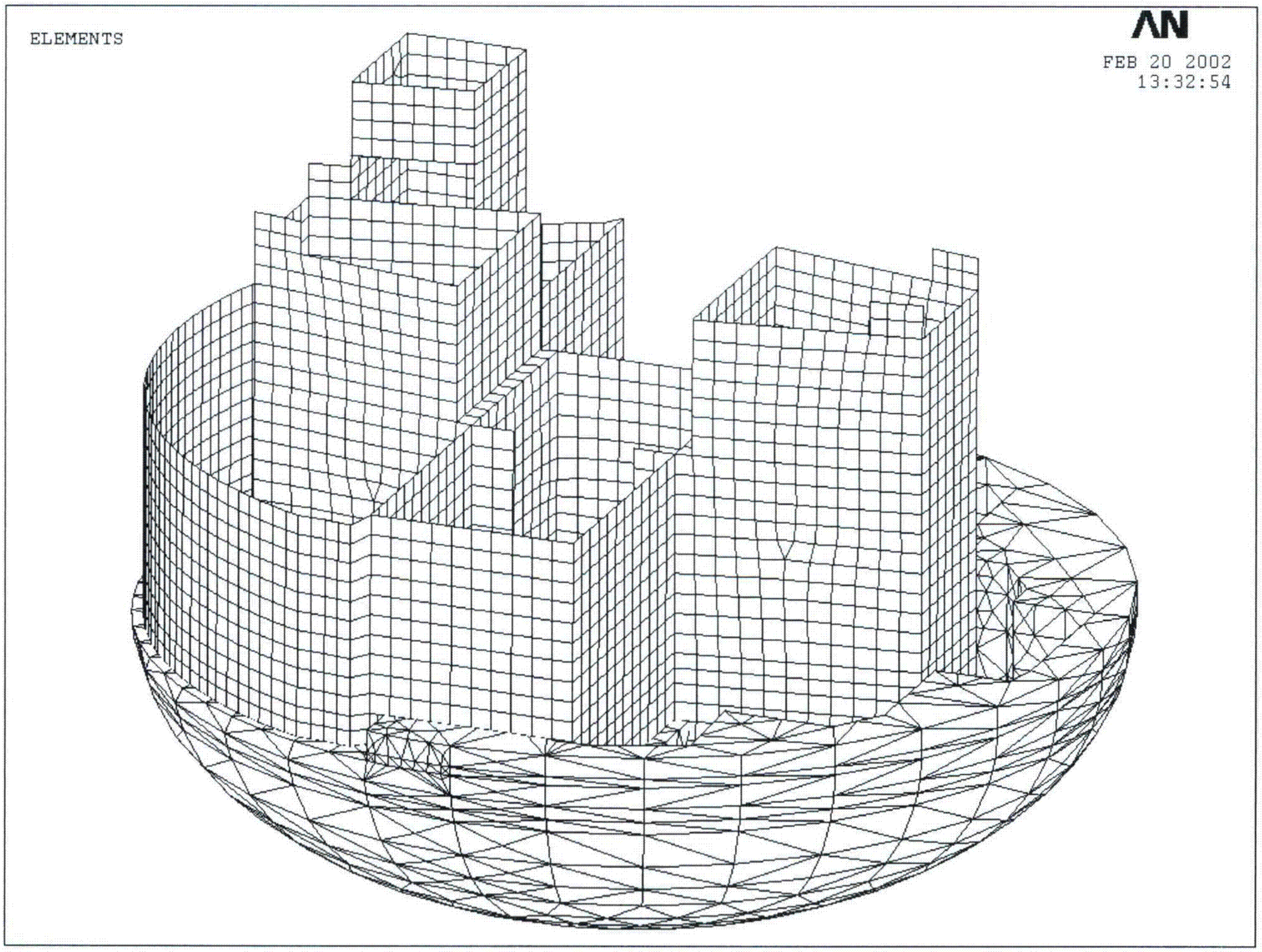


Figure 3G.2-1

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

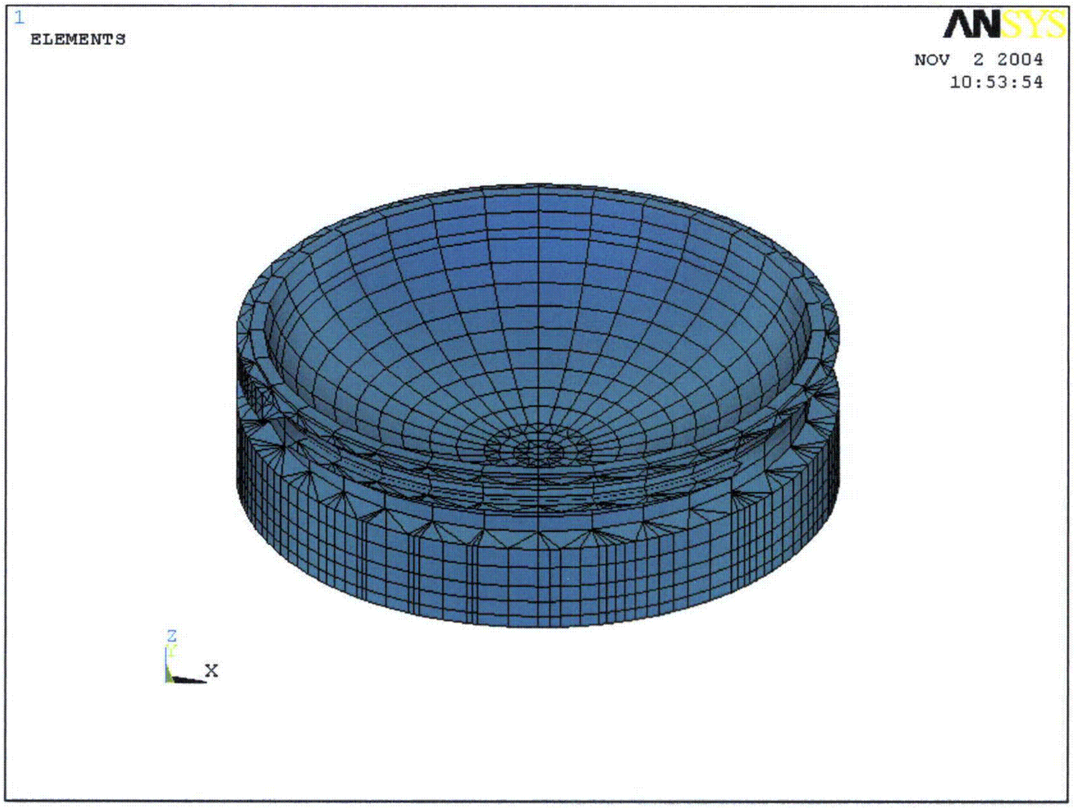


Figure 3G.2-3

3D Finite Element Model of Containment Outer Basemat (Dish)

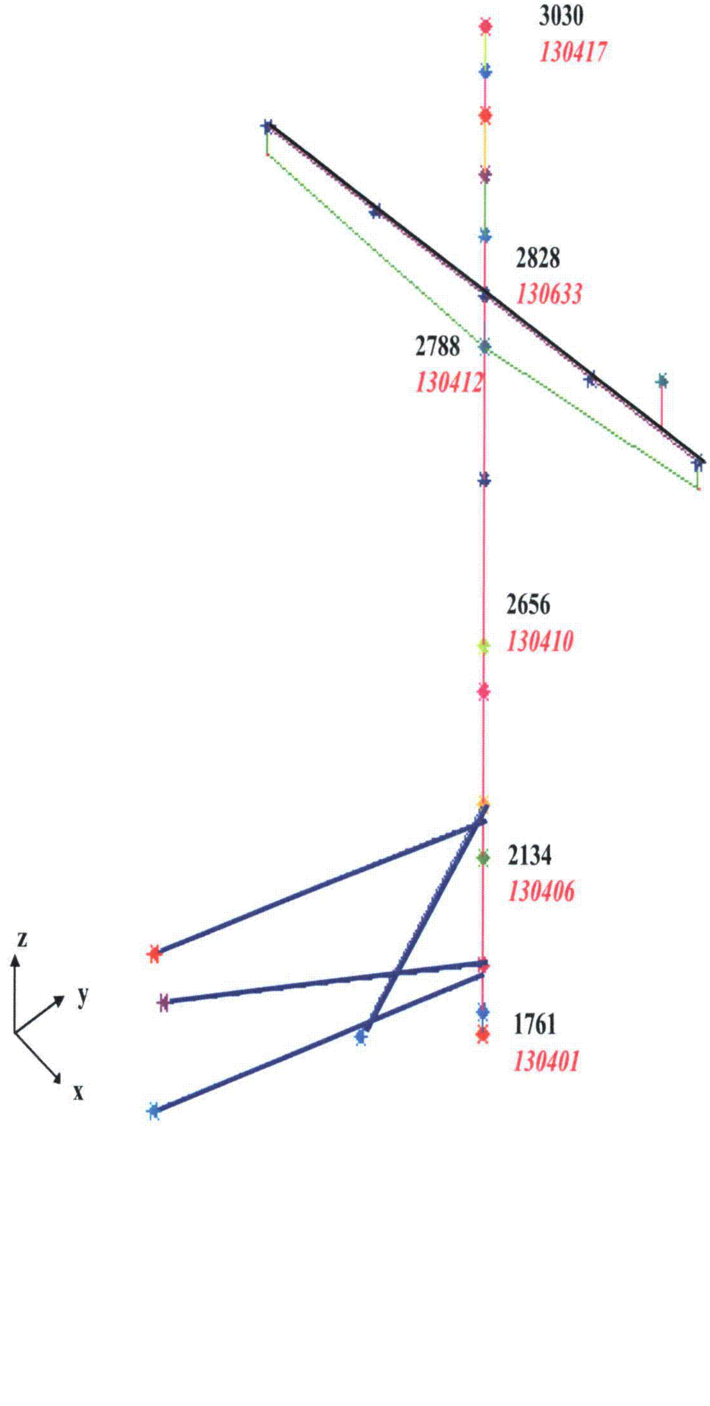
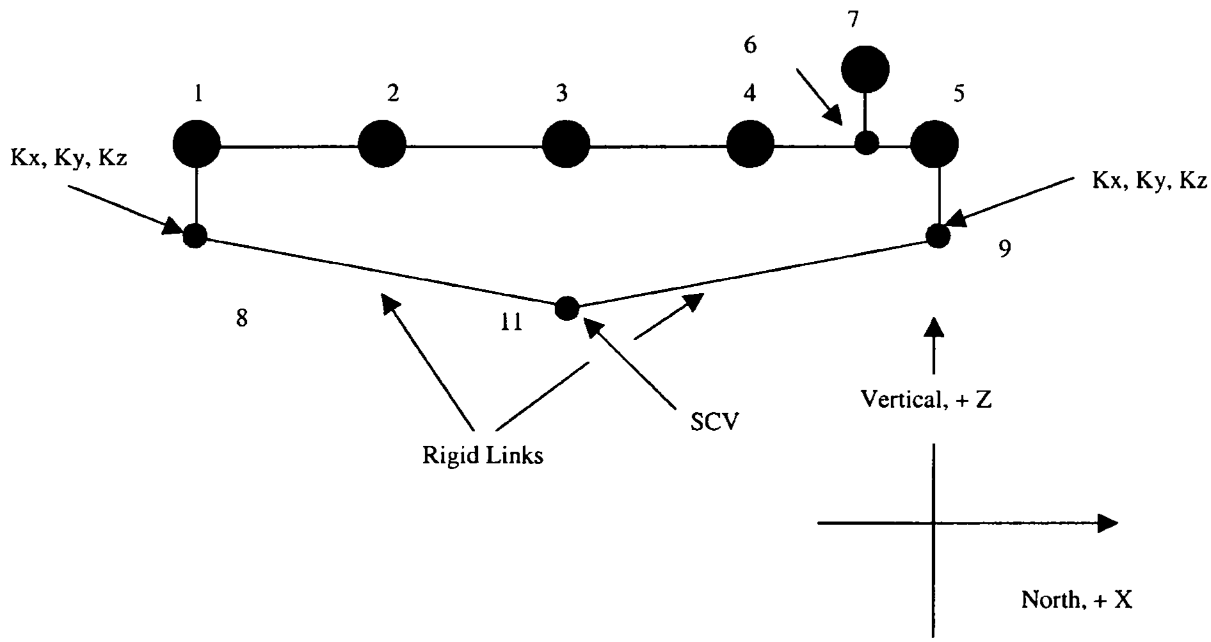


Figure 3G.2-4

Steel Containment Vessel and Polar Crane Models



Local SCV Stiffness are Kx, Ky, Kz

Dynamic Degrees of Freedom

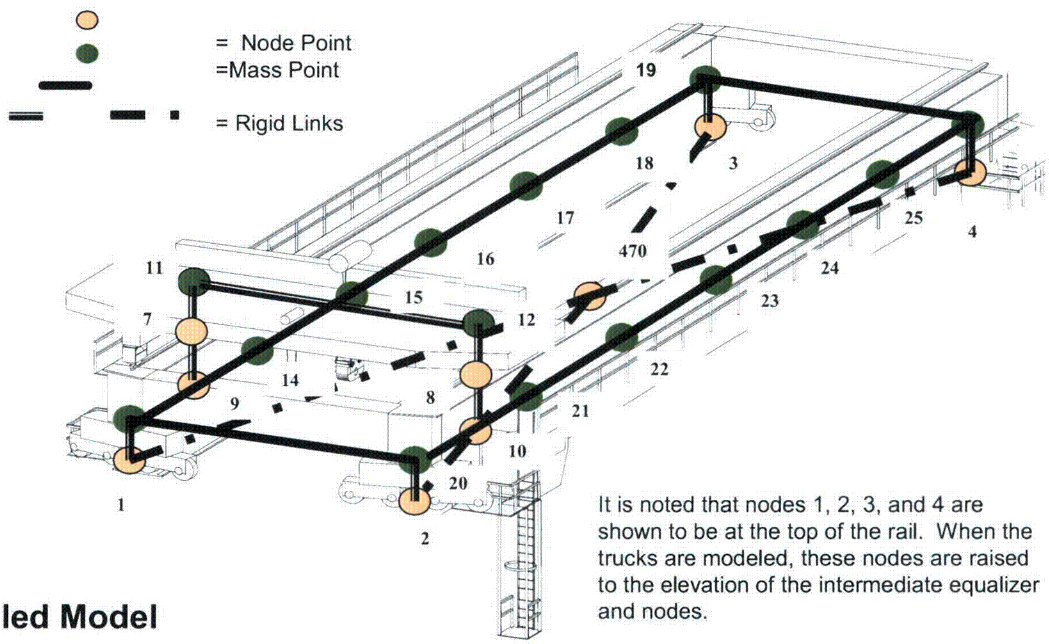
- Masses at nodes 1, 2, 3, 4, 5, and 7
- All Mass nodes have DOFs in X, Y, and Z directions

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



Detailed Model

It is noted that nodes 1, 2, 3, and 4 are shown to be at the top of the rail. When the trucks are modeled, these nodes are raised to the elevation of the intermediate equalizer and nodes.

Figure 3G.2-5B

Polar Crane Model Detailed Model

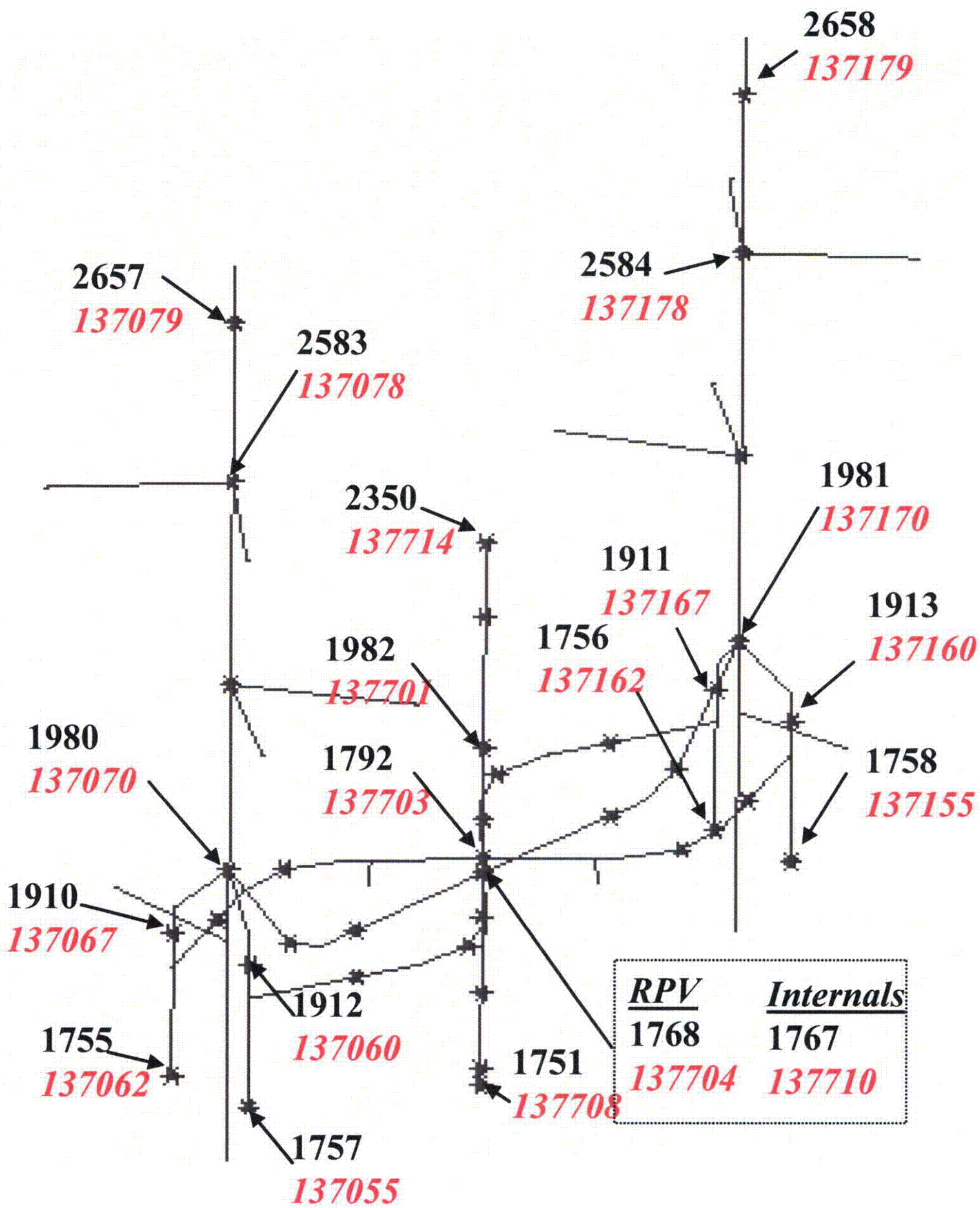


Figure 3G.2-6

Reactor Coolant Loop Lumped-Mass Stick Model

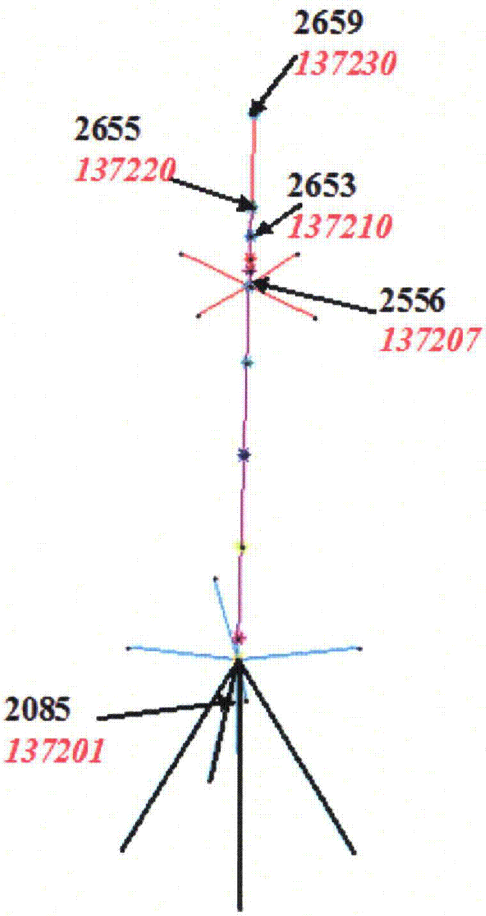


Figure 3G.2-7

Pressurizer Model

Figure 3G.2-8

Core Makeup Tank Models

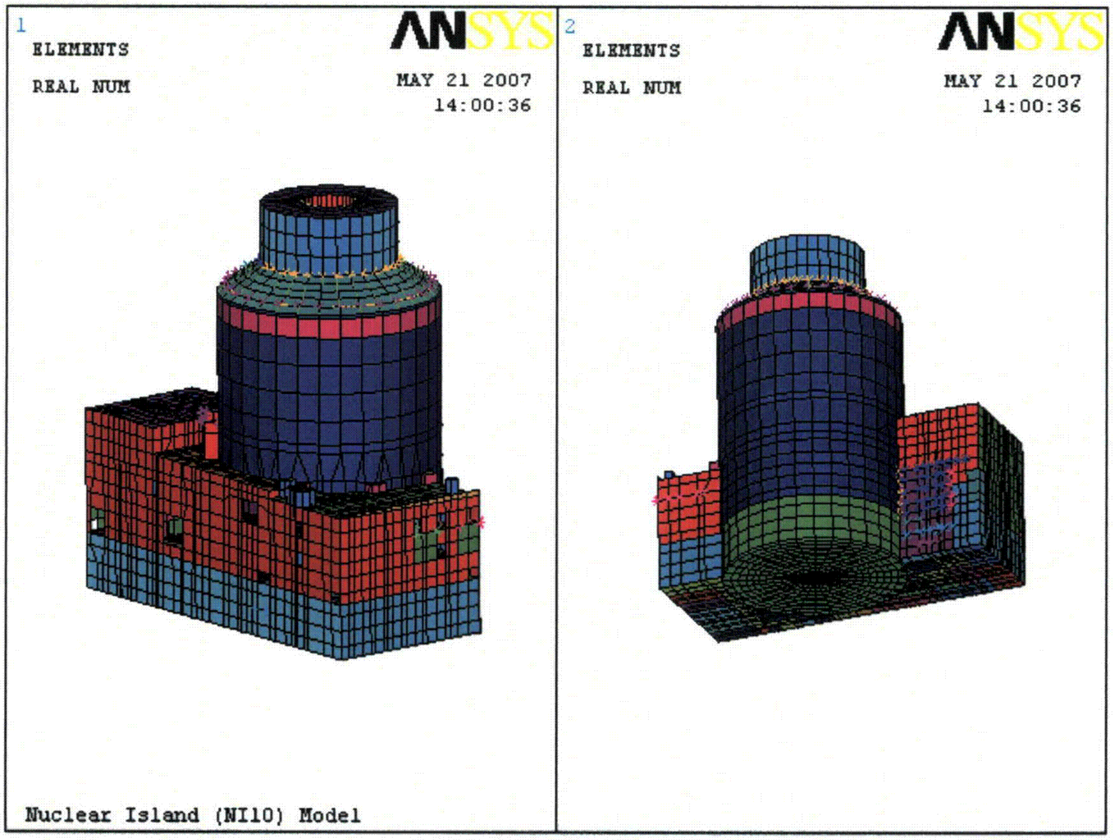


Figure 3G.2-9

AP1000 Nuclear Island Solid-Shell Model (NI10)

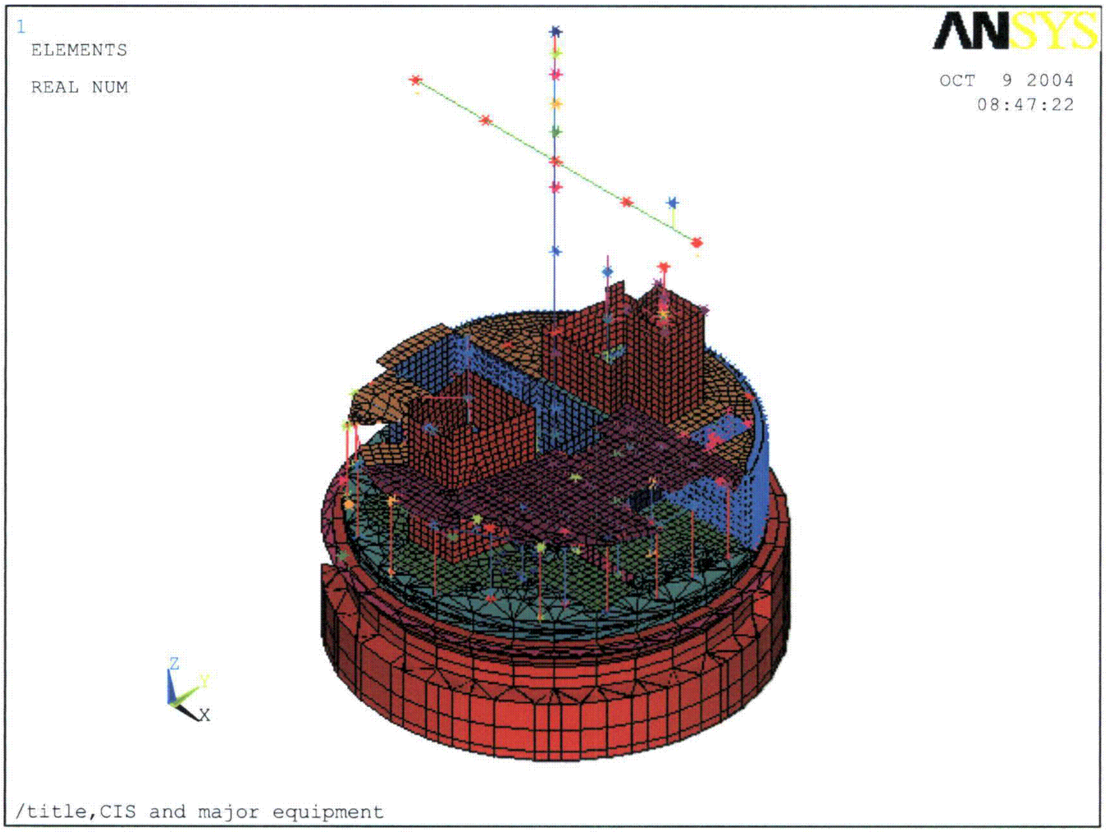
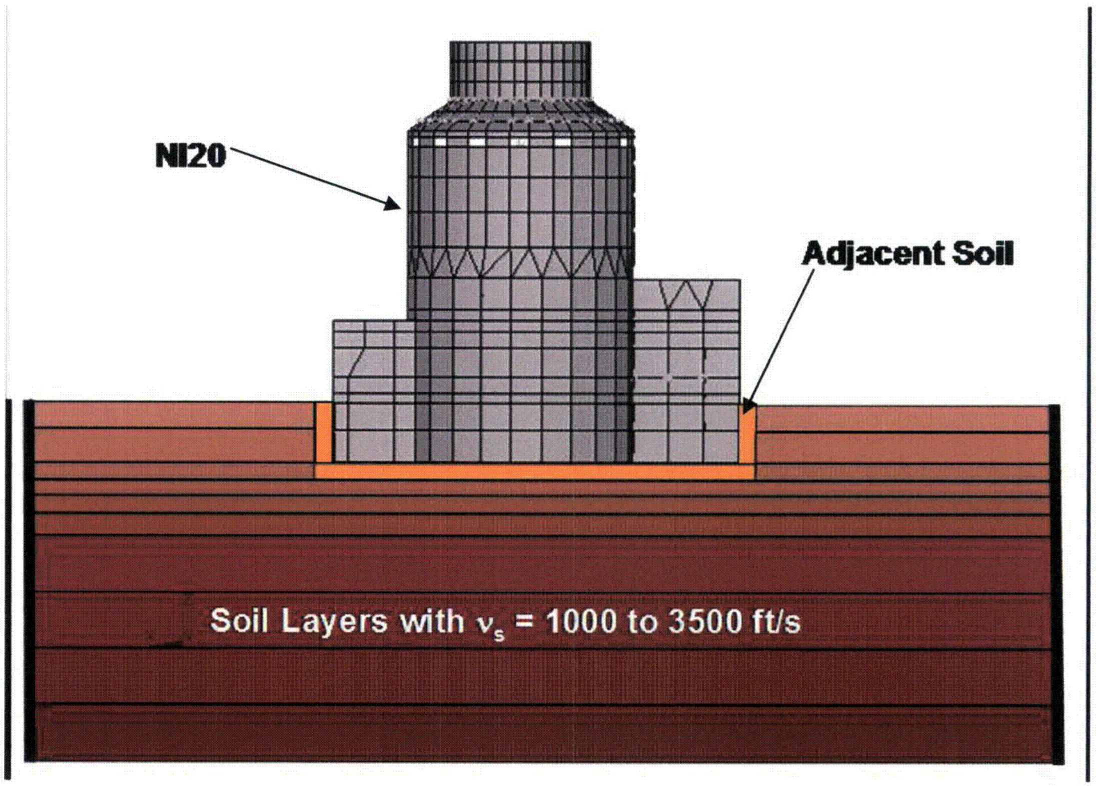


Figure 3G.2-10

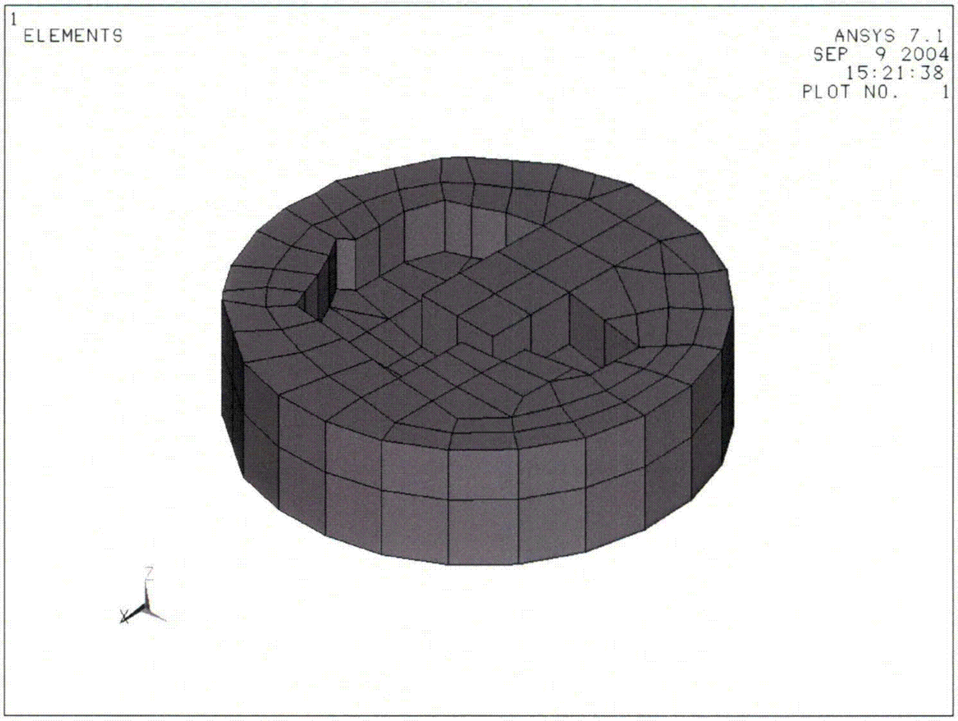
Containment Internal Structure with the SCV, PC, Reactor Coolant Loop, and Pressurizer

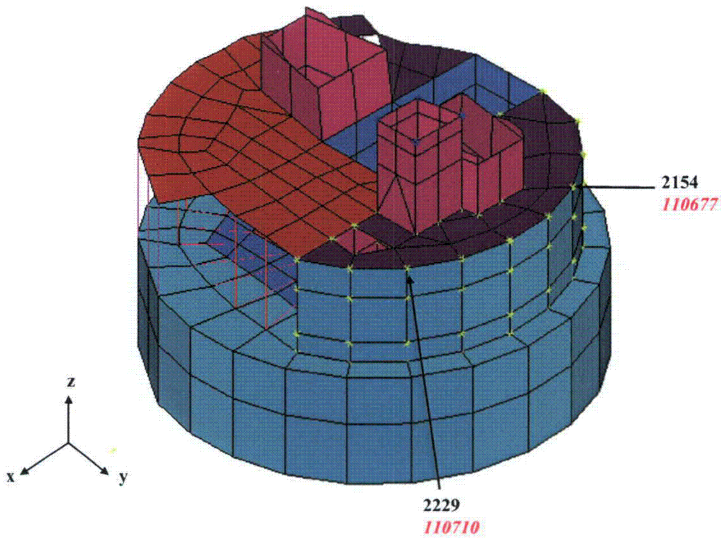


Note: The adjacent soil elements are part of the structural portion of SASSI and have the same material properties as the soil. These elements are used to obtain soil lateral and bearing soil pressures.

Figure 3G.2-11

Soil Structure Interaction Model – NI20 Looking East

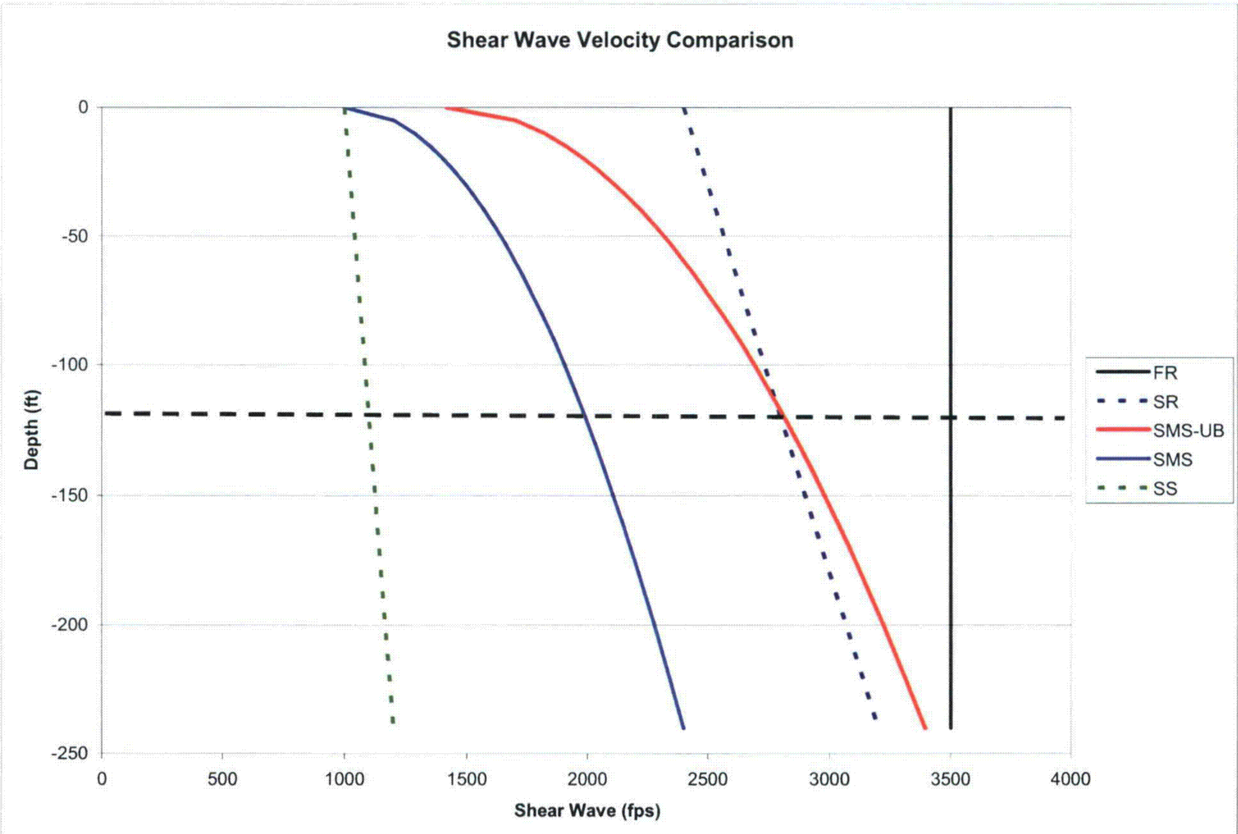




Critical nodes at isometric view

Figure 3G.2-12

Coarse Model of Containment Internal Structures



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

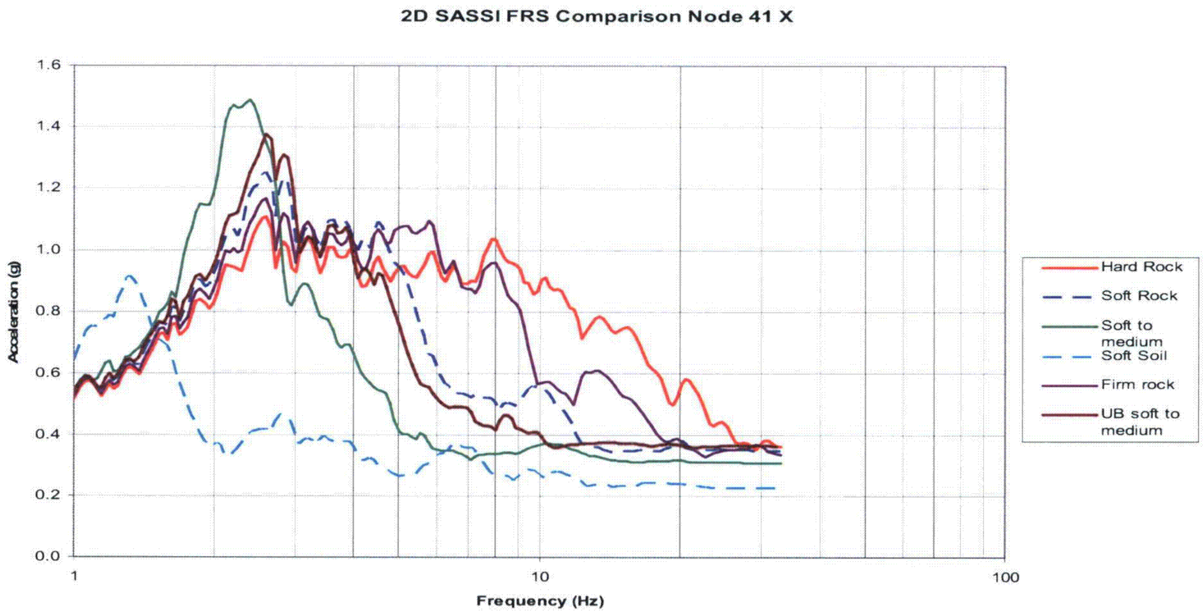


Figure 3G.3-2

2D SASSI FRS – Node 41 X (ASB El. 99′)

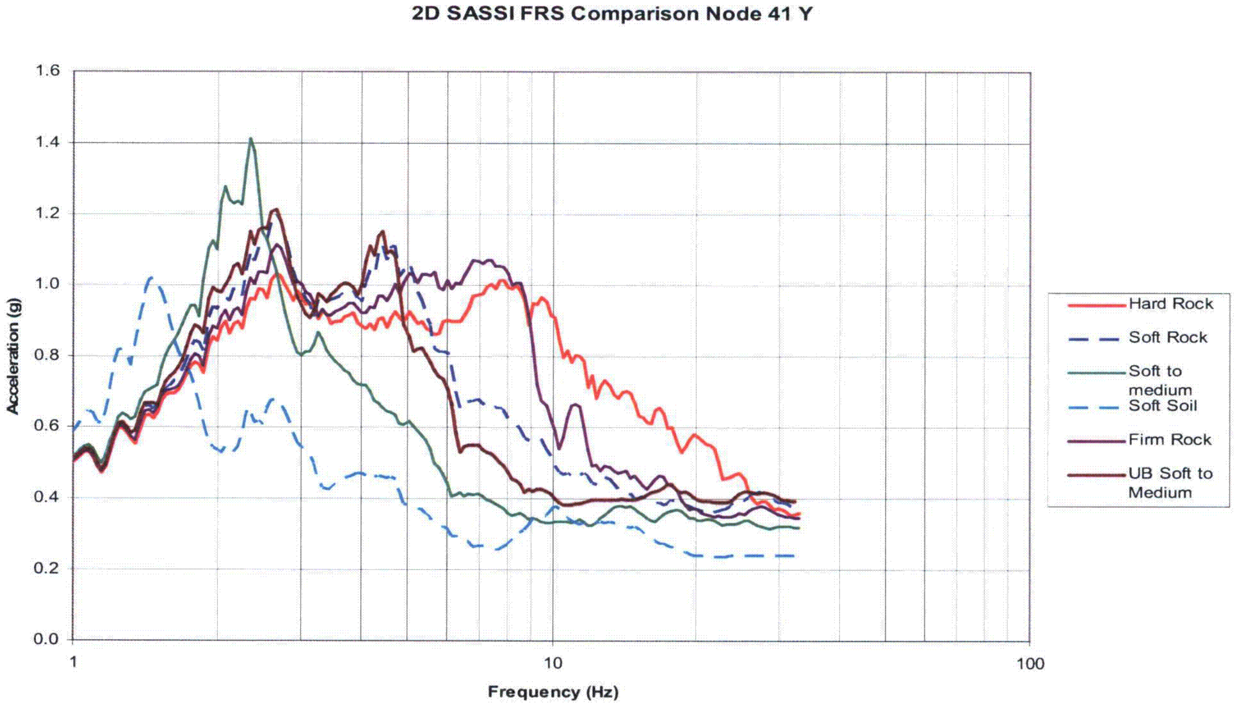


Figure 3G.3-3

2D SASSI FRS – Node 41Y (ASB El. 99′)

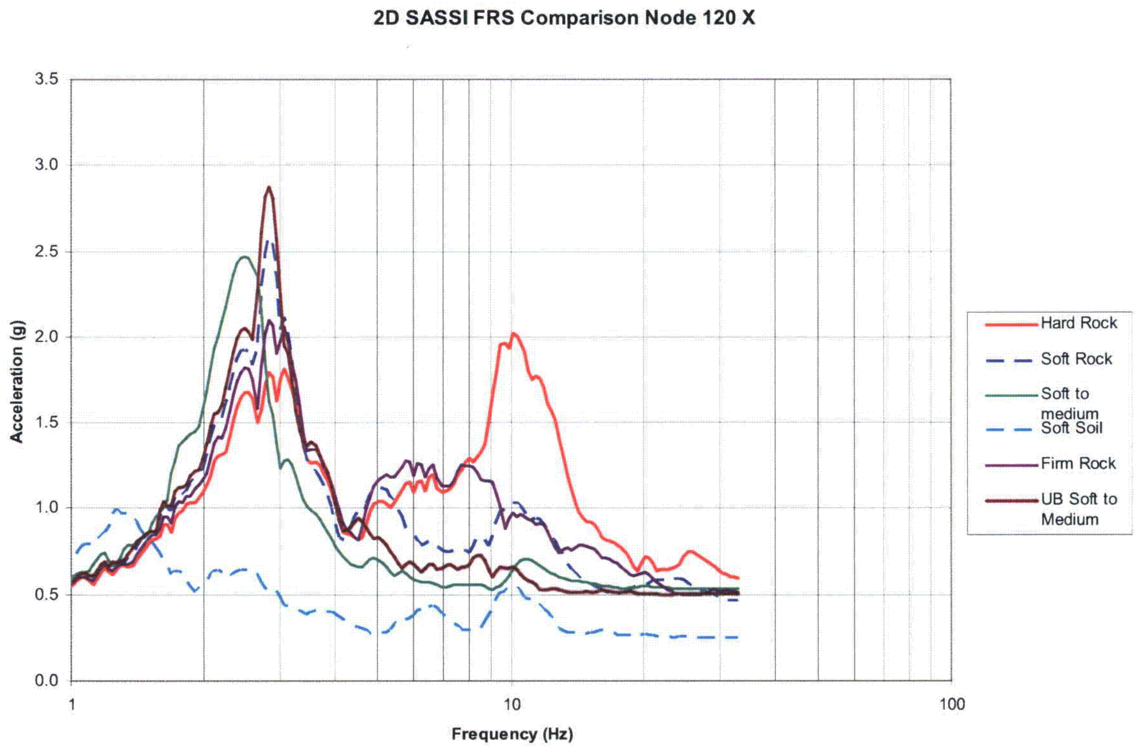


Figure 3G.3-4

2D SASSI FRS – Node 120 X (ASB El. 179.6′)

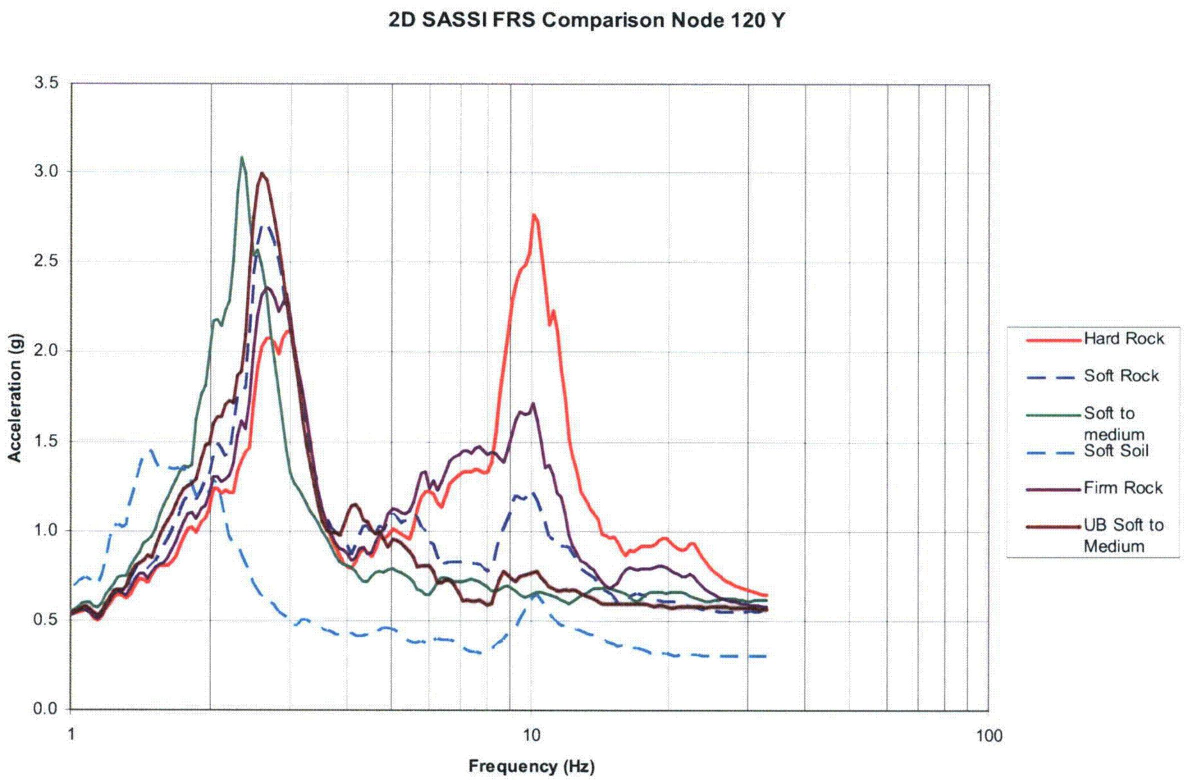


Figure 3G.3-5

2D SASSI FRS – Node 120 Y (ASB El. 179.6′)

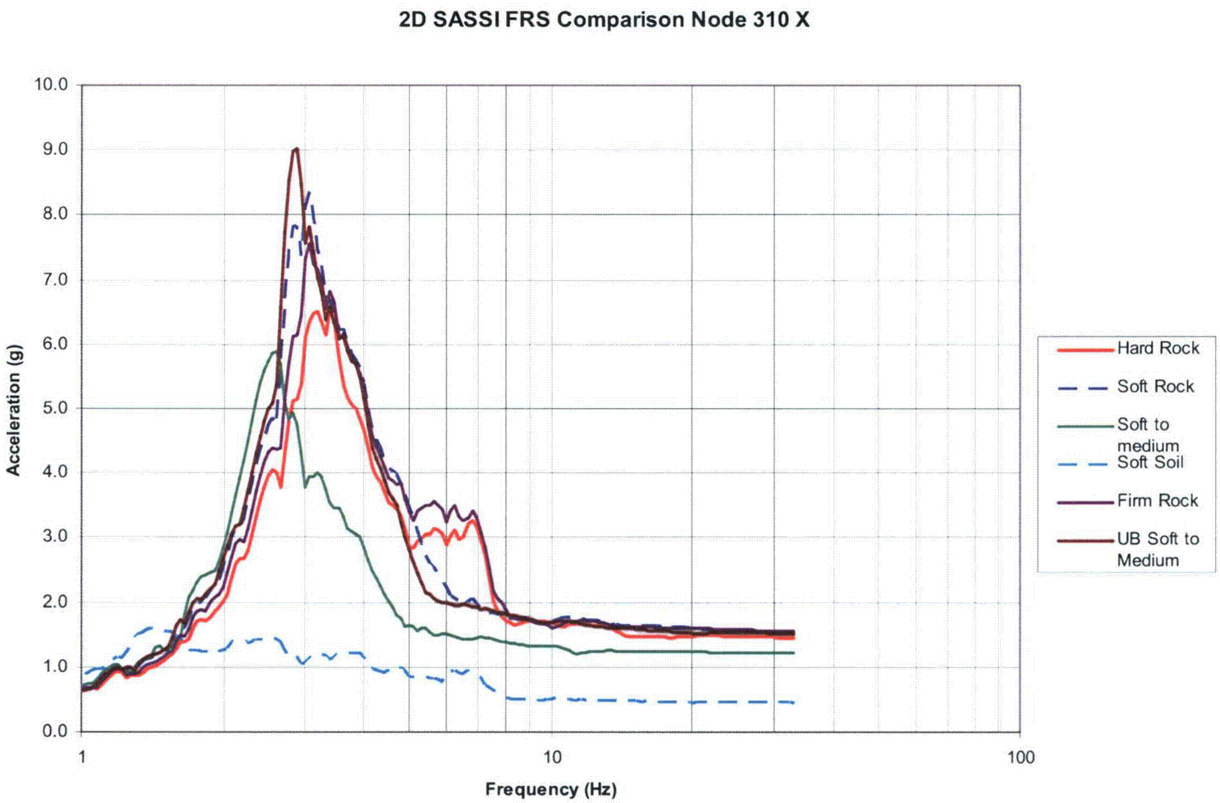


Figure 3G.3-6

2D SASSI FRS – Node 310 X (ASB El. 333.2′)

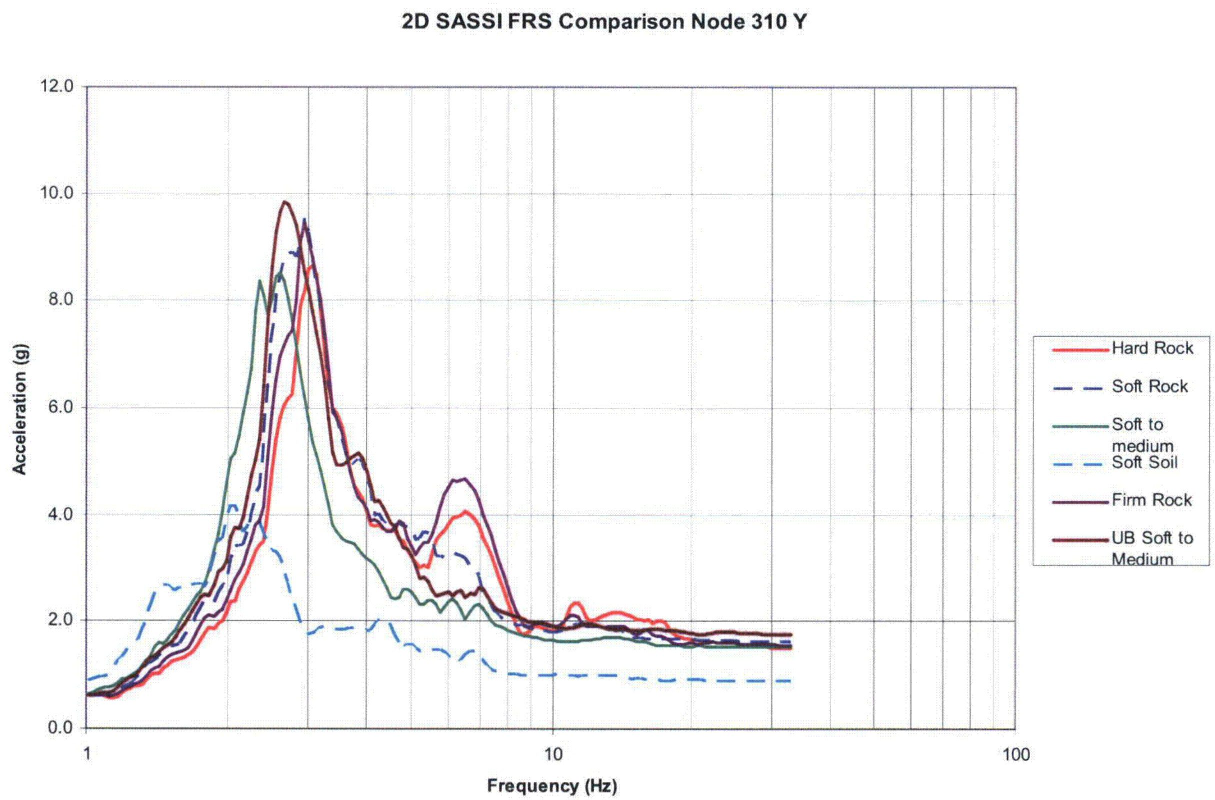


Figure 3G.3-7

2D SASSI FRS – Node 310 Y (ASB El. 333.2′)

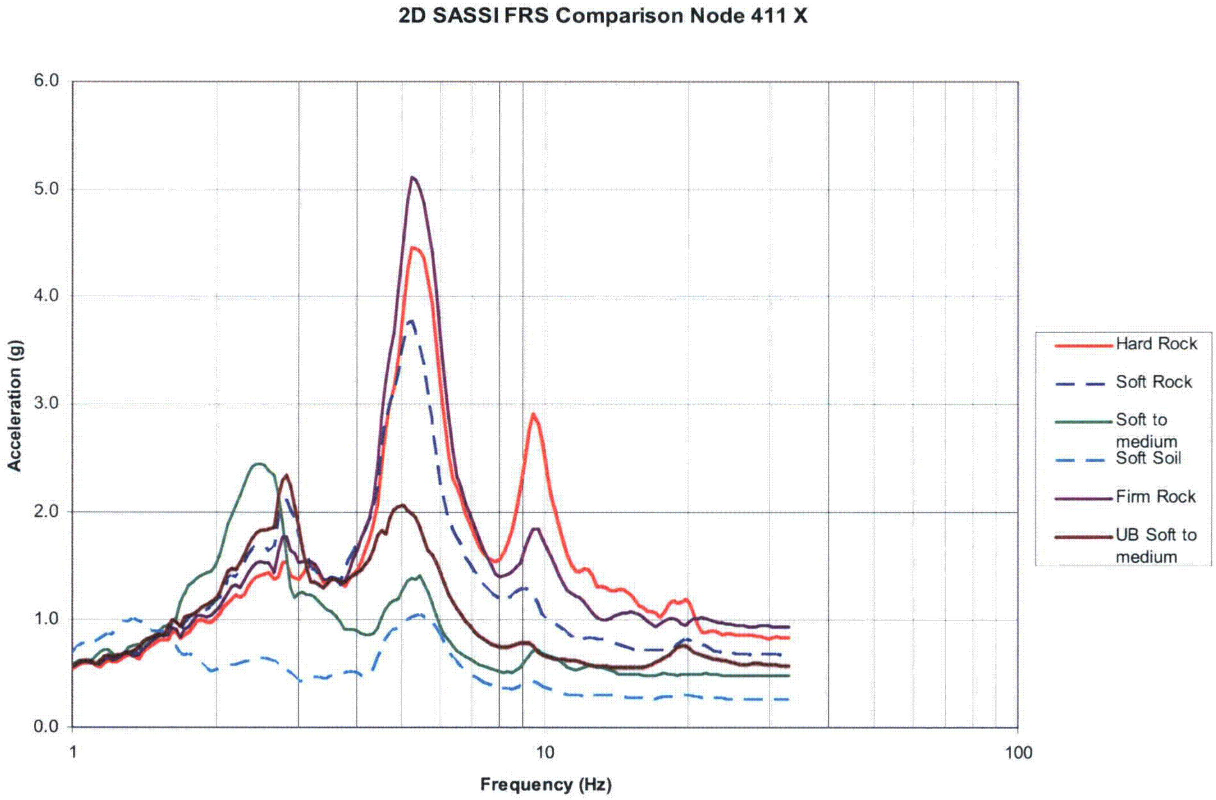


Figure 3G.3-8

2D SASSI FRS – Node 411 X (SCV El. 200.0′)

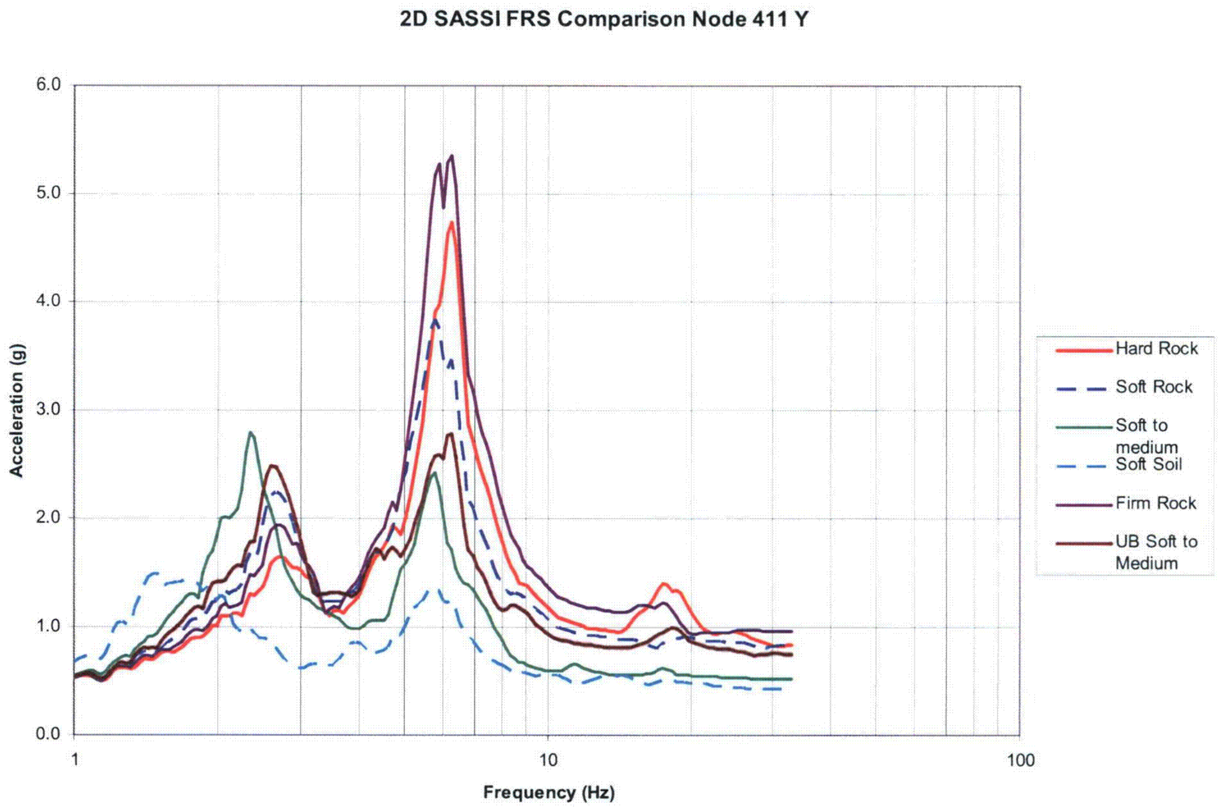


Figure 3G.3-9

2D SASSI FRS – Node 411 Y (SCV El. 200.0′)

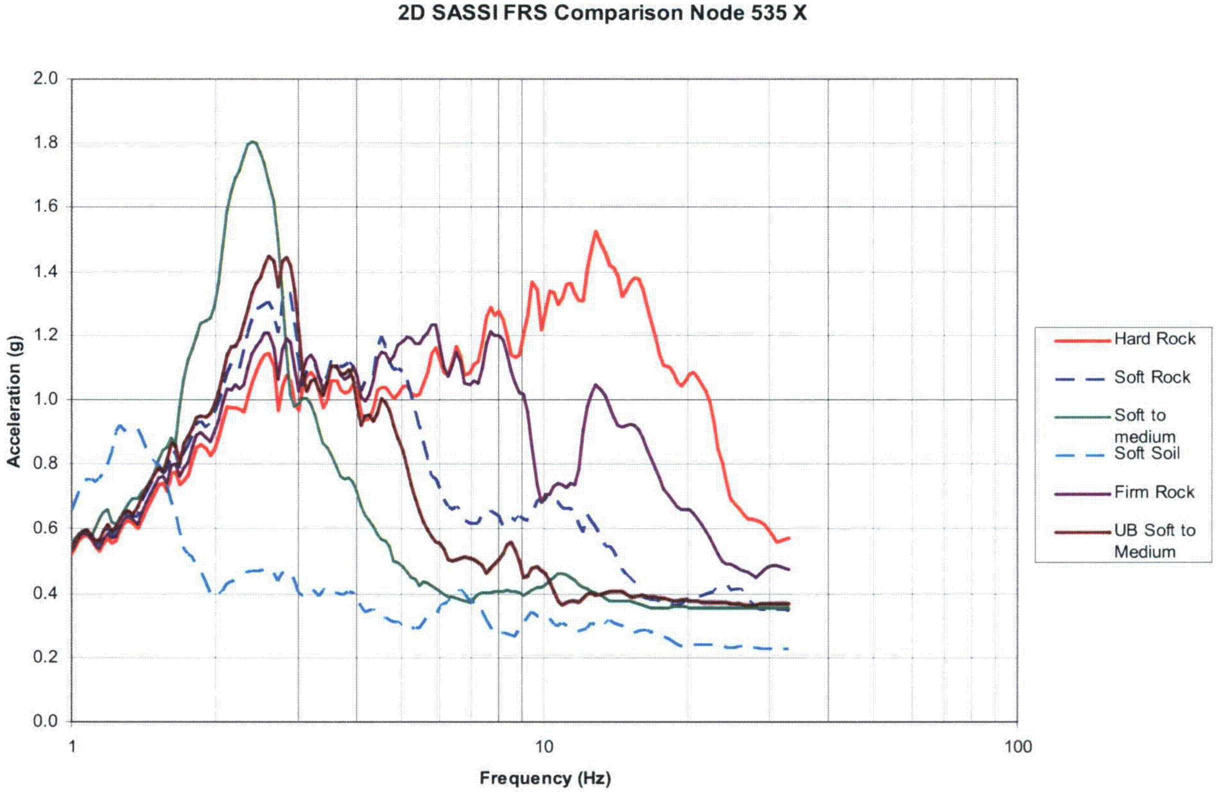


Figure 3G.3-10

2D SASSI FRS – Node 535 X (CIS El. 134.3′)

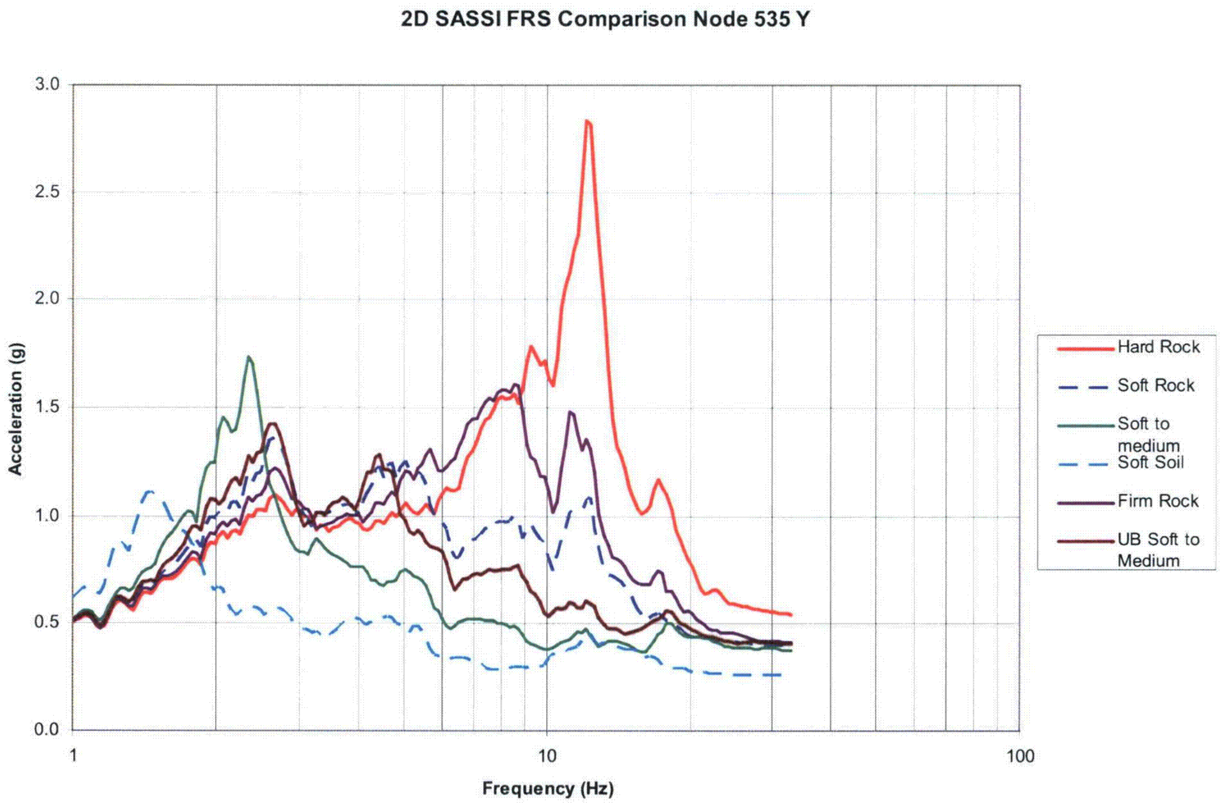


Figure 3G.3-11

2D SASSI FRS – Node 535 Y (CIS El. 134.3′)

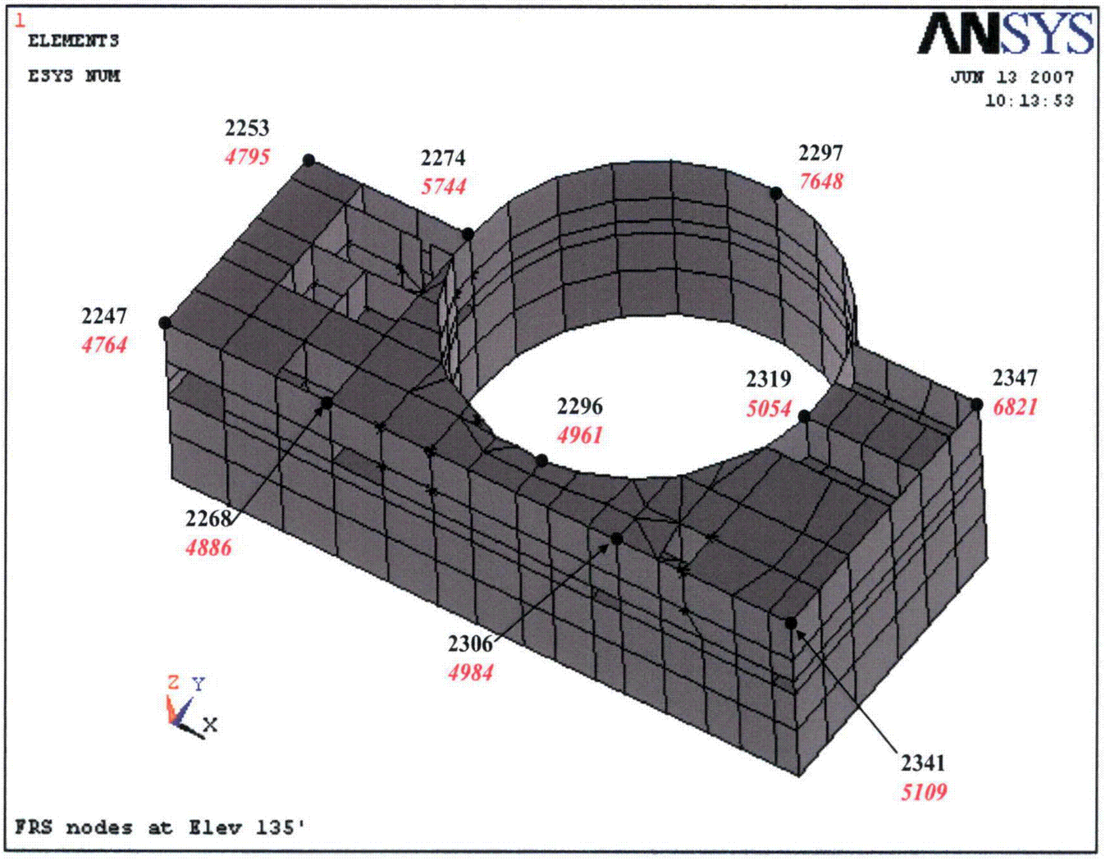


Figure 3G.4-1

Auxiliary Shield Building "Rigid" Nodes at El. 135′

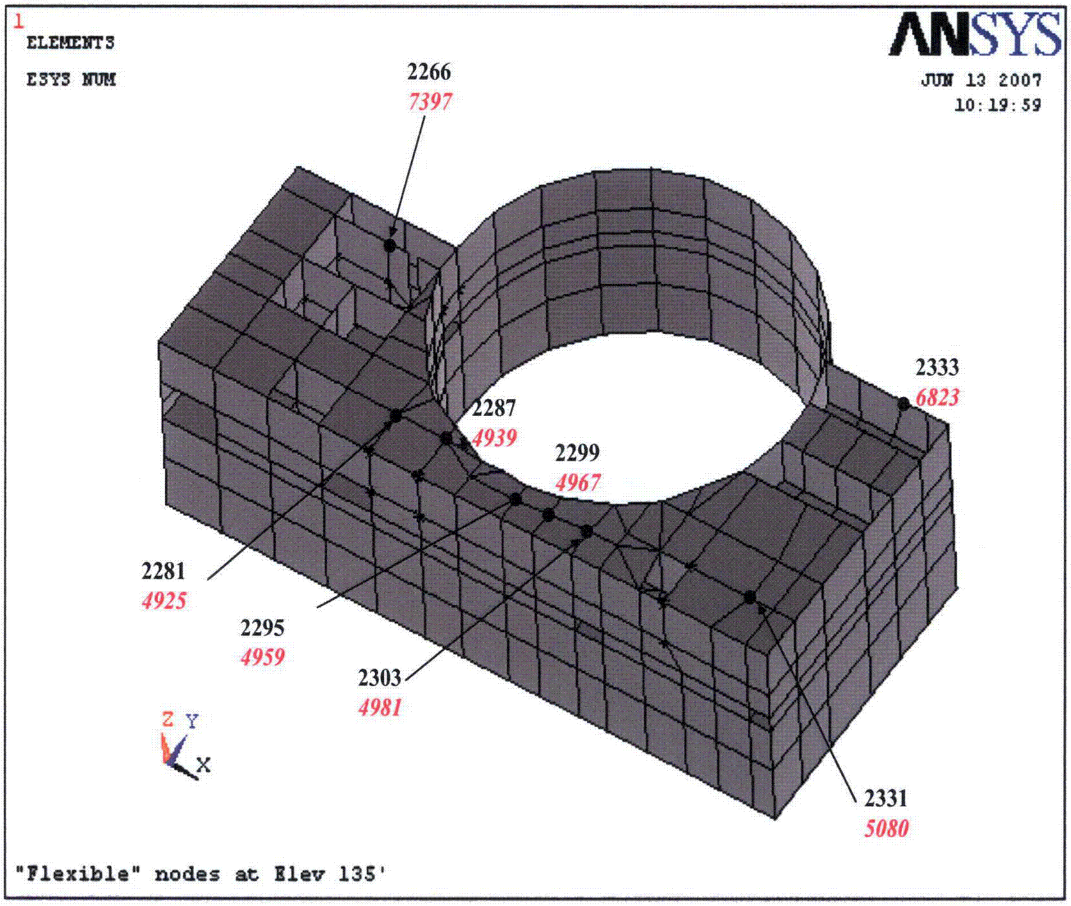


Figure 3G.4-2

Auxiliary Shield Building "Flexible" Nodes at El. 135′

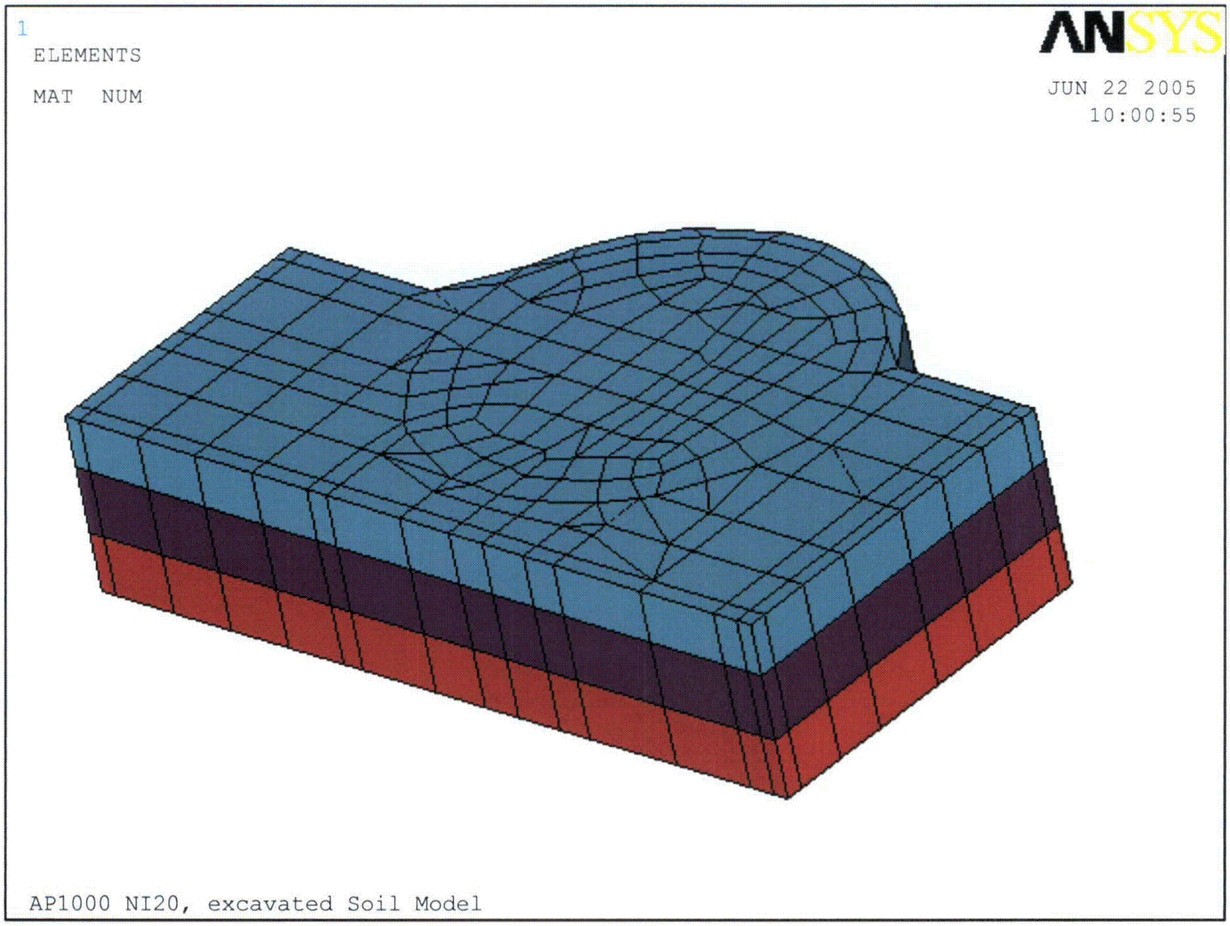


Figure 3G.4-3

Excavated Soil

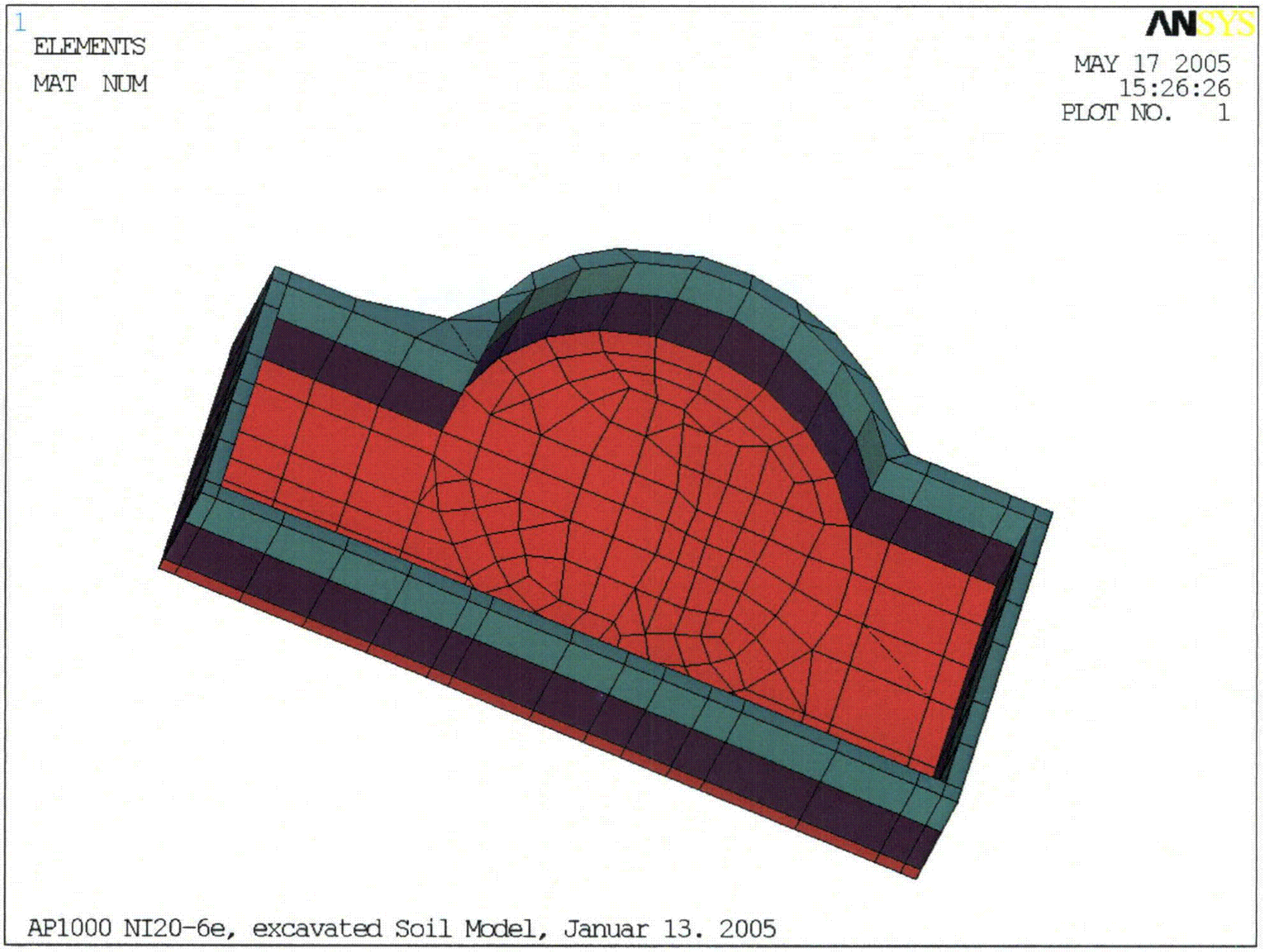


Figure 3G.4-4

Additional Elements for Soil Pressure Calculations

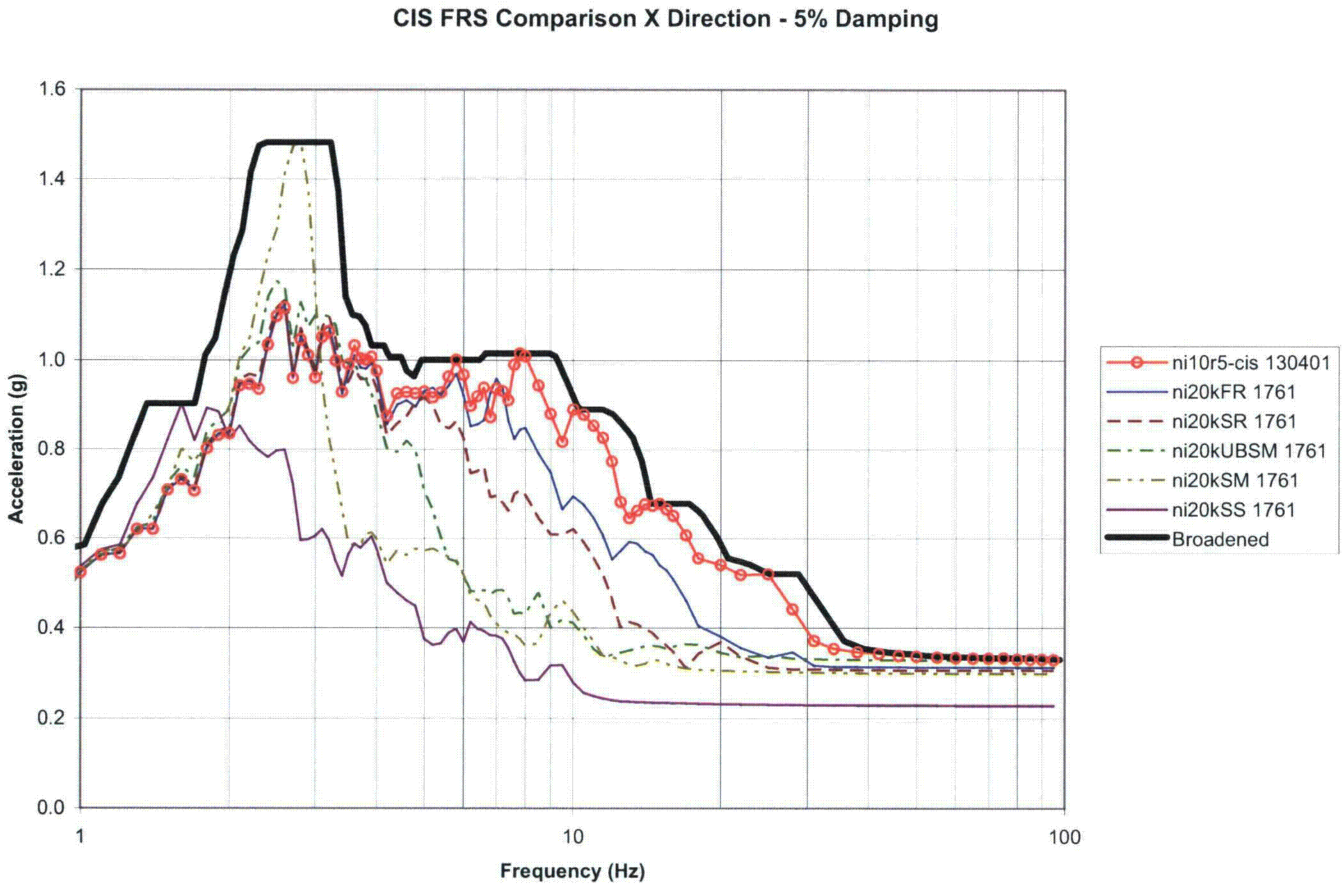


Figure 3G.4-5X

X Direction FRS for node 130401 (NI10) or 1761 (NI20)
CIS at Reactor Vessel Support Elevation of 100’

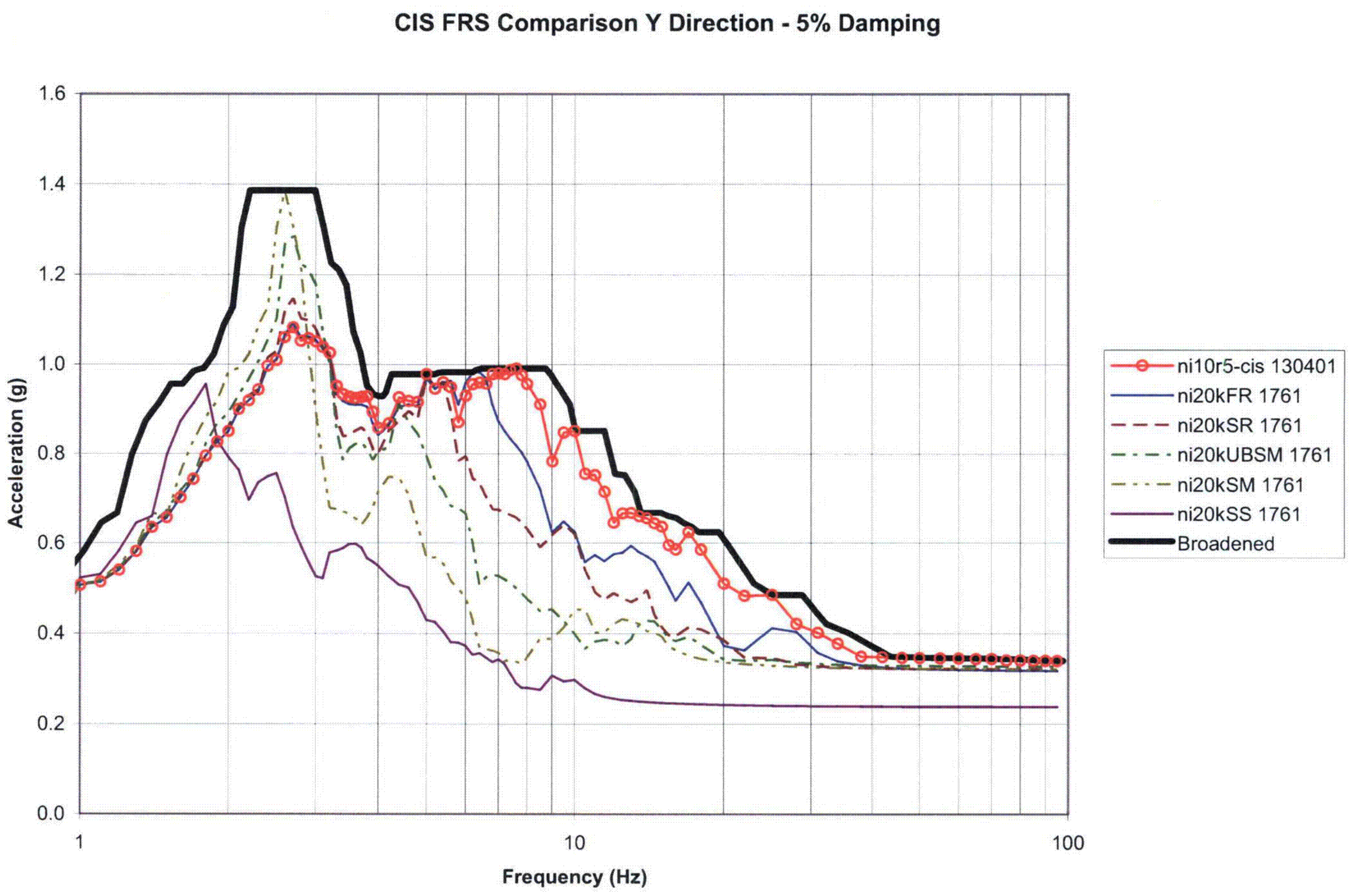


Figure 3G.4-5Y
Y Direction FRS for node 130401 (NI10) or 1761 (NI20)
CIS at Reactor Vessel Support Elevation of 100'

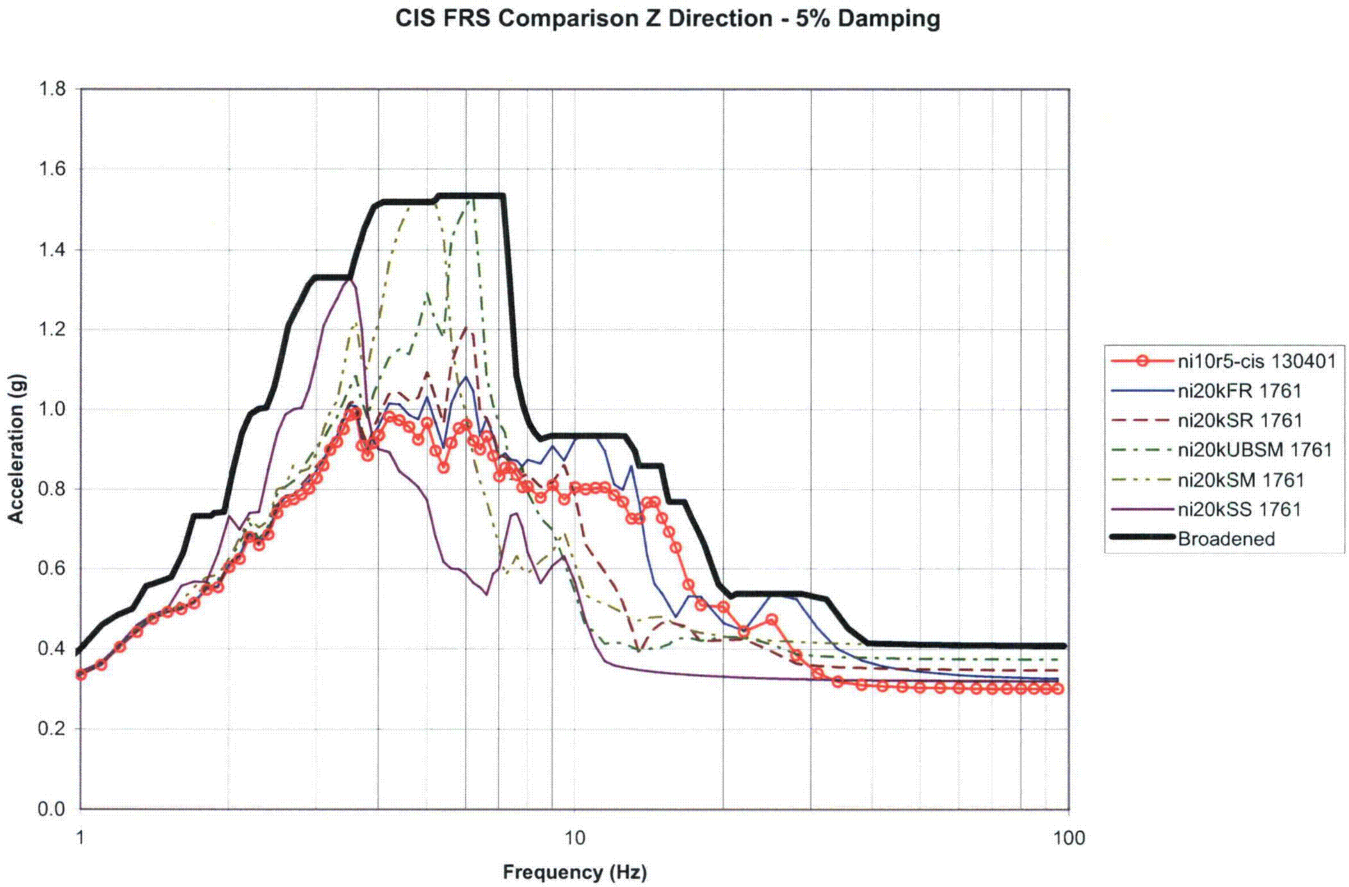


Figure 3G.4-5Z
Z Direction FRS for node 130401 (NI10) or 1761 (NI20)
CIS at Reactor Vessel Support Elevation of 100'

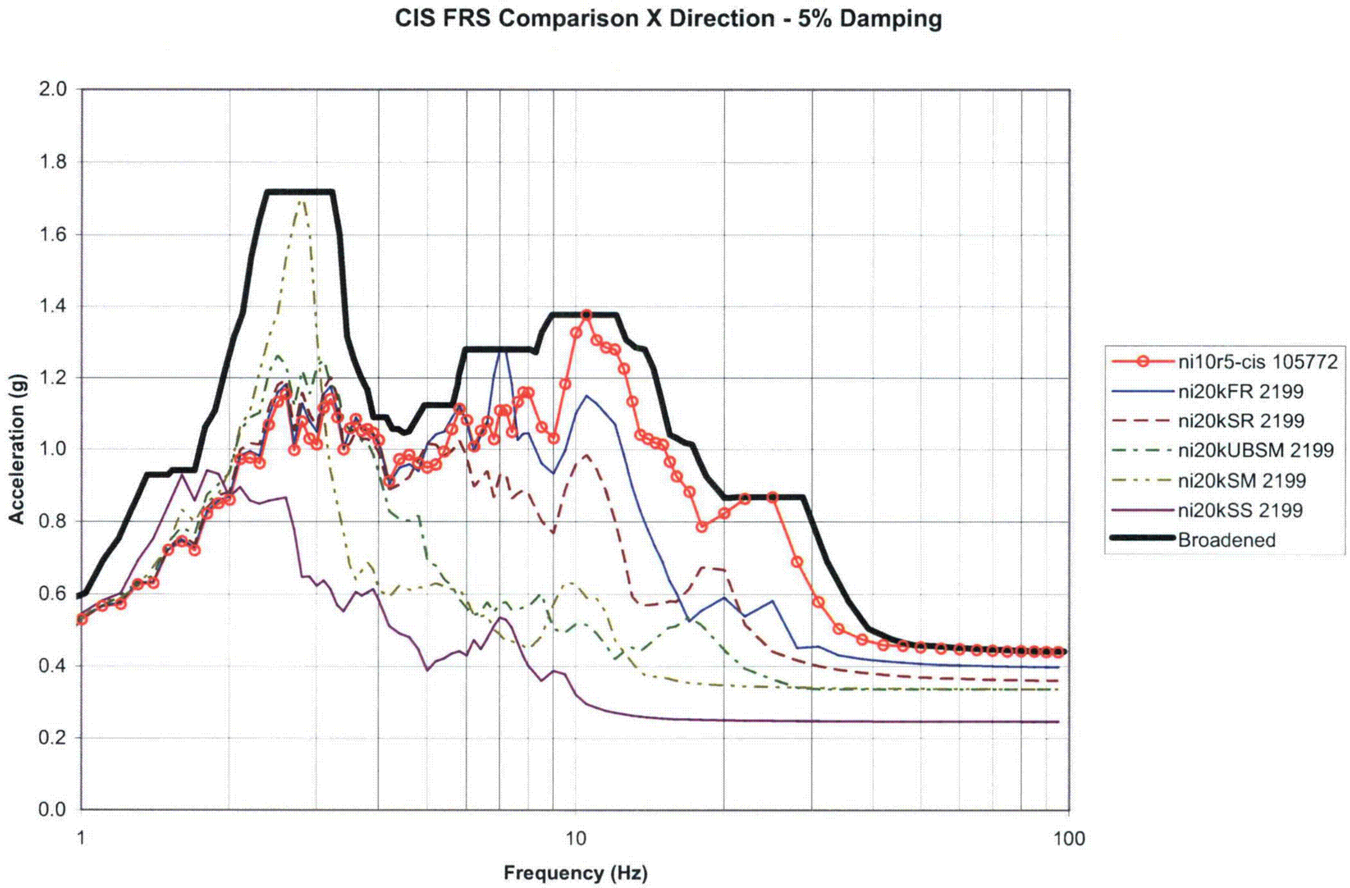


Figure 3G.4-6X
X Direction FRS for node 105772 (NI10) or 2199 (NI20)
CIS at Operating Deck Elevation 134.25'

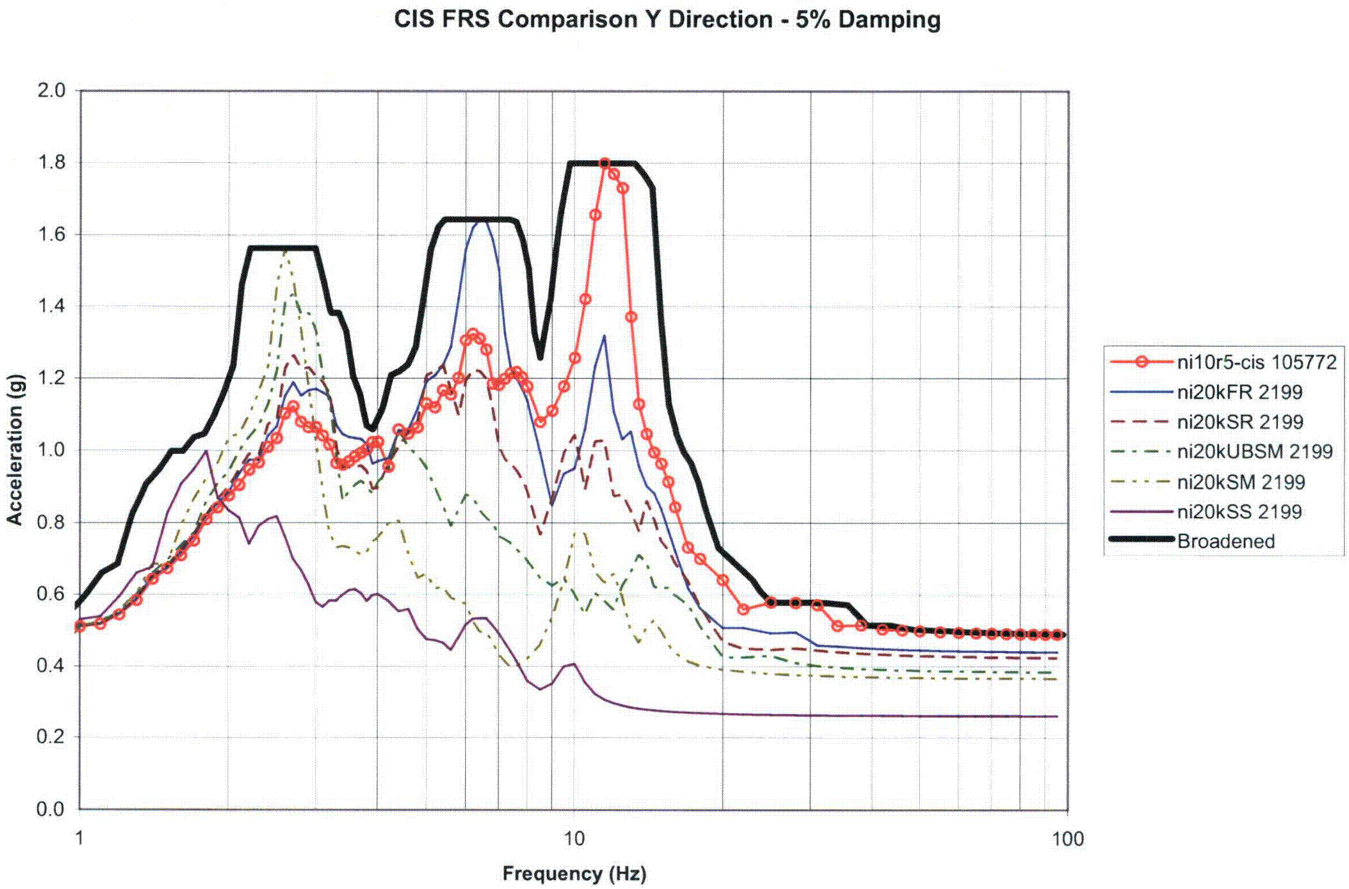


Figure 3G.4-6Y
Y Direction FRS for node 105772 (NI10) or 2199 (NI20)
CIS at Operating Deck Elevation 134.25'

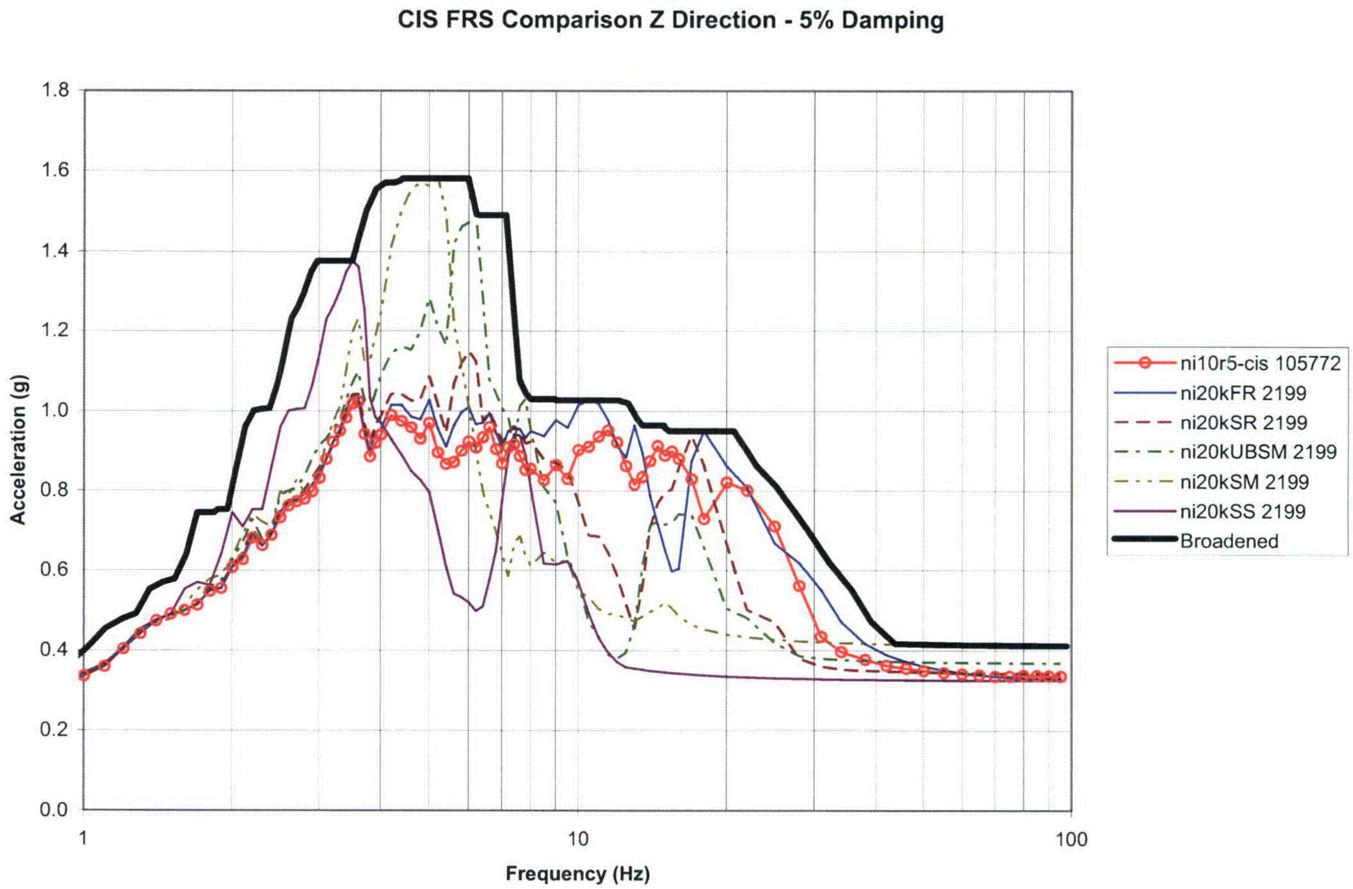


Figure 3G.4-6Z
Z Direction FRS for node 105772 (NI10) or 2199 (NI20)
CIS at Operating Deck Elevation 134.25'

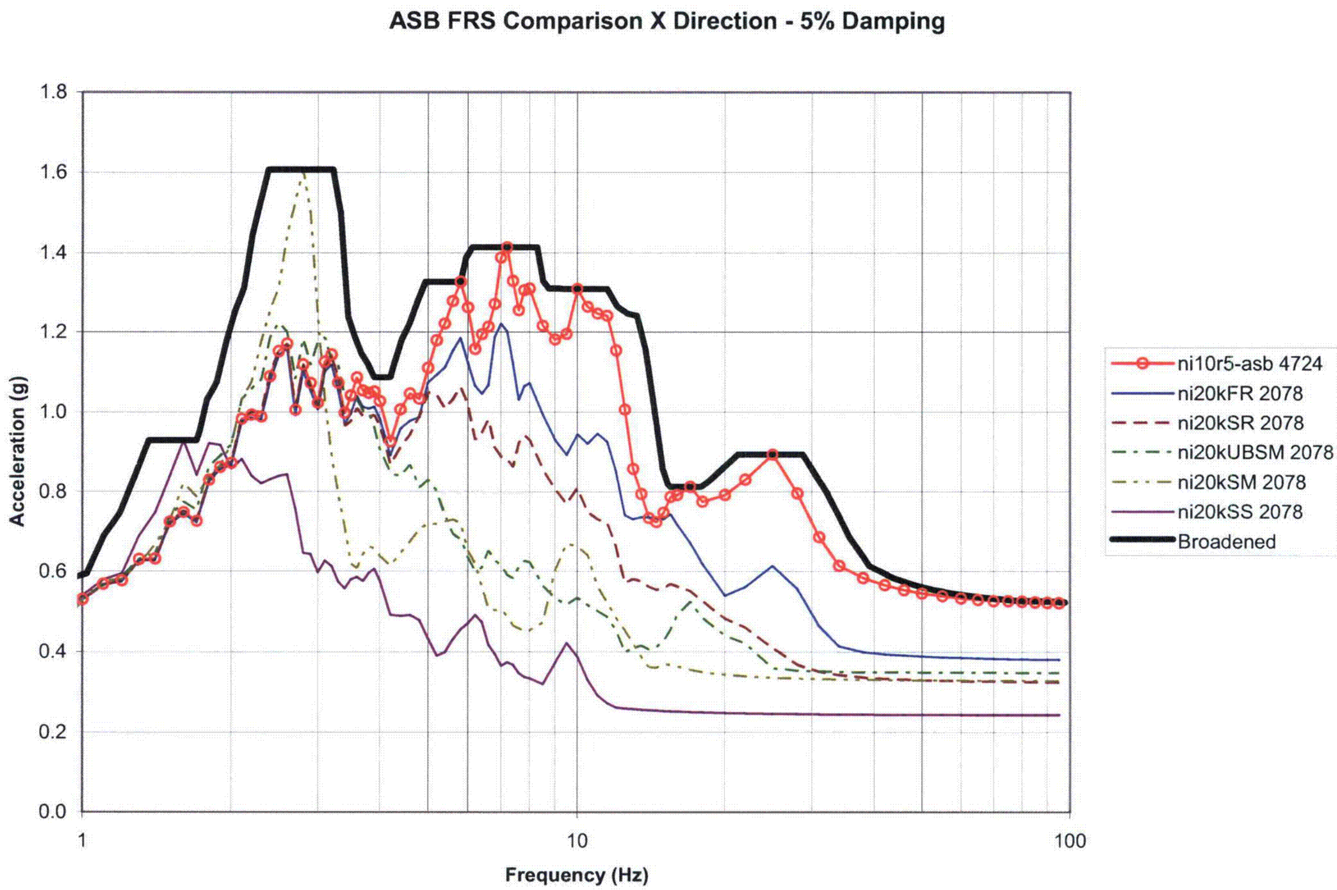


Figure 3G.4-7X
X Direction FRS for node 4724 (NI10) or 2078 (NI20)
ASB Control Room Side Elevation 116.50'

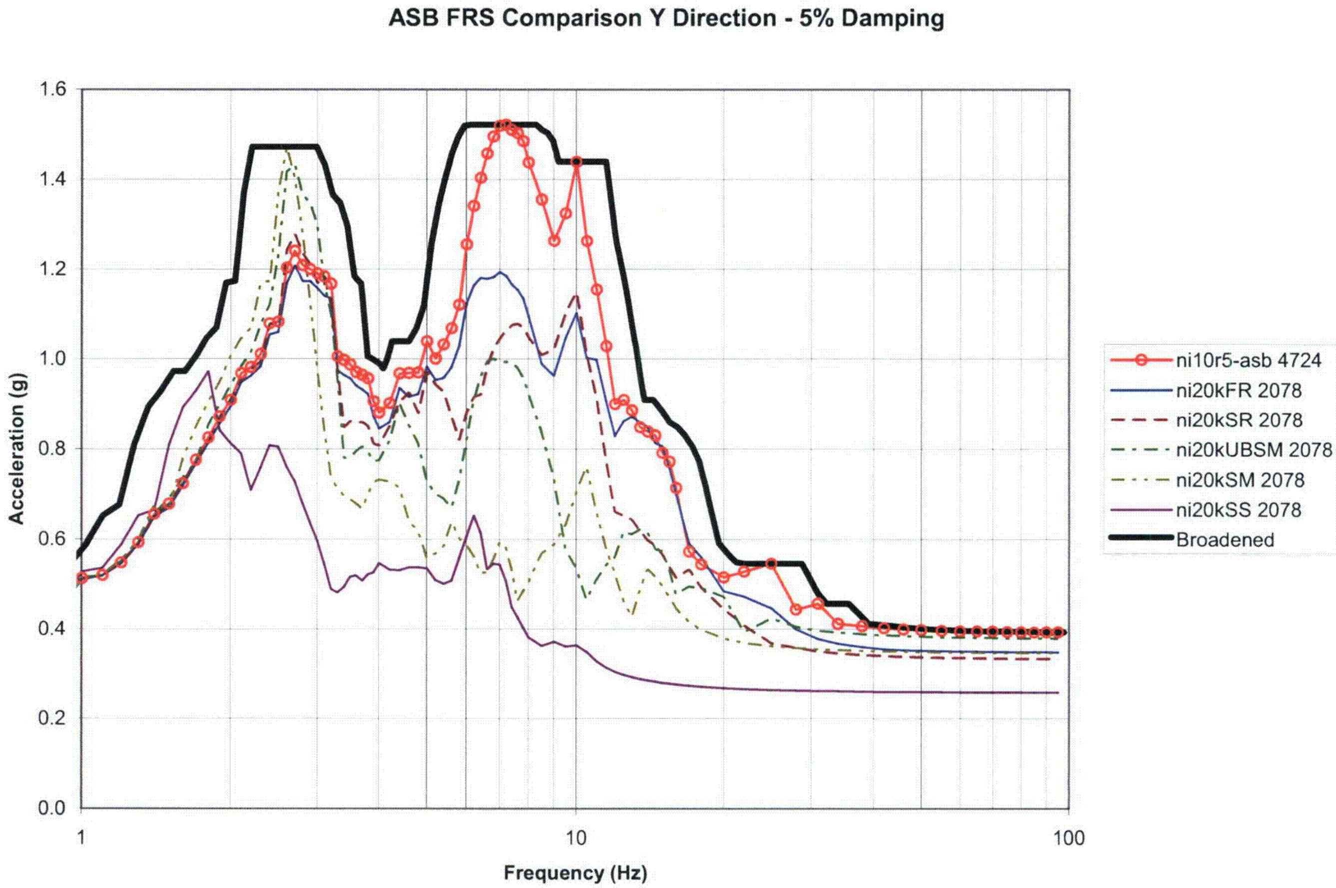


Figure 3G.4-7Y
Y Direction FRS for node 4724 (NI10) or 2078 (NI20)
ASB Control Room Side Elevation 134.88'

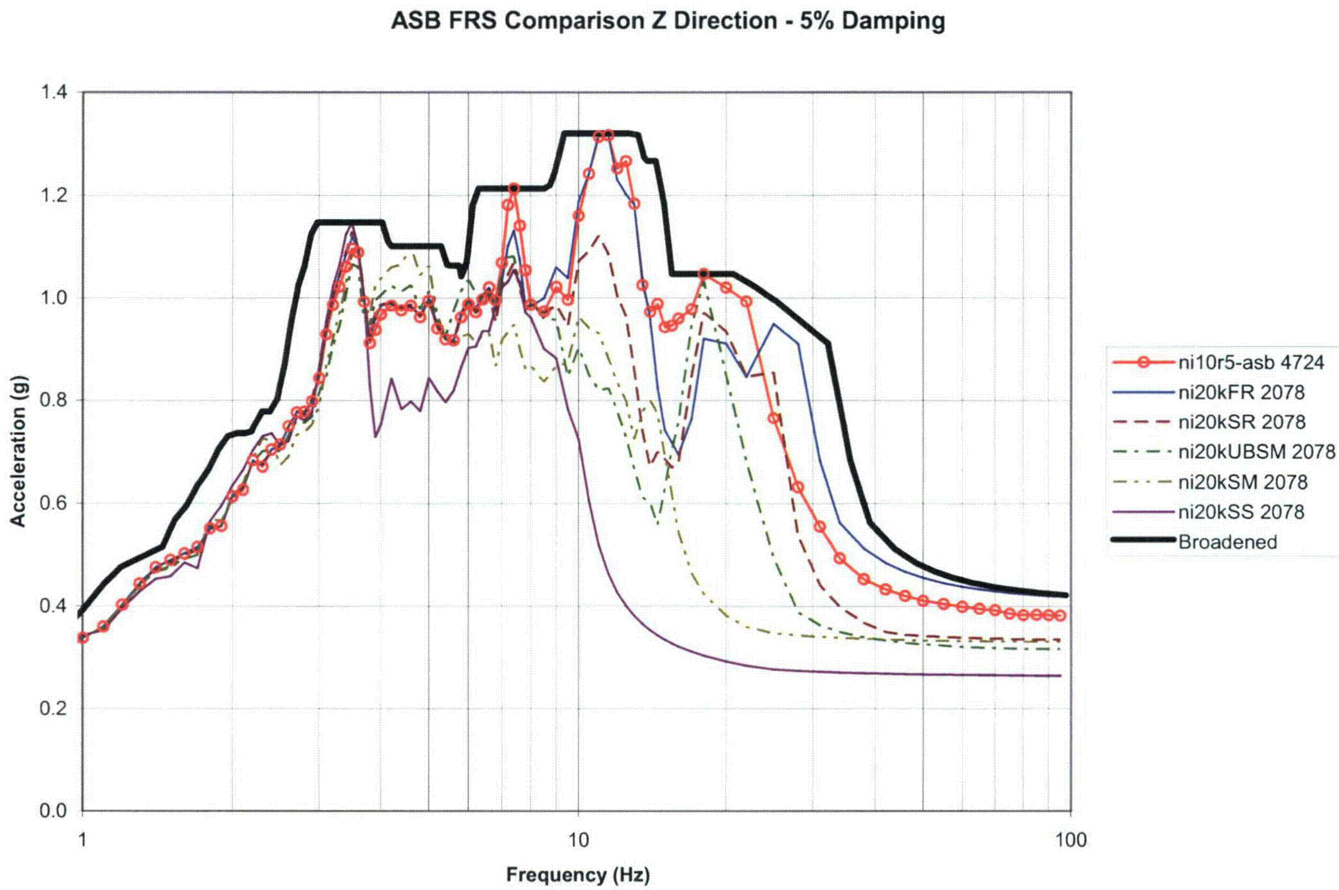


Figure 3G.4-7Z
Z Direction FRS for node 4724 (NI10) or 2078 (NI20)
ASB Control Room Side Elevation 134.88'

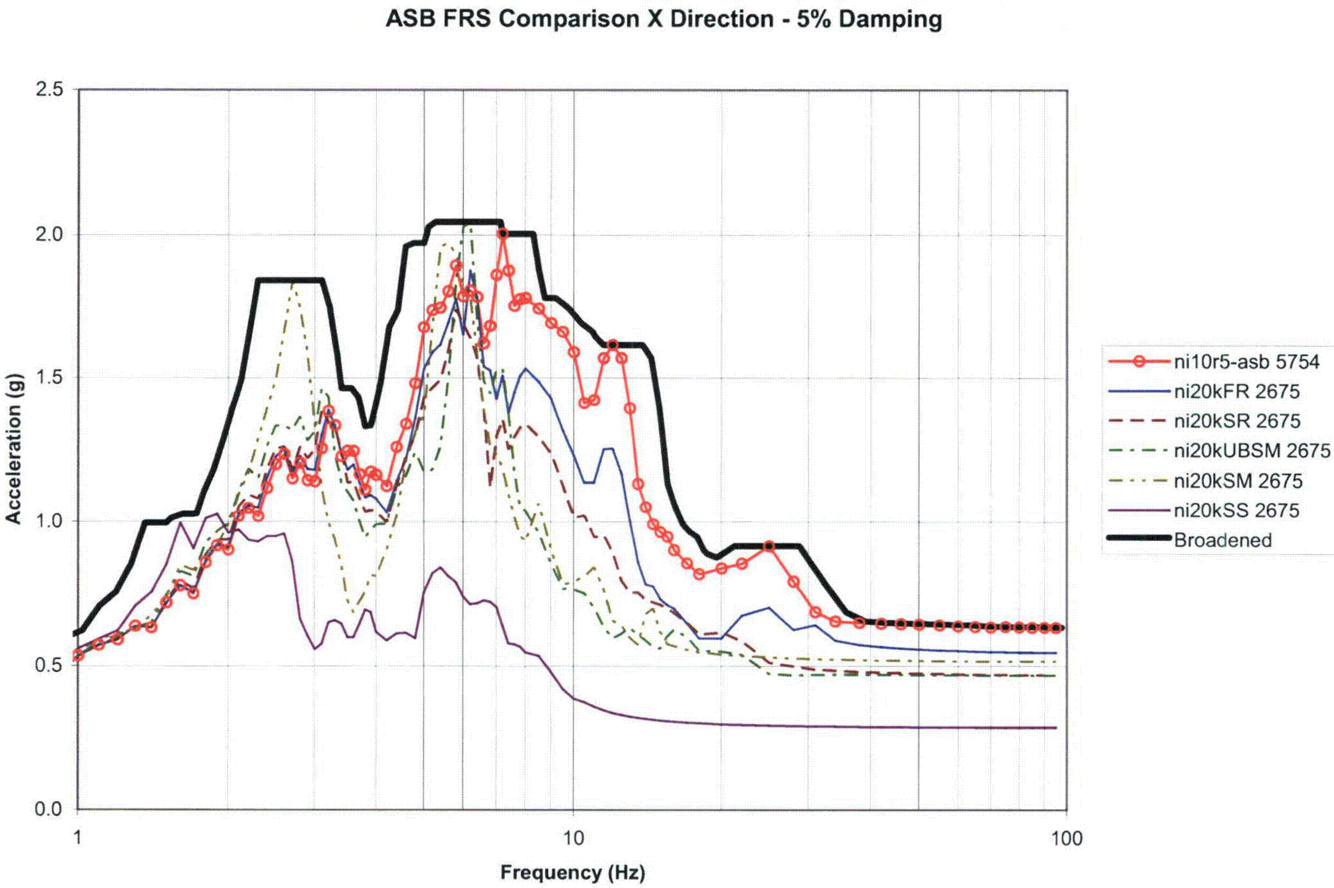


Figure 3G.4-8X
Direction FRS for node 5754 (NI10) or 2675(NI20)
ASB Fuel Building Roof Elevation 179.19'

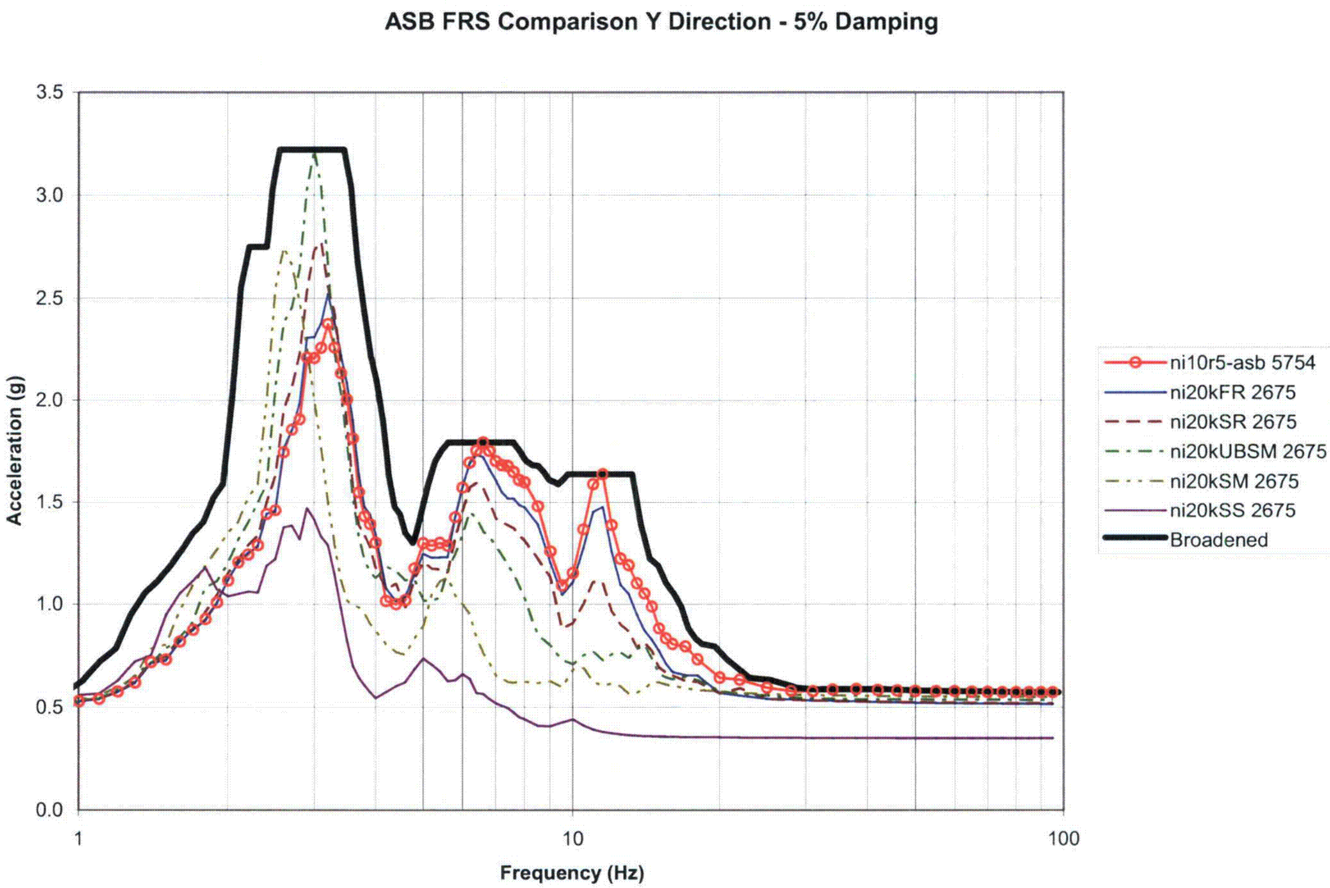


Figure 3G.4-8Y
Y Direction FRS for node 5754 (NI10) or 2675 (NI20)
ASB Fuel Building Roof Elevation 179.19'

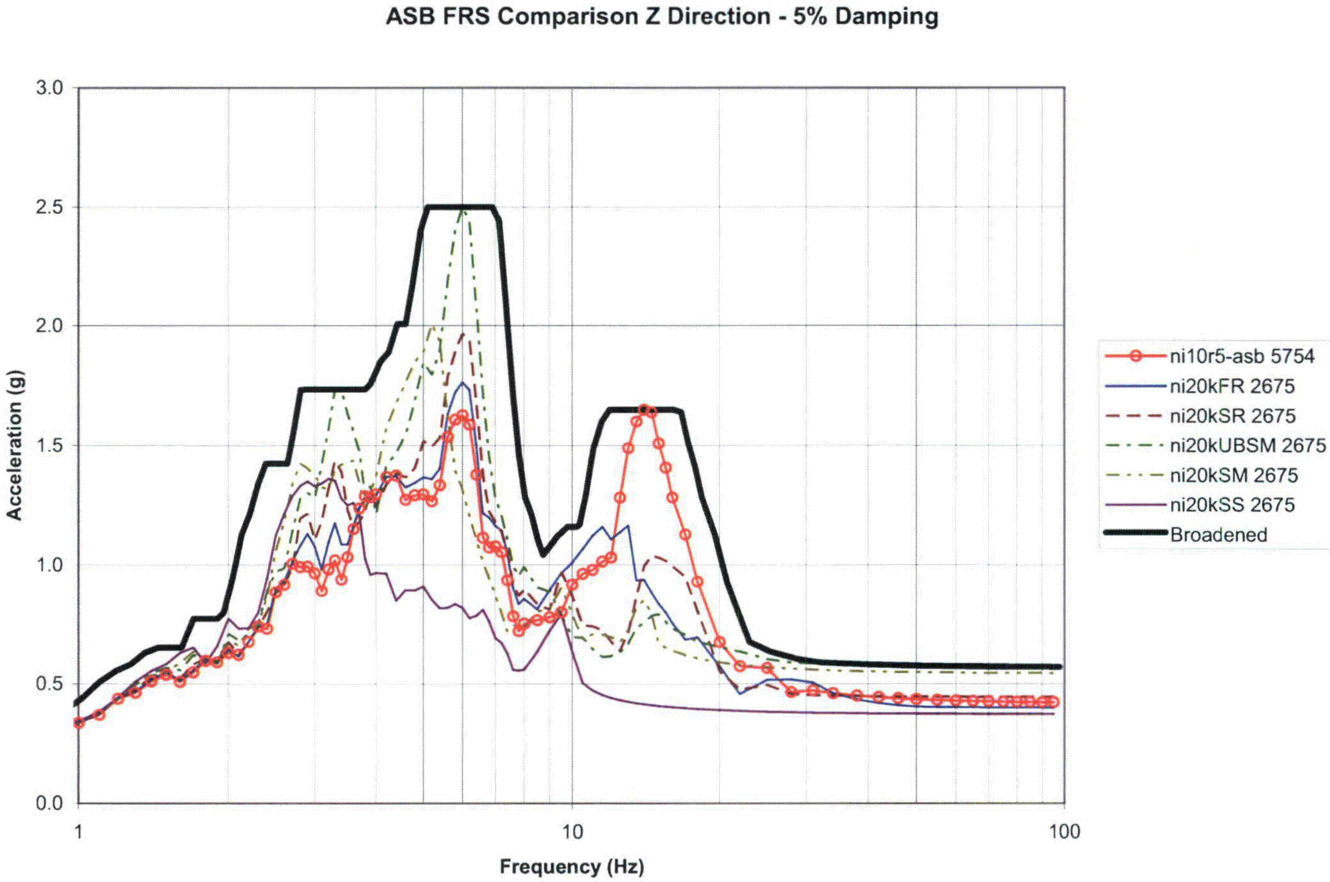


Figure 3G.4-8Z
Z Direction FRS for node 5754 (NI10) or 2675 (NI20)
ASB Fuel Building Roof Elevation 179.19'

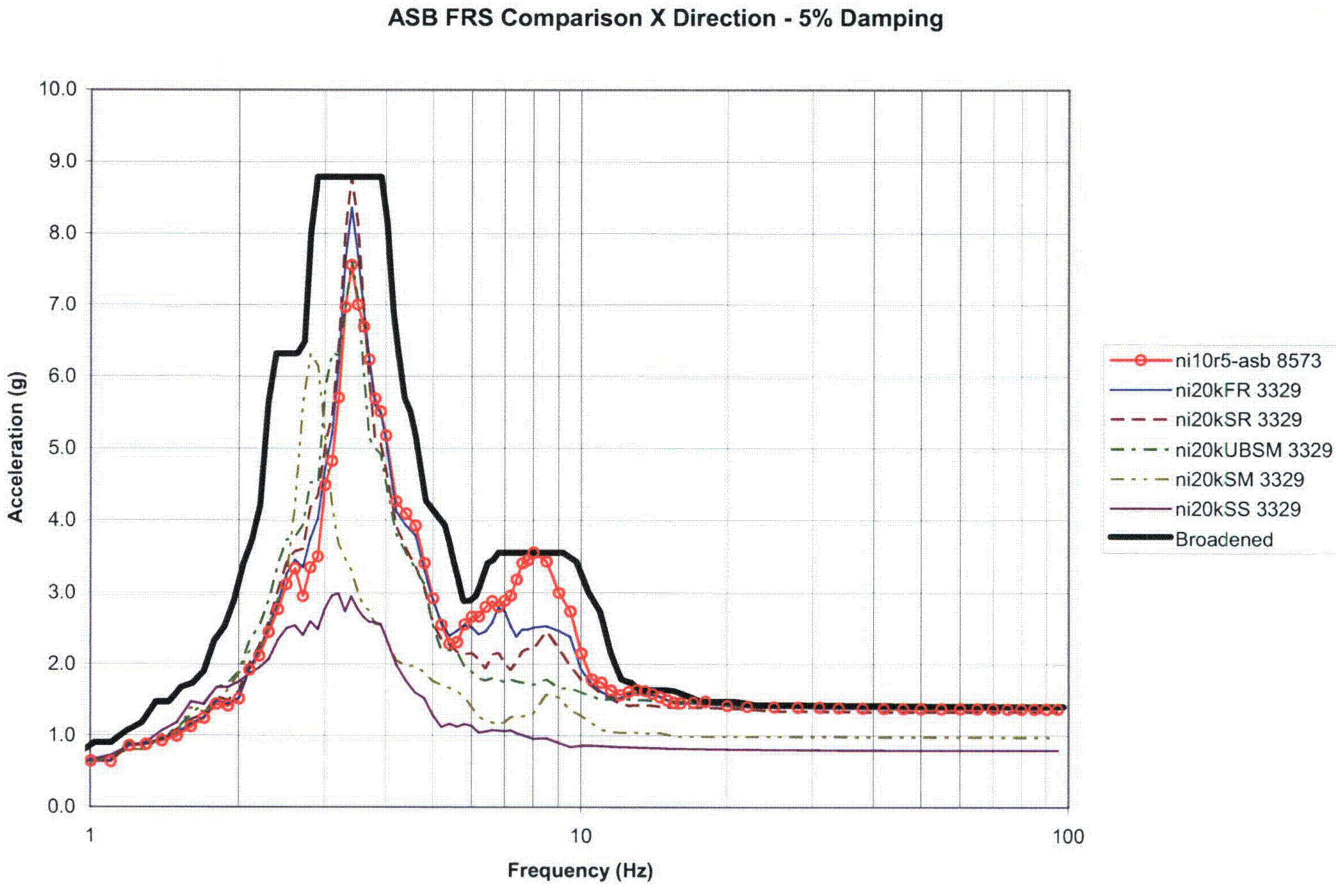


Figure 3G.4-9X
X Direction FRS for node 2862 (NI10) or 3329 (NI20)
ASB Shield Building Roof Elevation 327.41'

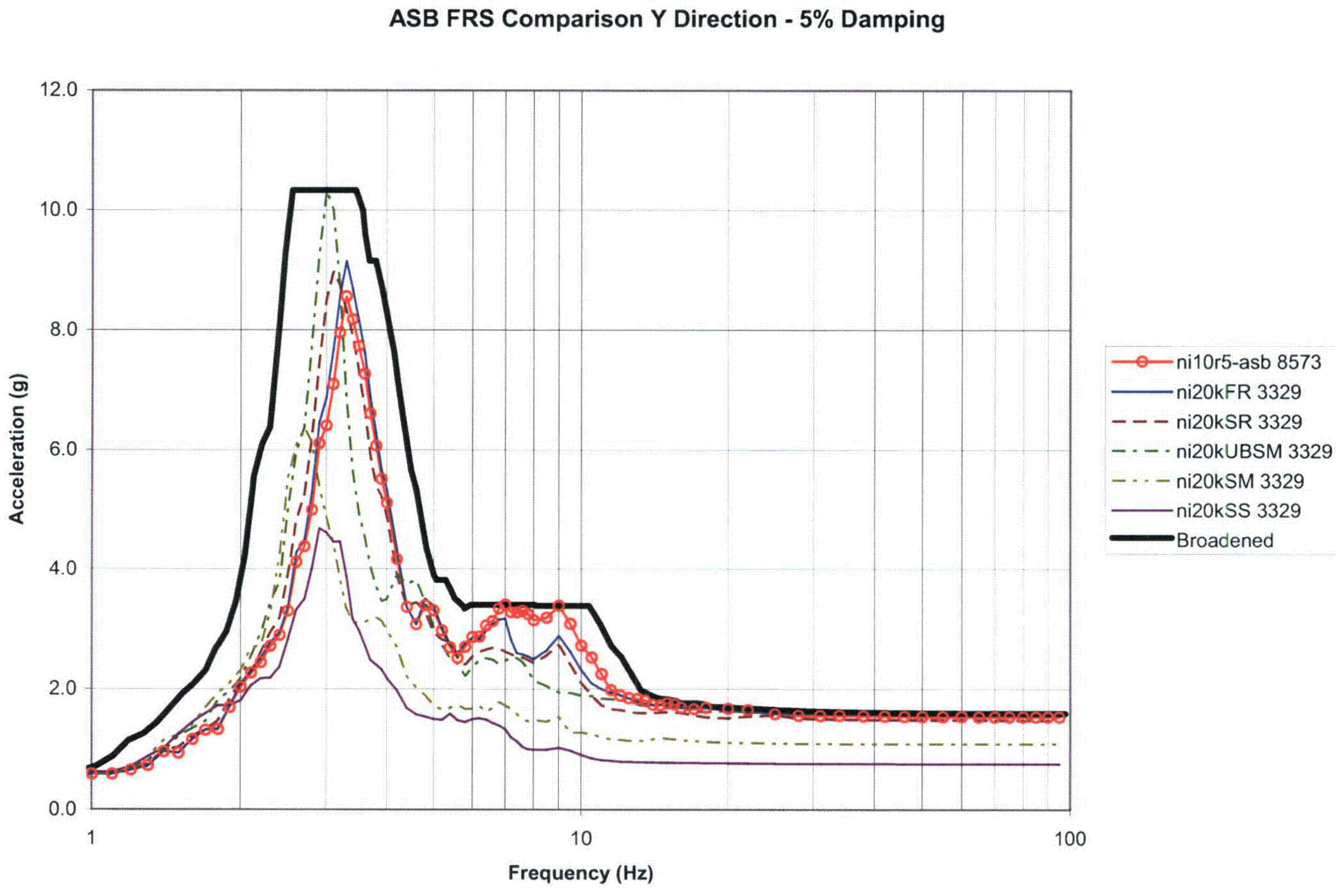


Figure 3G.4-9Y
Y Direction FRS for node 2862 (NI10) or 3329 (NI20)
ASB Shield Building Roof Elevation 327.41'

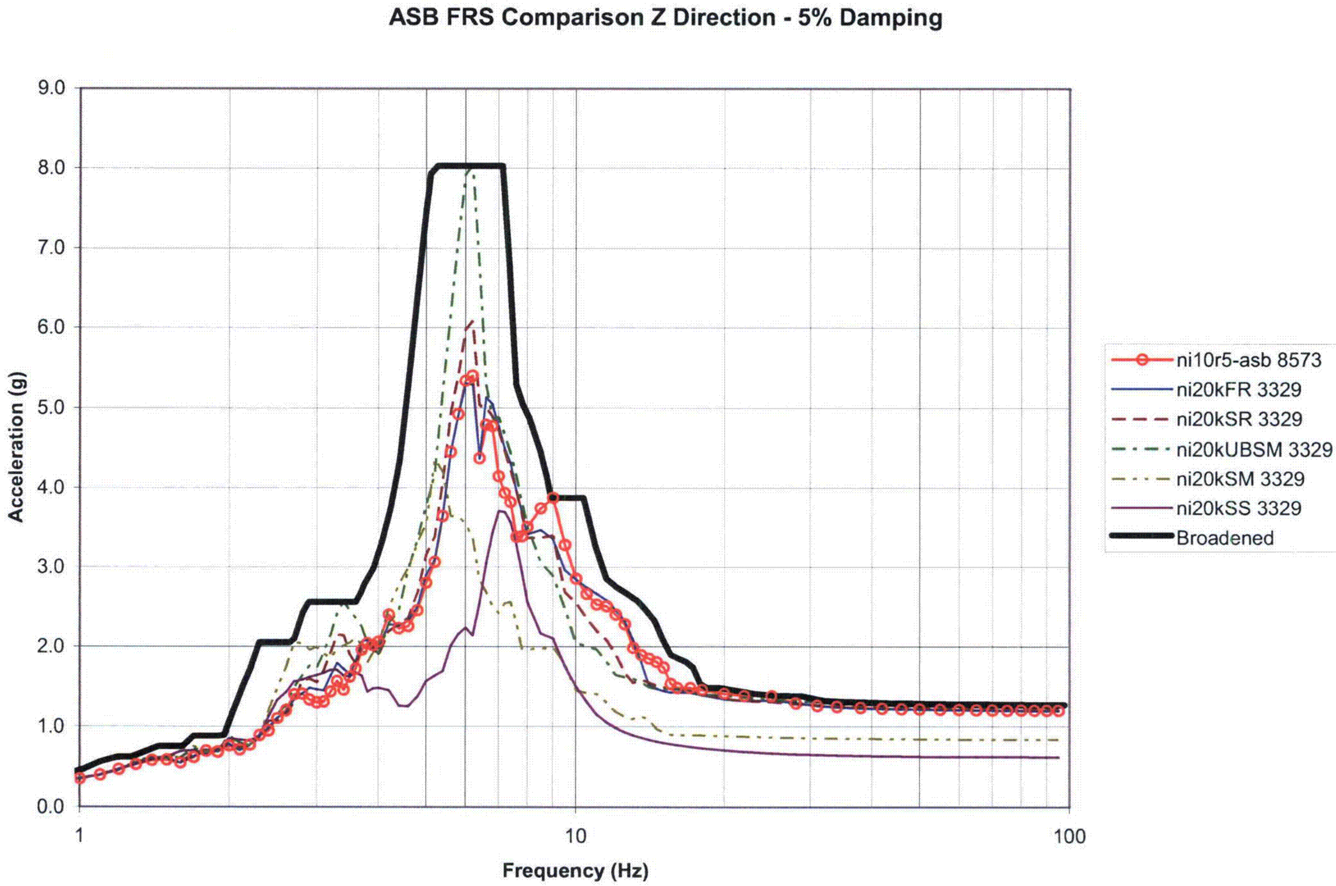


Figure 3G.4-9Z
Z Direction FRS for node 2862 (NI10) or 3329 (NI20)
ASB Shield Building Roof Elevation 327.41'

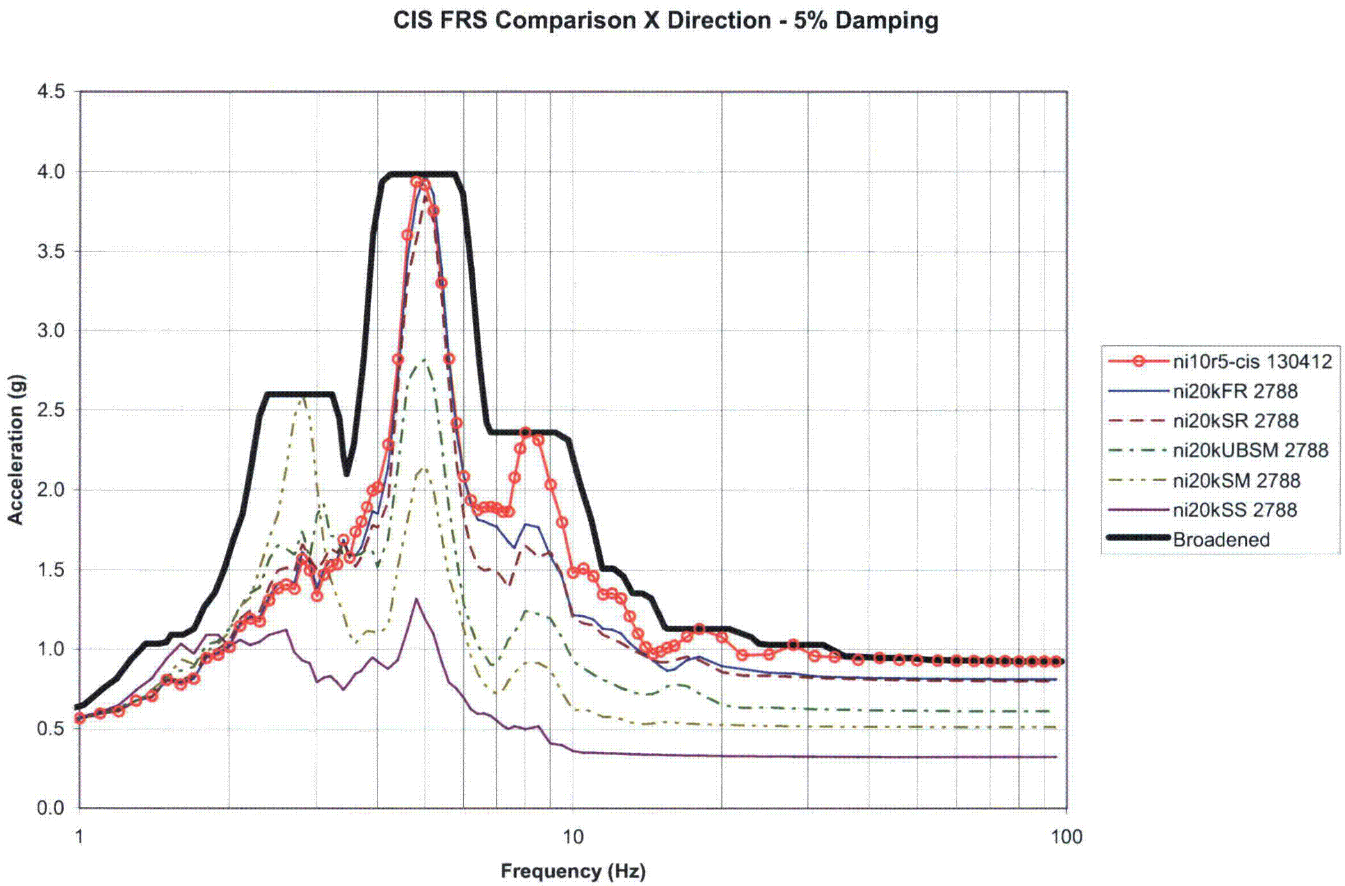


Figure3G.4-10X

X Direction FRS for node 130412 (NI10) or 2788 (NI20)
SCV near Polar Crane elevation 224.00'

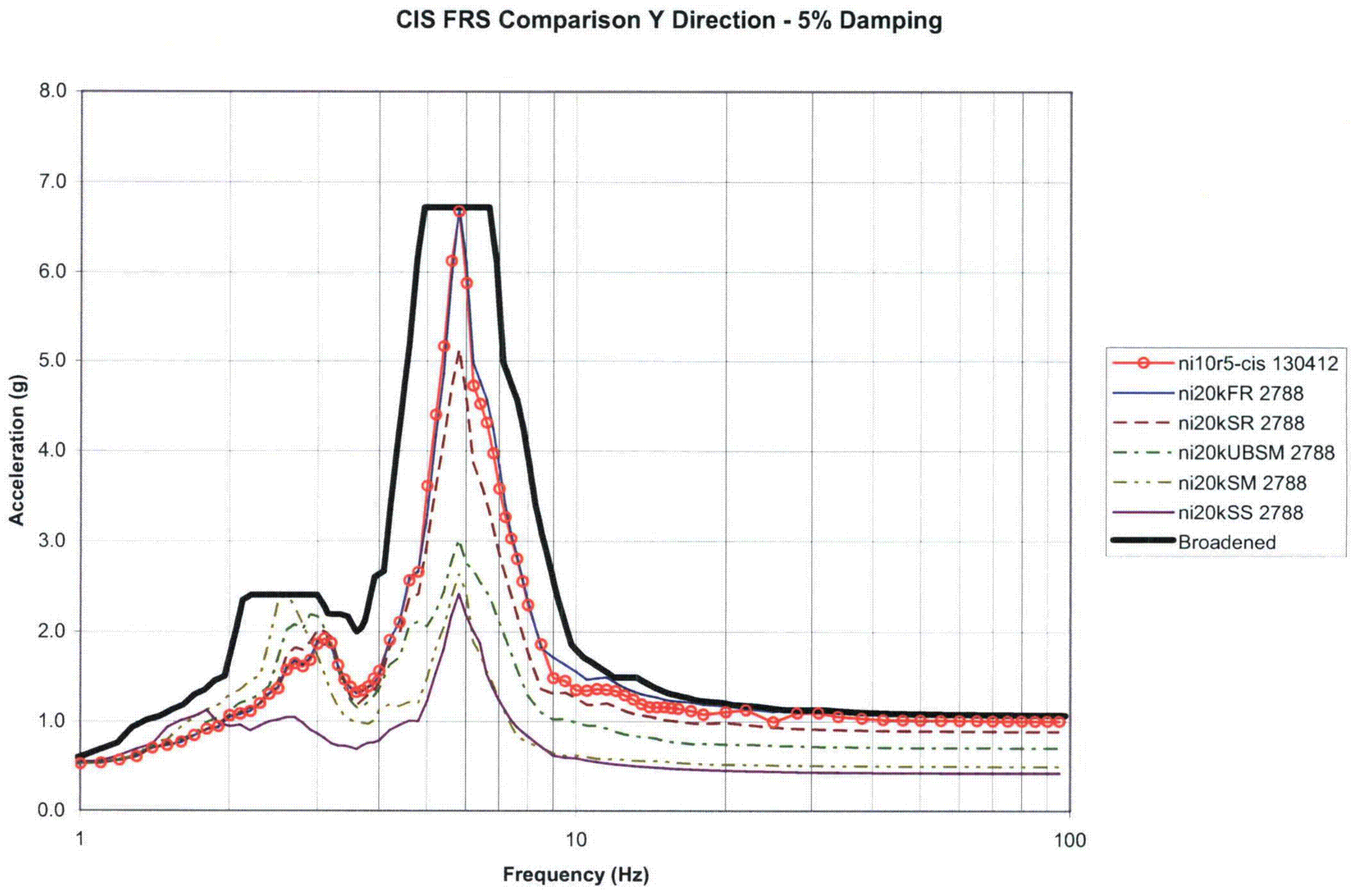


Figure 3G.4-10Y
Y Direction FRS for node 130412 (NI10) or 2788 (NI20)
SCV near Polar Crane elevation 224.00'

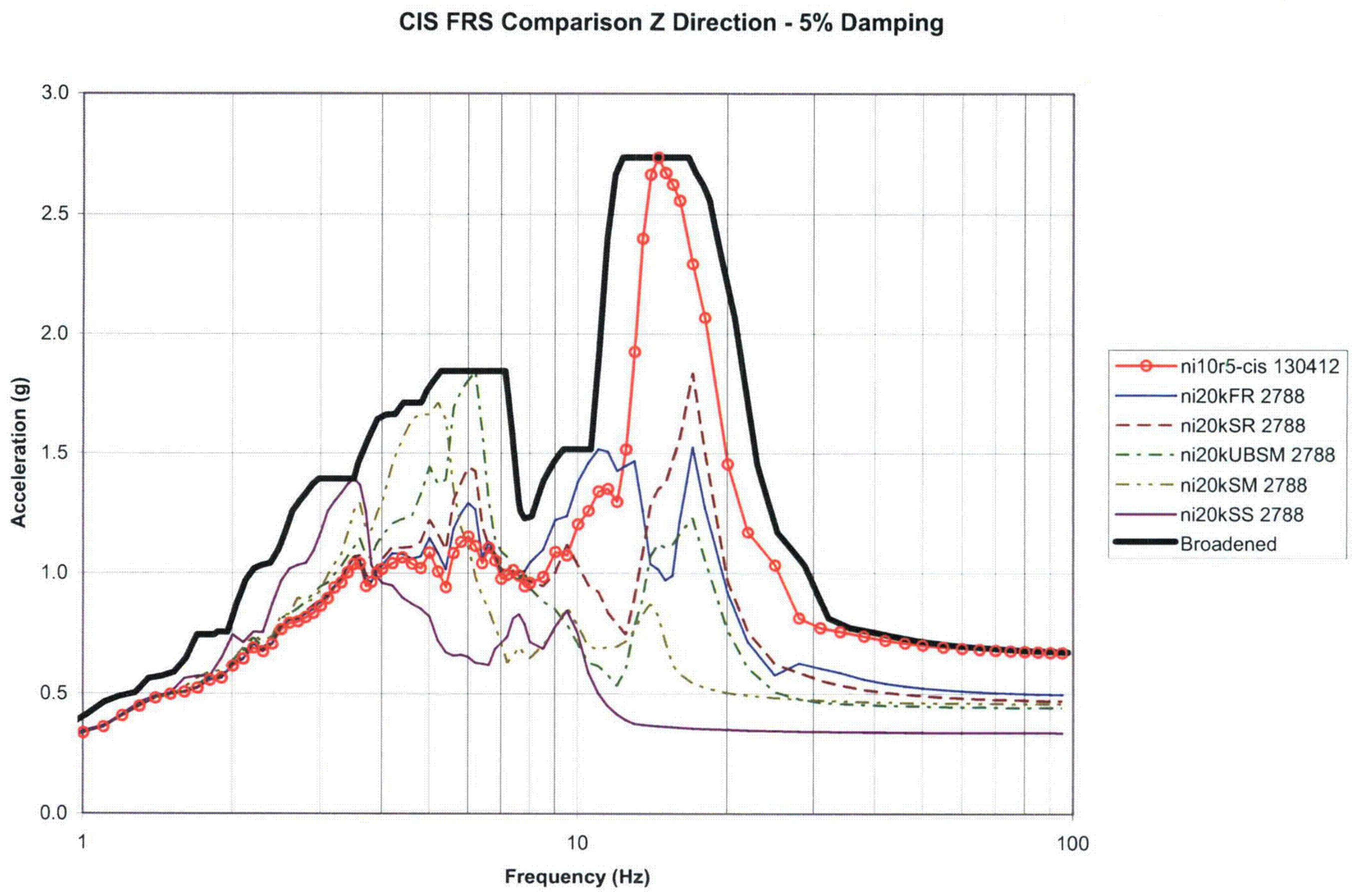


Figure 3G.4-10Z
Z Direction FRS for node 130412 (NI10) or 2788 (NI20)
SCV near Polar Crane elevation 224.00'