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Your ref: Project Number 740
Our ref: DCP/NRC1751

June 14, 2006

Subject: AP1000 COL Standard Design Change Submittal

Westinghouse is developing changes to the structural and seismic analyses that support application of the AP1000. These changes include the use of finite element models instead of stick models for the building models used to evaluate structural seismic response. Also, the soil conditions used for evaluation of seismic effects on the structures, systems, and components are extended to rock and soil conditions other than the hard rock conditions use for the AP1000 Design Certification review. These changes are discussed in Enclosure 1, AP1000 report APP-GW-S2R-010, "Extension of Nuclear Island Seismic Analysis to Soil Sites." The information discussed in this report is to be developed into changes to the Design Control Document (DCD). In many cases, the text and figures in the DCD will be the same or similar to the text and figures in the enclosed report. In the interest of efficiency, Westinghouse is waiting for initial NRC review of the report to finalize the changes for the DVD. Westinghouse has determined the portions of the DCD that will be modified. The portions of the DCD expected to be revised are identified in Enclosure 2 to this letter, "Changes to DCD for Model Change and Extension to Soil Sites."

The Enclosure 1 represents the initial report containing information identified in the Westinghouse letter DCP/NRC1730, dated April 5, 2006, to the NRC on seismic analyses and structural design technical report reviews. Future reports, including evaluation of the building and foundation design and the reconciliation of the structural critical sections, will build on the information discussed in this report and NRC review of the report.

Westinghouse is requesting NRC review of the finite element models proposed to replace the building model stick models currently in the AP1000 Design Control Document. Since finite element methods were used to develop the stick models and also used in the time history analysis, the use of finite element building models does not represent a departure from a method of evaluation used in a design basis analysis.

Westinghouse is requesting NRC review of the extension of the AP1000 seismic evaluations of soil conditions other than hard rock. This review would consider the selection and screening process for soil cases evaluated, review of soil structure evaluations, development of floor response spectra for equipment design, and development of equivalent static accelerations for building design.

D079

The changes are generic and are expected to apply to all projects referencing the AP1000 Design Certification. This information is submitted as part of the NuStart Bellefonte COL Project (NRC Project Number 740).

Pursuant to 10 CFR 50.30(b), APP-GW-S2R-010, Rev. 0, "Extension of Nuclear Island Seismic Analysis to Soil Sites," Technical Report Number 15, is submitted as Enclosure 1 under the attached Oath of Affirmation.

The review of this report was included in a table of COL technical reports in a March 8, 2006 letter from NuStart to the NRC.

Questions or requests for additional information related to the content and preparation of these reports 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.

Very truly yours,

D. F. Hutchings for

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

/Attachment

1. "Oath of Affirmation," dated June 14, 2006

/Enclosures

1. APP-GW-S2R-010, Rev. 0, "Extension of Nuclear Island Seismic Analysis to Soil Sites," (Technical Report Number 15), dated June 2006

2. "Changes to DCD for Model Change and Extension to Soil Sites," dated June 14, 2006

cc:	S. Bloom	-	U.S. NRC	1E	1A
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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

Stephen R. Tritch, being duly sworn, states that he is President and CEO 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.

S.R. Tritch

Stephen R. Tritch
President and CEO

Subscribed and sworn to
before me this 14th day
of June 2006.

Lorraine M. Piplica
Notary Public

COMMONWEALTH OF PENNSYLVANIA
Notarial Seal
Lorraine M. Piplica, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires Dec. 14, 2007
Member, Pennsylvania Association Of Notaries

ENCLOSURE 1

APP-GW-S2R-010, Rev. 0

"Extension of Nuclear Island Seismic Analysis to Soil Sites"

Technical Report Number 15

Dated June 2006

AP1000 DOCUMENT COVER SHEET

TDC: ________ Permanent File: ________ APY: ________

RFS#: ________ RFS ITEM #: ________

AP1000 DOCUMENT NO.	REVISION NO.		ASSIGNED TO
APP-GW-S2R-010	0	Page 1 of 161	W-A. Sterdis

ALTERNATE DOCUMENT NUMBER: WORK BREAKDOWN #:

ORIGINATING ORGANIZATION: Westinghouse Electric Company

TITLE: **Extension of Nuclear Island Seismic Analyses to Soil Sites**

ATTACHMENTS:	DCP #/REV. INCORPORATED IN THIS DOCUMENT REVISION:
CALCULATION/ANALYSIS REFERENCE:	

ELECTRONIC FILENAME	ELECTRONIC FILE FORMAT	ELECTRONIC FILE DESCRIPTION
COL005	Microsoft Word	

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T. J. WHITE	T. J. White 14 June '06
PATENT REVIEW	SIGNATURE/DATE
F. L. CARPENTINO	SIGNATURE ON FILE JUNE 14, 2006

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ORIGINATOR	SIGNATURE/DATE		
W.S. LaPay	Approval on file		
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L. Tunon-Sanjur	Leonardo Tunon-Sanjur	Detailed	
AP1000 RESPONSIBLE MANAGER	SIGNATURE*	APPROVAL DATE	
R. Mandava	R. Mandava	6/14/06	

* Approval of the responsible manager signifies that document is complete, all required reviews are complete, electronic file is attached and document is released for use.

APP-GW-S2R-010
Revision 0

June 2006

AP1000 Standard Combined License Technical Report

Extension of Nuclear Island Seismic Analyses to Soil Sites

Revision 0

Westinghouse Electric Company LLC
Nuclear Power Plants
Post Office Box 355
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Table of Contents

List of Tables

List of Figures

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
- Equivalent Static Accelerations 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
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 General Discussion of Hard Rock Licensing

The seismic design of the AP1000 for hard rock sites is described in Section 3.7 of the Design Control Document (DCD, Reference 1). The NRC review is described in the Final Safety Evaluation report (FSER, Reference 2). This certified design is applicable at hard rock sites where the shear wave velocity exceeds 8000 feet per second.

2.1 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.

2.2 Finite element models

The AP1000 nuclear island (NI) consists of three seismic Category I structures founded on a common basemat. The three structures that make up the nuclear island are the coupled auxiliary and shield buildings, the steel containment vessel, and the containment internal structures. Stick models were developed to match dynamic properties of more detailed models of each building. The following ANSYS models were described in the DCD:

1. The finite element shell dynamic model of the coupled auxiliary and shield building 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 was used to develop modal properties (frequencies and mode shapes). Static analyses were also performed on portions of this model to define properties for the stick model. This model is shown in DCD Figure 3.7.2-1. This finite element shell dynamic model is part of the NI10 model.

2. The finite element shell model of the containment internal structures is a finite element model using primarily shell elements. It is developed using the solid model features of ANSYS, which allow definition of the geometry and structural properties. This model was used in both static and dynamic analyses. It models the basemat, the concrete structures embedding the lower portion of containment, and the concrete structures inside the shield building. This model was used to develop modal properties (frequencies and mode shapes). Analyses were performed on portions of this model to define properties for the stick model. This finite element shell dynamic model is part of the NI10 model. Static analyses were also performed on the model to obtain member forces in the walls. The walls and basemat inside containment for this model is shown in DCD Figure 3.7.2-2. This model was also used as a superelement in the finite element shell dynamic model of the nuclear island.

3. The finite element model of the containment vessel is an axisymmetric model fixed at elevation 100'. This model is used in both static and dynamic analyses. The model was used to develop modal properties (frequencies and mode shapes). Analyses were performed on portions of this model to define properties for the stick model. Static analyses were also performed on the model to obtain shell stresses. This model is shown in DCD Figure 3.8.2-6.

4. 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 1, 2, and 3 above. Modal analyses and seismic time history analyses were performed using this model. Plant design response spectra were developed from these analyses along with equivalent static seismic accelerations for analysis of the building structures. The individual stick models are shown in DCD Figures 3.7.2-4, 3.7.2-5, and 3.7.2-6. The reactor coolant loop model is shown in DCD Figure 3.7.2-7. The polar crane model is shown in DCD Figure 3.7.2-8. The interconnection between the sticks is shown in DCD Figure 3.7.2-18.

The nuclear island lumped mass stick model has been replaced in the analyses described in this report by analyses using the finite element shell dynamic model of the nuclear island described in 5 below and previously reviewed as part of the AP1000 Design Certification.

5. The finite element shell dynamic model of the nuclear island was also used in seismic time history analyses. This model uses the coupled auxiliary and shield building described in 1 above. It also includes the finite element model of the basemat inside the shield building and a superelement of the containment internal structures generated from the finite element model described in 2 above. Results from time history analyses from this model were compared to the results from the nuclear island lumped mass stick model. The results were used for development of vertical response spectra and for the equivalent static seismic acceleration of flexible floors and walls and the shield building roof.

The models of the containment internal structures and containment vessel described in 2 and 3 above were also used in equivalent static analyses to provide design member forces in each structure. A separate GTSTRUDL model as shown in DCD Figure 3.8.4-3 was used for static analyses of the shield building roof. Member forces in the auxiliary and shield building were obtained from static analyses of the following model:

6. The equivalent static ANSYS finite element model of the auxiliary and shield building (ASB) is more refined than the finite element model described in 1 above. 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 dynamic model is referred to as the NI05 model. This refinement is used to calculate the design member forces and moments for the equivalent static accelerations obtained from the time history analyses of the nuclear island stick model. The stick model of the containment internal structures, which includes the basemat within the shield building, is also included.

The stick model of the containment internal structures (CIS) has been replaced in the analyses described in this report by analyses using the finite element shell model described in 2 above.

2.3 Time-History Analysis

Time history seismic analyses of the AP1000 nuclear island were performed using fixed base models with the time history input at the bottom of the foundation. The effects of side soils above the foundation elevation were demonstrated to be negligible to the overall response of the nuclear island. The side soils were considered in the design of the exterior walls below grade.

The in-structure responses were generally obtained from time history analyses of the three-dimensional, lumped-mass stick model of the nuclear island structures (model 4 above in Section 2.2). Typical results from these analyses are included in the DCD.

The responses from the stick model were supplemented by results from time history analyses of the three-dimensional finite element model of the auxiliary and shield building (model 5 above in Section 2.2). These analyses were used for the in-structure vertical response spectra of the auxiliary building including flexible floors. This model was used for the vertical analysis of the auxiliary building since the stick model matched the fundamental vertical frequency of the shield building but did not represent the fundamental vertical frequencies of the auxiliary building very well since this building is significantly lower than the shield building.

2.4 Interface for site specific analyses

DCD subsection 2.5.2.3 establishes interface requirements to permit site specific evaluation at sites that are outside the range evaluated for AP1000 design certification. A similar interface was identified in the AP600 specification which included both hard rock and soil sites. The site specific evaluation consists of a site-specific dynamic analysis and generation of in-structure response spectra to be compared with the design floor response spectra at 5-percent damping. 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 in DCD figures in subsection 3.7.2 at the following six key locations:

1. Containment internal structures at elevation of reactor vessel support
2. Containment operating floor
3. Auxiliary building on control room side
4. Shield building at fuel building roof
5. Shield building roof
6. Steel containment vessel at polar crane support

These locations are further defined in subsection 4.4.3.

2.5 Equivalent static accelerations based on mass center of stick models

Equivalent static loads were applied to detailed three dimensional finite element models to generate (1) the in-plane and out-of-plane forces for the design of floors and walls of the ASB and CIS, (2) the design bearing reaction and member forces in the basemat, (3) the design member forces for the shield building roof structures, and (4) stresses for the containment vessel design. Model 6 was used for the auxiliary building; model 2 for the containment internal structures and the model 3 for the containment vessel. The analysis for each earthquake component was performed by applying equivalent static loads to the structural model at each finite element nodal point. The static load at each nodal mass point was the corresponding mass times the maximum absolute acceleration response at the corresponding elevation at the center of mass of the corresponding stick. In addition torsional loads were applied about the vertical axis.

2.6 Liftoff

The effects of basemat uplift were evaluated using non-linear seismic time history analyses. The East-West lumped-mass stick model of the NI structures was supported on a rigid plate with nonlinear springs that transmit reactions in horizontal and vertical directions to simulate the foundation contact area. Peak accelerations, floor response spectra, and member forces from seismic time history analyses that included basemat uplift were compared to seismic time history analyses that did not include these effects. The comparisons (described in part A of the response to DSER Open Item 3.7.2.3-1, Reference 4) show that the basemat uplift effect is insignificant.

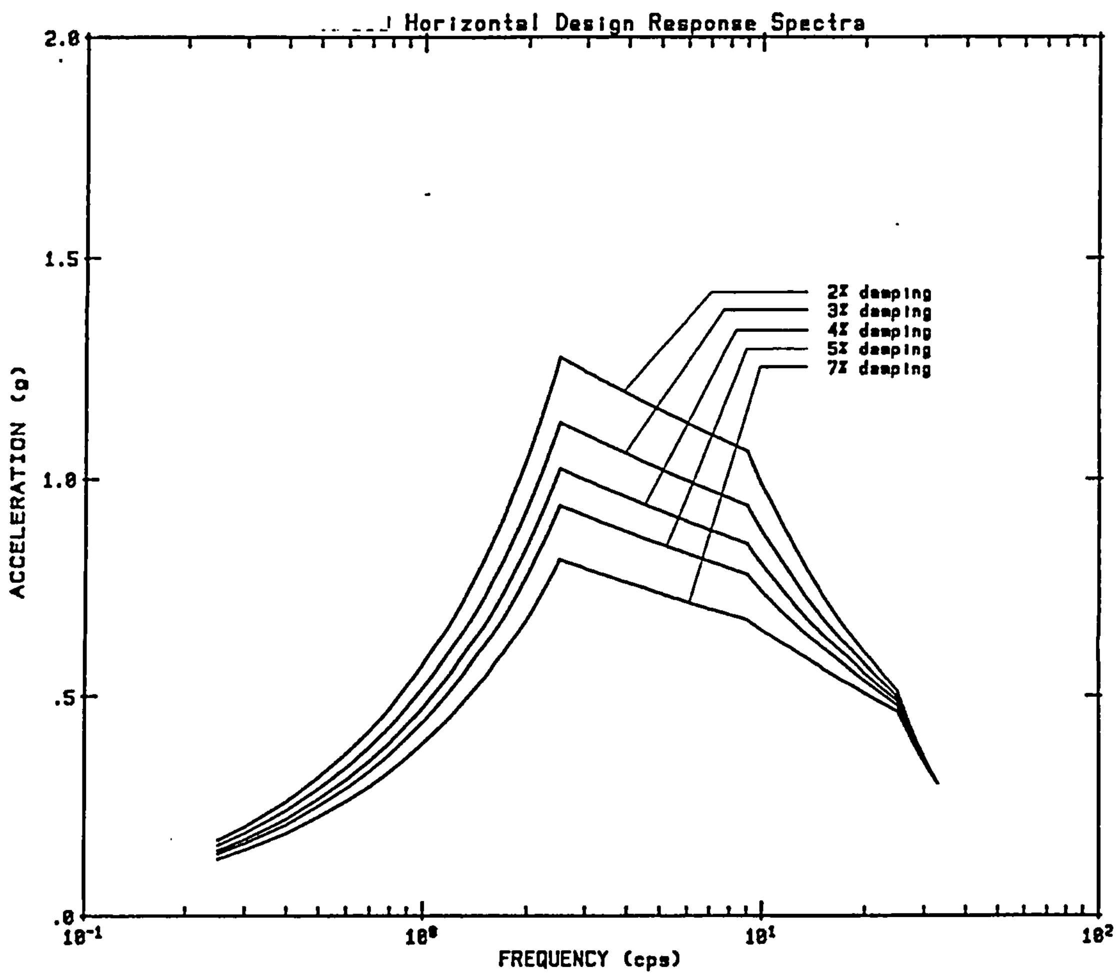


Figure 2.1-1 – AP1000 Horizontal Design Response Spectra for Safe Shutdown Earthquake

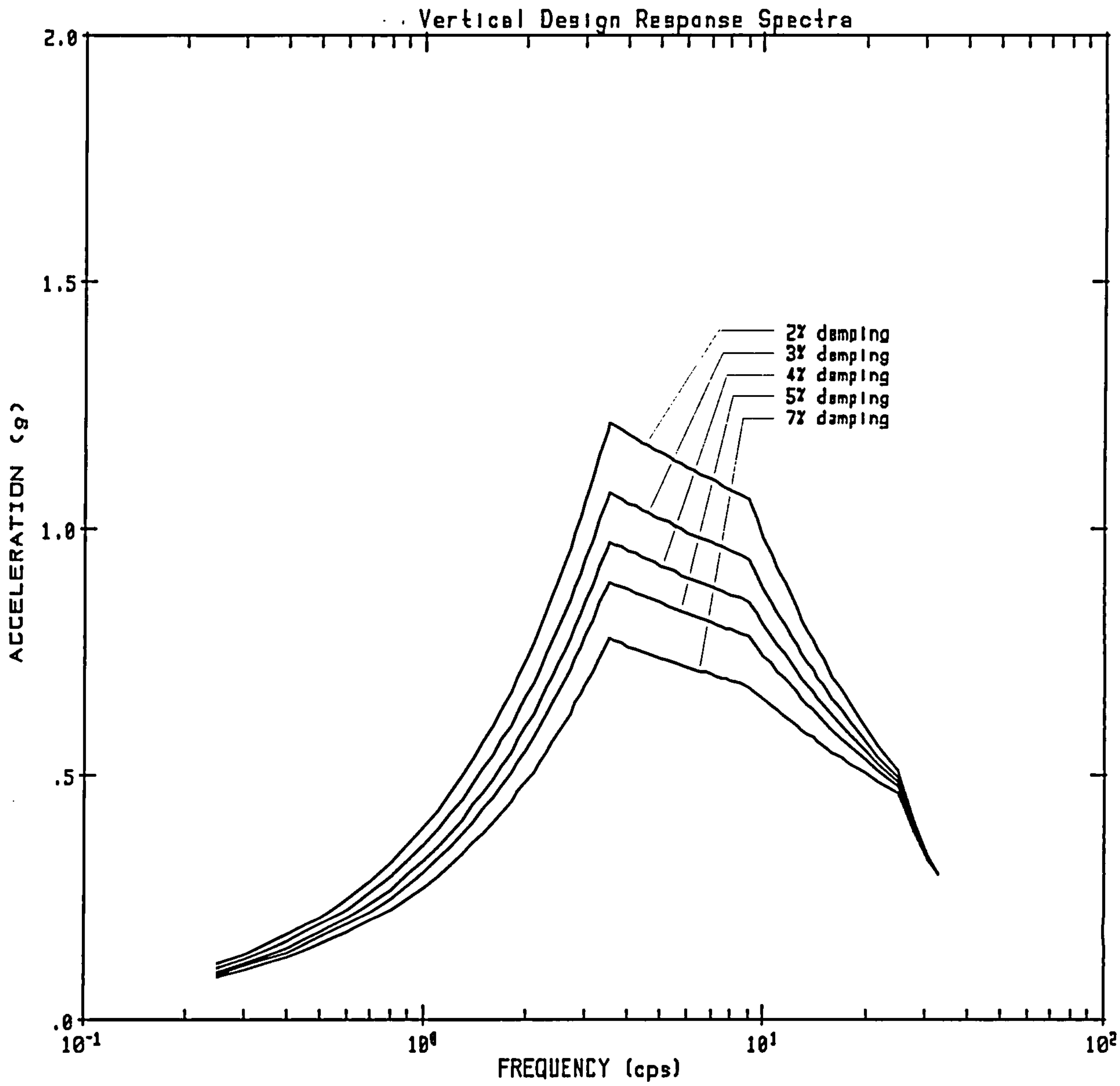


Figure 2.1-2 - Vertical Design Response Spectra Safe Shutdown Earthquake

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 thickness of the basemat, floor slabs, roofs and walls, of the seismic Category I building structures are shown in DCD Figure 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.

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 simulate cracking.

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 model is updated as described in section 3.2 from the model described in the DCD (identified in item 5 of section 2.2 of this report). 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.

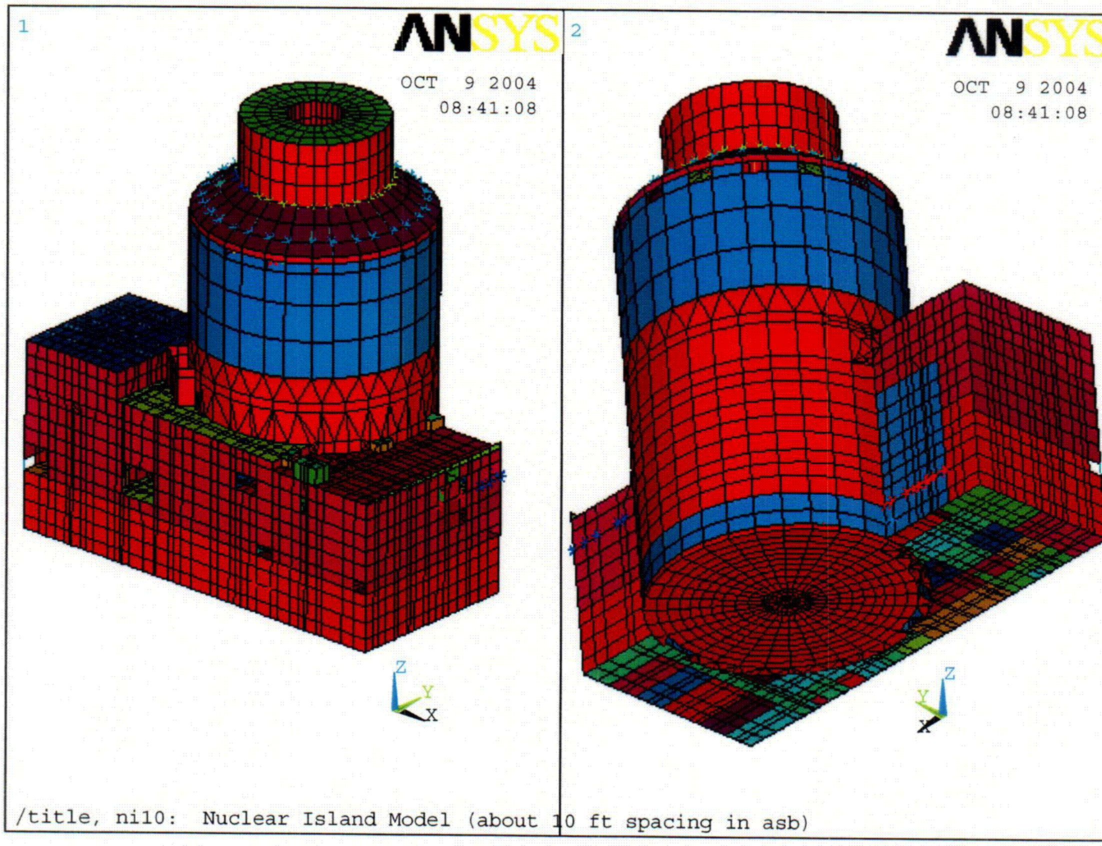


Figure 4.2.1-1 - AP1000 Nuclear Island solid-shell model

CO1

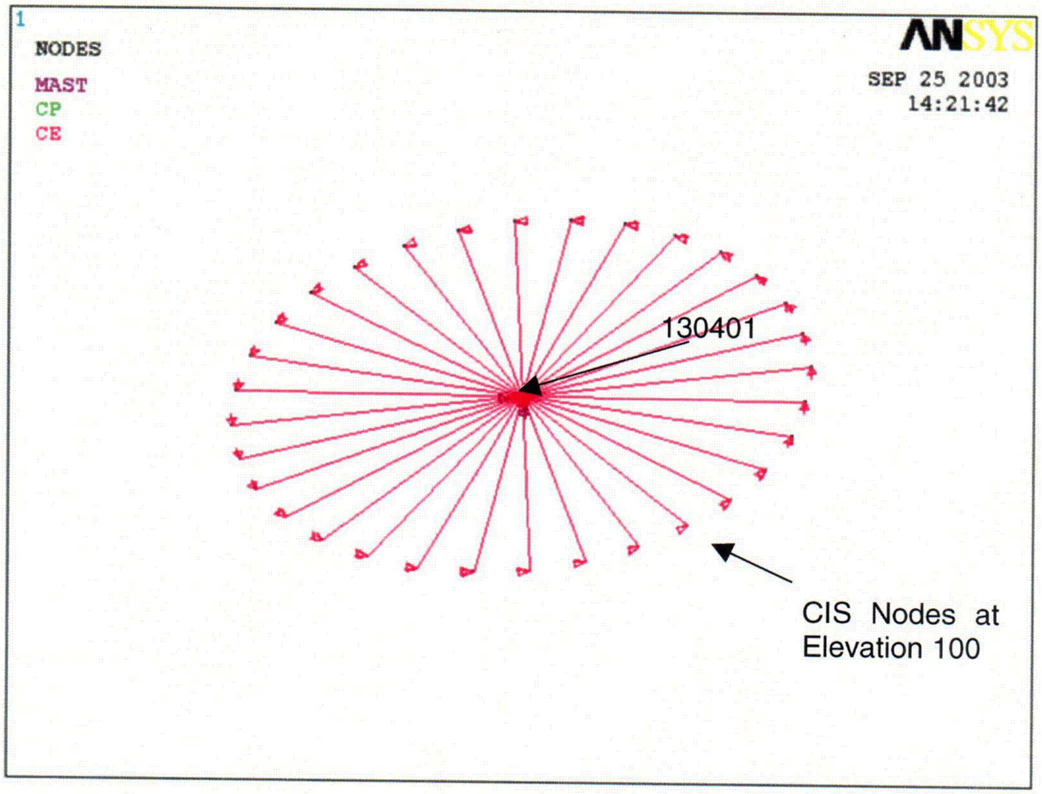


Figure 4.2.1-2 - SCV Connections to CIS

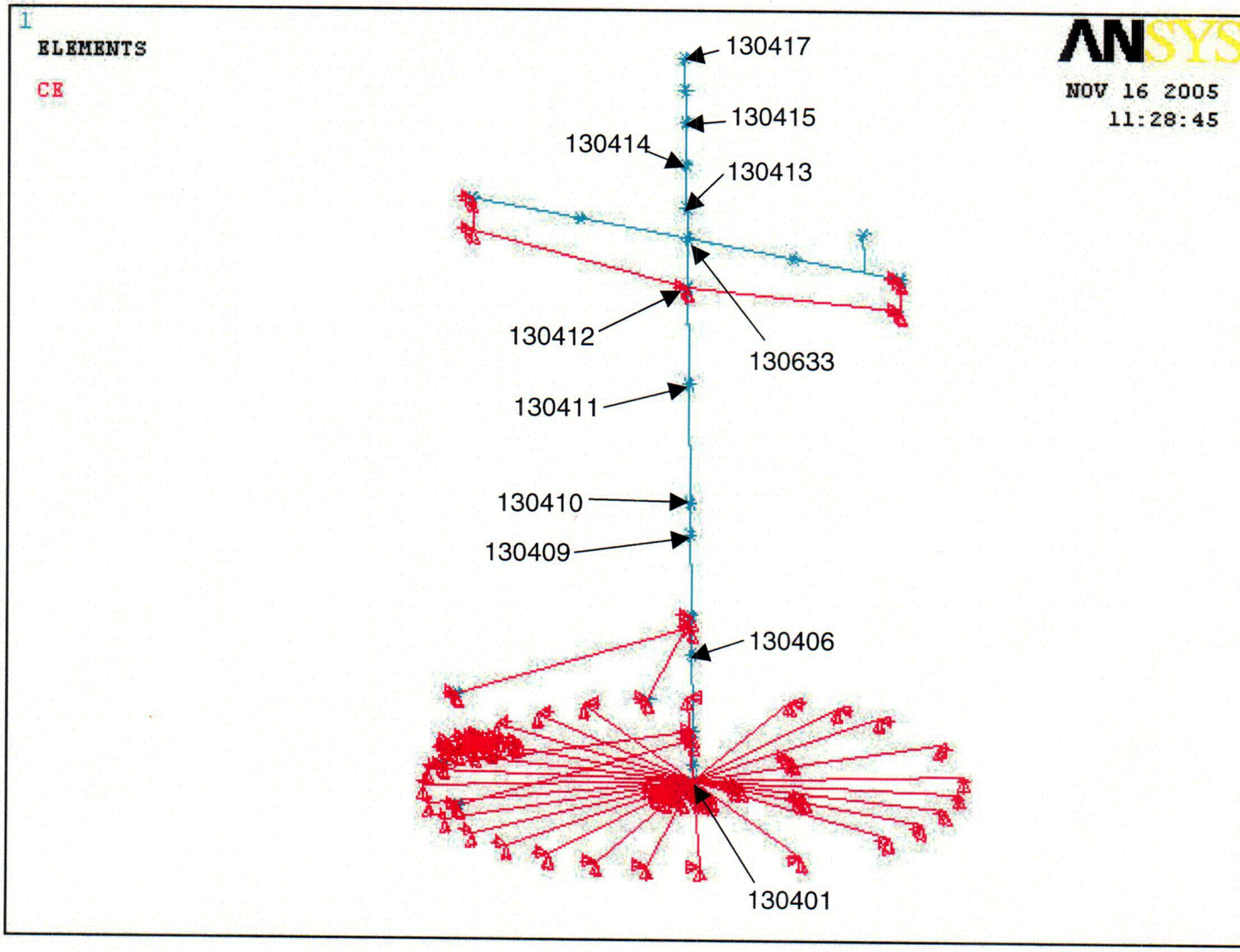


Figure 4.2.1-3 - Polar Crane and Steel Containment Vessel Nodes

C03

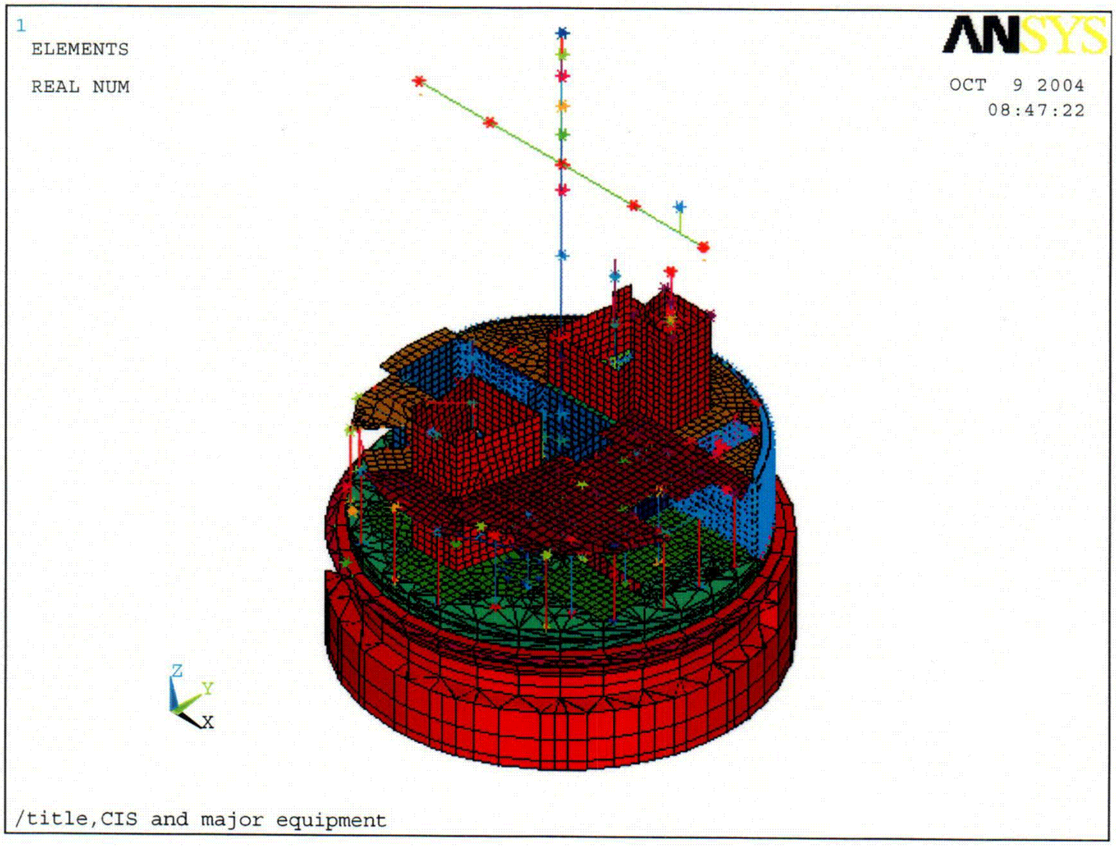


Figure 4.2.1-4 - CIS with the SCV, PC, RCL and PZR

C04

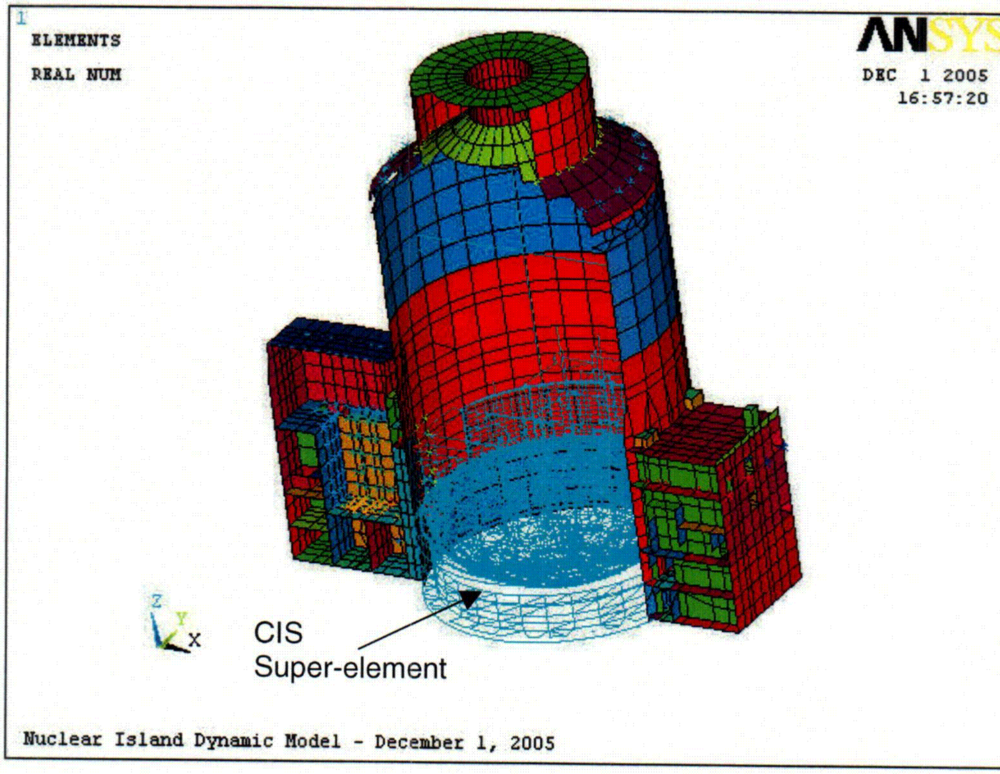


Figure 4.2.1-5 - ni10-asb model, ASB FEM with CIS and major equipment as Super-element

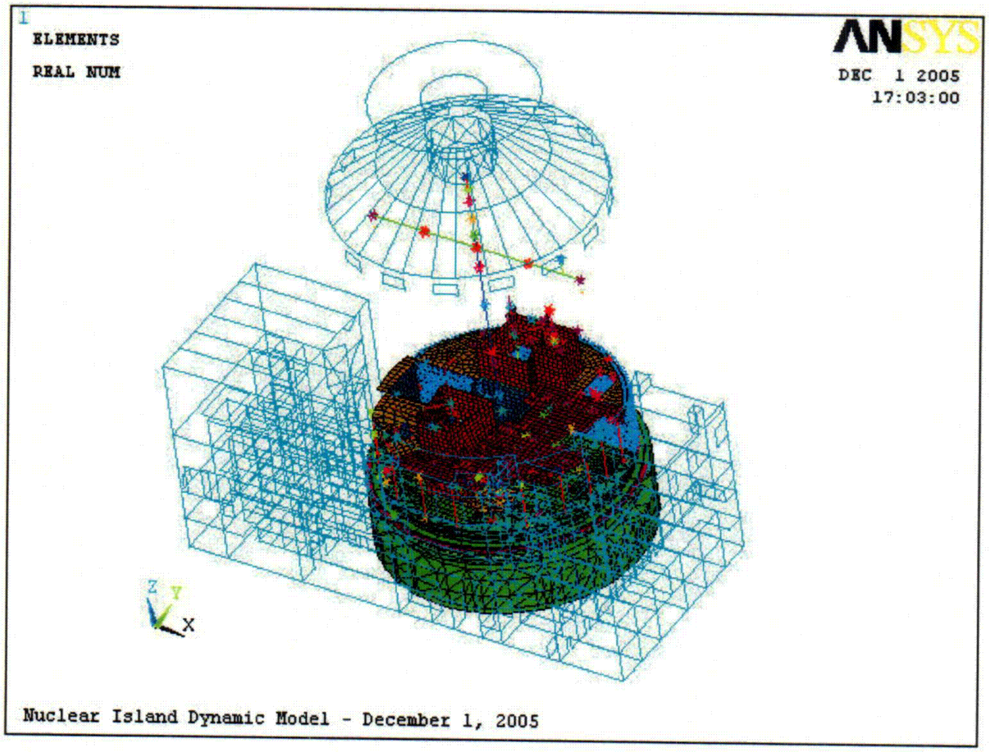
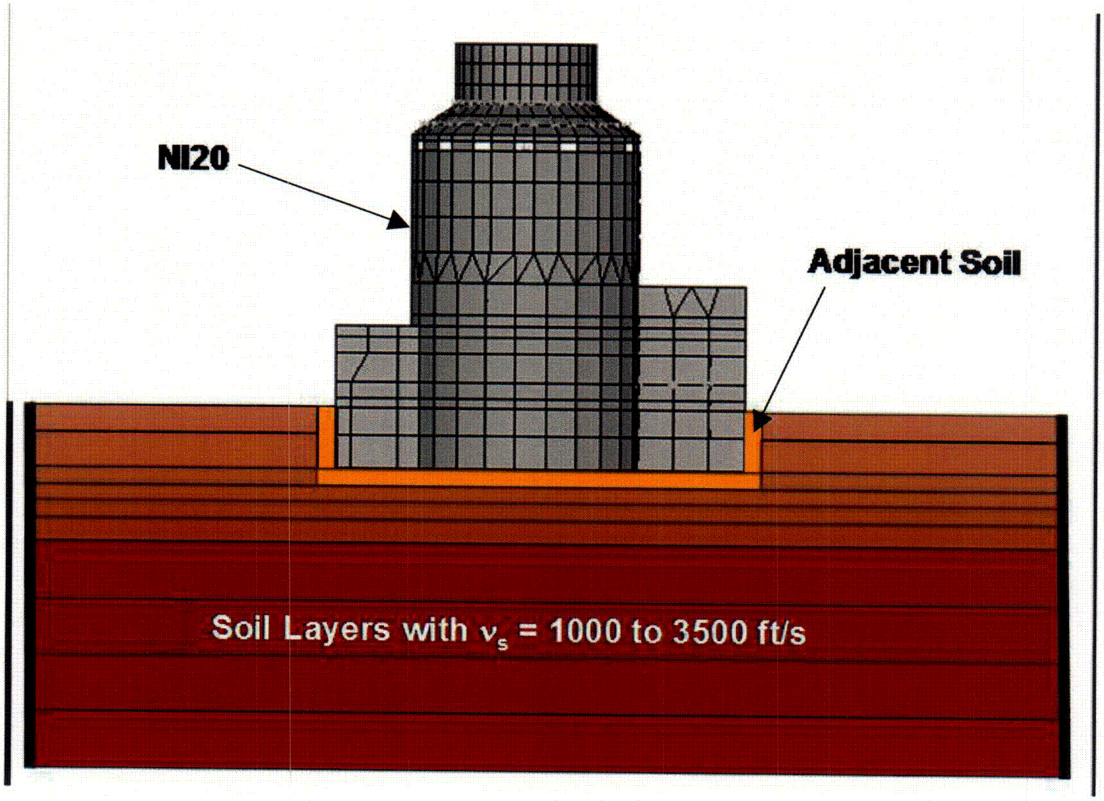


Figure 4.2.1-6 - ni10-cis model, CIS and major equipment FEM with ASB as Super-element

C06



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

C07

4.2.3 NI10 and NI20 Model Nodes

Figures 4.2.3-1 to 4.2.3-11 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 4.2.3-12 to 4.2.3-15 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 grouping is based on the building (i.e., ASB and CIS) and elevation. For example, the nodes shown in Figure 4.2.3-1 are grouped and the design response spectra for the ASB at or below elevation 100' are the enveloped spectra of the nodes shown in Figure 4.2.3-1. 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 6.3.

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

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

Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
1473	2392	1070.5	992	99	SBC north
1406	2376	1005.2	929.19	99	SBC east
1340	2406	929	1000	99	SBC south
1407	2595	1000	1071	99	SBC west
1313	4084	862.5	913	99	ASB SE 1I
1319	4115	862.5	1000	99	ASB SW 1N
1455	4233	1045.8	913	99	ASB 7.3I
1488	4380	1116.5	913	99	ASB NE 11I
1494	4399	1116.5	1027.5	99	ASB NW 11Q
1334	6614	929	913	99	ASB 4I
1756	4548	1005.2	922.25	116.5	ASB 7I
1760	4556	1018.2	923	116.5	ASB 7I
1764	4570	1034.2	924.5	116.5	ASB 7I
2032	5054	1070.5	992	134.88	SBC north
2010	4961	1005.2	929.19	134.88	SBC east
1988	5744	929	1000	134.88	SBC south
2011	7648	1000	1071	134.88	SBC west
2053	6821	1116.5	1027.5	134.88	ASB NW
1961	4764	862.5	913	134.88	ASB SE
1967	4795	862.5	1000	134.88	ASB SW
1982	4886	929	913	134.88	ASB 4I
2020	4984	1045.8	913	134.88	ASB 7.3I
2047	5109	1116.5	913	134.88	ASB NE (11I)
2009	4959	1005.2	922.25	134.87	ASB 7I
2013	4967	1018.2	923	134.87	ASB 7I
2017	4981	1034.2	924.5	134.87	ASB 7.3I
1995	4925	950	931	134.88	ASB 4I
2001	4939	970.3	931	134.87	ASB 4I
2202	5538	1070.55	992	152.96	SBC north
2317	5487	1005.25	929.19	160.56	SBC east
2327	5510	1045.8	913	159.69	ASB 7.3I
2330	5515	1045.8	945.71	159.69	SBC 7.3
2218	5351	1116.5	913	154.69	ASB NE
2224	5370	1116.5	1027.5	152.19	ASB NW
2290	6955	929	913	162.19	ASB 4I
2316	5485	1005.2	921.33	160.56	ASB 7-7.2I
2320	5494	1018.2	924.5	160.28	ASB 7-7.2I
2324	5507	924.5	924.5	159.93	ASB 7-7.2I

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

Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
2412	6153	1069.6	986.15	179.19	SBC north
2400	6054	1000	929	179.19	SBC east
2365	5754	929	1000	179.19	SBC south
2401	7719	1000	1071	179.19	SBC west
2358	5574	862.5	1000	179.19	ASB SW
2352	5543	862.5	913	179.19	ASB SE
2359	5703	929	913	179.19	ASB 4I
2385	5628	895.75	942.83	179.94	ASB fuel bldg roof
2387	5633	895.75	971.17	179.94	ASB fuel bldg roof
2476	6352	1070.7	1006.1	222.75	SBC north
2462	6345	1006.1	929.26	222.75	SBC east
2447	6337	929.26	1006.1	222.75	SBC south
2463	6329	1006.1	1070.7	222.75	SBC west
2556	7730	1070.7	1006.1	265	SBC north
2541	7752	1006.1	929.26	265	SBC east
2526	7766	929.26	1006.1	265	SBC south
2542	7762	1006.1	1070.7	265	SBC west
2728	2613	1043.3	1003.8	294.93	SBR north
2713	2997	1003.8	956.66	294.93	SBR east
2698	2853	956.66	1003.8	294.93	SBR south
2714	2725	1003.8	1043.3	294.93	SBR west
2984	2622	1043.3	1003.8	333.12	SBR north
2969	3006	1003.8	956.66	333.12	SBR east
2954	2862	956.66	1003.8	333.12	SBR south
2970	2734	1003.8	1043.3	333.12	SBR west

Table 4.2.3-3 – CIS Nodes

Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
1397	130401	1000	1000	100	CV stick
1931	106962	1022.75	1040.75	134.25	Pressurizer
1930	106958	1022.75	1024.25	134.25	Pressurizer
1902	106805	1002.07	1046.25	134.25	SG west
1913	105772	1007.59	1016.25	134.25	SG west
1882	105773	978	1014	134.25	SG west
1888	106819	982.93	1046.25	134.25	SG west
1911	105805	1008	986	134.25	SG east
1901	107241	1002.07	953.75	134.25	SG east
1886	107252	982.93	953.75	134.25	SG east
1878	105806	978	986	134.25	SG east
1958	105852	1057	1024.25	134.25	IRWST North
1856	105955	942.5	1014	134.25	RC south
1854	106300	942.5	986	134.25	RC south
1899	111745	992.5	936.94	134.25	South
2236	106806	1002.07	1046.25	153	SG west
2242	105868	1007.59	1016.25	153	SG west
2226	105875	978.34	1016.25	153	SG west
2230	106760	982.93	1046.25	153	SG west
2237	106899	978.34	1016.25	153	PZR
2240	106428	982.93	1046.25	153	PZR
2250	106166	978.34	1016.25	153	PZR
2252	106160	982.93	1046.25	153	PZR
2241	105975	1007.59	983.75	153	SG east
2235	107235	1002.07	953.75	153	SG east
2229	107256	982.93	953.75	153	SG east
2225	105982	978.34	983.75	153	SG east
2336	106216	1004.5	1032.5	164.95	PZR US
2337	106204	1012.9	1040.8	164.95	PZR US
2340	106174	1014.4	1024.5	164.95	PZR US
2342	106174	1022.8	1032.5	164.95	PZR US
1872	108348	971.45	1055.8	134.25	IRWST
1943	107922	1036.7	1050.9	134.25	IRWST

Table 4.2.3-4 – Steel Containment Vessel

Soil Site Node	Hard Rock Site Node	X	Y	Z	Location
1852	130406	1000	1000	131.68	Lower stiffener
2346	130410	1000	1000	169.93	mid
2478	130412	1000	1000	224	@ Polar Crane
2486	130633	1000	1000	236.5	Polar Crane
2655	130417	1000	1000	281.9	Top of SCV

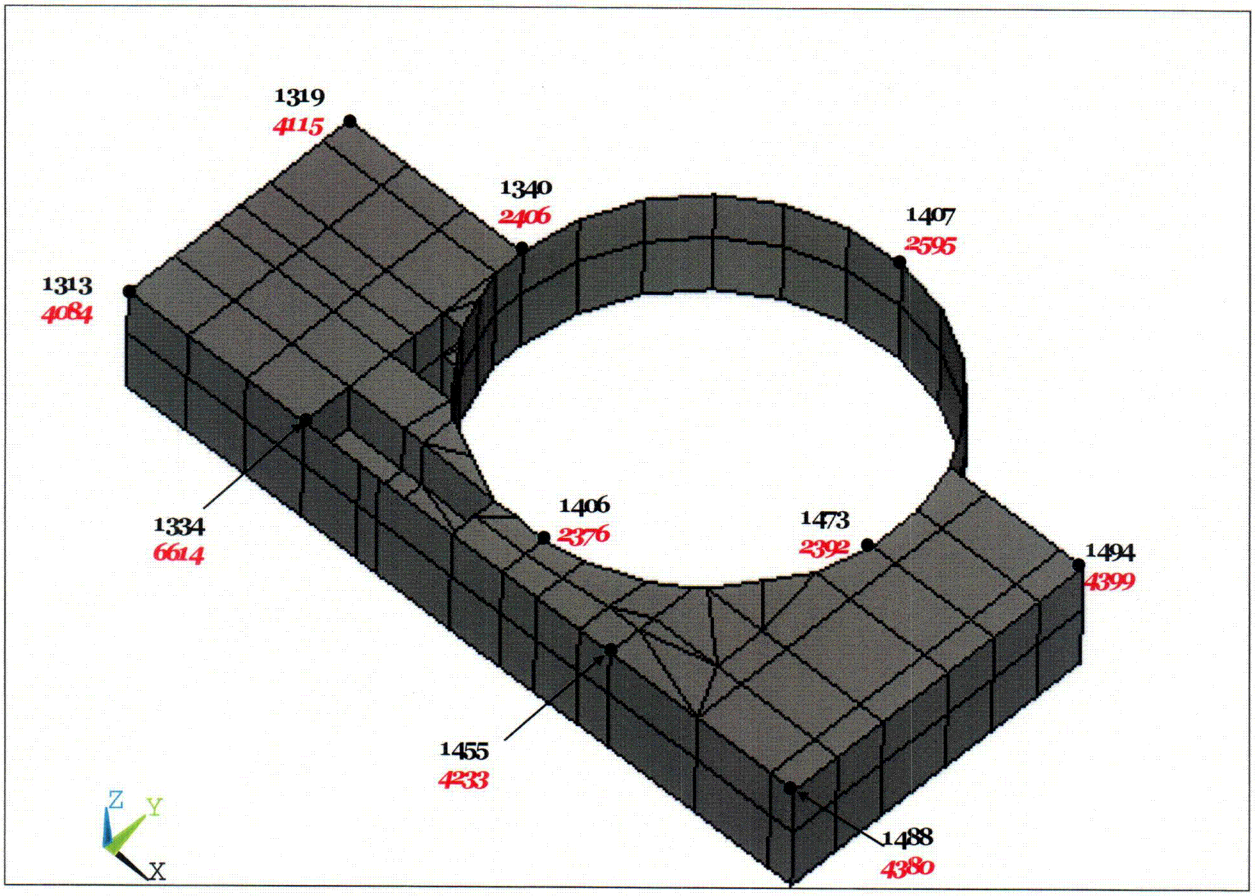


Figure 4.2.3-1 – ASB Nodes at or below El. 100'

C08

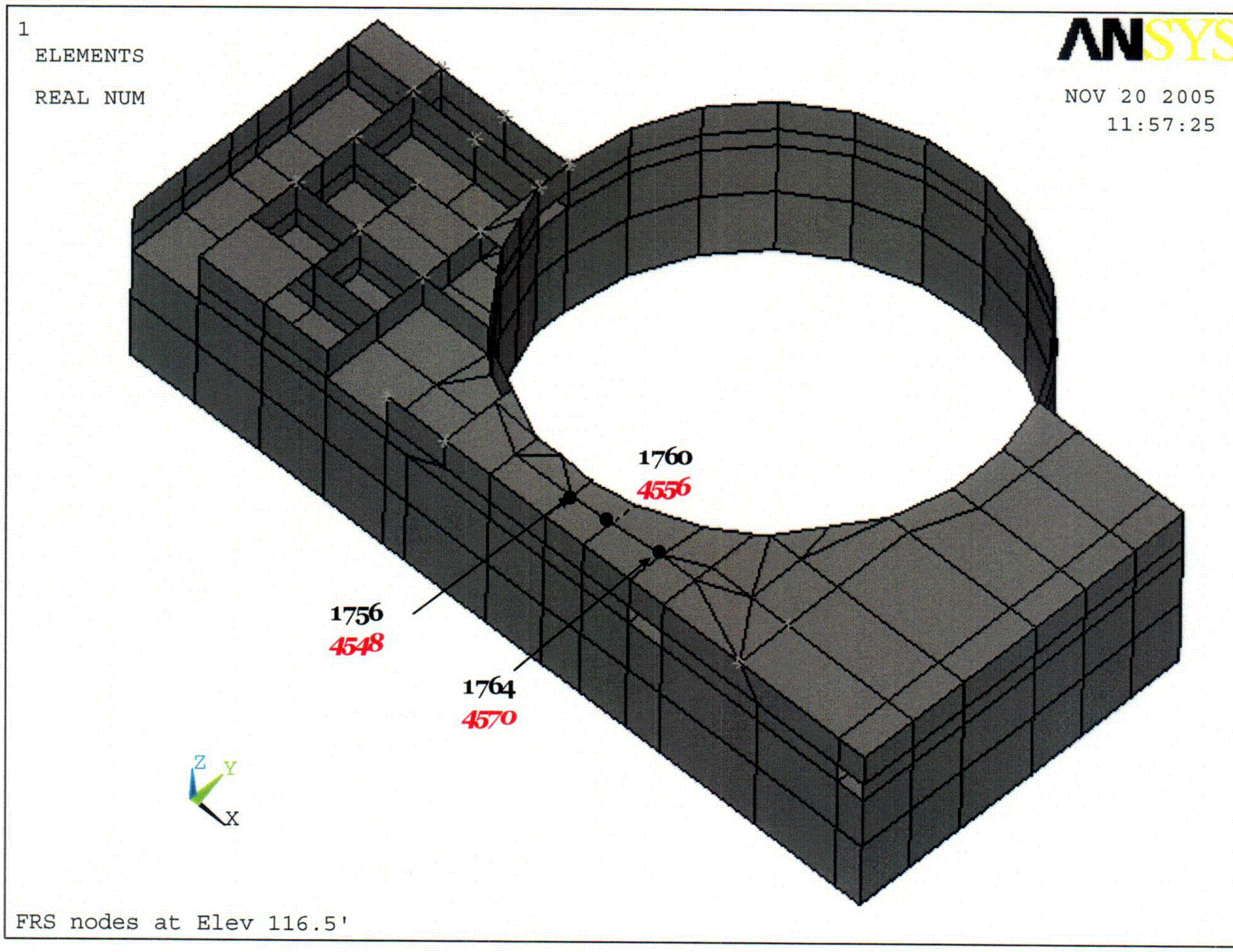


Figure 4.2.3-2 – ASB Nodes at or below El. 116.5'

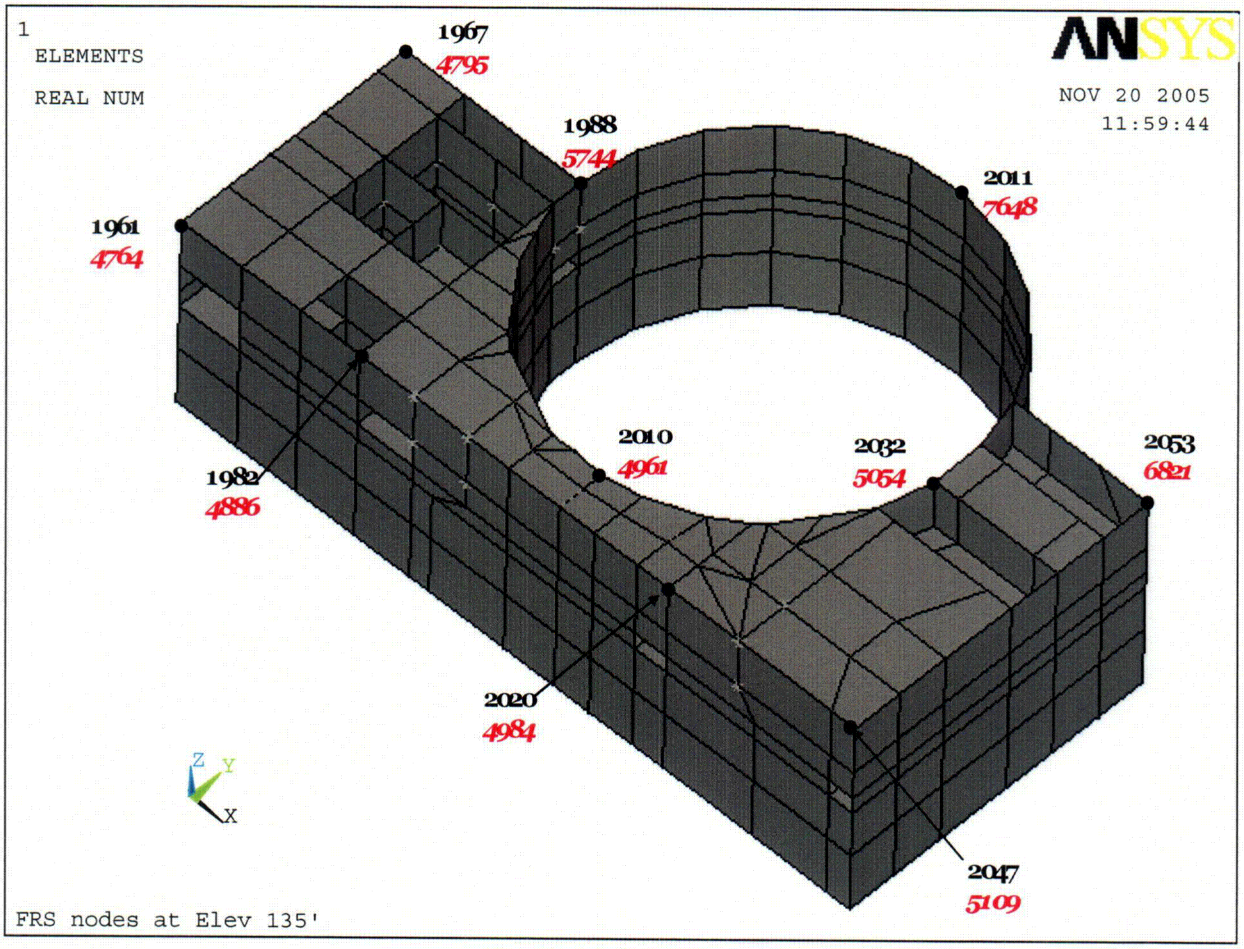


Figure 4.2.3-3 – ASB Nodes at or below El. 135' (1 of 2)

C10

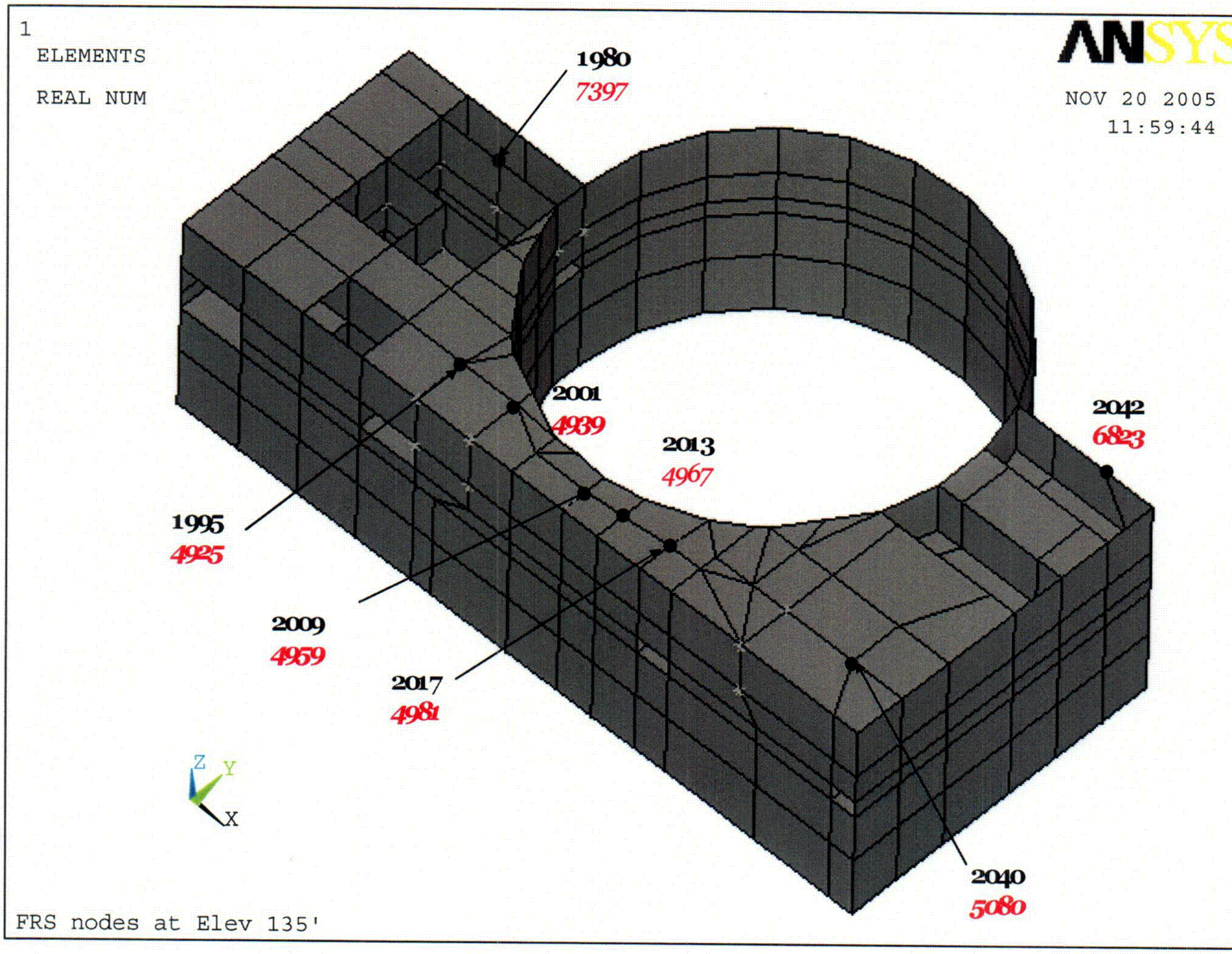


Figure 4.2.3-4 – ASB Nodes at or below El. 135' (2 of 2)

C11

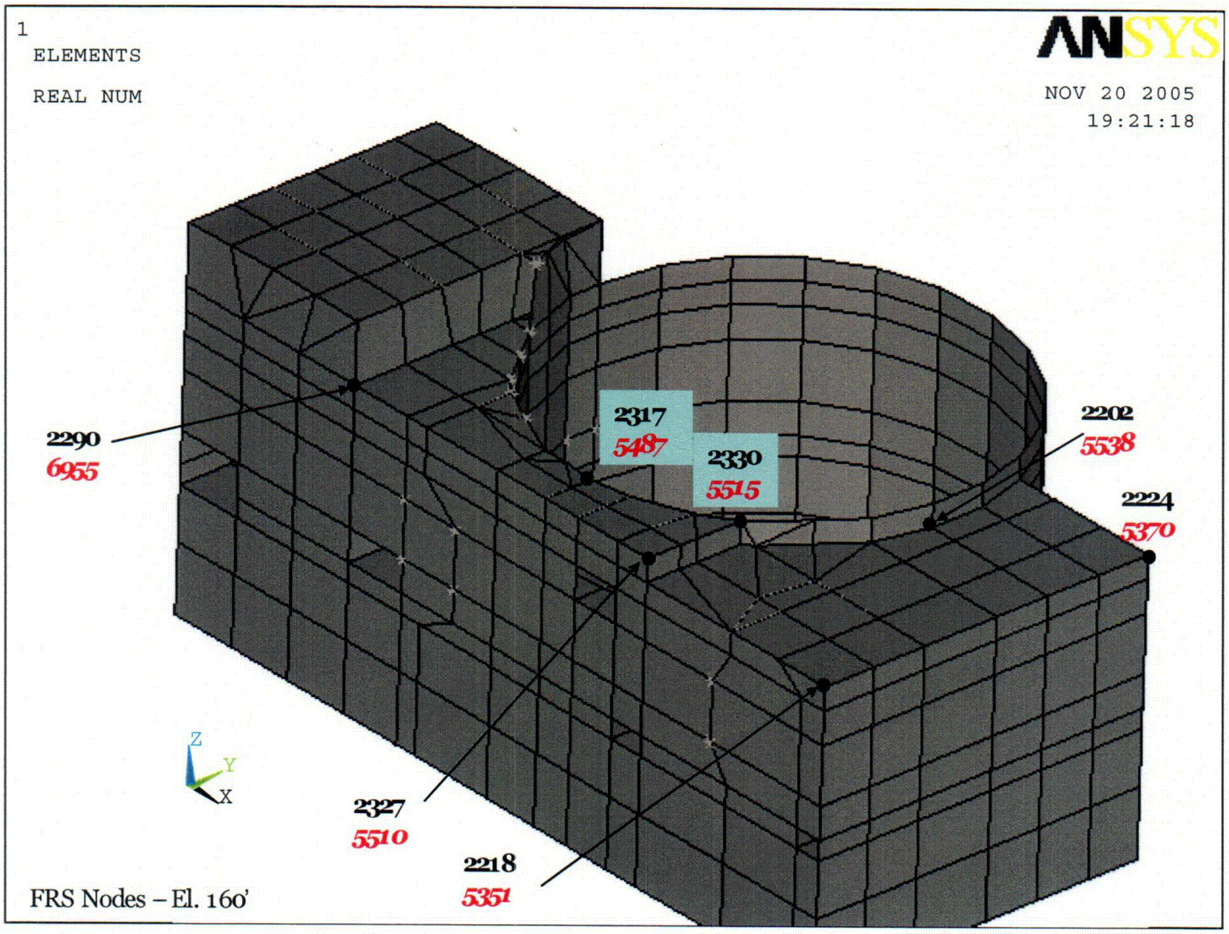


Figure 4.2.3-5 – ASB Nodes at or below El. 162.19' (1 of 2)

C12

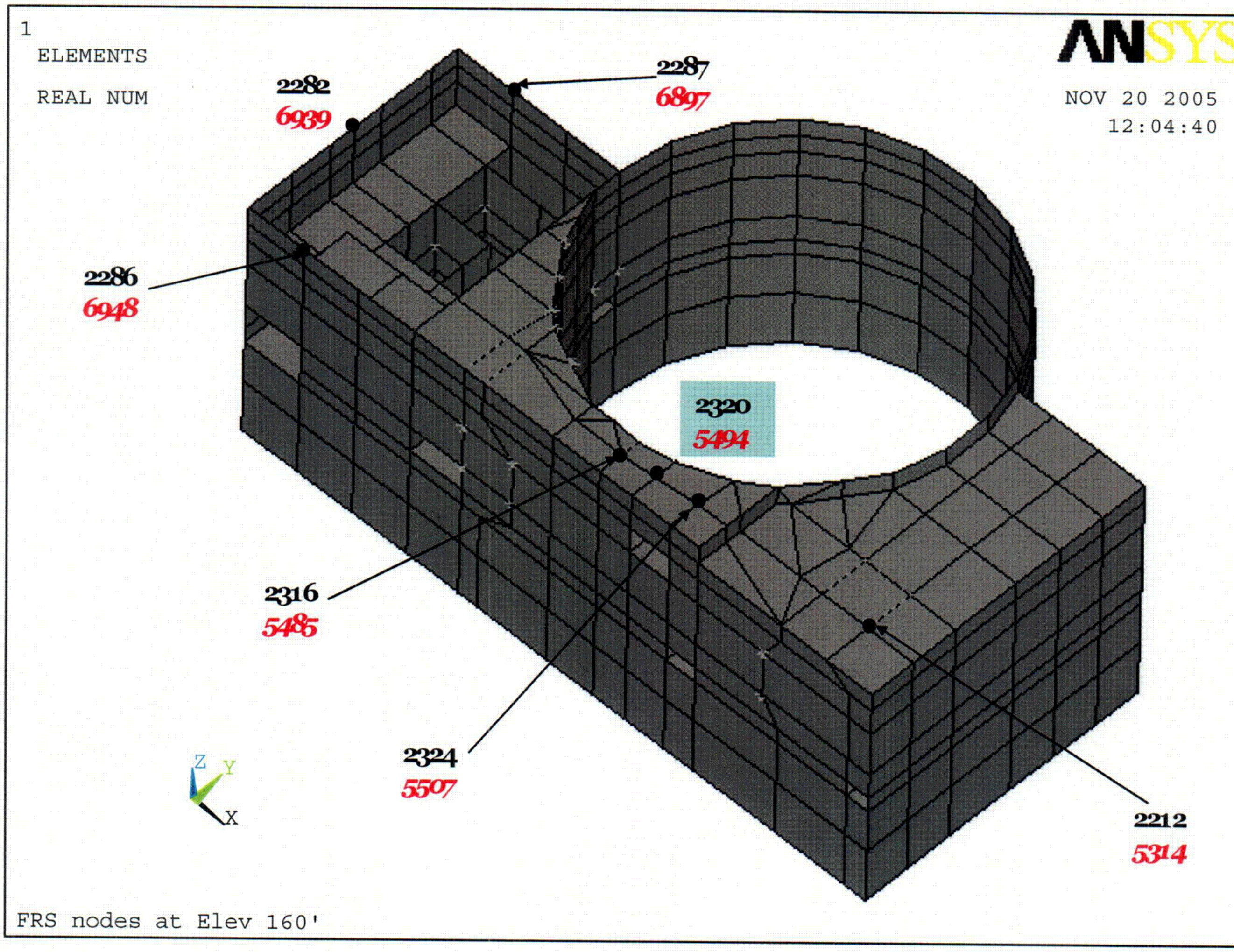


Figure 4.2.3-6 – ASB Nodes at or below El. 162.19' (2 of 2)

C13

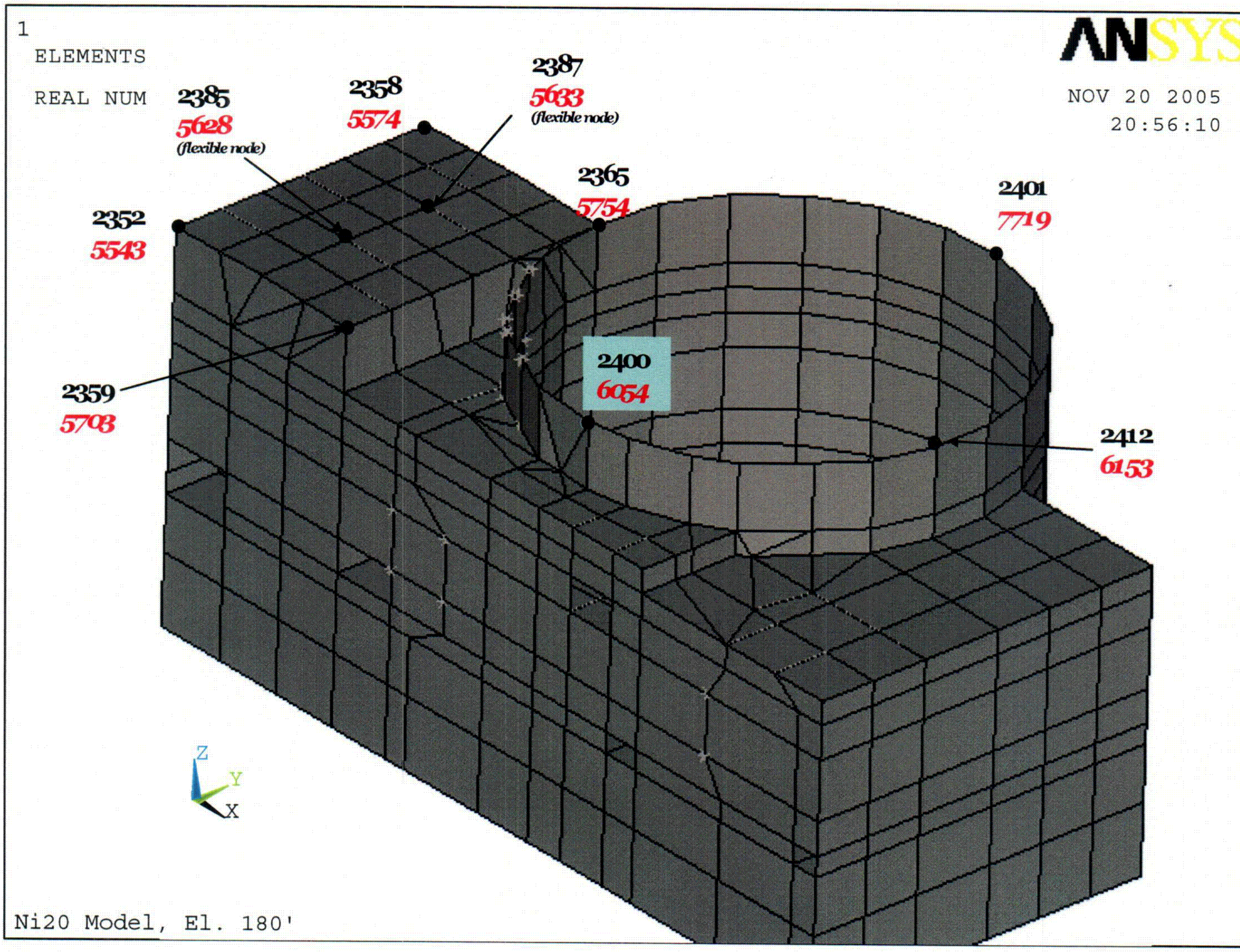


Figure 4.2.3-7 – ASB Nodes at or below El. 180'

C14

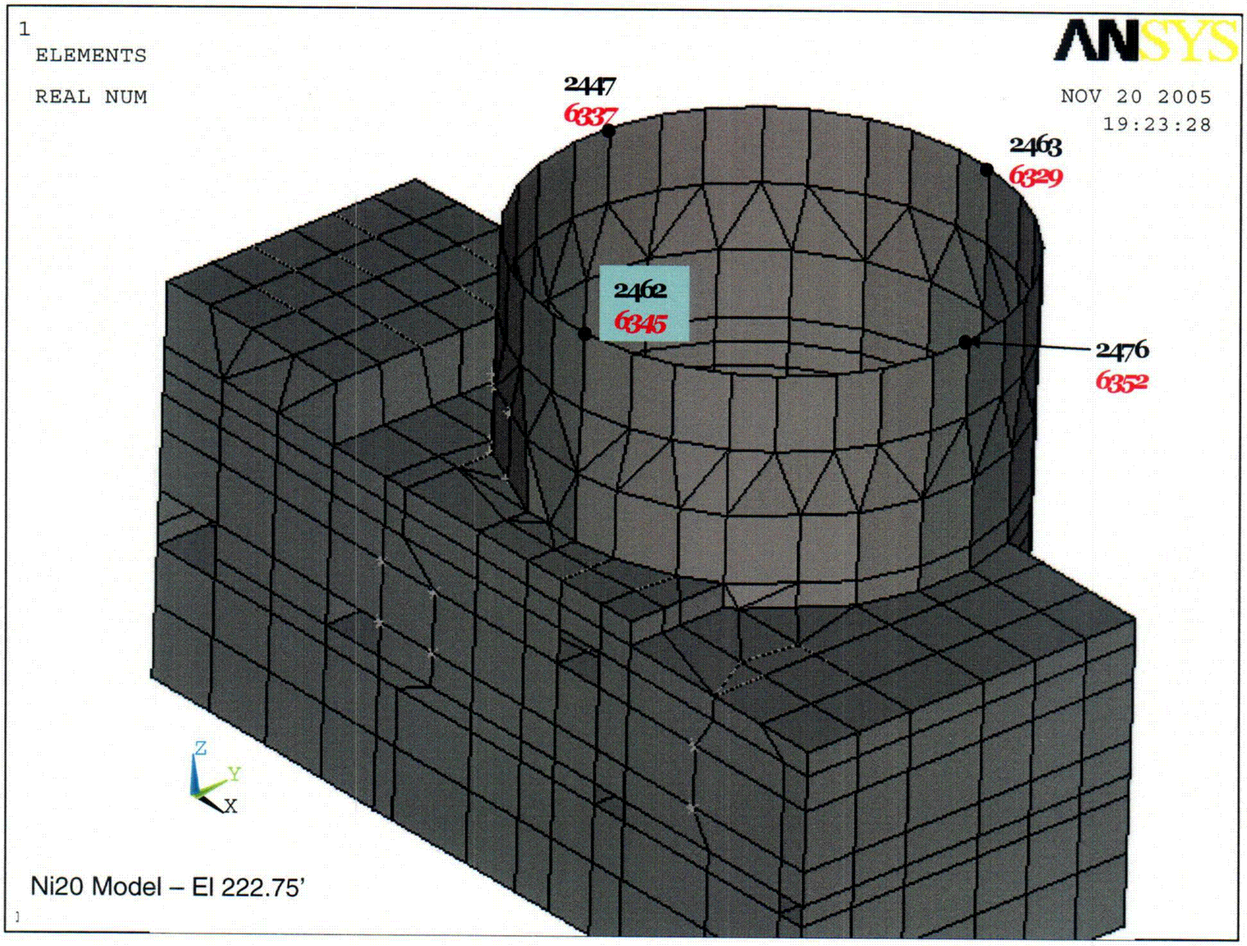


Figure 4.2.3-8 – ASB Nodes at or below El. 230'

C15

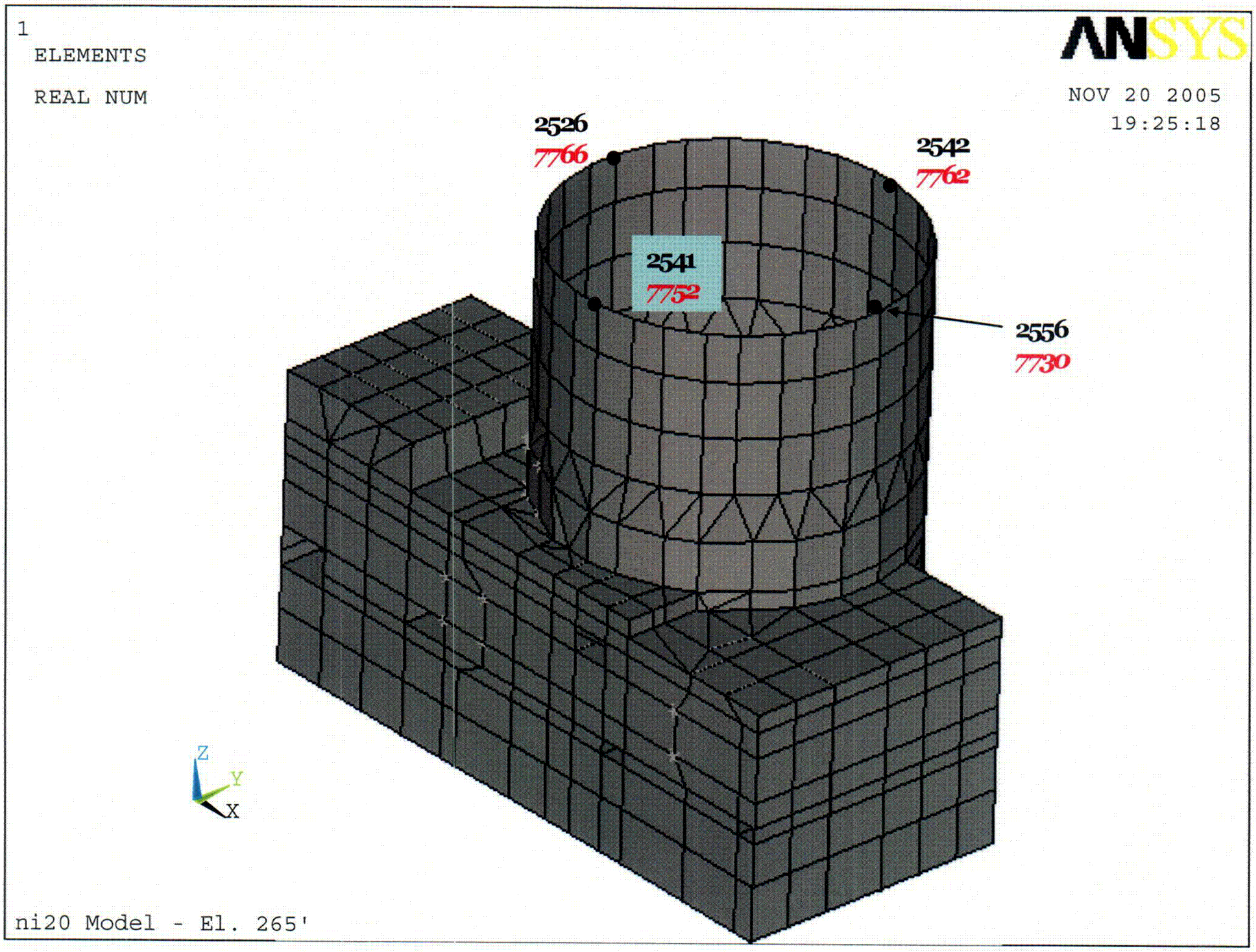


Figure 4.2.3-9 – ASB Nodes at or below El. 265'

C16

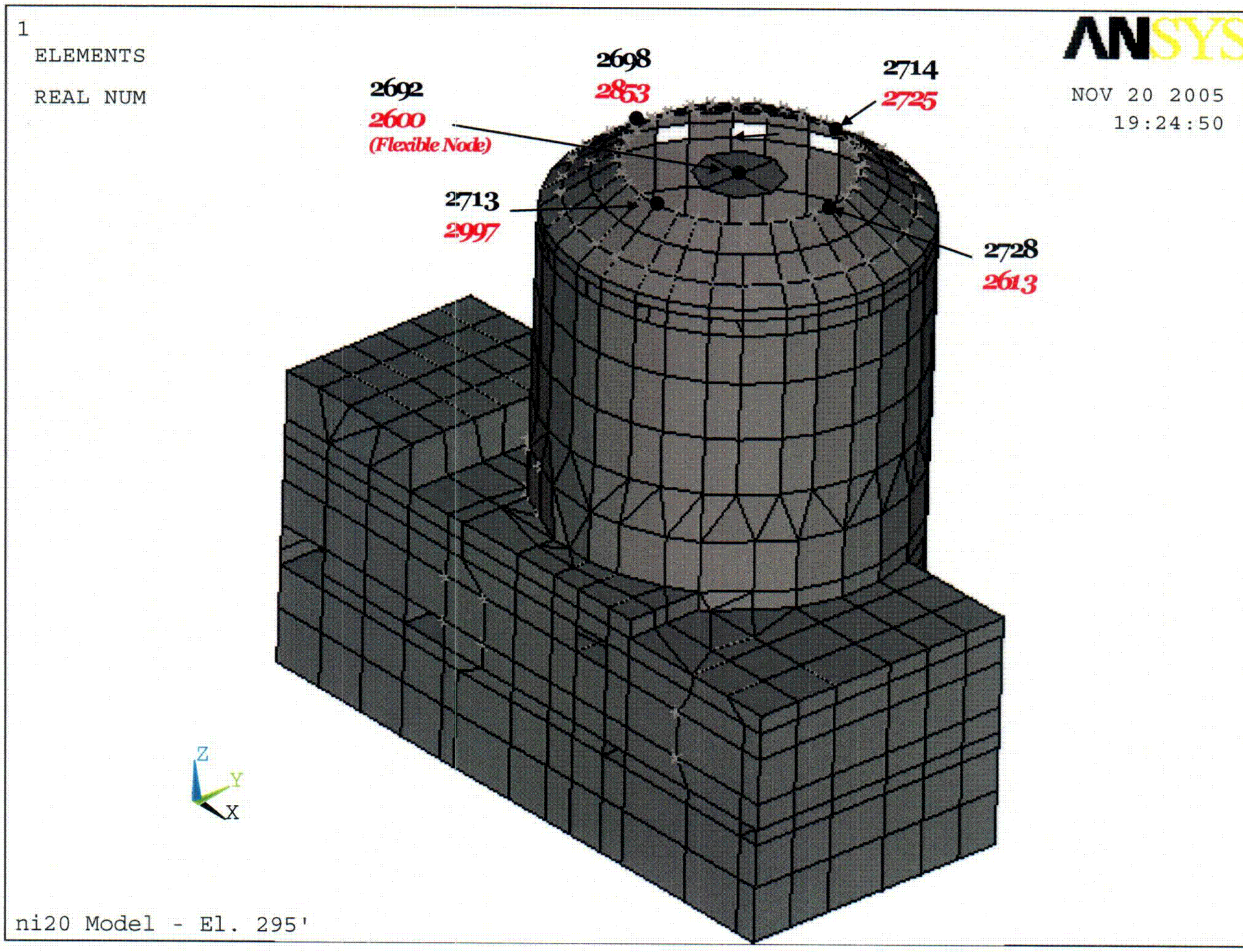


Figure 4.2.3-10 – ASB Nodes at or below El. 294.93'

C17

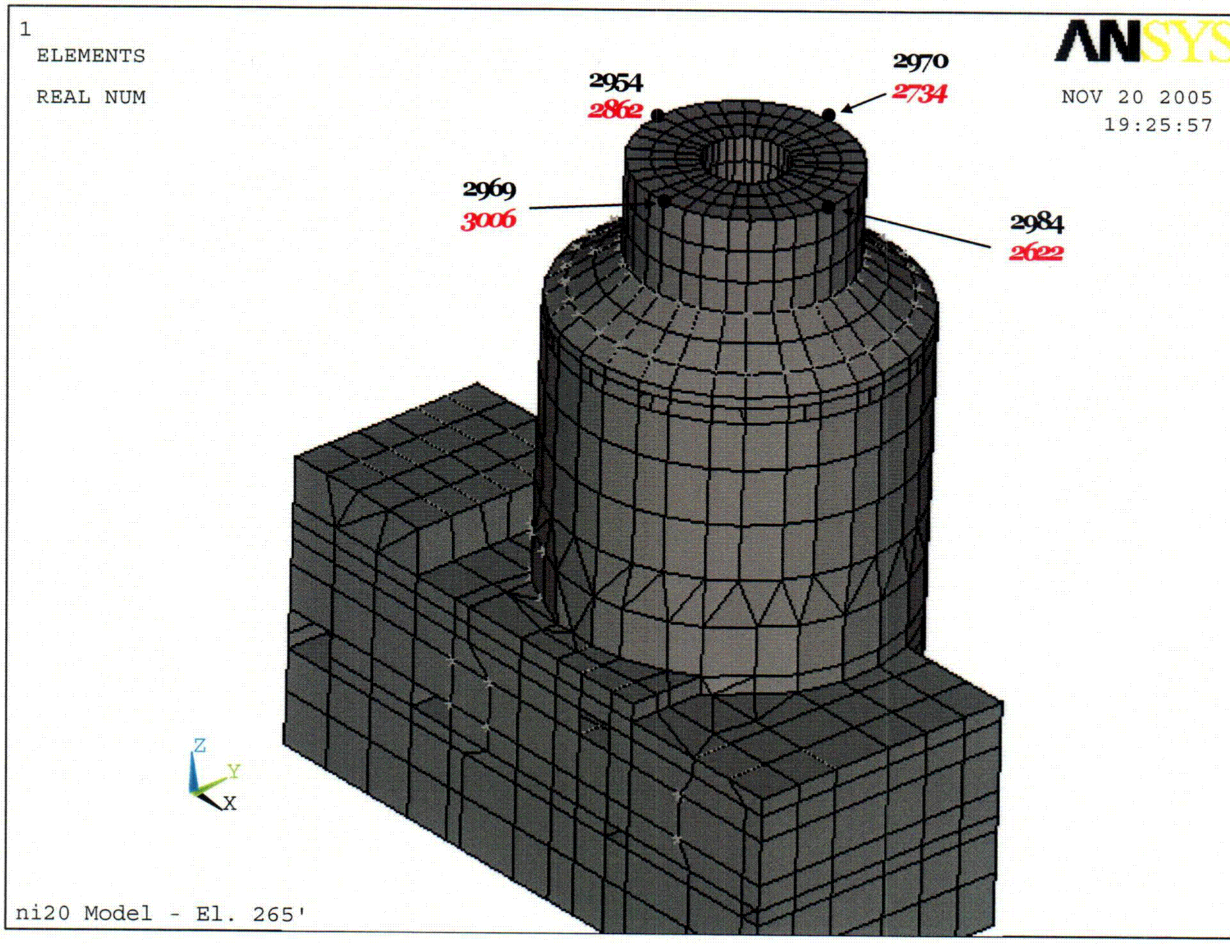


Figure 4.2.3-11 – ASB Nodes at or below El. 333'

C18

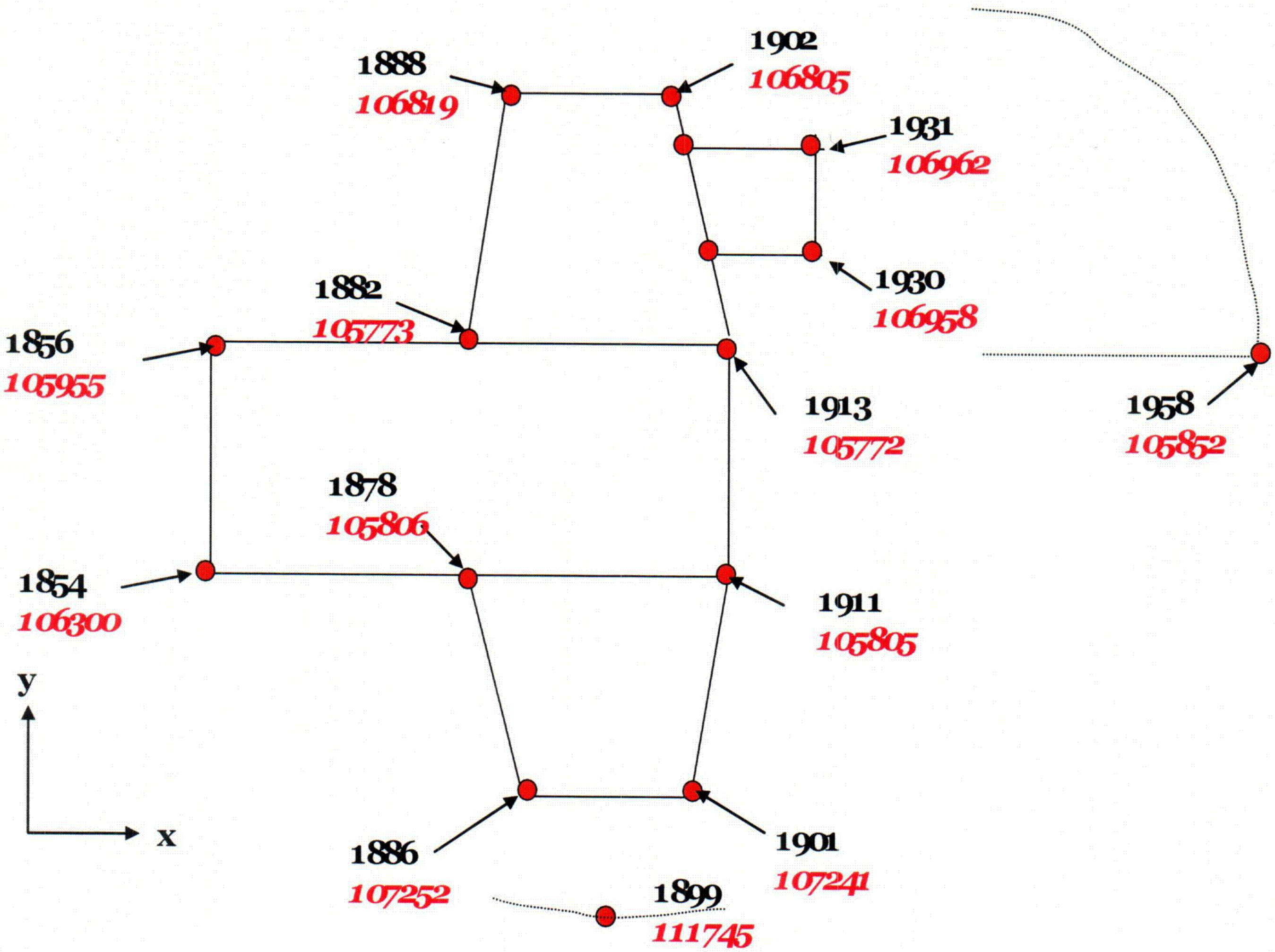


Figure 4.2.3-12 – CIS Nodes at Elevation 134.25'

C19

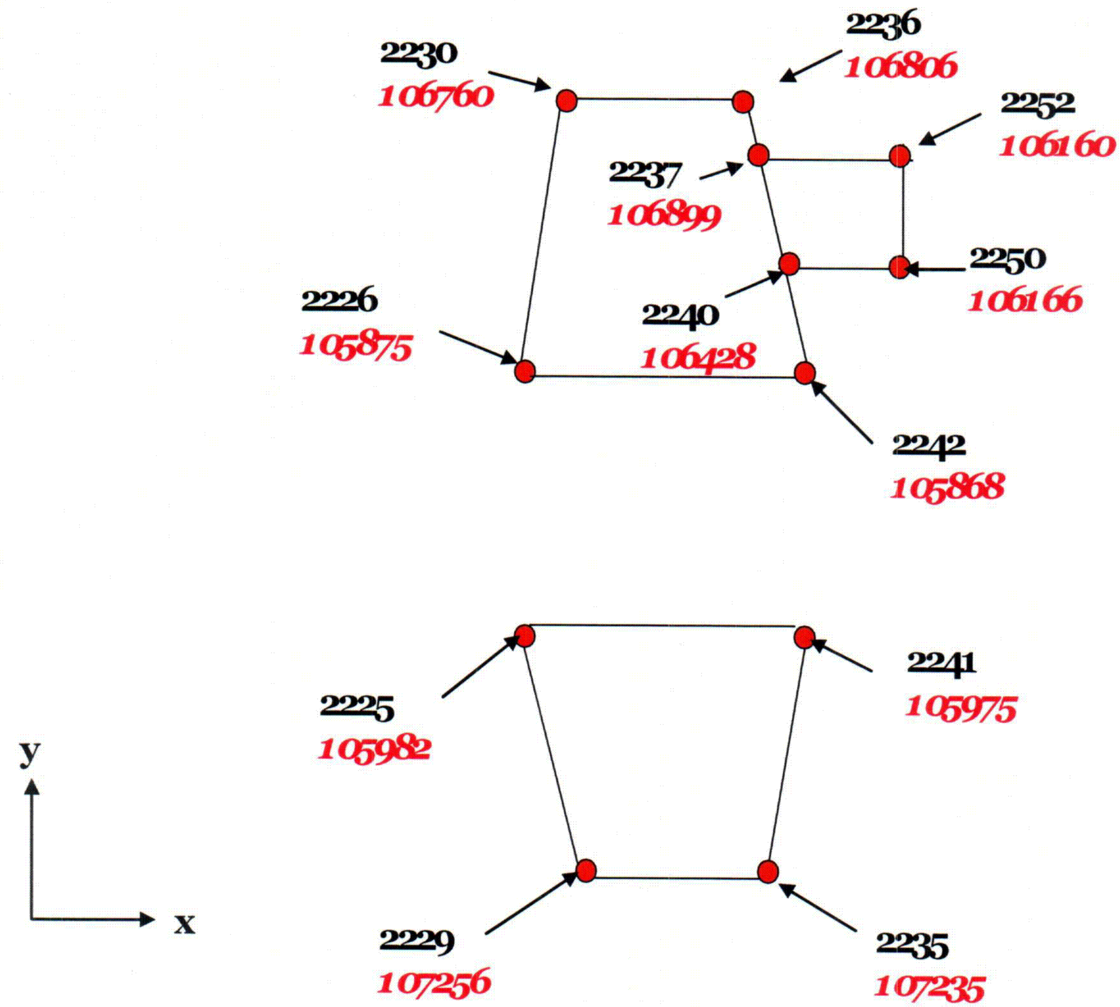


Figure 4.2.3-13 – CIS Nodes at Elevation 153'

C20

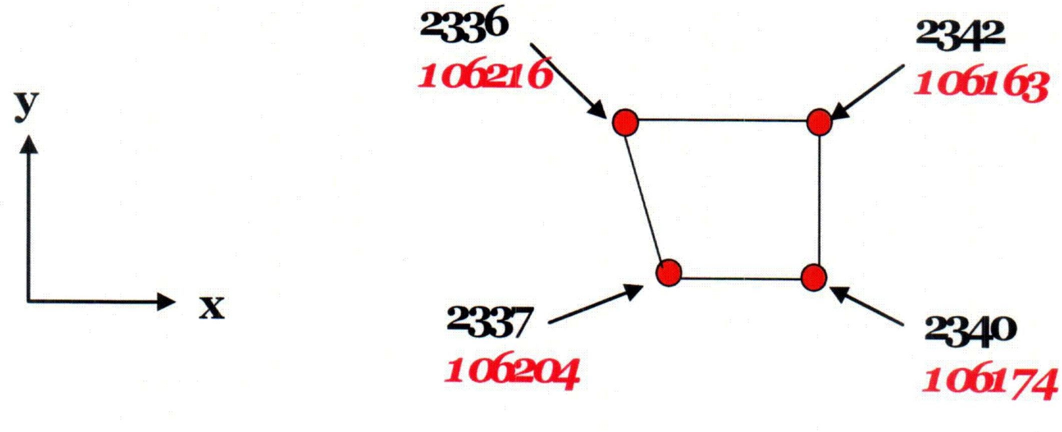


Figure 4.2.3-14 – CIS Nodes at Elevation 160'

C21

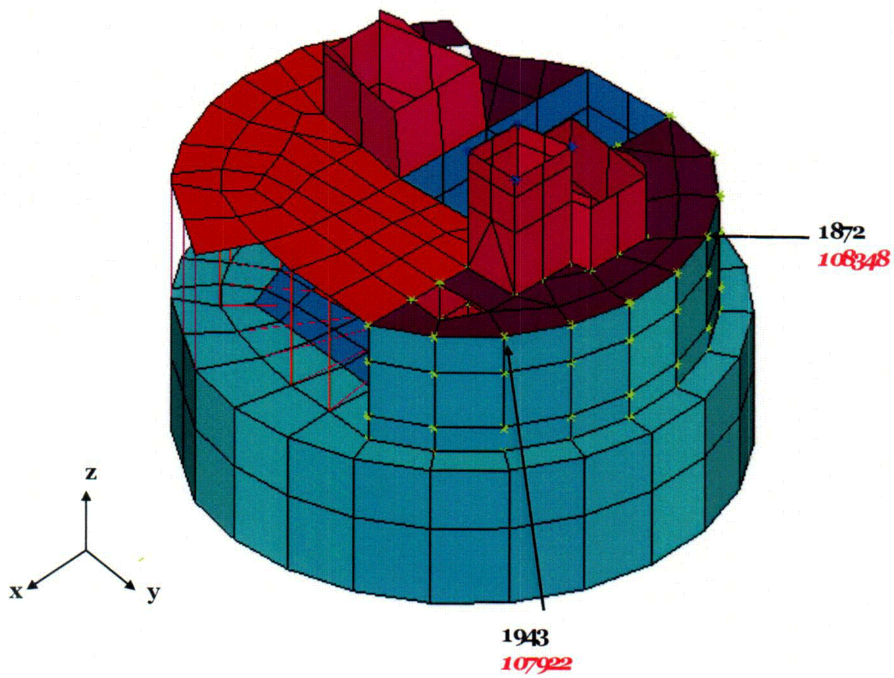


Figure 4.2.3-15 – CIS Nodes at or near the top of the IRWST Wall

C22

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	Equivalent static analysis using accelerations from time history analyses	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 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 [NI20] (including steel containment vessel ,	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
polar crane, RCL, and pressurizer)			
2D finite element lumped mass stick model of auxiliary and shield building.	Time history analysis	SASSI	Performed parametric soil studies to help establish the bounding generic soil conditions.
3D finite element coarse shell model of auxiliary and shield building [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 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
Static analyses			
3D finite element refined shell model of auxiliary and shield building (ASB05)	Equivalent static analysis using accelerations from time history analyses	ANSYS	To obtain SSE member forces for the auxiliary and shield building.
3D finite element model of the shield building roof	Equivalent static analysis using accelerations from time history analyses	GT STRUDL	To obtain SSE member forces for the shield building roof.

Model	Analysis Method	Program	Type of Dynamic Response/Purpose
3D finite element refined shell model of nuclear island (NI05)	Equivalent static non-linear analysis using accelerations from time history analyses	ANSYS	To obtain SSE member forces for the nuclear island basemat

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.

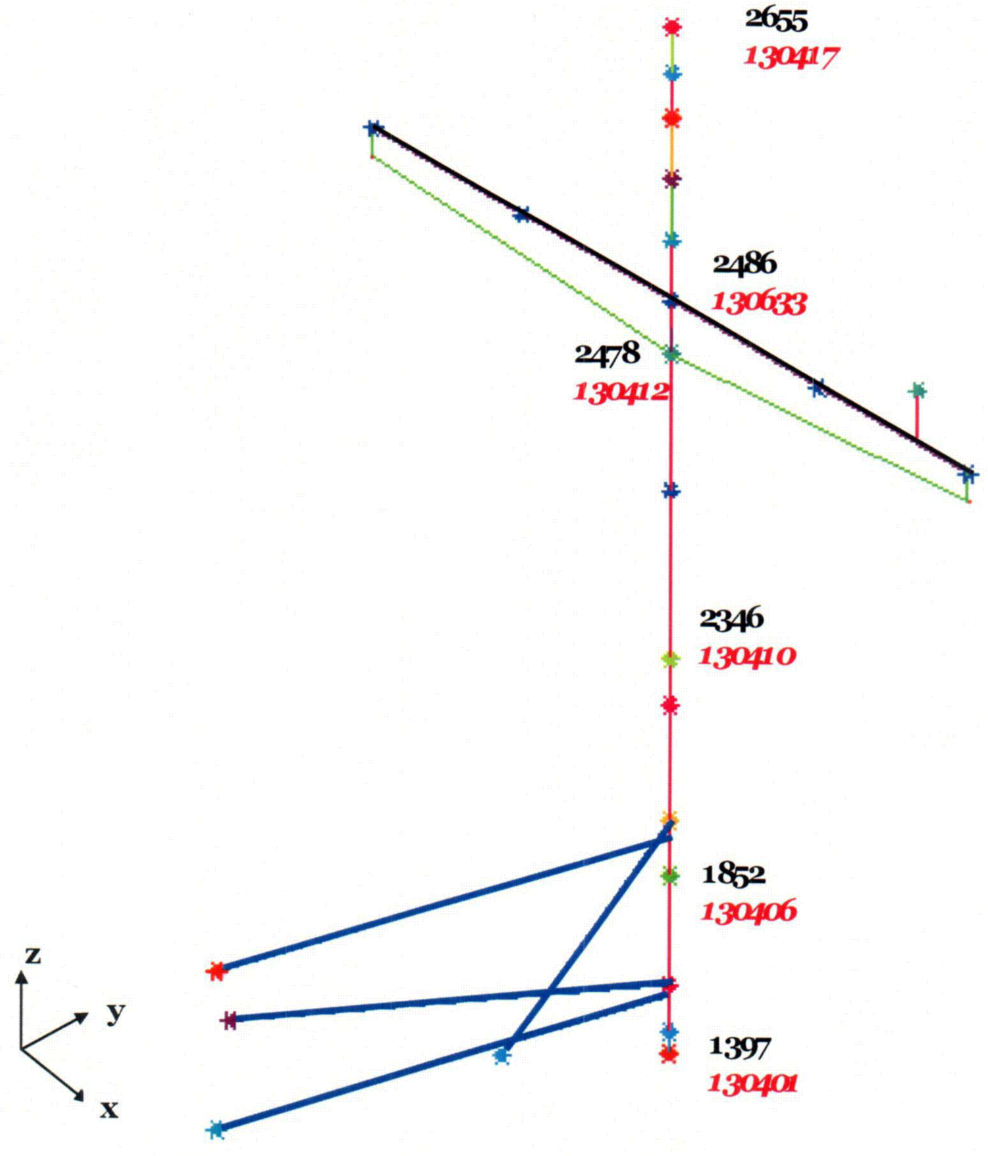


Figure 4.3-1– Steel Containment Vessel with Polar Crane

C23

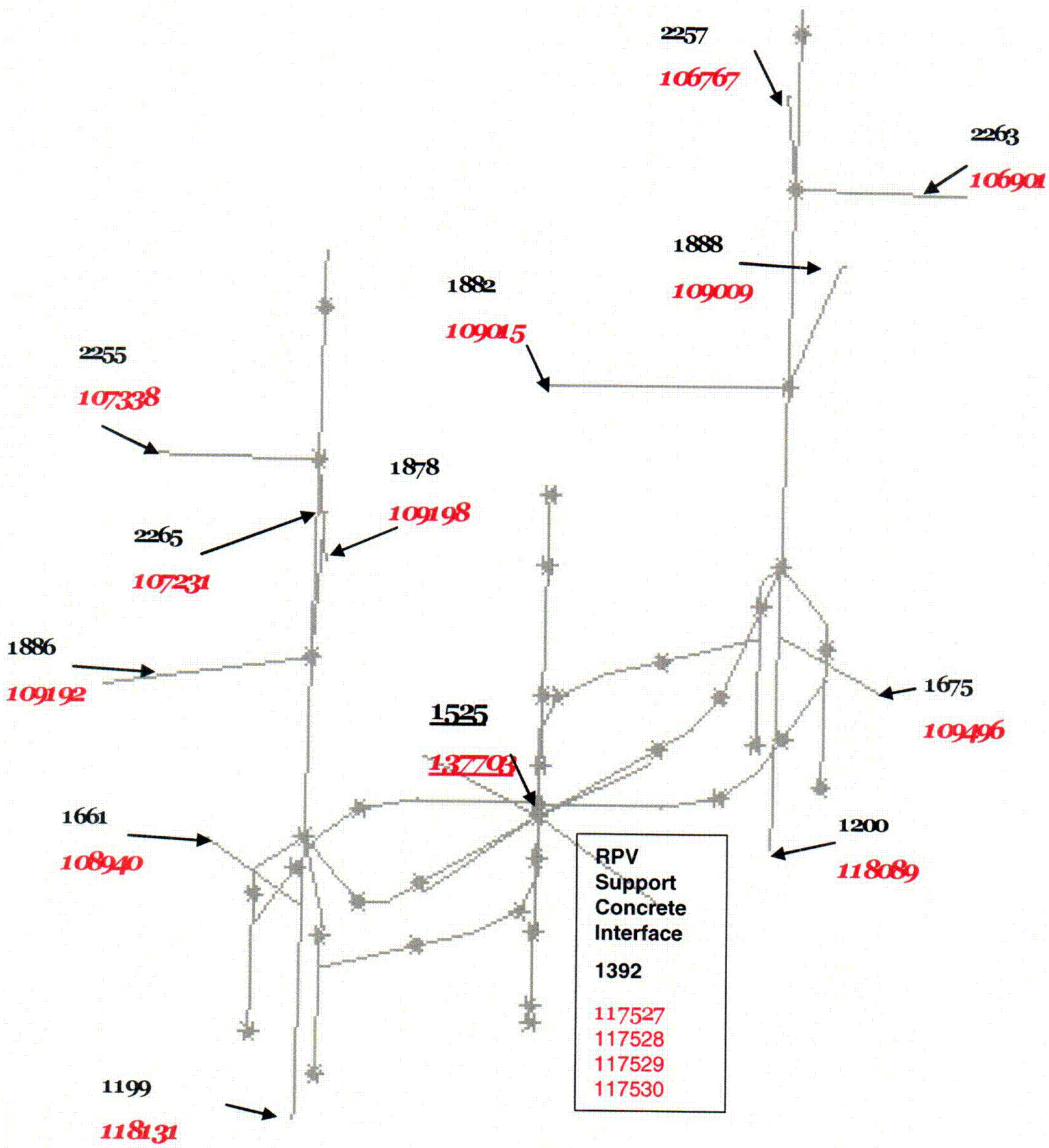


Figure 4.3-2 – Reactor Coolant Loop Support Nodes

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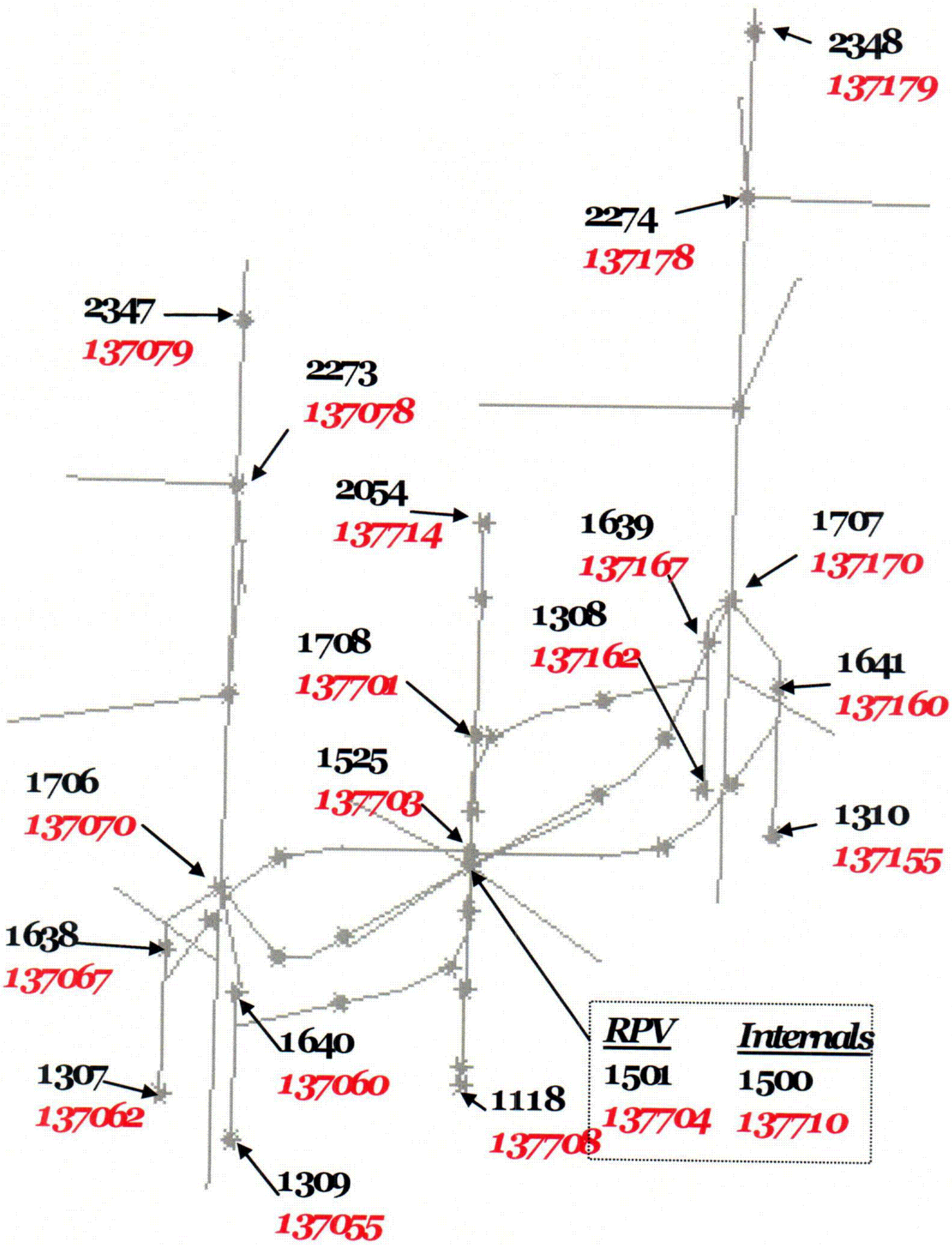


Figure 4.3-3 – Reactor Coolant Loop: Nodes on Major Equipment

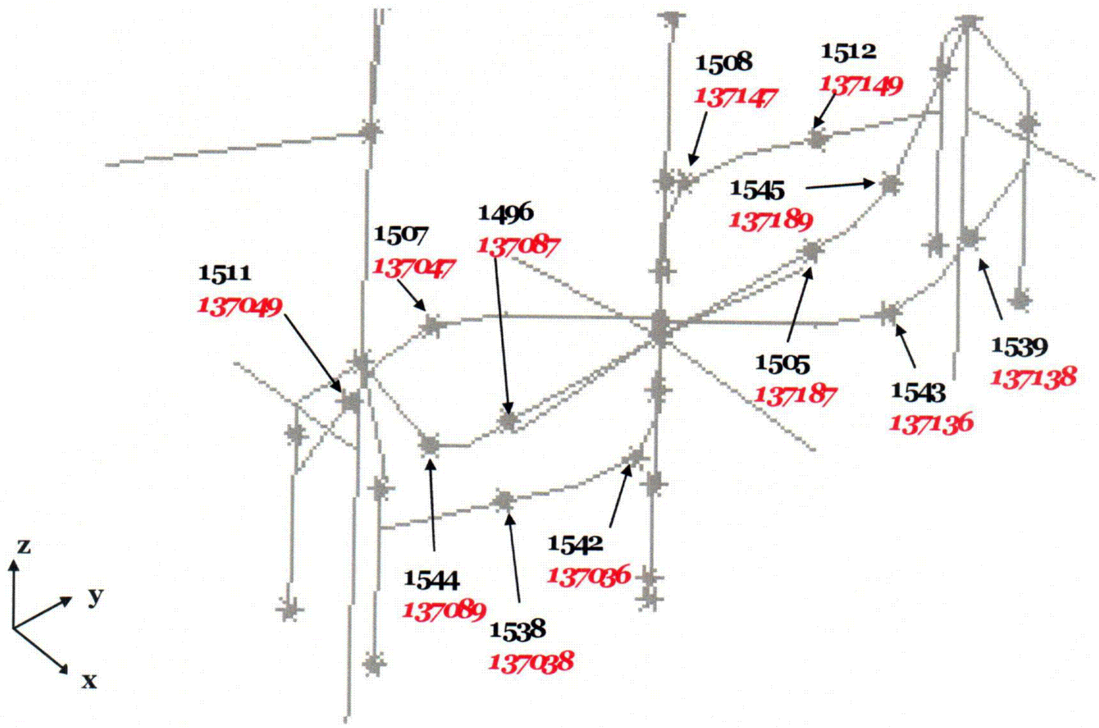


Figure 4.3-4 – Reactor Coolant Loop Nodes

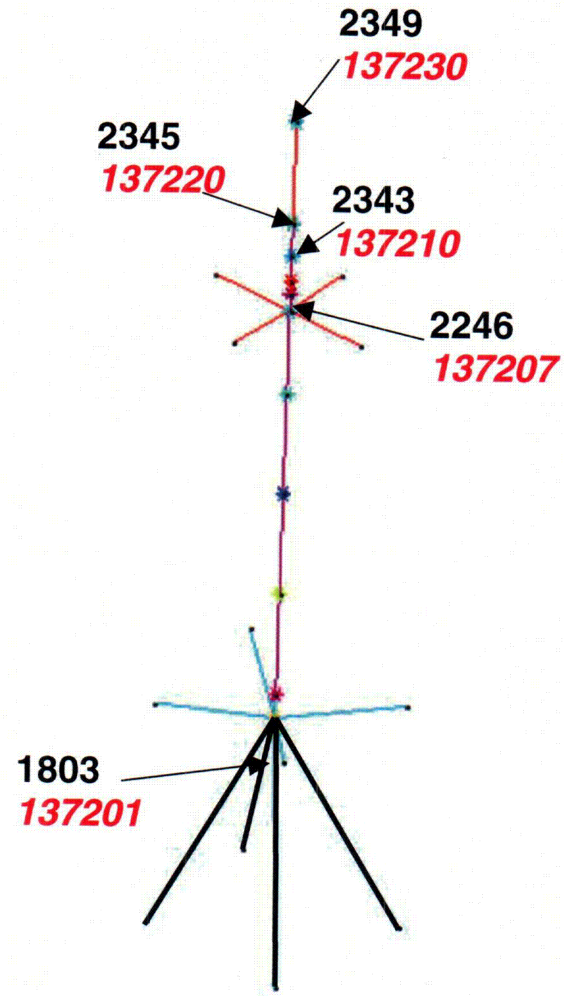


Figure 4.3-5 – Pressurizer Nodes

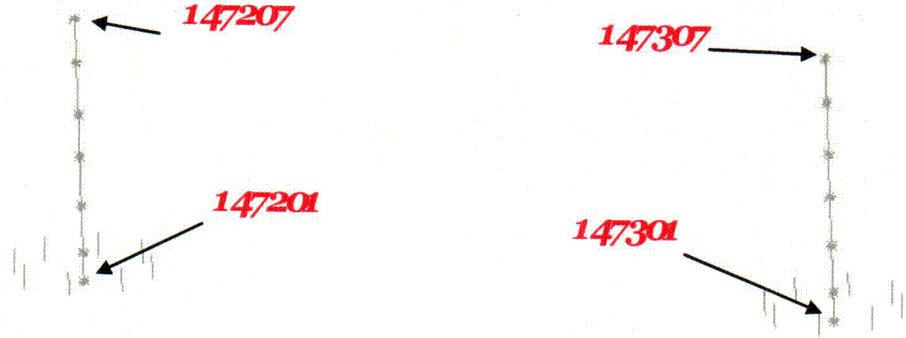


Figure 4.3-6– Core Make-Up Tank

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 25' 6" taller than AP600. Many of the results and conclusions from the AP600 soil studies are applicable to AP1000. Analyses of AP1000 are described similar to key soil cases analyzed for AP600. Four soil and rock cases are selected 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 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 Rockies. 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

C28

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, along with a discussion of their validity for the AP1000 configuration.

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. The depth-to-base rock of 120 ft is the governing soil profile and was therefore specified for the 3D SASSI design cases. At high frequencies the shallower depth models gave a higher building response, but for the AP600 configuration a depth of 120 ft gave the highest overall response. Since the dominant AP1000 building frequencies are lower than for AP600, the shallower depth conditions would provide even less of an effect and thus using a depth-to-base rock of 120 ft is also appropriate.

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. SHAKE and SSI analyses were performed. Based on this, no further work needs to be done with clay profiles for the generic design.

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. 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. Thus, the water table was specified at grade for the 3D SASSI design cases. This specification is also appropriate for the AP1000.

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. Based on this study 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.

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 similar to those performed for the AP600.

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 are shown in Figures 4.4.1-2 to 4.4.1-5. Floor response spectra 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			Notes
			(X-shaking)	(Y-shaking)	(Z-shaking)	
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

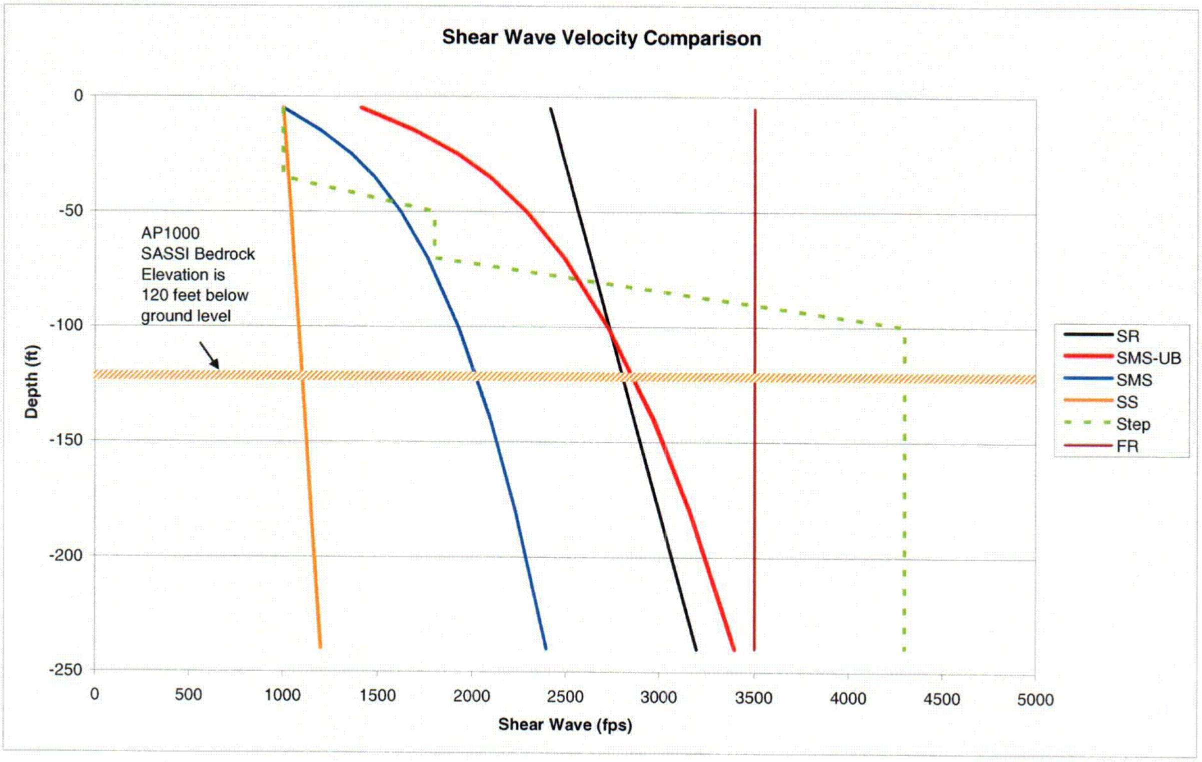
☒ EPRI soil degradation curves

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

C29



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

C30

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*

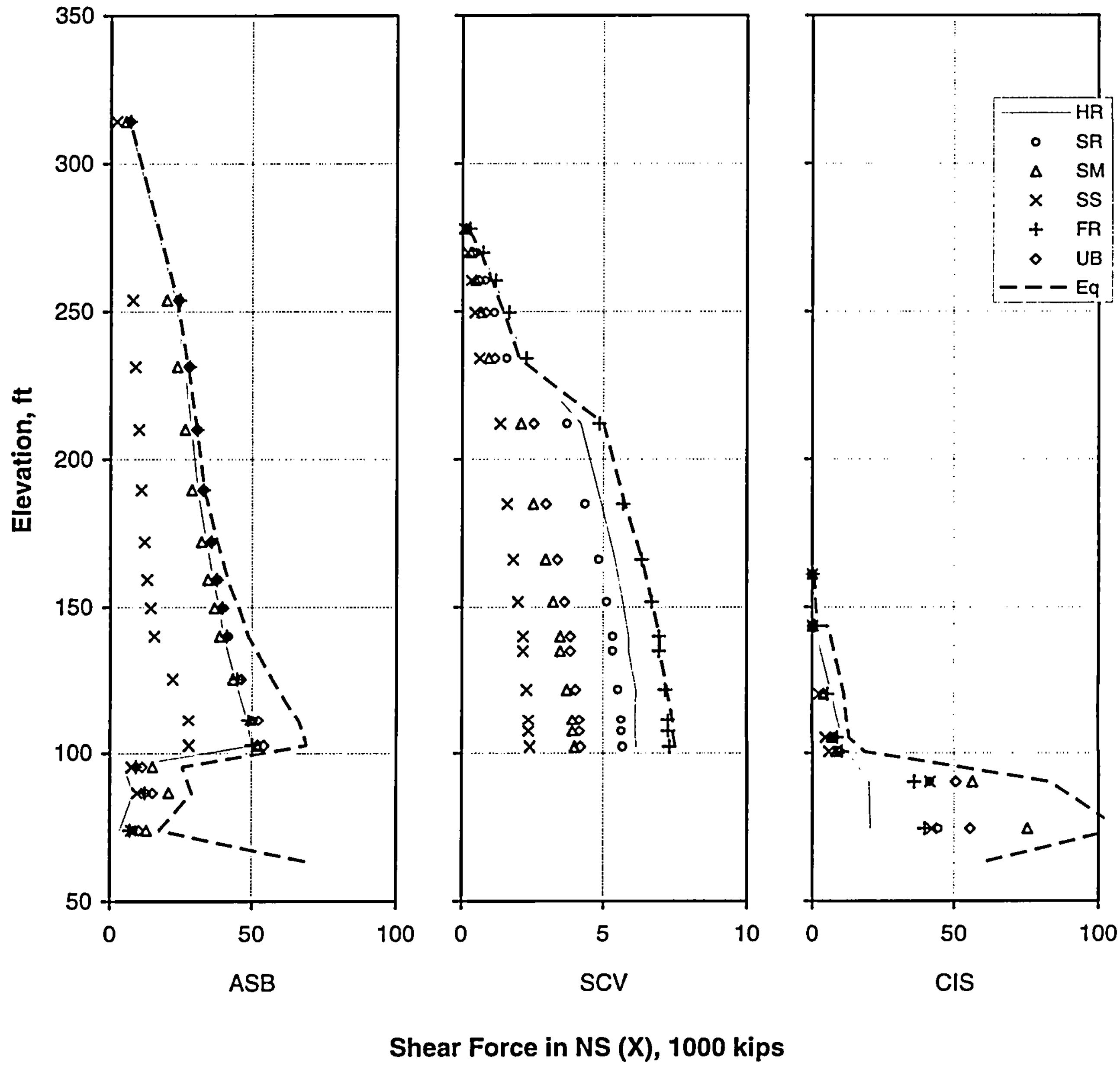


Figure 4.4.1-2 - 2D SASSI NS Shear Force

HR:	Hard Rock	*Table 35, Ref 1*
SR:	Soft Rock	*Table 35, Ref 1*
SM:	Soft-to-medium Soil	*Table 36, Ref 1*
SS:	Soft Soil	*Table 36, Ref 1*
FR:	Firm Rock	*Table 9, Ref 8*
UB:	Upper Bound SM	*Table 9, Ref 8*
Eq:	Equivalent Static	*NISASSIstatic*

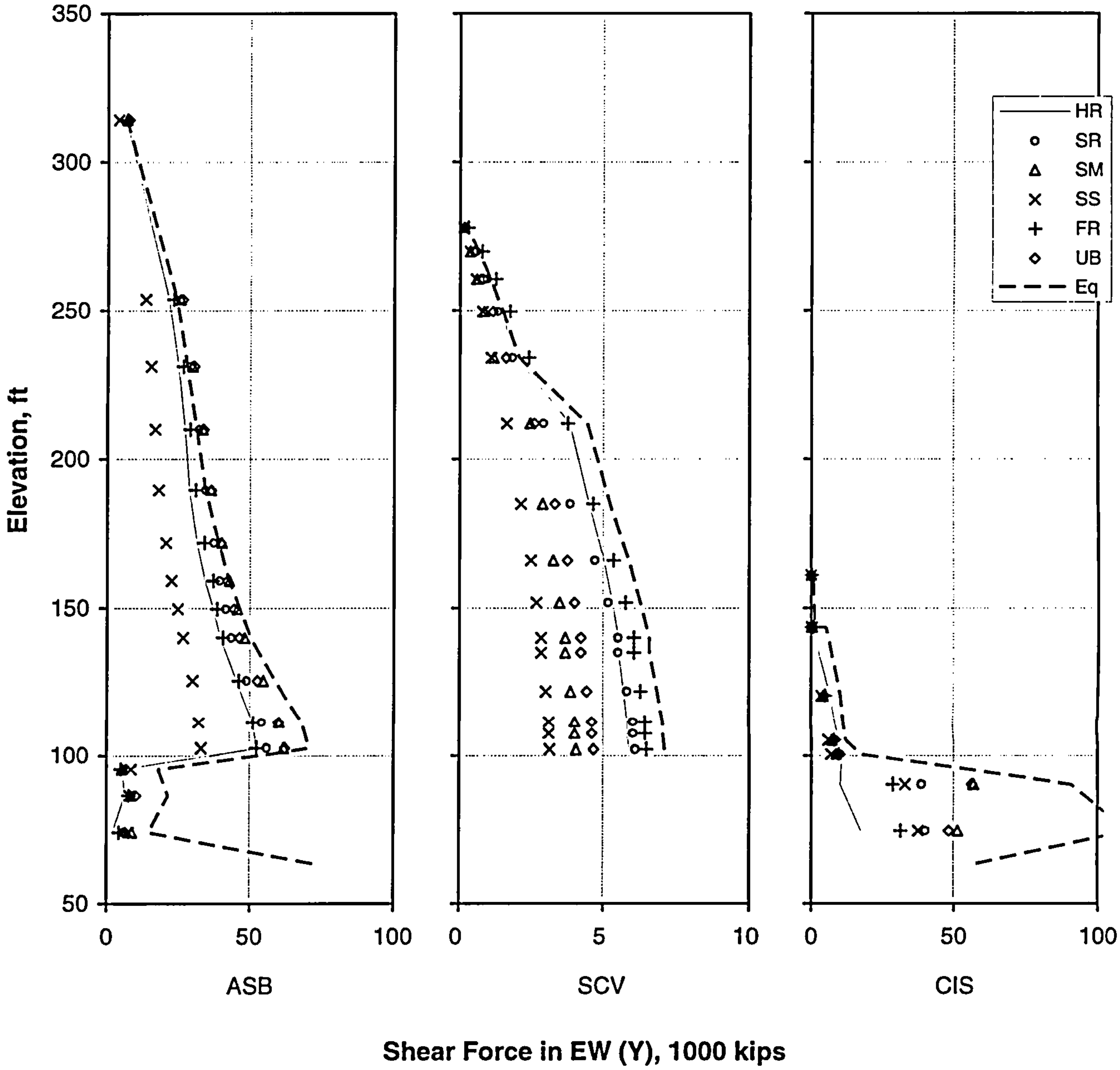
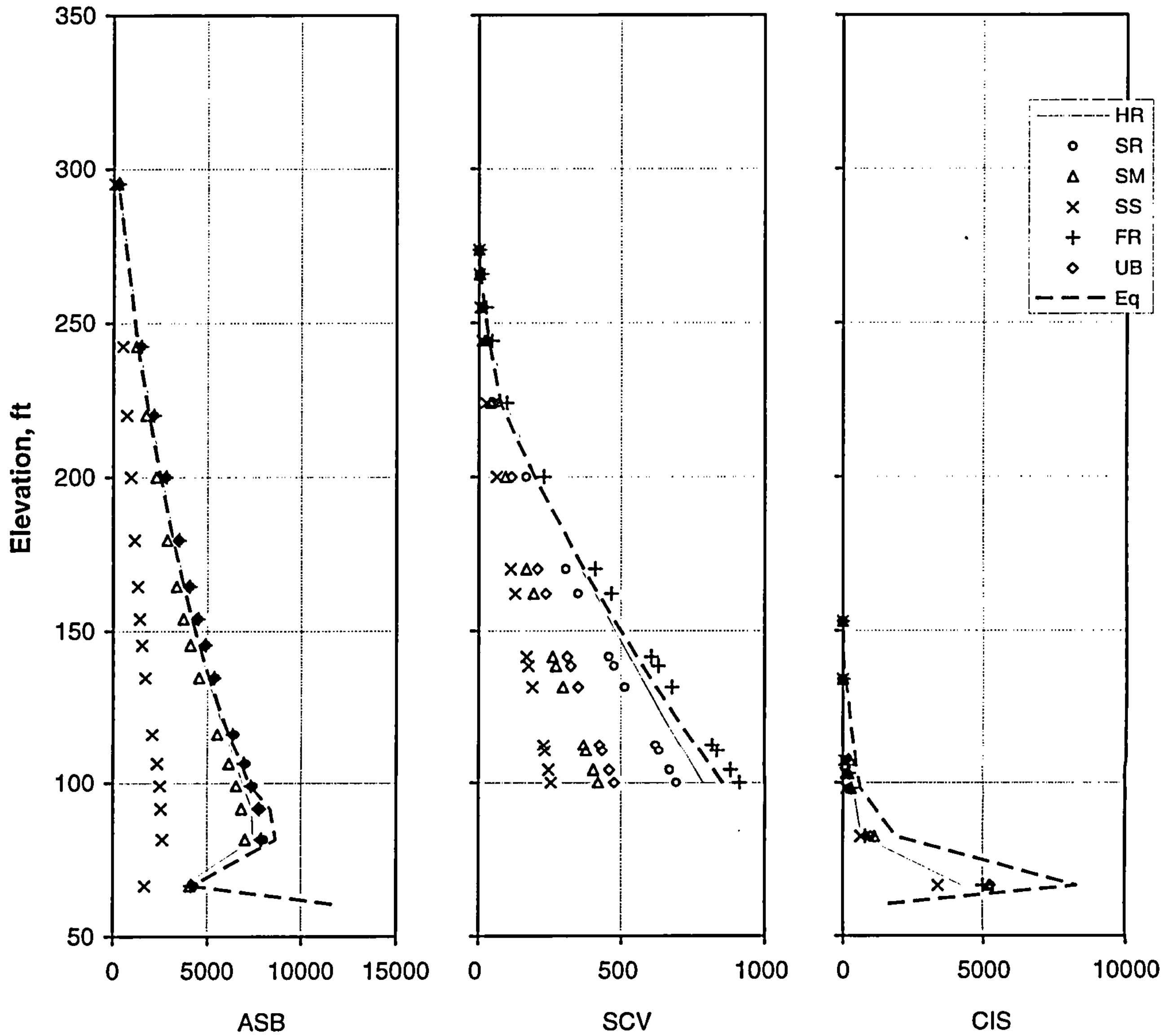


Figure 4.4.1-3 - 2D SASSI EW Shear Force

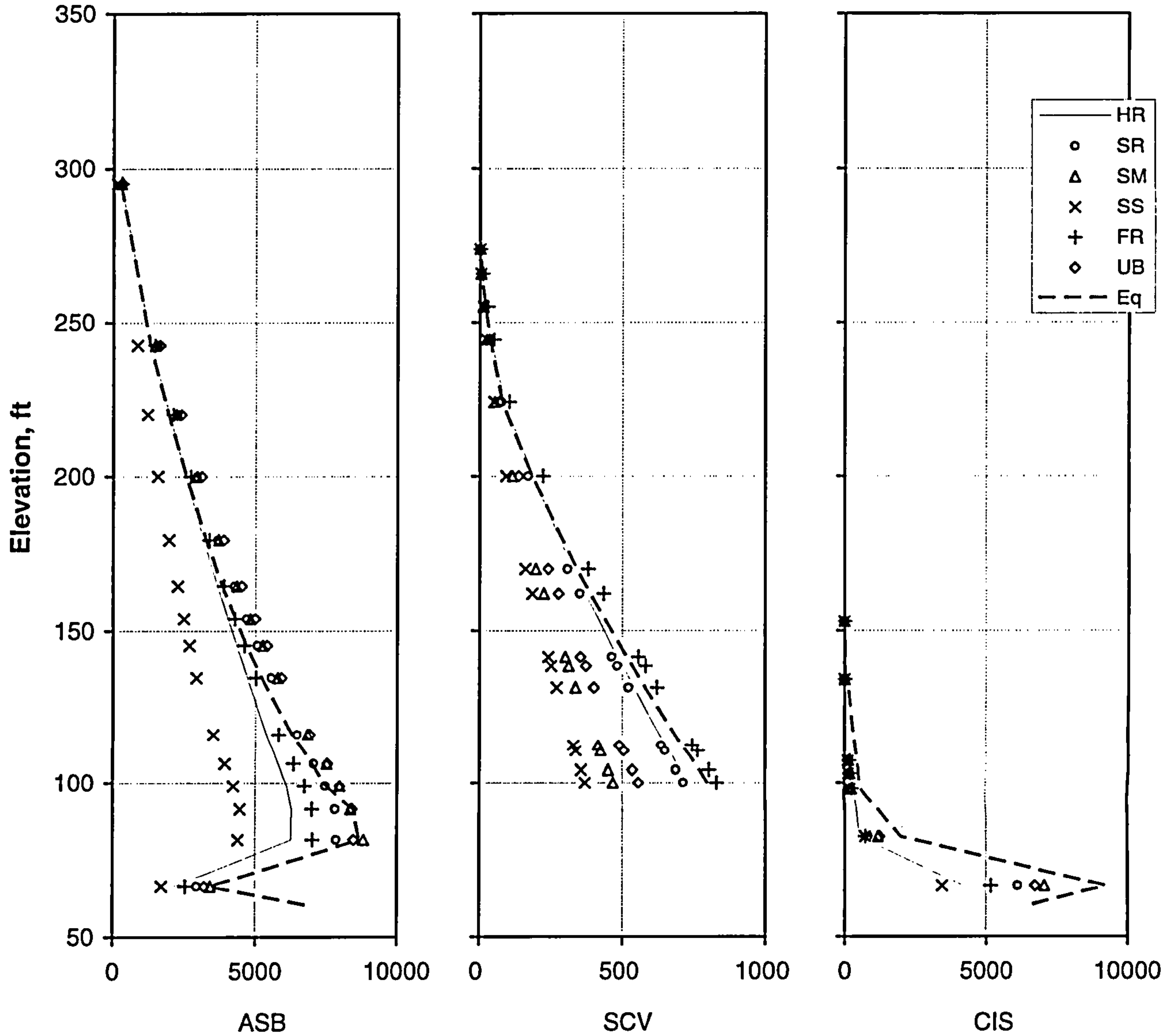
HR:	Hard Rock	*Table 37, Ref 1*
SR:	Soft Rock	*Table 37, Ref 1*
SM:	Soft-to-medium Soil	*Table 38, Ref 1*
SS:	Soft Soil	*Table 38, Ref 1*
FR:	Firm Rock	*Table 10, Ref 8*
UB:	Upper Bound SM	*Table 10, Ref 8*
Eq:	Equivalent Static	*NISASSIstatic*



Overturning Moment about EW (Y) Axis, 1000 k.ft

Figure 4.4.1-4 - 2D SASSI EW Overturning Moment

HR:	Hard Rock	*Table 35, Ref 1*
SR:	Soft Rock	*Table 35, Ref 1*
SM:	Soft-to-medium Soil	*Table 36, Ref 1*
SS:	Soft Soil	*Table 36, Ref 1*
FR:	Firm Rock	*Table 9, Ref 8*
UB:	Upper Bound SM	*Table 9, Ref 8*
Eq:	Equivalent Static	*NISASSIstatic*



Bending Moment about NS (X) Axis, 1000 k.ft

Figure 4.4.1-5 - 2D SASSI NS Bending Moment

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.

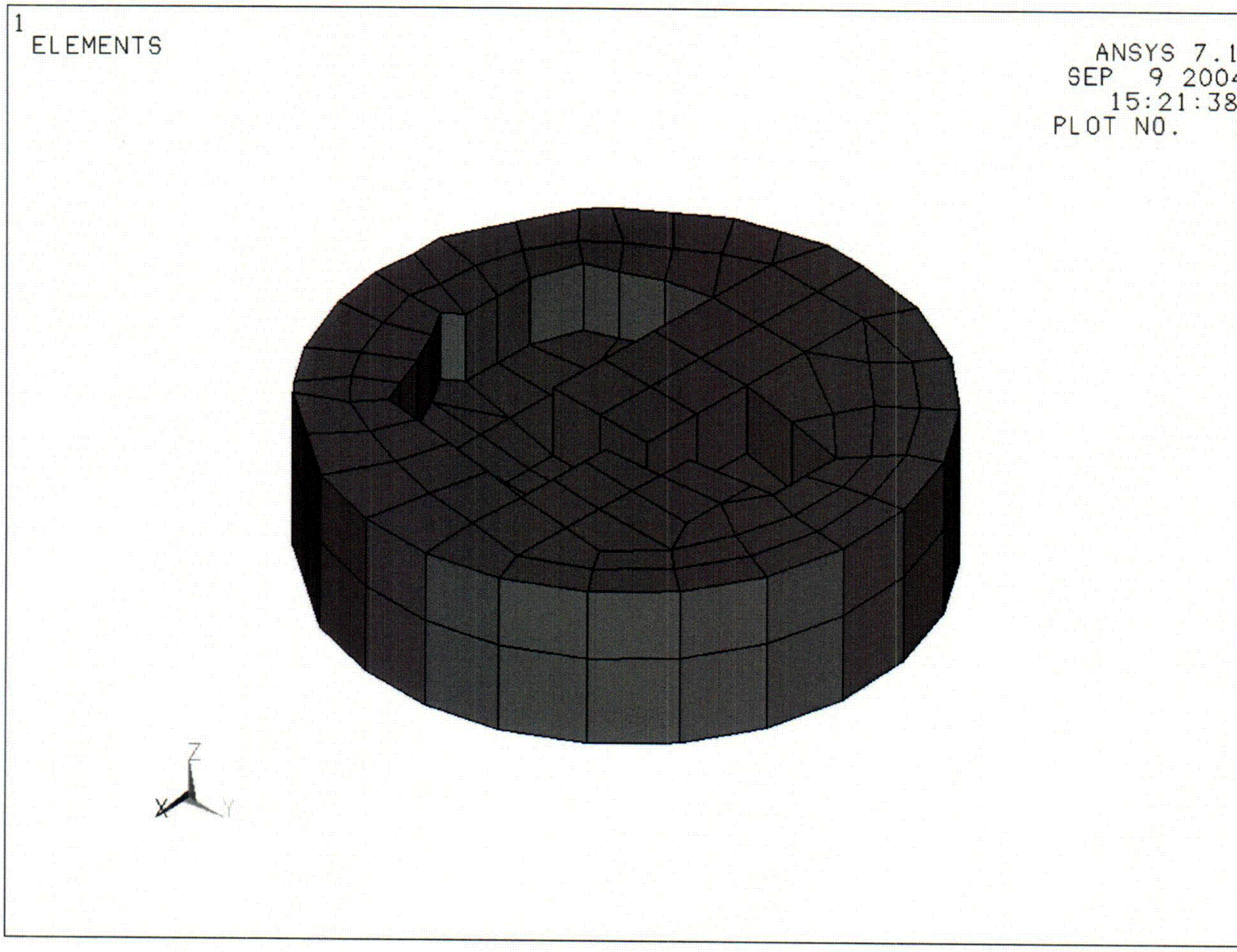


Figure 4.4.2-1- NI 3-D SASSI Model Solid Elements

C31

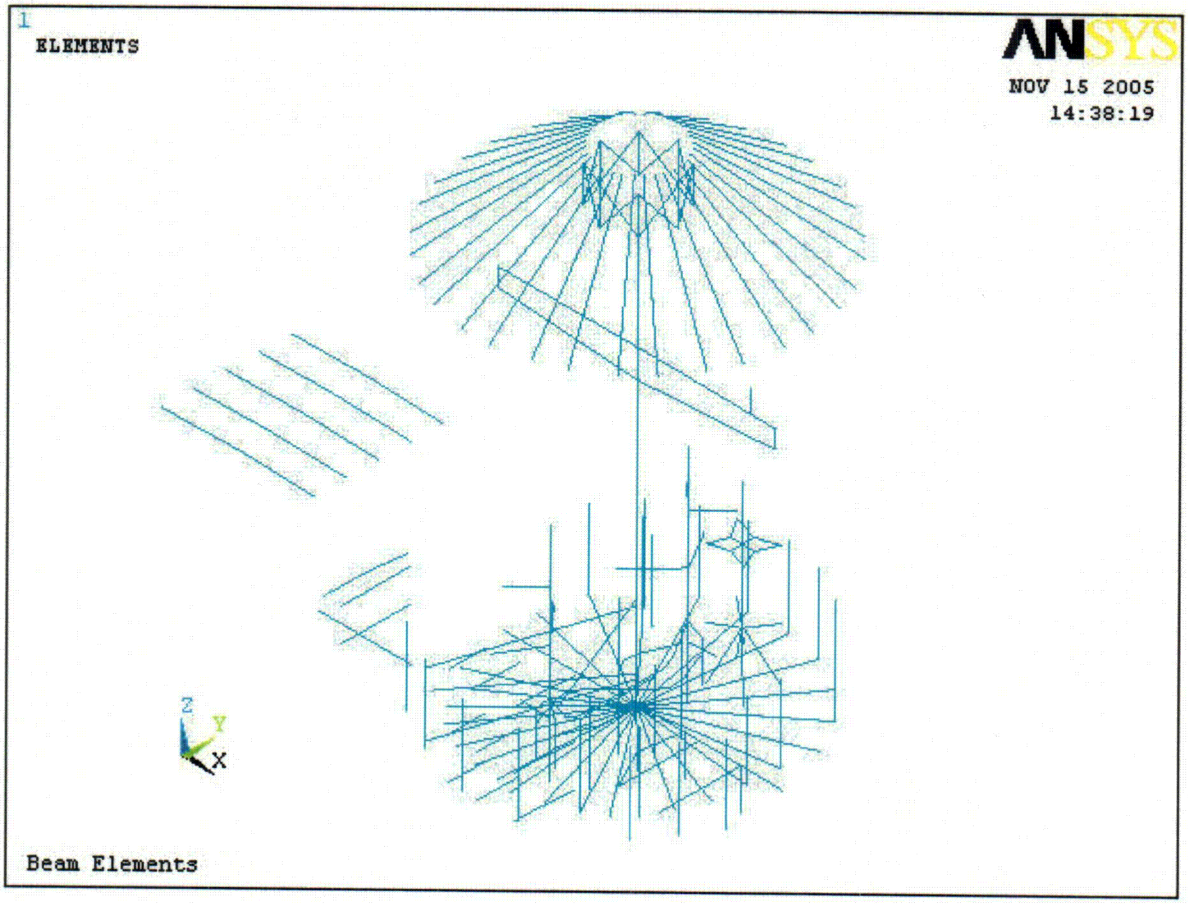


Figure 4.4.2-2 NI 3-D SASSI Model Beam Elements

C32

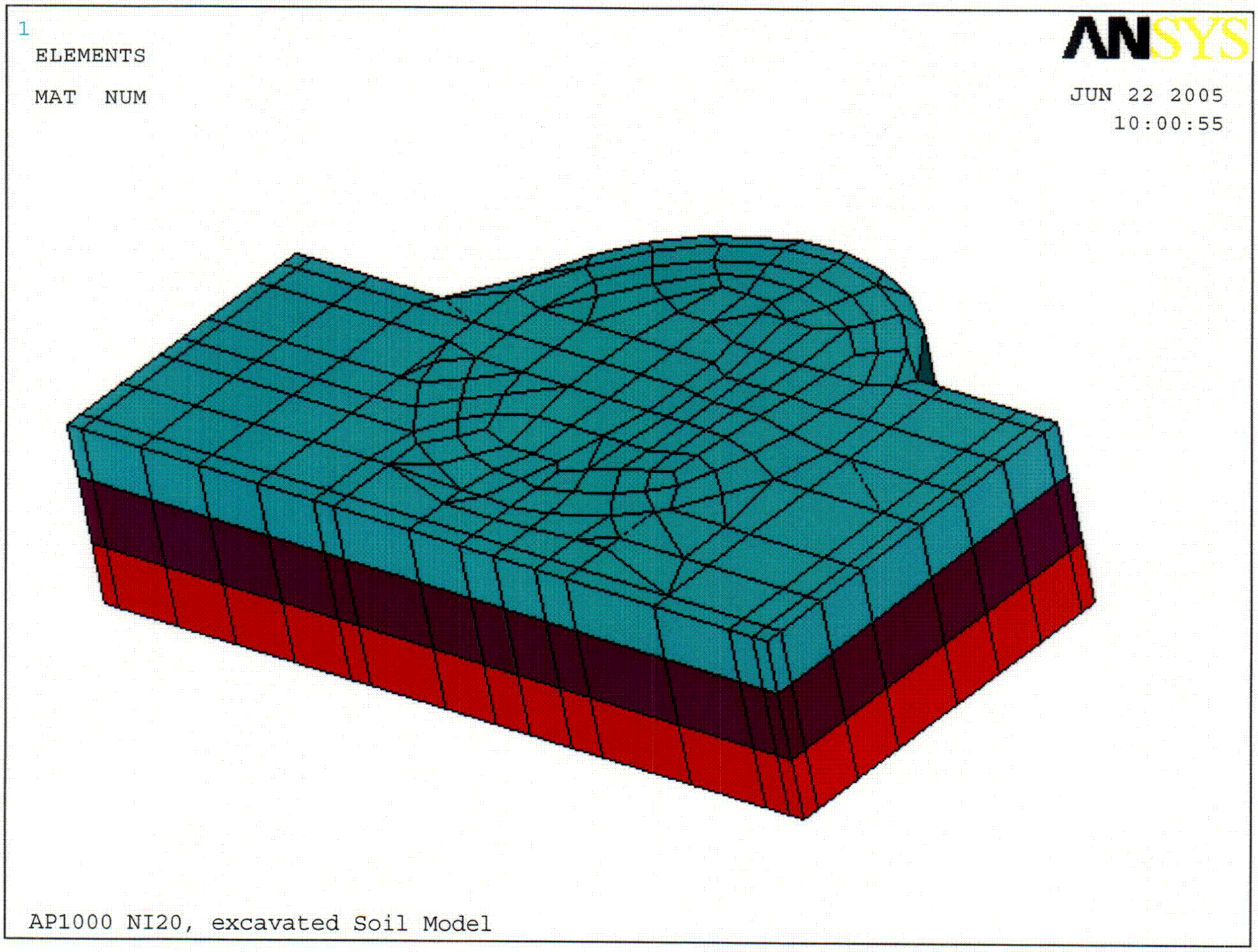


Figure 4.4.2-3 - Excavated Soil

C33

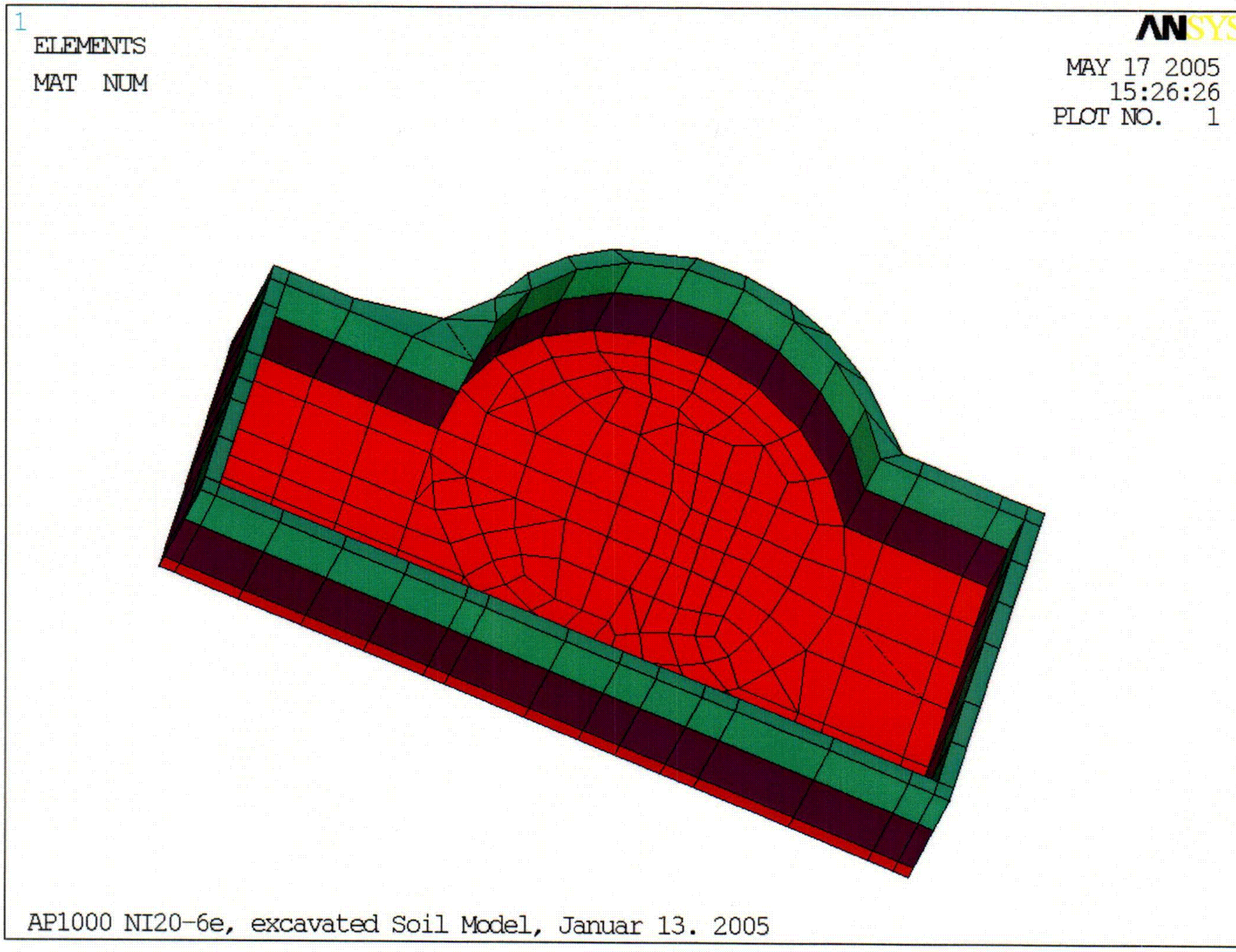


Figure 4.4.2-4 - Additional Elements for Soil Pressure Calculations

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 Ceiling
- ASB Corner of Fuel Building Roof at Shield Building
- ASB Shield Building Roof Area

C34

- 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 4.4.3-1 to 4.4.3-18. 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	1397	SCV Center	100.00
CIS at Operating Deck	105772	1913	SG West compartment, NE	134.25
ASB NE Corner at Control Room Ceiling	5109	2047	NE Corner	134.88
ASB Corner of Fuel Building Roof at Shield Building	5754	2365	NW Corner of Fuel Bldg	179.19
ASB Shield Building Roof Area	2862	2954	South side of Shield Bldg	333.12
SCV Near Polar Crane	130412	2478	SCV Stick Model	224.00

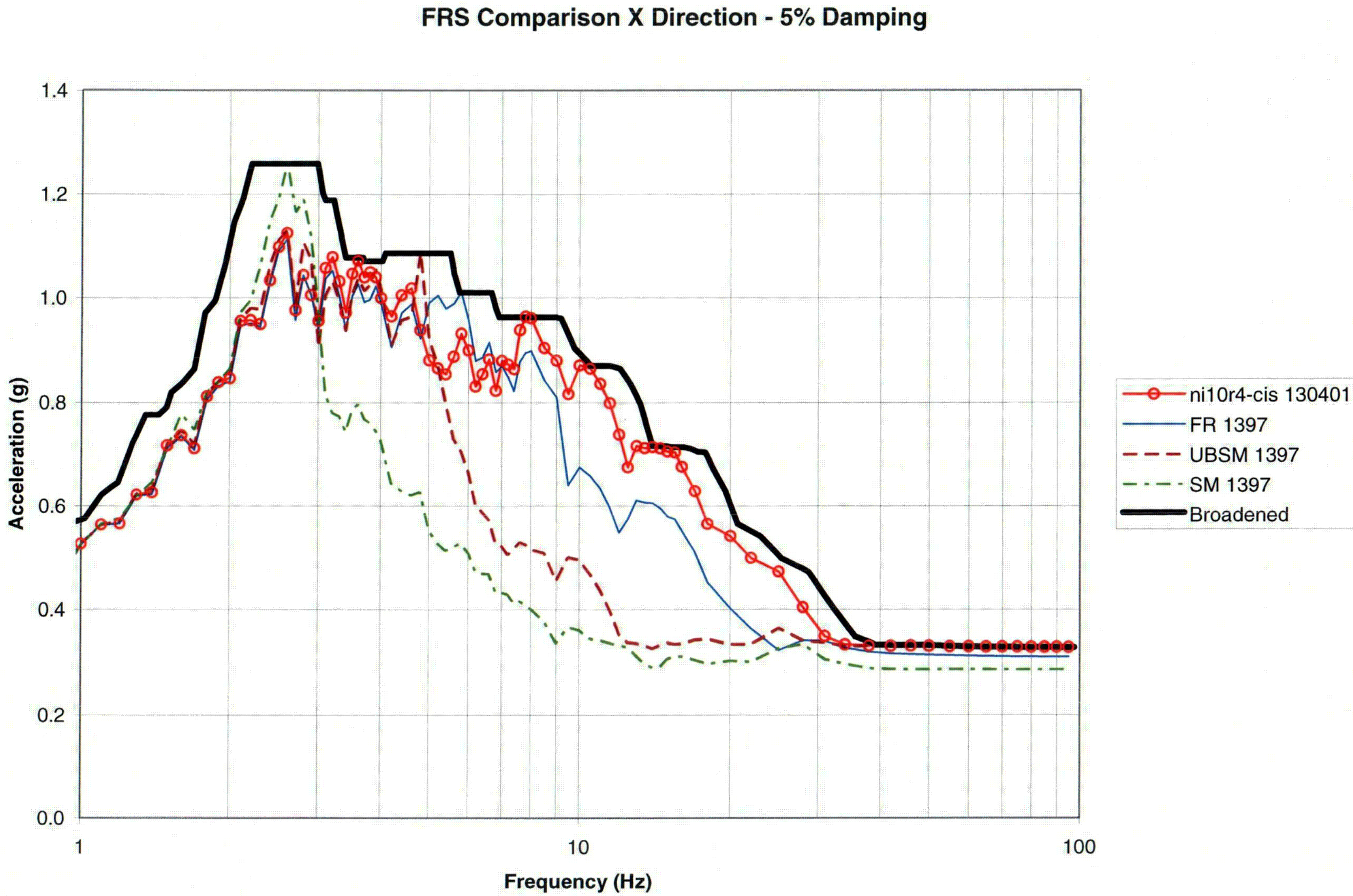


Figure 4.4.3-1 – X Direction FRS for node 130401 (NI10) or 1397 (NI20)
CIS at Reactor Vessel Support Elevation of 100'

C35

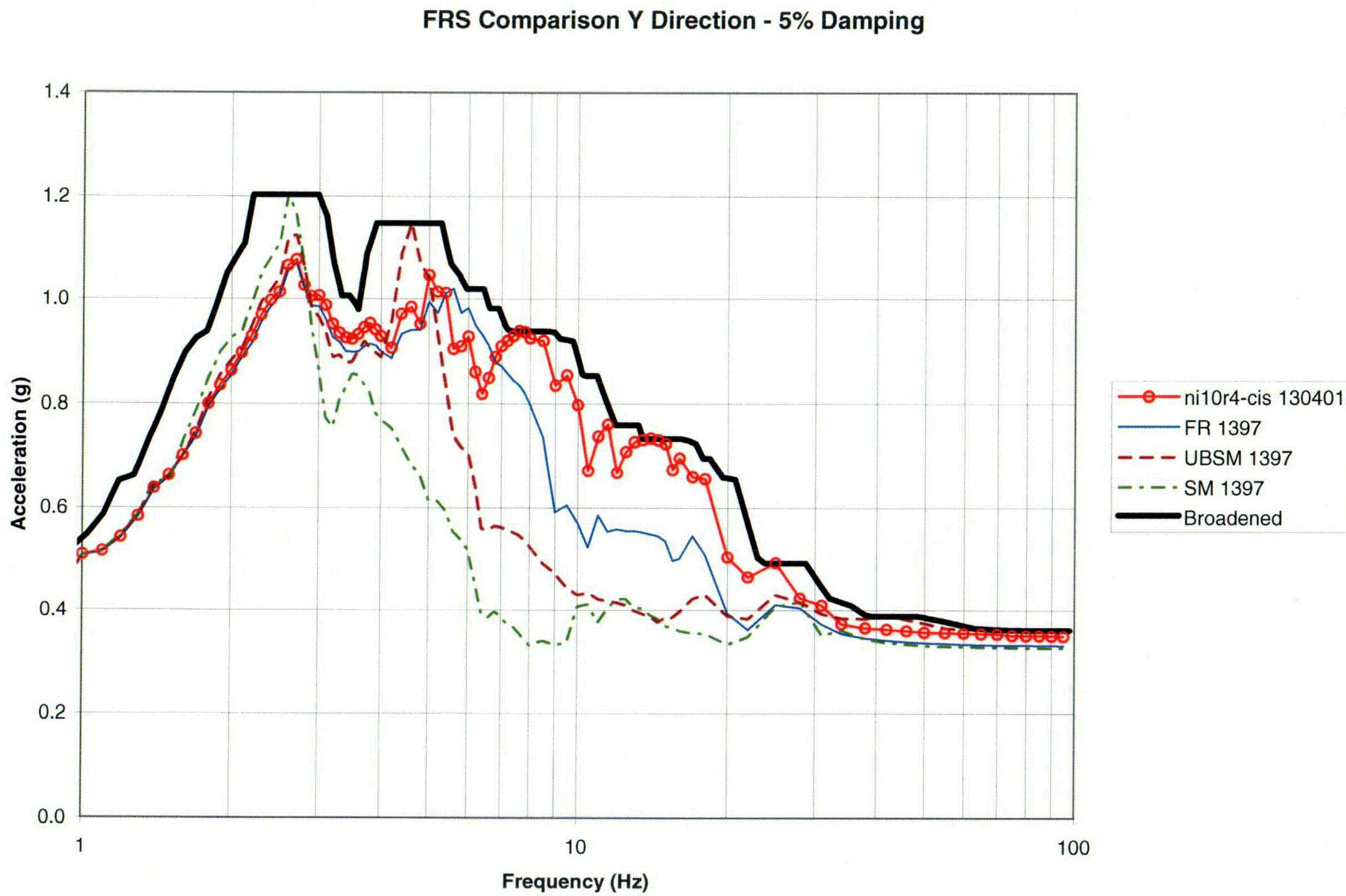


Figure 4.4.3-2 – Y Direction FRS for node 130401 (NI10) or 1397 (NI20)
CIS at Reactor Vessel Support Elevation of 100'

C36

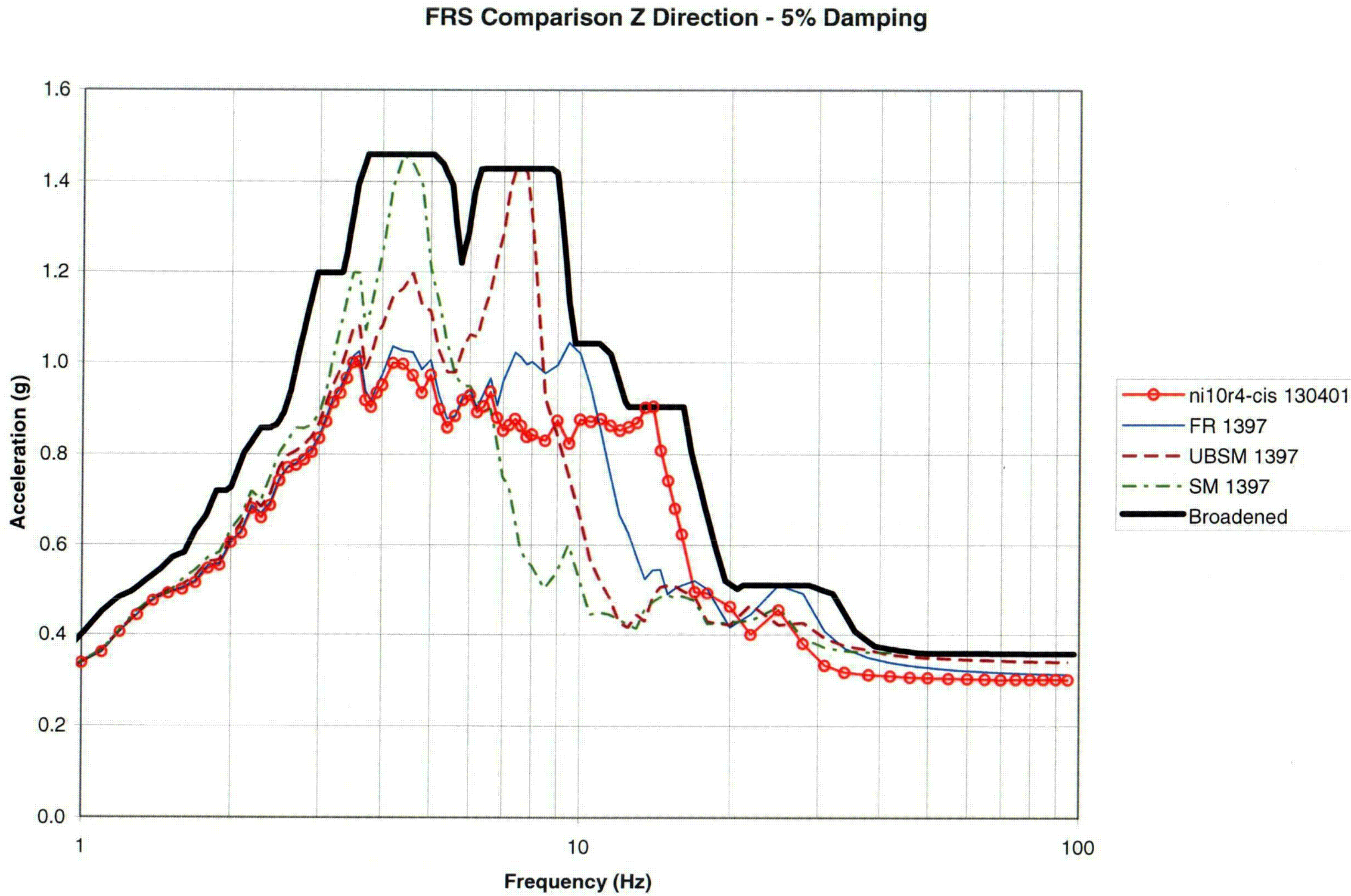


Figure 4.4.3-3 – Z Direction FRS for node 130401 (NI10) or 1397 (NI20)
CIS at Reactor Vessel Support Elevation of 100'

C37

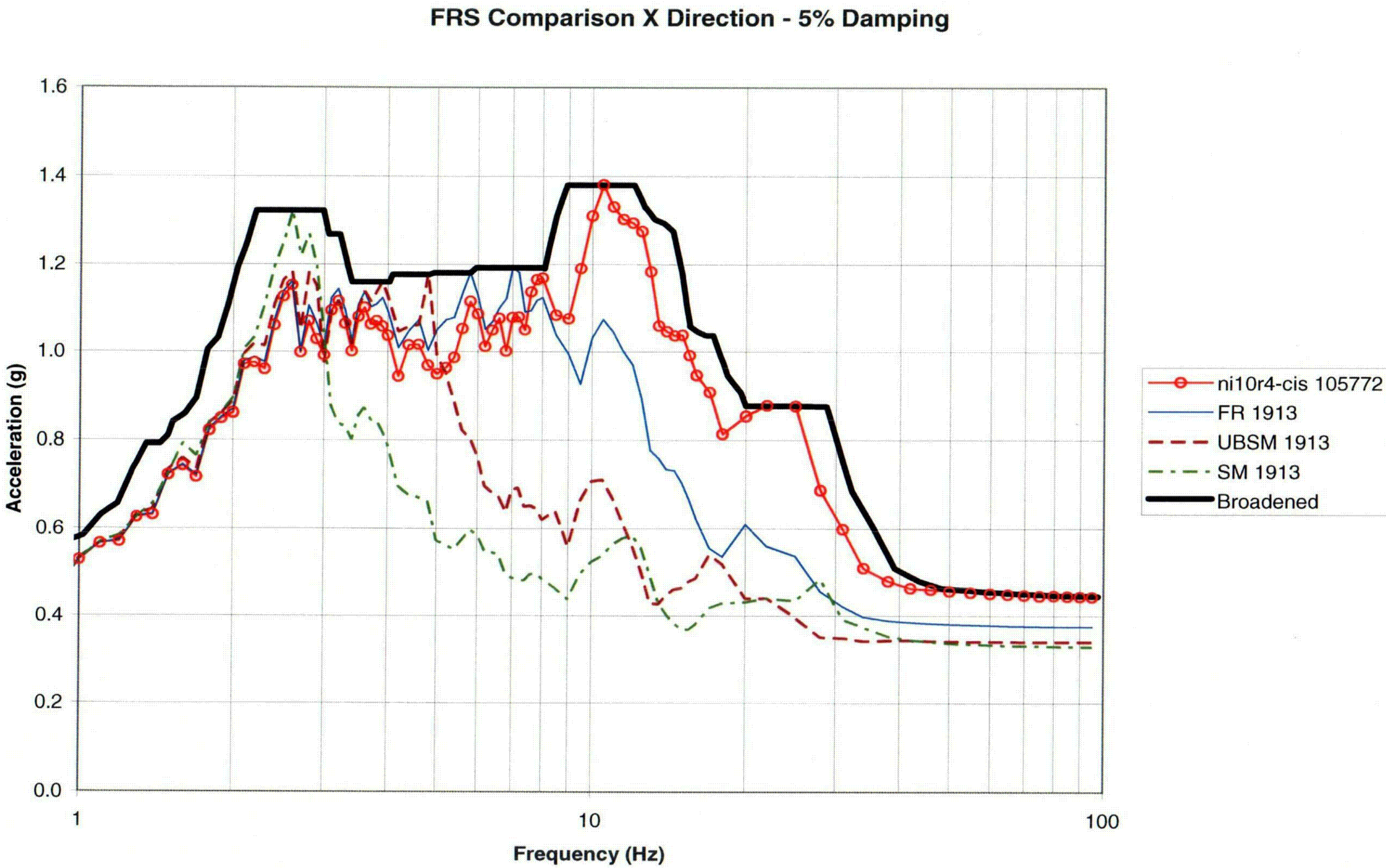


Figure 4.4.3-4 – X Direction FRS for node 105772 (NI10) or 1913 (NI20)
CIS at Operating Deck Elevation 134.25'

C38

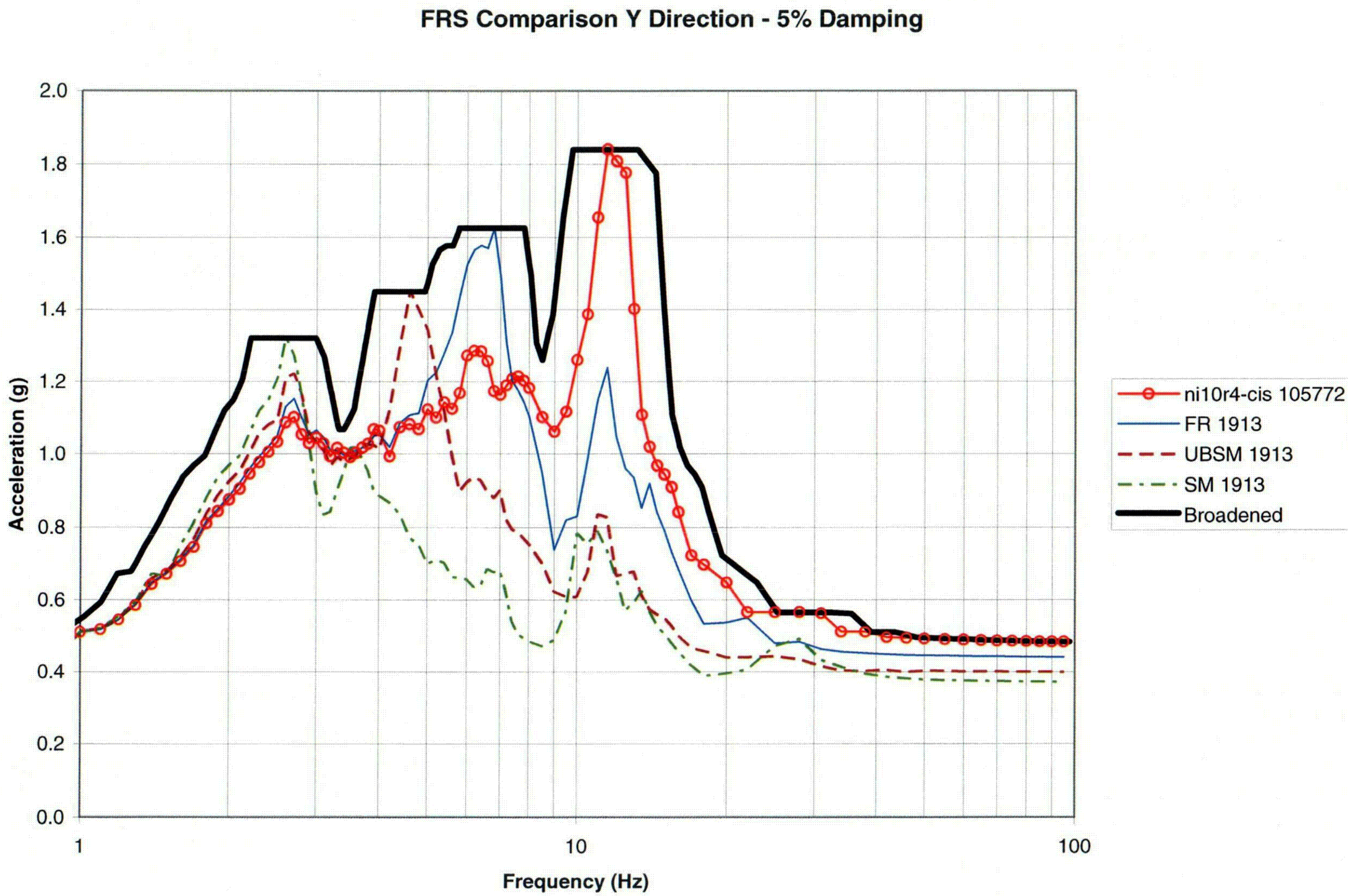


Figure 4.4.3-5 – Y Direction FRS for node 105772 (NI10) or 1913 (NI20)
CIS at Operating Deck Elevation 134.25'

C39

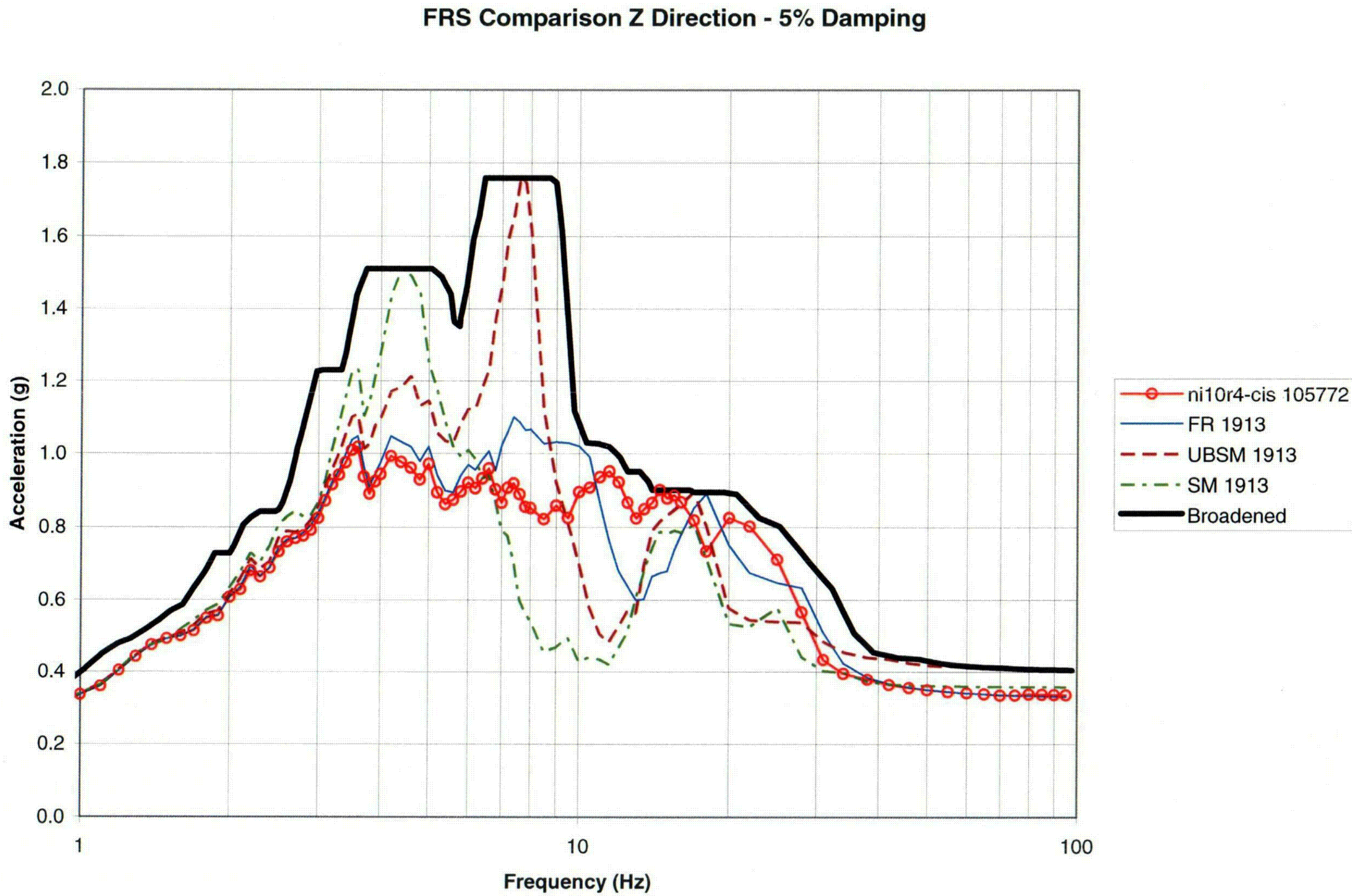


Figure 4.4.3-6 – Z Direction FRS for node 105772 (NI10) or 1913 (NI20)
CIS at Operating Deck Elevation 134.25'

C40

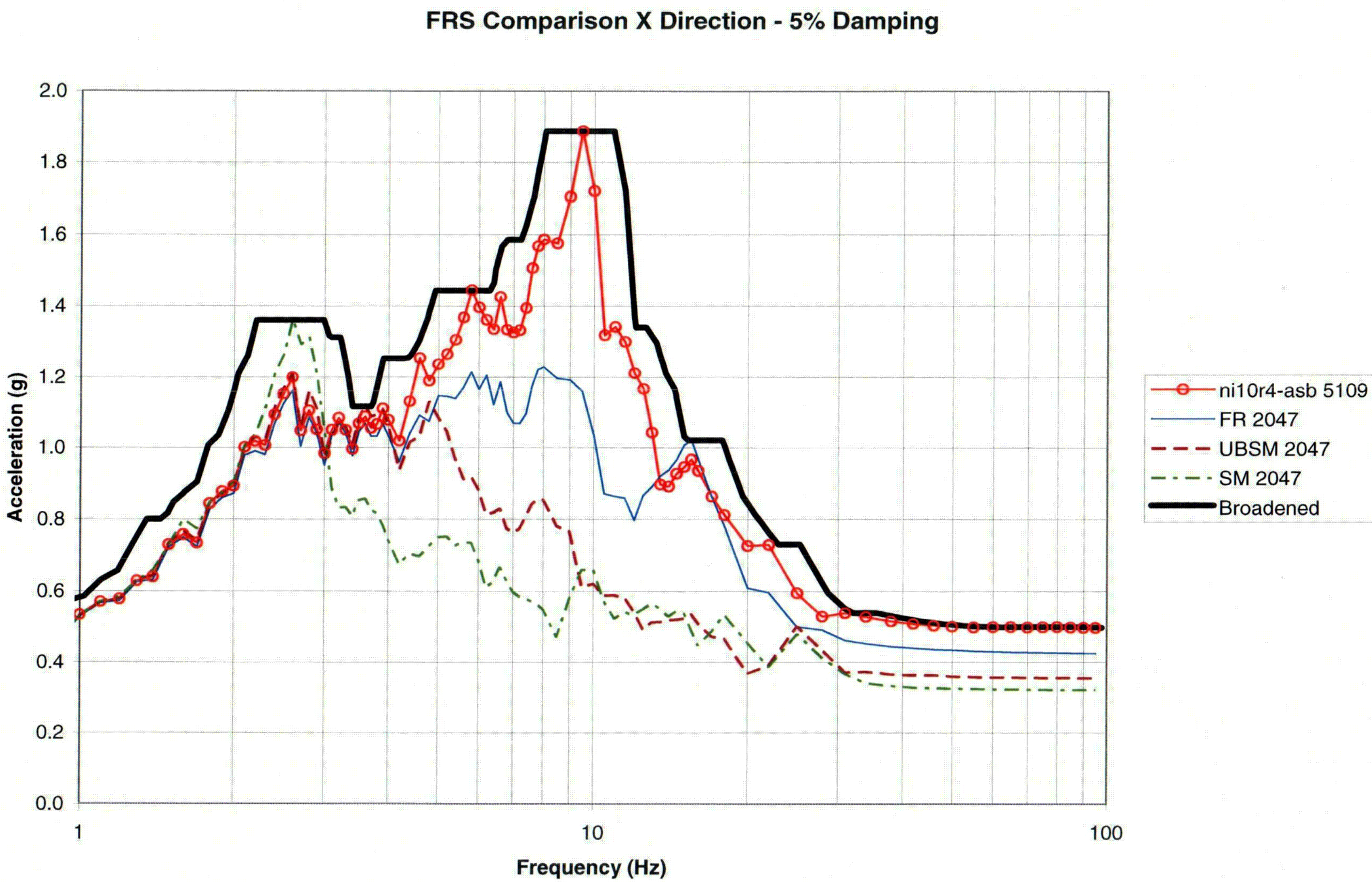


Figure 4.4.3-7 – X Direction FRS for node 5109 (NI10) or 2047 (NI20)
ASB Control Room Side Elevation 134.88'

C41

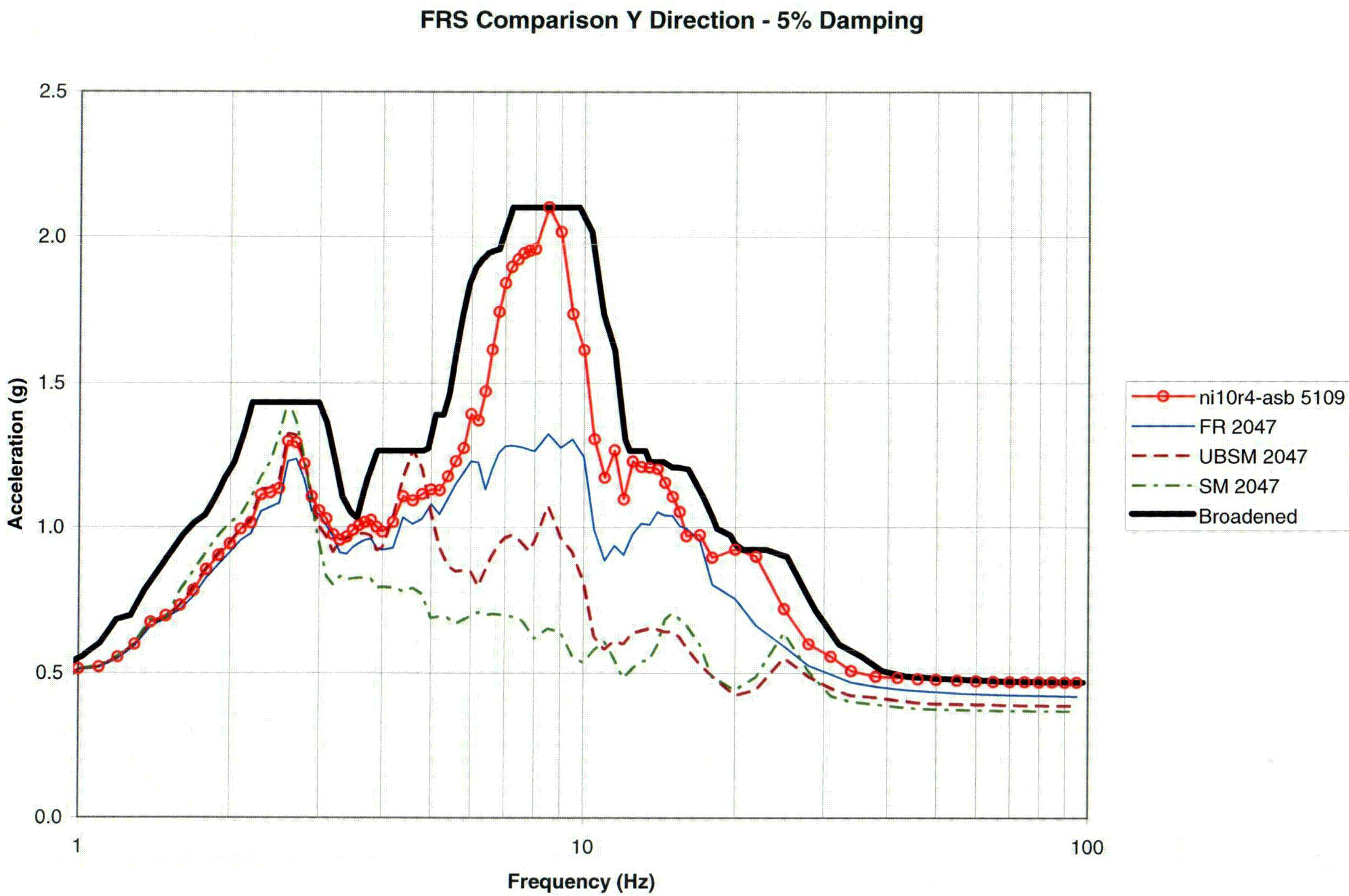


Figure 4.4.3-8 – Y Direction FRS for node 5109 (NI10) or 2047 (NI20)
ASB Control Room Side Elevation 134.88'

C42

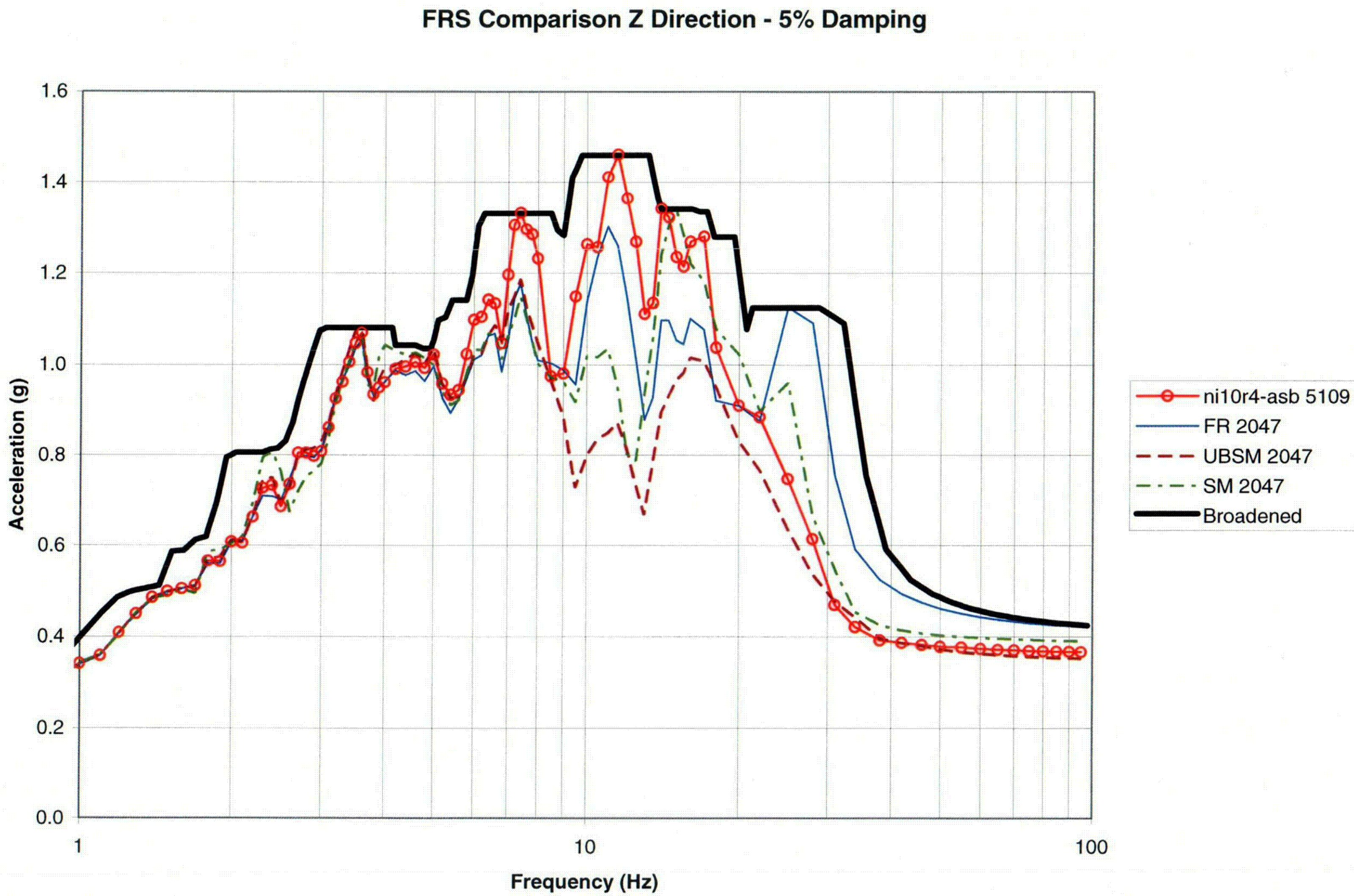


Figure 4.4.3-9 – Z Direction FRS for node 5109 (NI10) or 2047 (NI20)
ASB Control Room Side Elevation 134.88'

C43

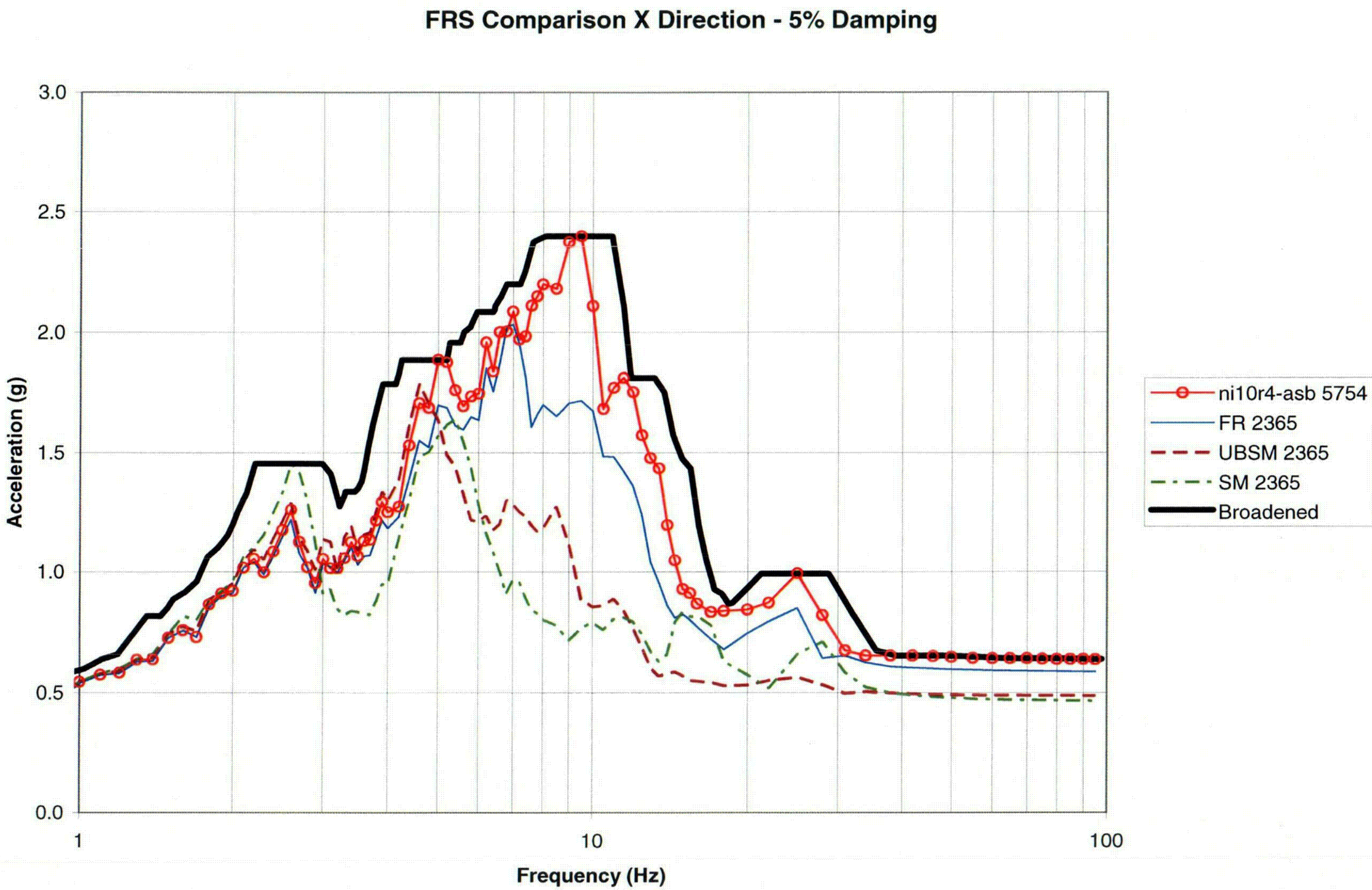


Figure 4.4.3-10 – X Direction FRS for node 5754 (NI10) or 2365 (NI20)
ASB Fuel Building Roof Elevation 179.19'

C44

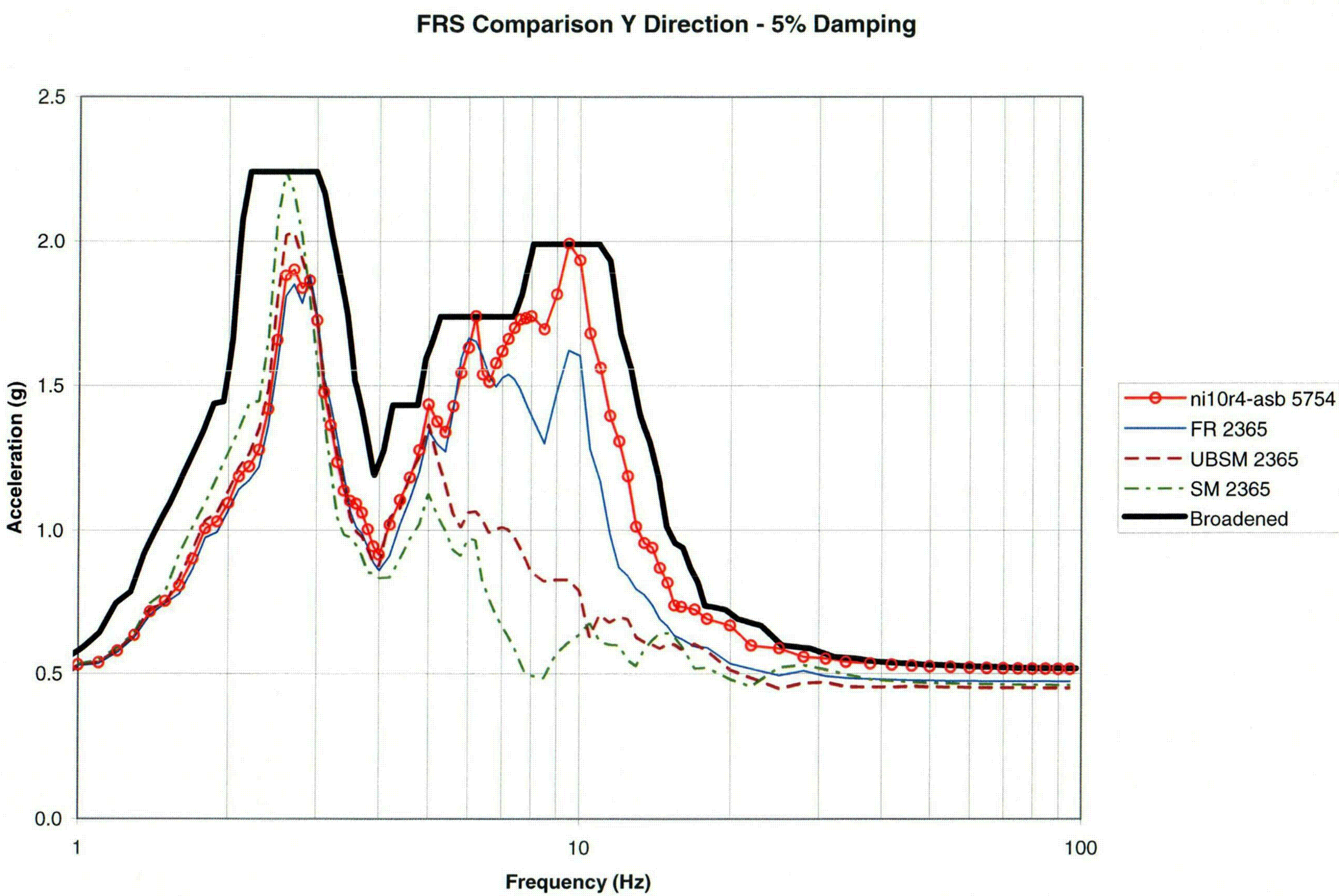


Figure 4.4.3-11 – Y Direction FRS for node 5754 (NI10) or 2365 (NI20)
ASB Fuel Building Roof Elevation 179.19'

C45

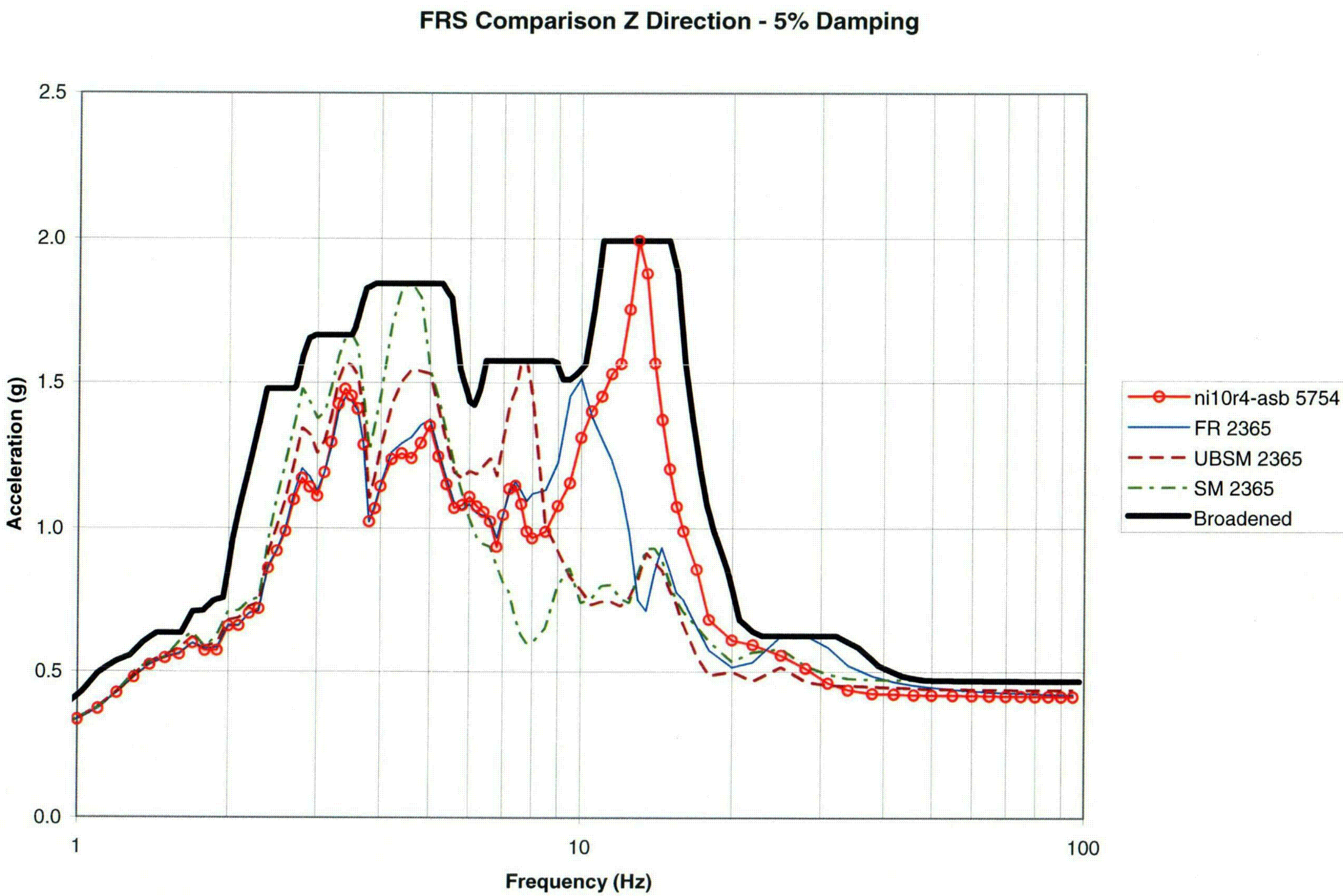


Figure 4.4.3-12 – Z Direction FRS for node 5754 (NI10) or 2365 (NI20)
ASB Fuel Building Roof Elevation 179.19'

C46

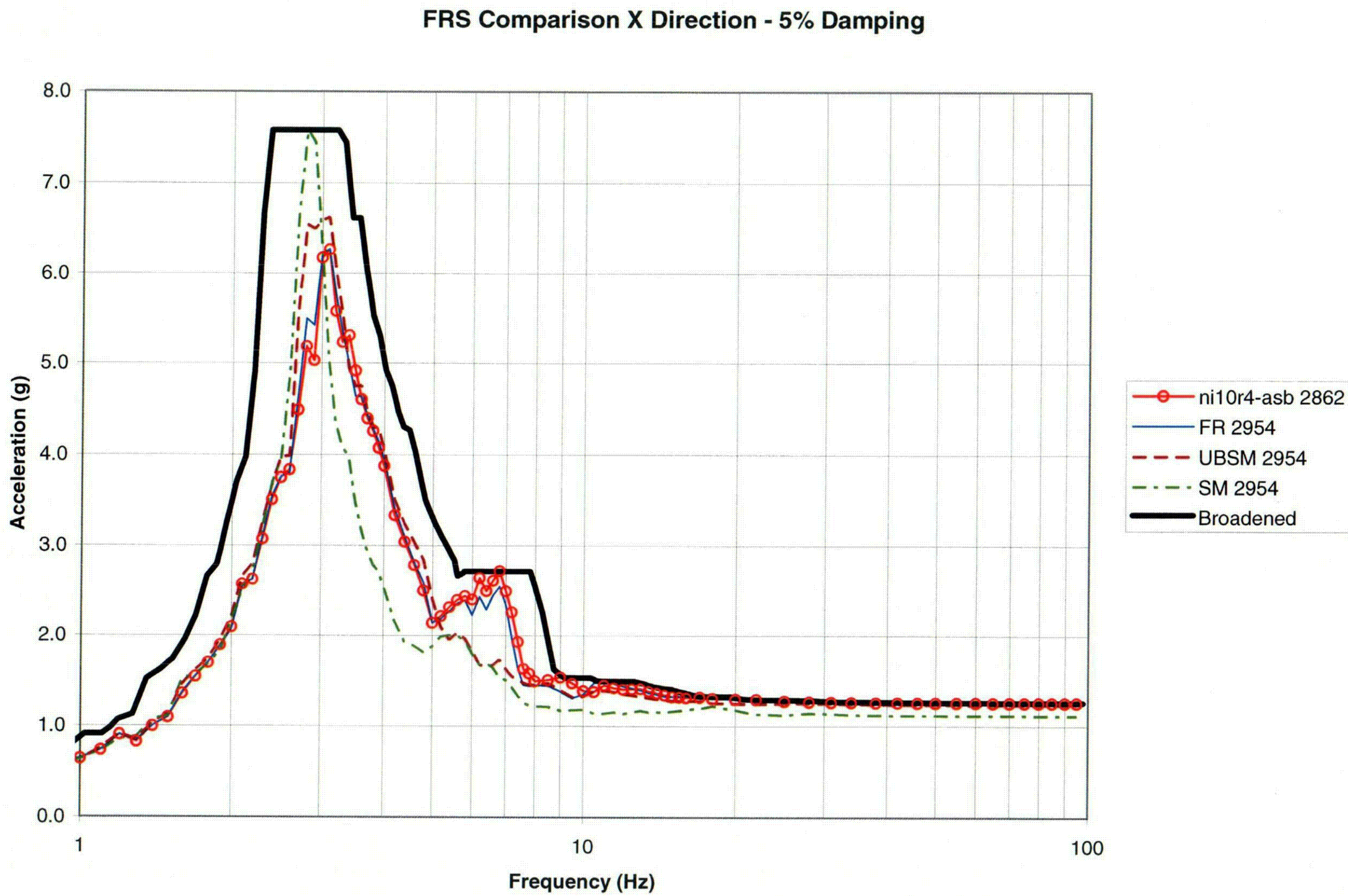


Figure 4.4.3-13 – X Direction FRS for node 2862 (NI10) or 2954 (NI20)
ASB Shield Building Roof Elevation 333.12'

C47

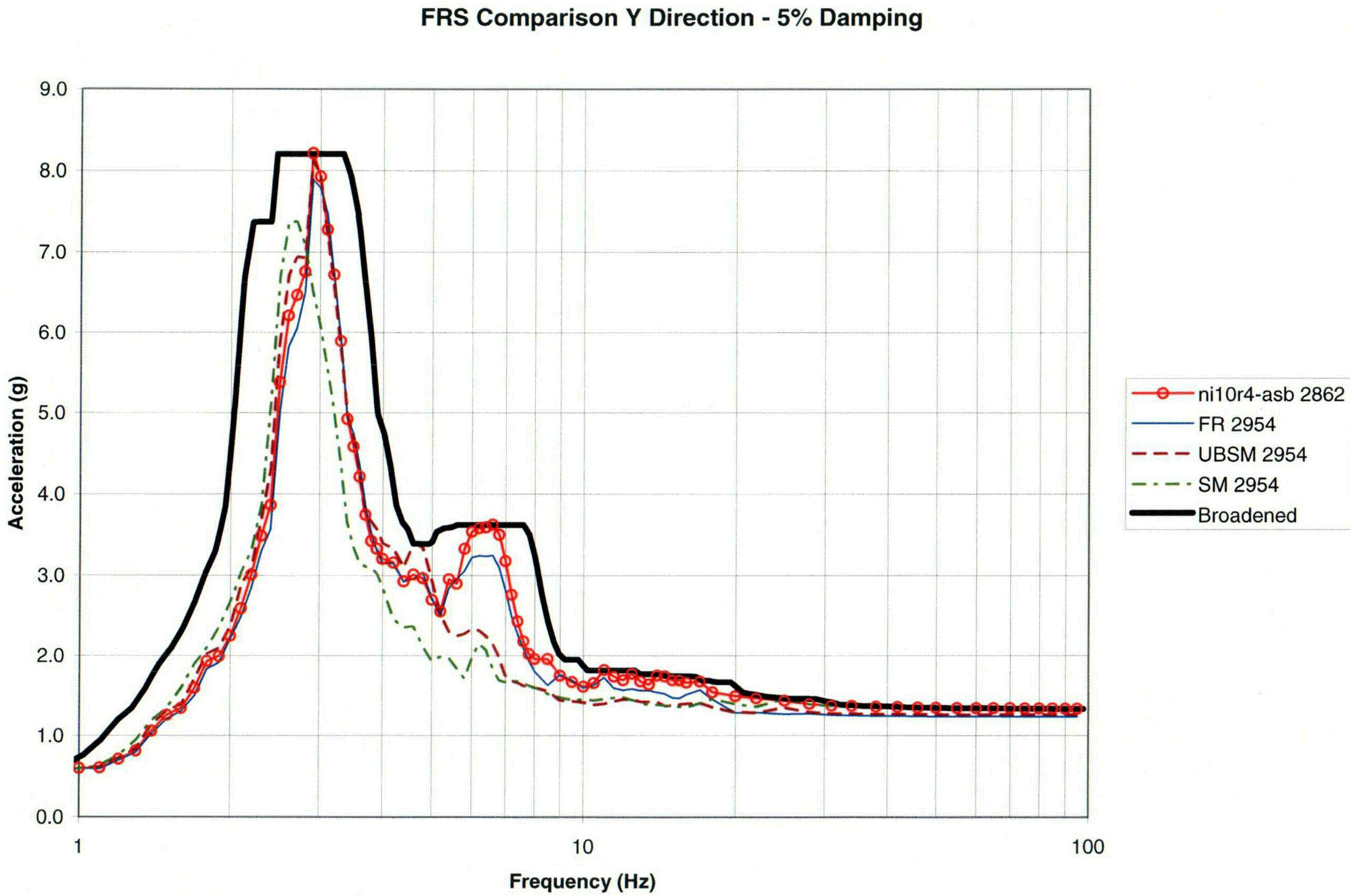


Figure 4.4.3-14 – Y Direction FRS for node 2862 (NI10) or 2954 (NI20)
ASB Shield Building Roof Elevation 333.12'

C48

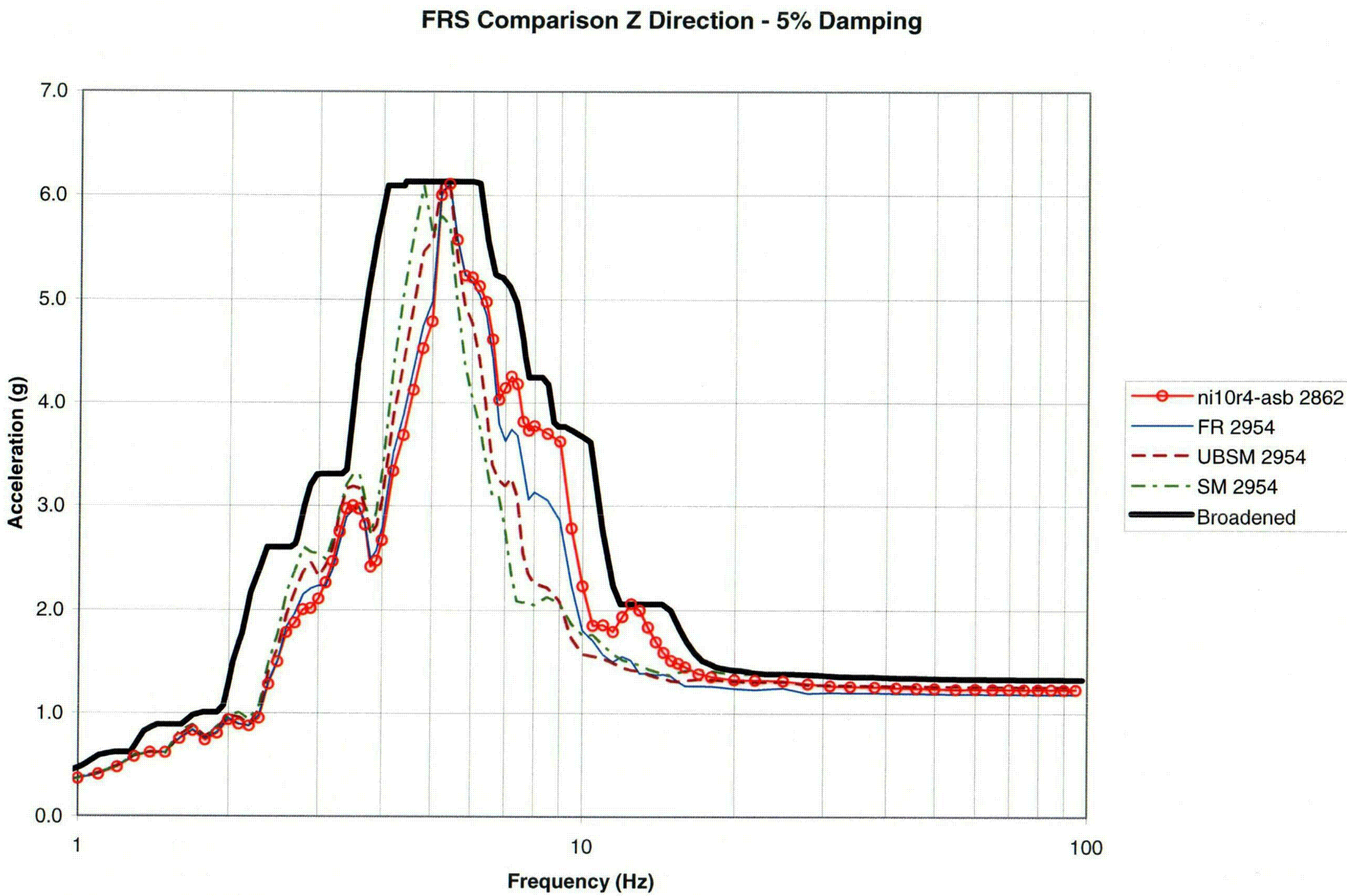


Figure 4.4.3-15 – Z Direction FRS for node 2862 (NI10) or 2954 (NI20)
ASB Shield Building Roof Elevation 333.12'

C49

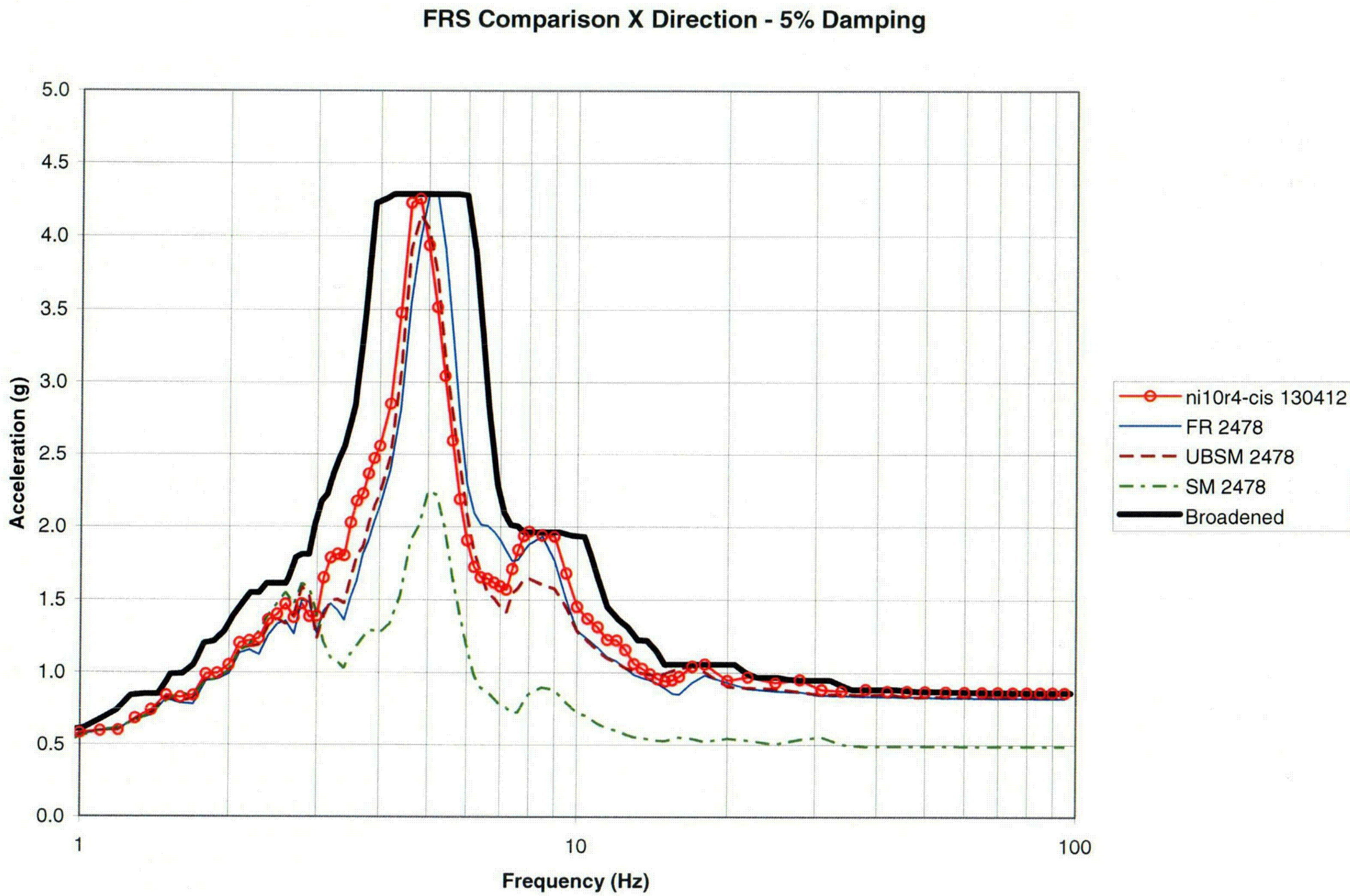


Figure 4.4.3-16 – X Direction FRS for node 130412 (NI10) or 2478 (NI20)
SCV near Polar Crane elevation 224.00'

C50

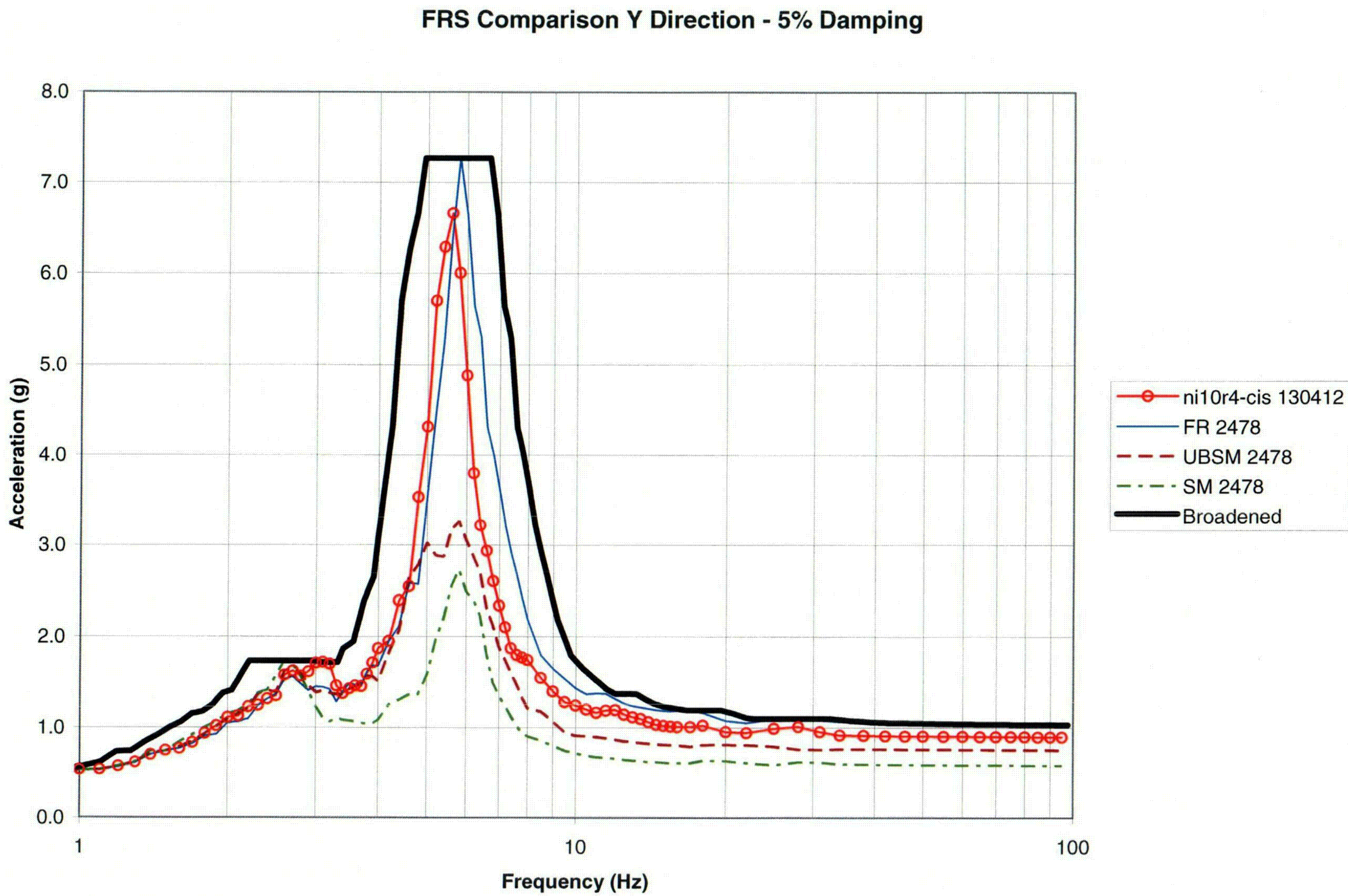


Figure 4.4.3-17 – Y Direction FRS for node 130412 (NI10) or 2478 (NI20)
SCV near Polar Crane elevation 224.00'

C51

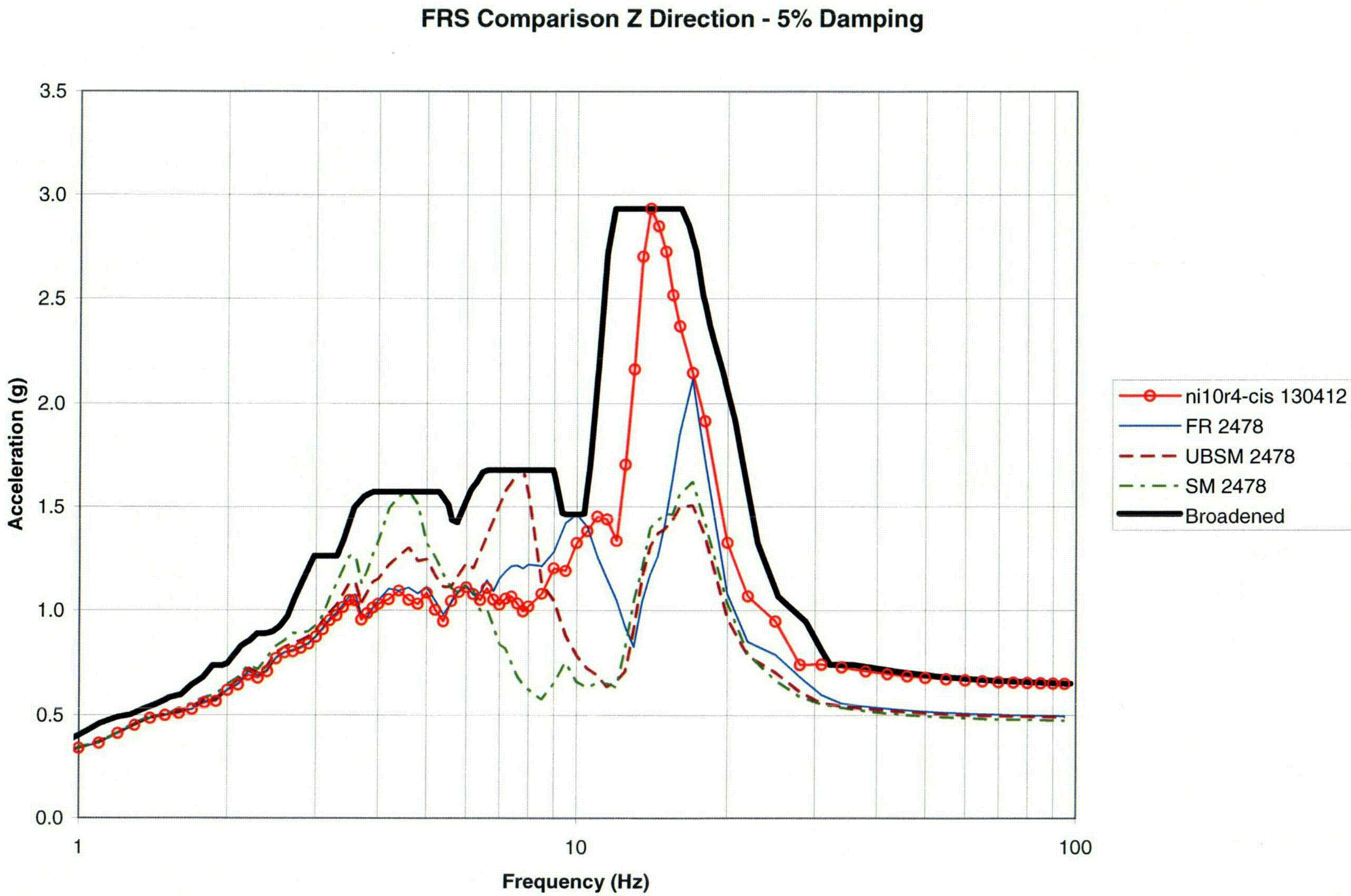


Figure 4.4.3-18 – Z Direction FRS for node 130412 (NI10) or 2478 (NI20)
SCV near Polar Crane elevation 224.00'

C52

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:

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 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 (*these spectra are shown in Figures 2.1-1 and 2.1-2 of this report*). Analyses are performed with seismic input specified at foundation level for the hard rock analyses and at the finished grade level for the soil analyses. The AP1000 design response spectra were developed using the Regulatory Guide 1.60 response spectra as the base and modified to address high frequency amplification effects observed in eastern North America earthquakes. The peak ground accelerations in the two horizontal and the vertical directions are equal.

DCD Subsection 2.5.2.1 Combined License Seismic and Tectonic Characteristics Information

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 design response spectra at the finished grade level in the free-field are less than or equal to those given in Figures 3.7.1-1 and 3.7.1-2 (*these spectra are shown in Figures 2.1-1 and 2.1-2 of this report*).

3. In lieu of (1) and (2) above, for a site where the nuclear island is founded on competent rock with shear wave velocity greater than 3500 feet per second and there are thin layers of soft material overlying the rock, the site specific peak ground acceleration and spectra may be developed at the top of the competent rock and shown at the foundation level to be less than or equal to those 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 shear wave velocity of the soil is greater than or equal to 1000 feet per second.

DCD Subsection 2.5.2.3 Sites with Geoscience Parameters Outside the Certified Design

If the site-specific spectra 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 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 given in the figures *in subsection 4.4.3* at the following six key locations:

- Containment internal structures at elevation of reactor vessel support
- Containment operating floor
- Auxiliary building on control room side
- Shield building at fuel building roof
- Shield building roof
- Steel containment vessel at polar crane support

Site-specific soil structure interaction analyses may be performed using the 2D SASSI models described in subsection 4.4.1 of this report 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 section 4.4.1.

Site-specific soil structure interaction analyses should be performed using the 3D SASSI models described in section 4.4.2 of this report for variations in site conditions that can not be adequately represented in two dimensions. Results should be compared to the results of the 3D SASSI analyses described in section 4.4.2.

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 enveloping criteria of Standard Review Plan 3.7.1 for the response spectrum for damping values of 2, 3, 4, 5, and 7 percent and the enveloping criterion for power spectral density function. 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.

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 (nodes: 5109, 5754, 2862), CIS (nodes: 130401, 105772) and SCV (node 130412). 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. 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.

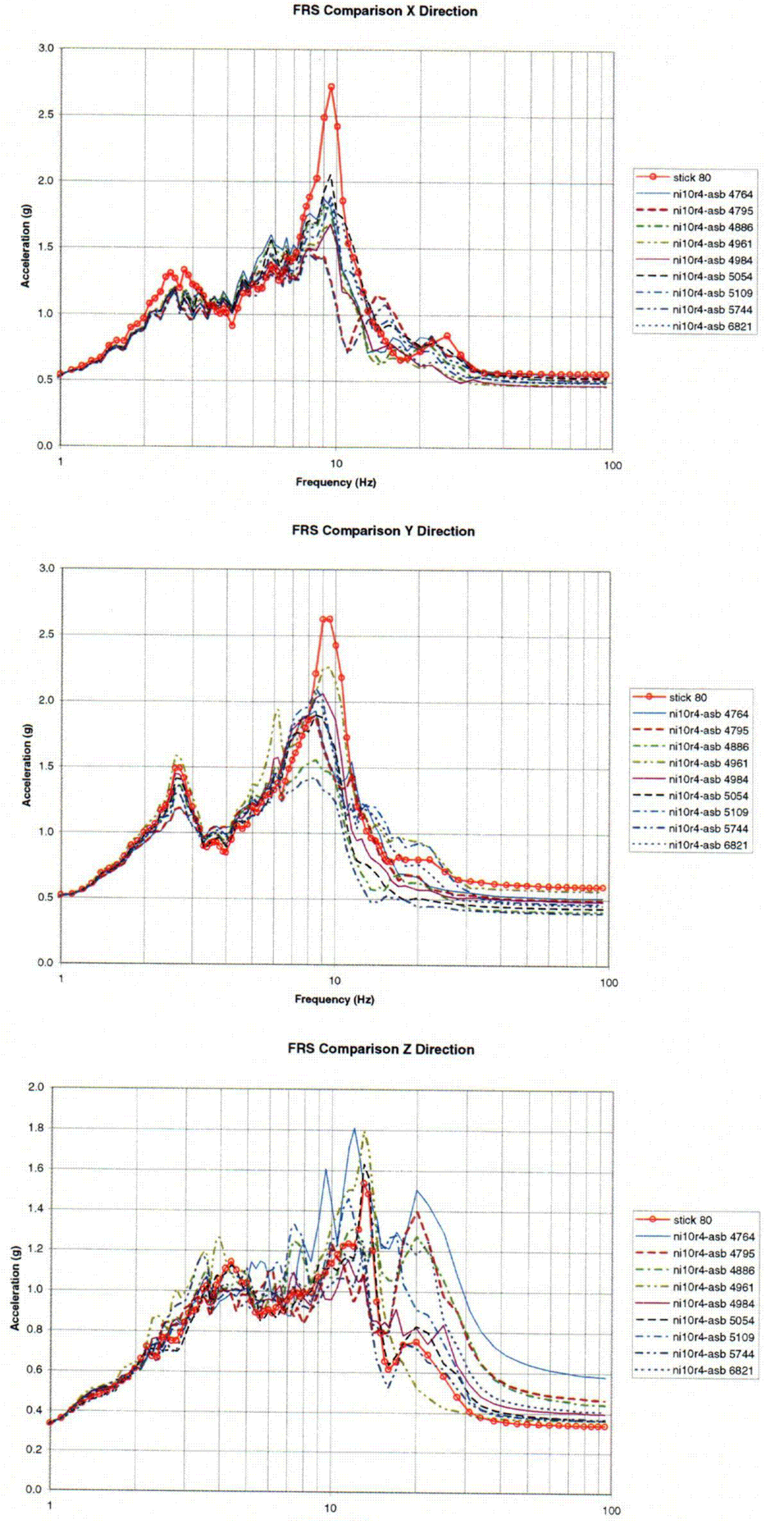


Figure 6.1-1 - Auxiliary Building at Elevation 135 feet

C53

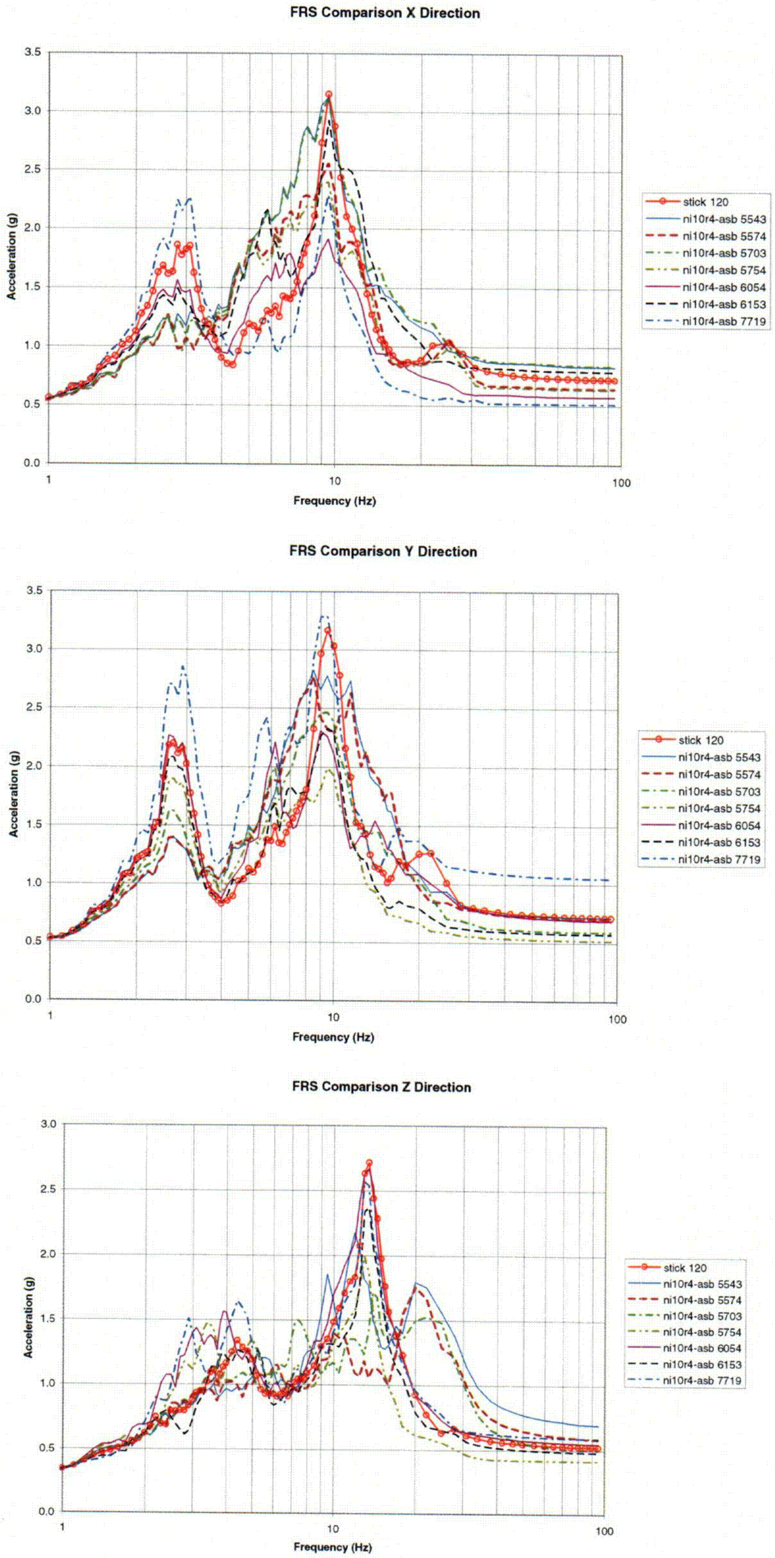


Figure 6.1-2 - Auxiliary and Shield Building at Elevation 180 feet

C54

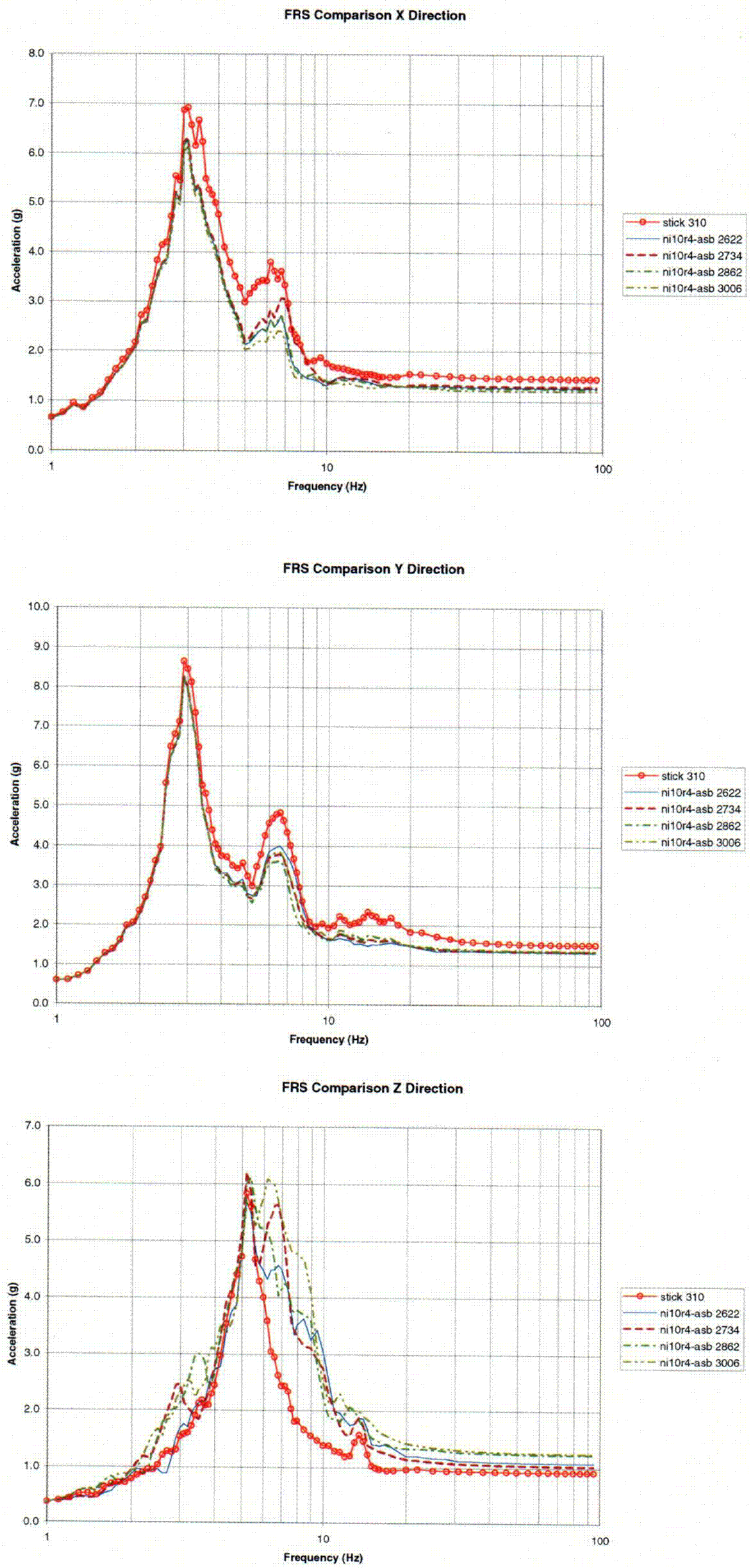


Figure 6.1-3 - Shield Building at Elevation 333 feet

C55

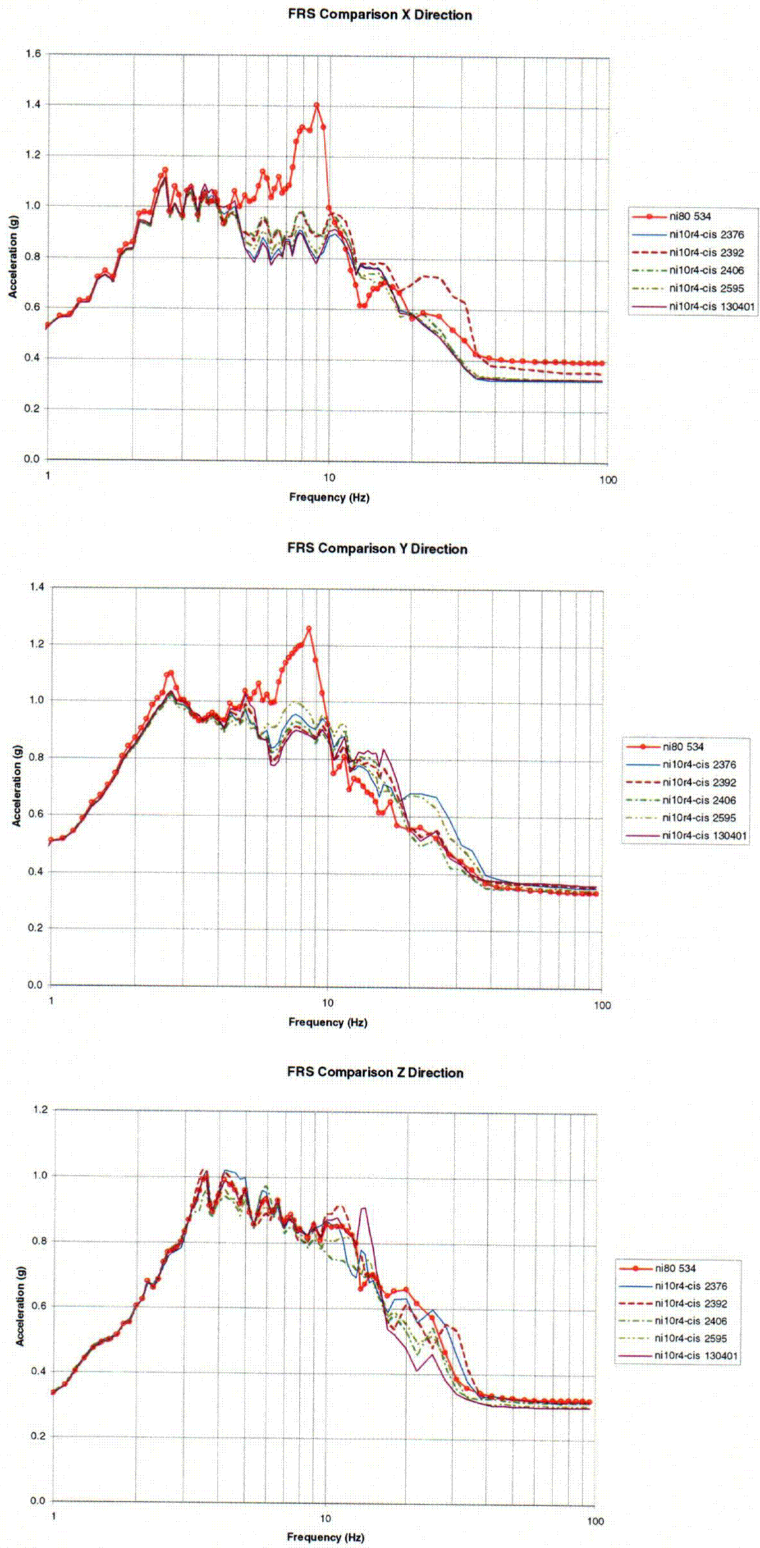


Figure 6.1-4 - CIS at Elevation 99 feet

C56

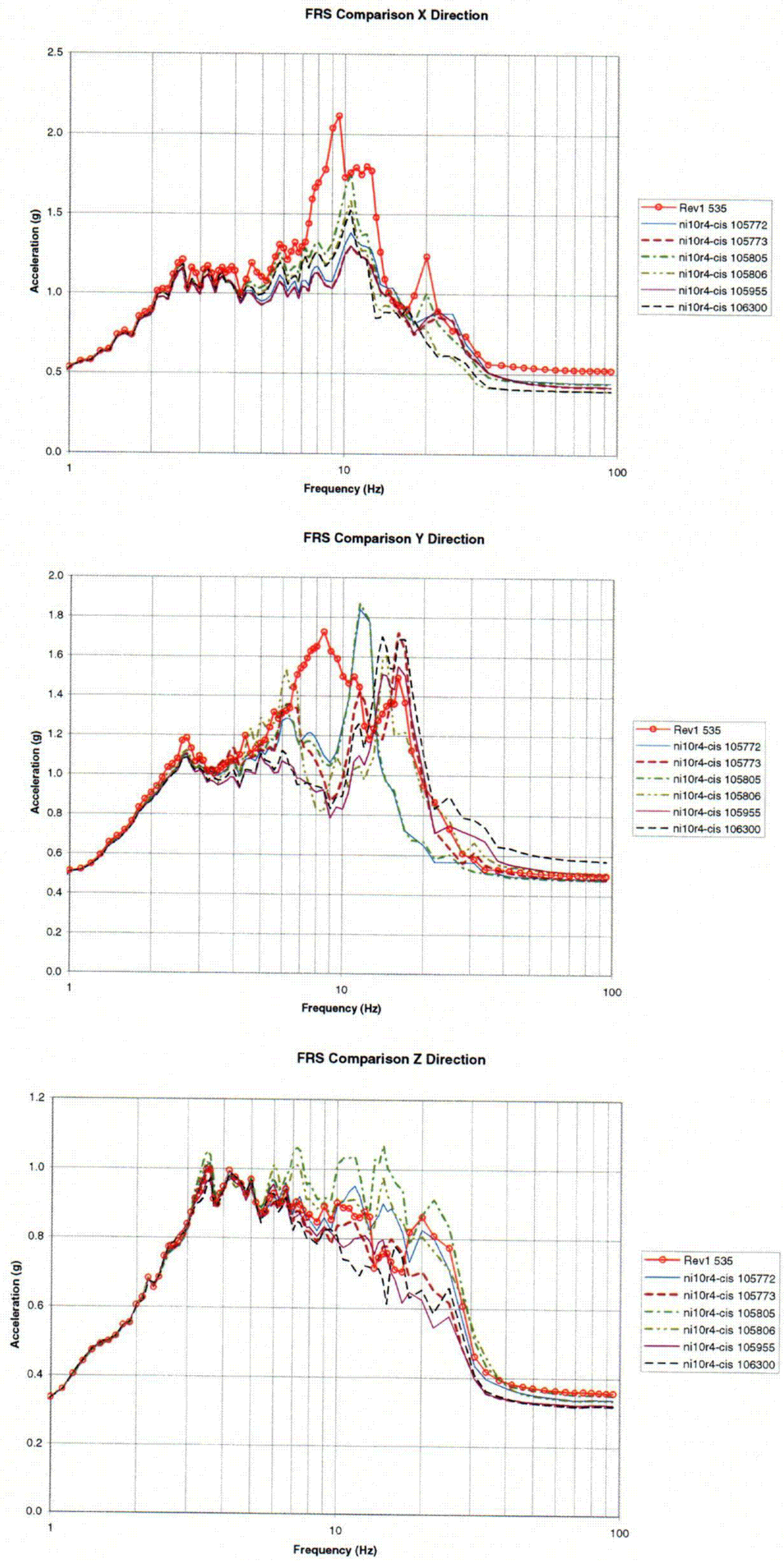


Figure 6.1-5 - CIS at Elevation 135 feet

C57

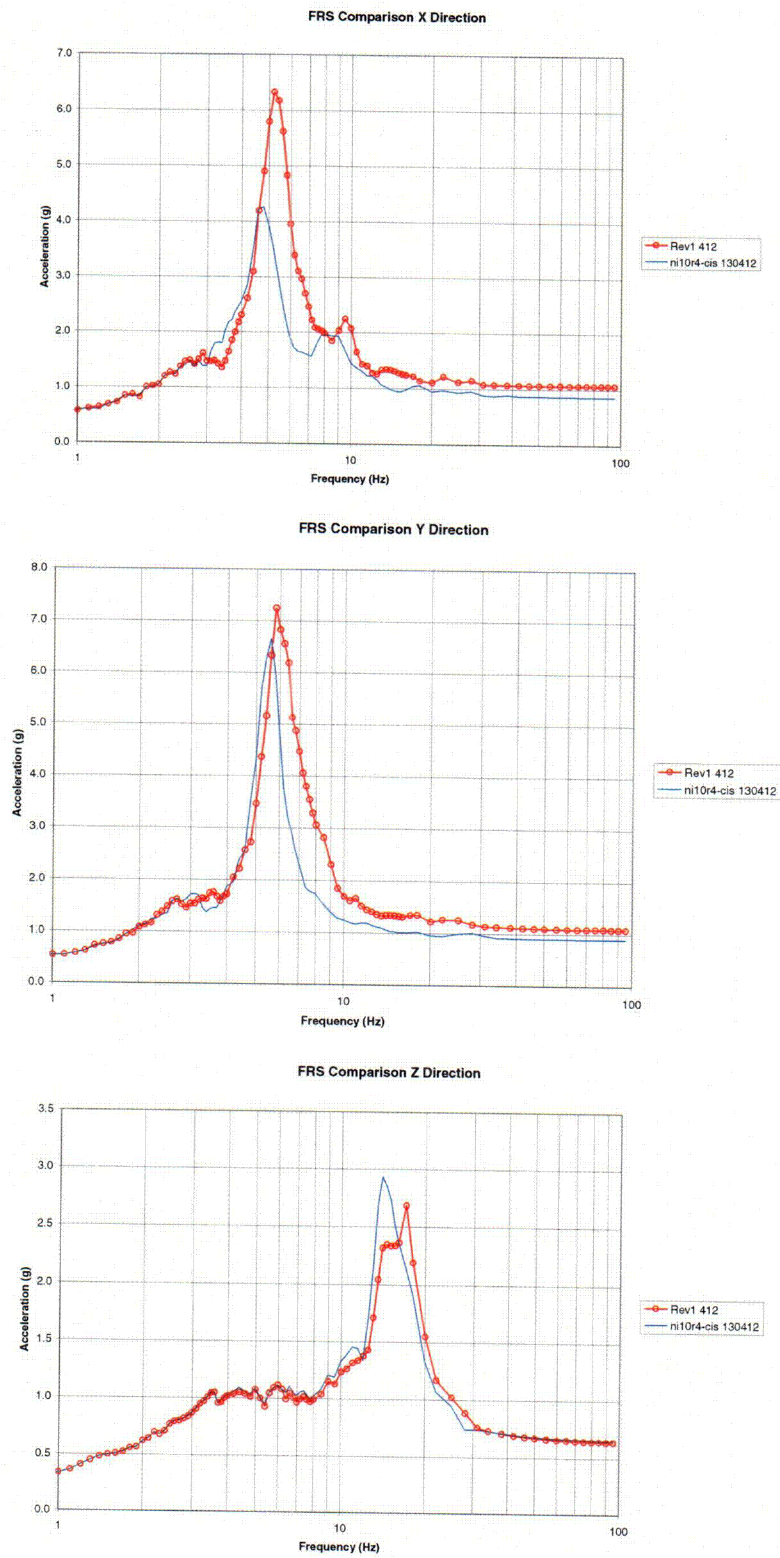


Figure 6.1-6 - SCV at Polar Crane Elevation 224 feet

C 58

6.2 Equivalent Static Accelerations

As described in subsection 2.5, equivalent static loads were applied to the detailed three dimensional finite element models to generate member forces for design. The analysis for each earthquake component was performed by applying equivalent static loads to the structural model at each finite element nodal point. The static load at each nodal mass point was the corresponding mass times the maximum absolute acceleration response at the corresponding elevation at the center of mass of the corresponding stick.

The accelerations at the center of mass of the stick models are replaced by maximum accelerations from the time history results of the shell model at representative locations at the edges of the following portions of the nuclear island:

Shield building cylinder and roof
Auxiliary building – south side
Auxiliary building – north side
Containment internal structures – east side
Containment internal structures – west side
Steel containment vessel

Results of the time history analyses are obtained at locations described in subsection 4.2.3 and 4.3, and shown in Figures 4.2.3-1 to 4.2.3-15 and 4.3-1 to 4.3-6. Results at locations without local flexibility are considered in establishing the equivalent static accelerations. These equivalent static accelerations are compared against the maximum results of the stick model given in DCD section 3.7.2 in the tables and figures in this section.

Loads are developed for application to detailed 3D finite element models that are conservative for the full range of soil sites at which the AP1000 may be located. In Section 6.3 a comparison of member forces obtained from seismic static and time history analyses is given. This comparison is made to provide additional validation of the equivalent static acceleration method.

Two sets of loads are specified. The first set is intended for use in design of the buildings. The second set is intended for seismic stability of the Nuclear Island and non-linear global analyses that consider uplift of the nuclear island from the soil. The results of these nonlinear analyses will be used for the design of the base mat.

When using the set of accelerations for design of the building the following procedure is used:

Apply equivalent static accelerations based on response at "rigid" locations of the structure to all of the building structures. These are applied in separate load vectors for each direction.

For those local flexible structures that are amplified, apply an additional acceleration to these structures equal to the difference between the average uniform amplified component accelerations and rigid body component equivalent static accelerations. These accelerations are to be considered in local design of the flexible portion of the structure but do not need to be considered in areas of the structure away from the local flexibility. They can be applied in a series of individual load vectors.

This procedure is followed to avoid applying the rigid body component accelerations twice.

For design, a 5% margin on forces and moments for accidental torsion is included. In the previous equivalent static acceleration analyses of the nuclear island a 10% increase was used since the accelerations were based on the magnitudes at the center of mass on the stick model. It is not necessary to add this additional conservatism for torsion since the equivalent static accelerations have been selected considering the maximum accelerations throughout the 3D Shell model, including edges of the building, obtained from the seismic time history analyses.

The design and overturning accelerations are applied uniformly for the region that they apply. Linear interpolation is used to define seismic accelerations between elevations.

The shell model results are compared to the hard rock stick model results that are documented in Section 3.7 of the DCD in Appendix E.

Application of Equivalent Static Seismic Accelerations

Equivalent static accelerations are a set of accelerations applied to the masses in a finite element model such that static analyses give member forces similar to the maximum member forces in a dynamic analysis. In many cases, the equivalent static accelerations are taken equal to the maximum values resulting from the dynamic analysis. This normally gives conservative results for the member forces.

Equivalent static accelerations are applied in static analyses of the detailed NI05 models to obtain design member forces. Two sets of loads and analyses are considered:

Building structural design

Linear fixed base analyses to provide member forces for design of all structures except the nuclear island basemat. These accelerations must address both global and local responses, and accidental torsion of the nuclear island. The resulting member forces must envelope all soil conditions.

Nuclear island Basemat

Non-linear analyses are preformed to address lift off of the basemat from the soil. These analyses are used for design of the nuclear island basemat. They are also used to check the walls that act as buttresses to transfer loads from the shield building into the portion of basemat in contact with the soil.

Shield Building

The maximum seismic acceleration values obtained from the seismic time history analyses of the different soil cases and hard rock case are used to define the equivalent static seismic accelerations for the Shield building. Table 6.2-1 shows the values for the South, East, North, and West sides of the shield building. The seismic accelerations are averaged to obtain the representative acceleration associated with a specific elevation on the shield building. It is recognized that the nodes in the radial direction of excitation are influenced by local mode effects. Consequently, the nodes that are tangent to the direction of excitation are used to define the equivalent static seismic accelerations for this seismic component. The average value of the

North and South Sides of the shield building is used for an East-West Earthquake and the average value of the East and West sides of the shield building for a North-South Earthquake. The vertical acceleration is the average of the four nodes defined by the nodes on the North, South, East, and West sides of the shield building. The vertical equivalent static seismic accelerations at elevations 294.93' and 333.13' are obtained directly from the maximum time history results by taking the average of locations at opposite ends of a diameter. The vertical accelerations from the 3D finite element model at the shield building edges at these elevations are significantly influenced by the horizontal loading. If they are used for the vertical equivalent accelerations, the horizontal response would be double counted in the vertical direction.

The average values of Table 6.2-1 are repeated in Table 6.2-3 that is applicable for the ASB. The table is similar to Table 3.7.2-5 in the AP1000 Design Control Document, Section 3.7, since the results for the shield building can be compared to those at the mass center of the stick model and those of the auxiliary building are comparable to those at the edge of the stick model.

Table 6.2-1 – Shield Building Seismic Acceleration Distribution

Units: g

Maximum Value from Each Individual Soil Case

Elevation feet	Shield Building South Side			Shield Building East Side			Shield Building North Side			Shield Building West Side			Average Values		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
99	0.362	0.367	0.376	0.352	0.360	0.388	0.376	0.365	0.349	0.345	0.370	0.343	0.35	0.37	0.36
134.88	0.515	0.416	0.397	0.489	0.584	0.447	0.551	0.452	0.424	0.452	0.725	0.470	0.47	0.43	0.41
179.19	0.650	0.533	0.468	0.587	0.647	0.559	0.802	0.591	0.463	0.536	1.045	0.582	0.55	0.56	0.51
222.75	0.802	0.731	0.565	0.659	0.912	0.676	0.745	0.718	0.616	0.724	0.990	0.704	0.69	0.72	0.64
265	0.802	0.847	0.649	0.777	1.032	0.693	0.911	0.868	0.704	0.855	1.062	0.747	0.79	0.85	0.69
294.93	1.069	1.028	1.309	0.934	1.194	1.223	0.918	1.119	1.081	1.029	1.007	1.045	0.98	1.07	0.901 (1)
333.13	1.258	1.334	1.329	1.210	1.364	1.253	1.268	1.393	1.102	1.294	1.363	1.061	1.25	1.36	0.948 (1)

Notes to Table 6.2-1:

(1) These values have been obtained by averaging the time history response at each end of the shield building diameter to provide the response on the center line at the axis of the shield building. This avoids double counting the horizontal seismic component. The Z component (vertical) values given for the South, East, North, and West side have the effect of the horizontal component.

Auxiliary Building

The maximum accelerations throughout the ASB (auxiliary shield building) are obtained from the seismic time history analyses for the hard rock and soil cases. They are evaluated separately for the South Side and North Side of the building. For each side accelerations at the corners are enveloped and the maximum value is specified for design. Since the south and north sides are found to have comparable accelerations the values for the two sides of the building are then enveloped to specify a single design value for all of the auxiliary building. Table 6.2-2 shows the values for each side of the building and the enveloped values used in the finite element analysis to determine member forces for building design. The response of the auxiliary building in the vertical direction is influenced by horizontal input and by the height of the Auxiliary Building. Therefore, the vertical seismic acceleration values used for design are taken as the average of the accelerations of the shield building cylinder shown in Table 6.2-1.

The static seismic accelerations in Tables 6.2-3 are applied to all of the ASB structures. An additional uniform acceleration is applied for flexible walls and floors over local portions of the building structure. This acceleration is determined from the maximum response of a node representing this flexible location in the time history analyses. The peak magnitude is adjusted based on the deflection of the flexible location (e.g. cantilever beam, pin end supported beam), and applied uniformly to the flexible member so that the resulting member forces are consistent with the flexible response. The combined results from the "rigid" acceleration (Table 6.2-3) in a given direction, and the additional seismic acceleration in the same direction due to flexibility are combined absolutely to define the member forces for the building design of the flexible structures.

Table 6.2-2 – Auxiliary Building Equivalent Static Seismic Acceleration Summary

Maximum Value from Each Individual Soil Case at Corners of Area

Elevation feet	South Side			North Side			Equivalent Static Seismic Accelerations		
	X	Y	Z	X	Y	Z	X	Y	Z[1]
66.5 [2]							0.32	0.37	0.36
81.5 [2]							0.36	0.37	0.36
99	0.42	0.40	0.41	0.38	0.40	0.39	0.42	0.40	0.36
116.5				0.43	0.43	0.40	0.43	0.43	0.37
134.88	0.58	0.52	0.53	0.55	0.58	0.45	0.58	0.58	0.41
152.19									
152.96									
154.69				0.71	0.58	0.46	0.71	0.58	0.44
159.69									
160.56									
162.19	0.66	0.58	0.47	0.66	0.69	0.48	0.71[3]	0.69	0.46
179.19	0.86	0.73	0.64				0.86	0.73	0.51

Notes to Table 6.2-2:

(1) The values in the vertical direction are the average values at the edge of the shield building see Table 6.2-1. Linear interpolation is used for intermediate elevations.

(2) Value is linear interpolated for hard and firm rock using 0.3g at 66.5' elevation, or represents the value at 99' for upper bound soft to medium or soft to medium soil sites.

(3) Value increased to equal value at elevation 154.69'.

Table 6.2-3 - ASB Design Accelerations

Units: g

Elevation Feet	North South		East West		Vertical
	Shield Building	Auxiliary Building	Shield Building	Auxiliary Building	Shield and Auxiliary Building
333.13	1.25		1.36		0.95
294.93	0.98		1.07		0.90
265	0.79		0.85		0.69
242.5	0.74		0.78		0.66
222.75	0.69		0.72		0.64
200	0.62		0.64		0.57
180	0.55	0.86	0.56	0.73	0.51
162	0.52	0.71	0.51	0.69	0.46
153.98	0.51	0.71	0.49	0.58	0.44
134.88	0.47	0.58	0.43	0.58	0.41
116.5	0.41	0.43	0.38	0.43	0.37
99	0.35	0.42	0.37	0.40	0.36
81.5	0.32	0.36	0.37	0.37	0.36
66.5	0.32	0.32	0.37	0.37	0.36

Steel Containment Vessel & Polar Crane

The steel containment vessel and polar crane are represented in the time history analyses by the same stick models as were used in the nuclear island stick models described in the DCD. The equivalent static seismic acceleration values are given in Table 6.2-4 for the steel containment vessel (SCV). They are based on the maximum values obtained from the time history analyses of the hard rock and different soil cases. The maximum seismic accelerations at the center of the polar crane are given in Table 6.2-5.

Table 6.2-4 –Recommended SCV Equivalent Static Accelerations Values

Units: g

Elevation feet	Equivalent Static Seismic Accelerations (1)		
	X	Y	Z
99	0.33	0.36	0.36
131.68	0.41	0.48	0.44
169.93	0.56	0.65	0.55
224	0.87	1.03	0.66
244.21	0.98	1.15	0.70
255.02	1.04	1.22	0.75
265.83	1.10	1.28	0.86
273.83	1.14	1.33	1.03
281.9	1.18	1.37	1.21

Notes to Table 6.2-4:

(1) Linear interpolation can be used between elevations.

Table 6.2-5 – Polar Crane Equivalent Static Accelerations Values

Units: g

	Coordinates			Equivalent Static Seismic Accelerations		
	X	Y	Z	X	Y	Z
Girder	1000.00	1000.00	236.50	2.14	2.31	1.89

Containment Internal Structure

Maximum seismic accelerations from the time history analyses are used to define the equivalent static seismic accelerations. Nodes are grouped according to different general areas within the containment internal structure (CIS): base & center; steam generator compartments (East & West); edges & sides; pressurizer compartment. The accelerations associated with the nodes within these groups are then averaged to obtain the equivalent static seismic acceleration values, and are given in Table 6.2-6 for the CIS.

Table 6.2-6 – CIS Equivalent Static Seismic Accelerations

Units: g [1]

Elevation [2]	East Side			West Side		
	X	Y	Z	X	Y	Z
66.5	0.33	0.36	0.36	0.33	0.36	0.36
82.5	0.33	0.36	0.36	0.33	0.36	0.36
99	0.35	0.36	0.36	0.35	0.36	0.36
103	0.38	0.39	0.37	0.38	0.39	0.37
107.17	0.40	0.41	0.37	0.41	0.41	0.37
134.25	0.58	0.56	0.42	0.59	0.56	0.40
153	0.71	0.59	0.41	0.74	0.66	0.41
164.95				0.85	0.83	0.41

Notes to Table 6.2-6:

(1) X = North-South; Y = East-West; Z = Vertical
(2) Linear interpolation between elevations is acceptable.

Seismic Accelerations for Evaluation of Building Overturning

In the evaluation of the basemat and overturning stability of the Nuclear Island, the equivalent static seismic accelerations are different than those used to design the individual walls and floors of the building structures. The global seismic response of the building structures that causes the basemat to uplift must be considered. The dynamic response of the structure affecting overturning and basemat lift off is primarily the first mode response at about 3 hertz on hard rock. This reduces to about 2.4 hertz on soil sites as shown in the 2D ANSYS and SASSI analyses. The accelerations of the shield building are also applied to the auxiliary building which is integral with the shield building. The higher auxiliary building accelerations of Table 6.2-2 are not considered in overturning since they are from higher frequency modes greater than 2.4 hertz. Amplified response of individual walls in the Auxiliary Building and the IRWST need not be considered since they are local responses that do not effect overturning. Torsional building response is not considered since it will not contribute to overturning and uplift since loads on the building will be increased on one side and reduced on the other.

It is also noted that loads from the Reactor Coolant Loop and Pressurizer are not considered in the overturning analysis since they are not significant to overturning. Their mass is small compared to the rest of the nuclear island.

Table 6.2-7 gives the equivalent static seismic accelerations to be used for the overturning analyses.

Table 6.2-7 – Equivalent Seismic Static Accelerations for Overturning Evaluation

	Elevation feet	Equivalent Static Seismic Accelerations (1) X	Y	Z	Notes
ASB	66.5	0.32	0.37	0.36	Table 6.2-4 Shield Bldg
	81.5	0.32	0.37	0.36	
	99	0.35	0.37	0.36	
	116.5	0.41	0.40	0.38	
	134.88	0.47	0.43	0.41	
	179.19	0.55	0.56	0.51	
	222.75	0.69	0.72	0.64	
	265	0.79	0.85	0.69	
	294.93	0.98	1.07	0.90	
	333.13	1.25	1.36	0.95	
SCV	99.00	0.33	0.36	0.36	Table 6.2-5
	131.68	0.41	0.48	0.44	
	169.93	0.56	0.65	0.55	
	224.00	0.87	1.03	0.66	
	244.21	0.98	1.15	0.70	
	255.02	1.04	1.22	0.75	
	265.83	1.10	1.28	0.86	
	273.83	1.14	1.33	1.03	
	281.90	1.18	1.37	1.21	
Polar Crane	236.5	2.14	2.31	1.89	Table 6.2-6
CIS	66.5	0.33	0.36	0.36	Table 6.2-7 Average of East and West Sides
	82.5	0.33	0.36	0.36	
	99	0.35	0.36	0.36	
	103	0.36	0.37	0.36	
	107.17	0.37	0.38	0.37	
	134.25	0.58	0.56	0.39	
	153	0.73	0.62	0.39	
	164.95	0.85	0.83	0.41	

Notes to Table 6.2-7:

(1) X = North-South; Y = East-West; Z = Vertical
(2) Linear interpolation between elevations is acceptable.

6.3 Maximum Seismic Displacements

The maximum seismic deflections that were obtained from the time history analyses and SASSI analyses are given in Tables 6.3-1 to 6.3-3 for the auxiliary and shield building, containment internal structure, and steel containment vessel.

Table 6.3-1 – Maximum Seismic Deflections for Auxiliary and Shield Building

Units - inches

Elevation feet	Shield Building	Auxiliary Building	Shield Building	Auxiliary Building	Shield Building	Auxiliary Building
	North-South		East-West		Vertical	
333.13	1.3251		1.5522		0.5521	
294.93	1.0143		1.1836		0.5407	
265	0.8749		1.0933		0.3576	
222.75	0.6840		0.8634		0.3242	
179.19	0.4369	0.1513	0.6355	0.2280	0.2573	0.0863
160	0.3343	0.1238	0.5039	0.2020	0.2167	0.0852
134.88	0.1998	0.0878	0.3316	0.1679	0.1636	0.0838
99	0.0408	0.0407	0.0678	0.0678	0.0548	0.0674

Table 6.3-2 – Maximum Seismic Deflections for Containment Internal Structure

Units - inches

Elevation feet	North-South		East-West		Vertical	
	East	West	East	West	East	West
160		0.0816		0.1704		0.0375
153	0.1440	0.0726	0.1550	0.1314	0.0592	0.0374
134	0.0987	0.0644	0.0839	0.1048	0.0496	0.0357
100	0.0361	0.0361	0.0653	0.0653	0.0130	0.0130

Table 6.3-3 – Maximum Seismic Deflections from SCV Stick Model

Units - inches

Elevation feet	North-South	East-West	Vertical
282	0.4590	0.4335	0.0770
224	0.3404	0.3212	0.0352
170	0.1983	0.1907	0.0254
132	0.1001	0.0988	0.0174

6.4 Comparison of Forces, Moments, and Stress for Building Design

Design of the ASB and CIS building has been performed using equivalent static seismic accelerations. To show that static equivalent results are bounding, a comparison is made to the time history results. Forces and stresses obtained from the equivalent static seismic analyses within the auxiliary building at the interface of the shield building, along the shield building, shield building roof beams, and within the containment internal structure are compared at the same locations to results obtained from seismic time history analyses. These locations are shown in Figure 6.4-1 and 6.4-2 for elevation 107' and 211' of the ASB. Figure 6.4-3 shows the shield building roof beams, and Figure 6.4-4 shows the locations in the CIS. The CIS locations are at the refueling canal (element 1846), steam generator compartment south west wall (element 1808), and structural module CA02 wall (element 1832). The coordinate system for the ASB and CIS elements is defined in Figure 6.4-5, X is horizontal, and Y is vertical for the local coordinate system.

A comparison of the ASB stress results is given in Table 6.4-1. The equivalent static stresses are the square root sum of squares (SRSS) of the three static equivalent components [north-south (NS), east-west (EW), and vertical (VT)] that were analyzed separately. As seen from this comparison the static equivalent stresses envelop the dynamic stresses, with the exception of (T_y) at ASB south elevation 107', and SB north elevation 211'. These differences are not great, and are attributed to the use of the more refined model NI05 in the static analysis that is better at calculating the localized stresses in this area than the NI20 model. It is also noted that at a few locations the equivalent static analyses have much higher values than those obtained from the time history analyses (e.g. ASB east (T_y) at elevation 107'). The reason is that the NI05 model has more detail, and therefore better representations of localized high peak stresses can be calculated.

The shield building roof beams comparison is given in Table 6.4-2. In this table it is seen that the static seismic equivalent moments envelop the moments obtained from the seismic time history analyses.

The comparisons for the containment internal structure is given in Table 6.4-3, the static equivalent stresses envelop the results obtained from the time history seismic analyses.

Therefore, the use of static seismic equivalent accelerations is acceptable.

Table 6.4-1 - ASB Stress Comparisons

Local Coordinates

		Static Equivalent Stress Results (KSF)			Time History Envelope Stress Results (KSF)		
		Tx	Ty	Txy	Tx	Ty	Txy
Elevation 107'	North	17.9	63.8	52.2	7.9	45.1	37.1
	East	68.9	160.0	40.2	8.8	68.2	10.5
	West	23.1	132.0	60.8	18.9	117.7	54.9
	South	50.0	76.7	70.8	14.8	89.5	33.0
Elevation 211'	North	20.2	59.2	45.7	8.0	61.3	41.5
	East	13.0	53.0	44.4	12.9	51.8	38.8
	West	13.7	48.2	35.1	13.9	47.5	32.1
	South	37.8	71.4	57.1	15.6	70.0	47.1

Table 6.4-2 - Shield Building Roof Beams Moment Comparisons

Global Coordinates

	Static Equivalent Stress Results (KSF)			Time History Envelope Stress Results (KSF)		
Element	Mx	My	Mz	Mx	My	Mz
1562	529.1	45.2	6.6	373.2	30.4	3.0
1610	44.2	519.2	8.0	32.2	382.0	5.1
1658	525.1	44.8	7.8	402.7	34.9	3.8
1706	44.5	523.8	7.9	30.9	352.3	4.8

Table 6.4-3 – CIS Stress Comparisons

Local Coordinates

	Static Equivalent Stress Results (KSF)			Time History Envelope Stress Results (KSF)		
	Tx	**Ty**	**Txy**	**Tx**	**Ty**	**Txy**
Refueling Canal Wall	12.0	10.0	48.0	7.8	8.3	23.2
SG Compartment Wall	31.0	42.0	79.0	22.1	14.5	34.8
CA02 Module Wall	34.0	35.0	51.0	12.6	18.4	31.4

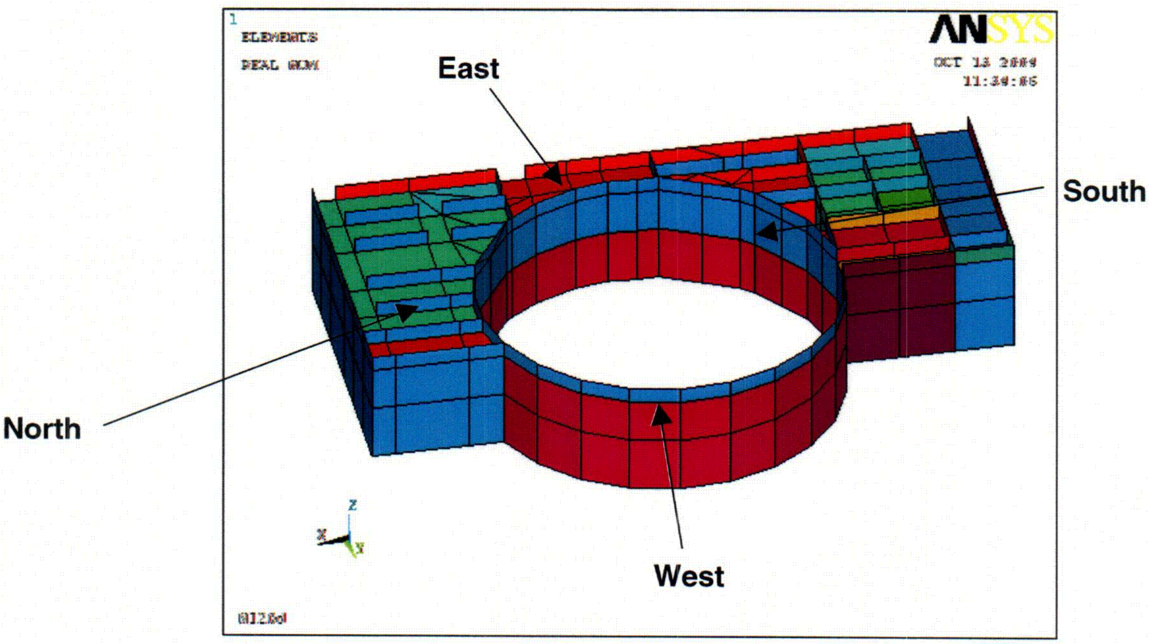


Figure 6.4-1 - Locations used for Comparison at Elevation 107'

C59

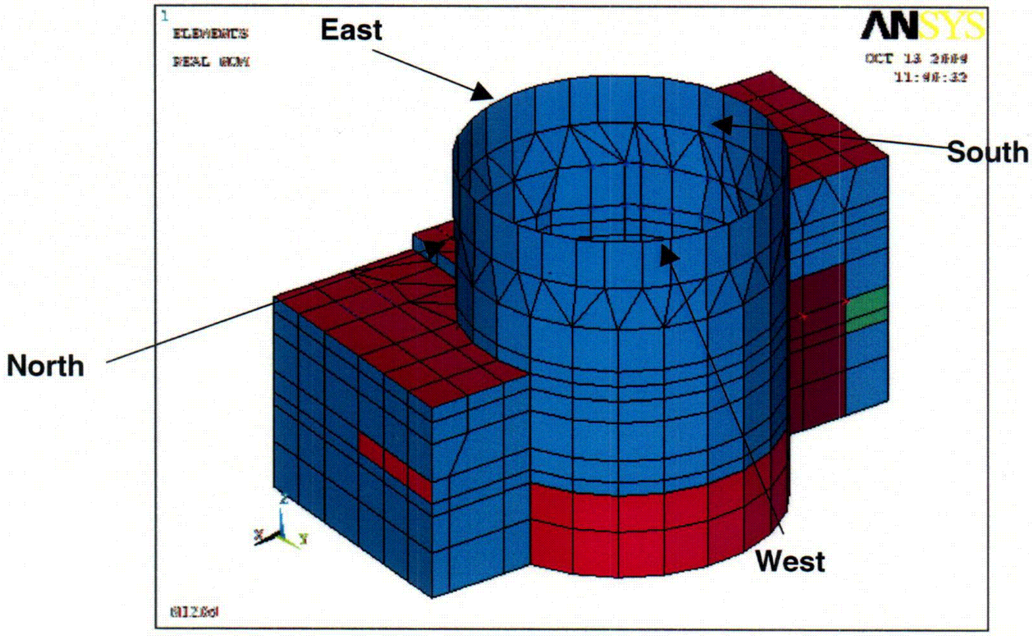


Figure 6.4-2 - Location for Comparison at Elevation 211'

C60

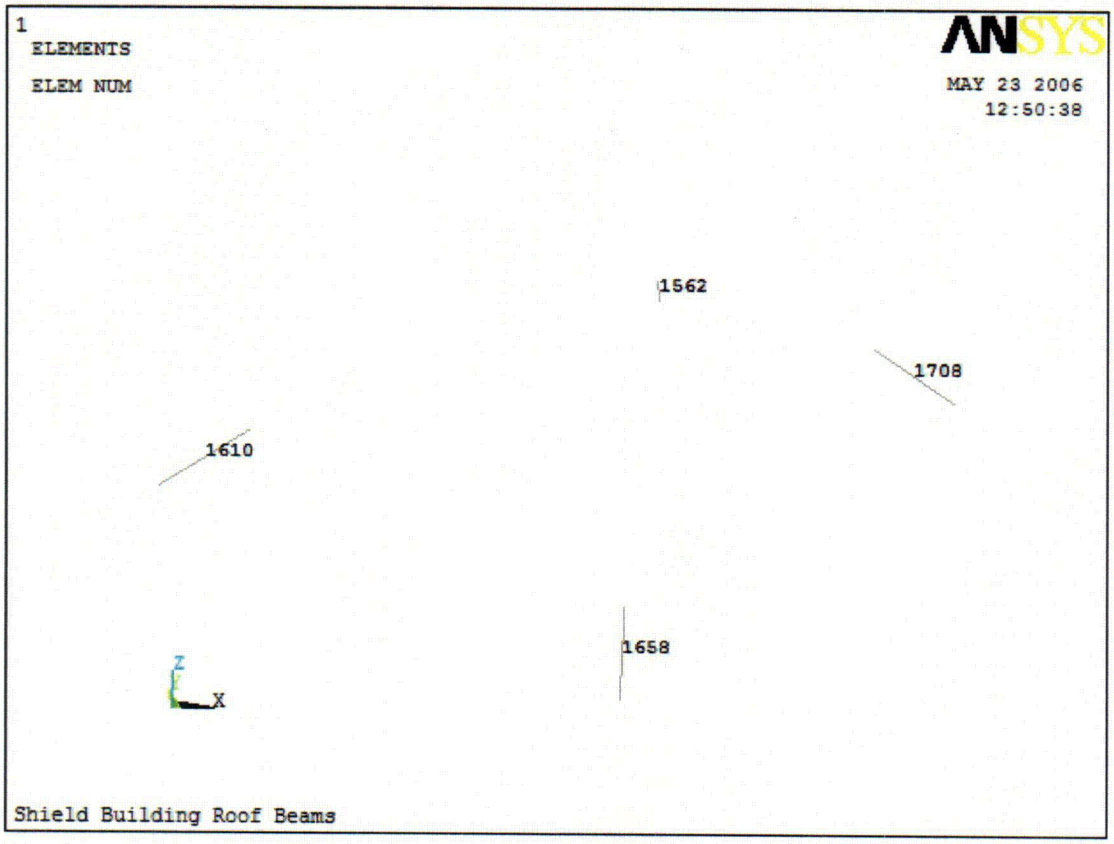


Figure 6.4-3 - Shield Building Roof Beam

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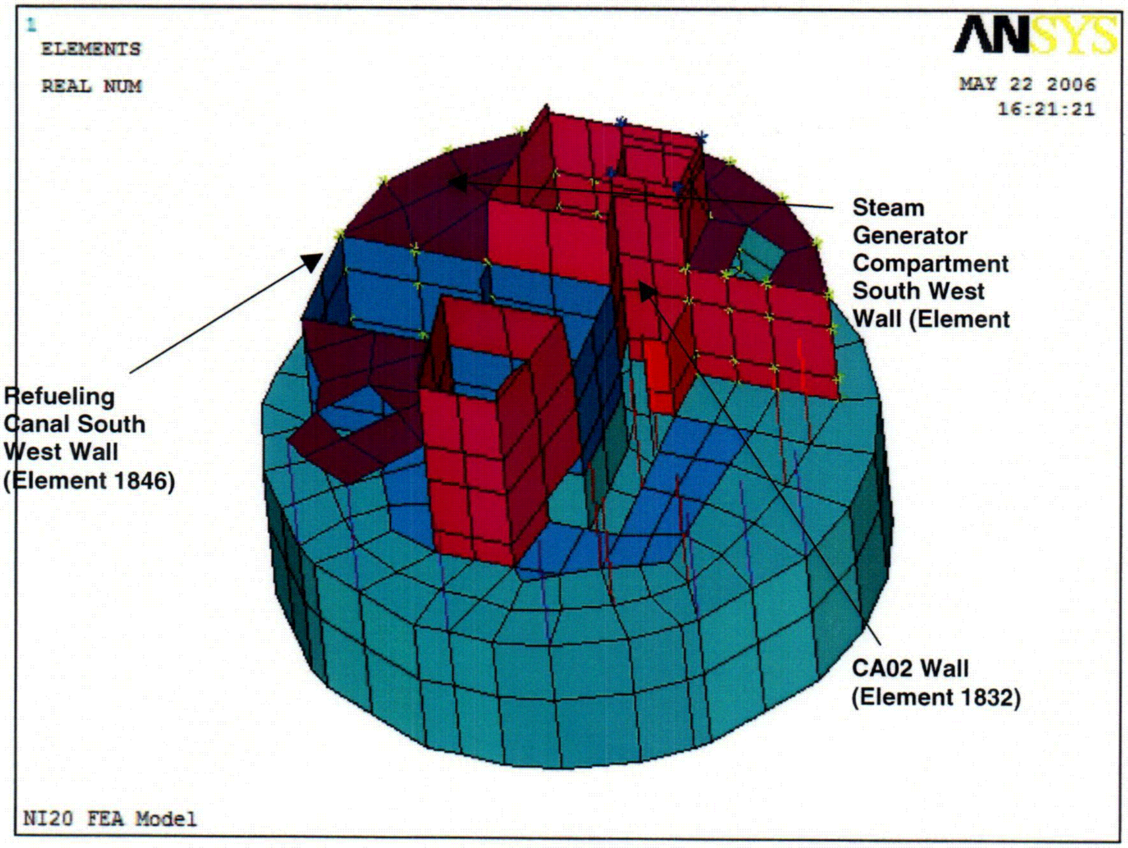


Figure 6.4-4 - Containment Internal Structures

C62

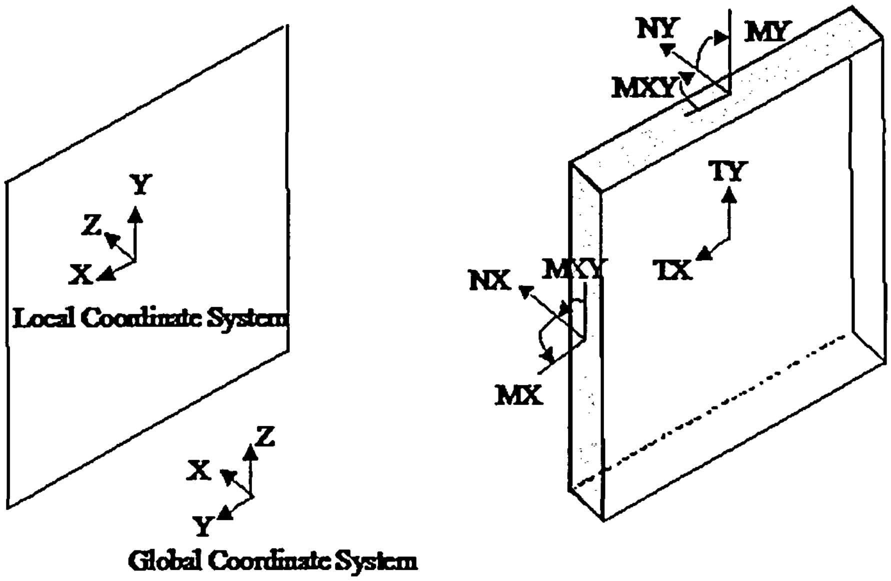


Figure 6.4-5 - Local and Global Coordinate System for ASB and CIS

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' x 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.

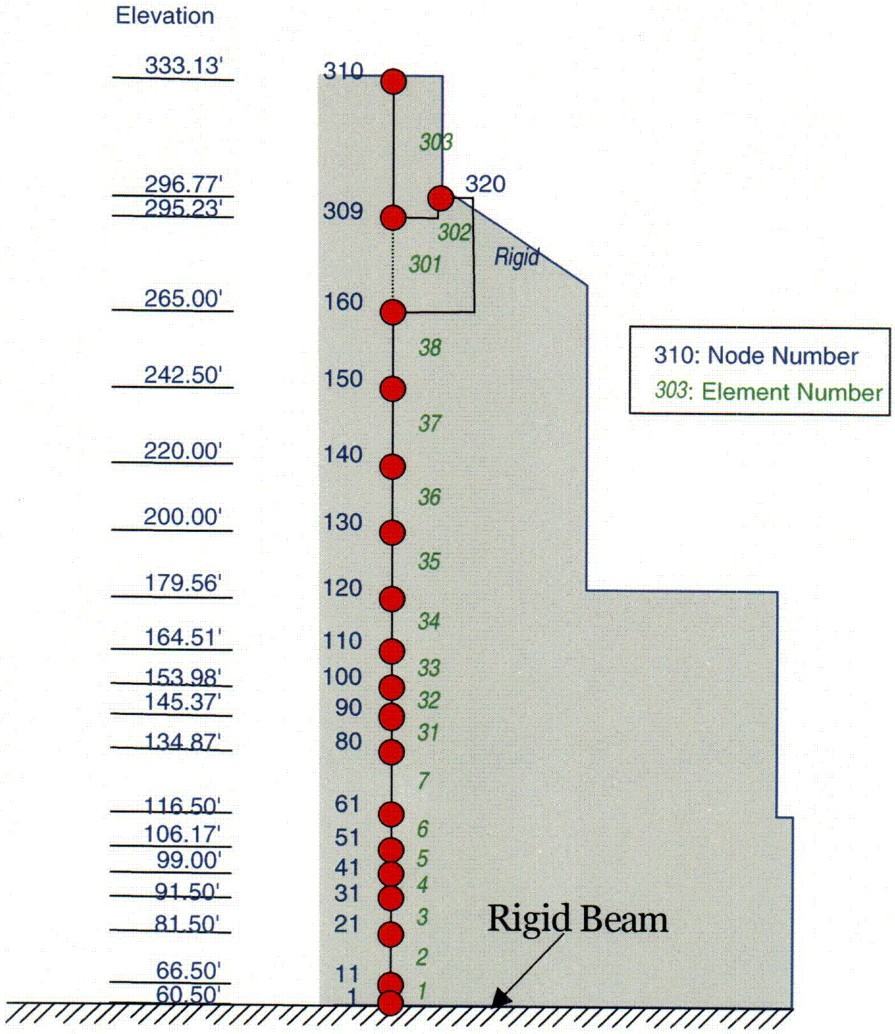
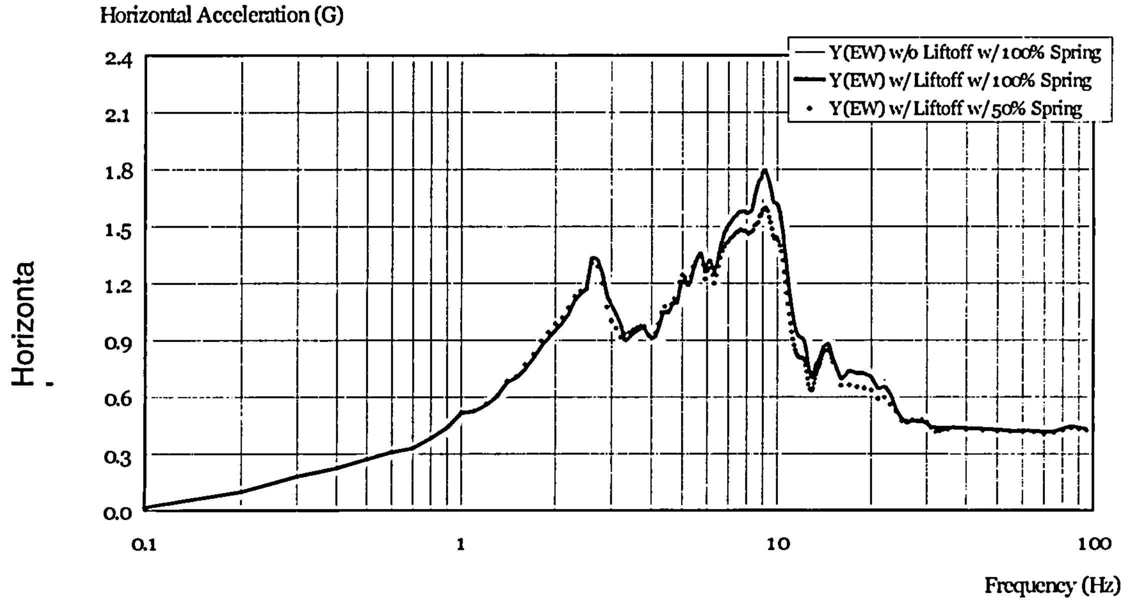


Figure 7.1-1 - ASB Stick portion of NI combined model

C63



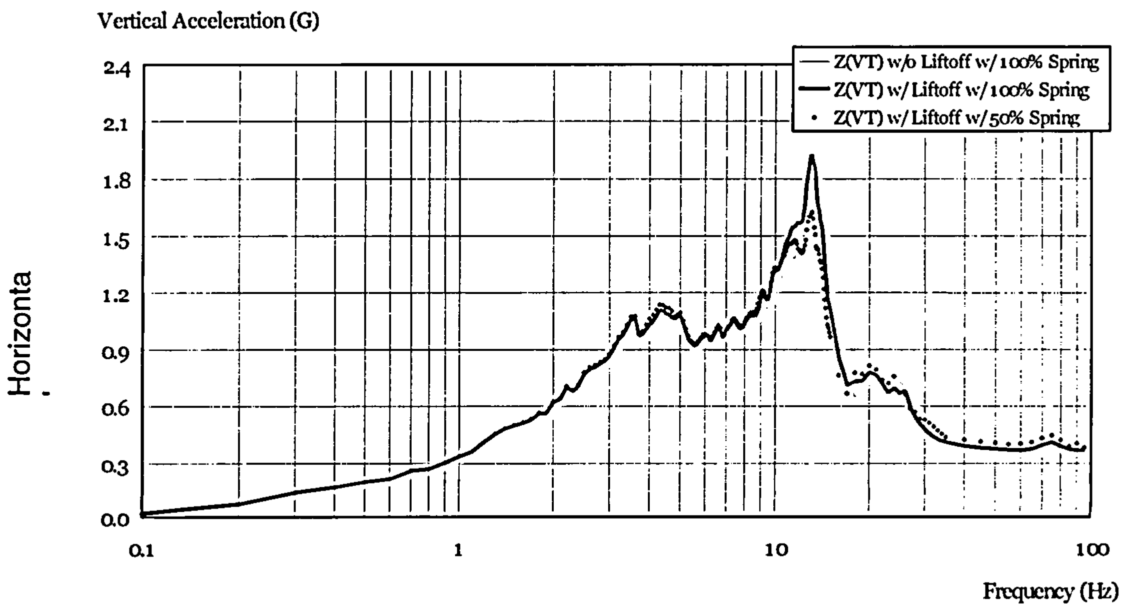
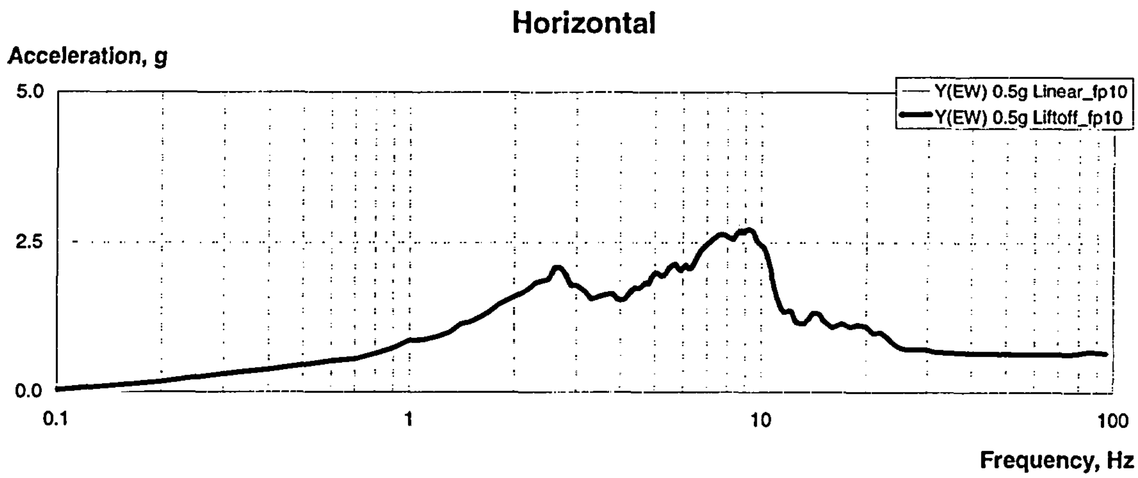


Figure 7.1-2 - SSE Floor Response Spectra at 5 % Damping – Node 61 (EL. 116.50')



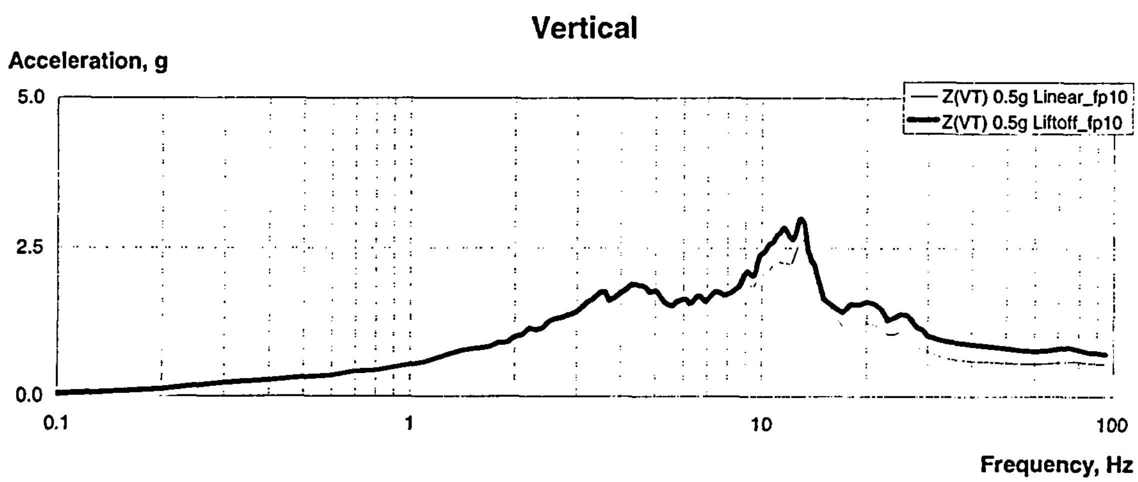


Figure 7.1-3 - RLE Floor Response Spectra of ASB Node at EL. 116.50'

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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 actual footprint of the basemat was used in these analyses.

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 7-1 - 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 Rock	150	0.25	3200	2782	2
Soft-to-medium Soil	110	0.35	1000	814	5
Soft Soil	110	0.40	300	234	30

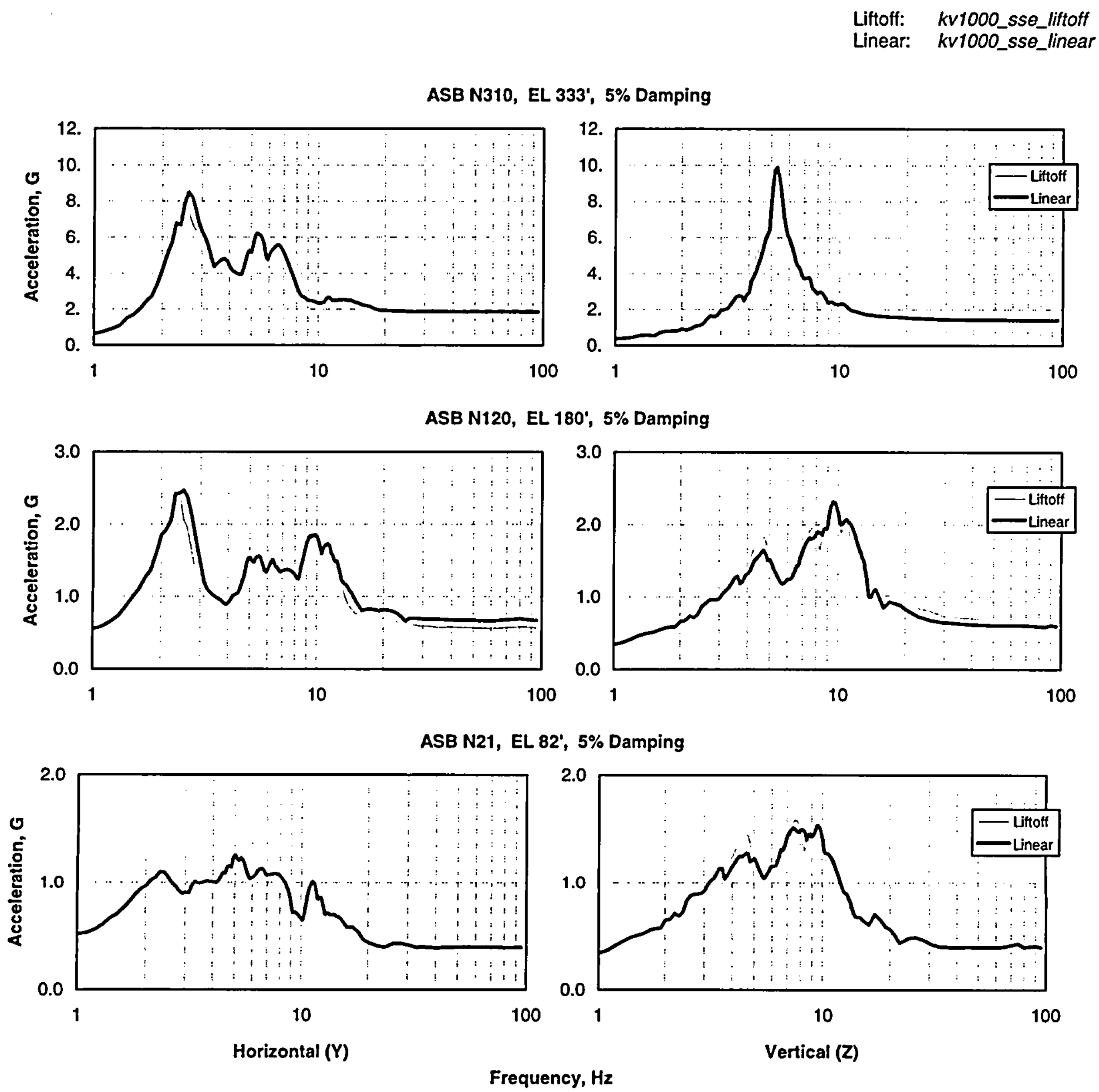


Figure 7.2-1 - ANSYS Lift Off Effects on FRS (SSE) Soft to medium Soil

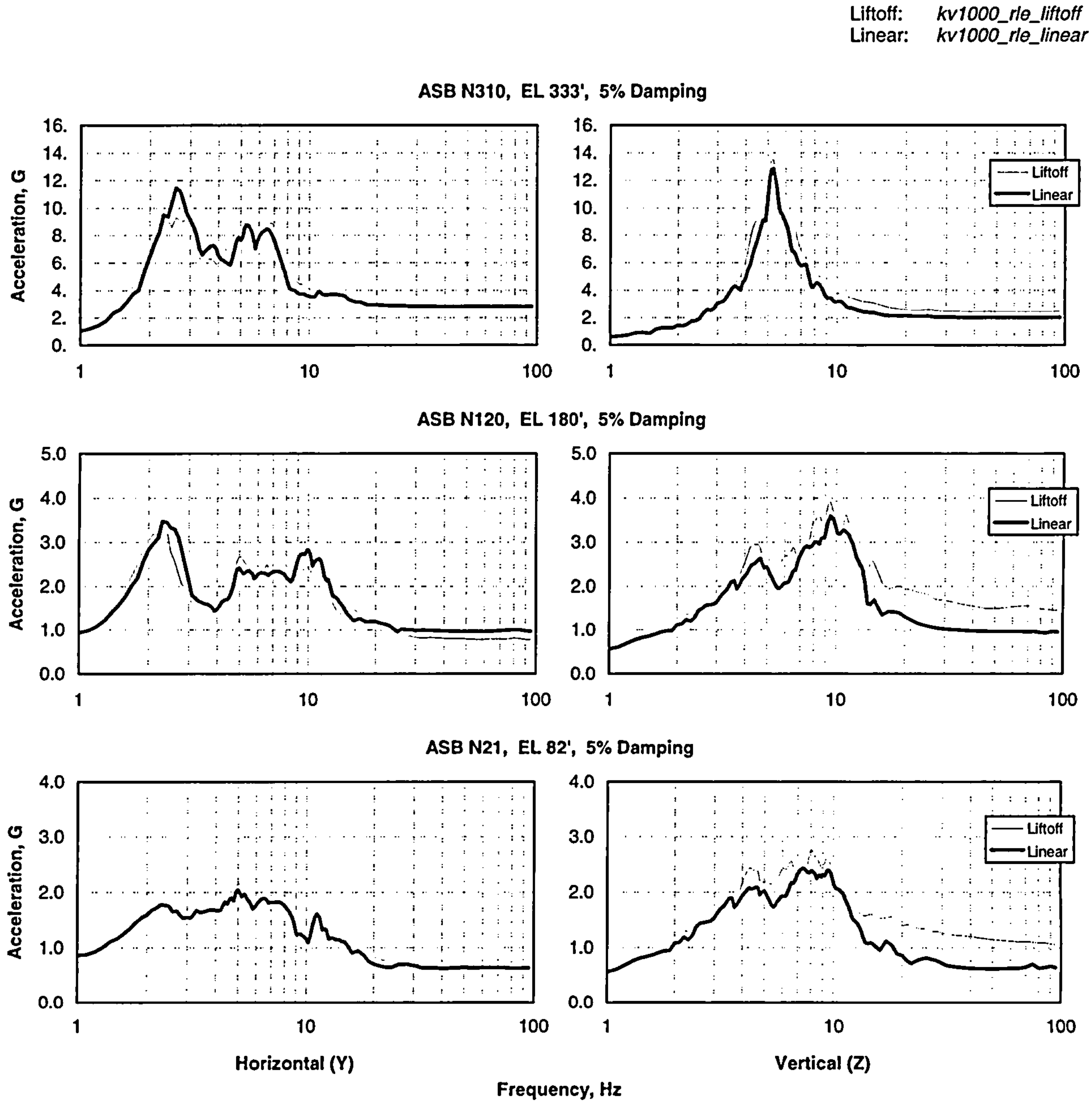


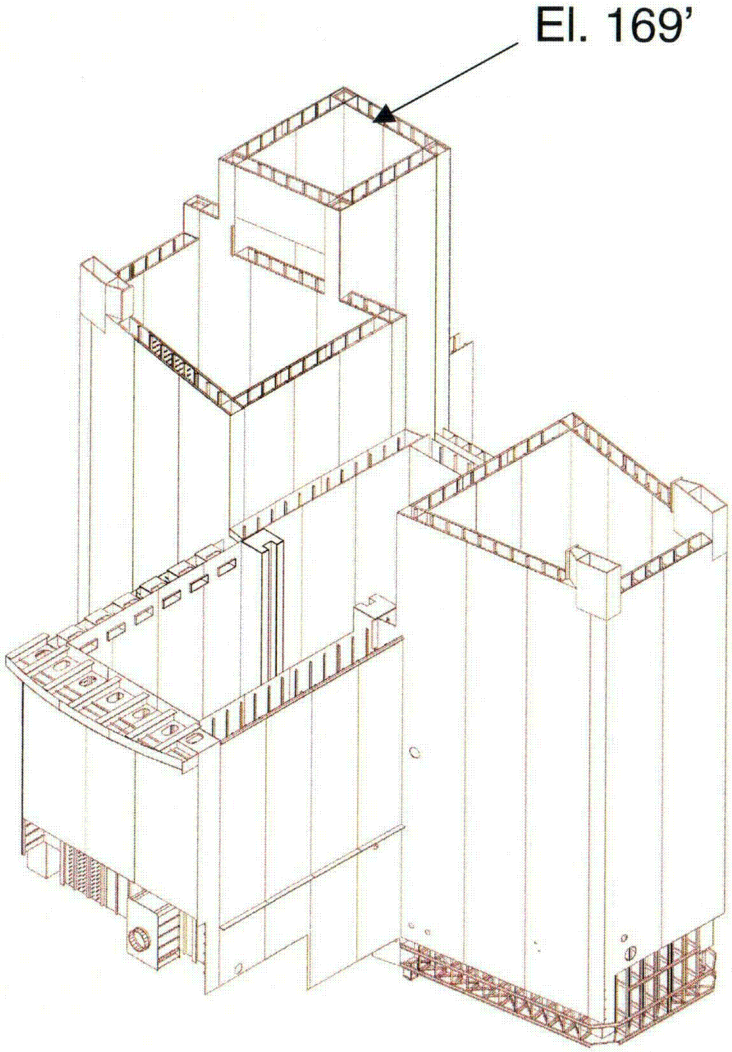
Figure 7.2-2 - ANSYS Lift off Effects on FRS (RLE) Soft to Medium soil

8.0 References

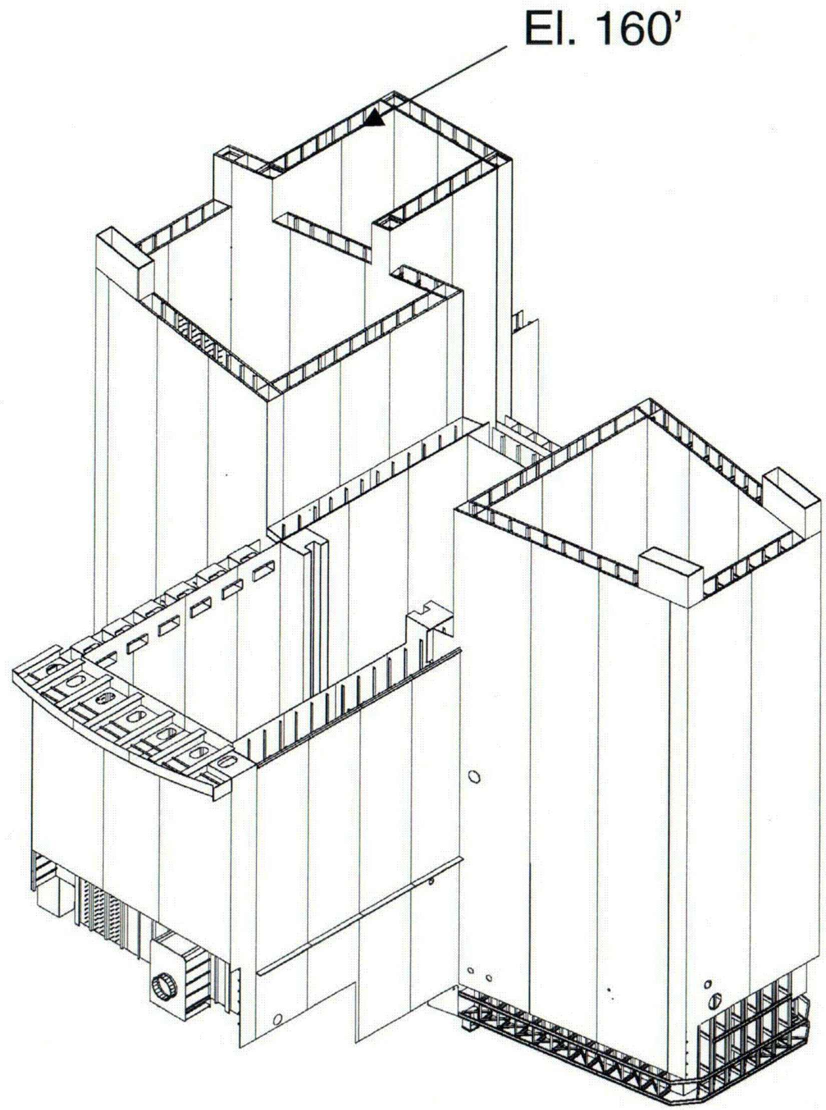
1. APP-GW-GL-700, AP1000 Design Control Document, Section 3.7, Revision 15.
2. NUREG 1793, NRC "Final Safety Evaluation Report for AP1000 Design," September 2004.
3. Regulatory Guide 1.60, Design Response Spectra for Seismic Design of Nuclear Power Plants, Rev. 1.
4. DSER Open Item 3.7.2.3-1, Rev. 1, 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. Regulatory Guide 1.132, Site Investigations for Foundations of Nuclear Power Plants, Rev. 2.
9. DSER Open Item 19A.2-8, Transmitted in DCP/NRC 1599, June 24, 2003.

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

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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.

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

FRS name	Soil Site Node	Hard Rock Site Node	Location
ASB99	1473	2392	SBC north
	1406	2376	SBC east
	1340	2406	SBC south
	1407	2595	SBC west
	1313	4084	ASB SE 1I
	1319	4115	ASB SW 1N
	1455	4233	ASB 7.3I
	1488	4380	ASB NE 11I
	1494	4399	ASB NW 11Q
	1334	6614	ASB 4I
ASB34-116	1756	4548	ASB 7I
	1760	4556	ASB 7I
	1764	4570	ASB 7I
ASB134	2032	5054	SBC north
	2010	4961	SBC east
	1988	5744	SBC south
	2011	7648	SBC west
	2053	6821	ASB NW
	1961	4764	ASB SE
	1967	4795	ASB SW
	1982	4886	ASB 4I
	2020	4984	ASB 7.3I
	2047	5109	ASB NE
ASB160	2202	5538	SBC north
	2317	5487	SBC east
	2327	5510	ASB 7.3I
	2330	5515	SBC 7.3
	2218	5351	ASB NE
	2224	5370	ASB NW
	2290	6955	ASB 4I

Table B-2 – ASB Nodes for FRS Envelopes (EL. 163' to EL. 333')

FRS name	Soil Site Node	Hard Rock Site Node	Location
ASB180	2412	6153	SBC north
	2400	6054	SBC east
	2365	5754	SBC south
	2401	7719	SBC west
	2358	5574	ASB SW
	2352	5543	ASB SE
	2359	5703	ASB 4I
	2385	5628	ASB 2
	2387	5633	ASB 2
ASB223	2476	6352	SBC north
	2462	6345	SBC east
	2447	6337	SBC south
	2463	6329	SBC west
ASB265	2556	7730	SBC north
	2541	7752	SBC east
	2526	7766	SBC south
	2542	7762	SBC west
ASB295	2728	2613	SBR north
	2713	2997	SBR east
	2698	2853	SBR south
	2714	2725	SBR west
ASB333	2984	2622	SBR north
	2969	3006	SBR east
	2954	2862	SBR south
	2970	2734	SBR west

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

FRS name	Soil Site Node	Hard Rock Site Node	Location
CIS99	1340	2406	SBC south
	1397	130401	CV stick
	1406	2376	SBC east
	1407	2595	SBC west
	1473	2392	SBC north
CIS134	1931	106962	Pressurizer
	1930	106958	Pressurizer
	1902	106805	SG west
	1913	105772	SG west
	1882	105773	SG west
	1888	106819	SG west
	1911	105805	SG east
	1901	107241	SG east
	1886	107252	SG east
	1878	105806	SG east
	1958	105852	IRWST North
	1856	105955	RC south
	1854	106300	RC south
	1899	111745	South
CIS153	2236	106806	SG west
	2242	105868	SG west
	2226	105875	SG west
	2230	106760	SG west
	2237	106899	PZR
	2240	106428	PZR
	2250	106166	PZR
	2252	106160	PZR
	2241	105975	SG east
	2235	107235	SG east
	2229	107256	SG east
	2225	105982	SG east
CIS160	2336	106216	PZR US
	2337	106204	PZR US
	2340	106174	PZR US
	2342	106174	PZR US

Table B-4 – CIS Nodes for Selected FRS Envelopes

FRS name	Soil Site Node	Hard Rock Site Node	Location
134cisWEST	1888	106819	SG west
	1902	106805	SG west
	1882	105773	SG west
	1913	105772	SG west
	1930	106958	Pressurizer
	1931	106962	Pressurizer
134cisEAST	1886	107252	SG east
	1878	105806	SG east
	1901	107241	SG east
	1911	105805	SG east
153cisWEST	2230	106760	SG west
	2236	106806	SG west
	2226	105875	SG west
	2242	105868	SG west
	2250	106166	PZR
	2252	106160	PZR
	2237	106899	PZR
	2240	106428	PZR
153cisEAST	2241	105975	SG east
	2235	107235	SG east
	2229	107256	SG east
	2225	105982	SG east

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 NI20 ANSYS is compared to the SASSI analysis results.

Comparison response spectra are provided 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. Both 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 to compare the Nuclear Island SASSI Surface Structure Model and the Embedded Structure Model results with the Nuclear Island ANSYS Coarse Model results for hard rock conditions.

As seen from the comparison (see Figures C-7 to C-12), for the horizontal response, the SASSI and ANSYS results are very similar to about 15 Hz horizontal and about 10 Hz vertical. At the higher frequencies SASSI calculates higher accelerations. One reason for this conservatism 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. Since SASSI will only be used for soil cases and not hard rock, the significant responses will be occurring 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). Although these cases are believed to be 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	Coarse Model Nodes (1)	NI20	Figure NI10 & NI20 FRS Comparison	Figure ANSYS & SASSI FRS Comparison	General Area	Elevation (feet)
CIS at Reactor Vessel Support Elevation	130401	465	1397	C-1	C-7	RPV Center	100.00
CIS at Operating Deck	105772 [(2)]	981	1913	C-2	C-8	SG West compartment, NE	134.25
ASB NE Corner at Control Room Ceiling	5109	1115	2047	C-3	C-9	NE Corner	134.88
ASB Corner of Fuel Building Roof at Shield Building	5754	1433	2365	C-4	C-10	NW Corner of Fuel Bldg	179.19
ASB Shield Building Roof Area	2862	2022	2954	C-5	C-11	South side of Shield Bldg	333.12
SCV Near Polar Crane	130412	1546	2478	C-6	C-12	SCV Stick Model	224.00

Notes to Table C-1:

(1) The response spectra given in the figures have different node numbers than defined in 4.2.3 for the NI20 model. This is because the NI20 nodes have been renumbered since the comparison response spectra were generated. The coarse model nodes are at the same location as the NI20 nodes.

(2) When the comparison response spectra were created this node was 105783. It was renumbered to 105772..

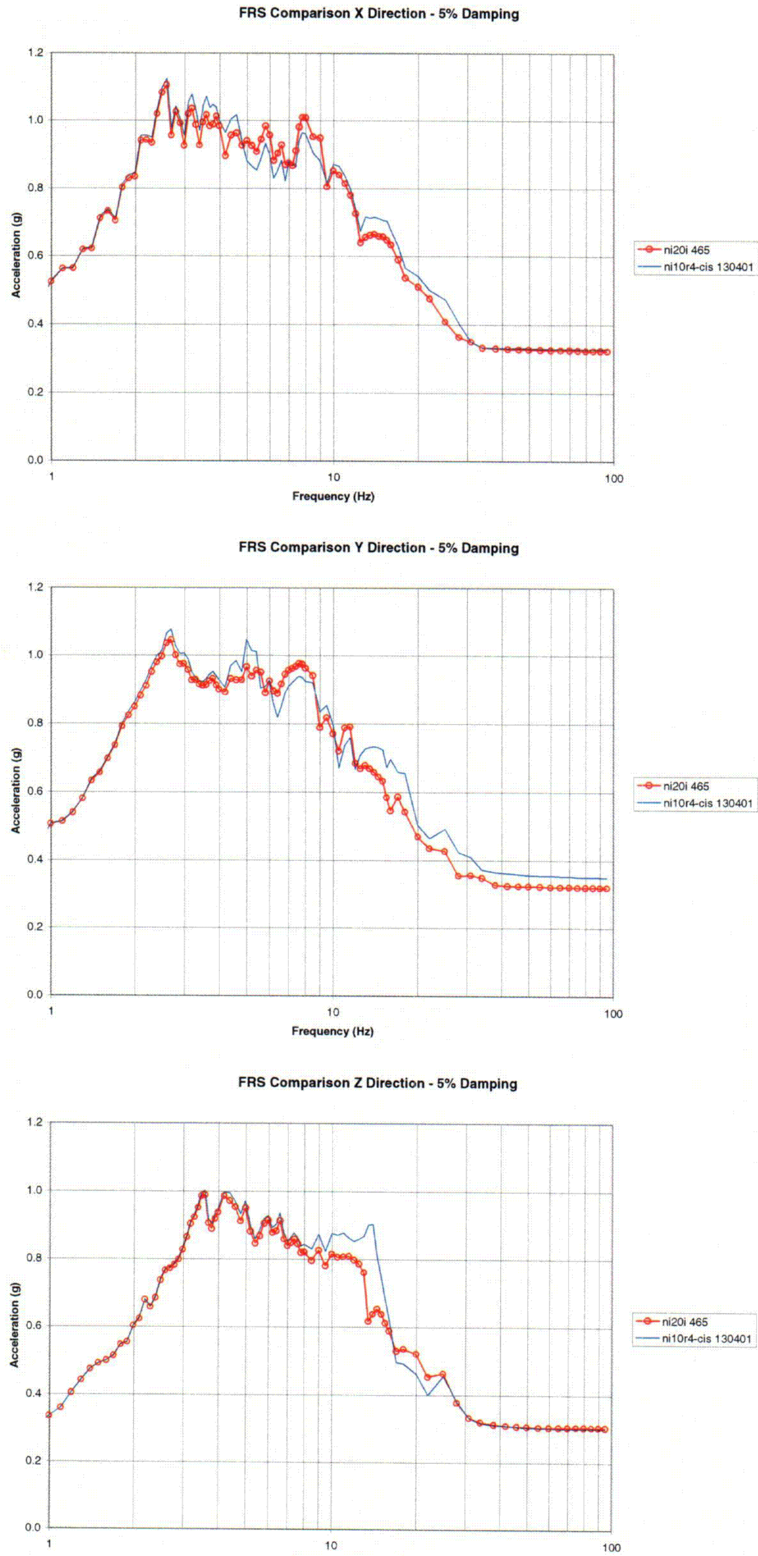


Figure C-1 - FRS Comparison at Base of SCV on CIS at RPV Center

C65

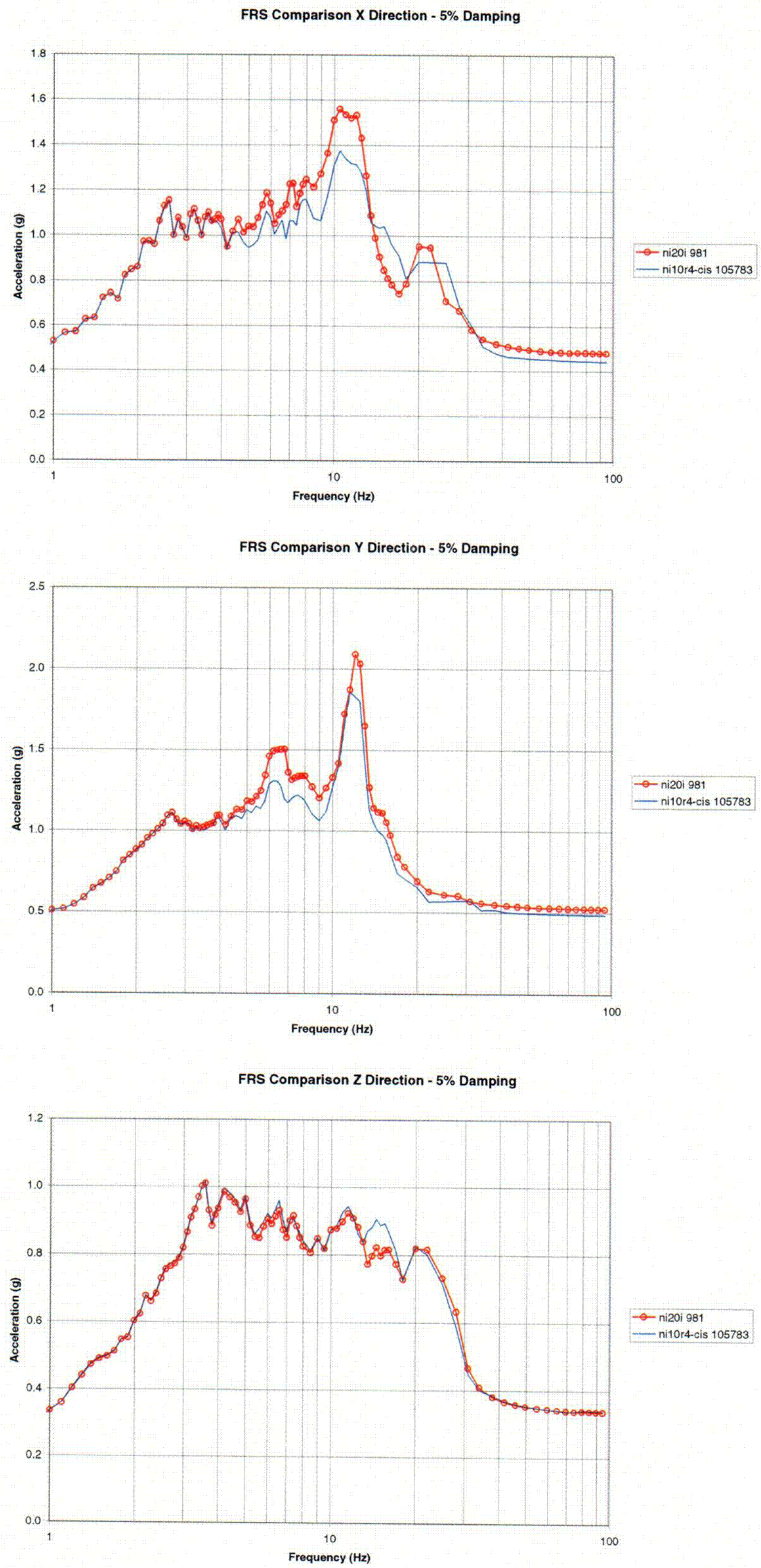


Figure C-2 - FRS Comparison at NE Corner of SG West Compartment, El. 134'

C66

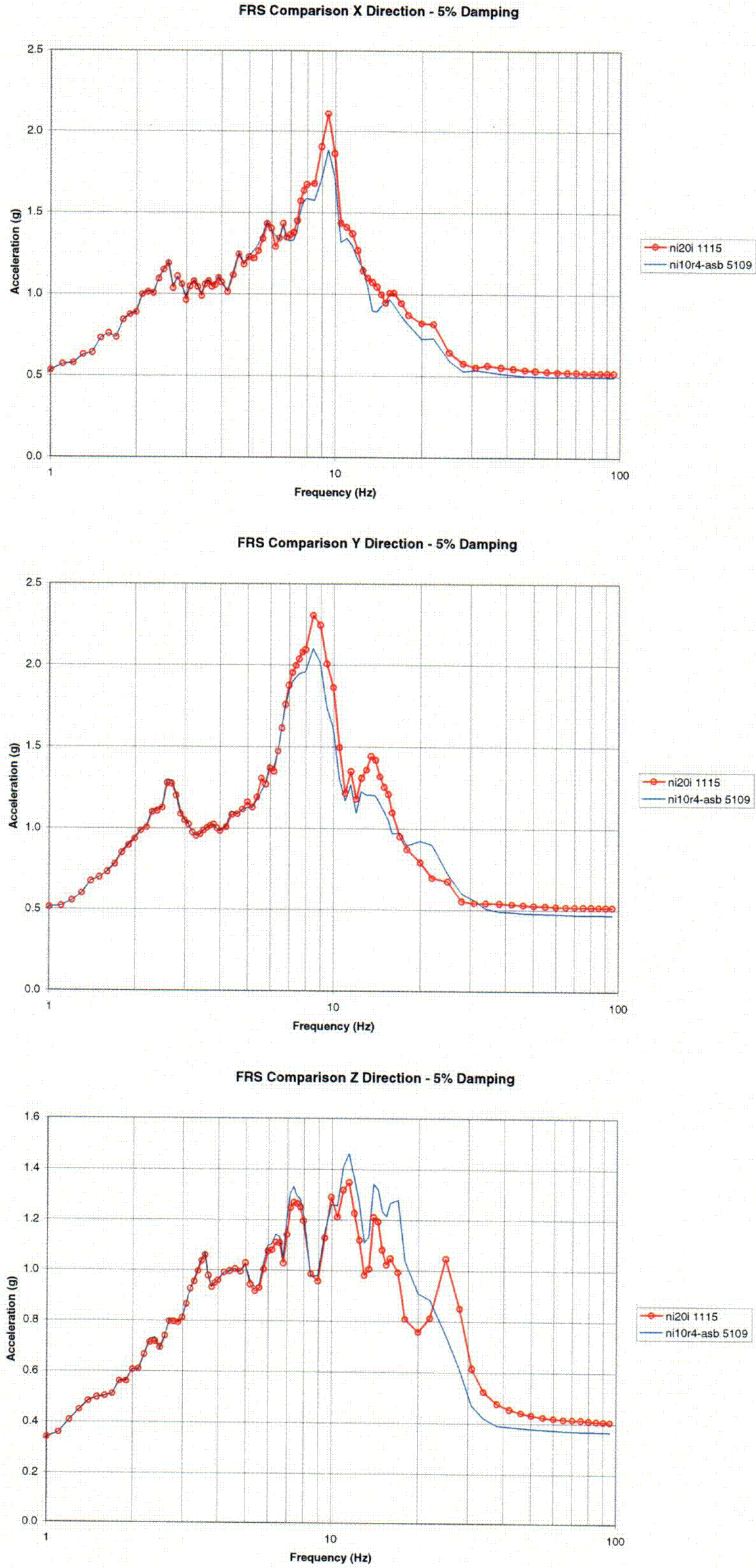


Figure C-3 - FRS Comparison at NE Corner of Control Room Ceiling

CC7

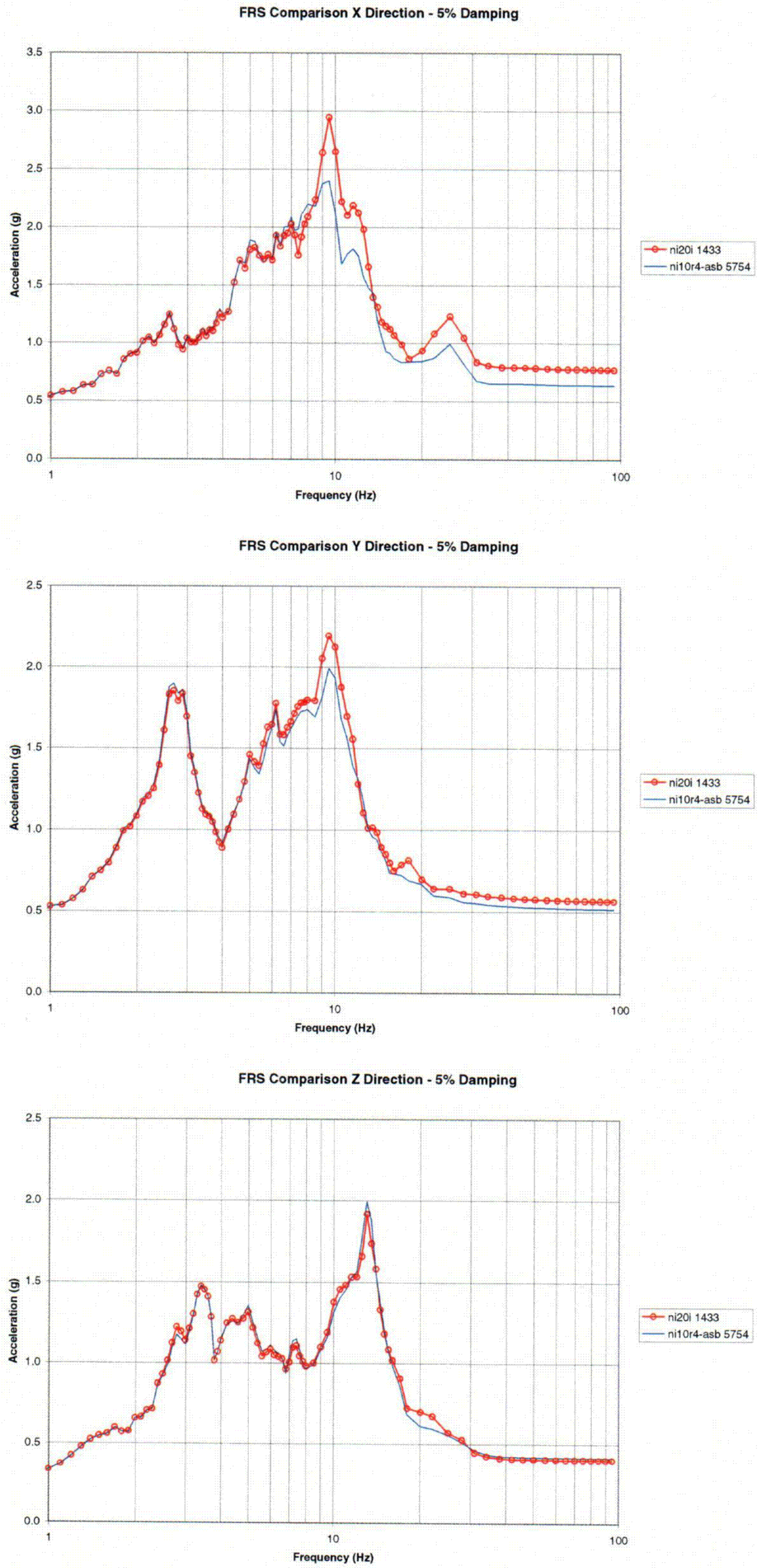


Figure C-4 - FRS Comparison at NW Corner of Fuel Building Roof

C68

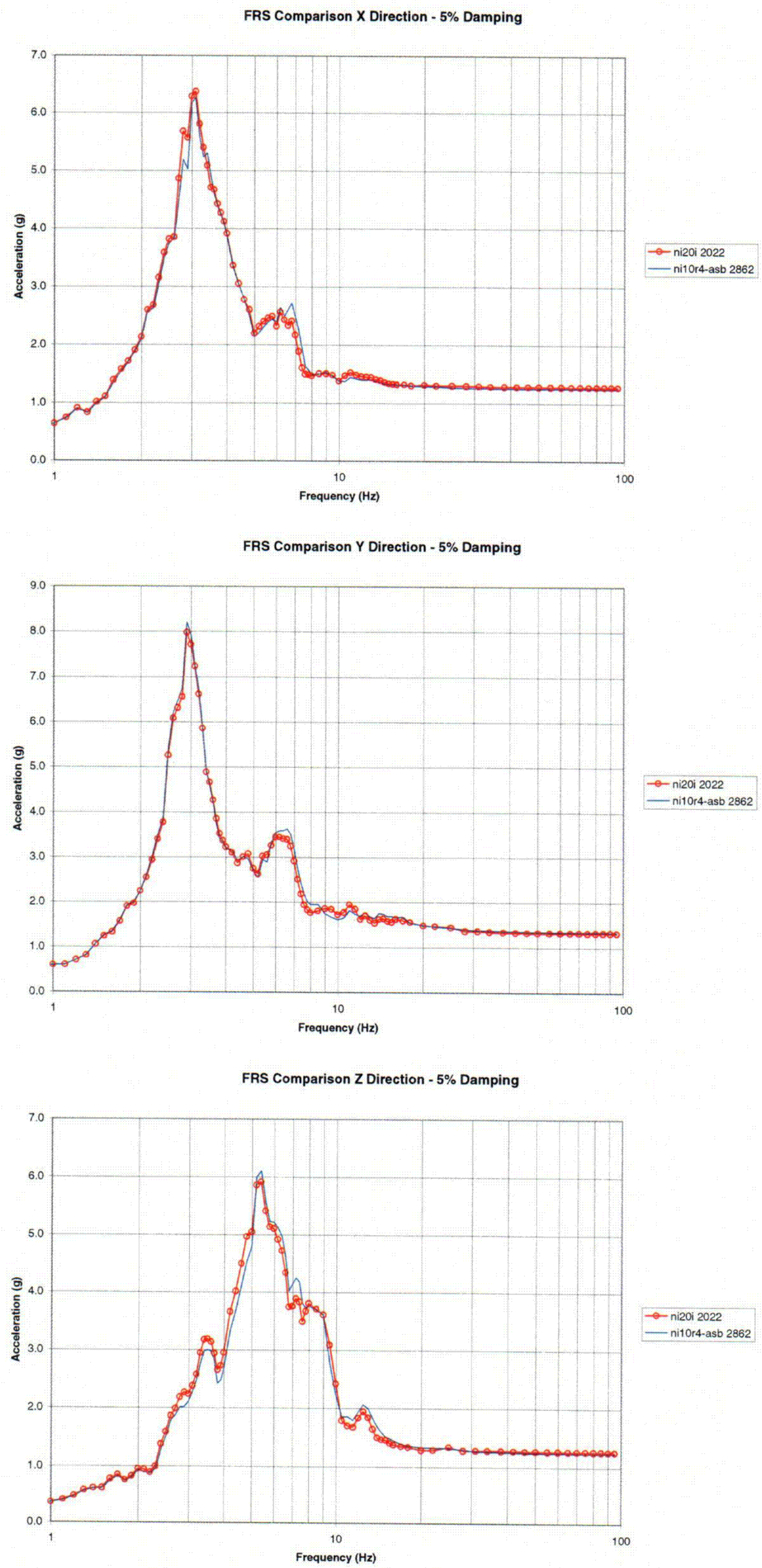
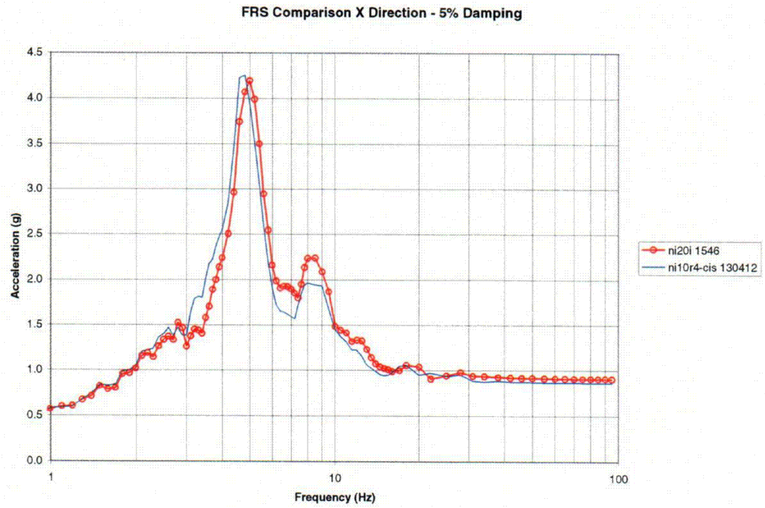
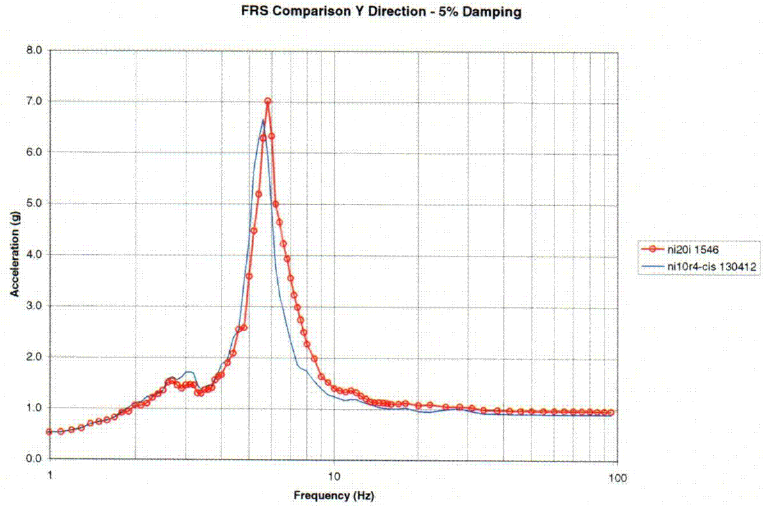


Figure C-5 - FRS Comparison at South Side of Shield Building at El. 333'

C69





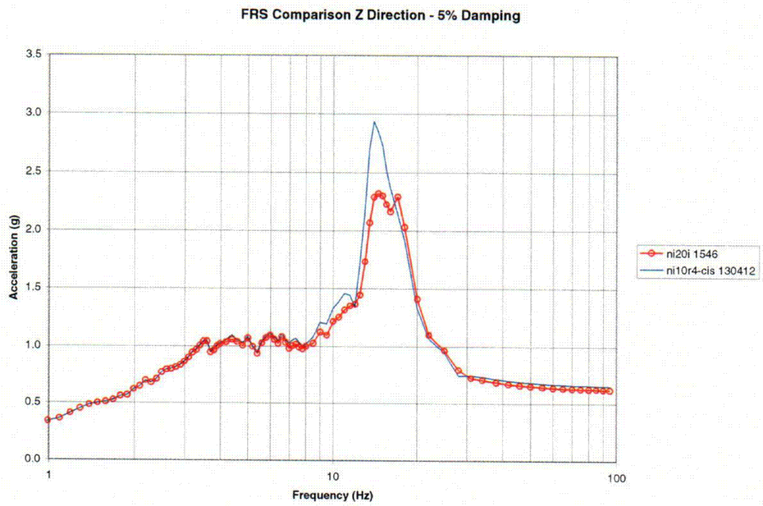
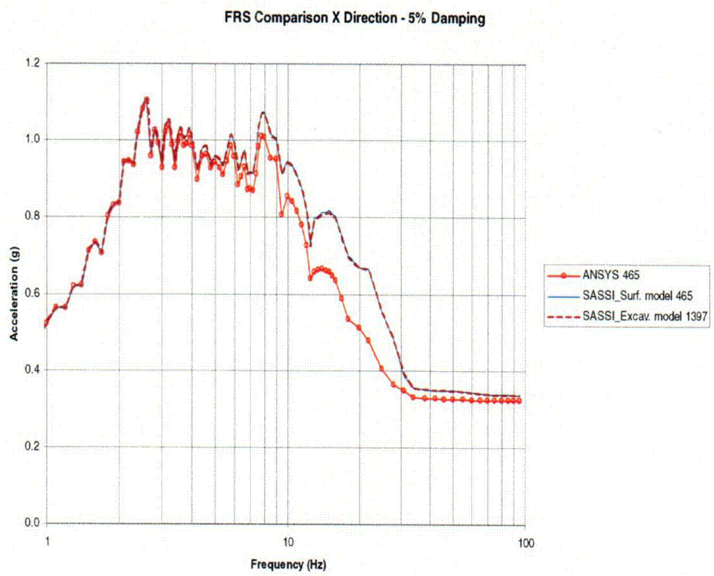
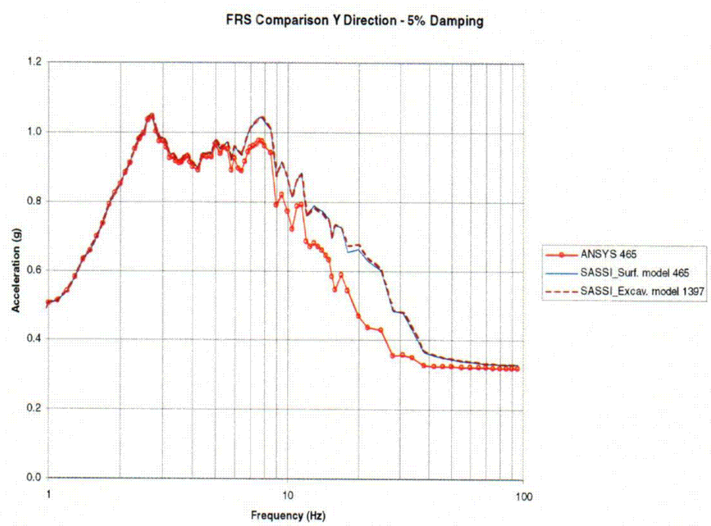


Figure C-6 - FRS Comparison on SCV near Polar Crane, El. 224'

C70





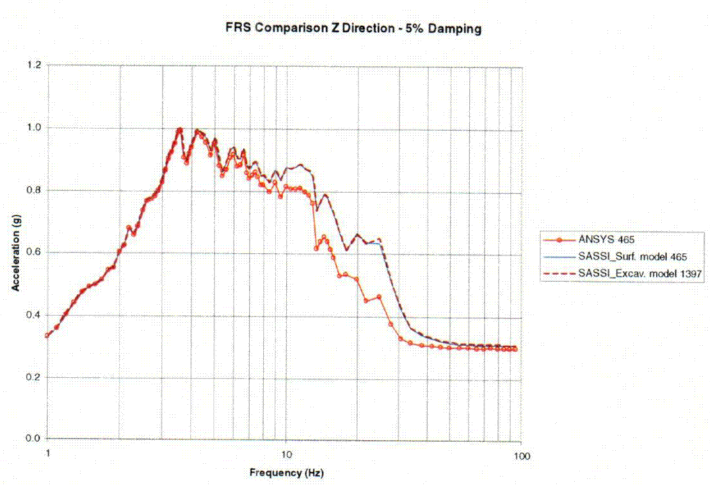


Figure C-7 - FRS Comparison at Base of SCV on CIS at RPV Center

C71

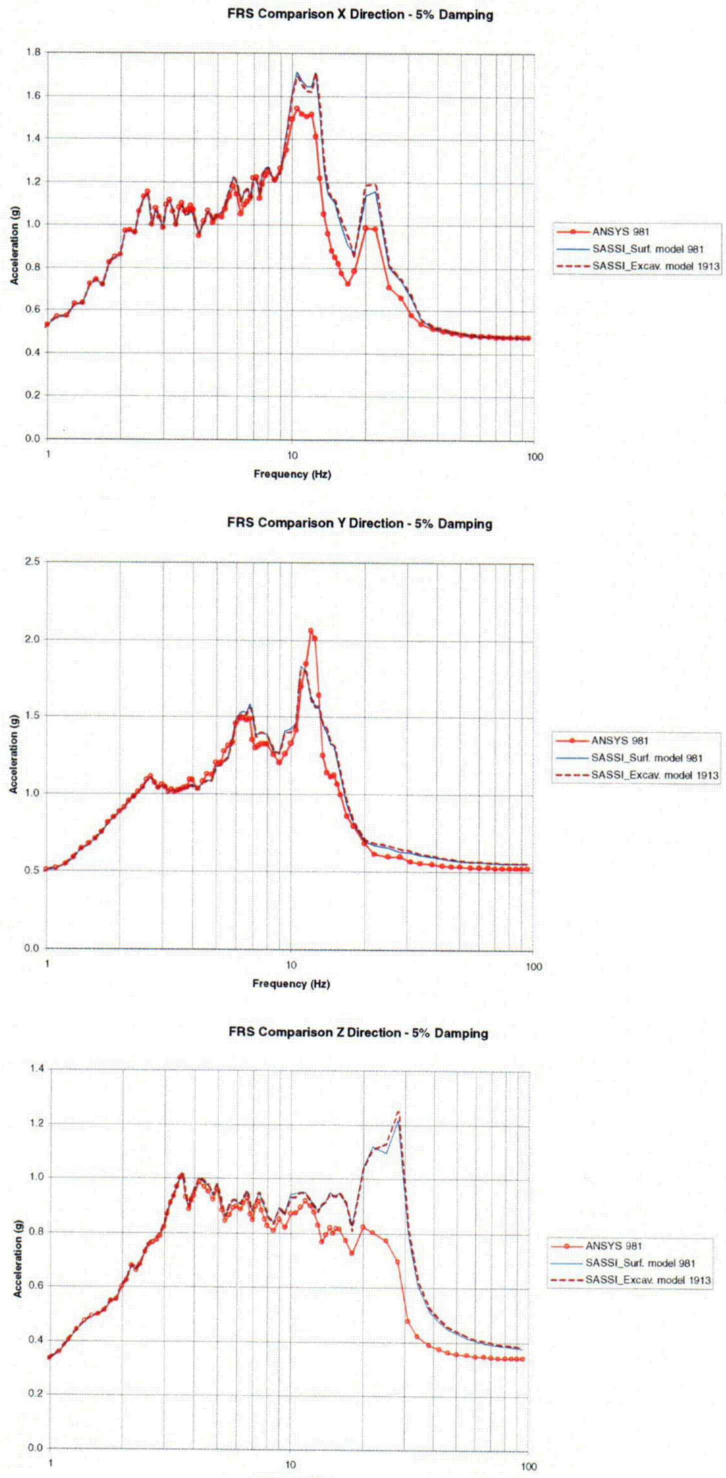


Figure C-8 - FRS Comparison at NE Corner of SG West Compartment, El. 134'

C72

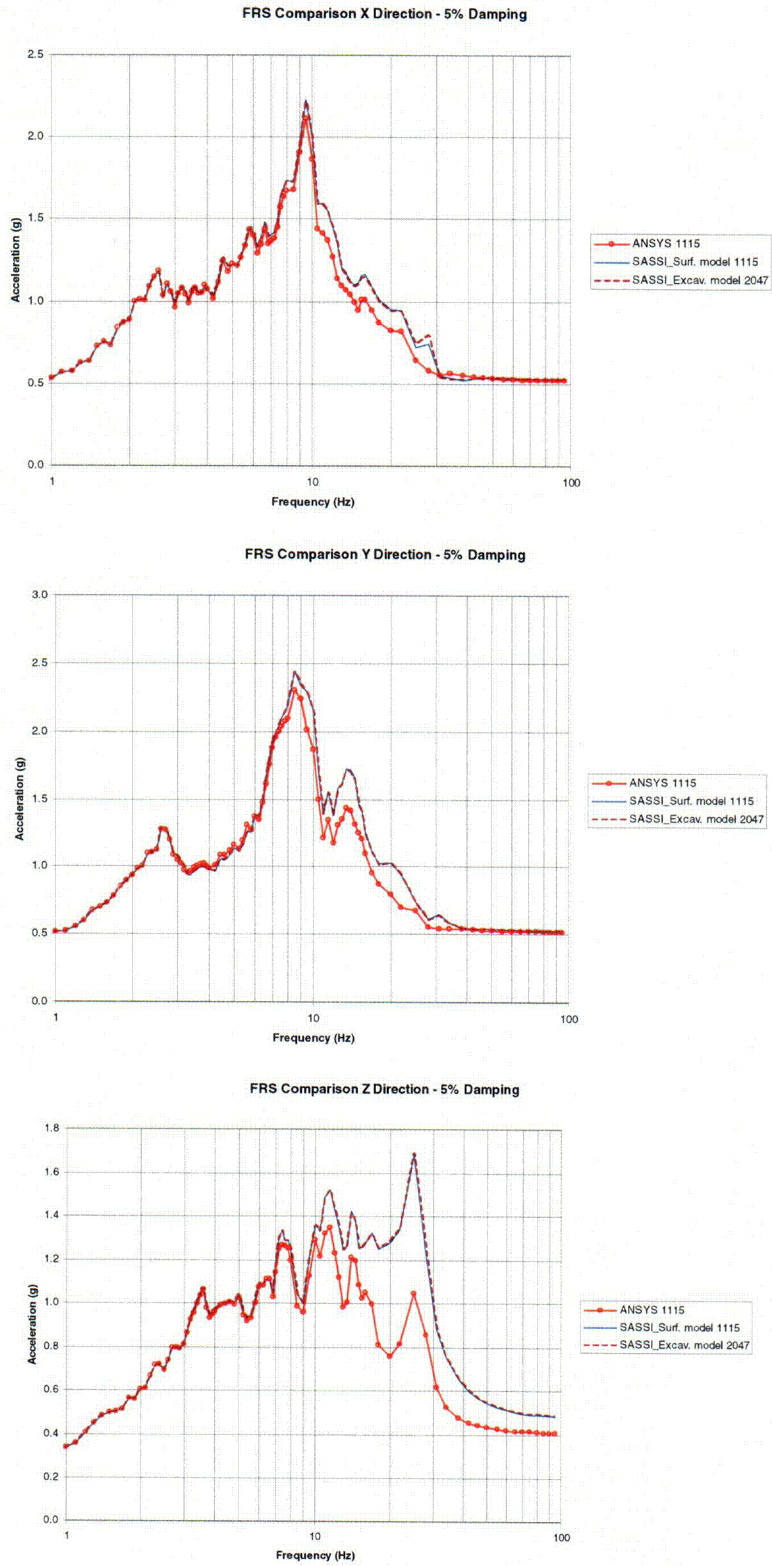
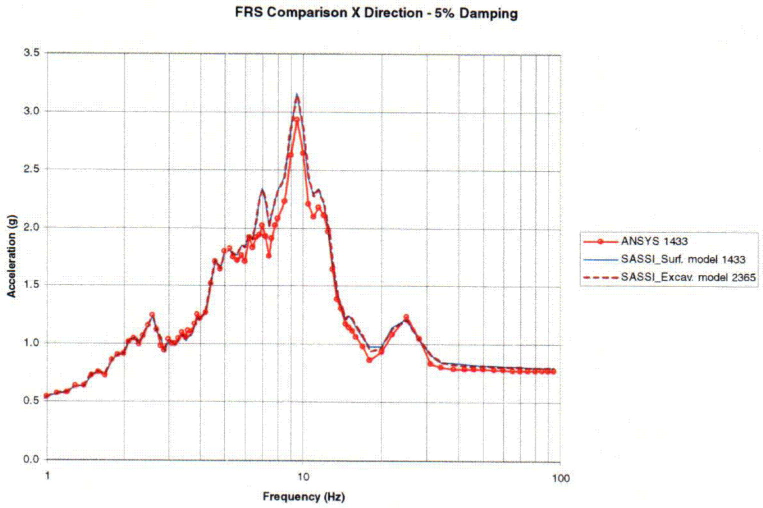
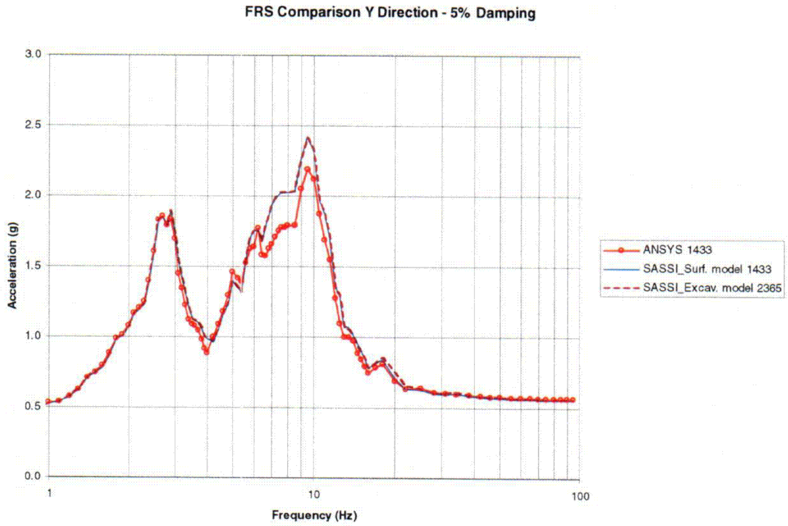


Figure C-9 - FRS Comparison at NE Corner of Control Room Ceiling

C73





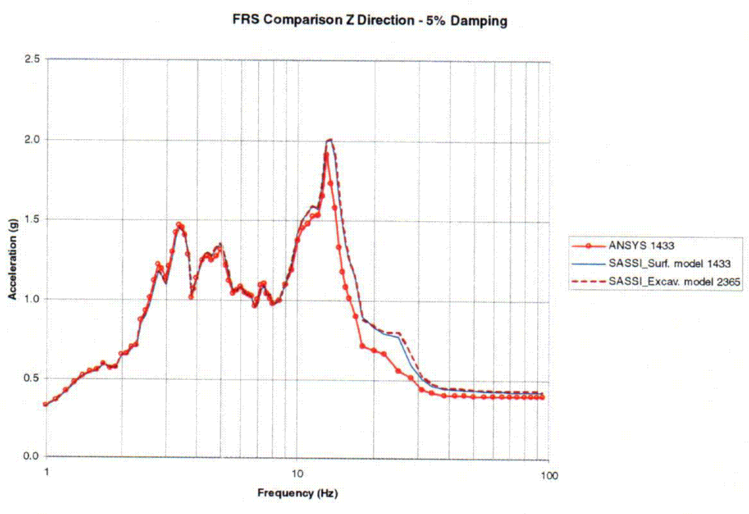


Figure C-10 - FRS Comparison at NW Corner of Fuel Building Roof

C74

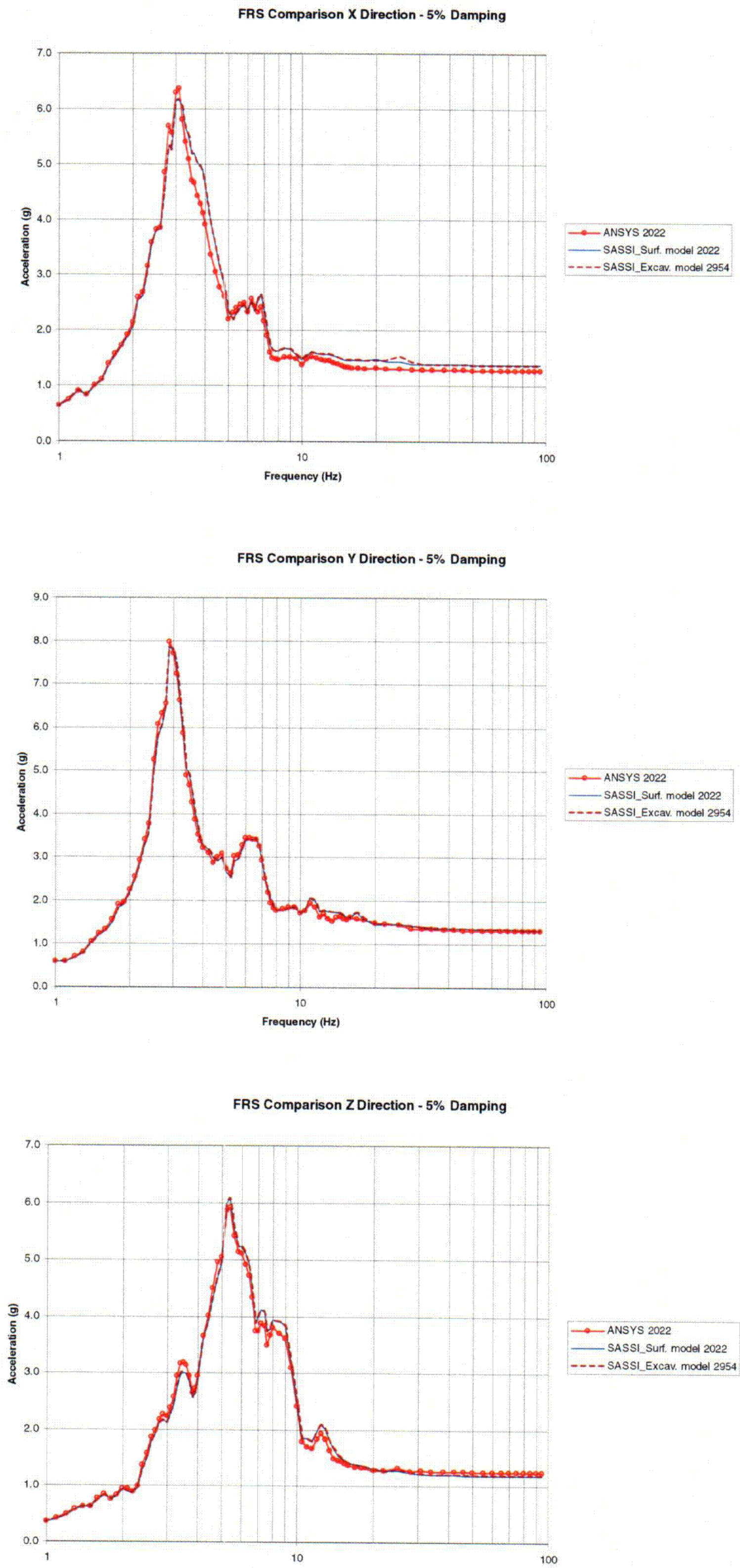


Figure C-11 - FRS Comparison at South Side of Shield Building at El. 333'

C75

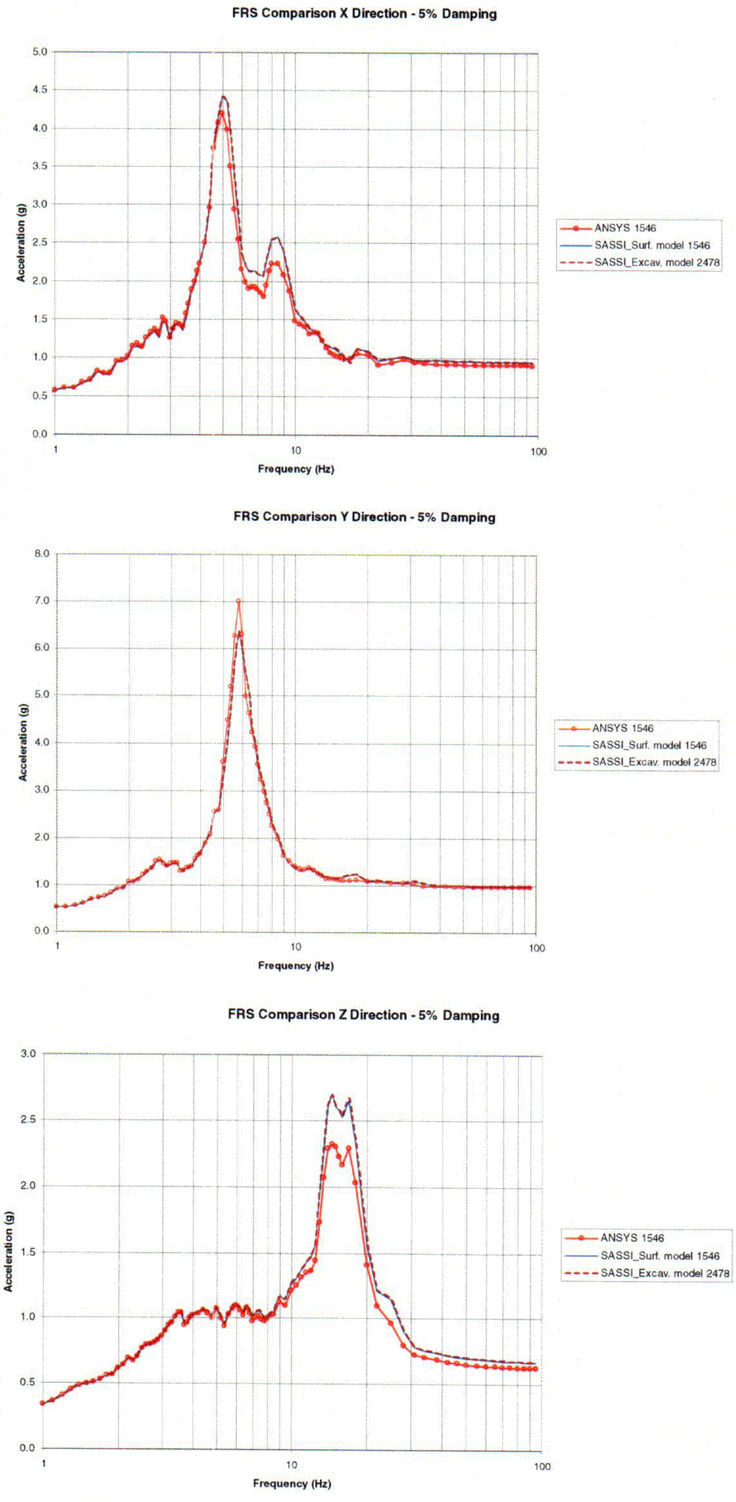


Figure C-12 - FRS Comparison on SCV near Polar Crane, El. 224

C76

Appendix D - Response Spectra for Six AP1000 soil cases

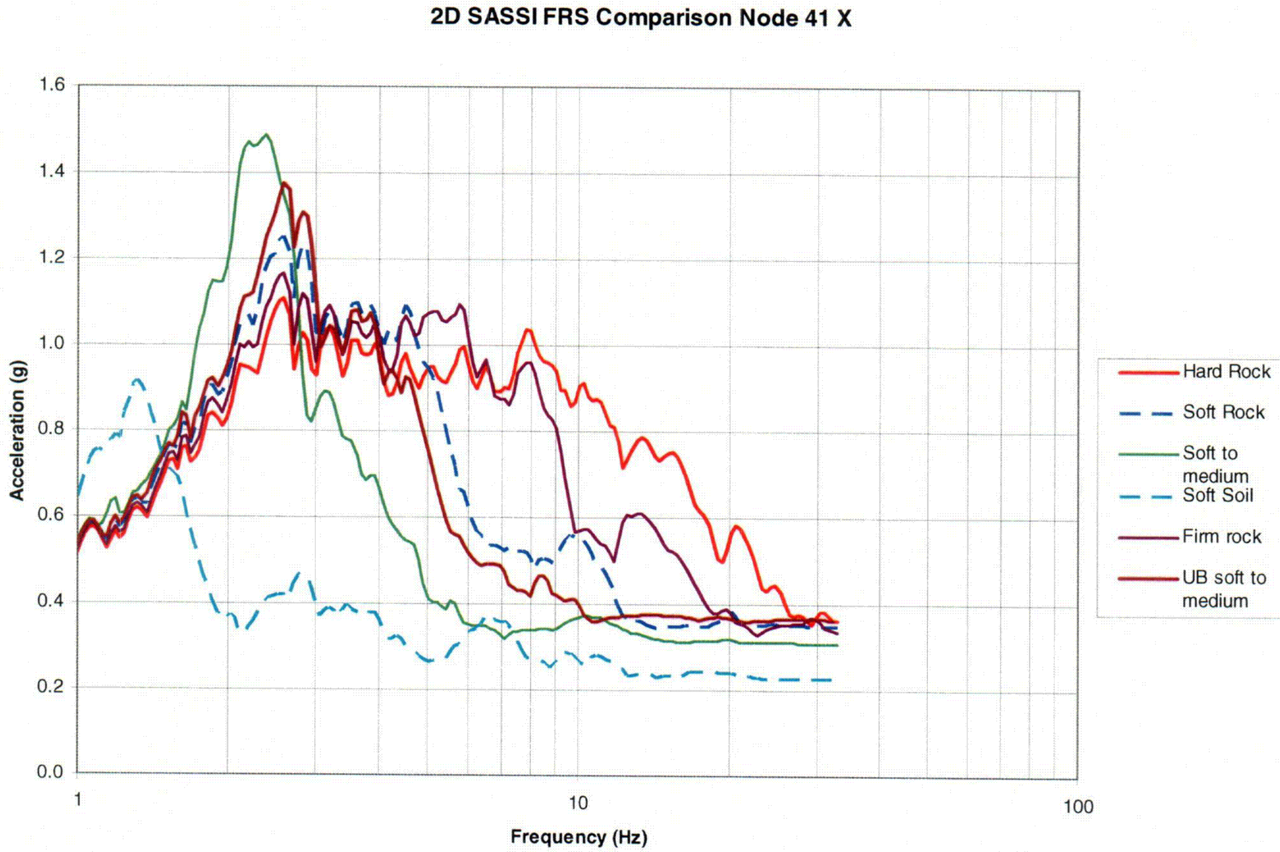


Figure D-1 - 2D SASSI FRS Comparison Node 41 X (ASB El. 99')

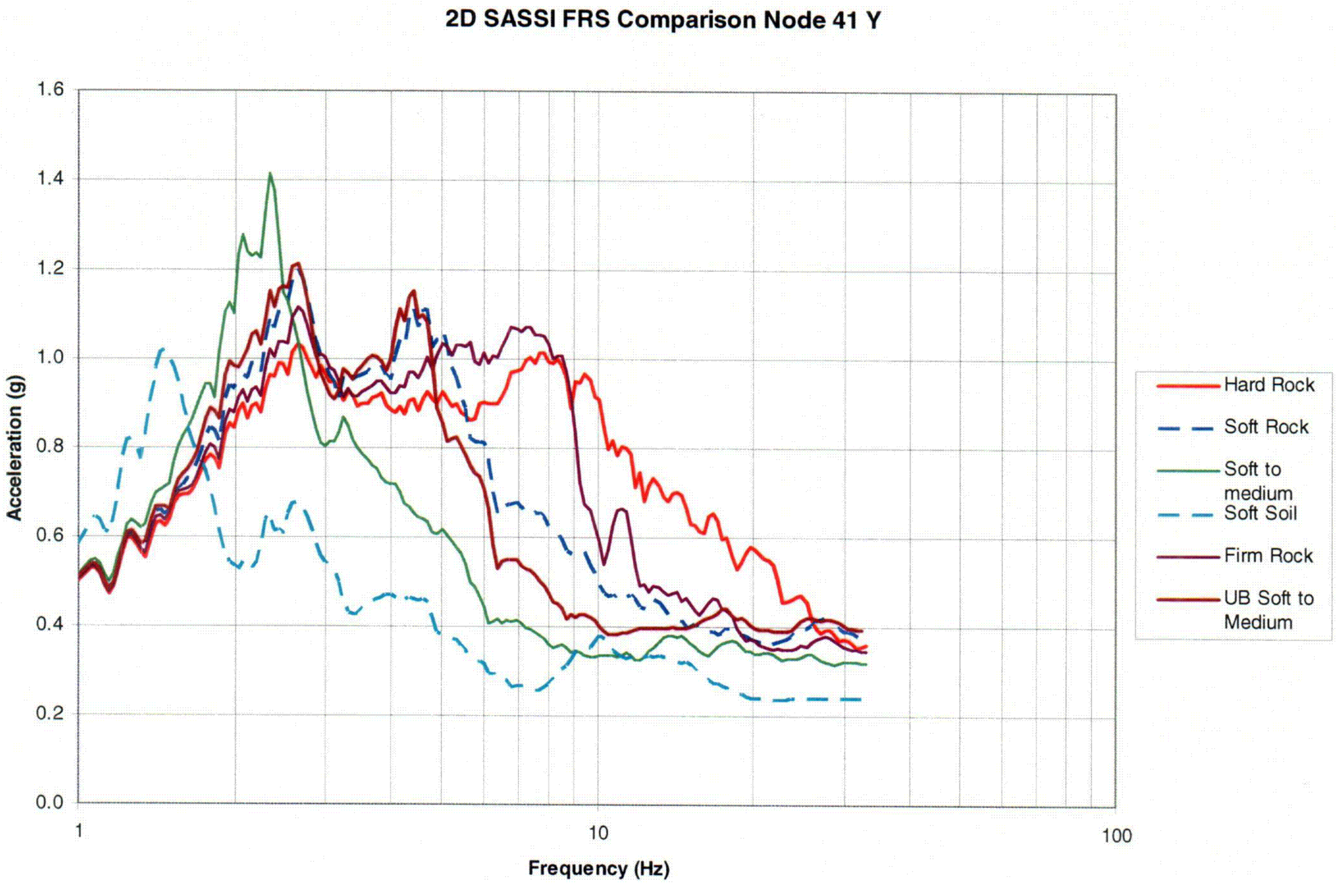


Figure D-2 - 2D SASSI FRS Comparison Node 41Y (ASB El. 99')

C78

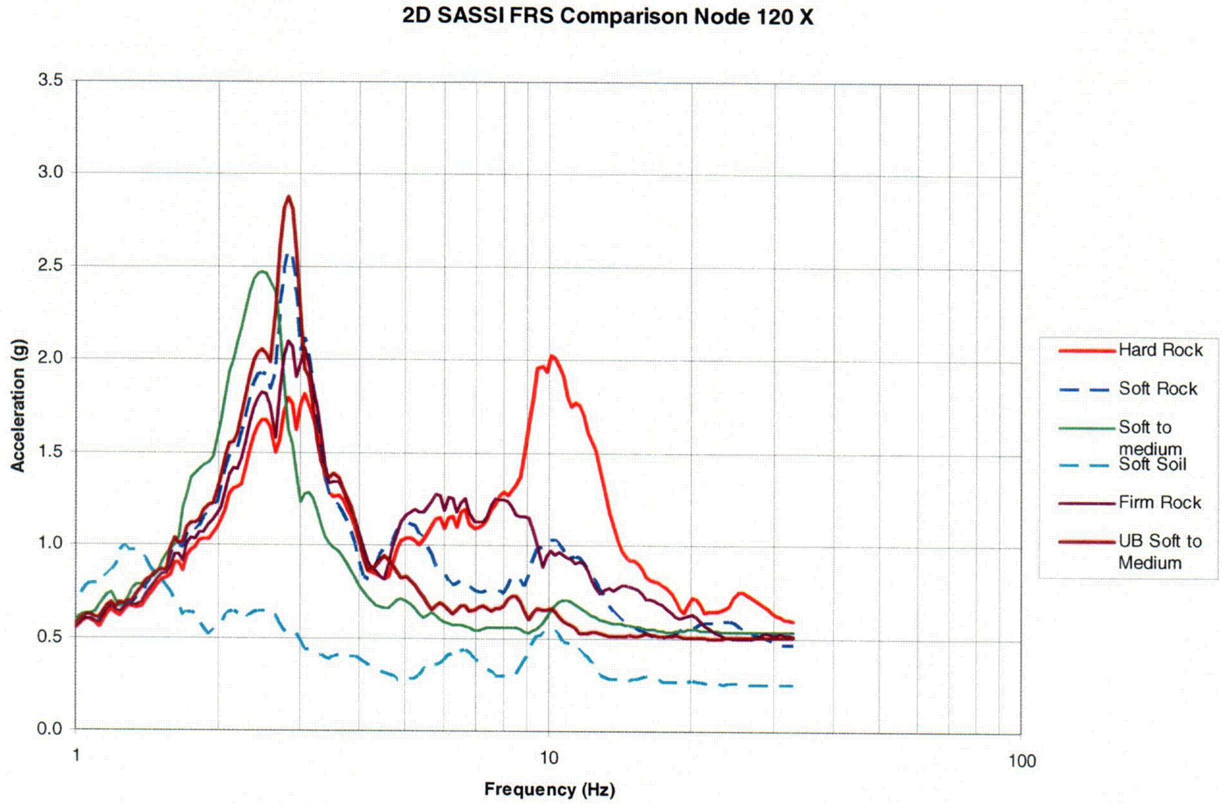


Figure D-3 - 2D SASSI FRS Comparison Node 120 X (ASB El. 179.6')

C79

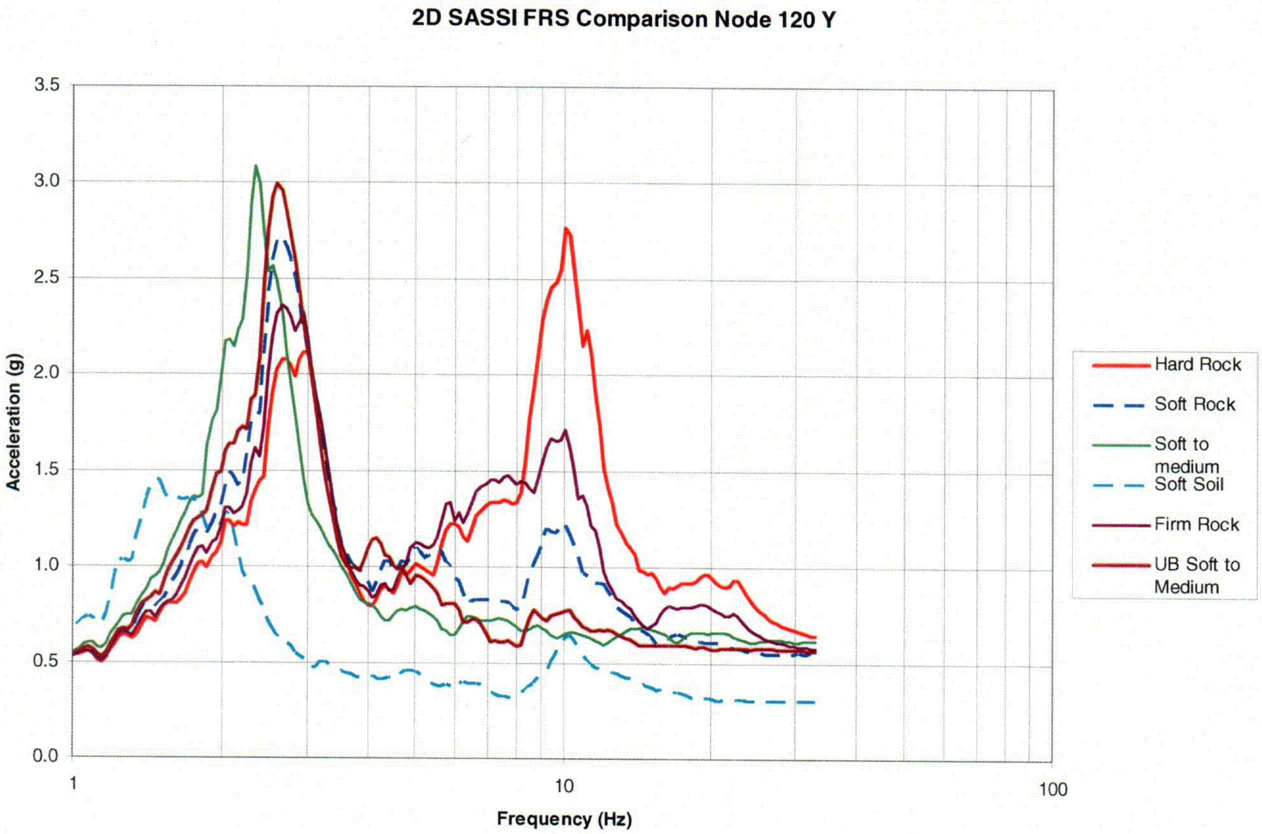


Figure D-4 - 2D SASSI FRS Comparison Node 120 Y (ASB El. 179.6')

C900

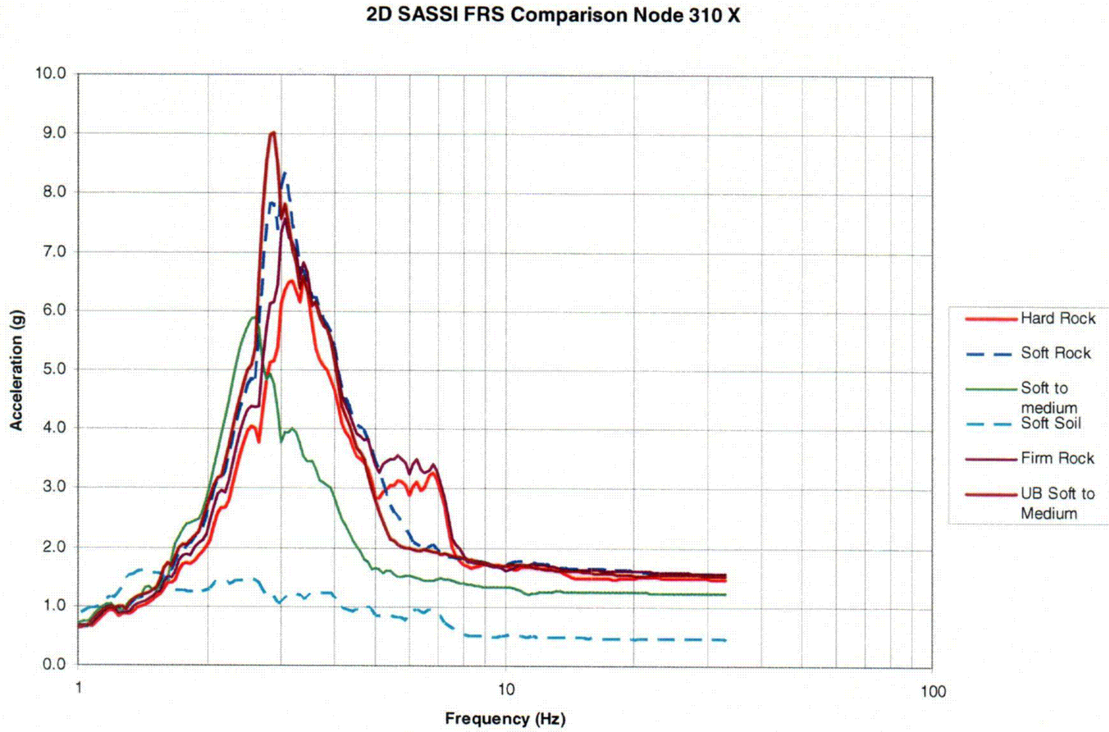


Figure D-5 - 2D SASSI FRS Comparison Node 310 X (ASB El. 333.2')

C01

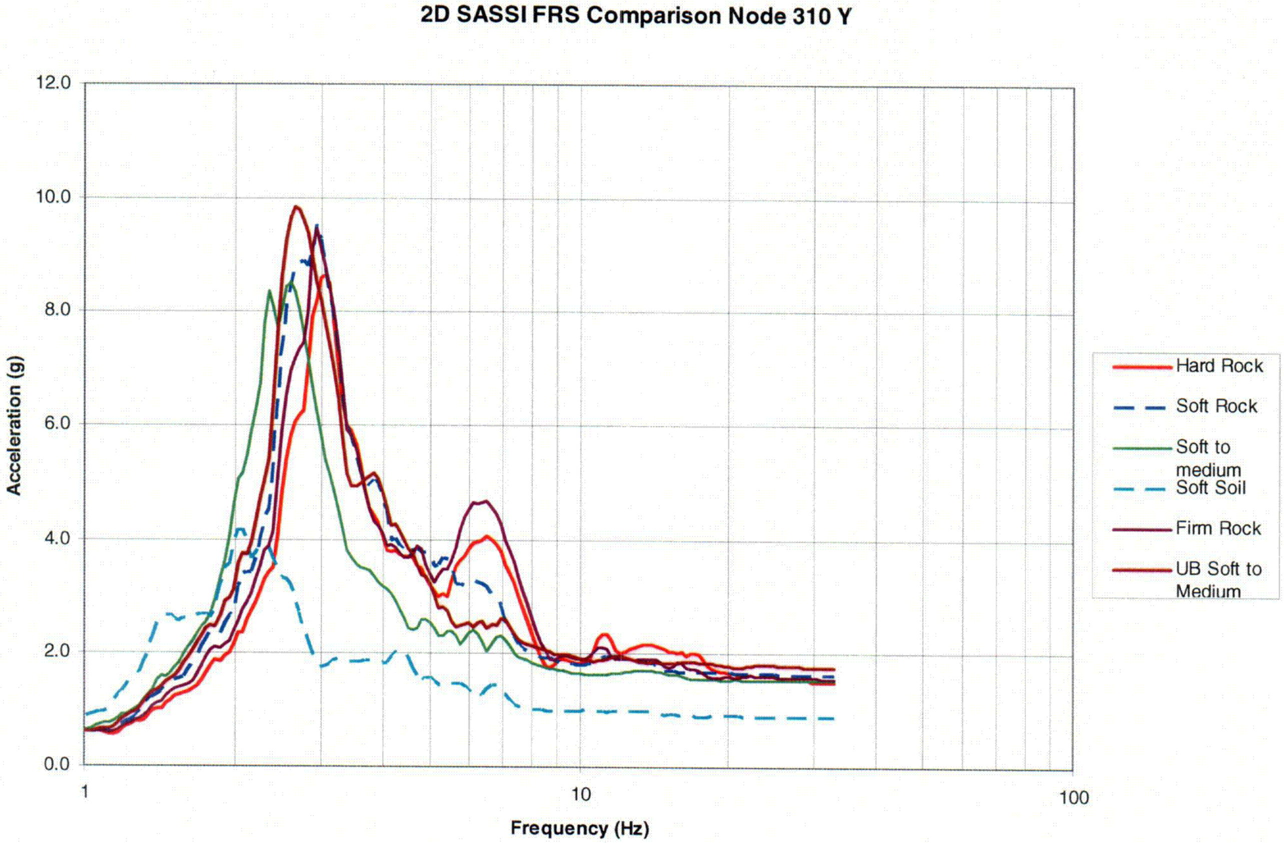


Figure D-6 - 2D SASSI FRS Comparison Node 310 Y (ASB El. 333.2')

C82

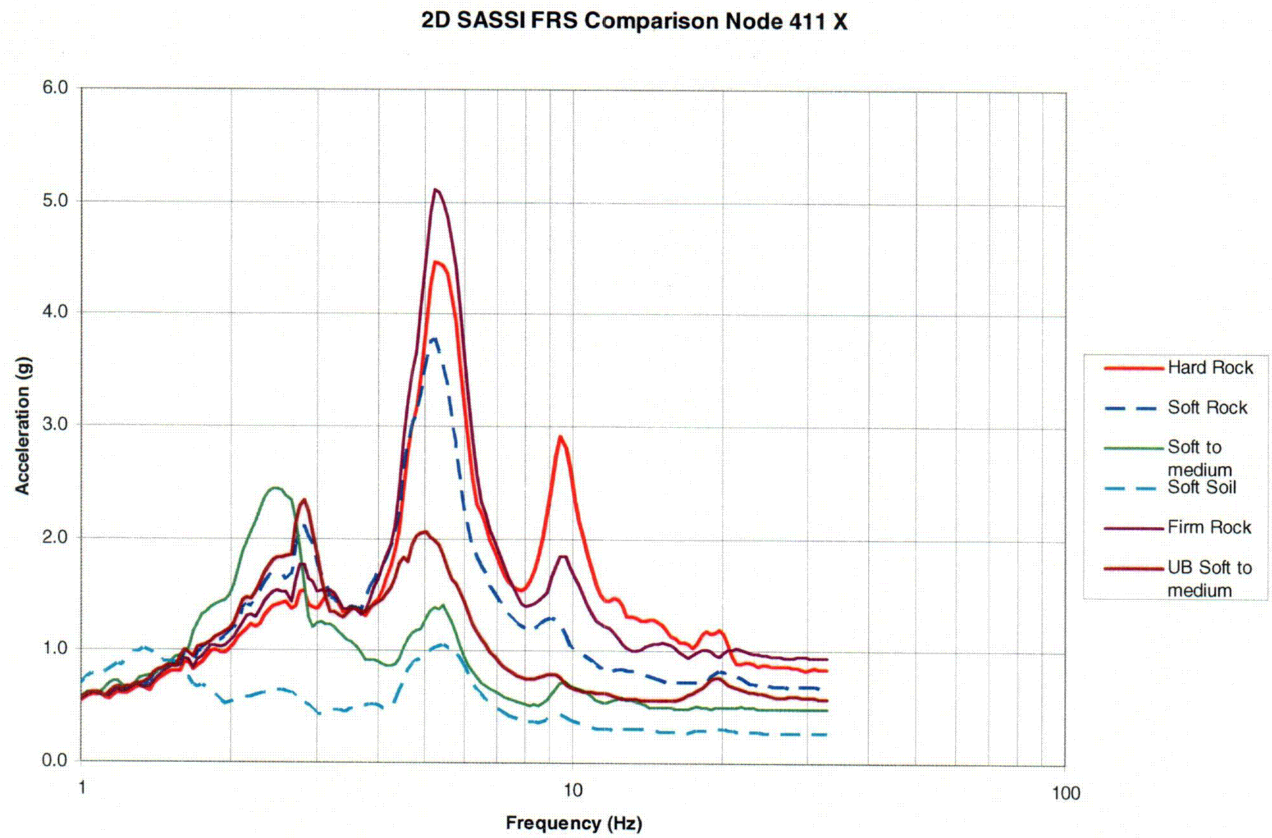


Figure D-7- 2D SASSI FRS Comparison Node 411 X (SCV El. 200.0')

C83

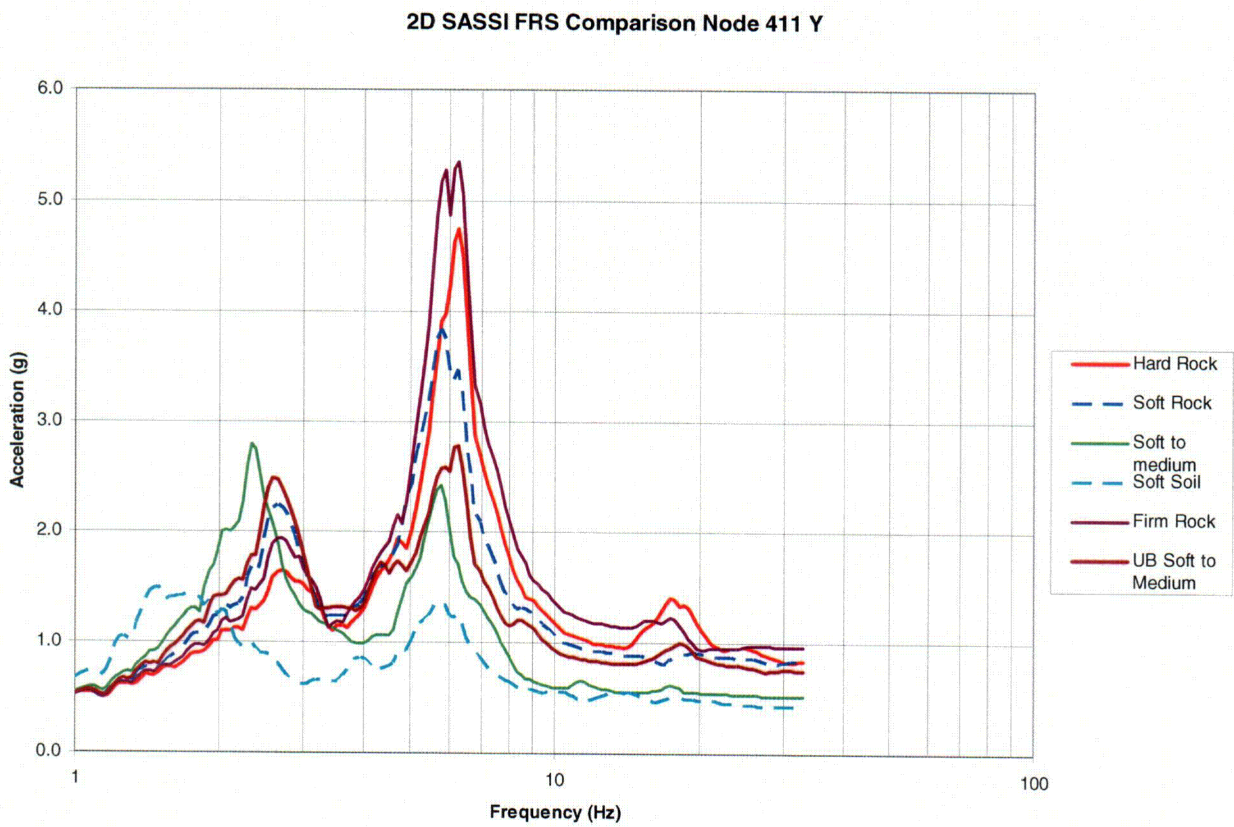


Figure D-8 - 2D SASSI FRS Comparison Node 411 Y (SCV El. 200.0')

C84

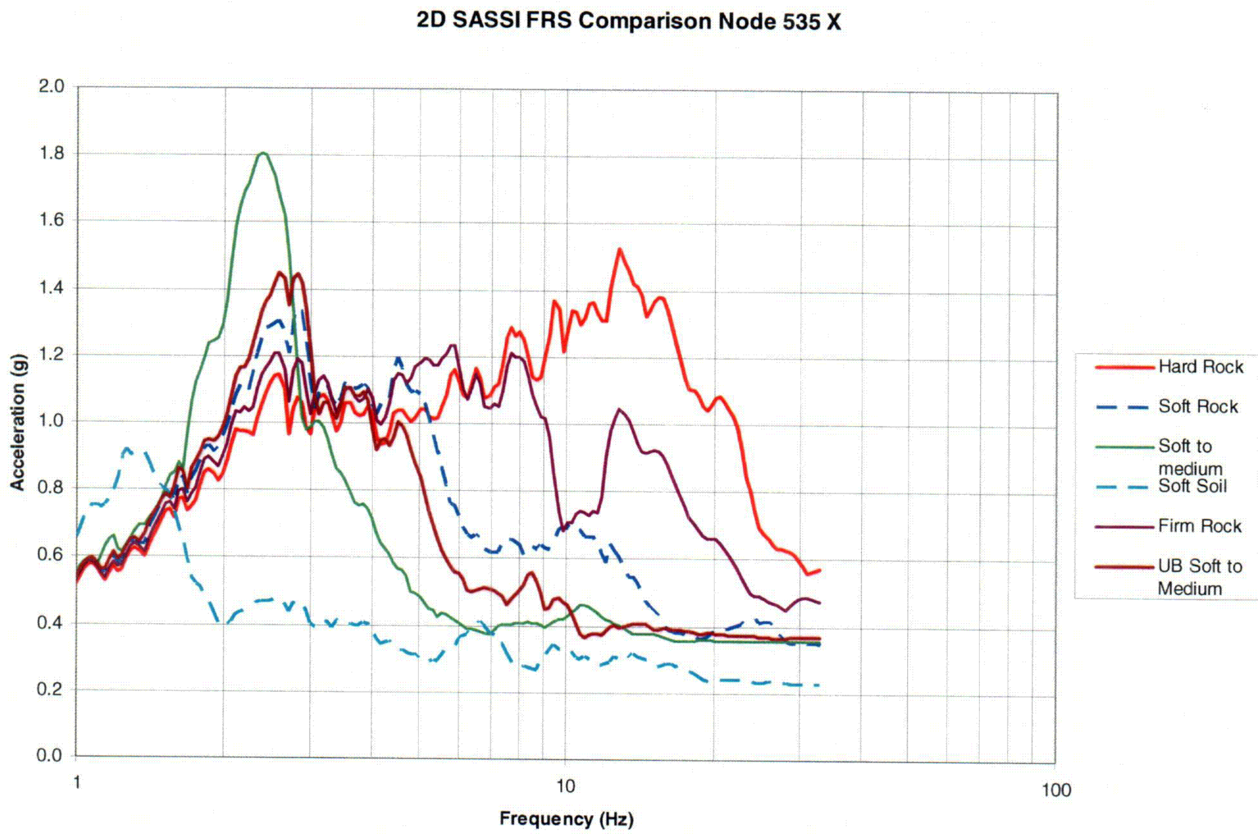


Figure D-9 - 2D SASSI FRS Comparison Node 535 X (CIS El. 134.3')

C85

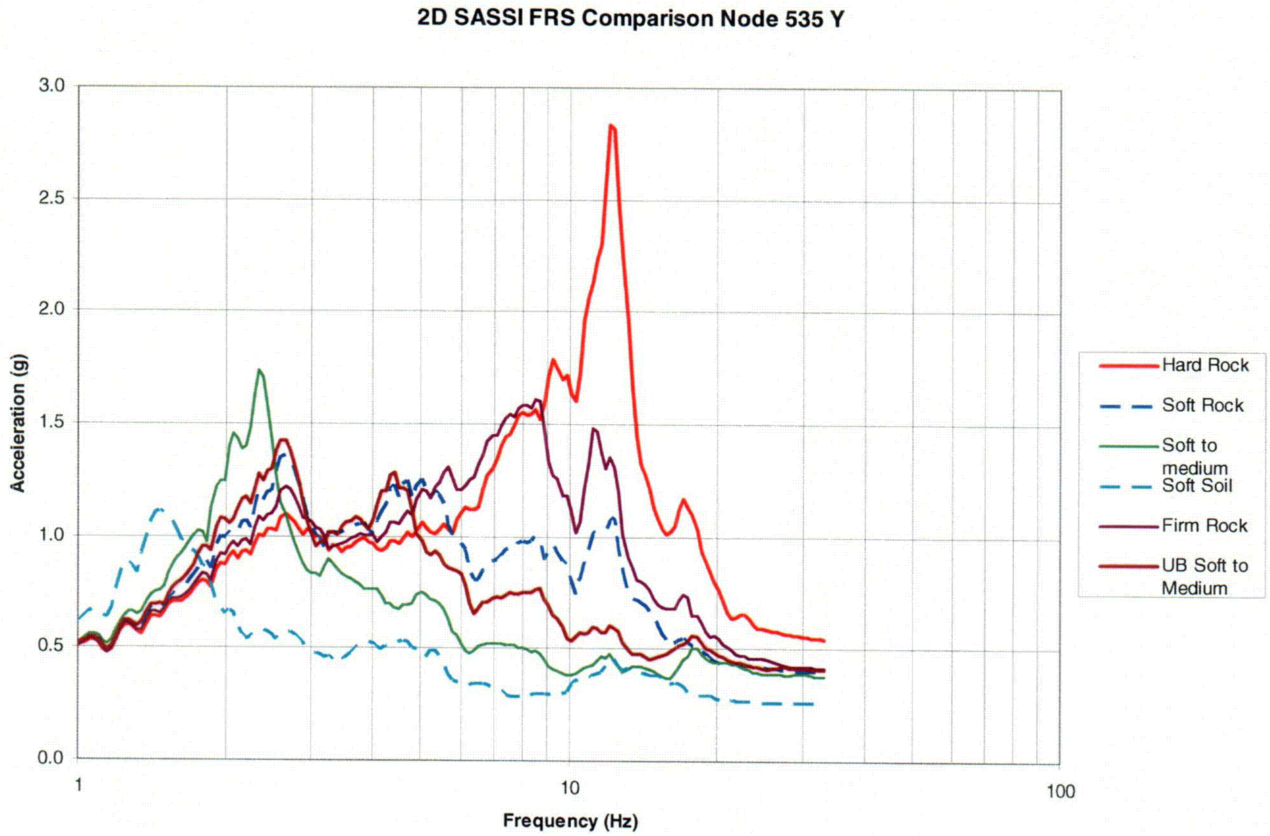


Figure D-10 - 2D SASSI FRS Comparison Node 535 Y (CIS El. 134.3')

C86

Appendix E - Comparison of Shell Model to Hard Rock Stick Model Results

Seismic accelerations have been provided in Section 3.7 of the AP1000 Design Control Document (DCD) for the hard rock sites. These accelerations are given for the auxiliary and shield building, steel containment vessel, and containment internal structure in Tables 3.7.2-5 to 3.7.2-7. The dynamic analysis of the Nuclear Island used stick models. In this section these results are compared to those obtained for the hard rock and soil sites using the 3D finite element models.

Table 6.2-3 of this report provided the maximum seismic accelerations for the ASB considering all of the soil and hard rock sites. The soil cases are: firm rock (FR), upper bound soft to medium (UBSM), and soft to medium (SM). The maximum equivalent static seismic accelerations (MAX) are defined by the envelope of all of the soil and HR cases. It is noted that the hard rock site predominately controls the ASB structural seismic response except at the lower elevations below 100'. In Figures E-1 and E-2 the maximum response (MAX) is compared to the seismic response documented in the DCD that is based on the stick models. As seen from this comparison the maximum seismic accelerations developed using the ASB stick model for the hard rock site are higher except for the locations below 100' elevation, and the auxiliary building North-South response at 180'. The finite element models of the ASB are more detailed than the stick models, and provide more realistic seismic response without excessive conservatism, and are therefore used to define the equivalent static seismic acceleration design values for the ASB considering all of the soil and hard rock sites.

Table 6.2-4 of this report are provided the equivalent static seismic acceleration values for the steel containment vessel. The hard rock site predominately controls for the North South and Vertical seismic components. The firm rock site controls for the East West seismic excitation. The Table 6.2-4 values are the maximum (MAX) seismic accelerations enveloping all the cases. In Figure E-3 are shown the comparisons of the MAX values from the finite element analyses, and the values given in the DCD (Table 3.7.2-6 mass center values) obtained from the hard rock site stick model analyses. The edge values given in DCD Table 3.7.2-6 are close to the mass center values. As seen from this comparison the stick model results are higher for the NS and EW seismic components, and very similar for the vertical seismic component. The SCV is designed for the mass center values given in DCD Table 3.7.2-6.

Table 6.2-6 of this report gives the equivalent static seismic accelerations (MAX values) for the containment internal structure. The hard rock site controls the North South response except below 100', HR and UBSM results define the MAX values for the East West response, and UBSM and SM results define the MAX values for the vertical response. The stick model results (DCD Table 3.7.2-7) are compared to the shell model MAX results in Figure E-4. From this figure it is seen that the stick models are higher for the NS and EW seismic response except below 100' where UBSM sites result in higher accelerations. For the vertical seismic excitation the hard rock site stick model results are lower. This is because the finite element model results are controlled by the soil sites UBSM and SM.

Table 6.2-7 of this report gives the accelerations used for overturning. DCD Tables 3.7.2-5, 3.7.2-6, and 3.7.2-7 (mass center values) were used in the Nuclear Island and SCV overturning analyses for the hard rock site. Comparing Table 6.2-7 accelerations to the DCD hard rock stick model results, DCD values envelope the finite element hard rock and soil sites except for the CIS vertical direction that is controlled by soil sites UBSM and SM. It is noted that for the horizontal seismic response the DCD stick model results are also slightly exceeded below 100' due to the soil sites.

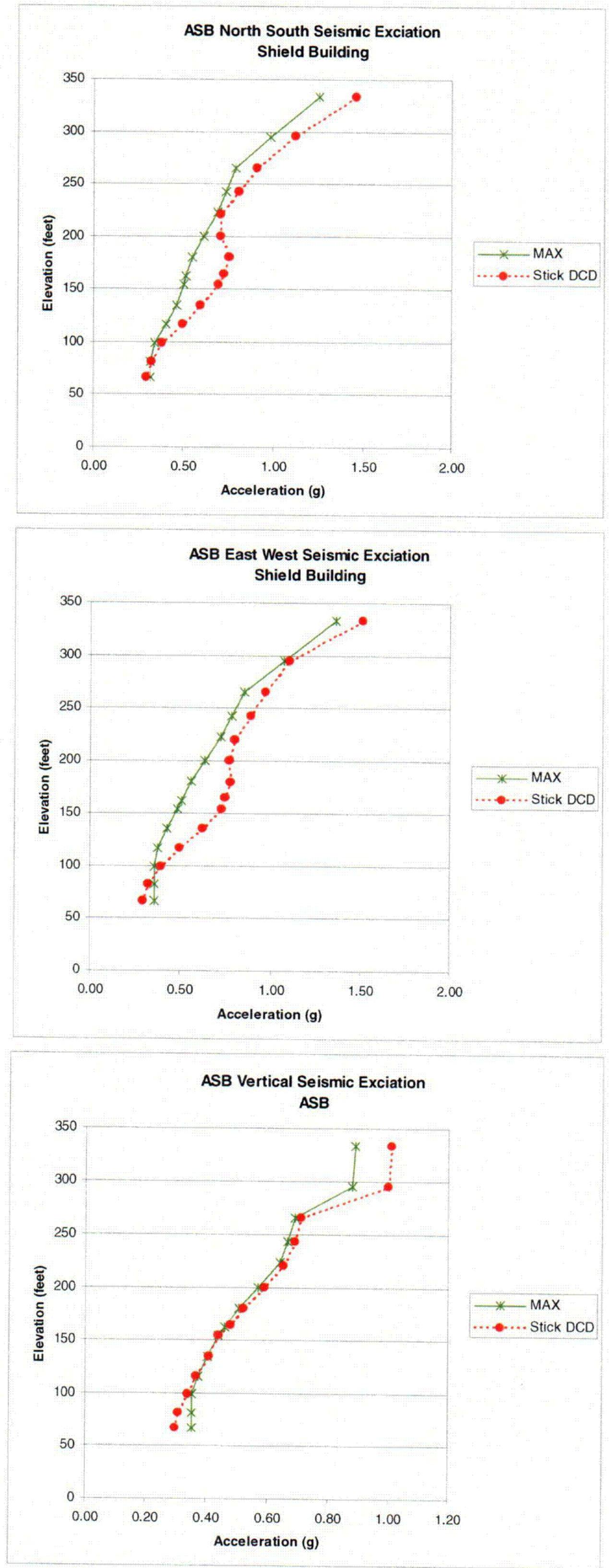
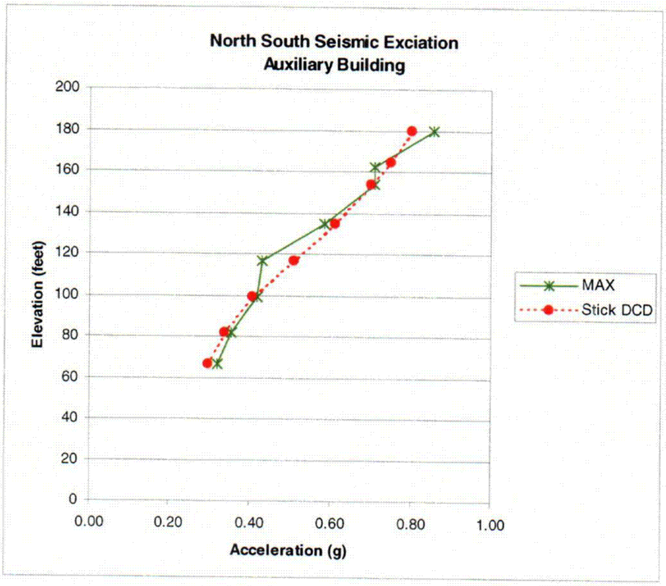


Figure E-1 – Comparison of ASB Response

C07



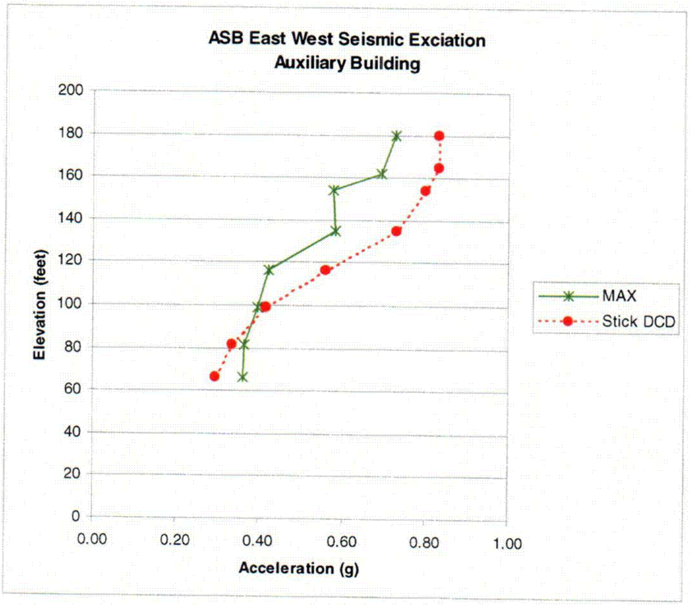


Figure E-2 – Comparison of Auxiliary Building Response

C88

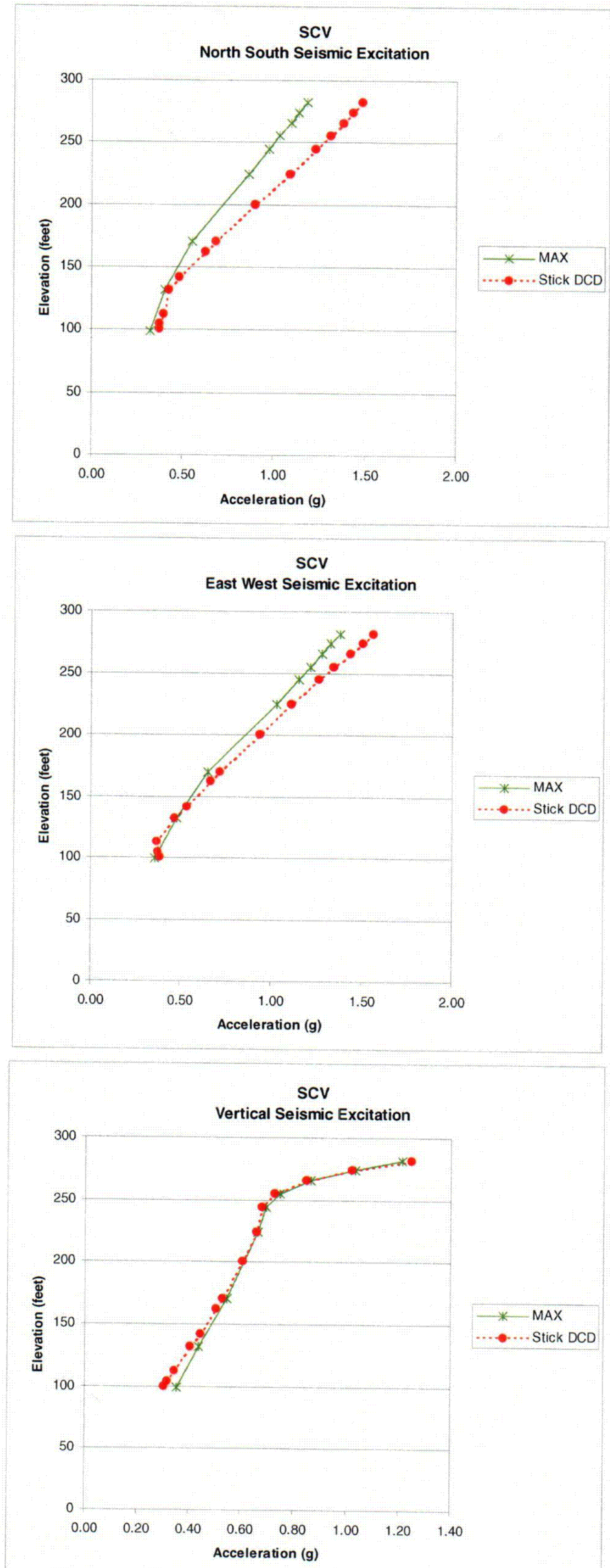
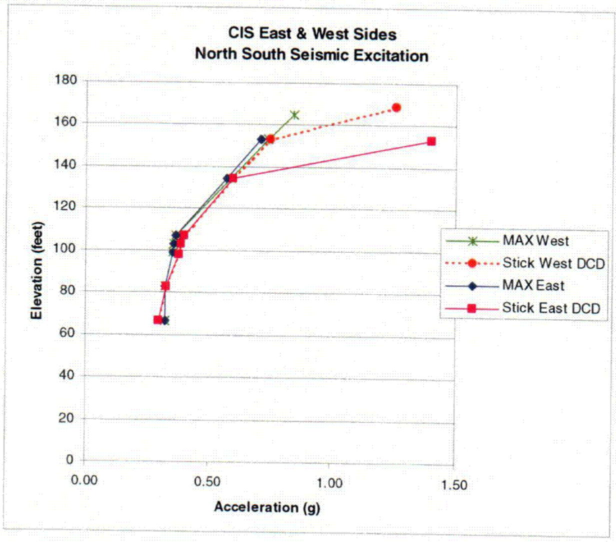
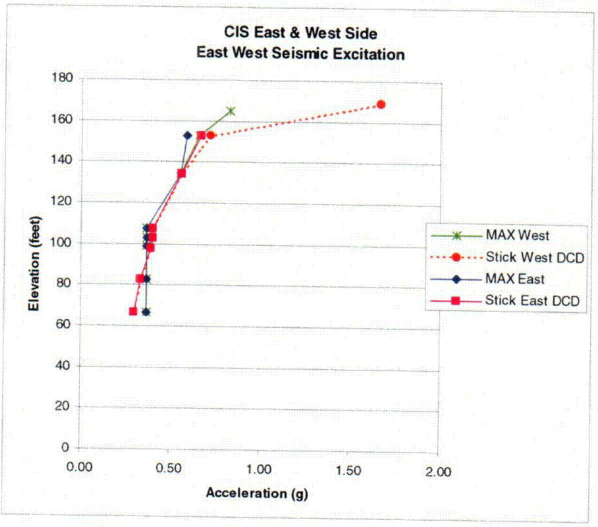


Figure E-3 – Comparison of SCV Response

C89





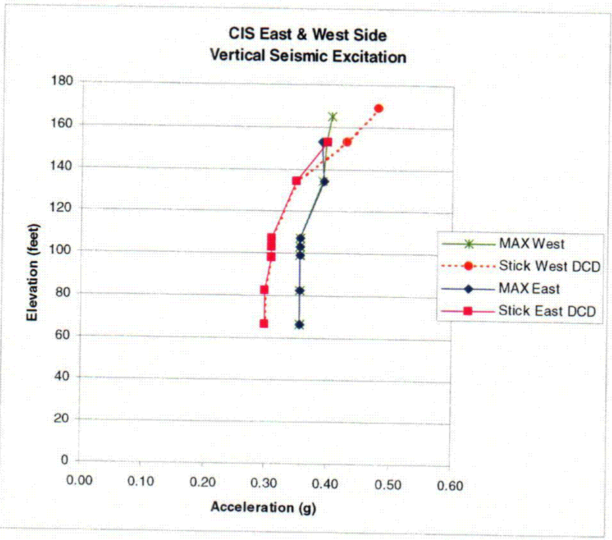


Figure E-4 – Comparison of CIS Response

C90

DCP/NRC1751
June 14, 2006

ENCLOSURE 2

"Changes to DCD for Model Change and Extension to Soil Sites"

dated June 14, 2006

ENCLOSURE 2

Changes to DCD for Model Change and Extension to Soil Sites

The replacement of building stick models with finite element shell/solid models and the extension of the seismic evaluations to non-hard rock sites will require changes in the DCD. In many case the text and figures in the DCD will be the same or similar to the text and figures in the enclosed report. In the interest of efficiency, Westinghouse is waiting for initial NRC review of the report to finalize the changes for the DCD. Westinghouse has determined the portions of the DCD that will be modified. The changes are outlined below:

Section 2.5.2.3 - Sites with Geoscience Parameters Outside the Certified Design – Site specific FRS will be compared against spectra enveloping the generic soil analysis results defined in Chapter 3 from shell models instead of stick models.

Section 3.7.2 – Seismic System Analysis – Revise items 1 to 6 to show increased use of shell models and reduced use of stick models in the design of the AP1000 plant changed. Add paragraph that discusses this change in model philosophy. Replace the reference to the Westinghouse internal "seismic analysis summary report" to the report to be submitted for NRC review.

Section 3.7.2.1.1 –Equivalent Static Acceleration Analysis – Revise first paragraph to describe equivalent static accelerations obtained from shell models. Modify under heading "Coupled Shield and Auxiliary Buildings on Fixed Base" to reflect that the containment internal structures are represented by shell models and not by a stick model.

Section 3.7.2.1.2 – Time-History Analysis – Modify the section to state that the NI building combined shell model is used for the development of seismic response and response spectra. Retain the discussion of the coupled lumped-mass stick models that are interconnected to form the overall dynamic model of the nuclear island since the seismic results from this model are still used for sensitivity studies and for comparison of results from the shell and stick models in the report.

Section 3.7.2.2 – Natural Frequencies and Response Loads – Retain results from stick models and refer to WCAP for results of shell models.

Section 3.7.2.3 – Procedure Used for Modeling – Retain but describe change in the use of the models described in this section.

Section 3.7.2-5 – Development of Floor Response Spectra – Revise to show that the design response spectra are developed using the NI shell model.

Section 3.7.2.11 – Method Used to Account for Torsional Effects – Retain but reference section in WCAP that discusses torsional effects for the NI building combined shell and stick model.

Table 3.7.2-14 – Summary of Models and Analysis Methods – Revise to show use of shell and stick models.

Table 3.7.2-16 – Summary of Dynamic Analyses & Combination Techniques - Revise to show use of shell and stick models.

Figure 3.7.2-13 - Nuclear Island Seismic Analysis Models - Revise to show use of shell and stick models.

Figures 3.7.2-15 to 17 – delete spectra from stick models. Comparisons between shell and stick models will be included in WCAP. Add spectra from shell models; these spectra will be used as design limits for site specific analyses described in subsection 2.5.4.

Section 3.8

Seismic results given in Section 3.8 based on the NI combined stick model are expected to be conservative, and there is no effect on design.