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Your ref: Project Number 740
Our ref: DCP/NRC2050

December 4, 2007

Subject: AP1000 COL Responses to Requests for Additional Information (TR 85)

In support of Combined License application pre-application activities, Westinghouse is submitting responses to the NRC requests for additional information (RAIs) on AP1000 Standard Combined License Technical Report 85, APP-GW-GLR-044, Nuclear Island Basemat and Foundation. These RAI responses are submitted as part of the NuStart Bellefonte COL Project (NRC Project Number 740). The information included in the responses is generic and is expected to apply to all COL applications referencing the AP1000 Design Certification.

Responses are provided for RAI-TR85-SEB1-04, -06, -08, -22, and -23 transmitted in an email from Dave Jaffe to Sam Adams dated August 9, 2007. Additionally, a revised response is provided to RAI-TR85-SEB1-34, transmitted in an email from Dave Jaffe to Sam Adams dated August 9, 2007, to be consistent with the updated seismic stability evaluation. With these responses, thirty-three of forty total requests received to date for Technical Report 85 have been completed. Responses to RAI-TR85-SEB1-03, -13, -27, and -38 were submitted under Westinghouse letter DCP/NRC1999 dated September 18, 2007. Responses to RAI-TR85-SEB1-01, -09, and -16 were submitted under Westinghouse letter DCP/NRC2002 dated September 21, 2007. Responses to RAI-TR85-SEB1-02 and -21 were submitted under Westinghouse letter DCP/NRC2006 dated September 28, 2007. Responses to RAI-TR85-SEB1-12, -14, -18, -20, -26, -31, and -33 were submitted under Westinghouse letter DCP/NRC2022 dated October 19, 2007. Responses to RAI-TR85-SEB1-10, -11, -15, -24, -25, -28, -29, -30, -34, -35, -37, and -39 were submitted under Westinghouse letter DCP/NRC2025 dated October 19, 2007.

Pursuant to 10 CFR 50.30(b), the responses to the requests for additional information on Technical Report 85, are submitted as Enclosure 1 under the attached Oath of Affirmation.

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

00297psa.doc

D063
D079
NRO

Very truly yours,

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

/Attachment

1. "Oath of Affirmation," dated December 4, 2007

/Enclosure

1. Responses to Requests for Additional Information on Technical Report No. 85

cc:	D. Jaffe	-	U.S. NRC	1E	1A
	E. McKenna	-	U.S. NRC	1E	1A
	G. Curtis	-	TVA	1E	1A
	P. Hastings	-	Duke Power	1E	1A
	C. Ionescu	-	Progress Energy	1E	1A
	A. Monroe	-	SCANA	1E	1A
	J. Wilkinson	-	Florida Power & Light	1E	1A
	C. Pierce	-	Southern Company	1E	1A
	E. Schmiech	-	Westinghouse	1E	1A
	G. Zinke	-	NuStart/Entergy	1E	1A
	R. Grumbir	-	NuStart	1E	1A
	B. LaPay	-	Westinghouse	1E	1A

ATTACHMENT 1

"Oath of Affirmation"

ATTACHMENT 1

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

In the Matter of:	)
NuStart Bellefonte COL Project	)
NRC Project Number 740	)

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

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

W. E. Cummins
Vice President
Regulatory Affairs & Standardization

Subscribed and sworn to
before me this 4th day
of December 2007.

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

Notary Public

ENCLOSURE 1

Responses to Requests for Additional Information on Technical Report No. 85

RAI Response Number: RAI-TR85-SEB1-04
Revision: 0

Question:

Sections 2.3.1, 2.4.1, 2.4.2, and 2.6.1 indicate that equivalent static nonlinear analysis (not clear whether 2D or 3D), 2D SASSI analysis, 2D ANSYS linear dynamic analysis, 2D ANSYS nonlinear time history analysis, 3D ANSYS equivalent static non-linear analysis, etc. were performed. Westinghouse needs to develop a table (or tables) similar to AP1000 DCD Tables 3.7.2-14 and 3.7.2-16 to show: (1) the purpose of the analysis; (2) the model type(s); (3) analysis method(s); (4) soil condition(s); (5) loads, load combinations, combination method (for combining loads and directional combination for SSE); (6) governing design loads; and (7) reference location in this technical report or other report for the detailed description.

Westinghouse Response:

DCD Tables 3.7.2-14 and 3.7.2-16 in Revision 15 were moved to Appendix 3G and renumbered to Tables 3G.1-1 and 3G.1-2. These Tables were included in TR03, Rev 1 and in TR134. The tables have been edited as shown in the DCD Revisions below to show additional information requested in this RAI as well as revisions due to changes in methodology described in other RAI responses.

Portions of these tables related to the basemat design analyses, soil bearing reactions, and stability evaluation are shown below including reference to the location in this technical report for the detailed description.

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. <u>See section 2.6 as modified by response to RAI-TR85-SEB1- 21</u>
3D finite element coarse shell model of auxiliary and shield building and containment internal structures [NI20] (including steel containment vessel, polar crane, RCL, and pressurizer)	Response spectrum analysis with seismic input enveloping all soils cases	ANSYS	To obtain total basemat reactions for overturning and stability evaluation. To obtain total basemat reactions for comparison to reactions in equivalent static analyses using NI05 model. <u>See section 2.6.1.2 as modified by response to RAI-TR85-SEB1-07 and 22</u>
Finite element lumped mass stick model of nuclear island	Time history analysis	ANSYS	Performed 2D linear and non-linear seismic analyses to evaluate effect of lift off on Floor Response Spectra and bearing. <u>See section 2.4.2</u>

Design Control Document (DCD) Revision:

Proposed revisions to Tables 3G.1-1 and 3G.1-2 are shown on the next pages. These tables were included in DCD Rev 16. Table 3G.1-1 was modified in TR03 Rev 1. This table was further edited in TR134 which identified all changes from DCD Rev 16. Revision bars shown in this RAI response show revisions to Table 3G.1-1 from those provided in TR134 Rev.0, and revisions to Table 3G.1-2 from those provided in DCD Rev 16.

These revised tables will be included in the next revision of TR134.

PRA Revision:

None

Technical Report (TR) Revision:

None

Revision marks show changes from TR134 Rev 0.

Table 3G.1-1 (Sheet 1 of 3)
SUMMARY OF MODELS AND ANALYSIS METHODS

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

Table 3G.1-1 (Sheet 2 of 32)
SUMMARY OF MODELS AND ANALYSIS METHODS

Model	Analysis Method	Program	Type of Dynamic Response/Purpose
Finite element lumped mass stick model of nuclear island	Time history analysis	SASSI	Performed 2D parametric soil studies to help establish the bounding generic soil conditions ~~and to develop loads for overturning and stability evaluation~~.
Finite element lumped mass stick model of nuclear island	Time history analysis	ANSYS	Performed 2D linear and non-linear seismic analyses to evaluate effect of lift off on Floor Response Spectra and bearing.
3D finite element coarse shell model of auxiliary and shield building and containment internal structures [NI20] (including steel containment vessel, polar crane, RCL, and pressurizer)	Time history analysis	SASSI	Performed for the five~~three~~ soil profiles of firm rock, soft rock, upper bound soft to medium soil, ~~and~~ soft to medium soil and soft soil. To develop time histories for generating plant design floor response spectra for nuclear island structures. To obtain maximum absolute nodal accelerations (ZPA) to be used in equivalent static analyses To obtain maximum displacements relative to basemat. To obtain maximum member forces and moments in selected elements for comparison to equivalent static results.
3D shell of revolution model of steel containment vessel	Modal analysis; Equivalent static analysis using accelerations from time history analyses	ANSYS	To obtain dynamic properties. To obtain SSE stresses for the containment vessel.
3D lumped mass stick model of the SCV	-	ANSYS	Used in the NI10 and NI20 models
3D lumped mass stick model of the RCL	-	ANSYS	Used in the NI10 and NI20 models
3D lumped mass stick model of the pressurizer	-	ANSYS	Used in the NI10 and NI20 models
3D lumped mass stick model of the CMT	-	ANSYS	Used in the NI10 model

3D lumped mass detailed model of the polar crane	Modal analysis	ANSYS	To obtain dynamic properties. Used with 3D finite element shell model of the containment vessel
Table 3G.1-1 (Sheet 3 of 3) **SUMMARY OF MODELS AND ANALYSIS METHODS**			
3D lumped mass simplified (single beam) model of the polar crane		ANSYS	Used in the NI10 and NI20 models
3D finite element shell model of containment vessel~~-(1)~~	Mode superposition time history analysis Equivalent static analysis~~; response spectrum analysis~~	ANSYS	Used with detailed polar crane model to obtain acceleration response of equipment hatch and airlocks. To obtain shell stresses in vicinity of the large penetrations of the containment vessel.
Static and Response Spectrum analyses			
3D finite element refined shell model of nuclear island (NI05)	Equivalent static non-linear analysis using accelerations from time history analyses; R~~r~~esponse spectrum analysis with seismic input enveloping all soils cases	ANSYS	To obtain SSE member forces for the nuclear island basemat. To obtain SSE member forces for the auxiliary and shield building and the containment internal structures. To obtain maximum displacements relative to basemat.
3D finite element coarse shell model of auxiliary and shield building and containment internal structures [NI20] (including steel containment vessel, polar crane, RCL, and pressurizer)	Mode superposition time history analysis with seismic input enveloping all soils cases	ANSYS	To obtain total basemat reactions for overturning and stability evaluation. To obtain total basemat reactions for comparison to reactions in equivalent static linear analyses using NI05 model.

Revision marks show changes from DCD Rev 16.

Table 3G.1-2

SUMMARY OF DYNAMIC ANALYSES AND COMBINATION TECHNIQUES

Model	Analysis Method	Program	Three Components Combination	Modal Combination
3D lumped mass stick, fixed base models	Mode superposition time history analysis	ANSYS	Algebraic Sum	n/a
3D finite element, fixed base models, coupled auxiliary and shield buildingASB shell model, with superelement of containment internal structures (NI10 and NI20)	Mode superposition time history analysis	ANSYS	Algebraic Sum	n/a
3D finite element nuclear island model (NI20)	Complex frequency response analysis	SASSI	Algebraic Sum	n/a
3D finite element, fixed base models, coupled auxiliary and shield buildingASB and containment internal structures including shield building roof (NI05)	Equivalent static analysis using nodal accelerations from 3D stick modelResponse spectrum analysis	ANSYS	SRSS or 100%, 40%, 40%	n/aLindley - Yow
3D finite element model of the nuclear island basemat (NI05)	Equivalent static analysis using nodal accelerations from 3D stickshell model	ANSYS	100%, 40%, 40%	n/a
3D shell of revolution model of Steel Containment Vessel	Equivalent static analysis using nodal accelerations from 3D stick model	ANSYS	SRSS or 100%, 40%	n/a
3D finite element model of the shield building roof	Equivalent static analysis using nodal accelerations from 3D stick model	ANSYS GT STRUDL	SRSS	n/a

Table 3G.1-2

SUMMARY OF DYNAMIC ANALYSES AND COMBINATION TECHNIQUES

Model	Analysis Method	Program	Three Components Combination	Modal Combination
PCS valve room and miscellaneous steel frame structures, miscellaneous flexible walls, and floors	Response spectrum analysis	ANSYS	SRSS or 100%, 40%, 40%	Grouping or Lindley - Yow
2D stick model analyses with lift off	Direct integration time history	ANSYS	Algebraic Sum	n/a

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-TR85-SEB1-06
Revision: 0

Question:

In Section 2.4.1, the second paragraph (Page 10 of 83) which describes the 2D SASSI analyses, states that the "moments provide a direct measure of the effect of soils on the total overturning moments. These overturning moments lead to the maximum bearing pressures which control design of the basemat." This statement appears to be inconsistent with Section 2.4.2 of the Technical Report, where the 2D ANSYS nonlinear model is used to obtain the governing maximum bearing pressure in the soil. Also, according to Section 2.6.1, the 3D ANSYS analysis is used to obtain member forces directly from the model and not the 2D SASSI calculated "maximum bearing pressures which control design of the basemat." Explain what was meant by the above statement taken from Section 2.4.1 and clarify the inconsistency.

In Section 2.4.1, the fourth paragraph indicates that 2D SASSI was used to calculate pressures for dead load and the SSE in the east west direction. Since SASSI only performs dynamic analyses, the use of SASSI to generate pressures for the dead load case needs to be clarified.

Westinghouse Response:

The results of the 2D SASSI analyses described in section 2.4.1 are used to select the soil case for additional non-linear analyses in ANSYS. For the selected soil case analyses are described in section 2.4.2 using ANSYS. These analyses include a linear analysis to compare results against the SASSI results followed by a non-linear analysis considering lift-off of the basemat from the soil.

The 2D SASSI calculated "maximum bearing pressures" do not control design of the basemat. The paragraph states that the overturning moments control design of the basemat. SASSI is a linear analysis code. The 2D ANSYS linear analysis is performed to check the ANSYS results against the SASSI results. Then the 2D ANSYS non-linear analyses provide the maximum bearing pressures to be used in the site specific bearing assessment.

The 3D ANSYS equivalent static non-linear analysis described in Section 2.6.1 is used to obtain member forces directly for sizing basemat reinforcement.

The calculations for dead load using SASSI were performed for a very low frequency sinusoidal input. This prevents amplification in the model and member forces are in phase with the input.

Design Control Document (DCD) Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:

Revise second paragraph of section 2.4.1 as follows:

Bending moments in the building sticks for the six AP1000 cases are shown in Figure 4.4.1-5 of Reference 3. The ASB and CIS sticks are coupled below grade. The bending moments in the ASB stick above grade are shown in Table 2.4-1. These bending moments provide a direct measure of the effect of soils on the total overturning moment. These overturning moments lead to the maximum bearing pressures which control design of the basemat and the demand on the soil.

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-TR85-SEB1-08
Revision: 0

Question:

In Section 2.4.1 reference is made to the 2D SASSI analyses in Westinghouse technical report TR-03, Revision 0. Table 4.4.1-1B of TR-03 indicates that only X shaking and Y shaking in the two horizontal directions are performed. Please explain why the third (vertical) direction was not performed, and how are the responses from the three directions combined?

Westinghouse Response:

The 2D SASSI horizontal analyses were performed to determine how the AP1000 responses compared to the AP600. These studies were then used to select the design soil profiles for the 3D analyses. At the time it was judged that the vertical response of the AP1000 would be similar to that of the AP600 and vertical analyses were not performed for the AP1000.

Results of the 2D SASSI analyses were combined with results of vertical analyses using ANSYS in the evaluation of stability. This use has been eliminated and nuclear island stability is now assessed using base reactions from the updated time history analyses of the nuclear island using time history inputs that envelope the basemat response given by the 3D SASSI analyses at the corners and centers of the basemat for all the specified generic soil cases. This is described in the Revision 1 response to RAI-TR85-SEB1-34.

Results of the 2D SASSI horizontal analyses are used as a benchmark in the evaluation of lift off and bearing pressures. A 2D ANSYS linear analysis is performed to check the ANSYS results against the SASSI results. Then the 2D ANSYS non-linear analyses provide the maximum bearing pressures to be used in the site specific bearing assessment. This is addressed further in the response to RAI-TR85-SEB1-05.

2D SASSI analyses may be used for evaluation of site specific features as described in DCD subsection 2.5.2. Such an evaluation will include comparison of the vertical response against the response calculated for the generic design soil cases.

Design Control Document (DCD) Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:
None

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-TR85-SEB1-22
Revision: 0

Question:

Section 2.6.1.2 indicates that the seismic loads for the evaluation of the basemat of the NI are developed from the results of the global seismic analyses as described in Section 6.2 of TR-03, Revision 0. The referenced report however, states that the set of equivalent static seismic accelerations used for the evaluation of the basemat and overturning stability are different than the acceleration values used for the design of the walls and floors of the building structures. The dynamic response of the structure affecting overturning and basemat uplift corresponding to about 3Hz on hard rock and 2.4 Hz on soil is utilized. The contributions from higher frequency modes are not considered. Based on this information address the following items:

a) The staff is concerned that this approach may not predict the true shear and overturning forces since some of the higher modes may also contribute to the forces imposed on the basemat and the foundation walls. Therefore, provide the technical justification for neglecting all modes above the fundamental mode of vibration, which may affect the design of the basemat and foundation walls as well as the sliding and overturning stability evaluation.

b) A sound technical justification, beyond the current explanation given in Section 6.2, is needed to show why (1) the amplified response from individual walls in the auxiliary building and the IRWST and (2) the loads from the reactor coolant loop and pressurizer are not included, since they may contribute additional loads to the evaluation of the basemat and overturning/sliding.

c) Section 6.2 of TR-03, Revision 0, indicates that the equivalent static approach is utilized for evaluation of the basemat and overturning stability. However, Section 2.4.1 of the Technical Report, which describes the 2D SASSI analysis for developing loads for evaluation of sliding and overturning, and Section 2.9, which uses the 2D SASSI analysis results for evaluation of the NI stability, are based on time history analyses not equivalent static analyses. Also, Section 2.4.2 of the Technical Report, which describes the 2D ANSYS nonlinear uplift analysis, is based on a time history analysis not equivalent static analysis. Therefore, explain this inconsistency regarding the method of analysis used for evaluation of the NI stability.

d) Table 6.2-7 in Section 6.2 of TR-03, Revision 0, does not appear to identify correctly the table numbers listed under the "Notes" column (e.g., "Table 6.2-4 Shield Bldg" should be Table 6.2-3). Clarification is needed.

Westinghouse Response:

Section 6.2 of TR-03, Rev 0 was substantially revised in TR-03, Rev 1 when the seismic design methodology was revised from the equivalent static acceleration method to the response spectrum method for the auxiliary and shield building and for the containment internal structures. The description of the equivalent static accelerations used in the nuclear island basemat analyses is provided in a revised section 2.6.1.2 of TR-85, Rev 1 as shown below in the Technical Report Revisions. The adequacy of the equivalent static accelerations has been confirmed in updated time history analyses of the nuclear island using time history inputs that envelope the basemat response given by the 3D SASSI analyses at the corners and centers of the basemat for all the specified generic soil cases. This is described in the proposed revision to TR85.

a) The equivalent static accelerations do not neglect all modes above the fundamental mode of vibration. They were the maximum values from a time history analysis which included all significant modes of vibration. As shown in the revised section 2.6.1.2, the bearing reactions in the design analysis are comparable to those from the time history analyses.

b) The time history base reactions reported in the revised Table 2.6-2(b) are from nuclear island models that include (1) the amplified response from individual walls in the auxiliary building and the IRWST and (2) the loads from the reactor coolant loop and pressurizer. The base reactions in the design analysis are comparable to those from the time history analyses, thus supporting the statement that these effects were not significant.

c) Section 6.2 of TR-03, Revision 0, was incorrect when it implied that the equivalent static approach was utilized for evaluation of overturning stability. This section has been rewritten in TR-03, Revision 1. Equivalent static loads are only used for the nuclear island basemat design analyses.

d) Table 6.2-7 of TR-03, Revision 0, has been deleted in TR03, Rev 1.

Design Control Document (DCD) Revision:
None

PRA Revision:
None

Technical Report (TR) Revision:

Revise sections 2.6 and 2.6.1 as shown below. These changes include those identified in the response to RAI-TR85-SEB1-21.

2.6 *Nuclear island basemat design*

The design of the nuclear island basemat is described in the basemat design summary report prepared in accordance with the guidelines of Standard Review Plan 3.8.4. The design is based on the worst combination of seismic loads and soil properties. Non-linear equivalent static analyses are performed which consider lift off of the basemat from the soil. The analyses use the detailed model of the nuclear island (NI05) shown in Figures 2.6-1, ~~and~~ 2.6-2 and 2.6-2 (a) thru (d). The soft-to-medium soil case is considered as described in section 2.4.1. These analyses are similar to those described in section 2.2.1 for the AP600 and in section 2.3.1 for the AP1000 on hard rock. The equivalent static loads are developed from ~~the maximum~~ accelerations given by time history analyses of the nuclear island on hard rock and soil sites. No credit is taken in these analyses for the effect of side soils.

The design analyses of the nuclear island basemat were performed with the finite element model of the nuclear island prior to the design changes to enhance the shield building. These changes affected the upper portions of the shield building and did not affect the structure close to the basemat. Member forces in the basemat due to the equivalent static accelerations are therefore valid for the given loads. The adequacy of the equivalent static acceleration loads are addressed in Section 2.6.1.2.

The 3D ANSYS equivalent static nonlinear finite element model, used to evaluate the basemat and foundation walls, is the NI05 model described in DCD Rev 16 Appendix 3G, subsection 3G.2.3. The NI05 model is a large solid-shell finite element model of the AP1000 nuclear island which combines the ASB solid-shell model described in DCD subsection 3G.2.1.1, and the CIS solid-shell model described in DCD subsection 3G.2.1.2. Dead and seismic loads from the containment vessel and polar crane are applied as loads at elevation 100'. The nominal element size in the ASB portion of this NI05 model is about 4.5 feet so that each wall has four elements for the wall height of about 18 feet between floors. Views of this model are provided in Figures 2.6-1, 2.6-2 and 2.6-2 (a) thru (d).

The nuclear island is modeled using the following shell, solid and spring elements:

- Basemat (6 foot thick portion): SHELL43 elements
- Basemat (DISH): SOLID45 elements
- Containment internal basemat (mass concrete): SOLID45 elements
- Auxiliary building walls and floors: SHELL43 elements
- Containment internal structure walls and floors: SHELL43 elements
- containment shell: SHELL43 elements
- shield building: SHELL43 elements
- Linear springs at CV interface: COMBIN14 elements
- Nonlinear soil springs: COMBIN37 elements

The basemat below the containment vessel (DISH) is modeled with solid elements. There are three elements through the thickness as shown in Figures 2.6-2 (a) and (b). Member forces across a section through the solid elements are calculated along a path using the PATH stress function of ANSYS. The accuracy of member forces using three solid elements was confirmed by comparison of results to those from a shell model.

Soil Spring elements (COMBIN37) are attached on each node on the underside of the basemat. For the 6' thick basemat, the nodes are on the center of the 6' thick basemat shell elements (elevation is EL63'-6" at the center of the 6' thick basemat). For the central basemat (DISH), the nodes are on the bottom of the solid elements (elevation is EL60'-6"). At each node three COMBIN37 springs are attached for NS, EW and vertical directions respectively.

The connection of the ASB portion of the model to the DISH representing the mass concrete below the containment vessel is shown in Figure 2.6-2 (c). The solid model extends to the mid-plane of the cylindrical wall (radius of 71 feet). The shell elements of the shield building cylindrical wall extend down to the underside of the basemat at elevation 60'- 6". The vertical shell elements have a thickness of 1.5 feet (half the thickness of the wall above) in areas where the shell element forms the surface of the solid elements of the mass concrete. Shell elements from the auxiliary building including the basemat connect to the vertical shell elements which in turn are connected to the solid elements, thus providing rotational continuity.

Figure 2.6-2 (d) shows the locations of nodes on the DISH which interface with the containment vessel shell and the containment internal structure basemat. The bottom head of the containment vessel is modeled by shell elements to permit analyses for containment pressure. Coincident nodes are provided for the DISH, the containment vessel and the containment internal structure basemat. The boundary between the CV and CIS, and the boundary without studs between the CV and DISH are modeled with linear spring elements (COMBIN14) normal to the boundary to transmit normal forces only. The boundary with studs between the CV and DISH is modeled with linear spring elements (COMBIN14) normal and parallel to the boundary. In each analysis the spring forces in the normal spring elements are checked for lift off and spring elements are eliminated if liftoff occurs.

2.6.1 3D ANSYS Equivalent Static Non-Linear Analysis

2.6.1.1 Subgrade modulus

The basemat under the auxiliary building is 6 feet thick and supports a grid work of walls. These walls in turn stiffen the slab by producing relatively short spans, in the range of 3 to 4 times the thickness. The design of the 6' thick portion of the mat is controlled by the maximum bearing pressure under the slab during a seismic event. Maximum bearing pressures occur for the case of maximum overturning moment. Due to the shape of the footprint of the nuclear island seismic loads in the east-west direction give the largest bearing pressures and the greatest potential for lift off.

Table 2.6-1 shows the subgrade modulus calculated for each of the ~~2D SASSI~~generic soil cases using the Steinbrenner method previously used for the AP600. These calculations used the same degraded shear modulus properties in each layer as used in the SASSI analyses. They used a constant Poisson's ratio and do not consider the effect of the water table up to grade. The subgrade moduli shown in the left hand column of Table 2.6-1 were used in the 2D ANSYS analyses described in section 2.4.2. The subgrade moduli were subsequently revised based on comparisons against results of an ANSYS study. These revised values are shown in the right hand column of the table. Floor response spectra from the ANSYS analyses compared well in the frequency range of soil structure interaction to the results of 2D SASSI. These comparisons confirmed that the subgrade moduli provide a close match for the overall dynamic response.

Reinforcement design uses member forces from analyses of the nuclear island on soil springs. The shear and bending moment in the basemat are dependent on the relative stiffness of material supporting the foundation and the global stiffness of the nuclear island buildings and the local bending stiffness of the basemat. The walls of the nuclear island are stiff relative to a soil. The contact pressure is nearly linearly distributed and the actual magnitude of the subgrade modulus has small effect on the member forces in walls of the nuclear island. The local slabs of the basemat, spanning 18 to 25 feet between walls, are flexible relative to the subgrade. For such a case, there will be a decrease in pressure near the center of the slab and an increase in pressure near the walls. This redistribution decreases as the subgrade modulus decreases. It is therefore conservative for the design of the basemat to use a low value of the subgrade modulus. This is discussed further in section 2.7 which describes analyses of a detailed model of portions of the basemat on both soil springs and soil finite elements.

The AP600 basemat analysis used the soft to medium linear profile (this profile was subsequently changed to the parabolic profile thus increasing shear wave velocity below the nuclear island). Soil springs of 520 kcf were established by the Steinbrenner method using undegraded properties and soil up to grade.

Although the subgrade modulus calculated for the AP1000 soil cases in Table 2.6-1 could have justified use of a subgrade modulus of 1000 578 kcf for the dry soft to medium soil or 1300 963 kcf with the water table above the foundation level, it was decided to retain the 520 kcf used in the AP600 analyses. As described above this is conservative since it maximizes the bending moments in the slabs. It also permitted a direct comparison of the AP1000 analyses to those for the AP600.

2.6.1.2 Equivalent static accelerations

Seismic loads for the evaluation of the basemat of the Nuclear Island weare developed from the results of the global seismic analyses on hard rock using models prior to the design change to enhance the shield building. They are specified as equivalent static seismic accelerations as shown in Table 2.6-.2 (a) 7 of Reference 3. These accelerations envelope the response of all soil conditions.

The equivalent static accelerations used in the non-linear design analyses of the nuclear island basemat were evaluated for the revised design with the enhanced shield building by comparing total base reactions and bearing pressures in a linear analysis using these equivalent static accelerations to those from a dynamic analysis of the updated nuclear island model (NI20). A time history fixed base analysis of the updated model was performed using time history inputs that envelope the basemat response given by the 3D SASSI analyses at the corners and centers of the basemat for all the specified generic soil cases. The floor response spectra and broadened envelope at the center of the containment for the five soil cases analyzed in SASSI are shown in the left side of Figure 2.6-2 (e). The envelopes of the broadened spectra at the center and corners of the basemat are shown in the right hand side of the figure. The spectra for the time history developed enveloping these broadened spectra are shown in Figure 2.6-2 (f).

Table 2.6-2 (b) compares the sum of the soil reactions on the basemat for the equivalent static accelerations applied in the design analyses of the basemat on soil springs to those obtained from linear time history analyses of the nuclear island. The values for the fixed base analyses are from the nuclear island stick shell model (NI20)time history analyses documented in the AP1000 DCD for the hard rock analyses. - The values for the soft to medium soil are from 2D SASSI analyses described in section 2.4.1. The basemat reactions for the equivalent static analyses compare well against those of the "all soils" time history with the exception of the horizontal FY and vertical FZ components. The exceedance of the horizontal component is not important to the design of the basemat which is controlled primarily by vertical soil pressures induced by the vertical FZ component and the overturning moments. The exceedance of the vertical component was evaluated by comparing the bearing pressures at the corners and west edge of the nuclear island due to the vertical FZ component and the overturning moments. These bearing pressures were calculated from the basemat reactions assuming a rigid basemat for dead, live and seismic loads. Seismic loads were considered using the 1.0, 0.4, 0.4 combination method. Maximum bearing pressures for the two cases are shown in Table 2.6-2 (c). The bearing pressures resulting from the equivalent static accelerations are similar to those due to the "all soils" time history analysis demonstrating the adequacy Comparison of the base reactions demonstrate the conservatism of the equivalent static accelerations applied in the basemat analyses.

2.6.1.3 Normal load bearing reactions

The bearing reactions under dead and live load from the 3D ANSYS analyses on soil springs with subgrade modulus of 520 kcf are shown in Figure 2.6-3.

2.6.1.4 Normal plus seismic reactions

Liftoff analyses were performed for 16 load cases of dead, live and seismic loads for the soil site with subgrade modulus of 520 kcf. Seismic loads are applied with unit factor in one direction and with 0.4 factor in the other two directions. Maximum bearing reactions at the corners of the auxiliary building and at the west side of the shield building are shown in Table 2.6-3. Bearing pressure contours are shown in Figures 2.6-4 to 2.6-8 for the five load cases resulting in these maximum bearing reactions. The seismic load combination is shown for each figure. Note that the bearing pressures reduce rapidly away from the corners. These figures show lift off for equivalent static loads which are higher than the maximum time history loads as discussed in section 2.4.2. This is particularly the case for load combinations with unit seismic load in the Y direction (East-West) where the footprint dimension is smaller. The results of the equivalent static analyses are used for basemat design. The maximum bearing capacity reactions for defining minimum dynamic soil bearing capacity are based on time history analyses as discussed in Section 2.4.2.

Table 2.6-1

Subgrade modulus for AP1000 Soil Cases

Soil case	Subgrade modulus	Revised subgrade modulus
	kcf	kcf
Hard rock	6267	6267
Firm rock		3760
Soft rock	3230	1630
Upper bound soft to medium (dry)	2334	1320
Soft to medium (water table to grade)	1280	780
Soft to medium (dry)	963*	578
Soft (dry)	312	189

*Note: For water table up to grade this increases to 1280 kcf

Table 2.6-2 (a)

Equivalent Seismic Static Accelerations for Nuclear Island Basemat Analyses

	Elevation	Equivalent Static Seismic Accelerations (1)				Elevation	Equivalent Static Seismic Accelerations (1)		
-	feet	X	Y	Z	-	feet	X	Y	Z
Shield Bldg	66.5	0.3	0.3	0.3	SCV	100	0.32	0.33	0.31
& Aux Bldg	81.5	0.32	0.33	0.32	-	104.13	0.32	0.35	0.32
-	99	0.32	0.34	0.35	-	112.5	0.34	0.39	0.35
-	116.5	0.46	0.4	0.37	-	131.68	0.37	0.49	0.41
-	134.88	0.6	0.47	0.38	-	141.5	0.42	0.54	0.44
-	153.98	0.63	0.5	0.44	-	162	0.51	0.65	0.49
-	162	0.65	0.52	0.46	-	169.93	0.55	0.69	0.51
-	180	0.68	0.55	0.51	-	200	0.72	0.83	0.58
-	200	0.68	0.61	0.56	-	224	0.89	0.97	0.63
-	222.75	0.67	0.68	0.62	-	244.21	1.02	1.1	0.66
-	242.5	0.73	0.76	0.65	-	255.02	1.09	1.16	0.71
-	265	0.79	0.85	0.69	-	265.83	1.16	1.23	0.82
-	294.93	0.96	1.06	0.88	-	273.83	1.2	1.28	0.98
-	333.13	1.23	1.35	0.89	-	281.9	1.25	1.32	1.21
Platform	290.5	2.16	1.93	1.01	Polar Crane	233.5	1.45	2.51	1.34
-	-	-	-	-	-	-	-	-	-
CIS	60.5	0.3	0.3	0.3	CIS	107.2	0.35	0.34	0.32
-	66.5	0.3	0.3	0.3	-	134.3	0.5	0.5	0.37
-	82.5	0.31	0.31	0.3	SGE	153	0.61	0.69	0.4
-	98	0.32	0.33	0.31	SGW	153	0.61	0.69	0.4
-	103	0.34	0.34	0.31	Press	169	0.81	1.18	0.46

Notes:

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

Table 2.6-2 (b)

Nuclear Island Base Reactions

Units: 1000 kips & 1000 ft-kip

Seismic Reactions		**Base Reactions**	
		Equivalent Static Accelerations applied to NI in Basemat Design Analyses	**Fixed Base Time History Analysis (NI20 ~~Hard Rock~~All soils)**
Shear NS	FX	124.48	116.45~~100.68~~
Shear EW	FY	120.51	127.51~~94.84~~
Vertical	FZ	110.38	129.68~~98.78~~
Moment about NS	MXX	11,357	11,700~~9,670~~
Moment about EW	MYY	11,520	11,200~~10,323~~

Notes:

1. Moment summation point is at the center of the shield building at EL 60'-6" (X=1000, Y=1000, Z=60.5).
2. Equivalent static results for three directions are combined by SRSS
3 See Table 2.4-2 for 2D analysis results for other soils.

Table 2.6-2 (c)

Maximum soil bearing pressures (ksf) at corners from basemat reactions

Location	**Equivalent static accelerations**	**Fixed base time history all soils**
West side of shield building	35.9	36.9
NW corner of auxiliary building	24.4	24.8
NE corner of auxiliary building	25.1	25.5
SE corner of auxiliary building	24.7	25.1
SW corner of auxiliary building	27.0	27.1

Table 2.6-3

Maximum soil pressure at corners from equivalent static non-linear analyses

Location	**Maximum bearing pressure (ksf)**	**Load Case**	S_{NS}	S_{EW}	S_{VT}
West side of shield building	52.8	3-13	-0.4	1.0	0.4
NW corner of auxiliary building	28.9	3-2	1.0	0.4	-0.4
NE corner of auxiliary building	29.7	3-11	0.4	-1.0	0.4
SE corner of auxiliary building	26.7	3-15	-0.4	-1.0	0.4
SW corner of auxiliary building	33.1	3-5	-1.0	0.4	0.4

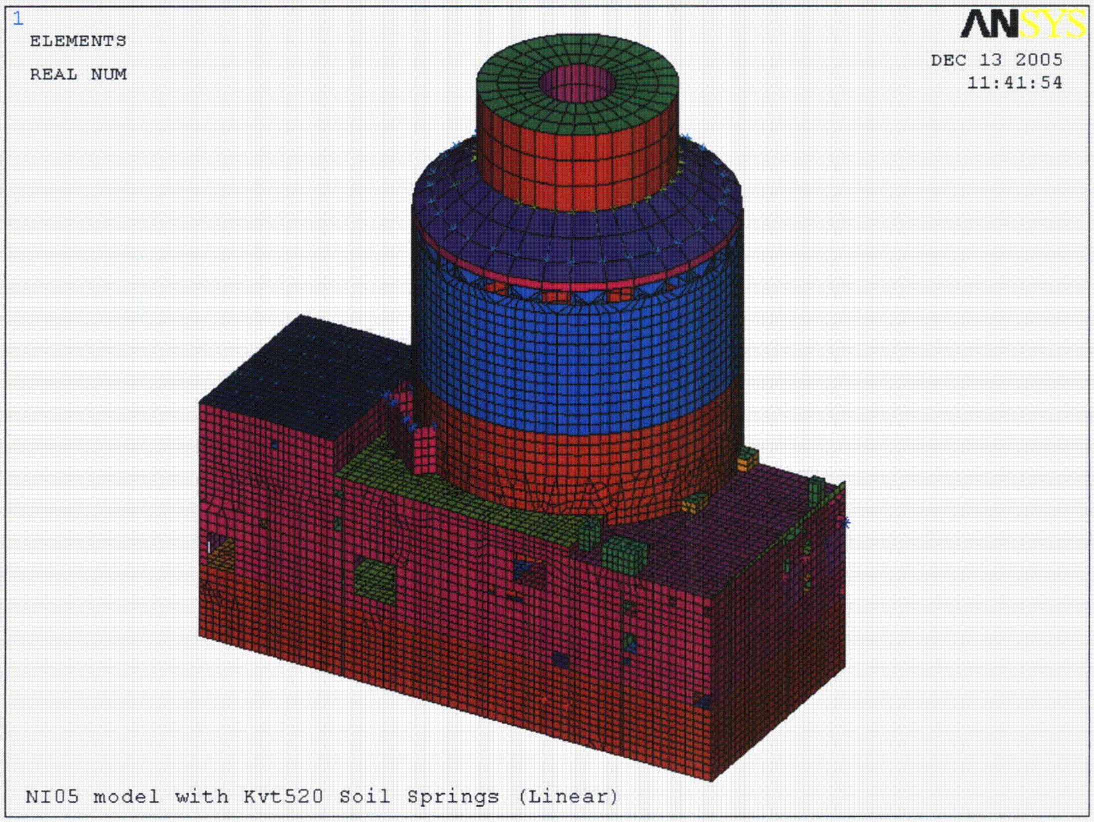


Figure 2.6-1 NI05 Model with Soil Springs

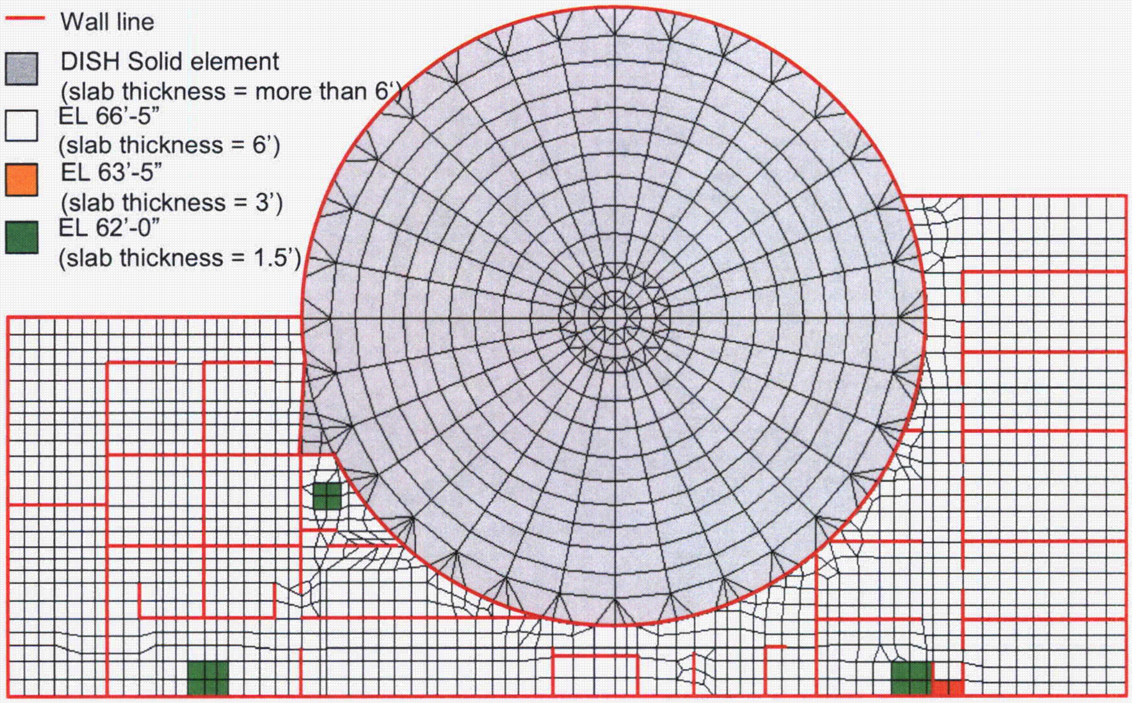


Figure 2.6-2 Basemat Elements along with Wall Lines above the Basemat

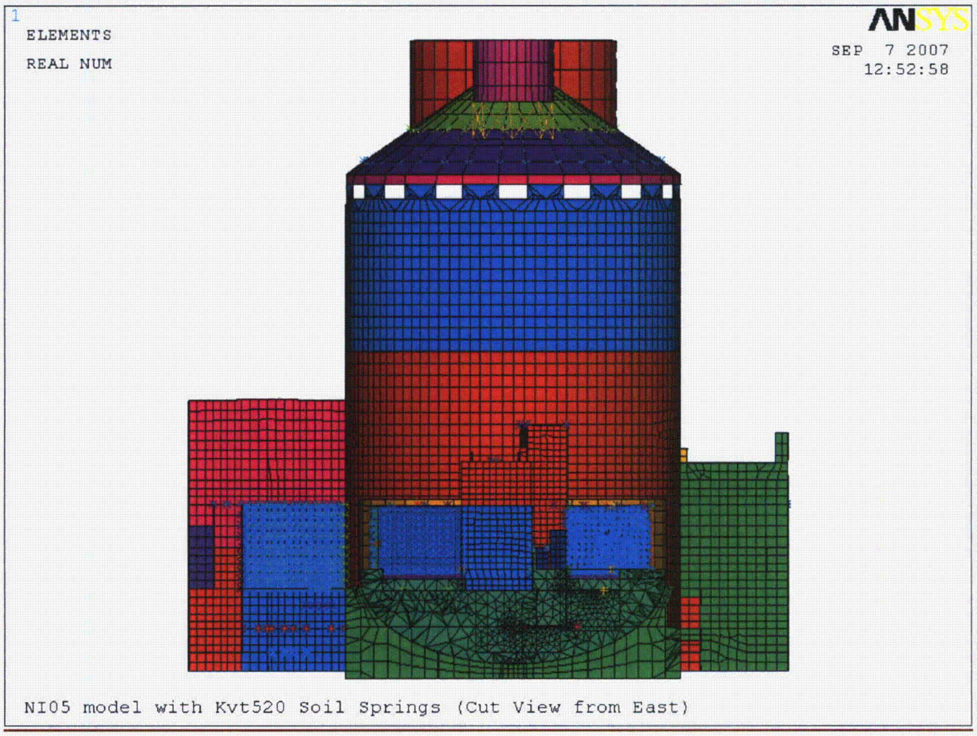


Figure 2.6-2 (a) Section View of NI05 Model from East

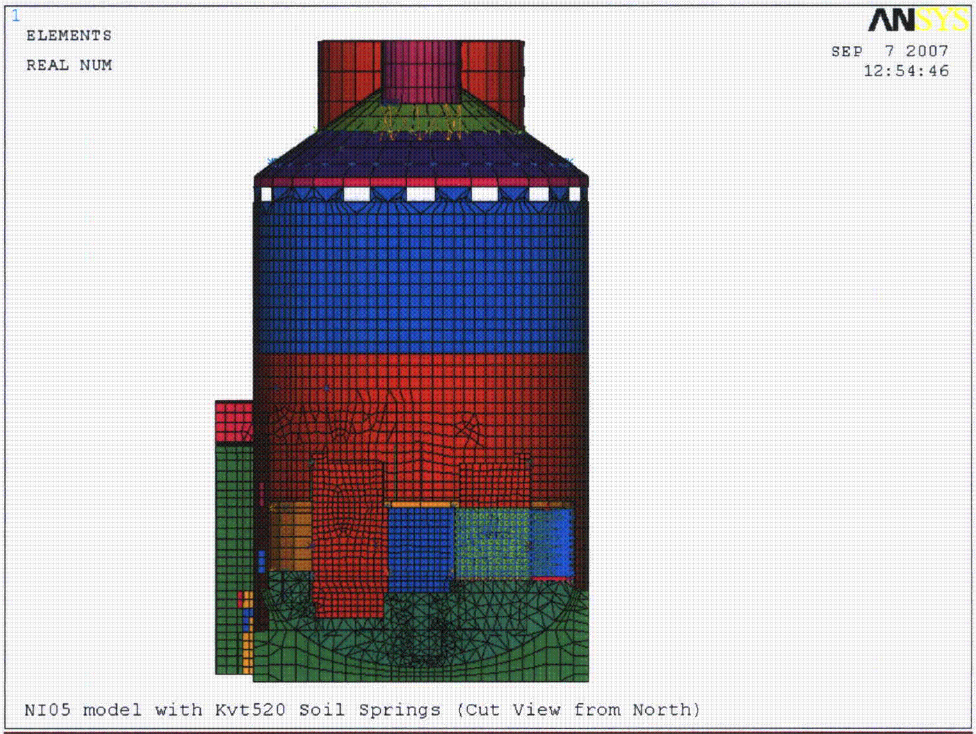


Figure 2.6-2 (b) Section View of NI05 Model from North

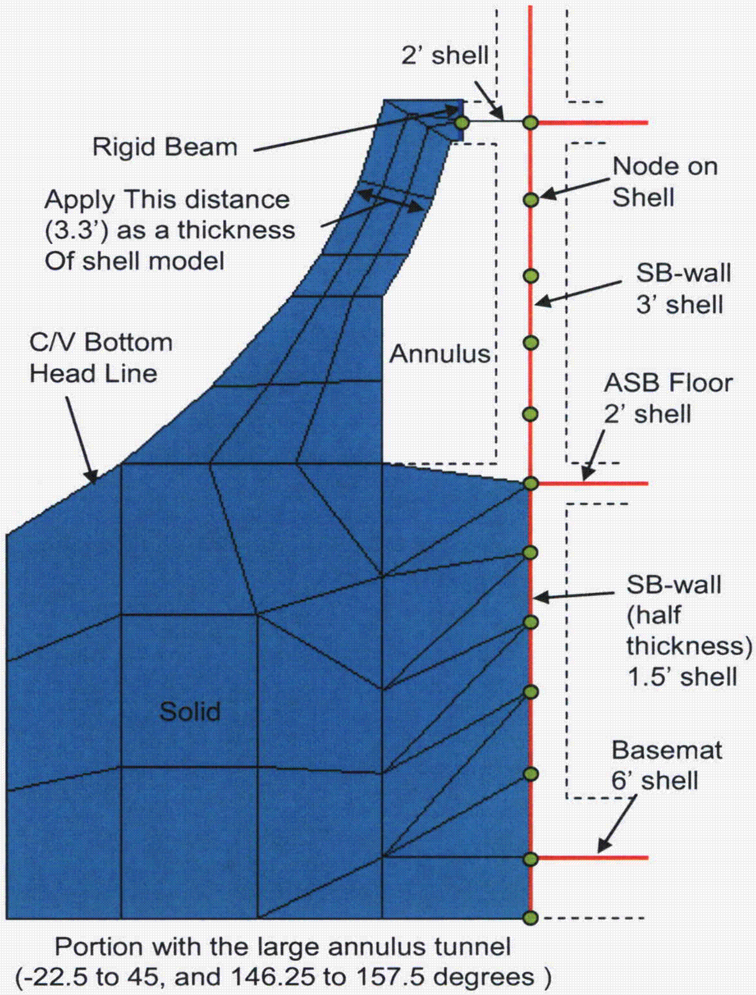


Figure 2.6-2 (c) Typical Connection of Auxiliary Building to Dish

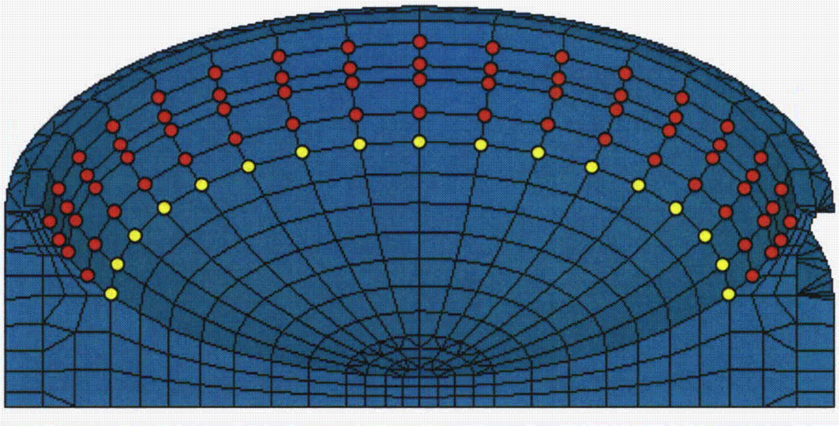
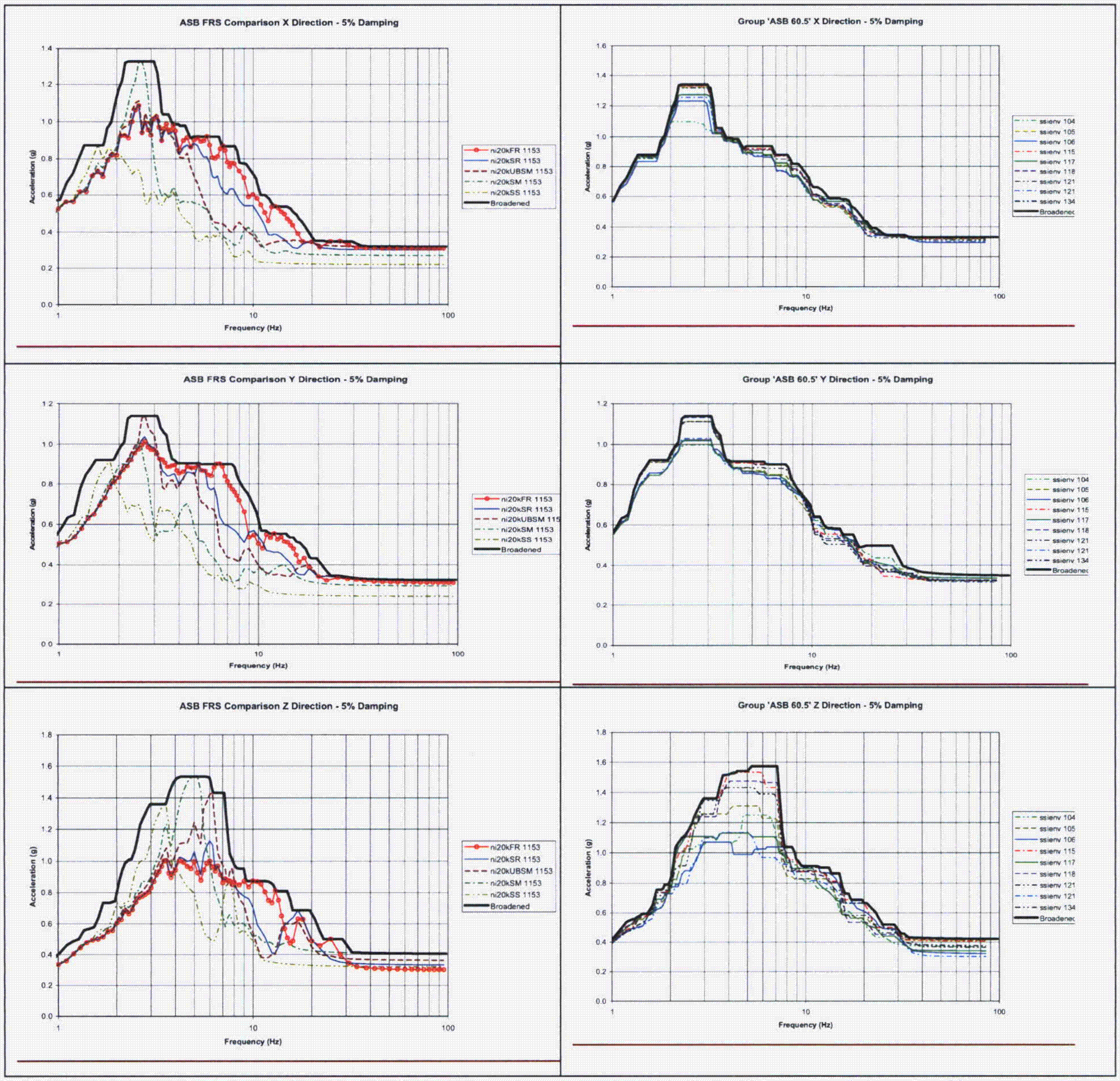


Figure 2.6-2 (d) Connection Nodes between Containment vessel and DISH



<u>Center of containment (Node 1153)</u> <u>Envelope of center and corners of basemat</u>

<u>Figure 2.6-2 (e) Basemat response spectra from SASSI analyses</u>

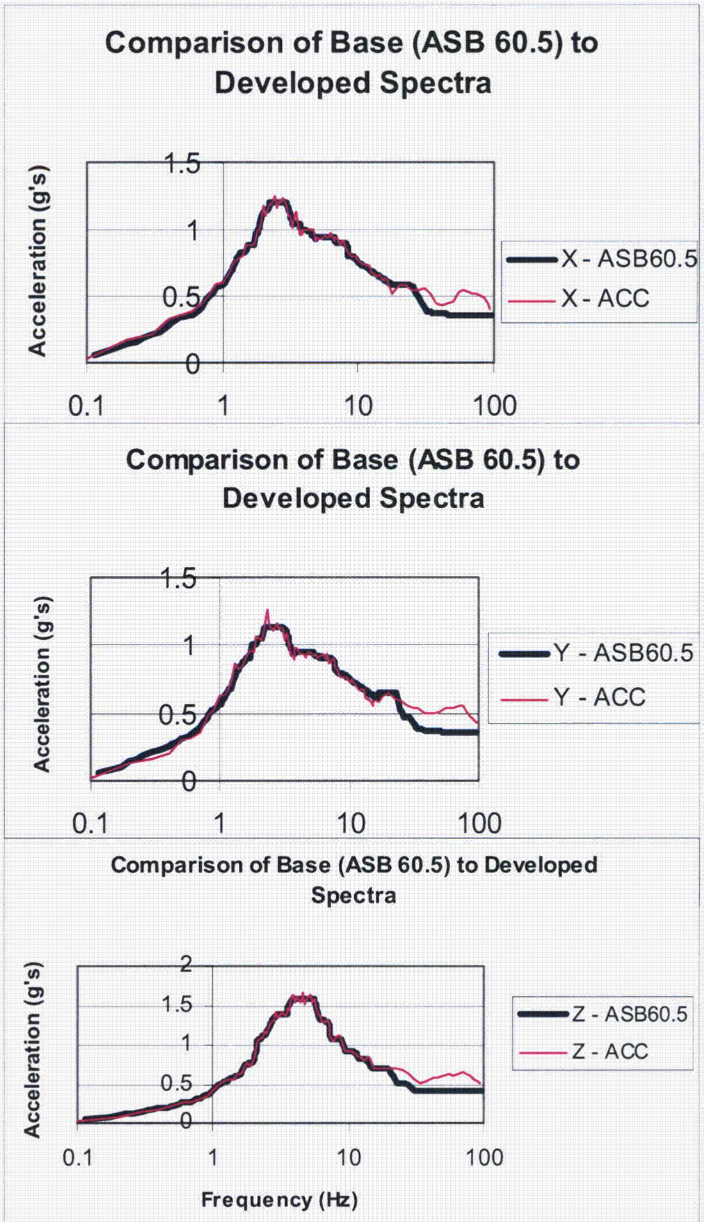


Figure 2.6-2 (f) Comparison of Time History Response Spectra against 'ASB 60.5' envelope

RAI Response Number: RAI-TR85-SEB1-34
Revision: 1

Question:

Section 2.9 describes the nuclear island stability evaluation for various load combinations. Table 2.9-1 lists the load combinations and corresponding factors of safety for sliding, overturning, and flotation. For the overturning case with the SSE loading, factors of safety of 1.06 and 1.07 are shown, both of which are less than the NRC SRP 3.8.5 acceptance criteria of 1.10. Since footnote 1 to the table indicates that the factors of safety for overturning are 1.12 and 1.10 when active and passive pressures on the external walls below grade are considered, then why don't the entries in the table reflect these values which would then meet the acceptance criteria. If the passive soil pressure is relied upon to meet the acceptance criteria for overturning, then DCD Section 3.8.5.5.4, which describes overturning evaluation of the foundation, also needs to be revised to include this effect. Confirm that the foundation walls have been designed for the passive soil pressures as well.

Westinghouse Response:

Westinghouse agrees and will make the change as recommended in the question. It is confirmed that the foundation walls have been designed for the passive soil pressures as well.

The nuclear island seismic stability evaluation has been updated for the envelope of the six site profiles of hard rock, firm rock, soft rock, upper bound soft-to-medium soil, soft-to-medium soil, and soft soil site. A time history analysis was performed using the AP1000 nuclear island 3D shell model NI20. The time history input is developed from the envelope of the broadened floor response spectra of the six site profiles at the edges, along the side walls, and at the center of the AP1000 nuclear island basemat. There was very little change in the seismic factors of safety associated with overturning and sliding. This is seen below comparing minimum safety factors.

Factor of Safety	2D Model	NI20 3D Shell Model
Sliding north-south earthquake	1.28	1.28
Sliding east-west earthquake	1.33	1.33
Overturning NS earthquake	1.39	1.35
Overturning EW earthquake	1.10	1.12

The NI20 model is the model used in the most recent seismic analyses of the nuclear island described in TR03, Rev. 1. The factors of safety obtained from the new analyses are being included in the proposed revisions to the DCD and TR85.

Design Control Document (DCD) Revision:

Post Revision 16 change to Section 3.8.5.5.4 is given below. The changes that are made post TR134, Rev. 0, are underlined.

3.8.5.5.4 Overturning

The factor of safety against overturning of the nuclear island during a tornado or a design wind is shown in Table 3.8.5-2 and is calculated as follows:

$$F.S. = \frac{M_R}{M_O}$$

where:

F.S. = factor of safety against overturning from tornado or design wind
M_R = resisting moment
M_O = overturning moment of tornado or design wind

The factor of safety against overturning of the nuclear island during a safe shutdown earthquake is shown in Table 3.8.5-2 and is evaluated using the static moment balance approach assuming overturning about the edge of the nuclear island at the bottom of the basemat. The factor of safety is defined as follows:

$$\underline{F.S. = (M_R + M_P) / (M_O + M_{AO})}$$

where:

F.S. = factor of safety against overturning from a safe shutdown earthquake
M_R = nuclear island's resisting moment against overturning
M_O = maximum safe shutdown earthquake induced overturning moment acting on the nuclear island, applied as a static moment
M_P = Resistance moment associated with passive pressure
M_{AO} = Moment due to lateral forces caused by active and overburden pressures.

The resisting moment is equal to the nuclear island dead weight, minus buoyant force from ground water table, multiplied by the distance from the edge of the nuclear island to its center of gravity. The overturning moment is the maximum moment about the same edge from the time history analyses of the nuclear island lumped mass stick model described in subsection 3.7.2.

Table 3.8.5-2 is changed as follows.

Table 3.8.5-2

FACTORS OF SAFETY FOR FLOTATION, OVERTURNING AND SLIDING OF NUCLEAR ISLAND STRUCTURES

~~HARD ROCK CONDITION~~

Environmental Effect	Factor of Safety[1]
Flotation	
High Ground Water Table	3.7
Design Basis Flood	3.5
Sliding	
Design Wind, North-South	23.2
Design Wind, East-West	17.4
Design Basis Tornado, North-South	12.8
Design Basis Tornado, East-West	10.6
Safe Shutdown Earthquake, North-South	1.28[2]
Safe Shutdown Earthquake, East-West	1.33[2]
Overturning	
Design Wind, North-South	51.5
Design Wind, East-West	27.9
Design Basis Tornado, North-South	17.7
Design Basis Tornado, East-West	9.6
Safe Shutdown Earthquake, North-South	1.35
Safe Shutdown Earthquake, East-West	1.12[3]

Note:

1. Factor of safety is calculated for the envelope of the soil and rock sites described in subsection 3.7.1.4. ~~Minimum value for all sites is shown in this table.~~
2. Factor of safety is shown for soils below and adjacent to nuclear island having angle of internal friction of 35 degrees.
3. ~~The factor of safety of 1.07 does not consider active and passive soil pressures on the external walls below grade. When these soil pressures are considered for overturning (as they are in the sliding evaluation), the minimum factor of safety against overturning increases to 1.12. This factor of safety is slightly below 1.1 based on the conservative moment balance formula treating the seismic moment as static loads.~~ ASCE/SEI

43-05, Reference 42, recognizes that there is considerable margin beyond that given by the moment balance formula and permits a nonlinear rocking analysis. The nonlinear (liftoff allowed) time history analysis described in Appendix 3G.10 showed that the nuclear island basemat uplift effect is insignificant. Further, these analyses were performed for free field seismic ZPA input as high as 0.5g without significant uplift. Therefore the factor of safety against overturning is greater than 1.67 (0.5g/0.3g).

PRA Revision:

None

Technical Report (TR) Revision:

2.9 Nuclear island stability

The factors of safety associated with stability of the nuclear island are shown in Table 2.9-1 for the following cases:

- Flotation Evaluation for ground water effect and maximum flood effect
- The Nuclear Island to resist overturning during a Safe Shutdown Earthquake (SSE)
- The Nuclear Island to resist sliding during the SSE
- The Nuclear Island to resist overturning during a tornado/wind/hurricane condition
- The Nuclear Island to resist sliding during a tornado/wind/hurricane condition.

The factors of safety for sliding and overturning for the SSE are calculated for each soil case for the base reactions in terms of shear and bending moments about column lines 1, 11, I and the west side of the shield building as shown in Table 2.9-2. The base reactions are obtained from the all soil time history analysis using the NI20 model. The minimum values are reported in Table 2.9-1. The method of analysis is as described in subsection 3.8.5.5 of the DCD (Rev. 16) and TR 134 (Rev.0). ~~with the exception that the sliding resistance is based on the friction force developed between the basemat and the foundation using a coefficient of friction of 0.70.~~ The governing friction value at the interface zone is a thin soil layer (soil on soil) under the mud mat assumed to have a friction angle of 35 degrees. The Combined License applicant will provide the site specific angle of internal friction for the soil below the foundation. In the case of a rock foundation, the mud mat will interlock with the rock, and therefore, the friction angle will be at least 55 degrees.

Table 2.9-1 – Factors of Safety Related to Stability of AP1000 NI

Load Combination	Sliding		Overturning		Flotation	
	Factor of Safety	Limit	Factor of Safety	Limit	Factor of Safety	Limit
D + H + B + W	Design Wind					
North-South	23.2	1.5	51.5	1.5	–	–
East –West	17.4	1.5	27.9	1.5	–	–
D + H + B + Wt	Tornado Condition					
North-South	12.8	1.1	17.7	1.1	–	–
East –West	10.6	1.1	9.6	1.1	–	–
D + H + B + Wh	Hurricane Condition					
North-South	18.1	1.1	31	1.1	–	–
East –West	14.2	1.1	16.7	1.1	–	–
D + H + B + ES	SSE Event					
North-South	1.28	1.1	–	–	–	–
East-West	1.33	1.1	–	–	–	–
Line 1	–	–	1.35	1.1	–	–
Line 11	–	–	1.41	1.1	–	–
Line I	–	–	1.12(1)	1.1	–	–
West Side Shield Bldg	–	–	1.14(1)	1.1	–	–
	Flotation					
D + F	–	–	–	–	3.51	1.1
D + B	–	–	–	–	3.7	1.5

Notes:

(1) ~~Considering active and passive soil pressures on the external walls below grade, the minimum factor of safety against overturning (1.07 and 1.06) increases to 1.12 (Line I) & 1.10 (West Side of Shield Building). This factor of safety meets the requirement of 1.1 based on the conservative moment balance formula treating the seismic moment as static loads.~~ ASCE/SEI 43-05, Reference 7, recognizes that there is considerable margin beyond that given by the moment balance formula. Reference 7 permits a nonlinear rocking analysis. A nonlinear (liftoff allowed) time history analysis is described in Section 2.4.2 showing that the nuclear island basemat uplift effect is insignificant. Further, these analyses were performed for free field seismic ZPA input as high as 0.5g without significant uplift. Therefore the factor of safety against overturning is greater than 1.67 (0.5g/0.3g).

Table 2.9-2

Nuclear Island Base Reactions Used for Stability Analysis

Time History Analysis (NI20 All soils)

Units: 1000 kips & 1000 ft-kip

Seismic Reaction	Component	Forces and Moments
Shear NS	Fx	116.45
Shear EW	Fy	127.51
Vertical	Fz	129.68
Moment about I	MI	15,178
Moment about SB West	MSBw	15,988
Moment about 11	M11	19,515
Moment about EW	M1	20,149