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June 23, 2009

Subject: AP1000 Response to Request for Additional Information (TR 85)

Westinghouse is submitting responses to NRC requests for additional information (RAI) on Technical Report No. 85. This RAI response is submitted in support of the AP1000 Design Certification Amendment Application (Docket No. 52-006). The information included in this response is generic and is expected to apply to all COL applications referencing the AP1000 Design Certification and the AP1000 Design Certification Amendment Application.

Enclosure 1 provides the response for the following RAI(s):

RAI-TR85-SEB1-32 R2

Questions or requests for additional information related to the content and preparation of this response 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. O. Lindgren / FOR
Robert Sisk, Manager
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Regulatory Affairs and Standardization

/Enclosure

1. Response to Request for Additional Information on Technical Report No. 85

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NRO

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ENCLOSURE 1

Response to Request for Additional Information on Technical Report No. 85

AP1000 TECHNICAL REPORT REVIEW

Response to Request For Additional Information (RAI)

RAI Response Number: RAI-TR85-SEB1-32
Revision: 2

Question:

As shown by the studies in Section 2.7.1.2.1, when the soil is represented as solid elements rather than Winkler soil springs, higher bearing pressures occur at the edges and lower bearing pressures away from the edges. This is referred to as the effects of the Boussinesq distribution. Although this indicates that the basemat slab away from the walls would have higher bearing pressures using the Winkler soil spring approach (see Figure 2.7-2), the calculation of the maximum bearing pressure would still exist at the building edges if the soil is modeled as solid elements. Therefore, explain why the maximum bearing pressure for the AP1000 design, discussed in Section 2.4.2, should be based on the 2D ANSYS nonlinear dynamic analysis using Winkler soil springs rather than solid soil elements?

Additional Request (Revision 1):

The staff reviewed the RAI response submitted in Westinghouse letter dated March 31, 2008, and notes that the outstanding issues raised by this RAI are considered to be very significant. The RAI response states that the DCD "revision now indicates the line of lift-off, thereby defining the maximum total load applied to the foundation at the time of maximum demand...the dynamic bearing capacity is related to the overall loading on the foundation and to the shear strength mobilized over a failure surface in the foundation soils. The local maximum values close to the edge are not significant to this capacity and will redistribute if local stresses in the soil are excessive. This total load rather than a peak stress below an edge is to be considered by the Combined License applicant in demonstrating stability of the foundation material." Westinghouse is requested to address the following:

1. The above statements are not consistent with the criteria in the DCD because the statements indicate that the total load is used by the Combined License applicant to demonstrate the adequacy of the soil whereas, the DCD requires comparison of the maximum bearing pressure demand to bearing pressure capacity (e.g., DCD Tier 2, Section 2.5.4.2 and DCD Tier 1, Chapter 5.). Explain this inconsistency.

2. As noted in the original RAI, the studies in Section 2.7.1.2.1 demonstrate that when the soil is represented as solid elements, higher bearing pressures occur at the edges than when uniform Winkler type soil springs are used. This is a well known behavior in soil mechanics and is referred to as the Boussinesq effect. Since the current dynamic soil bearing pressure demand criterion of 35 ksf is still based on the 2D ANSYS stick model analysis, Westinghouse is requested to either (1) justify the statement that the localized peak soil pressures will redistribute if local stresses in the soil are excessive and the NI will still be stable or (2) explain what is the technical basis for using a uniform soil spring representation rather than soil brick

finite element or a soil spring distribution which more accurately captures the actual pressure distribution beneath the basemat.

3. The proposed revision to DCD Section 2.5.4.2 - Bearing Capacity, states that the "The maximum demand of 35 ksf occurs under the west edge of the shield building and is primarily due to the response to the east-west component of the earthquake. The east edge of the nuclear island lifts off the soil. The Combined License applicant will verify that the site specific allowable soil bearing capacities for static and dynamic loads at the site will exceed this demand. The evaluation may be limited to response in the east-west direction since the bearing demand is lower in the north-south direction." Explain what is meant by the statement that an "evaluation" may be limited to response in the east-west direction, because no "evaluation" or analysis to be performed by the applicant can be located in the DCD; instead the allowable soil bearing capacity needs to be shown to be greater than the bearing demand under static and dynamic loads.

Additional Request (Revision 2):
(Follow-up RAIs dated 4/27/09)

The RAI response indicates that the seismic analysis for determining the soil bearing pressure demand has been revised to utilize the SASSI 3D finite element NI20 model using a seismic time history soil-structure interaction analysis. This analysis was performed for the hard rock case and five soil conditions. The model includes a surrounding layer of excavated soil and the existing soil media. The soil media in SASSI is an idealization of the various horizontal soil layers. This representation of the soil in SASSI is considered to be more realistic and accurate than the uniform Winkler type soil springs used in the 2D ANSYS analyses, and thus addresses the concern regarding the calculation of soil bearing pressure demand. However, for the design of the basemat, Westinghouse has not demonstrated that its use of uniform Winkler type soil springs is adequate. As noted in the prior RAI, due to the Boussinesq effect in soil, the distribution of stiffness would be higher at the edges and lower away from the edges. Therefore, Westinghouse is requested to demonstrate that the use of the uniform soil springs for the design of the foundation is acceptable, when it is known that the actual distribution of the soil stiffness would not be uniform.

Westinghouse Response:

Subsection 2.5.4.2 is being revised to clarify the maximum bearing pressure of 35 ksf, as stated in the DCD, it is obtained from analyses using uniform soil springs. The revision now indicates the line of lift off, thereby defining the maximum total load applied to the foundation at the time of maximum demand. Unlike the static case, where the allowable bearing capacity is controlled by settlements, the dynamic bearing capacity is related to the overall loading on the foundation and to the shear strength mobilized over a failure surface in the foundation soils. The local maximum values close to the edge are not significant to this capacity and will redistribute if local stresses in the soil are excessive. This total load rather than a peak stress below an edge is to be considered by the Combined License applicant in demonstrating stability of the foundation material.

Various analyses described in the report investigate the effect of modeling the soil with uniform spring and solid element representations. Comparisons are made in linear analyses using SASSI and ANSYS. Comparisons are made in ANSYS linear and non-linear analyses to show the effect of lift off. The analyses show small differences in the distribution of the bearing pressures but good agreement in the total loads imposed on the foundation material. The small differences in distribution (the Boussinesq effect) are not significant to the evaluation of the stability of the foundation material.

Westinghouse Response (Revision 1):

The maximum seismic bearing pressure demand defined for comparison to the subgrade pressure capacity is consistent with the DCD. See RAI-TR85-SEB1-03, Rev. 1 for discussion of the 35 ksf maximum bearing seismic demand.

In response to the many questions in this and other RAIs, Westinghouse has revised the basis for the bearing demand. The demand is now based on 3D SASSI analyses using the 3D NI20 finite element model as described in the response to RAI-TR85-SEB1-03, Rev 1. This change to use of the 3D SASSI results addresses the original question in this RAI. The additional questions in Rev 1 of this RAI apply to the Rev 0 response which has now been superseded.

The statement in the DCD Section 2.5.4.2, "The evaluation may be limited to response in the east-west direction since the bearing demand is lower in the north-south direction" has been removed. See DCD revision section below.

Westinghouse Response (Revision 2):

Table RAI-TR85-SEB1-32-1 shows the summary of the maximum reactions of the nuclear island for various soil and analysis methods. The results from Table 2.4-5 of the technical report, APP-GW-GLR-044, R1 (TR85), are shown for Item 1. Two other sources are contained in the table as comparison. The results of the linear analyses show consistent results demonstrating that the equivalent static analyses of the basemat result in bearing pressures similar to a more realistic model represented in the 3D SASSI analyses presented in Table 2.4-5.

Section 2.7.1 of the technical report describes studies performed to evaluate the effect of different soil modeling. These studies analyzed a 3D finite element model of the complete nuclear island on soil finite elements or soil springs. Additional comparisons are provided in this response for the following soil models:

- Winkler soil springs of 520 kcf similar to the design analyses of the basemat (Model W)

- Finite element model of 80-foot deep soil layer below the nuclear island. The properties for this soil were selected to match the 520 kcf soil (Model L080).

Figure RAI-TR85-SEB1-32-1 shows bearing pressures due to dead load. The sections are located as shown in Figure 2.7-2 of the technical report. The RAI figure only shows the two cases identified above. The finite element soil model shows high local bearing pressures close to the edge. This is due to the Boussinesq effect. The higher pressures at the edge result in lower pressures away from the edge. Figures RAI-TR85-SEB1-32-2 and 3 show bending moment contours MX and MY for these two cases. It is seen that the bending moments for the soil spring case are higher than those for the soil finite element model even in the bays immediately adjacent to the edge.

Section 2.7.2 of the technical report describes an additional study performed to evaluate the basemat soil interaction. The north-west corner of the AP1000 shown in Figure RAI-TR85-SEB1-32-4 was modeled and analyzed in two dimensions using the non-linear VECTOR2 structural analysis program. The model of the basemat and soil is shown in Figure RAI-TR85-SEB1-32-5. The model of the basemat is 20269.2 mm (66.5') long, simulating 3 bays of 18' and ½ bay of 25', and 1828.8 mm (6') high. The element size is 152.4 mm (6") x 304.8 mm (12") for the first 55' and 152.4 mm (6") x 292.1 mm (11.5") for the last 11.5'. The total number of nodes and elements for the basemat is 884 and 804, respectively. The model of the soil is 23104.8 mm (75.8' depth) and 61069.2 mm (200.3'). The soil model extends almost twice the soil depth beyond the end of the basemat. The total number of nodes and elements for the soil is 4794 and 4642, respectively. The soil properties are chosen to give the same vertical displacement of the nuclear island under dead load as the 520 kcf soil springs. X-direction is horizontal and Y is vertical. The nodes on the last column are restrained in the X-direction to simulate symmetry. The VECTOR2 program considers cracking of the concrete and non-linear behavior of the reinforcement. Structural response is calculated up to failure for monotonically applied vertical displacement of the shear walls. Contact pressures on the soil are shown in Figure RAI-TR85-SEB1-32-6 (Figure 2.7-10, TR85) as a function of the applied displacement. They indicate substantial Boussinesq effect with high bearing pressures below the edge of the basemat. The analyses showed significant redistribution of soil bearing pressures as the load increased. The basemat withstood loading about three and a half times the design loads with final failure occurring in shear close to the exterior wall.

The studies documented in section 2.7 of the technical report and summarized above show the Boussinesq effect in rock and soil with an effective stiffness that is higher at the edges and lower away from the edges. This distribution is presented on Figure RAI-TR85-SEB1-32-7. The influence values represent the effect of the contact on a half space beneath a rigid circular footing. The Boussinesq equation does not account for the influence of the basemat's embedment depth of 39.5 feet which would increase the bearing capacity of the foundation. Because of the basemat dimensions (plan and thickness), the foundation would be considered flexible. The studies demonstrate that the use of uniform Winkler type soil springs is adequate for a flexible mat foundation.

Table RAI-TR85-SEB1-32-1

Maximum Basemat Bearing Pressure (Summary)

No.	Method of Analysis	Foundation Conditions					
		HR (ksf)	FR (ksf)	SR (ksf)	UBSM (ksf)	SM (ksf)	SS (ksf)
1	3D SASSI, NI20 Model, TH + vertical earthquake	35.0 *	27.9	24.0	25.7	23.1	21.9
2	2D SASSI, ni2D model	29.1	24.0	24.5	27.4	30.2	20.2
3	2D Time History, ni2D model: Linear	32.8	N/A	N/A	31.7	30.8	N/A
	: Lift off	34.9	N/A	N/A	33.5	32.2	N/A

Notes:

* 38.3 ksf was the maximum localized peak calculated; a limit of 35 ksf for maximum bearing seismic demand is obtained by averaging the soil pressure about the West edge of the shield building where the maximum stress occurs.

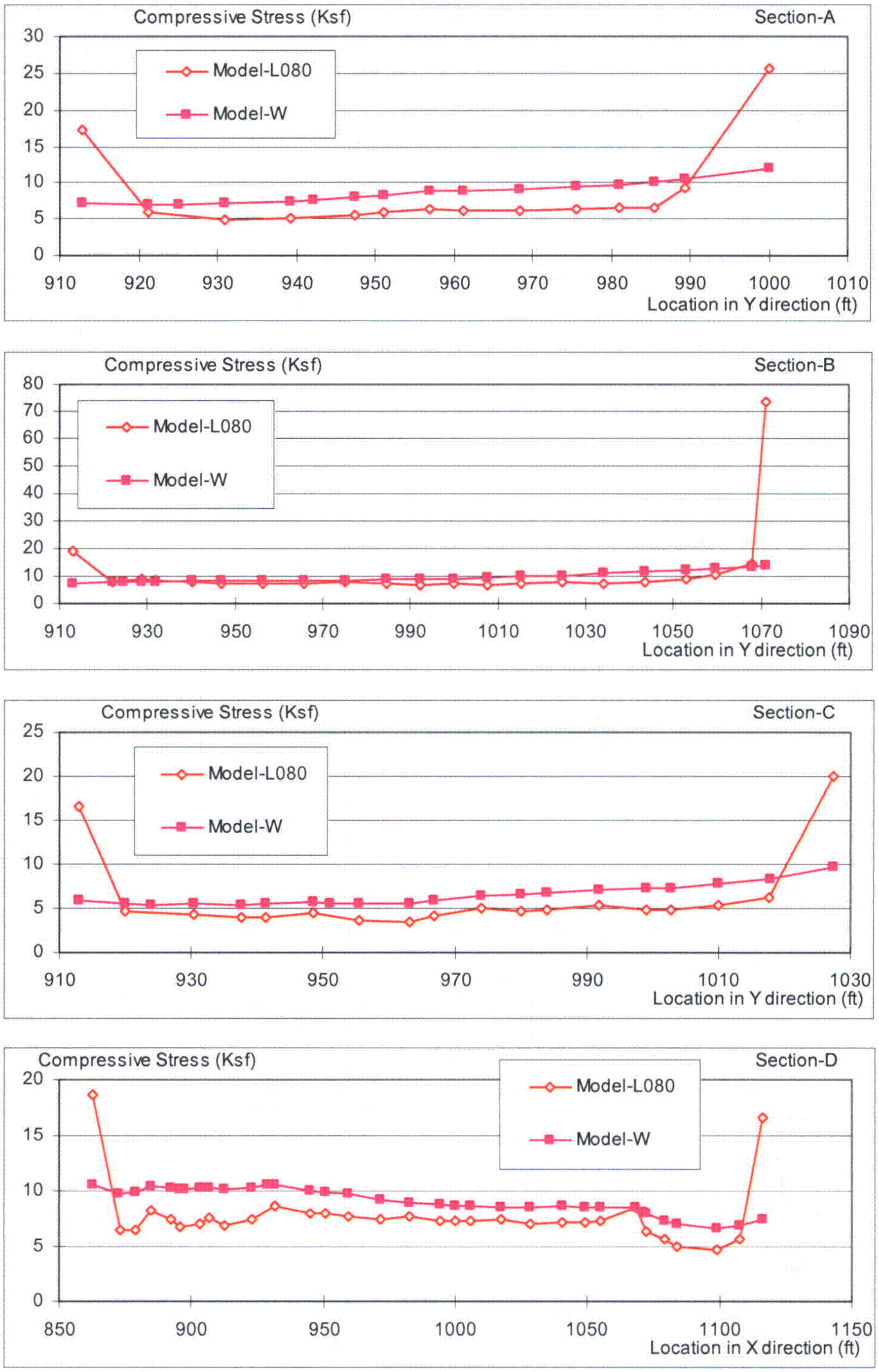


Figure RAI-TR85-SEB1-32-1
Comparison of Vertical Stress at Basemat Bottom Node – No embedment

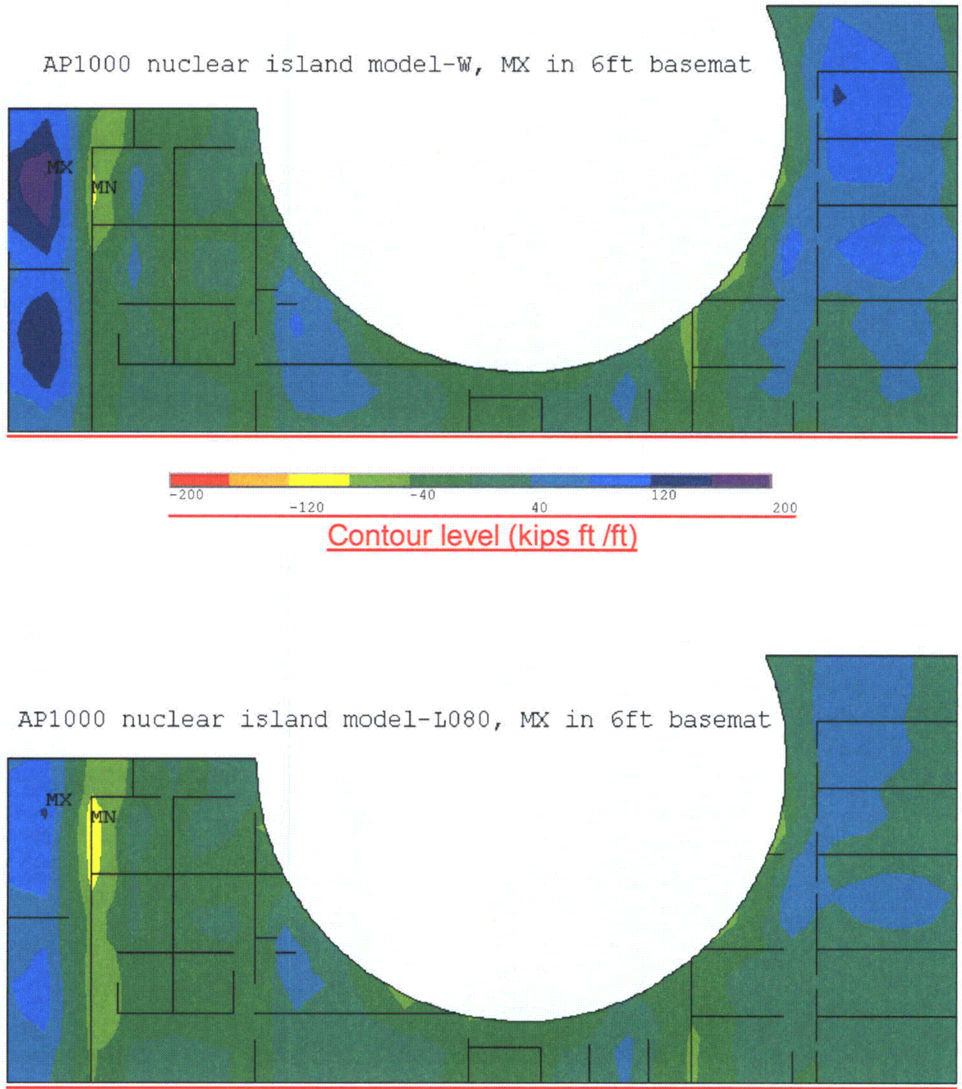


Figure RAI-TR85-SEB1-32-2 Bending Moment MX for Model-W and Model-L080

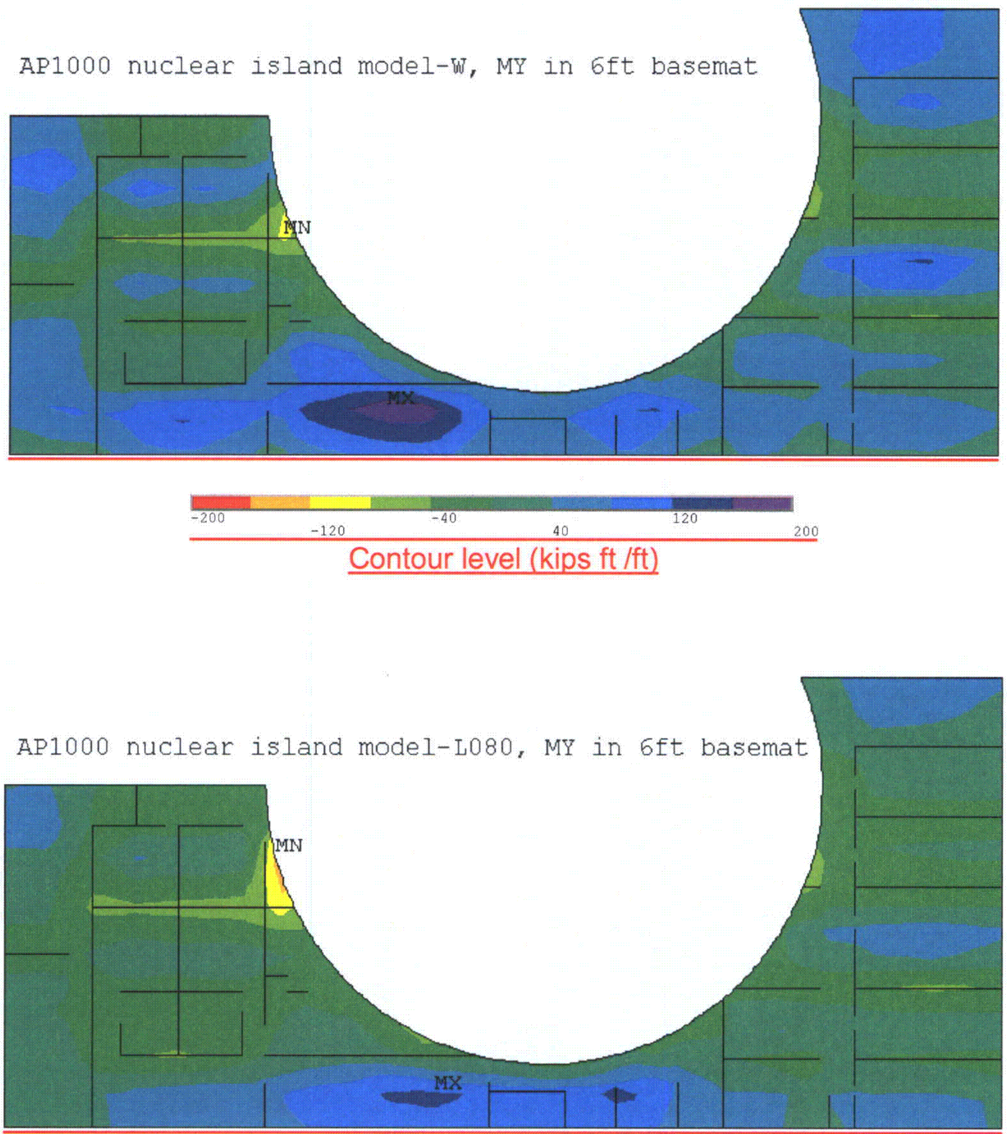


Figure RAI-TR85-SEB1-32-3 Bending Moment MY for Model-W and Model-L080

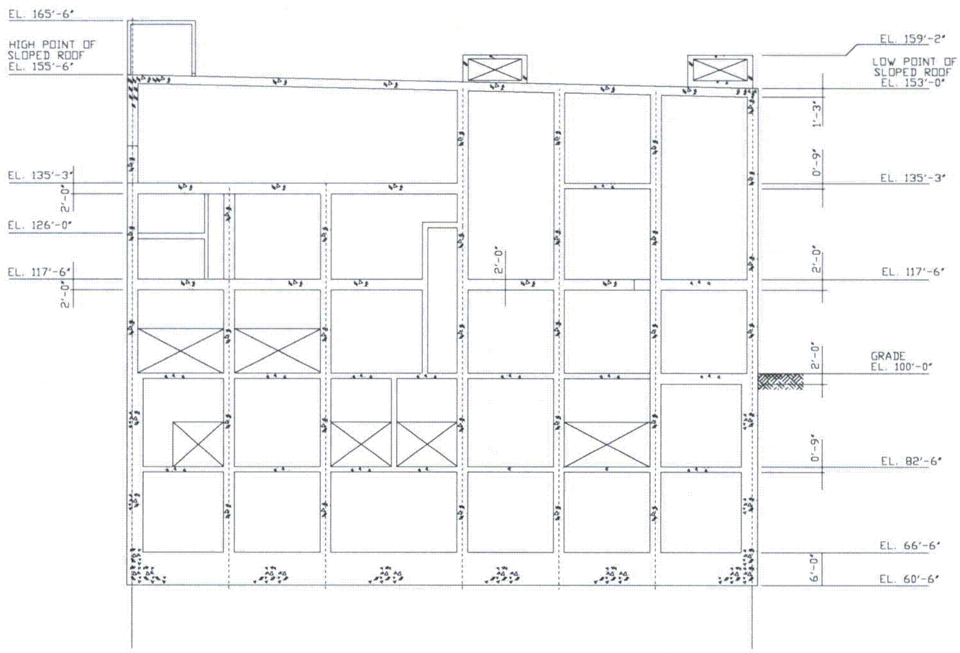


Figure RAI-TR85-SEB1-32-4

Cross section through north end of auxiliary building looking south.

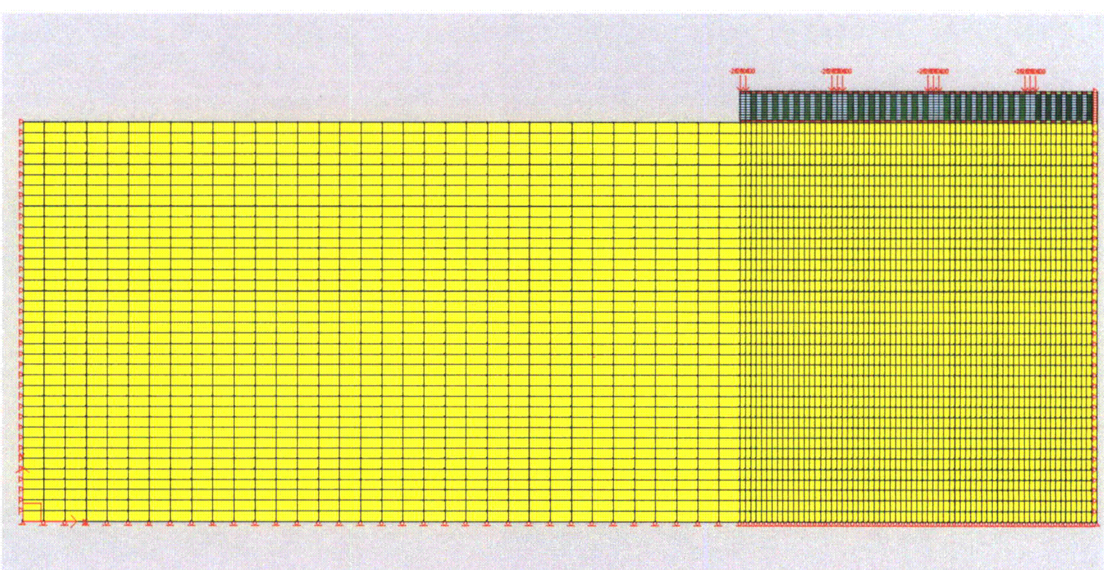


Figure RAI-TR85-SEB1-32-5

Vector2 model looking north with Soil Elements

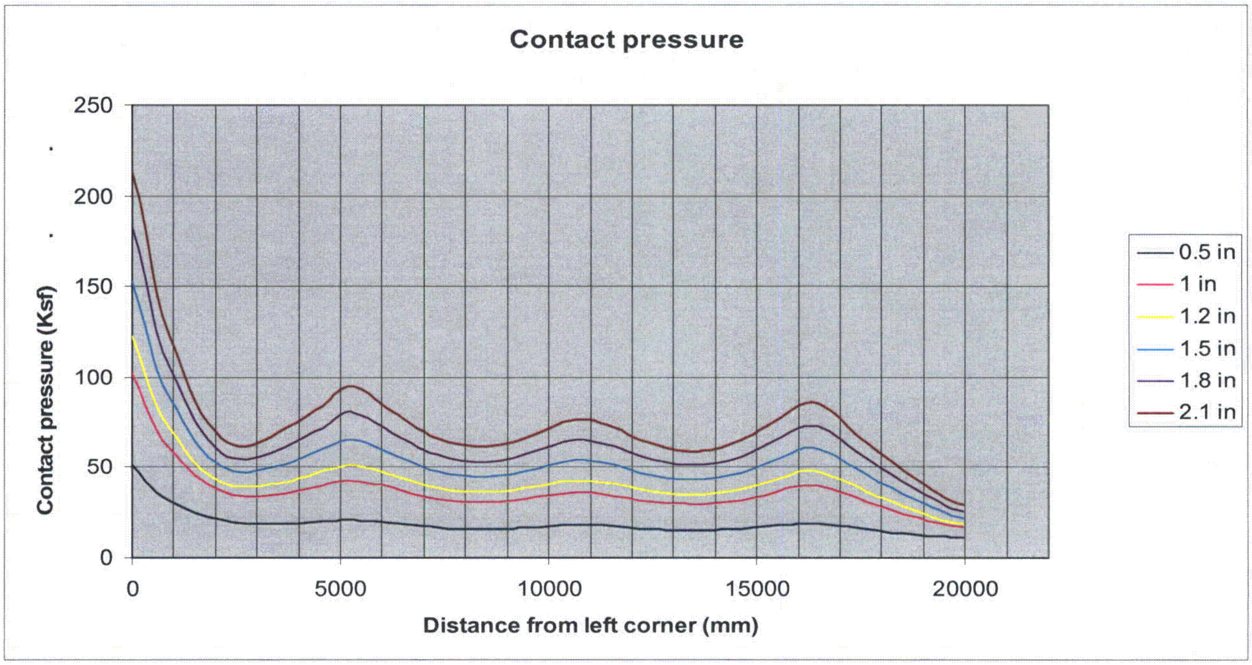
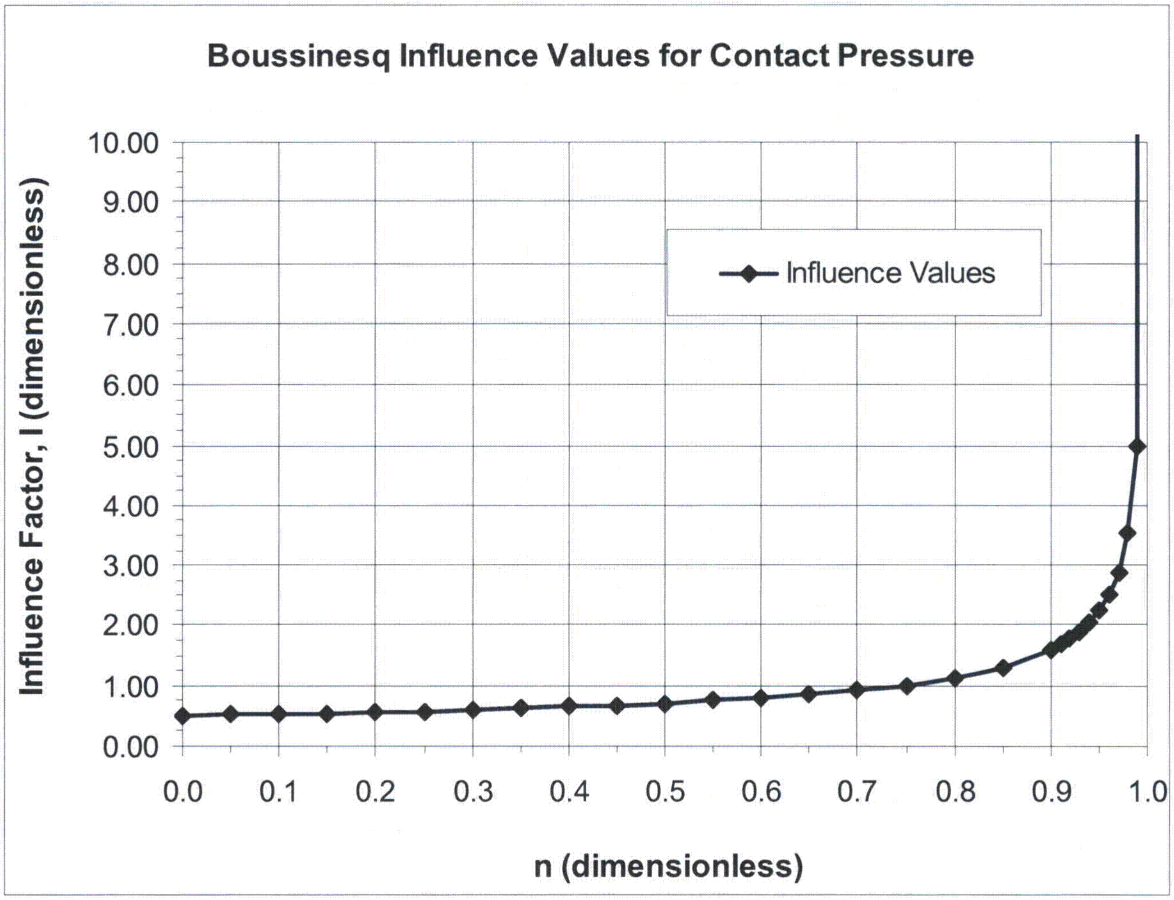


Figure RAI-TR85-SEB1-32-6
Contact Stresses along Mat for Half Space



Notes:
Area (sf) = 32,480 (for NI footprint)
r (ft) = 101.68 (r for equivalent area)
If n = 0.0 is the center of the area (r = 0.0 ft)
then n = 1.0 at the perimeter (r = 101.68 ft),

Boussinesq Method (rigid circular footing)
Qo = Footing Contact Pressure
P = Foundation Load, A = Footing Area
$Qo = (P / A) \times (1 / 2x(1-n)^{0.5})$

with $I = \dfrac{1}{2\,(1-n)^{0.5}}$

Figure RAI-TR85-SEB1-32-7
Boussinesq Influence Values for Footing Contact Pressure
(rigid circular footing at ground surface, for half space)

Design Control Document (DCD) Revision:

The changes to the DCD shown in Rev 0 of this RAI response have been implemented in DCD Rev 17. Revise first paragraph of DCD Rev 17 subsection 2.5.4.2 as follows:

2.5.4.2 Bearing Capacity

The maximum bearing reaction determined from the 3D SASSI analyses described in Appendix 3G is less than 35,000 lb/ft^2 under all combined loads, including the safe shutdown earthquake. ~~These analyses use uniform soil springs below the basemat.~~ The maximum dynamic bearing demand of 35 ksf occurs under the west edge of the shield building and is primarily due to the response to the east-west component of the earthquake. The east edge of the nuclear island lifts off the soil. The Combined License applicant will verify that the site-specific allowable soil bearing capacities for static and dynamic loads at the site will exceed the static and dynamic bearing demand given in Table 2-1. ~~The evaluation may be limited to response in the east-west direction since the bearing demand is lower in the north-south direction.~~

PRA Revision:

None

Technical Report (TR) Revision:

Revise Tables 2.6-2 (b), 2.6-2 (c) and 2.6-4 as shown below:

Table 2.6-2 (b), revise footnote 2 as follows:

2. Equivalent static results are shown for the response from one direction, (i.e FX and MYY due to X input, FY and MXX due to Y input, and FZ due to Z input. The increase due to combination of three directions is small.

Table 2.6-2(c)

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

Location	Equivalent static accelerations Linear analyses	Fixed base time history all soils
West side of shield building	36.8	36.9
NW corner of auxiliary building	27.1	24.8
NE corner of auxiliary building	22.8	25.5
SE corner of auxiliary building	21.1	25.1
SW corner of auxiliary building	29.6	27.1

Table 2.6-4, revise footnotes as follows:

Note 1: See Figures 2.6-9 and 2.6-10 for plan and elevation schematic views of the reinforcement layout.

Note 2: Figures 6-1 and 6-2 in APP-1010-CCC-004, Rev.0 provide graphical presentation of the "Required" (red dash line) and "Provided" (solid black line) areas of radial reinforcement for the top face of the Dish.