RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

12/27/2013

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 1044-7140 REVISION 3**
SRP SECTION:	**03.08.04 – Other Seismic Category I Structures**
APPLICATION SECTION:	**3.8.4**
DATE OF RAI ISSUE:	**07/08/2013**

QUESTION NO. 03.08.04-56:

On April 3, 2013, the applicant submitted a markup of DCD Tier 2 Section 3.8 to provide updated information related to a seismic design change.

In Subsection 3.8.4.4.1, "R/B [reactor building]," the fourth paragraph (page 3.8-75) states, "The design considers normal loads (including construction, dead, live, and thermal), and the SSE [safe shutdown earthquake]. Seismic forces are obtained from the dynamic analysis described in Subsection 3.7.2. These loads are applied to the linear elastic FE [finite element] model. The design of the R/B complex is performed considering a fixed base condition at the top of the basemat. Loads and load combinations are given in Subsection 3.8.4.3." Also, the sixth paragraph states, "The R/B is analyzed using a three-dimensional FE model with the ANSYS computer codes."

The staff notices that a 3D FE model of R/B complex is used in Subsection 3.7.2 for the soil-structure interaction (SSI) analysis using the ACS-SASSI computer code. The ACS-SASSI code does not consider a fixed base condition at the top of the basemat. The displacements, forces and moments for the R/B complex should be available from the SSI analysis of the ACS-SASSI model. The staff requests the SASSI results be compared with those obtained from the ANSYS model to assess the accuracy of the analyses performed in this section.

The applicant is requested to provide a table which lists the results obtained from the ANSYS analysis including the displacements at the four corners of the top of the R/B complex and the top-center of the prestressed concrete containment vessel (PCCV) dome in the x, y, and z directions. Also, the table should list the maximum forces (axial, shear, and torsion) and moments at the four sections listed in Subsection 3.8.4.4.1.1, "Structural Design of Structural Elements."

ANSWER:

As discussed with the Nuclear Regulatory Commission (NRC) staff during the Design Certification Document (DCD) Tier 2, Section 3.8 Audit conducted on November 4-8, 2013,

MHI provides its response to this Request for Additional Information (RAI), as well as additional items discussed during the Audit.

Displacement

The requested ACS-SASSI and ANSYS analyses x, y, and z seismic displacements at the top corners of the respective R/B Complex structures and top-center of the PCCV dome are presented in Table 1 and the locations are shown graphically in Figure 1. The three translational displacements Ux, Uy, and Uz Displacements are provided at the following locations:

1. the four corners at the top of the R/B (see Figure 1, points A, B, D and E)
2. the North West corner at the top of the Auxiliary Building (point C)
3. the South West corner at the top of the West Power Source Building (point F), and
4. Apex of the PCCV (point G).

These are the North-South, East-West and Vertical displacements, respectively, from both the Response Spectrum Analysis (RSA) and ACS-SASSI analysis. They are displacements that consider the combined response from the three directions of seismic input. All displacements are associated with uncracked concrete. The displacements shown are relative to the top of the basemat and they represent the maximum displacement at the referenced locations. The RSA analysis uses the enveloped and broadened input spectra at the top of the basemat in a fixed base model. Therefore the load induced displacements relative to the top of the basemat are taken directly from the analysis results. The displacements from the ACS-SASSI analyses are the envelopes from analyses for all six soil profiles. However, the ACS-SASSI analyses consider the soil, basemat and superstructure as a system; therefore, the ACS-SASSI results include the deflection of the superstructure and the displacements caused by translation, rotation, torsion and flexibility of the basemat on the soil. Thus the displacements for each of the points on the superstructure are the displacements relative to a point in the same location in plan, but at the top of the basemat. They are, therefore, the displacements of the superstructure relative to the top of the basemat. The results were evaluated and the total displacements above the basemat are reported in Table 1 to allow comparison.

The following observations are made:

1. The largest displacement difference for the enveloped-broadened input spectrum is -0.081 inch (ACS-SASSI is greater) to 0.099 inch (RSA is greater). The total displacement difference between the two models is less than ± $^{1}/_{10}$ inch.
2. The RSA to SASSI capacity ratio, i.e. $\frac{\text{RSA Displacement}}{\text{SASSI Displacement}}$, corresponding to the differences provided in Item 1 is 0.91 and 1.08 respectively indicating the deflection difference between the two models varies less than 10%.

Force and Moments

The five vertical critical sections are shown in Figure 2. Table 2 presents the following maximum forces and moments for each section and compares the results from the RSA and ACS-SASSI analyses:

1. in-plane shear
2. out-of-plane shear
3. vertical (axial) force, and
4. out-of-plane moment

The tabulated ACS-SASSI results are the maximum forces and moments of the 12 SSI cases, i.e., six soil profiles considering both the uncracked and cracked structure. The RSA results are the sectional forces and moments obtained from the seismic analyses using the enveloped and broadened response spectra (Critical Sections 1, 2, 3, 4, and below elevation 3'-7" for Critical Section 5) and the unbroadened soil profile 2032-100 spectra (Critical Section 5 in the superstructure above elevation 3'-7").

Critical Section 5 is a primary structural element spanning perpendicularly between the perimeter wall and the PCCV pedestal. The large shear forces in this section of the wall resulted in a Demand Capacity Ratio (DCR) greater than 1.0 when subjected to the conservative enveloped and broadened spectra. The wall was re-evaluated considering the unbroadened spectra from the 6 soil profiles and the spectra for soil profile 2032-100 generated the largest forces and moments, and thus controls. The 2032-100 RSA story shears enveloped the ACS-SASSI story shears and was considered in the design of the shear wall above elevation 3'-7". It was considered acceptable to use unbroadened spectra in this application following the guidance provided in ASCE 4-98, paragraph 3.4.4.1(d). The basis is that the subsystems in the analysis model, in this case are the superstructure and the basemat, have significant interaction effects. Thus the mass and stiffness properties of the superstructure have an influence on the response of the system at the interface between the superstructure and basemat, and therefore the input response spectra do not need to be broadened.

The RSA and ACS-SASSI story shears and axial force are provided on Figures 4 to 6. The corresponding 2032-100 soil profile spectra RSA curve is provided on Figures 7 to 9. The results indicate that the baseline ACS-SASSI in-plane shear demand is conservatively enveloped, with two minor exceptions, for all elevations above 3'-7". The RSA approach is not always conservative in Zone 1, as evidenced by Critical Section 5, requiring additional analyses to consider the effects of displacement and a flexible basemat. The additional analyses performed on the Zone 1 sections are described subsequently in this response.

The design approach used in the analyses is in accordance with ACI 349-2006, Chapter 21 and it considers the loads, shears, and moments separately for the in-plane and out-of-plane conditions. The In-Plane and Out-of-Plane RSA and SASSI ratios are shown in Table 2..

In summary, the values in Table 2 indicate that predominately the broadened and enveloped RSA envelops the ACS-SASSI, i.e. $\frac{RSA}{SASSI}$ ratio ≥ 1.0 for the In-Plane conditions and the ratios are low for Out-of-Plane. In the two cases above elevation 3'-7" where the In-Plane $\frac{RSA}{SASSI}$ ratio < 1.0 (0.93 and 0.96), the ACS-SASSI demand verses capacity values is substantially enveloped (0.18 and 0.79, respectively).

The NRC Audit of the US-APWR Chapter 3.8, November 4-8, 2013, resulted in Audit Open Items and as part of the resolution the following Items were identified to be made part of this RAI Response.

October 31 Public Meeting Item 7. RSA used for the R/B Complex did not utilize broadened response spectra.

<u>Shear Wall Design – Enveloped Broadened Spectra – Step-1</u>

A flow chart of the design methodology used for the design evaluation of shear walls is provided as Figure 3. This section describes the analysis results from Step-1 using Enveloped/Broadened Response Spectra as input to the RSA analysis.

A conservative response spectrum was applied to the model of the superstructure that is fixed at the top of the basemat. The response spectrum is based on enveloping and broadening the response spectra from 6 different sites and two cracking conditions (cracked and uncracked) of the superstructure. The response spectra are taken from the respective SASSI analyses. Conservatism was obtained by using the envelope of four corner nodes at each site and each cracking condition. The corner nodes include the effect of translation, torsion and rocking from the 3D SASSI analysis.

The calculated loads (Figure 3, Step-1) were used to evaluate the walls. Story shears were calculated and compared to the ACS-SASSI results. Most walls had a capacity greater than demand. Walls where the Demand to Capacity Ratio (DCR) exceeded 1.0 using the conservative enveloped and broadened spectra received additional evaluations as defined in Step-2.

The story shear for the R/B Complex was determined for both the RSA and ACS-SASSI analyses and the results were compared. Critical sections 1, 2, 3, and 4 walls were qualified using the broadened/enveloped response spectra of the six soil profiles for both the cracked and uncracked structures. A story shear comparison for the enveloped and broadened RSA is provided as Figures 4 through 6.

<u>Shear Wall Design – Unbroadened Spectra – Step-2</u>

Two soil profiles (2032-100 soil profile and 900-100 soil profile) were established as the governing soil profiles for Step-2 based on the acceleration response spectrum, story shear force, and vertical force comparisons as determined from the ACS-SASSI analysis using 6 soil profiles. The 2032-100 soil profile produced the largest seismic demand within the R/B Complex and the 900-100 soil profile producing the second largest seismic demand. The response spectra curves for these two soils were determined from the ACS-SASSI analysis and the refined spectral input using the unbroadened spectra were applied to the fixed base RSA model. The primary purpose of spectra broadening is to account for the affects of uncertainties by spreading response spectrum peaks which is almost always used when a single site spectrum is used for design. In this condition, the 6 soil profiles were evaluated with the largest resulting loads being considered in the design. Additionally the effects of the design forces and moments were compared to the baseline results governed by the ACS-SASSI analysis. Conservatism was reduced using the unbroadened spectra but by completely enveloping the ACS-SASSI results (six soil profiles for both the cracked and uncracked structures); therefore, the results remain conservative

The unbroadened response spectra associated with Soil Profile 2032-100 generated the greatest shear demands when Figure 3, Step 2 methodology was applied such as in the design qualification of Critical Section 5. The story shear comparison between ACS-SASSI and RSA using the unbroadened response spectra for soil profile 2032-100 is provided in Figures 7 through 9. Direct comparison of corresponding figures, i.e. comparison of Figures 4 and 7, 5 and 8, and 6 and 9, reveals that there is virtually no difference between the broadened and unbroadened curves and that the RSA story shear envelopes the ACS-SASSI story shear for all elevations above Elevation 3’-7”.

All structural elements within the above grade superstructure, above elevation 3’-7”, were qualified using either Step-1 or Step-2 methodologies.

Basemat Displacements Considered in the Walls Below Elevation 3’-7” – Step 3

The differences between the ACS-SASSI and RSA methods resulted in divergences and reduced margins in the below grade elevations, i.e. below elevation 3’-7”, as revealed when comparing Figures 4 and 7, and 5 and 8. This is especially denoted in Figure 8 where the RSA does not envelope the ACS-SASSI story shear. Further review indicates that the gross story shear for an entire elevation may be satisfied with margin but individual walls have larger differences in Zone 1. This is attributed to differences in boundary conditions between the fixed base RSA model and the flexible ACS-SASSI analysis which accounts for:

1. basemat flexibility
2. affects of soil stiffness
3. the presence of the thickened basemat “pedestal” supporting the PCCV and CIS

A separate ANSYS analyses was performed considering the affects of a flexible basemat and the resulting affects on the superstructure. The rocking and displacement affects on the walls directly bearing on the basemat is considered in the design. The methodology used to design the walls is provided in the following response to 3.8 Audit Containment Open Item 8.

3.8 Audit - Containment Item 8. MHI to provide technical basis for not considering the rocking effects in the response spectra analysis for the design of the R/B Complex.

Figure 3 identifies the three step design approach for the R/B Complex with considering a difference in the design for the R/B Complex above and below elevation 3’-7”. The RSA approach always envelopes the story shears from ACS-SASSI above elevation 3’-7”. However, basemat flexibility and the affects of rocking are included in the design of the shear walls below elevation 3’-7”.

The design of the superstructure above the elevation 3’-7” (at grade elevation) was designed using Figure 3 Steps 1 and 2. The story shears presented on Figures 4 through 9 indicate that the RSA approach exceeds and envelopes the ACS-SASSI story shears in the superstructure above the top elevation of the PCCV pedestal. However, it is acknowledged that a flexible basemat can locally affect design loads that are not adequately captured in the Fixed Base model. The use of displacements envelope the ACS-SASSI story shears as indicated in Figure 10.

Figure 3 Step 3 was performed separately and concentrated on the structure from elevation 3’-7” down to the basemat which represents the embedded part of the structure. The effects of displacement in the walls below Elevation 3’-7” were calculated using input from the basemat model which is described in the response to RAI 1045-7141 Question 03.08.05-51. The basemat model did include the applied seismic loads obtained from the ACS-SASSI nodal accelerations at the time steps at which the maximum base and overturning moment occur.

The equivalent static forces are applied to the basemat model and linear and uplift analysis were performed to calculate the nodal displacements of the basement walls. Two methods were used to extract displacements: (1) linear static analysis without thermal load (i.e. bonded contact between basemat and underlying soil strata); and (2) uplift analysis with thermal load (i.e. uplift allowed between basemat and underlying soil strata) to determine the structural responses from all major load cases. From both analyses, the nodal

displacements of the basement walls were determined and applied to the refined RSA model to determine the forces in the shear walls bearing directly on the basemat.

3.8 Audit - Foundation Item 1. REB-13-05-230-001, pg 95, 2nd bullet, Wall designed to RSA results, which are less than SSI results. Please explain.

Steps 1 or 2 were used to design all shear walls above elevation 3'-7" using enveloped and broadened spectra. The below grade section of the R/B Complex, below elevation 3'-7", was influenced by the flexible basemat, displacements, and the stiffened pedestal such that the RSA approach under predicted the design shear forces in some areas when compared to the ACS-SASSI results. Examples of this are provided on Figure 10. To assure that the design loads always enveloped the ACS-SASSI results the shear walls below elevation 3'-7" were designed using the methodology described in the flow chart provided as Figure 3. The displacements in the walls below Elevation 3'-7" were calculated using input from the basemat model considering all loading conditions. A bounding approach was used to design the basement shear walls where the greater demand determined in Figure 3 Steps 1 / 2 or Step 3 was used which results in the design always being equal to or enveloping the results of the SSI analyses.

3.8 Audit - Foundation Item 4. REB-13-05-230-001, pg 79, Statement that maximum displacement shown is conservative. Where does the maximum displacement occur and why is it conservative?

The maximum R/B Complex displacement occurs in the Fuel Handling area of the Reactor Building. This area has the greatest height above the basemat in the R/B complex and it is also the location of the Spent Fuel Pool and Fuel Handling Crane. The maximum deflection indicated in Figure 11 is 0.17506 feet (2.1 inch). The design considers the local effect of the total load, concurrent with the enveloped and broadened seismic spectra resulting in a design that is maintained within code allowable with margin.

References

1. US Nuclear Regulatory Commission (NRC) Regulatory Guide (RG) 1.92, Revision 2, "Combining Modal Responses and Spatial Components in Seismic Response Analysis," U.S. Nuclear Regulatory Commission, July 2006.

2. ACS-SASSI: Version 2.3.0 Including "Option A" & NQA "Option FS", An Advanced Computational Software for 3D Dynamic Analysis including Soil-Structure Interaction, Users Manuals, Revision 7.0, Ghiocel Predictive Technologies, Inc., September 26, 2012

3. ANSYS, Advanced Analysis Techniques Guide, Release 13.0, ANSYS, Inc., 2010.

4. ACS-SASSI-ANSYS Integration Capability, Version 2.3.0, Option A, User Manual Revision 0, Ghiocel Predictive Technologies, Inc., December 30, 2010

5. Gerdes, L.D. and R.P. Kassawara, "Uncertainties in Seismic Design of Equipment Mounted Subsystems," 1980 ASCE Conference, Knoxville, TN. (Copy Attached for Reference)

Table 1 Comparison of Building Roof Corner Displacements between Results of RSA and ACS-SASSI

Table 2 Maximum Forces of R/B Critical Sections

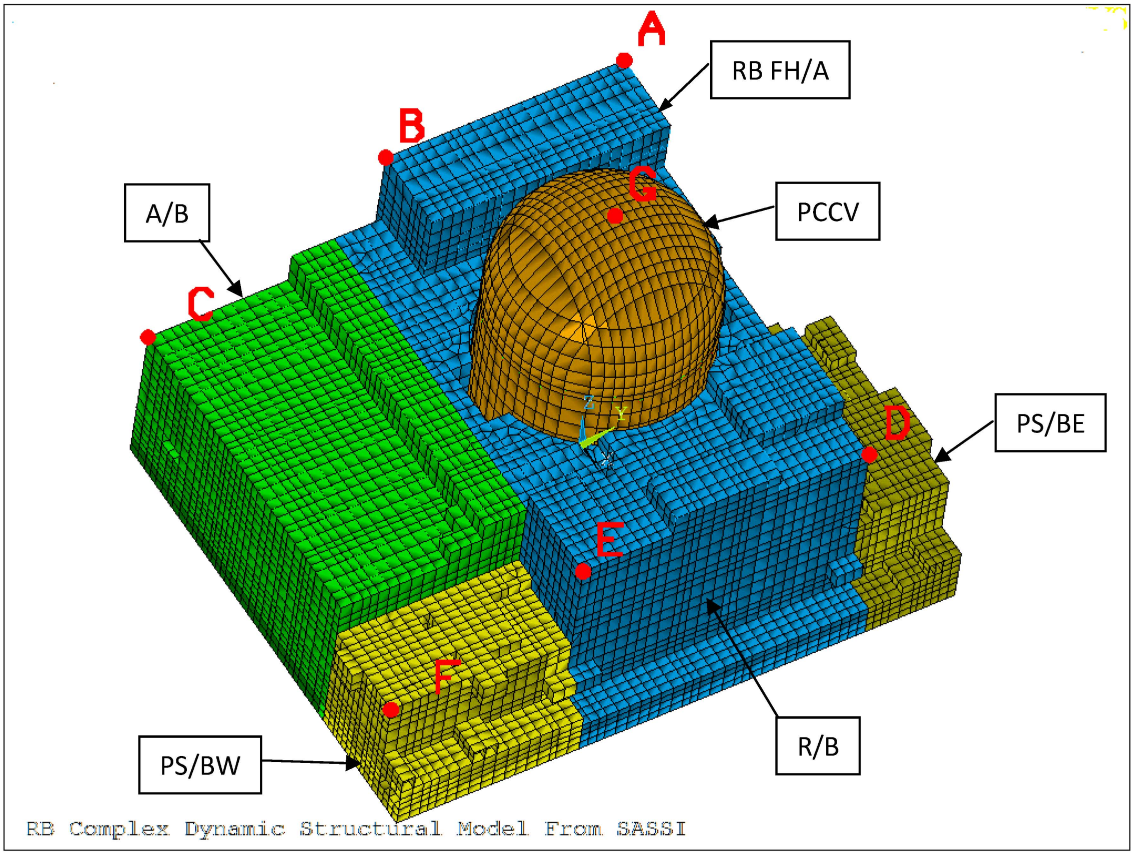

Figure 1 Building Roof Corners

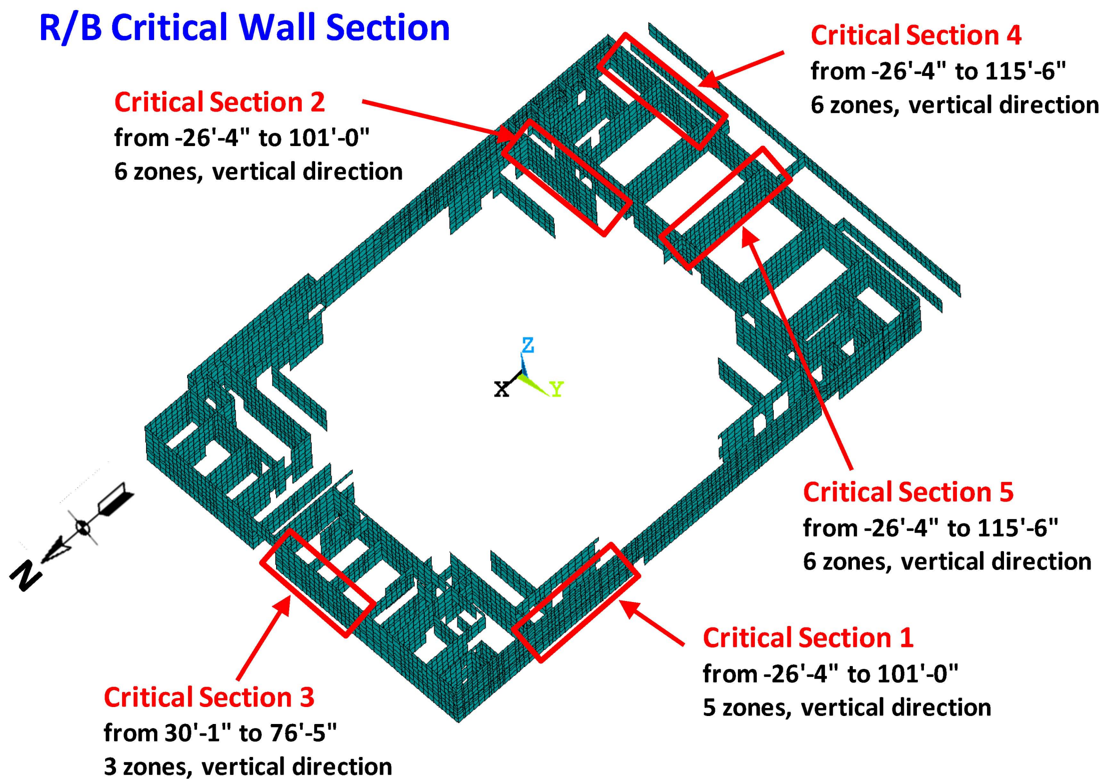

Figure 2 R/B Critical Section Location

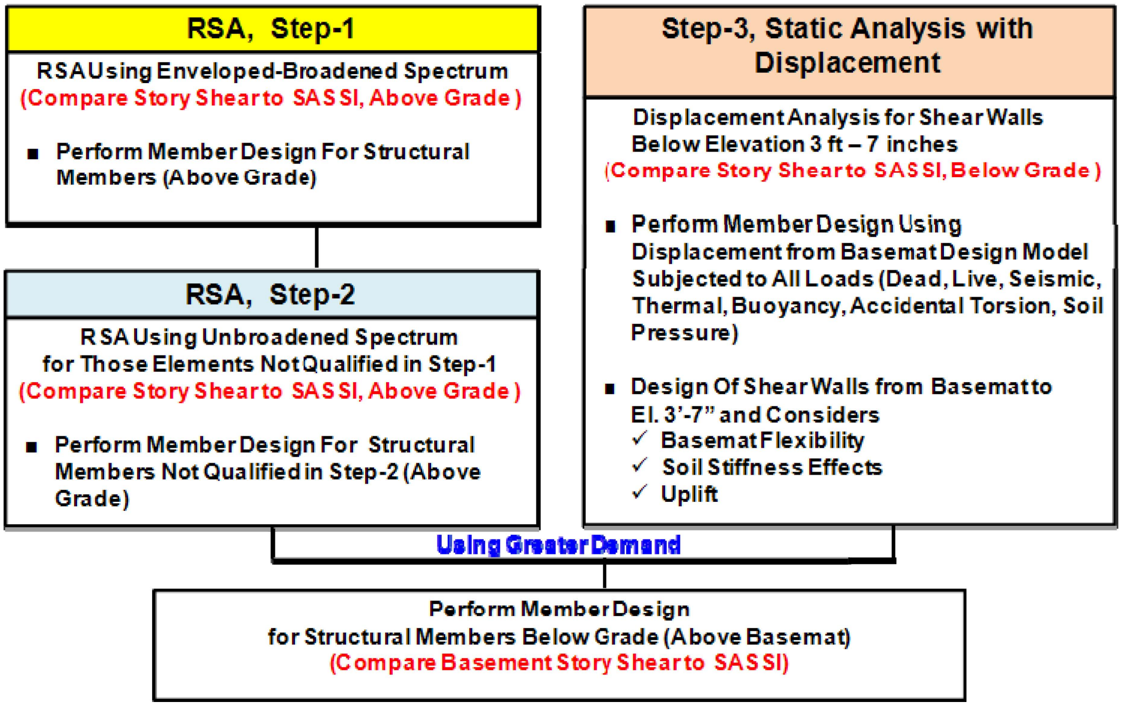

Figure 3: R/B Complex, Seismic Design Flow Chart

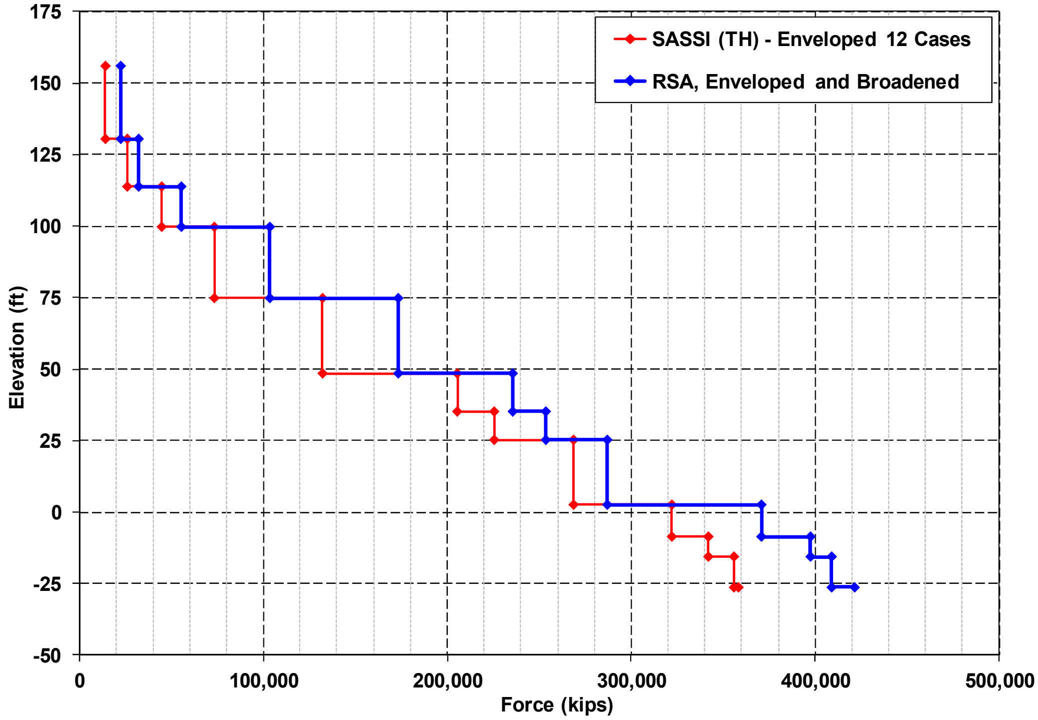

Figure 4: Horizontal Shear Force Comparison, RSA with Enveloped and Broadened Soil Case (NS)

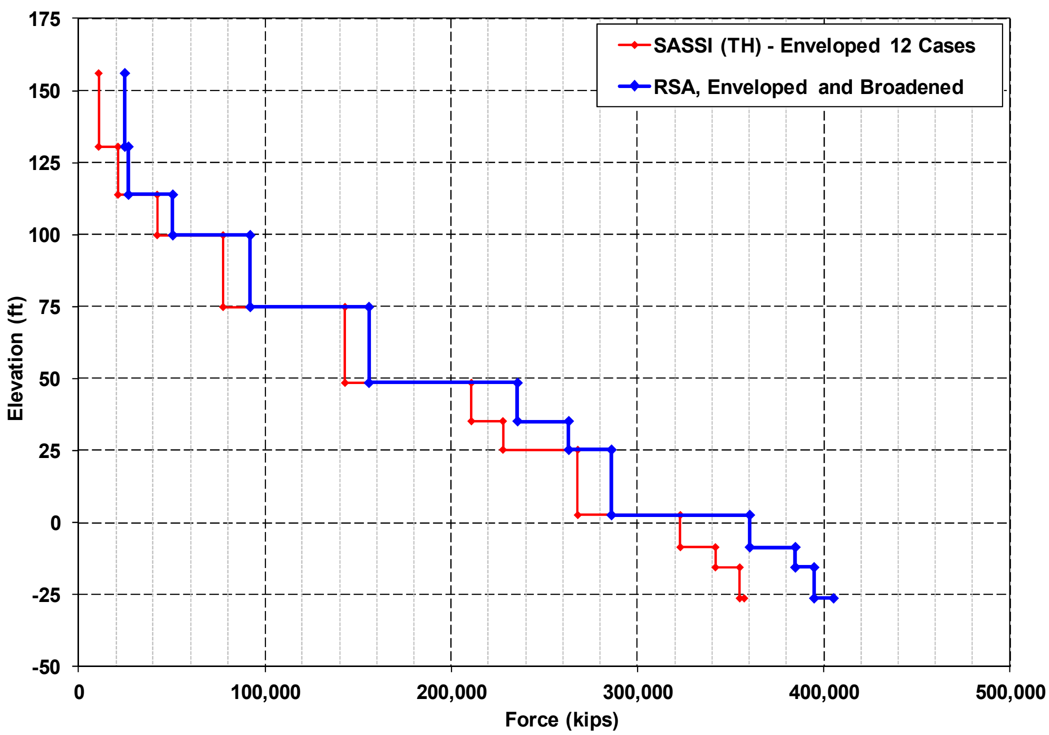

Figure 5: Horizontal Shear Force Comparison, RSA with Enveloped and Broadened Soil Case (EW)

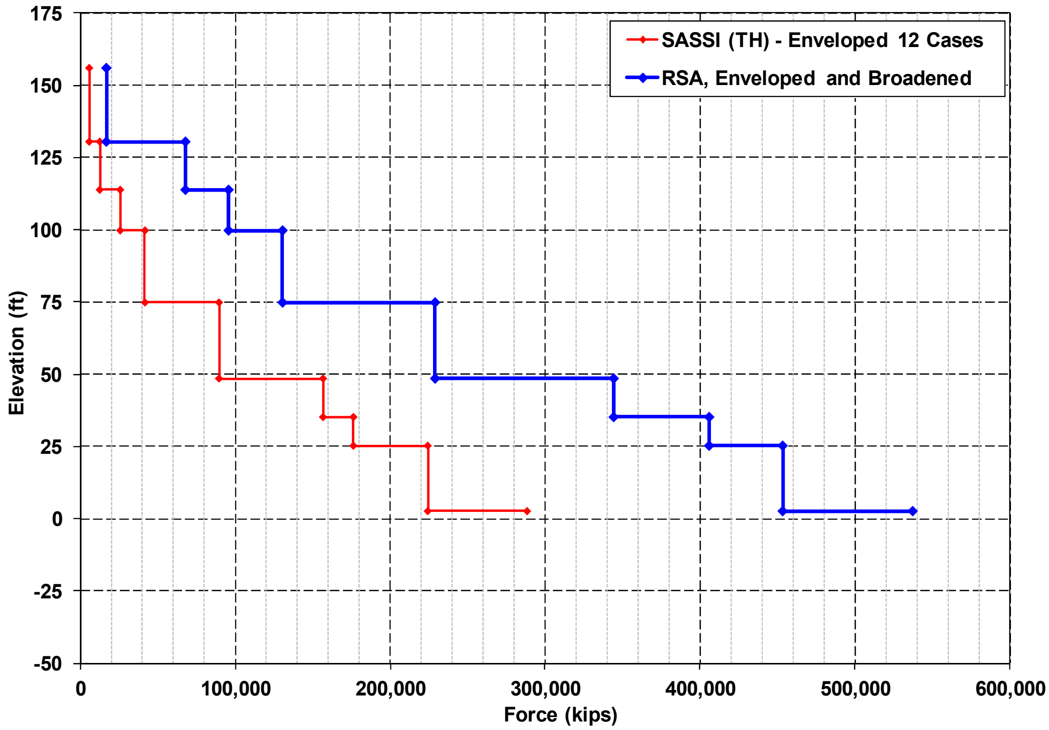

Figure 6: Vertical Shear Force Comparison, RSA with Enveloped and Broadened Soil Case

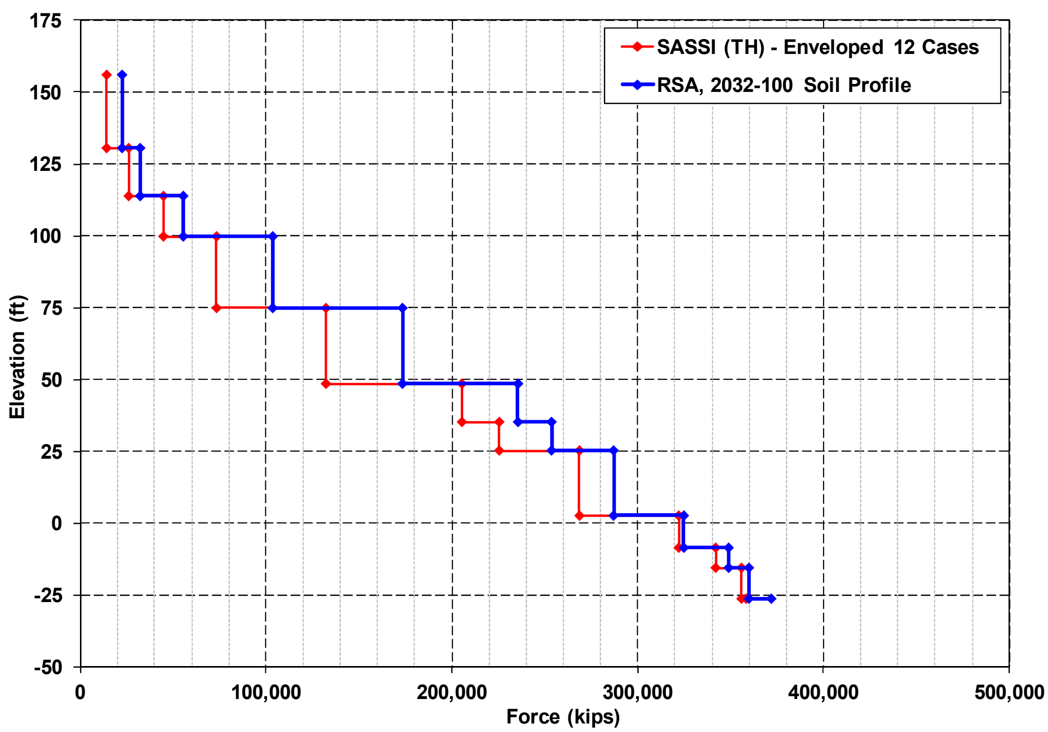

Figure 7: Horizontal Shear Force Comparison, RSA with 2032-100 Soil Profile (NS) (Non-Broadened)

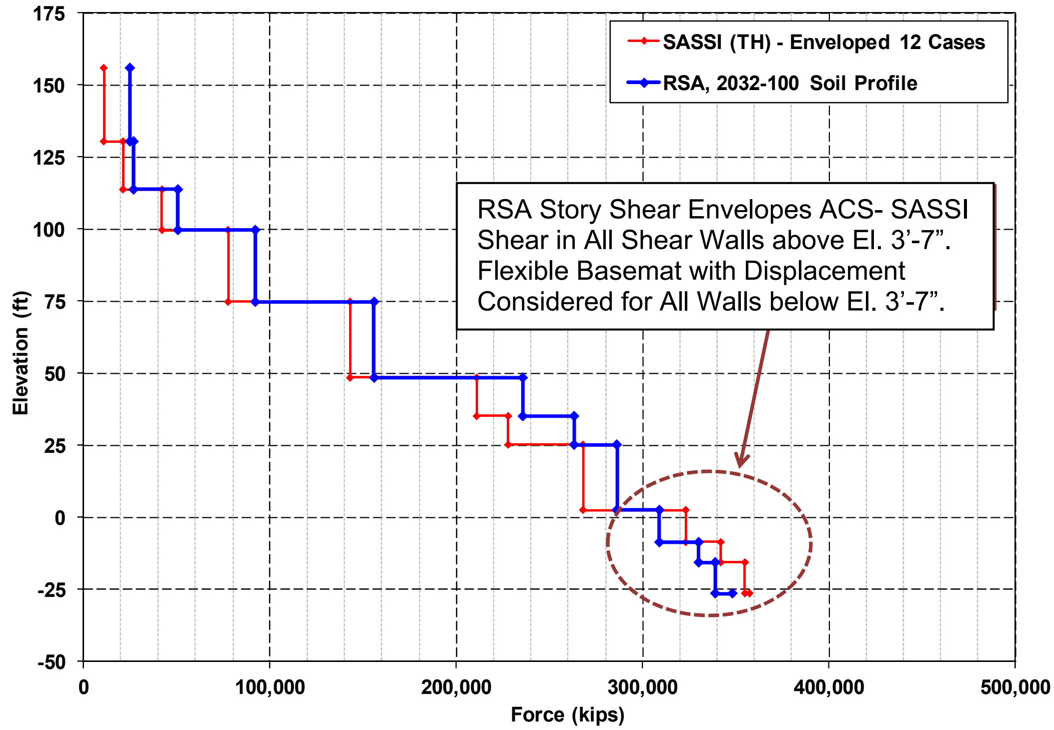

Figure 8: Horizontal Shear Force Comparison, RSA with 2032-100 Soil Profile (EW) (Non-Broadened)

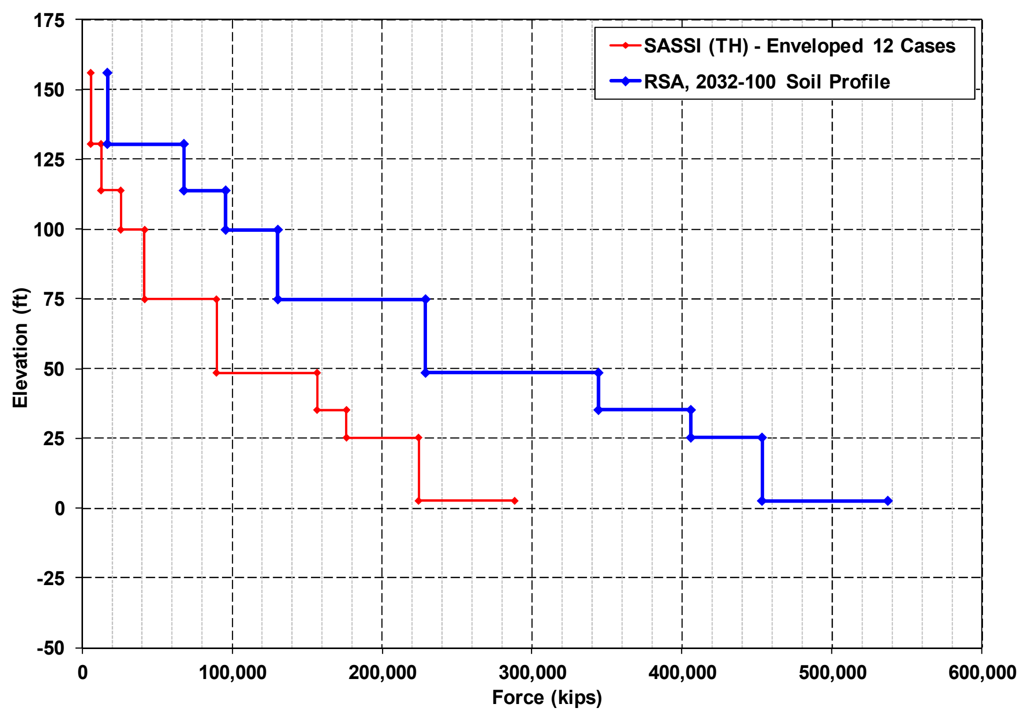

Figure 9: Vertical Shear Force Comparison, RSA with 2032-100 Soil Profile (Non-Broadened)

Figure 10: Critical Section Force from RSA, SASSI, and Displacement Analysis
(Below Elevation 3 feet – 7 inches)

Figure 11: Deflected Shape Considering Total Loads (Looking South-West)

Impact on DCD

There is no impact on the DCD.

Impact on R-COLA

There is no impact on the R-COLA.

Impact on PRA

There is no impact on the PRA.

Impact on Technical/Topical Report

There is no impact on the Technical/Topical Report.

This completes MHI's response to the NRC's question.