RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

3/24/2014

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 1060-7285 REVISION 4**
SRP SECTION:	**03.07.02 – Seismic System Analysis**
APPLICATION SECTION:	**3.7.2**
DATE OF RAI ISSUE:	**11/15/2013**

QUESTION NO. 03.07.02-232:

Part 1

Figure 03.3.4.1-3, "Excavated Soil Volume Elements," of technical report MUAP-10006, "Soil-Structure Interaction Analysis and Results for the US-APWR Standard Plant," Revision 3, shows the finite element mesh used to model the excavated soil volume of the embedded Reactor Building (R/B) complex. The staff notes that under the Pre-stressed Concrete Containment Vessel (PCCV) there are regions where the mesh is irregular and the elements are highly distorted. To ensure the ACS SASSI soil-structure interaction (SSI) solution is not sensitive to such irregularly meshed regions, the applicant is requested to provide the following additional information:

(1) What is the value of the parameter “R” (radius of the central zone in the point load solution) used in the design basis analysis, how was it determined, and how does it compare to the generic SASSI recommendations for a uniform mesh?

(2) Provide the results of a comparison study that demonstrates the ACS SASSI SSI solution is insensitive to the mesh irregularity noted above. The two SSI analyses to be compared should have (a) the irregular mesh and the parameter “R” used in the design basis analysis, and (b) a uniform mesh and the parameter “R” that satisfies the generic SASSI recommendations. For the purpose of this study, soil case 900-100 should be used; the superstructure may be represented by a lumped-mass stick model. The S-wave passing frequency should be at least as high as the passing frequency in the design basis analysis for soil case 900-100 (approx. 40 Hz). The Modified Subtraction Method (MSM) may be used and the results should be provided in terms of transfer functions and In-Structure Response Spectra (ISRS) at the following locations: four (4) corners, both top and bottom, of the excavated volume; center of bottom of the excavated volume; center of PCCV, at the top of the excavated volume; and top of the PCCV (11 locations total).

Part 2

Table 03.3.5-1, "Matrix of ACS SASSI Runs," of technical report MUAP-10006, Revision 3, indicates the cut-off frequency of the SSI analysis is 40 Hz for generic soil profiles 270-200 and 270-500, and 50 Hz for generic soil profiles 560-500, 900-100, 900-200 and 2032-100. However, the staff notes that the passing frequency of several SSI model soil profiles are lower than the analysis cut-off frequency. Based on layer thickness, the S-wave passing

frequency for cases 270-200, 270-500, and 560-500 is indicated as 36.2 Hz, 33.6 Hz, and 38.2 Hz, respectively (Tables 03.3.1-1, "Input 270-200 Soil Properties," 03.3.1-2, Input 270-500 Soil Properties 03.3.1-3, "Input 560-500 Soil Properties," and 03.3.4.1-1, "S-Wave Vertical Mesh Passage Frequencies of the Excavated Volume Element"). Based on average horizontal dimension of the excavated volume mesh in the East-West direction, the passing frequencies for cases 270-200, 270-500, 560-500, 900-100, and 900-200 are indicated as 32.7 Hz, 31.9 Hz, 29.1 Hz, 41.4 Hz, and 42.7 Hz, respectively (Table 03.3.4.1-3, "EW Wave Passage Frequencies of the Excavated Volume Element"; slightly larger values are given in Table 03.3.4.1-2, "NS Wave Passage Frequencies of the Excavated Volume Element," for the North-South direction). Below the basemat, the passing frequencies for cases 270-200, 270-500, and 560-500 are indicated as 32.5 Hz, 34.3 Hz, and 44.5 Hz, respectively (Table 03.3.5-2, "Wave Passage Frequencies of the Model Below Foundation").

Section 03.3.5 of the report indicates that passing and cutoff frequencies below 50 Hz for the soil sites are acceptable because (a) for the soil sites, the relatively softer soil will filter out high frequency content of the input motion propagated from the hard rock basement (supporting reference identified); and (b) cases 270-200 and 270-500 control the seismic response, in terms of the ISRS at various locations, only at frequencies far below 30 Hz.

However, the report provides no justification for the acceptability of the passing frequencies for cases 560-500, 900-100, and 900-200 (29.1 Hz, 41.4 Hz, and 42.7 Hz, respectively), which are all below 50 Hz.

To assist the staff in determining the adequacy of the SSI models developed for the analysis of the six (6) generic soil profiles, the applicant is requested to provide the following additional information:

(1) Revise Section 03.3 of MUAP-10006, Revision 3, (e.g., pgs. 3.3-6 and 3.3-9) to clarify the distinction between model passing frequencies and analysis cutoff frequencies.

(2) In light of a passing frequency of 29.1 Hz for soil case 560-500, confirm that this soil case does not control the seismic response at frequencies above 29.1 Hz, and supplement the justification provided in Section 03.3.5 of the report to cover this soil case.

(3) Revise DCD Tier 2, Section 3.7 to be consistent with the revisions to MUAP-10006, Revision 3, indicated in items (1) and (2) above.

(4) The stiff profiles 900-100 and 900-200 appear to control the seismic response in the frequency range of 30-50 Hz; however, the passing frequency for these two cases is only slightly above 40 Hz. Provide the results of a study that demonstrates the sensitivity of seismic response for the 900-100 case when the passing frequency is increased from 40 Hz to 50 Hz. It is not necessary to consider the 900-200 case because its seismic response is expected to be very similar to the 900-100 case. The simplified model described in Part (1) of this RAI should be used to perform this study, with the uniform mesh for the excavated volume and the MSM. The results should be provided in terms of transfer functions and ISRS at the locations identified in Part (1). Add a statement to MUAP-10006, Revision 3, documenting that the SSI models for the 900-100 and 900-200 profiles are adequate up to 50 Hz, if the study results support such a conclusion.

ANSWER:

Part 1

(1) A value of 7.0 ft is used for “R” (radius of the center zone in the point load solution) in design basis soil-structure interaction analysis. This value was determined as follows: the average mesh size of the basemat of the design basis dynamic finite element model is 6.62 ft in North-South (NS) direction and 7.32 ft in East-West (EW) direction. The average element surface area (6.62 ft x 7.32 ft) is equivalent to a square mesh with side length of about 7.0 ft.

The selection of “R” value is based on past experience on the models with non-uniform mesh and a study of sensitivity of “R” value. This sensitivity study was limited to the evaluation of the impedances of the basemat, as a rigid foundation, with design basis non uniform mesh using various “R” values versus a comparable uniform mesh model using “R” value specified by generic SASSI recommendation. Recognizing the limitation of comparing the rigid foundation impedance only, further verification of the adequacy of the “R” value will be performed as discussed next.

(2) A comparison study as outlined by the staff in Part 1 item (2) of this RAI will be performed to verify the “R” value used in design basis analysis.

Two models, model 1 and model 2, will be developed for the study. A basement model with the same mesh pattern as basement part of design basis model combined with a lumped mass stick model (LMSM) that approximately represents the dominant dynamic characteristic of the superstructures will be developed as Model 1. Model 2 will use the same LMSM as model 1 to represent the superstructure but will use uniform mesh in regular shape to discrete the simplified basement. The equivalency of the two models in terms of dynamic characteristic will be validated to ensure the two models are comparable. As outlined by the staff, the two models will be analyzed for soil profile 900-100 using Modified Subtraction Method (MSM) and the responses in terms of Transfer Function and In Structure Response Spectra at locations specified will be compared to evaluate the effect of “R” value.

Part 2

(1) The Section 3.3 of MUAP 10006 Rev. 3 will be revised as shown in Attached mark-up pages of the Report to clarify issue regarding model maximum passing frequency and maximum frequency analyzed or cut-off frequency of analysis.

(2) Section 03.4.1.2 of MUAP 10006 Rev.3 discusses the effect of soil profiles on seismic response in terms of Acceleration Response Spectra (ARS). Based on review of the ARS at various locations of the Reactor Building Complex, the section concludes that “… soil profiles 270-200, 270-500 and 560-500 control the response up to frequency of approximately 5.0 Hz.” This section presents ARS at the reactor vessel support (or top of the reactor cavity) to demonstrate the conclusion. Figure 1 through Figure 6 present the ISRS at top center of the PCCV as an additional example. Under the curve of ISRS, the ARS for the six generic soil profiles from which the ISRS are developed are plotted. The plots indicate that for the top center of the PCCV, the 560-500 soil profiles control the response up to about 3.5Hz. MHI believes that a revision to Section 03.3.5 of MUAP 10006 Rev. 3 is not necessary at this point.

(3) Section 3.7 of DCD will be revised to be consistent with mark-up of MUAP 10006 Rev.3 as attached.

(4) A study of sensitivity of model mesh passing frequency on the seismic response will be performed as outlined by the Staff in Part 2 item (4) of this RAI.

Model 2 as described in response to Part 1 item (2) will be refined to have model passing frequency of 50 Hz for soil profile 900-100. Analysis for the model with 900-100 soil profile will be performed using MSM and the responses in terms of Transfer Function and In Structure Response Spectra at locations specified will be provided to demonstrate if the results are sensitive to this further refinement of the model mesh.

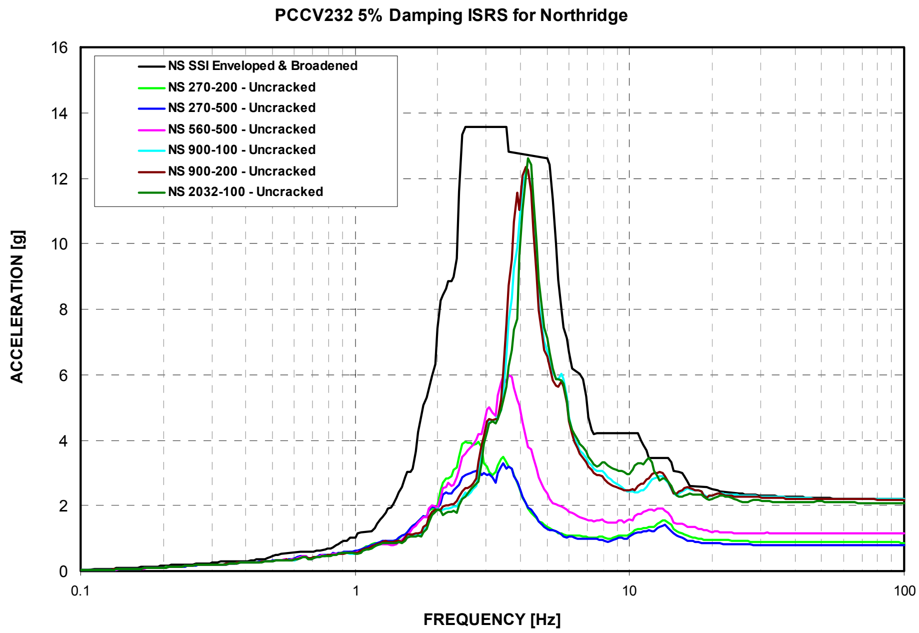

Figure 1 PCCV ISRS Plot - Response in NS Direction - Uncracked - Model Elevation 232 ft

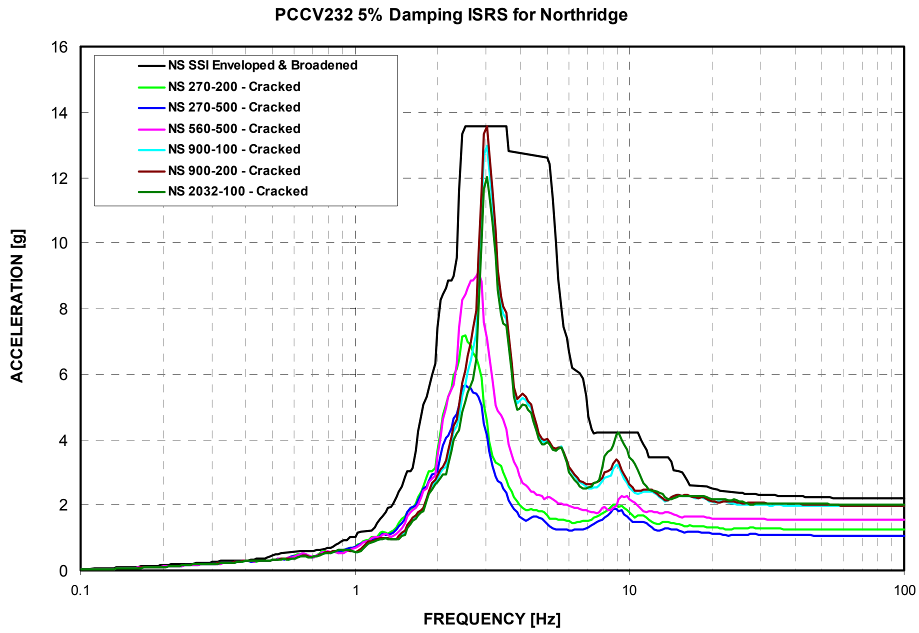

Figure 2 PCCV ISRS Plot - Response in NS Direction - Cracked - Model Elevation 232 ft

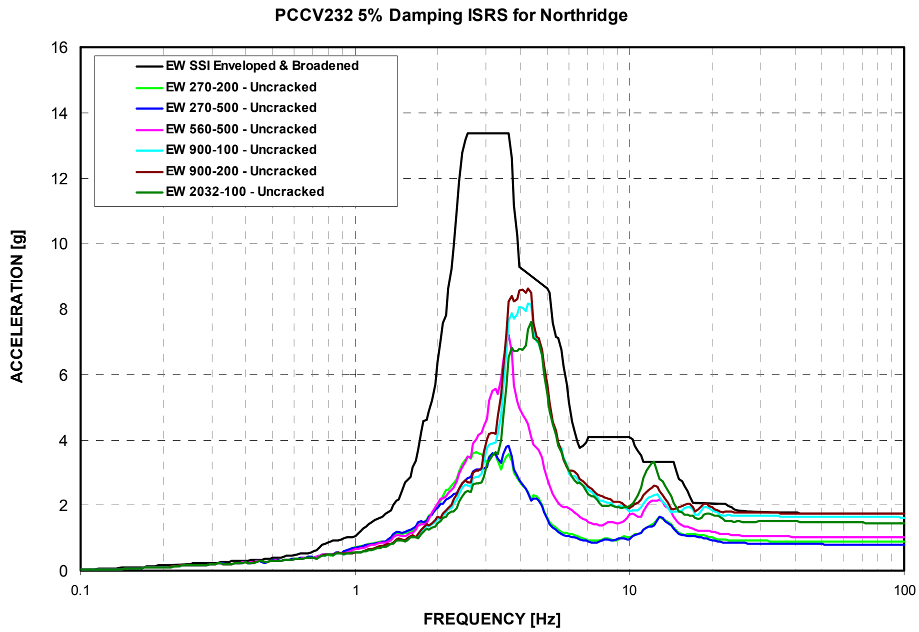

Figure 3 PCCV ISRS Plot - Response in EW Direction - Uncracked - Model Elevation 232 ft

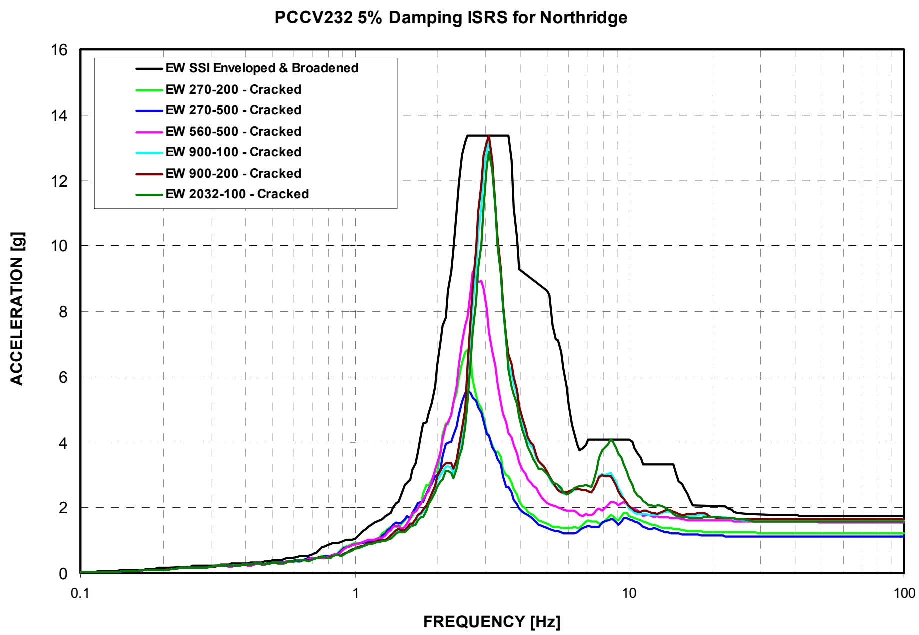

Figure 4 PCCV ISRS Plot - Response in EW Direction - Cracked - Model Elevation 232 ft

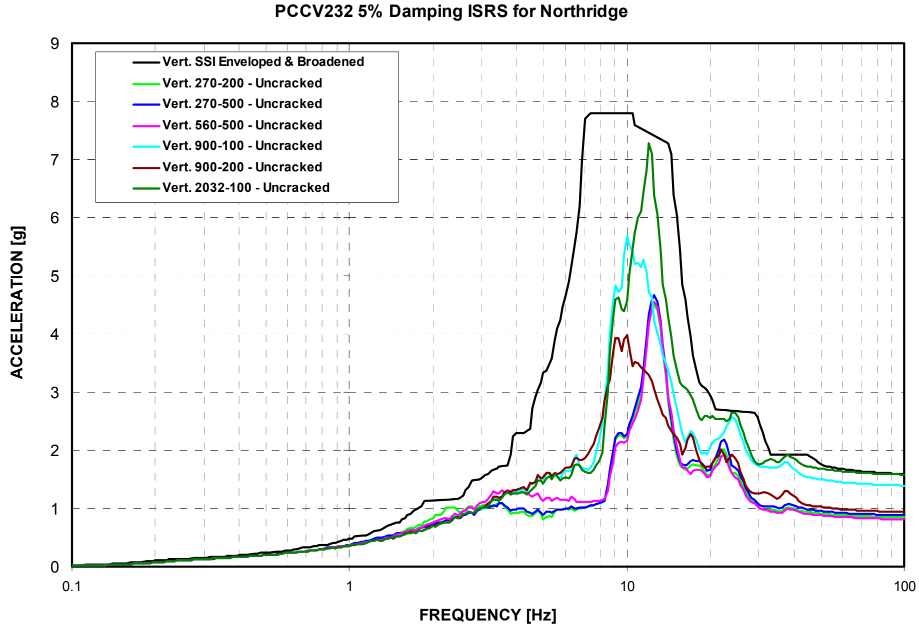

Figure 5 PCCV ISRS Plot - Response in Vertical Direction - Uncracked - Model Elevation 232 ft

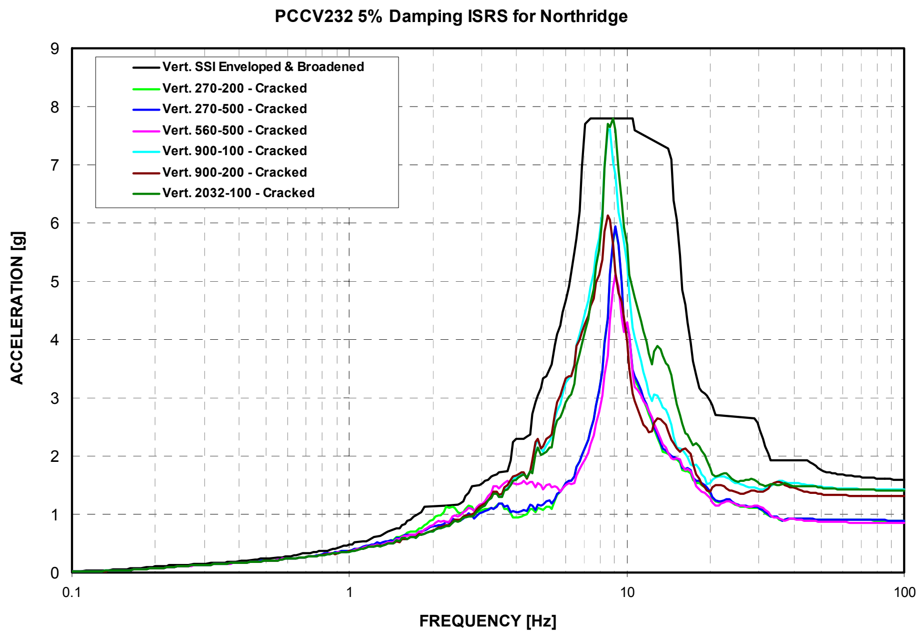

Figure 6 PCCV ISRS Plot - Response in Vertical Direction - Cracked - Model Elevation 232 ft

Impact on DCD

Section 3.7 of DCD will be revised.

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

Technical Report MUAP-10006, Rev.3 will be revised as shown in attachment 1.

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

primarily by Rayleigh and Love surface waves. It is very important to have a SSI modeling to appropriately describe the motion of the excavated soil nodes situated at the ground surface nodes. The vibration of these nodes at the ground surface is primarily controlled by surface wave components. Including surface nodes as interaction nodes greatly improves the excavation soil response accuracy.

A review of ATFs at various locations throughout the R/B complex indicates that the MSM model reasonably captures the seismic responses for the analyzed frequency (See Appendix 3-C). MSM is an accurate and robust method for the R/B complex, which has a large footprint shallow embedded foundation for the frequency range analyzed.

03.3.3.5 Cut-off Frequency of the Analyses

The cut-off frequency is the highest frequency to be used in the dynamic analysis of the soil structure(s) system. It sets an upper limit on the number of frequencies to be analyzed., and controls the maximum allowable element size which in turn controls the size of the problem to be solved. The maximum frequency of analysis is determined from the wave passage frequency (f_{pass}) of the soil layer and soil element size. The wave passage frequency is the maximum wave frequency that the soil layer and excavated soil mesh can accurately transmit. It is determined using Equation 03.3.3.5-1 below (Reference 03-2) and provided that the soil element mass matrix is constructed from the combination of consistent and lump mass matrices (50% each), which is built in to the SASSI mass matrix computation that:

$$f_{pass} = \frac{V_s}{5 \cdot d} \qquad \text{Equation 03.3.3.5-1}$$

- where V_s is the shear wave velocity of the soil and d is either the thickness of the soil layer or the maximum size of the FE mesh of the structural model at the SSI interface or the excavated soil volume mesh size.

The maximum cut-off frequency in the analyses should be as close as possible to the wave passage frequency, but it could be slightly greater than the wave passage frequency. The ATFs are reviewed to ensure that the maximum cut-off frequency of the analysis yields smooth curves with no anomalies. A list of the wave passage frequencies for the R/B complex SSI model including both soil layering and excavated volume is presented in Section 03.3.4.

The maximum cut-off frequencies in the analyses are determined to be 40 Hz for 270-200, 270-500 soil profiles, and 50 Hz for 560-500, 900-100, 900-200 and 2032-100 soil profiles. Refer to Section 03.3.5 for detailed discussion. Based on the maximum cut-off frequencies and intervals of frequency points as discussed in Section 03.3.3.2, for both SSI and SSSI analysis, a total number of 132 frequencies is analyzed for soil profiles 270-500 and 270-200, and a total number of 152 frequencies is analyzed for soil profiles 560-500, 900-100, 900-200 and 2032-100. For a graphical representation of the selected frequencies of analyses, see ATFs in Appendix 3-C.

03.3.4 SSI and SSSI Analyses – ACS SASSI Model Description

The R/B complex SSI analysis and R/B complex combined with T/B SSSI analysis address foundation embedment effects by directly analyzing the soil structure or structure soil structure system using embedded models. The corresponding SSI and SSSI embedded models are the design basis models for seismic analysis of the R/B complex.