RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

1/31/2013

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 810-5874 REVISION 3**
SRP SECTION:	**03.07.02 – Seismic System Analysis**
APPLICATION SECTION:	**3.7.2**
DATE OF RAI ISSUE:	**08/22/11**

QUESTION NO. RAI 03.07.02-91:

In Subsection 3.7.2.1 of DCD (R3), "Seismic Analysis Methods", the second paragraph (page 3.7-15) states in part, "The seismic response is obtained in the frequency domain from solution of complex algebraic equations for a selected set of frequencies of analysis. The solutions obtained for the selected set of frequencies of analysis are then interpolated and transformed into the time domain using Inverse Fast Fourier Transformation."

The Applicant is requested to specify how many frequencies are in the selected sets, how these frequencies are selected, and how the interpolation is performed. The Applicant is also requested to provide acceptance criteria for comparing the interpolated transfer functions to the uninterpolated transfer functions.

ANSWER:

This answer revises and replaces the previous MHI answer that was transmitted by letter UAP-HF-11402 (ML11332A148).

Section 03.3.3.2 of Technical Report MUAP-10006, Rev. 3 discusses the adequacy of frequencies analyzed and the accuracy of the resulting transfer function. The ACS SASSI transfer function interpolation option 0 (Reference 1) was used for the US-APWR Standard Plant SSI and SSSI analysis.

Table 03.3.5-1 of Technical Report MUAP-10006, Rev. 3, shows the number of frequencies of analysis and cut-off frequency for uncracked and cracked concrete conditions of each generic soil profile used in the soil-structure interaction (SSI) and structure-soil-structure interaction (SSSI) analyses of the reactor building (R/B) complex. The figures in Appendix 3-C of MUAP-10006, present the results of the site independent SSI analyses for amplitudes of the acceleration transfer functions for responses at selected locations within the R/B complex dynamic finite element (FE) model. These figures show the calculated transfer functions with dots and the interpolated transfer functions with solid lines.

The interpolation of the transfer function is performed in the complex frequency domain to obtain the response transfer function for all Fourier frequencies. The complex frequency interpolation is used to determine the values of the response transfer function for frequencies in between the calculated transfer function values. Therefore, as shown in the figures in Appendix 3-C of Technical Report MUAP-10006, the values of the interpolated transfer functions at the selected frequencies of analyses are identical to the values calculated from the SSI analyses. The employed interpolation scheme is based on the analytical form of a complex response transfer function of a two-degree-of-freedom dynamic system. This complex transfer function for a two-degree-of-freedom dynamic system has the form of a ratio of two fourth order polynomials with complex coefficients. The complex transfer function of a two-degree-of-freedom dynamic system subjected to a harmonic base excitation can be written for each degree-of-freedom in the following general form:

$$U^i(\omega)=\frac{C_1^i\omega^4+C_2^i\omega^2+C_3^i}{\omega^4+C_4^i\omega^2+C_5^i} \qquad (1)$$

Where the interpolated response is the response at a frequency for which the complex coefficients can be computed, if the solution is known at five frequency points. To compute the complex coefficients a five equation system needs to be solved. This system is

$$\begin{bmatrix} \omega_1^4 & \omega_1^2 & 1 & -\omega_1^2U_1 & U_1 \\ \omega_2^4 & \omega_2^2 & 1 & -\omega_2^2U_2 & U_2 \\ \omega_3^4 & \omega_3^2 & 1 & -\omega_3^2U_3 & U_3 \\ \omega_4^4 & \omega_4^2 & 1 & -\omega_4^2U_4 & U_4 \\ \omega_5^4 & \omega_5^2 & 1 & -\omega_5^2U_5 & U_5 \end{bmatrix} \begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \end{bmatrix} = \begin{bmatrix} \omega_1^4U_1 \\ \omega_2^4U_2 \\ \omega_3^4U_3 \\ \omega_4^4U_4 \\ \omega_5^4U_5 \end{bmatrix} \qquad (2)$$

Following this technique, the frequency range is subdivided into smaller regions each of which contains the transfer function solution for 5 frequencies of the analysis. For the last region, the solution from the previous region can be augmented, if necessary, to form the solution of 5 frequencies needed for the interpolation. Using the above technique, the transfer function in each region is interpolated, so that by covering all the regions, the transfer function values are computed for all frequencies shown in equation (1).

As a simple rule to get accurate results, the frequency window defined by each subset of five frequency points should not include more than two transfer function spectral peaks, so it can be approximated accurately by the two-degree-of-freedom dynamic system transfer function interpolation scheme. If the structural response includes more than 2 resonant peaks in the five point frequency window, then, the interpolation scheme will deviate from the correct solution. Therefore, the SSI analysis has to be performed for frequencies that create a sufficiently dense grid for interpolation in order to accurately reconstruct the spectral peaks and valleys of the transfer functions.

In ACS SASSI version 2.3.0 (Reference 1) there are six interpolation options available based on the interpolation technique described by Equations (1) and (2). The six interpolation options assume that the complex coefficients are computed using either non-overlapping or overlapping, moving average five frequency point windows without and with frequency point shifts between the five points (References 1 and 2). The ACS SASSI interpolation option 0 was used for the US-APWR stand plant site independent SSI analyses. This interpolation option is based on overlapping, moving average five frequency point windows. For typical SSI problems with well separated transfer function spectral peaks, all the six interpolation options provide very close results.

The adequacy of the selected number of frequencies of analyses and their distribution is checked based on the observation of the interpolated transfer function amplitudes, as the ones presented in Appendix 3-C of MUAP-10006. Frequencies are added to the SASSI analyses as needed to produce smooth interpolation of the transfer functions that accurately capture resonant peaks. The interpolation is deemed accurate when added frequencies have an insignificant effect on the results. The ACS SASSI User's Manual (Reference 1), Section 4.1.2, Item 8, gives further guidance on adding frequencies. This approach for establishing acceptance criteria is applied for the MHI US-APWR SSI analyses.

The acceleration transfer function results presented in Appendix 3-C of MUAP-10006 demonstrate that the density of the selected frequencies analyses is sufficient to ensure the accuracy of the frequency domain analysis results. These transfer functions results show that the response approaches 1.0 at zero frequency for the response in the direction of input motion and approaches 0.0 for cross-terms. The plots of interpolated transfer function amplitudes are smooth without having any major interpolation peak coming from interpolation approximation rather than SSI analysis results. Spurious, narrow peaks are observed infrequently in the SASSI transfer functions, often in the high-frequency range. However, these spurious peaks only amplify and are very narrow and sharp, with a negligible influence on the calculated in-structure response spectra or the structural seismic demands. Thus, the influence of these spurious peaks is conservative.

References:

1. "An Advanced Computational Software for 3D Dynamic Including Soil-Structure Interaction," ACS SASSI NQA Version 2.3.0 including "Option A" and NQA "Option FS," User Manuals, Rev. 7.0, Ghiocel Predictive Technologies, Inc., September 26, 2012.
2. "ACS SASSI Application to Linear and Nonlinear Seismic SSI Analysis of Nuclear Structures Subjected to Coherent and Incoherent Inputs," Ghiocel, D.M. (2011) Handouts for the 3-day ACS SASSI training, Bethesda, MD, January 25-27 http://www.ghiocel-tech.com/enggTools/ACS_SASSI_3-Day_Training_Notes-PART-2-Jan-25-27-2011.pdf.

Impact on DCD

There is no impact on the DCD.

Impact on R-COLA

There is no impact on the COLA.

Impact on S-COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

Impact on Technical/Topical Report

There is no impact on a Technical/Topical Report.

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