RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

1/31/2012

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 852-6003 REVISION 3**
SRP SECTION:	**03.07.02 – Seismic System Analysis**
APPLICATION SECTION:	**3.7.2**
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QUESTION NO. RAI 03.07.02-116:

In Subsection 4.3.1.3 of MUAP-10001(R3), "Modeling of Stiffness and Damping," the first paragraph (Page 4-23) states "The ACS SASSI house module introduces the stiffness and damping properties of the structure into SSI analysis in the form of a frequency-independent complex stiffness matrix."

The staff noticed that the damping values listed in Table 4.3.1.1-2 of this report for the OBE and SSE are taken from Regulatory Guide 1.61, and they are viscous modal damping. The corresponding damping forces are thus frequency-dependent real numbers. The applicant is requested to provide technical information that shows how to convert the frequency-dependent real numbers to frequency-independent complex numbers used in ACS SASSI. Additionally, the applicant is requested to provide numerical values of the complex damping used in the ACS SASSI input and numerical value of the shear wave velocity used in ACS SASSI to simulate a rigid elastic halfspace.

This information is required by the staff in order to assess the effects of these damping parameters on the seismic response of the SSCs and the results of the SSI analyses.

ANSWER:

Technical Report MUAP-10001, Rev. 3 has been replaced by Technical Report MUAP-10006, Rev. 3.

The models developed using the ACS SASSI computer program (Reference 1) for site-independent seismic response analyses of the US APWR standard plant buildings provide an adequate representation of the dissipation of energy in the structure that is consistent with the provisions of US NRC Regulatory Guide (RG) 1.61. RG 1.61 specifies viscous damping values to be used for elastic dynamic seismic analyses and design of system, subsystems and components. The values for critical damping specified in RG 1.61 are intended to be used for response spectra analyses but are also appropriate to represent hysteretic damping input to SASSI as further described in this answer.

Using the same viscous damping values of RG 1.61, the frequency-dependent real numbers associated with viscous damping are converted to frequency-independent complex numbers associated with hysteretic damping internal to the house module of the ACS SASSI computer program and are not modified for input by the user. The SSI models used for seismic response analyses are assigned the damping values provided in Tables 02.4.1.1.1-2 and 02.4.1.1.3-1 of Technical Report MUAP-10006.

The ACS SASSI computer program uses complex response analyses in the frequency domain to obtain the solution of the equations of motion of the SSI system subjected to the design ground motion. The fraction of critical damping is defined as $\beta = c / (2(km)^{0.5}) = c / (2m\omega) = c\,\omega / (2k)$. In this formula for critical damping the physical constant of damping is the dashpot value c, k is the stiffness, m is the mass, and ω is the natural frequency of vibration. The dissipation of energy in the structure is represented by a linear hysteretic damping defined as $d = E_d / (4\pi E_s)$, where E_d is the energy dissipated per cycle (area of the hysteresis loop) and E_s is the maximum strain energy. The hysteretic damping used in SASSI is independent of frequency. Considering the comparison of cyclic behavior of a hysteretic damped system to that of a linear viscous damped system both having the same amplitude of vibration, a formula for $d = \beta\,\omega / \omega_o$ can be established where ω_o is the frequency of the steady state vibration.

Converting frequency-dependent real numbers to frequency-independent complex numbers used in ACS SASSI:

Hysteretic damping that is frequency independent and proportional to stiffness (or displacement) will remain constant and not increase as frequency increases in contrast to viscous damping that is frequency dependent and increases as frequency increases. Depending on the type of damping used to account for the dissipation of energy in the structure, the complex stiffness can be formulated as follows:

$k_d = k + i\,\omega\,c - \omega^2 m$ (for viscous damping)

$k_d = k + i\,2\,d\,k - \omega^2 m$ (for hysteretic damping)

To simulate the effect of viscous damping with a linear hysteretic model, d would have to increase proportionally with frequency and to simulate hysteretic (frequency independent) damping with a linear viscous system c would have to decrease with increasing frequency. Since damping is particularly important at or near resonance, it is common to make simply $d = \beta$ where 1.0 is substituted for ω / ω_o resulting in $c = 2\,d\,k / \omega$. This results in the same amplitude of response at resonance for viscous and hysteretic damping with conservatively less damping at other frequencies when hysteretic damping is used in SASSI.

Separately from the global assembly of the mass matrix, damping is included in the local element stiffness matrices of subgrade layers for assembly of the dynamic stiffness for the dynamic analysis in the frequency domain using the complex moduli of each material. In the seismic analysis methods for SASSI, the critical damping values (ξ) specified in RG 1.61, are used to define the hysteretic damping that is proportional to the material elastic stiffness constants, the elastic shear modulus (G) and constrained modulus (M). The shear modulus is computed, $G = pv_s^2$, where (v_s) is the shear wave velocity. The constrained modulus is computed, $M = pv_p^2$, where (v_p) is the compression wave velocity. Poisson's ratios is related to the shear and constrained modulus, where

$$v = (M - 2G)/(2M - 2G) = \left(v_p^2 - v_s^2\right)/\left(2\left(v_p^2 - v_s^2\right)\right) \ and \ E = 2G(1 - v)$$

Numerical values of complex damping that are generated internally to the SASSI computer program from damping values and are not an input to or output of SASSI. The complex shear, *G**, and complex constrained moduli, *M**, for each material are computed internal to the SASSI computer program as follows:

$$G^* = G\left(1 - 2\xi^2 + 2i\xi\sqrt{1 - \xi^2}\right) \text{ and } M^* = M\left(1 - 2\xi^2 + 2i\xi\sqrt{1 - \xi^2}\right)$$

Where ξ used in the above equations are the damping values listed in Tables 02.4.1.1.1-2 and 02.4.1.1.3-1 of MUAP-10006.

<u>Providing numerical values of the complex damping used in the ACS SASSI input</u>:

Numerical values of complex damping are generated internally to the ACS SASSI computer program for each element in the finite element model and are not an input to or output of SASSI. Therefore, no numerical values of complex damping used as input to SASSI can be provided. To illustrate the difference in responses due to damping effects, the parametric case study (Reference 2) can be reviewed.

<u>Providing numerical values of the shear wave velocity used in ACS SASSI to simulate a rigid elastic half-space</u>:

To simulate fixed base conditions, the SASSI validation analyses are performed for the dynamic FE model resting on the surfaces of stiff elastic half spaces which use the following properties:

- Shear wave velocity of 50,000 ft/s
- Compression wave velocity of 100,000 ft/s
- Unit weight of 145 lb/ft^3
- Damping of 1 %.

References:

1) ACS SASSI, Version 2.3.0 including “Option A” and NQA “Option FS,” <u>An Advanced Computational Software for 3-D Dynamic Analysis Including Soil Structure Interaction</u>, User Manuals Revision 7.0, Ghiocel Predictive Technologies, Inc., September 26, 2012.

2) Ostadan, Deng, and <u>Roesset, Estimating Total System Damping for Soil-Structure Interaction Systems</u>, Proceedings Third UJNR Workshop on Soil-Structure Interaction, Menlo Park, CA, March 39-30, 2004.

Impact on DCD

There is no impact on the DCD.

Impact on R-COLA

There is no impact on the R-COLA.

Impact on S-COLA

There is no impact on the S-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.