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TOKYO, JAPAN

November 22, 2011

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Attention: Mr. Jeffery A. Ciocco

Docket No. 52-021
MHI Ref: UAP-HF-11402

Subject: Second MHI's Responses to US-APWR DCD RAI No. 810-5874 Revision 3 (SRP 03.07.02)

Reference: 1) "Request for Additional Information No. 810-5874 Revision 3, SRP Section: 03.07.02 – Seismic Systems Analysis," dated 8/22/2011.
2) "MHI's Responses to US-APWR DCD RAI No. 810-5874 Revision 3 (SRP 03.07.02)," UAP-HF-11324, dated 9/22/2011 (ML11269A024).

With this letter, Mitsubishi Heavy Industries, Ltd. ("MHI") transmits to the U.S. Nuclear Regulatory Commission ("NRC") a document entitled "Second Responses to Request for Additional Information No. 810-5874, Revision 3."

Enclosed are the responses to 12 RAIs contained within Reference 1. The enclosed responses are in addition to 5 RAI responses previously provided in Reference 2. The response to the remaining Question 03.07.02-18, which is scheduled to be transmitted by 11/28/2011, will complete the response to this RAI.

Please contact Dr. C. Keith Paulson, Senior Technical Manager, Mitsubishi Nuclear Energy Systems, Inc. if the NRC has questions concerning any aspect of this submittal. His contact information is provided below.

Sincerely,

Atsushi Kumaki for.

Yoshiki Ogata,
General Manager- APWR Promoting Department
Mitsubishi Heavy Industries, LTD.

Enclosure:

1. Second Responses to Request for Additional Information No. 810-5874, Revision 3

D081
NRO

CC: J. A. Ciocco
C. K. Paulson

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Enclosure 1

UAP-HF-11402
Docket No. 52-021

Second Responses to Request for Additional Information No. 810-5874, Revision 3

November, 2011

11/22/2011

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:	**8/22/2011**

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:

Tables J-25 and J-26 in Appendix J of MHI Technical Report MUAP-10006 Revision 2 (Reference 3) show, for the Reactor Building Complex and Power Source Building, respectively, the number of frequencies of analysis and cut-off frequency for each generic soil profile used in the soil-structure interaction (SSI) analyses.

The interpolation needs to be performed in the complex frequency domain because the response transfer functions are complex quantities. The complex frequency interpolation is used to determine the response transfer function values for frequencies in between the calculated transfer function values and to obtain the response transfer function for all Fourier frequencies. The employed interpolation scheme is based on the analytical form of a complex response transfer function of a two-degree-of-freedom dynamic system (2DOFs). This complex transfer function for a 2DOFs has the form of a ratio of two fourth order polynomials with complex coefficients as described in equation 1. Such an interpolation scheme is able of reconstructing accurately spectral peaks and valleys of the transfer functions, if the number of frequency points considered is sufficient to create a dense calculated point grid for interpolation.

The complex transfer function of a 2DOFs subjected to a harmonic base excitation can be written for each degree-of-freedom in the following general form:

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

where the interpolated response is the response at frequency and 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

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

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 Fourier frequencies shown in equation (1).

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). For typical SSI problems with well separated transfer function spectral peaks the six interpolation options provide very close results.

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 2DOFs transfer function interpolation scheme. If more than 2 peaks are included in the five point frequency window, then, the interpolation scheme might start to deviate from the correct solution.

As an application example to the MHI US-APWR project, the RB complex SSI analysis used 150 frequency points for a frequency span from 0 to 50 Hz. This is consistent with guidance given in ACS SASSI User's Manual (Reference 1), Section 1.5.5. For different locations within RB complex, the acceleration transfer functions have a number of 5 to 15 spectral peaks that indicates in average about 20 frequency points for two consecutive spectral peaks. This ensured accurate transfer function results, as shown in the figures included in the response to Question 03.07.02-103 in this RAI.

Typically in engineering practice over past decades, the interpolation scheme is considered reasonably accurate if the transfer function amplitude for the dominant spectral peaks computed by interpolation and SSI analysis solution show a trend of convergence. Typically, frequencies are added to the SASSI analysis as needed to produce smooth interpolation of the transfer functions to accurately capture peaks, and additional frequencies were added to observe that the results did not change significantly. The ACS SASSI User's Manual Section (Reference 1), Section 4.1.2 Item 8, gives further guidance on adding frequencies. For the MHI US-APWR SSI analysis, this approach is also applied for establishing acceptance criteria. This approach is inherent within the ACS SASSI program and is described in the ACS SASSI User's Manual (Reference 1). The frequency calculation density selected, using guidance in the ACS SASSI User's Manual, generally is sufficient to ensure the peaks are either sharp, and have little effect on the ISRS or element demands, or are sufficiently covered by calculated frequencies such that further addition of calculated frequencies will not significantly improve the interpolation.

Generally, in review of transfer functions by the analyst for acceptance of the SSI analyses results, it is not reasonable or necessary that a single SASSI analysis contain calculated frequencies at each and every peak of a transfer function. If sharp peaks not eliminated during the interpolation process have an effect, the results are generally conservative since the sharp peak typically shows a response value above the expected values. Transfer function reviews are performed to observe 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 transfer functions are reviewed to determine if the interpolations are reasonably smooth without major interpolation peaks that are not justified by adjacent calculated values. If spurious narrow peaks might infrequently occur, especially in high-frequency range, these peaks have less than about 0.25 Hz and, therefore, they are too sharp to affect the damped response spectra. Thus, in practice these peaks are considered acceptable because the potential error is very small and on the conservative side.

References:

1. ACS SASSI NQA Version 2.3.0 (2010) "An Advanced Computational Software for 3D Dynamic Including Soil-Structure Interaction", User Manuals, Rev. 3, December 30

2. Ghiocel, D.M. (2011) "ACS SASSI Application to Linear and Nonlinear Seismic SSI Analysis of Nuclear Structures Subjected to Coherent and Incoherent Inputs", 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

3. Technical Report MUAP-10006, "Soil-Structure Interaction Analyses and Results for the US-APWR Standard Plant," Revision 2.

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.

11/22/2011

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:	**8/22/2011**

QUESTION NO. RAI 03.07.02-92:

In Subsection 3.7.2.3.6.1 of DCD (R3), "Mass Points and Associated Weights (W)", the second paragraph (page 3.7-21) states, "Figure 3.7.2-5 depicts how the mass moments of inertia and weights associated with the lumped masses are computed."

The information presented in Figure 3.7.2-5 is not clear to the staff. The Applicant is requested to provide clarifying descriptions for the four rectangular-shape insertions in this figure.

ANSWER:

The information shown in Figure 3.7.2-5 of DCD Revision 3 is being deleted as shown in the revised figure provided in supplemental response to RAI 542-4262, Attachment 2 (ML11188A251). The figure is being revised to reflect the design basis approach of using plate models for the seismic analysis of the Reactor Building Complex, instead of stick models. The Lumped Mass Stick Model (LMSM) properties for the Reactor Building Complex and the validation of the LMSM are provided in Subsection 5.1.1 of Technical Report MUAP-11006 Revision 0.

Impact on DCD

There is no impact on the COLA.

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.

11/22/2011

US-APWR Design Certification

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RAI NO.:	**NO. 810-5874 REVISION 3**
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QUESTION NO. RAI 03.07.02-93:

In Subsection 3.7.2.3.7 of DCD (R3), "Shear Stiffness", item "i" of the fourth paragraph (page 3.7-22) states, "A FE model of the containment internal structure above the upper level of the basemat, considering the walls, columns and floor slabs, is developed using brick, shell and beam elements."

The Applicant is requested to provide information that explains how the SC module is modeled by finite element models. The information should include the type of the elements used and the name of the element (if ANSYS is used). The Applicant is also requested to demonstrate that the FE model for SC module can reproduce the test results of the SC module.

ANSWER:

The entire text of Subsection 3.7.2.3.7 will be revised as shown in the supplemental response to RAI 542-6242, Enclosure 2 (ML11188A251) because plate models are now used for the seismic analysis of the Reactor Building Complex instead of stick models. Technical Report MUAP-10001 (Reference 1) presents the revised approach for seismic analyses for development of the R/B, PCCV and Containment Internal Structures (CIS) dynamic finite element (FE) models.

The Steel Concrete (SC) modules consist of composite concrete encased by steel plates and are modeled in ANSYS (Reference 2) by 3-D structural solid elements (Solid45) representing the massive structural members of the CIS primary and secondary shield walls, and 4 node elastic shell elements (Shell63) representing the other SC walls as listed in Table 4.3.1.1-1 of Technical Report MUAP-10001. Figure 3.8.3-5 of DCD (R3) (Reference 3) shows SC module isometrics. Figure 3.8.3-7 of DCD (R3) shows typical details of SC modules. Table 4.3.1.1-2 of Technical Report MUAP-10001 defines the concrete strength of the SC modules as f'_c = 4,000 psi and the steel yield strength as F_y = 50 ksi. Refer to Section 4 of Technical Report MUAP-11018 (Reference 4) for the composite properties (stiffness) of the SC Modules used in the dynamic FE model. MUAP-11018 contains methodology for modeling stiffness and damping of the SC modules. These stiffnesses for walls with thicknesses less than or equal to 56" are derived from supporting experimental data for the SC modules. Table 4.3.1.1-3 of Technical Report MUAP-

10001 includes stiffness and damping values for SC modules for two loading conditions: A) seismic + operating thermal; and B) seismic + accident thermal.

Structural Category Definitions:

Overall thickness of the single-celled SC walls in the US-APWR CIS varies from 36" to 67". The multi-celled primary shielding walls have overall thickness in excess of 9'-11". The range of experimental data establishing the composite stiffness characteristics of SC walls is applicable to sections with overall thickness less than or equal to 56" and steel plate reinforcement ratio (r) greater than 1.5% (where $r = 2t_p/T$; t_p = plate thickness, T = overall wall thickness.) Therefore, the SC walls are separated into three categories, as follows:

Category 1: All walls with $T \leq 56"$ in the CIS meet the criteria above and are thus classified as 'SC'. This category comprises approximately 90% of the walls in the CIS.

Category 2: Non-primary shielding walls with $T > 56"$ (e.g., the 67"-thick single-celled walls) are to be treated as concrete walls with no additional stiffness imparted by the steel plates. This category comprises less than 10% of the walls in the CIS.

Category 3: The primary shielding walls below elevation 35'-11" are not only too thick to be considered as composite SC walls but also have a unique multi-celled arrangement consisting of inner and outer face plates, a mid-thickness longitudinal plate and numerous transverse plates. These walls are to be treated as concrete structures, but with different stiffness conditions for thermal loading than those applied to the Category 2 walls.

Note: The CIS also include some structural elements which are not steel-concrete modules, such as reinforced concrete slabs, massive reinforced concrete sections, and steel structures with nonstructural concrete infill. The stiffness and damping values for those structural elements are also listed in Table 4.3.1.1-3 of Technical Report MUAP-10001 (Reference 1) and are described in Technical Report MUAP-11018 (Reference 4).

Discussion of loading conditions:

As stated above, the CIS seismic analysis must consider the stiffness and damping levels appropriate for two basic loading conditions:

Condition A*: *Seismic + Operating Thermal. In accordance with the DCD (Reference 3), the normal operating thermal loading for the CIS involves ambient temperatures of 105°F to 120°F, which are not anticipated to cause cracking that would significantly reduce the stiffness of the SC modules or any of the reinforced concrete structures. The operating temperature of the reactor cavity is 150°F, such that a linear temperature distribution is postulated through the nominally 10 ft thickness of the primary shielding walls, varying from 150°F at the interior face to 105-120°F at the exterior face. This shallow linear gradient is not anticipated to cause significant cracking of the primary shielding walls. Therefore, the stiffness for Condition A may be reasonably estimated by evaluating stresses resulting from the seismic loading condition only.

Condition B: Seismic + Accidental Thermal. The accidental thermal condition postulated for the CIS involves initial temperatures of 580°F on the pipe-rupture side of a given wall, with a nearly immediate increase of temperature on the opposite face to 300°F. Within approximately 1000 seconds (17 minutes) the two face temperatures equilibrate to 300°F, which sets up a parabolic (U-shaped) temperature distribution through the thickness of the SC walls. Preliminary analysis indicates this distribution will cause through-thickness cracks in the SC walls that effectively reduce their in-plane shear stiffness, and also cause overall thermal deformations and attendant out-of-plane flexural cracking at restraints.

Estimated stiffness for each category and loading condition:

Category 1, Condition A: An assessment of the maximum seismic in-plane shear demands in each SC wall of the CIS indicated that in general these demands were lower than the cracking threshold for in-plane shear. Therefore the best estimate in-plane shear stiffness for Condition A is that of the uncracked composite section.

Note that the cracking threshold for SC walls was assumed at a concrete stress of $2(f'_c)^{1/2}$.

Typically the cracking threshold for concrete is related to concrete stress of $4(f'_c)^{1/2}$, but the limit for SC walls is reduced to account for shrinkage and other effects, as described in Varma and Malushte (Reference 5). This reduction is also corroborated by experimental data given by Ozaki et al. (Reference 6).

Category 1, Condition B: The through-thickness temperature gradient resulting from the accidental thermal condition can cause significant cracking that reduces the in-plane shear stiffness of the SC walls. An empirical relationship providing a best-estimate of secant in-plane shear stiffness of cracked SC walls is given in Varma and Malushte, as follows:

$$Kcr = 0.5\,(\bar{\rho}^{\,-0.42})G\,A$$

where:

$\bar{\rho} = A_s F_y/((f'_c)^{1/2} A_c)$, G_s = shear modulus of steel
A_s = 2·(face plate thickness)
F_y = yield strength of steel plates
f'_c = specified compressive strength of concrete
A_c = unit area of concrete core.

Category 2, Condition A: Stress evaluation indicates these thick walls remain uncracked for Condition A. Therefore uncracked stiffness values of the concrete section shall be used; i.e., G_cA_c for in-plane shear and E_cI_c for out-of-plane flexure.

Category 2, Condition B: Stiffness of these walls shall account for cracking due to accidental thermal loading. Stiffness values of $0.5G_cA_c$ and $0.5E_cI_c$ are assigned per the recommendations for cracked concrete walls given in ASCE 43-05 (Reference 7).

Category 3, Condition A: The linear temperature gradient through the primary shield walls for normal operating conditions is not anticipated to cause significant cracking, and seismic demands on these walls are limited. Thus the primary shield wall stiffness shall be modeled as that of uncracked concrete (G_cA_c and E_cI_c); no credit is taken for the stiffness of the steel plates.

Category 3, Condition B: The accident thermal loading conditions is anticipated to cause only localized cracking in the thick primary shielding walls, which are largely enclosed by the mass concrete at the base of the CIS. Therefore the stiffness for this condition is to be the same as that assigned for Condition A (uncracked).

Damping:

Damping is assigned to each structural category in the CIS based on the estimated level of cracking. Damping is assumed to be 4% for composite SC walls with uncracked conditions (Condition A), and 5% when significant cracking is anticipated (Condition B). This is based on the results of the 1/10th scale test discussed in MUAP-11005-P (Reference 8). For walls and slabs modeled as reinforced concrete structures with thickness greater than 56", 4% damping is specified in Regulatory Guide 1.61 (Reference 9) for the limited levels of cracking associated with the OBE, while 7% damping is specified for cracked response exhibited during SSE loading. Finally, the massive concrete of the primary shield walls in the CIS (Category 3) is not expected to exhibit significant cracking, such that 4% damping is considered appropriate in all cases. Given the similarity in the damping ratios specified for the uncracked response of SC and RC components, and recognizing that the amplified seismic response of the CIS is dominated by the response of the SC walls, constant damping ratios of 4% for Condition A and 5% for Condition B are to be used for the CIS seismic response analyses.

Adjustment of Dynamic Properties of SC Modules:

Simplifications in the geometry of the otherwise complex structure are introduced in the dynamic CIS model in order to produce a coarser FE mesh and to minimize the size of the model in order to be suitable for SSI analyses using ACS SASSI. Stiffness and mass properties of elements modeling some of the SC walls of the CIS are adjusted in order to calibrate the dynamic response of the simplified dynamic FE model to match the actual response of the CIS as represented in the Detailed FE Model. The adjustments of the unit density and the elastic moduli of the shell elements are introduced to capture the actual distribution of mass and stiffness. The calibration of the model properties is performed based on the results of a 1-g static analysis, and then verified using the results of modal and time history analyses.

As stated in Section 4.3.2 of Technical Report MUAP-10001 (Reference 1), due to the complexity of the CIS, different stiffness and damping values are assigned to different types of structural components for the two bounding stiffness and damping conditions.

Technical Report MUAP-11018 (Reference 4), describes the reduction of stiffness applied to the CIS to account for cracking of the concrete of SC modules, reinforced concrete slabs and massive concrete portions. This reduction of stiffness is based on test results as described in Technical Report MUAP-11018 and the recommendations provided in ASCE 43-05. Unlike the other US-APWR standard plant Category I structures, two sets of validation analyses are performed for the CIS to ensure the adequacy of the CIS dynamic FE model with higher stiffnesses associated with seismic plus operating temperature where concrete is mostly uncracked concrete for stiffness and with lower stiffness associated with seismic plus accidental thermal loading conditions where concrete under cracked conditions is reduced for stiffness as described in Technical Report MUAP-11013 (Reference 10).

References:

1. Technical Report MUAP-10001, "Seismic Design Bases of the US-APWR Standard Plant," Revision 4.
2. ANSYS, Advanced Analysis Techniques Guide, Release 11.0, ANSYS, Inc., 2007.
3. MUAP-DC003, "Design Control Document for the US-APWR," Revision 3, Mitsubishi Heavy Industries, March 2011.
4. Technical Report MUAP-11018, "Containment Internal Structure: Stiffness and Damping for Analysis," Revision 0.
5. Varma, A. and Malushte, S. "In-Plane Behavior of Concrete Filled Steel (CFS) Elements", Presentation, Enclosure 1 to DCP_NRC_00278, Electronic ADAMS, NRC. Item ID 100130037, Accession Number ML 100050190. http://adamswebsearch2.nrc.gov/IDMWS/ViewDocByAccession.asp?AccessionNumber=ML100050190
6. Ozaki, M. et al. "Study on Steel Plate Reinforced Concrete Panels Subjected to Cyclic In-plane Shear," Nuclear Engineering and Design, Volume 228, 2004.
7. ASCE 43-05, "Seismic Design Criteria for Structures, Systems, and Components", American Society of Civil Engineers, 2005.

8. MUAP-11005-P, "Research Achievements of SC Structure and Strength Evaluation of US-APWR SC Structure Based on 1/10th Scale Test Results", Revision 0, Mitsubishi Heavy Industries, January 2011.
9. Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants", Revision 1, U.S. Nuclear Regulatory Commission, March 2007.
10. MUAP-11013, "Containment Internal Structure Design and Validation Methodology," Revision 0

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.

11/22/2011

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**
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QUESTION NO. RAI 03.07.02-94:

In DCD (R3), Section 3.7.2.3.11 "Equivalent Masses due to Dead and Live Loads" the first paragraph states "In the design of seismic category I and seismic category II buildings and structures, dead loads and various portions of live loads are treated as equivalent masses for consideration in the global seismic analysis models. For example, 25% of the design floor live loads during normal operation (ASCE 7, Subsection 12.7.2 [Reference 3.7-24]) and 75% of the roof snow load, whichever is applicable depending on the specific location in the building or structure, have been considered in computing tributary mass at node points in the seismic models. This is consistent with SRP 3.7.2, Section II.3(d) (Reference 3.7-16). For the containment operating deck in the PCCV, the design floor live load for maintenance and refueling is 950 lb/ft^2 and the floor live load for normal operation is 200 lb/ft^2. Therefore, 50 lb/ft^2 (25% of 200 lb/ft^2) has been used as an equivalent live load (mass) for the seismic analysis models."

The Applicant is requested to provide the technical basis and justification for not considering 25% of the heavier floor loadings of 950 lb/ft^2 as an equivalent live load (mass) for the seismic analysis models and also discuss how the occurrence of design basis earthquake during the extended maintenance schedule is considered.

ANSWER:

As stated in DCD Subsections 3.7.2.3.11 "Equivalent Masses due to Dead and Live Loads", 3.8.3.3.1 "Floor Load Inside Containment", 3.8.4.3.4.1 "Building Floor Loads" and 3.8.4.3.6.2 "Safe Shutdown (E_{ss})", the containment operating deck load of 950 lb/ft^2 (due to reactor vessel head and related equipment storage on the operating deck) is only applicable during maintenance/refueling outage and "used only in load combinations involving non-seismic loads". The floor live load of 200 lb/ft^2 during normal operation is used in the concrete structure load combinations of DCD Table 3.8.4-3. The loading combinations consider, as per ACI 349-01 Sections 9.1 and 9.2, normal operating and normal shutdown conditions in conjunction with the SSE. As defined in DCD Chapter 16, Section 1.1 of the "Technical Specifications" and Table 1.1-1, the US-APWR plant is in Mode 6 when the reactor vessel is disassembled or opened. Mode 6 is the "refueling condition with one or more reactor vessel head closure bolts less than fully tensioned". During Mode 6, the reactor vessel head may be stored on the containment operating deck. MHI does not consider Mode 6 to be a normal operating or normal shutdown condition. Therefore, the live load used for seismic analyses is 25% of 200 lb/ft^2.

The SSE is a design basis event that is improbable to occur over the lifetime of the plant. An extended maintenance and refueling outage is a small percentage of the life of the plant. Since a SSE is assumed to occur only once during the life of the plant, it is highly unlikely to occur during an extended maintenance and refueling outage. In addition, during an extended maintenance outage, the licensee may evaluate the expected length of the outage and the possibility of replacing the reactor vessel head and fully tensioning the bolts, or full offload of the core. In the case of replacing the head, the mode of operation enters mode 5 which applies SSE loading. In the case of full offload, the plant is defueled and there is no design basis accident concern inside containment. Therefore, the design basis event is not considered or analyzed during the extended refueling or maintenance outages.

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.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

11/22/2011

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**
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DATE OF RAI ISSUE:	**8/22/2011**

QUESTION NO. RAI 03.07.02-95:

In Subsection 3.7.2.3.10.1 of DCD (R3), "Validation Method,", item (ii) under the subtitle of "Static Loading Analysis", (page 3.7-26) states, "By fixing the upper level of the basemat, a set of vertically distributed horizontal loads, which is established considering the earthquake excitation, is applied at each of the main floor levels of the FE model and the resulting horizontal displacements are evaluated at the top level of each floor."

The applicant's approach is different from the 1g static analysis specified in SRP Acceptance Criteria 1.A.iv.(2) in SRP 3.7.2. The Applicant is requested to provide a justification that shows that the proposed approach produces conservative or equivalent results relative to a 1g static analysis.

ANSWER:

Subsection 3.7.2.3.10.1 of DCD (R3) has been changed by the mark-ups of DCD (R3) associated with the Supplemental Response provided for RAI 542-4262 Rev. 2 Question 03.07.02-35 (ML11188A251). The mark-ups reflect the change in methodology from lumped mass stick models (LMSM) to the use of finite element models (FEM) for the design-basis seismic analyses. This change in methodology was to ensure a sufficient number of discrete mass degrees of freedom to adequately represent local vibration modes, such as individual floor slabs and walls, to ensure that the in-structure response spectra include any additional amplification, and to adequately capture responses with frequencies up to 50 Hz. Section 5.3.3 of Technical Report MUAP-10001 Revision 4 provides the following comparisons for purposes of model validation:

- Floor masses of the FEM model used for SSI analysis and those of the detailed FEM model are compared. ANSYS static analyses are performed for comparison of displacements on both the "dynamic FE model" used for SSI analysis and the more "detailed FEM model" used for static analyses and structural design, where 1g quasi-static accelerations are applied in the horizontal (X and Y) directions with full constraints at the bottom of the common basemat.

- Fixed base modal analyses using ANSYS are performed on both the detailed and the dynamic FE Models. Plots of cumulative mass versus frequency are provided to compare the two models for each of the three (3) excitation directions.

- A dynamic time history response analysis using modal superposition is performed on both the detailed and the dynamic FE Models using ANSYS. ARS with 5% damping are generated for each model at various locations for comparison.

The approach provided in Technical Report MUAP-10001 differs from the 1g static analysis specified in SRP Acceptance Criteria 1.A.iv.(2) in SRP 3.7.2 in that only horizontal responses without vertical responses are performed for comparison of displacements instead of each of the three (3) excitation directions. However, because more rigorous comparisons are performed using fixed base modal analyses and by generating amplified response spectra (ARS) for each of the three (3) excitation directions, it was not considered necessary to perform the less rigorous comparison of the vertical responses for a 1g static analysis.

Impact on DCD

See Attachment 2 for the markup of the DCD Tier 2, Section 1.9, changes to be incorporated.

Line 3.7.2 "Seismic System Analysis" of Table 1.9.2-3 of the DCD, Sheet 12 of 34, will be revised to add the following write-up at the end of the write-up in the third "Status" column:

> "SRP 3.7.2 acceptance criteria item 1.A.iv(2) suggest using 1g static analysis of the dynamic model for each of the three excitation directions. However, for validation of the dynamic analyses models, the methodology applies 1g static loads only in the two horizontal directions for comparison of the displacements. This is considered acceptable because more rigorous comparisons are performed using fixed base modal analyses, with comparison of cumulative mass versus frequency plots, and by generating amplified response spectra (ARS) for each of the three (3) excitation directions."

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.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

11/22/2011

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:	**8/22/2011**

QUESTION NO. RAI 03.07.02-96:

In Subsection 3.7.2.6 of DCD (R3), "Three Components of Earthquake Motion", the last sentence of the last paragraph (page 3.7-35) states, "Due to the uncertainties introduced by phasing effects, the design does not use time history results for other responses, such as accelerations or displacements at points in time that are indirectly related to the basic design inputs."

The Applicant should clarify the meaning of the above sentence. If the three components of earthquake are applied simultaneously, there are no uncertainties introduced by phasing effects. Also, the Applicant should clarify the meaning of the phrase "the design does not use time history results for other responses, such as accelerations or displacements at points in time that are indirectly related to the basic design inputs". Specifically, the Applicant should state when, and for which response parameters time history analysis is or is not used, the justification for determining which approach is appropriate, and the impact of each approach on the analysis.

ANSWER:

The two sentences preceding the one quoted in this RAI question state, "The time-history of the responses from the three earthquake components that are applied simultaneously can be combined algebraically at each time step to obtain the combined response time-history. The design seismic loads are selected from the maximum values or the most critical combination of values extracted from the time history results representing the responses directly related to the design of the particular member considering sign reversals, such as the relevant internal forces or stresses in the member." The intent of these sentences is to identify that time history analysis using three directional components applied simultaneously can be applied in the determination of element forces or stresses that are combined algebraically.

The intent of the sentence quoted is to explain that all other parameters such as accelerations and displacements do not use time history results that combine algebraically the three earthquake components when the time histories are not applied simultaneously.

It is agreed that if the three components of earthquake are applied simultaneously, there are no uncertainties introduced by phasing effects. Therefore, the sentence will be removed.

Impact on DCD

See Attachment 1 for the markup of the DCD Tier 2, Section 3.7, changes to be incorporated.

Subsection 3.7.2.6.iii of the DCD (R3) will be revised to read as follows:

> "The time-history of the responses from the three earthquake components that are applied simultaneously can be combined algebraically at each time step to obtain the combined response time-history. The design seismic loads are selected from the maximum values or the most critical combination of values extracted from the time history results representing the responses directly related to the design of the particular element considering sign reversals, such as the relevant internal forces or stresses in the element."

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.

11/22/2011

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:	**8/22/2011**

QUESTION NO. RAI 03.07.02-98:

In Subsection 3.7.2.8 of DCD (R3), "Interaction of Non-Seismic Category I Structures with Seismic Category I Structures", the sixth paragraph (page 3.7-39) states, "Maximum lateral earth pressure due to the backfill, surcharge due to live load or adjacent basemat bearing pressures, groundwater, and other such static-load effects on below-grade exterior walls are discussed in Section 3.8. The design of below grade exterior walls for US-APWR seismic category I structures takes into account any dynamic increases of these loads due to a seismic event. This is accomplished through the use of conservative maximum static and dynamic lateral pressure distribution profiles developed using analysis methods provided in Section 3.5.3 of ASCE 4-98 (Reference 3.7-9)."

The analysis methods provided in Section 3.5.3 of ASCE 4-98 do not consider the follow two effects on the dynamic lateral earth pressure:

1. The effect of high water table, and

2. The effect of the base rocking motion due to the effect of soil-structure interaction.

The staff reviewed DCD Section 3.8 and could not find any information regarding the two effects listed above. The Applicant is therefore requested to consider the two effects mentioned in the preceding paragraph. Alternatively, the Applicant is requested to provide technical basis and justification for not considering these two effects.

ANSWER:

MHI Technical Report MUAP-10006 R2 Section 3.7 describes methodology and parameters to determine design static and dynamic lateral earth pressures acting on basement exterior walls of the US-APWR R/B complex and PS/Bs. The horizontal earthquake excitation induced dynamic lateral pressures are calculated by interpolating and applying ASCE 4-98 Figure 3.5-1 for a soil saturated unit weight of 130 pcf and a horizontal seismic coefficient of 0.6, which is twice that of the free field peak ground acceleration. The high water table effect and base rocking motion due to the effect of soil-structure interaction (SSI) are accounted for in the design as further discussed in the previous response to RAI 657-5135 question 03.08.05-39 (ML110040127) and related response to RAI 496-3735 Question 03.08.05-30 (ML100430770).

As discussed in Part 1 of the response to RAI 657-5135 Question 03.08.05-39, use of saturated unit weight for the soils provides the most conservative case for including the effects of groundwater in the calculations of the dynamic earth pressures because it considers that the response of the two phases of the system, the groundwater and the soil, to be completely in-phase and does not consider the dissipation of energy due to the viscous flow of the groundwater. The total dynamic lateral pressure is based on the total unit weights for the saturated soil and assumes that the water table is at plant grade elevation. The total dynamic lateral pressure computed in this manner envelops the in-phase sum of the Wood's soil pressure (per ASCE 4-98) and the Westergaard formula for computing hydrodynamic groundwater pressure under seismic loads on a vertical wall bordering a free body (e.g. reservoir), as demonstrated in the response to RAI 496-3735 Question 03.08.05-30.

The high water table effect and the base rocking motion due to the effect of SSI as described in Part 3 of the response also are considered in the site specific SASSI analyses of the embedded structures based on total unit weight of the saturated embedment soil. The comparison of the SASSI-calculated site-specific dynamic earth pressures with the dynamic earth pressures used in the standard design, as required by COL Action Item 3.7(23), ensures that the site specific earth pressure demands are enveloped by the standard design. The DCD will be revised as described in "Impact on DCD" below to describe the methodologies addressed in Section 3.7 of Technical Report MUAP-10006.

Impact on DCD

See Attachment 1 for the markup of the DCD Tier 2, Sections 3.7 and 3.8, changes to be incorporated.

The third sentence of the sixth paragraph of Subsection 3.7.2.8 will be revised to read as follows:

> "This is accomplished through the use of conservative maximum static and dynamic lateral pressure distribution profiles developed using analysis methods provided in Section 3.5.3 of ASCE 4-98 (Reference 3.7-9) and as discussed in Subsection 3.8.4."

The sixth paragraph of Subsection 3.8.4.4.3 will be revised to read as follows:

> "Exterior concrete walls below grade and basemat of seismic category I structures are designed using load combinations accounting for sub-grade loads including static and dynamic lateral earth pressure, soil surcharges, and effects of maximum water table. Dynamic lateral earth pressure is as described in Section 3.7 of Technical Report MUAP-10006 (Reference 3.7-47). The calculation approach follows guidance given in ASCE 4-98 (Reference 3.8-34) for computing dynamic lateral earth pressure, and also accounts for increases in horizontal pressure due to the vertical component of earthquake excitation. The static and seismic lateral earth pressures due to the vertical and horizontal components of the earthquake are combined by conservatively assuming that the peak vertical and horizontal response accelerations in the embedment soil occur simultaneously. The use of saturated unit weight for the soil provides the most conservative case for including the effects of groundwater in the calculations of the dynamic earth pressures because it considers that the response of the two phases of the system, the groundwater and soil, to be completely in-phase and does not consider the dissipation of energy due to the viscous flow of the groundwater."

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.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

11/22/2011

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:	**8/22/2011**

QUESTION NO. RAI 03.07.02-100:

In Subsection 3.7.2.4.1 of DCD (R3), "Requirements for Site-Specific SSI Analysis of US-APWR Standard Plant," the second to last full sentence on p. 3.7-31 states that "If the strains in the subgrade media are less than 2%, the strain-compatible properties can be obtained from equivalent linear site-response analysis using soil degradation curves."

The Applicant should clarify if the 2% soil strains refer to low-strain soil values or strain compatible values and should also state the basis for the value of 2%. Also, the statement implies that if soil strains are greater than 2%, then strain-compatible soil properties would be obtained by other means. The Applicant is requested to discuss what other means of determining strain-compatible properties are proposed if soil strains are greater than 2%, and what affect other approaches will have on the determination of the subgrade properties.

ANSWER:

The 2% soil strain values refer to strain-compatible values selected from soil degradation curves during a time history analysis of a soil column using the software program SHAKE. Regarding the basis of the value of 2%, modulus reduction and hysteretic damping curves from EPRI TR-102293 (Reference 1) are used for the horizontal component site response analyses. The curves are appropriate for generic soils comprised of gravels sands, and low PI clays and are shown in Figure 4.2-2 of MHI Technical Report MUAP-10001 (Reference 2), and the supplementary response to RAI 659-5133 Question 03.07.01-17 (ML11178A071). These curves also provide realistic strain compatible properties for the generic rock materials when subjected to low intensity strains generated by ground motions that are consistent with the spectra at the ground surface that are enveloped by US APWR CSDRS. Various industry literatures such as "Geotechnical Earthquake Engineering" by Steven L. Kramer (Reference 3) provide discussion for how the non-linearity of soil behavior can be approximated by linear site response analysis. Reference 3 states that it is common to characterize the strain level of the transient record in terms of an effective shear strain that has been empirically found to vary from about 50% to 70% of the maximum shear strain. For equivalent linear approximation of the nonlinear response, the lower value of the range up to 50% is considered. The limiting value of 2% strain corresponds to 50% of the maximum shear strain value of 4% shown in Figure 4.2-2 of Technical Report MUAP-

10001. This is considered a conservative strain limit because it is often taken at 65% of the peak strain, above which linear approximation would not be used.

If soil or rock strains are greater than 2%, strain-compatible soil properties could be obtained by other means such as analyzing the actual nonlinear response of a soil deposit using direct numerical integration in the time domain. However, this has not been necessary because the strains have been found to be less than 2% in the standard plant analyses. Therefore, it is not necessary to consider what affect other approaches will have on the determination of the subgrade properties.

References:

1. EPRI TR-102293, Guidelines for Determining Design Basis Ground Motions, Vol. 4, Appendices for Laboratory Investigations, Electric Power Research Institute, Palo Alto, CA, 1993

2. Technical Report MUAP-10001, Seismic Design Bases of the US-APWR Standard Plant, Mitsubishi Heavy Industries, Ltd., Rev. 4

3. Steven L Kramer, "Geotechnical Earthquake Engineering," Prentice Hall International Series in Civil Engineering and Engineering Mechanics series, Upper Saddle River, NJ, 1996

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.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

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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:	**8/22/2011**

QUESTION NO. RAI 03.07.02-101:

In Subsection 3.7.2.7 of DCD (R3), "Combination of Modal Responses," the second paragraph (on p. 3.7-35) states in part, "When the modal superposition time history analyses or response spectra analyses are used for seismic design of other seismic category I and seismic category II systems and subsystems, all necessary modes are included in order to capture a minimum of 90% of the cumulative mass of the building or structure being analyzed."

The staff requests clarification of the intent of this statement. If the statement is intended to mean that capturing 90% of the cumulative mass of the building or structure is sufficient to preclude including the effects of missing mass, the staff disagrees with this position for two reasons. First, it is inconsistent with the statement in Section 1.4.1 of RG. 1.92, Rev. 2 that missing mass should be included in all response spectra analyses. Second, situations exist in which at least 90% of the structural mass can participate, but the additional mass can increase response parameters of interest by more than 10%, which could lead to unconservative solutions when using modal superposition or response spectrum methods.

ANSWER:

DCD Subsection 3.7.2.7 does not preclude accounting for the missing mass. The missing mass is included as described in the second and third paragraphs of Subsection 3.7.2.7, consistent with Section 1.4.1 of Regulatory Guide 1.92, Rev. 2 when using the missing mass method for response spectra analysis or time history analysis. Modal responses are also combined by another method identified as the Static ZPA method described in RG 1.92 Section 1.4.2, where the missing mass is included when using the Lindley-Yow method of response spectra analysis. Therefore, any mass not captured in the modal superposition time history analyses or response spectra analyses is captured using the missing mass method or the static ZPA method. RG 1.92 Section 1.4, states that "In most cases, it is not practical to accurately calculate these high-frequency modes, which are not excited by the seismic ground or in-structure motion." The second paragraph of DCD Subsection 3.7.2.7 will be revised as shown in "Impact on DCD" below to clarify that the missing mass method described in RG 1.92 Section 1.4.1 or the static ZPA method described in RG 1.92 Section 1.4.2 are used to capture "missing mass" in the analyses.

Further, the statement from DCD Subsection 3.7.2.7 requiring inclusion of all necessary modes to capture 90% of the cumulative mass will be revised to delete the reference to 90%.

Impact on DCD

See Attachment 1 for the markup of the DCD Tier 2, Section 3.7, changes to be incorporated.

Subsection 3.7.2.7 of the DCD will be revised to read as follows:

> "When the modal superposition time history analyses or response spectra analyses are used for seismic design of other seismic category I and seismic category II systems and subsystems, it may not be practical to capture higher frequency modes that are not excited by the input motion. In modal superposition, only modes with frequencies less than the frequencies defining the cutoff or ZPA response participate in the modal solution. The modal contribution of the residual rigid response for modes with frequencies greater than the cutoff or ZPA frequency is accounted for by using the missing mass method. As permitted in Section 1.4.1 of RG 1.92, Rev. 2 (Reference 3.7-27), the missing mass contribution, scaled to the instantaneous input acceleration, is treated as an additional mode in the algebraic summation of modal responses at each time step. The missing mass contribution is considered for all DOF. When using the Lindley-Yow method in response spectra analyses, the missing mass may be captured using the Static ZPA method as described in Section 1.4.2 of RG 1.92, Rev. 2 (Reference 3.7-27)."

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.

11/22/2011

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:	**8/22/2011**

QUESTION NO. RAI 03.07.02-103:

In Subsection 3.7.2.4 of DCD (R3), "Soil-Structure Interaction", the second paragraph (page 3.7-29) states in part, "The amplitudes of the interpolated transfer functions are plotted and investigated to ensure the accuracy of the interpolation of the response for the required range of frequencies."

The Applicant is requested to provide a description of how the accuracy of the interpolated transfer functions is checked and should also state if SSI effects are accounted for when checking the accuracy of the transfer functions. If SSI effects are not included when checking the accuracy of the transfer functions, the Applicant should explain how their approach conforms to the guidelines of SRP Acceptance Criteria 4 of SRP 3.7.2.

ANSWER:

The accuracy of the interpolated transfer functions is checked by comparing these curves with the computed transfer function values computed at the SSI frequency points. Tables J-25 and J-26 in Appendix J of MHI Technical Report MUAP-10006 Revision 2 show, for the Reactor Building Complex and Power Source Building, respectively, the number of frequencies of analysis and cut-off frequency for each generic soil profile used in the soil-structure interaction (SSI) analyses. The comparative plots presented in the figures in Appendix L of MHI Technical Report MUAP-10006 Revision 2 show that the number of SSI frequencies for each soil profile provides a sufficiently dense grid of points that captures all the significant spectral peaks that define the ATF shapes. In the plots the interpolated ATF are plotted with lines and the computed ATF values are plotted with markers. Appendix L shows that the reconstruction of ATF peaks at all Fourier frequencies up to the cutoff frequencies of the analyses is sufficiently accurate. The numbers of analyses frequencies are sufficiently large to create dense frequency calculation point grids that produce accurate interpolation of ATF curves. A cross-reference to the ATF plots in Appendix L will be added to Section 3.7.2.4 of the DCD as indicated in "Impact on DCD" below. It should be also noted that the computed ATF values are the solutions of the seismic SSI analysis, so that the SSI effects are fully accounted for when checking the accuracy of the interpolated ATF curves. Additional information on the ATF interpolation used for MHI US-APWR project is included in the response to Question 03.07.02-91 in this RAI.

Impact on DCD

See Attachment 1 for the markup of the DCD Tier 2, Section 3.7, changes to be incorporated.

Subsection 3.7.2.4 of the DCD will be revised to add the following statement immediately after the sentence that is quoted in the RAI question above:

> "Plots of transfer functions for various locations throughout the R/B Complex and PS/B are presented in Appendix L of Technical Report MUAP-10006 (Reference 3.7-48)."

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.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

11/22/2011

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:	**8/22/2011**

QUESTION NO. RAI 03.07.02-104:

In Subsection 3.7.2.5 of DCD (R3), "Development of Floor Response Spectra", the fifth paragraph (page 3.7-34) states, "ISRS developed from the site-independent seismic analyses of the R/B complex and PS/B's are used for design."

The ISRS developed here are the response spectra due to the motions in three-displacement degree-of-freedoms at the location. In accordance with SRP Acceptance Criteria 1.A.iii of SRP 3.7.2, the analysis of the structure should consider the rocking motion as well as the translational motion. The Applicant is requested to provide technical justification for designing a SSC without considering the rocking motion due to the effect of SSI.

ANSWER:

SSCs are designed considering the rocking motion due to the effect of SSI. The preceding sentence to the quoted sentence of this question states, "The ISRS envelope the spectra obtained from site-independent analyses for all generic subgrade conditions described in Subsection 3.7.1.3." Accordingly, ISRS generated from the SSI dynamic analyses described in Subsection 3.7.2.3.1 of the DCD (R3) include the subgrade conditions described in Subsection 3.7.1.3 of the DCD (R3), and do consider the torsional, rocking, and translational responses of three dimensional models of the supporting structures due to three components of earthquake motion input at the foundation interface location. Only translational ISRS are generated for development of floor response spectra. This is consistent with discussion in RG 1.122. The subsystems are modeled in sufficient detail in local models to capture the torsional, rocking, and translational responses of the supported subsystem structures using the ISRS generated from the SSI dynamic analyses per Section 3.7.2.3 of the DCD (R3) consistent with NUREG-0800, SRP Section 3.7.3. Please refer also to the response to RAI 799-5877 Question 03.07.03-10 for additional discussion of how rocking is accounted for in the subsystem design.

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.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

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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**
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QUESTION NO. RAI 03.07.02-105:

In Subsection 3.7.2 of DCD (R3), "Seismic System Analysis", the second paragraph (page 3.7-12) states in part, "The results from the seismic analyses serve as the basis for the development of equivalent static seismic loads that are applied in conjunction with other design loads on the detailed three-dimensional shell FE model in order to obtain the design stresses in the structural members and components."

The Applicant is requested to provide information on the boundary conditions assumed for the FE models when performing the equivalent static loading analyses. If the fixed-base condition is assumed, the Applicant is requested to provide technical information on how the forces and moments for the basemat design are obtained, and show that the approach used yields conservative results.

ANSWER:

Subsection 3.7.2 will be revised as shown in the supplemental response to RAI 542-4262, Attachment 2 (ML11188A251) because plate models now are used for the seismic analysis of the Reactor Building Complex instead of stick models. A fixed base condition is not assumed.

Boundary conditions used for the FE models of the R/B complex and PS/B when performing equivalent static loading analyses are described in Section 3.8.5.4.3 of the DCD. A fixed-base condition is not assumed; instead, the properties of the generic subgrade profiles are included in the FE model. Please note that text changes for Subsection 3.8.5.4.3 of the DCD were included in the supplemental response to RAI 542-4262, Attachment 3 (ML11188A252).

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.

Table 1.9.2-3 US-APWR Conformance with Standard Review Plan Chapter 3 Design of Structures, Systems, Components, and Equipment (Sheet 13 of 35)

SRP Section and Title	SRP Excerpt Indicating Acceptance Criteria for DCD	Status	Appears in DCD Chapter/Section
3.7.2 Seismic System Analysis	1. Seismic Analysis Methods. The seismic analysis of all seismic Category I SSCs should use either a suitable dynamic analysis method or an equivalent static load analysis method, if justified. The SRP acceptance criteria primarily address linear elastic analysis coupled with allowable stresses near elastic limits of the structures. However, for certain special cases (e.g., evaluation of as-built structures), reliance on limited inelastic/nonlinear behavior when appropriate is acceptable to the staff. Analysis methods incorporating inelastic/nonlinear considerations and the analysis results are reviewed on a case-by-case basis. A. Dynamic Analysis Method B. Equivalent Static Load Method 2. Natural Frequencies and Responses. 3. Procedures Used for Analytical Modeling. A. Designation of Systems Versus Subsystems B. Decoupling Criteria for Subsystems. C. Modeling of Structures. D. Representation of Floor Loads, Live Loads, and Major Equipment in Dynamic Model In E. Special Consideration for Dynamic Modeling of Structures.	Conformance with exceptions. COL Applicant need to consider site-specific subgrade condition (materials, layers, etc.) in the SSI modeling and analysis, and in the evaluating for overturning and sliding effects, and also need to design seismic Category II SSC based on the design criteria for seismic Category I SSC. SRP 3.7.2 acceptance criteria item 1.A.iv(2) suggest using 1g static analysis of the dynamic model should be performed for each of the three excitation directions. However, with more rigorous methods used for result comparisons for model validation, the current methodology used for the dynamic analysis used only the two horizontal responses without vertical responses for comparison of the displacements instead of each of the three excitation directions, and comparison of cumulative mass versus frequency plots and amplified response spectra(ARS) for each of the three (3) excitation directions..	3.7.2, 3.8

DCD_03.07.02-95

water table, and scattering of the input motion. The SSI analyses are performed with ACS SASSI (Reference 3.7-17) in the frequency domain utilizing the substructuring technique and complex stiffness representation of stiffness and damping properties of the structures and the subgrade. The subgrade media and SSI system damping to model the dissipation of energy due to material damping of the structural members and the soil are also discussed in Subsections 3.7.1.3 and 3.7.1.2. The response of the system at selected frequencies of analyses is obtained as the solution of a set of complex algebraic equations. The frequencies of analyses are selected to accurately capture the response of the structure at all important frequency ranges. The amplitudes of the interpolated transfer functions are plotted and investigated to ensure the accuracy of the interpolation of the response for the required range of frequencies. Plots of transfer functions for various locations throughout the R/B Complex and PS/B are presented in Appendix L of Technical Report MUAP-10006 (Reference 3.7-48). Approaches and methods used for the SSI analyses are discussed further in Technical Report MUAP-10001 (Reference 3.7-47). DCD_03.07.02-103

Table 3.7.2-3 provides the percent of stiffness reduction and damping values used for the different structural components for the site-independent SSI analyses of US-APWR R/B complex and PS/B. DCD_03.07.02-35

~~The ratio of basemat depth-to-equivalent-radius for the R/B-PCCV basemat is approximately 0.27. ASCE 4-98 Subsection 3.3.4.2 (Reference 3.7-9) considers that a basemat depth-to-equivalent radius ratio of less than 0.3 is an indication of a shallow embedment foundation, for which effects of the embedment on the seismic response of the building are generally not significant. SSI analysis performed as part of the site-independent US-APWR standard plant design neglects the effects of embedment of the common R/B and PCCV basemat. Therefore, the R/B-PCCV seismic models are not coupled with any subgrade or backfill material at the sides of the basemat or along the faces of below-grade exterior walls, and no credit is taken in the seismic analysis for reduction in amplitude of the response due to foundation embedment in the subgrade or backfill materials. Embedment effects, including shifts in the structural frequencies, are considered to be small enough to be enveloped by the variations of subgrade stiffness considered in the standard design seismic response analyses of a surface foundation. However, the effects of the embedment are required to be analyzed on a site specific basis as discussed in Subsection 3.7.2.4.1 to confirm suitability of design.~~ Technical Report MUAP-11007 (Reference 3.7-52) presents studies to assess embedment depth and groundwater level effects on the standard design of R/B complex and the PS/B. MIC-03-03-00066 DCD_03.07.02-35 MIC-03-03-00066

Effects of Groundwater Level - Sensitivity study of ground water fluctuation is based on comparison of responses obtained from SSI analyses of R/B Complex and PS/B supported on unsaturated and fully saturated subgrades. The comparisons of 5% damping ARS at representative locations show that the elevation of ground water table has small effect on the SSI responses and has insignificant impact on the standard design basis. DCD_03.07.02-35 MIC-03-03-00066

Effects of Embedment - Structural embedment studies are performed to assess embedment effects on R/B complex seismic response. US-APWR standard plant seismic design is based on enveloped seismic response parameters generated from seismic SSI analyses of major plant structures surface-founded the site soil profiles provided in Table DCD_03.07.02-35 MIC-03-03-00066

3.7.2.6 Three Components of Earthquake Motion

As previously discussed in Subsection 3.7.1.1, the seismic analyses of the major seismic category I structures are based on one set of three mutually orthogonal artificial time histories, with each of the three directional components being statistically independent of the other two. The acceleration time histories of the horizontal H1 and H2 components of the earthquake are applied in N-S direction and E-W directions respectively. The acceleration time history V is applied in the vertical direction.

The three components of the earthquake are applied on the seismic model separately in ACS SASSI (Reference 3.7-17) for obtaining the maximum accelerations of the response in the three orthogonal directions. The maximum responses of interest of SSCs obtained from the responses of each of the three components of motion are then combined using SRSS or the Newmark 100%-40%-40% method in accordance with RG 1.92, Rev.2 (Reference 3.7-27). The combined maximum accelerations, obtained through the process described previously in Subsection 3.7.2, are then used as basis for development of the SSE loads used for the design of structural members, components and connections of US-APWR standard plant. These SSE design loads are applied as static loads on the detailed FE model in conjunction with other design loads and load combinations.

The development of the ISRS uses the SRSS method to combine the responses from the three components of the earthquake motion.

Although the above approach has been used for seismic analysis of the major seismic category I structures, seismic responses of other seismic systems and subsystems due to the three components of earthquake motion can be combined using any one of the following methods in accordance with RG 1.92, Rev.2 (Reference 3.7-27):

i. The peak responses due to the three earthquake components from the response spectra and equivalent static analyses are combined using the SRSS method.

ii. The peak responses due to the three earthquake components are combined directly, using the Newmark combination method that assumes that when the peak response from one component occurs, the responses from the other two components are 40% of the peak (100%-40%-40% method). Combinations of seismic responses from the three earthquake components, together with variations in sign (plus or minus) are considered.

iii. The time-history of the responses from the three earthquake components that are applied simultaneously can be combined algebraically at each time step to obtain the combined response time-history. The design seismic loads are selected from the maximum values or the most critical combination of values extracted from the time history results representing the responses directly related to the design of the particular ~~member~~element considering sign reversals, such as the relevant internal forces or stresses in the ~~member~~element.~~Due to the uncertainties introduced by phasing effects, the design does not use time history results for other responses, such as accelerations or displacements at points in time that are indirectly related to the basic design inputs.~~ DCD_03.07.02-96

3.7.2.7 Combination of Modal Responses

As previously discussed, the seismic responses of the seismic category I building models are obtained using three-dimensional SSI models with the program ACS SASSI (Reference 3.7-17). ACS SASSI utilizes time history analysis in the frequency domain in which the equations of motion are solved using a global complex matrix that is assembled from the complex matrices for the soil and structural elements. Therefore modal combination is not utilized.

When the modal superposition time history analyses or response spectra analyses are used for seismic design of other seismic category I and seismic category II systems and subsystems, ~~all necessary modes are included in order to capture a minimum of 90% of the cumulative mass of the building or structure being analyzed~~it may not be practical to capture higher frequency modes that are not excited by the input motion. In modal superposition, only modes with frequencies less than the frequencies defining the cutoff or ZPA response participate in the modal solution. The modal contribution of the residual rigid response for modes with frequencies greater than the cutoff or ZPA frequency is accounted for by using the missing mass method. ~~As permitted by RG 1.92, Rev.2 (Reference 3.7-27)~~As permitted in Section 1.4.1 of RG 1.92 (Reference 3.7-27), the missing mass contribution, scaled to the instantaneous input acceleration, is treated as an additional mode in the algebraic summation of modal responses at each time step. The missing mass contribution is considered for all DOF. When using the Lindley-Yow method in response spectra analyses, the missing mass may be captured using the Static ZPA method as described in Section 1.4.2 of RG 1.92, Rev. 2 (Reference 3.7-27). DCD_03.07.02-101 DCD_03.07.02-101

When the response spectra method of analysis is used (see Subsection 3.7.3.1 for a discussion of response spectra methods of analysis), modal responses have been combined by one of the RG 1.92, Rev.2 (Reference 3.7-27), methods, or by the 10% grouping method described below. In some applications, the more conservative modal combination methods contained in Rev.1 of RG 1.92 (Reference 3.7-28) are also used, as permitted in Revision 2 of RG 1.92 (Reference 3.7-27).

For the grouping method, the total unidirectional seismic response for subsystems is obtained by combining the individual modal responses using the SRSS method for frequencies spaced more than 10%.

For subsystems having modes with closely spaced frequencies, this method is modified to include the possible effect of these modes. The groups of closely spaced modes are chosen so that the differences between the frequencies of the first mode and the last mode in the group do not exceed 10% of the lower frequency.

The combined total response for systems having such closely spaced modal frequencies is obtained by adding to the SRSS of all modes the product of the responses of the modes in each group of closely spaced modes.

This can be represented mathematically as follows:

$$R^2 = \sum_{k=1}^{N} R_k^{\ 2} + \sum_{q=1}^{P}\sum_{l=i}^{j}\sum_{m=i}^{j}\left|R_{lq} \cdot R_{mq}\right| \qquad l \neq m$$

3.7.2.1 to verify that they will not collapse or adversely interfere with seismic category I SSCs or adversely affect the MCR occupants. Seismic category II is defined in Section 3.2. By definition, seismic category II structures are designed to retain their position to the extent necessary to assure that they will not impact the function or integrity of seismic category I SSCs.

NS structures have been located such that, in case of their collapse or failure, they do not have the potential to impact seismic category I SSCs, either directly or indirectly.

~~NS structures that are not located beyond the range of impact are isolated by heavy concrete walls from seismic category I SSCs.~~ DCD_03.07.02-97

~~With respect to the coupling of the dynamic responses of adjacent structures through the soil, the phenomenon of structure-to-structure interaction is neglected in the SSI analyses for the standard plant discussed in Subsection 3.7.2.4. Instead, the variations of site properties considered by the four general subgrade conditions are deemed sufficient to address the uncertainties related to possible structure-to-structure interaction effects on the overall seismic response results.~~The same methodology used to evaluate structure-to structure interaction between seismic Category I structures and non-seismic Category I structures is used to evaluate structure-to-structure interactions between seismic Category I structures. This methodology is described in Subsection 3.7.2.4. It is the responsibility of the COL Applicant to further address structure-to-structure interaction if the specific site conditions can be important for the seismic response of particular US-APWR seismic category I structures, or may result in exceedance of assumed pressure distributions used for the US-APWR standard plant design. DCD_03.07.02-35

Maximum lateral earth pressure due to the backfill, surcharge due to live load or adjacent basemat bearing pressures, groundwater, and other such static-load effects on below-grade exterior walls are discussed in Section 3.8. The design of below grade exterior walls for US-APWR seismic category I structures takes into account any dynamic increases of these loads due to a seismic event. This is accomplished through the use of conservative maximum static and dynamic lateral pressure distribution profiles developed using analysis methods provided in Section 3.5.3 of ASCE 4-98 (Reference 3.7-9) and as discussed in Subsection 3.8.4. DCD_03.07.02-98

The COL Applicant is to assure that the design or location of any site-specific seismic category I SSCs, for example pipe tunnels or duct banks, will not expose those SSCs to possible impact due to the failure or collapse of non-seismic category I structures, or with any other SSCs that could potentially impact, such as heavy haul route loads, transmission towers, non safety-related storage tanks, etc. Alternately, site-specific seismic category I SSCs are designed for impact loads due to postulated failure of the non-seismic category I SSCs.

Following is a discussion of major structures in the power block area with respect to potential interaction with seismic category I structures.

3.7.2.8.1 AC/B

The AC/B is structurally designed as a NS structure on reinforced concrete foundation located at the west side of the A/B (seismic category II). The AC/B is not located adjacent

Individual structural members are further analyzed for localized loading as described in specific load cases.

Concrete components such as walls, slabs, and foundations are evaluated for the effects of frame interaction when the flexural moment from seismic loads is a large percentage of the flexural capacity. When at least two-thirds of the flexural capacity of a component is from seismic loads alone, the component is designed as a frame to assure design capacity even under a seismic margin earthquake equal to 150% of the SSE, in accordance with RG 1.142 (Reference 3.8-19), Regulatory Position 3.

Concrete members that are subject to torsion and combined shear and torsion are evaluated to the standards of Section 11.6 of ACI 349 (Reference 3.8-8).

Design and analysis of the spent fuel pit, the spent fuel racks, and the fuel handling system is in accordance with Appendix D of NUREG-0800, SRP 3.8.4 (Reference 3.8-40). Additional general information is provided by ANSI/ANS-57.7 (Reference 3.8-33). Subsection 9.1.2 describes the design bases and layout of the spent fuel pit, the spent fuel racks, and the fuel handling system.

Exterior concrete walls below grade and basemat of seismic category I structures are designed using load combinations accounting for sub-grade loads including static and dynamic lateral earth pressure, soil surcharges, and effects of maximum water table. Dynamic lateral earth pressure is calculated ~~in accordance with ASCE 4-98 (Reference 3.8-34).~~as described in Section 3.7 of Technical Report MUAP-10006 (Reference 3.7-47). The calculation approach follows guidance given in ASCE 4-98 (Reference 3.8-34) for computing dynamic lateral earth pressure, and also accounts for increases in horizontal pressure due to the vertical component of earthquake excitation. The static and seismic lateral earth pressures due to the vertical and horizontal components of the earthquake are combined by conservatively assuming that the peak vertical and horizontal response accelerations in the embedment soil occur simultaneously. The use of saturated unit weight for the soil provides the most conservative case for including the effects of groundwater in the calculations of the dynamic earth pressures because it considers that the response of the two phases of the system, the groundwater and soil, to be completely in-phase and does not consider the dissipation of energy due to the viscous flow of the groundwater. The total dynamic lateral pressure computed in this manner envelops the in-phase sum of the Wood's soil pressure (per ASCE 4-98) and the Westergaard formula for computing hydrodynamic groundwater pressure under seismic loads on a vertical wall bordering a free body of water (e.g. reservoir). DCD_03.07.02-98

Structural steel framing in seismic category I structures is primarily for the support of distribution systems, access platforms, and other plant appurtenances. Steel members are sized and detailed based on maximum stresses and reactions determined through conservative manual calculations and computer models based on pinned-end connections, including slotted hole clip angle connections, to relieve thermal expansion forces where appropriate, unless detailed to develop end moments in accordance with AISC N690 (Reference 3.8-9). The design of the support anchorage to the concrete structure is in accordance with ACI 349 Appendix B (Reference 3.8-8), RG 1.142 (Reference 3.8-19), and RG 1.199 (Reference 3.8-41).