REQUEST FOR ADDITIONAL INFORMATION 810-5874 REVISION 3

8/22/2011

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

SRP Section: 03.07.02 - Seismic System Analysis
Application Section: SRP 3.7.2

QUESTIONS for Structural Engineering Branch 1 (AP1000/EPR Projects) (SEB1)

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.

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.

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.

03.07.02-94

In DCD (R3), Section 3.7.2.3.11 “Equivalent Masses due to Dead and Live Loads” the first paragragh 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.

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 1*g* 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 1*g* static analysis.

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.

03.07.02-97

In Subsection 3.7.2.8 of DCD (R3), “Interaction of Non-Seismic Category I Structures with Seismic Category I Structures”, the fourth paragraph (page 3.7-38) states, “NS structures that are not located beyond the range of impact are isolated by heavy concrete walls from seismic category I SSCs.”
The Applicant should identify the locations of these heavy concrete walls and demonstrate how the presence of the heavy walls conforms to the guidelines of SRP Acceptance Criteria 8 of SRP 3.7.2.

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.

03.07.02-99

In Subsection 3.7.2.14 of DCD (R3), “Determination of Dynamic Stability of Seismic Category I Structures”, the last sentence of the second paragraph (page 3.7-44) states, “The site-specific factor of safety against liquefaction is determined to confirm the dynamic stability of seismic category I structures for the US-APWR standard design with respect to liquefaction.”
The staff expects this to be a COL item, but this information is not included in Subsection 3.7.5, “Combined License Information”. The applicant should include this as a COL item or provide a justification for not doing so.

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.

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.

03.07.02-102

In Subsection 3.7.2.3.4 of DCD (R3), “Subsystem Coupling Requirements”, the last paragraph (page 3.7-20) states in part, “In addition, the requirements of NOG-1 (Reference 3.7-22) for the design of cranes may require that the crane design analysis be performed by coupling the crane model with the overall building model. If found that is required, the site-specific seismic analysis of the US-APWR standard plant must be performed on models that incorporate the PCCV polar crane and the fuel handling crane, as appropriate.”
This is a required COL action item. However this information is not included in Subsection 3.7.5, “Combined License Information”. The Applicant is requested to discuss why this item is not included in Subsection 3.7.5. The same topic was addressed in RAI 542-4262, Question 3.7.2-7 (identified as question 3.7.2-34 in the Applicant's response) against DCD (R2), and the staff disagrees with the response that COL Action Items 3.7(4), 3.7(23), and 3.7(25) address the crane question. The staff’s position is that COL Action Item (11) should be reinstated in the DCD.

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.

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.

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.

03.07.02-106

In Subsection 3.7.2.4.1 of DCD (R3), “Requirements for Site-Specific SSI Analysis of US-APWR Standard Plant”, the fifth paragraph (page 3.7-31) states in part, “The input control motion that is derived from the site-specific GMRS, is applied in the SASSI analysis as within motion at the bottom of the basemat.”
The staff noticed that in DC/COL-ISG-017, the foundation input response spectrum (FIRS) is the starting point for conducting the soil-structure interaction analysis. Also, in the Nuclear Energy Institute (NEI) white paper entitled, “CONSISTENT SITE-RESPONSE/ SOIL-STRUCTURE INTERACTION ANALYSIS AND EVALUATION”

(Reference 3 of DC/COL-ISG-017), the FIRS is used rather than the GMRS. Therefore, the Applicant is requested to either delete the above quoted sentence or modify it to be consistent with DC/COL-ISG-017. Also, the applicant is requested to define the term "within motion" mentioned in the above quoted sentence.

03.07.02-107

In Subsection 3.7.2.4.1 of DCD (R3), the first paragraph states, "The COL Applicant referencing the US-APWR standard design is required to perform a site-specific SSI analysis for the R/B-PCCV-containment internal structure, and PS/B model, utilizing the program ACS SASSI SSI (Reference 3.7-17) which contains time history input incoherence function capability. The SSI analysis using SASSI is required in order to confirm that site-specific effects are enveloped by the standard design. After the SASSI analysis is first performed for a specific unit, subsequent COLAs for other units may be able to forego SASSI analyses if the FIRS and GMRS derived for those subsequent units are much smaller than the US-APWR standard plant CSDRS, and if the subsequent unit can also provide justification through comparison of site-specific geological and seismological characteristics."
The Applicant is requested to clarify the meaning and intent of this paragraph and provide the definition of "unit" as used in the above paragraph. Is the word "unit" intended to mean a site or a specific structure? Also, the Applicant is requested to define the situations in which SASSI analyses are or are not required for site-specific seismic qualification of Standard Plant SSC's and should state the regulatory basis for this position.
The staff notes that the first paragraph of Subsection 3.7.2.4.1 is repeated as COL Item 3.7(25). Therefore, any clarifications to Subsection 3.7.2.4.1 should be incorporated into COL Item 3.7(25) as applicable.

03.07.02-108

The Applicant is requested to clarify the following 15 items identified from various sections of DCD (R3).

1. In Subsection 3.7.2.3.7 of DCD (R3), "Shear Stiffness", item "ii" of the fourth paragraph (page 3.7-22) states in part, "To determine which portion of the resulting displacement at each floor is attributable to shear stiffness and which portion is related to bending stiffness, another analytical model in which the vertical DOF is constrained is also prepared separately. The flexibility coefficients for the equivalent beam are evaluated from the results of these analyses."

   The above quoted sentences do not provide enough detail for the staff to perform an evaluation. The Applicant is requested to provide more detailed information that shows how the shear and bending stiffnesses are determined. If desired, a simple example may be used to demonstrate the procedure.

2. In Subsection 3.7.2.4.1 of DCD (R3), "Requirements for Site-Specific SSI Analysis of US-APWR Standard Plant", the eighth paragraph (page 3.7-32) states in part, "FE analyses are employed to evaluate the flexibility of the basemat and the embedded

portion of the building. The floor slabs located at and above the ground surface are assumed absolutely rigid."

The Applicant is requested to verify the accuracy of the second statement in the above quoted statements. In DCD (R3) Subsection 3.7.2.3.10.1. "Validation Method", the item i of the first paragraph (page 3.7-26) states, "A FE model consisting of the portion of the building above the upper level of the basemat, including the walls, columns, and floor slabs, is developed using brick, shell, and beam elements." This paragraph does not mention that the floor slabs located at and above the ground surface are assumed absolutely rigid.

3. In Subsection 3.7.2.7.1 of DCD (R3), "Left-Out-Force Method (or Missing Mass Correction for High Frequency Modes)", the equation given in the third paragraph (page 3.7-38) has a notation "A_m", which is defined as "the maximum spectral acceleration beyond the flexible modes". Is its value the value of ZPA? If not, the Applicant is requested to provide what its value is and how to obtain that value.

4. In Subsection 3.7.3.1.7.1 of DCD (R3), "Uniform Support Motion Method", the equation for combined displacement response in the normal coordinate for mode i is given by the equation **q_i = d_j time the summation of P_{ij} times d_{ij}** and the corresponding equation in Subsection 3.7.3.1.7.2, "Independent Support Motion Method" is **q_i = the summation of p_{ij} times d_{ij}**. The Applicant is requested check the accuracy of these two equations, because, these two equations cannot be both correct unless d_j and d_{ij} are non-dimensional parameters. Also the free index is inconsistent on the two sides of the first equation.

5. In subsection 3.7.1.2 of DCD (R3), "Percentage of Critical Damping Values", the fourth paragraph (page 3.7-9) states in part, "The strain energy dependent modal damping values are computed based on Reference 3.7-18."

   Reference 3.7-18 has been deleted. The Applicant is requested to correct this mistake.

6. In Subsection 3.7.1.1 of DCD (R3),"Design Ground Motion", item "a" of the sixth paragraph under the subtitle "Design Ground Motion Time History" (page 3.7-6) states in part, "The US-APWR artificial time histories have a sufficiently small time increments (Δt =0.005 seconds) and a total duration of 22.005 seconds."

   In MUAP-11002 (R0), "Turbine Building Model Properties, SSI Analyses, and Structural Integrity Evaluation", the time duration is listed as 22.085 seconds. The Applicant is requested to correct or clarify this inconsistency.

7. DCD (R3) Section 3.7.2 provides an eleven step process for developing equivalent static loads from the results of the lumped mass seismic model of the R/B complex. Potentially, the staff has questions on the details of this process, but first, the staff would like the Applicant to clarify if the procedure for developing equivalent static loads from the lumped mass model is obsolete in light of the commitment by the Applicant to use a full three-dimensional finite element model for the SSI analysis of the of the R/B complex. If the procedure is still relevant, the Applicant should describe the situations in which this procedure will be used. The response should

also address the relevance of the procedures described in Section 3.7.3.10 of the DCD.

8. In Table 3.7.2-1 of DCD (R3), the analysis method listed for both the SASSI and ANSYS models is “Time History Analysis in the Frequency Domain”. The staff requests clarification of this terminology when referring to ANSYS analyses because ANSYS does not use the same methodology as SASSI.

9. In Subsection 3.7.2.1 of DCD (R3), “Seismic Analysis Methods”, the third paragraph (page 3.7-15) states in part, “As an alternative option for seismic category I systems and subsystems, it is also acceptable to utilize the composite modal damping method associated with the modal superposition of time history analysis when the equations of motion can be decoupled in accordance with SRP 3.7.2 (Reference 3.7-16), Section II.13.”

   The last sentence in the above quoted paragraph is confusing because the composite modal damping formulations in SRP Section II.13 are appropriate when the subgrade is modeled using a lumped soil spring approach, or for fixed base models. This is inconsistent with the stated approach in the DCD of modeling a frequency-dependent SSI system. The staff requests clarification of the quoted statement from the DCD.

10. In Subsection 3.7.2.3.7.1 of DCD (R3), “Effective Shear Area (A_x, A_y)”, (page 3.7-22), the symbol A_e is referred as “an equivalent shear area” and “the effective cross section area”. In Subsection 3.7.2.3.7.2, “Bending Moment of Inertia (I_{yy}, I_{xx})”, (page 3.7-23) the symbol I_e is referred as “equivalent moments of inertia” and “effective moment of inertia”. The Applicant is requested to explain why one symbol has two different names in each of the instances cited above.

11. In Subsection 3.7.2.5 of DCD (R3), “Development of Floor Response Spectra”, the last bullet of the fifth paragraph (page 3.7-34) states, “The broadened response spectra method discussed in Subsection 3.7.3.1 is used or alternatively in some locations, the peak shifting method described in Subsection 3.7.3.1 can be used.”

    The staff reviewed Subsection 3.7.3.1.5 of the DCD and notes that there is no description of spectral broadening, but rather a reference back to Subsection 3.7.2.5 of the DCD. The Applicant should delete the circular reference, and make it clear where the description of spectral broadening appears in the document.

12. In Subsection 3.7.2.8.2 of DCD (R3), “T/B”, the second bullet of the last paragraph (page 3.7-40) states, “The design of the T/B is based on a static analysis utilizing a three-dimensional FE model, and a seismic dynamic analysis using a three-dimensional lumped mass model.” In contrast, MUAP-11002 (R0) describes a full three-dimensional SSI model of the turbine building rather than a lumped mass model, and there is no mention of static analysis in MUAP-11002 (R0) to analyze the turbine building other than a 1*g* static analysis in the fixed-base condition that is used for model verification.

    The staff requests MHI to clarify in the DCD the approach for designing the turbine building. Also, the last sentence of Section 3.7.2.8.3 of the DCD refers to a stick

model of the T/B. This inconsistency with the model description in MUAP-11002 (R0) should be corrected.

13. In Subsection 3.7.2.8.4 of DCD (R3), “A/B”, the second bullet of the second paragraph (page 3.7-41) states, “The design of the A/B is based on a static analysis utilizing a three-dimensional FE model, and a seismic dynamic analysis using a three-dimensional lumped mass model.” In contrast, MUAP-11001 (R0) describes a full three-dimensional SSI model of the A/B in addition to a lumped mass model.

    The staff requests MHI to clarify in the DCD the models and approach used for designing the A/B building including the use lumped mass vs. distributed mass models and static vs. dynamic methods.

14. In Subsection 3.7.2.12, “Comparison of Responses”, the second paragraph (page 3.7-44) states in part, “Since only a time history analysis method is used, comparison of the responses between the response spectrum method and a time history analysis method, as per SRP Section 3.7.2.II.12 (Reference 3.7-16), is not applicable.” In contrast, MUAP-11001 (R0) documents a response spectrum analysis of the A/B.

    The staff recognizes that the A/B is an SC-II structure; however, the staff requests that the DCD Subsection 3.7.2.12 reflect the fact that response spectrum analysis was used for the A/B. Also, MHI should state whether there are any SSC’s for which the comparison of responses described in SRP 3.7.2.II.12 are applicable.

15. In Subsection 3.7.2.4.1 of DCD (R3), “Requirements for Site-Specific SSI Analysis of US-APWR Standard Plant”, the seventh paragraph (page 3.7-32) states, “The depth of the water table must be considered when developing the P-wave velocities of the submerged subgrade materials. Significant variations in the water table elevation and significant variations of the subgrade properties in the horizontal direction are addressed by using additional sets of site profiles.”

    The staff requests clarification on the meaning of this statement because variations of subgrade properties in the horizontal direction are not supported by SASSI.