REQUEST FOR ADDITIONAL INFORMATION 496-3735 REVISION 0

12/1/2009

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

SRP Section: 03.08.05 - Foundations
Application Section: 3.8.5

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

03.08.05-23

This Request for Additional Information was written based on Revision 1 of the DCD.

In its response to Question 3.8.5-1 (of RAI 340-2004 hereinafter unless indicated otherwise), MHI states that the reactor building (R/B) complex basemat is not perfectly rectangular over its entire depth. They explain that the FE models shown in the DCD are cross sections of the basemat at different elevations and they are correct as shown. MHI will revise the DCD to clarify this issue.

The applicant is requested to provide the following information:

1. In evaluating this response, the staff notes that MHI stated that Figure 3.8.5-5 and Figure 3.8.5-6 are cross sections of the R/B basemat taken at different elevations. This statement is confusing because Figure 3.8.5-6 is a 3-D finite element model of the basemat not a 2-D cross section view. The applicant is requested to change the figure caption if Figure 3.8.5-5 is not a cross section of Figure 3.8.5-6.

With regard to the design of the basemat, MHI is requested to provide a rationale for not maintaining the rectangular shape over its entire depth. As it is shown in the standard plant design, the corners at the notches are discontinuities and are more likely to crack. MHI is also requested to provide the coordinates of the mass center of the structures supported on the basemat including the mass of the basemat.

Reference: MHI response to RAI 340-2004, dated 7/3/2009, MHI Ref: UAP-HF-09363, ML091900557.

03.08.05-24

In their response to Question 3.8.5-2, MHI states that they have used four generic subgrade conditions for the standard plant, and that this meets the intent of ASCE 4-98. In addition, MHI states that in DCD, Subsection 3.7.2.4.1 the COL Applicant is required to perform a site-specific soil-structure interaction (SSI) analysis that considers the best estimate, upper bound, and lower bound cases.

The staff notices that In the response, MHI states that the use of shear wave velocities ranging from 1000 ft/s to 8000 ft/s captures the uncertainties in soil properties and in the

SSI analysis by intent. If this is what the applicant claims, the applicant is requested to change the DCD to "The standard plant design considers only one subgrade with the shear wave velocity ranging from 1000 ft/s to 8000 ft/s." If, however, the applicant wants to claim that four subgrade types are considered in their approach, then uncertainties in soil properties need to be assessed for each subgrade type.

Reference: MHI response to RAI 340-2004, dated 7/3/2009, MHI Ref: UAP-HF-09363, ML091900557.

03.08.05-25

In its response to Question 3.8.5-4, MHI states that the US-APWR standard plant design considers four generic subgrade conditions for the seismic design. Further, variations in dynamic properties and effects of non-linearity are to be determined on a site-specific basis by the COL Applicant. A description of the models used is provided in the response, along with a discussion of their use of soil degradation curves, and how non-linearity is treated. MHI explains in the response how dynamic properties of site-specific subgrade materials are obtained, citing the use of soil degradation curves for typical material published in open literature.

The applicant is requested to provide the following information:

1. In reviewing Part (a) of the response, the staff notes that MHI states that it is conservative to neglect the effect of the soil material damping. This position is not in compliance with SRP 3.7.2 II.4.C. The effect of soil material damping will lower the fundamental frequency of the soil-structure system. Depending on the fixed-based frequency of the structure, this frequency shift may increase or decrease the structural response. Hence, neglecting this effect may not be "conservative". MHI is requested to provide data to support their claim that it is conservative to neglect soil material damping.

In Part (b) of the response, MHI did not specify the values of C_v used in US-APWR standard plant design. MHI is requested to provide this information.

Reference: MHI response to RAI 340-2004, dated 7/3/2009, MHI Ref: UAP-HF-09363, ML091900557.

03.08.05-26

In its response to Part (a) of Question 3.8.5-5, MHI states that they will revise the DCD to reflect changes made to the DCD, Tier 1, Table 2.1-1, and DCD Tier 2, Table 2.0-1 in accordance with open item RGS 1.2.5.4. A discussion is presented in the response concerning the minimum allowable bearing capacity and the minimum allowable dynamic bearing capacity, including some specific values for the standard plant. For Part (b) MHI explains the choice of 60 ksf for the minimum allowable dynamic bearing pressure. For Part (c) MHI refers to their response to Part (a) above. For Part (d) the response includes the combinations of the seismic responses in three directions of the earthquake. A table is included that summarizes the results from the various load combinations considered, and identifies the critical load combinations. MHI will clarify the choices of allowable static and dynamic bearing pressures.

The applicant is requested to provide the following information:

1. For Part (a) of the response, MHI replaced the terms “average static bearing capacity” and “average dynamic bearing capacity” with “minimum allowable static bearing capacity” and “minimum allowable dynamic bearing capacity”, respectively. The staff considers these changes acceptable. MHI further stated that the minimum allowable static bearing pressure is 15 ksf and the minimum allowable dynamic bearing capacity is 60 ksf. These two values were based on the calculated values of 11.3 ksf for the static case and 53 ksf for the dynamic case. The staff calculates the safety factors associated with these two cases as 1.3 for the static case, and 1.1 for the dynamic case. The applicant is requested to provide the technical rationale and justification for choosing these safety factors.

In Part (d) of the response, MHI used the Highter and Anders equation provided in Section 3.12 of Principle of Foundation Engineering, 6^{th} edition to compute the effective contact area. The staff finds that the Highter and Anders equation is not well-known. The applicant is requested to provide additional technical information to verify the accuracy of the calculations. Was the Highter and Anders equation used to calculate any response quantities that were used in design?

Reference: MHI response to RAI 340-2004, dated 7/3/2009, MHI Ref: UAP-HF-09363, ML091900557.

03.08.05-27

In its response to Question 3.8.5-6, MHI explains the shell elements used in the three-dimensional FE models, including a figure that shows the types and locations of elements used.

In reviewing the response, the staff finds that MHI did not provide enough information for the staff to perform an evaluation of the response. The applicant is requested to provide additional information such as how the degree-of-freedoms of these elements (shell, brick, and rigid elements) are matched to each other shown in the left figure of Figure 1 in the response, and how the shell elements are connected to the brick elements in the right figure of Figure 1. MHI is also requested to provide technical information that verifies that the stresses and displacements are continuous through the shell to brick connections.

Reference: MHI response to RAI 340-2004, dated 7/3/2009, MHI Ref: UAP-HF-09363, ML091900557.

03.08.05-28

In its response to question 3.8.5-7, MHI points out that a similar topic was addressed in their response to Question 3.8.1-5 of RAI 223-1996. For Part (a) of the question MHI describes how the vertical and horizontal spring constants are calculated, including tables to show the resulting values. For Part (b) MHI states that there are two horizontal springs for each node. For Part (c) MHI states that it is not necessary to consider the boundary conditions at the "dent" (the area below the central region of the PCCV) in the bottom of the R/B, PCCV basemat because it will be filled with concrete, not soil.

The applicant is requested to provide the following information:

1. For Part (a) of the response, MHI indicated that the soil spring constants are calculated based on the equations given in American Society of Civil Engineers (ASCE) 4-98. ASCE 4-98 provides two sets of equations for calculating the soil spring constants, one for circular foundation and the other for rectangular foundation. The outer shape of the common basemat for the R/B, PCCV and internal structures is approximately a rectangle. However, the elevation of the bottom of the central region of the common basemat is about 10 feet above that of the peripheral portion of the basemat. For this annular foundation shape, the soil spring constants calculated based on ASCE 4-98 may not be adequate. The staff has not reviewed and endorsed ASCE 4-98 for this application. MHI is requested to validate the applicability of ASCE 4-98 equations for the common basemat. Also, per SRP 3.7.2 II.4, the frequency variation of the soil spring constants needs to be considered. MHI is requested to show that the frequency variation is not important in order to use frequency independent soil spring constants. In MHI's response, Table 1 in the response presents soil spring constants for the FE model. In this table, the area of basemat at its bottom, is A, and the geometrical moment of inertia at basemat, J, appears to consider the whole basemat area including the central dented region. MHI is requested to provide justification for including the central region ("dent") as part of the basemat since it is a filled volume not part of the structural basemat. The soil spring constants per unit area presented in Table 1 are considered to lack sound theoretical background because these per unit area soil spring constants do not reproduce the theoretical distribution of the soil pressure for a uniform displacement of the foundation. Finally, specified in Table 2.0-1 of the DCD, the water table is at 1 foot below the nominal plant grade. The applicant is requested to provide data that shows the effect of this high water table on the calculation of the soil spring constants.

MHI's response for Part (c) is acceptable. However, the applicant is requested to state explicitly in the DCD that the dent in the central region of the basemat bottom is filled with concrete.

References:

MHI response to RAI 340-2004, dated 7/3/2009, MHI Ref: UAP-HF-09363, ML091900557

MHI response to RAI 223-1996, dated 4/14/2009, MHI Ref: UAP-HF-09161, ML091060749

03.08.05-29

In its response to Question 3.8.5-8, MHI describes how the soil springs of the FE model are calculated. It is pointed out that for the case of uplift the soil springs in tension are cut off, and the remaining spring constants modified according to the uplift area. MHI states that there is no inconsistency between the two models.

In the response, MHI states that "The soil springs of the FE model are calculated by distributing the soil springs of the three dimensional lump-mass stick model to each node corresponding to the subjected area of each node." The staff finds that this approach is not acceptable because the distributed soil springs do not reproduce the soil pressure for a uniform foundation displacement. Furthermore, MHI states that "The sum of the remaining spring constant values are decreased accordingly corresponding to the uplifted area and the spring constants per unit area of the stick model and the FE model are the same." This statement is technically invalid because the spring constants per unit area of the stick model and those in the uplifted area of the FE model are not the same. The applicant is requested to justify the validity of the approach used above, taking into account the fact that the spring constants per unit area of the stick model are not the same as the spring constants for the uplifted area of the FE model.

Reference: MHI response to RAI 340-2004, dated 7/3/2009, MHI Ref: UAP-HF-09363, ML091900557.

03.08.05-30

In its response to Part (a) of Question 3.8.5-9, MHI explains the intent of the wording in the DCD, and agrees that the last two sentences of the first paragraph in the DCD, Subsection 3.8.5.4.2 can be confusing. These sentences will be deleted in Revision 2 to the DCD. For Part (b) of the question MHI refers to their response to Question 3.7.2-13 of RAI 212-1950.

The staff finds the response for Part (a) to be acceptable.

For their response to Part (b) of the question MHI refers to their response to Question 3.7.2-13 of RAI 212-1950, Rev. 1 for the calculation of the horizontal forces. A review of this response to Question 3.7.2-13 was made. In that response, MHI presents a detailed description of how the lateral soil pressures are calculated and presents technical references to support their approach. However, for the US-APWR standard plant design, the water table is 1 ft below the nominal plant grade. So, for underground walls, the soil is submerged under water from 1 ft below the surface. The applicability of Wood's equation to calculate the dynamic soil pressure for the US-APWR standard plant is, therefore, questionable. The applicant is requested to provide numerical data to prove that the effect of water table is negligible and that Wood's equation can, in fact, be applied to the US-APWR standard plant. In the response to Question 3.7.2-13, MHI indicated that a paper by Veletsos and Younan demonstrated that Wood's solution was conservative. However, Veletsos and Younan's paper assumed $\sigma_z=0$ (the vertical component of the stress tensor) in their study and this assumption is questionable for the case when the vertical component of the seismic motion is considered. In order to support the claim based on this paper, the applicant is requested to show that the conclusion of that paper is also valid if the vertical component of the seismic motion is included, and that the effect of high water table is considered. In addition, Wood's solution does not consider the earth pressure due to the rotation of the wall at its base. The applicant is requested to provide data to show that this pressure is negligible.

References:
MHI response to RAI 340-2004, dated 7/3/2009, MHI Ref: UAP-HF-09363, ML091900557
MHI response to RAI 212-1950, dated 3/30/2009, MHI Ref: UAP-HF-09113, ML090930727

03.08.05-31

In its response to Part (a) of Question 3.8.4-12, MHI describes the changes made to both DCD Tier 1 and DCD Tier 2 regarding the maximum differential settlement of 2 in. in the reactor building (R/B) complex basemat. MHI explains that the value of 2 in. was obtained considering a soft soil site (shear wave velocity of 1,000 fps), and that the maximum differential settlement represents 1/3 of the estimated maximum settlement of the R/B complex foundation. In the response for Part (b) of the question, MHI states that forces and moments resulting from differential settlement are not combined with other load cases. They explain that the 2 in. maximum differential settlement was intended for use in sizing gaps between adjacent buildings, and that stresses due to this differential settlement are not critical for the design of the foundation basemat.

The applicant is requested to provide the following information:

1. In the response for Part (a) of the question, MHI states that "The specified maximum differential settlement represents one third (1/3) of the estimated maximum settlement of the R/B complex foundation." MHI is requested to provide the technical rationale for choosing 1/3 of the estimated maximum settlement for the differential settlement. Also, in the response, MHI stated that a value of 27.6 lb/in^3 representing the stiffness of the soft soil generic subgrade is used in short term settlement calculation and one half of this value, 13.8 lb/in^3, is used in the long term settlement calculation. MHI is requested to provide technical information and rationale to support the use of one half the value of the stiffness used in the short term settlement to calculate the long term settlement. The staff also notices that the value of 27.6 lb/in^3 used in the calculation of the short-term foundation settlement is taken from Table 2(c) given in the MHI's response to RAI 3.8.5-7 of this RAI, and that it represents the average of soil spring constant of the lump-mass model. As discussed in the evaluation of RAI 3.8.5-7, this average value is theoretically unsound, and is not accepted by the staff. The applicant is requested to address this issue.

MHI's response for Part (b) of the question is not acceptable. Even if the forces and moments due to the 2 in differential settlement are not critical to the design, these forces and moments need to be combined with the forces and moments due to other loads. The staff considers that foundation uplift and differential settlement are two additive events. MHI is requested to consider these as additive events or to provide the rationale and justification for why these loads should not be combined in the analysis.

Reference: MHI response to RAI 340-2004, dated 7/3/2009, MHI Ref: UAP-HF-09363, ML091900557.

03.08.05-32

In its response to Part (a) of Question 3.8.5-13, MHI points out that the COL Applicant is responsible to demonstrate the structural integrity of the basemat during construction. Settlement calculations are to be made at several stages of the construction including immediate settlement, dewatering, and when applicable, longer term settlement. If site-specific settlements exceed those in the DCD standard plant, the COL Applicant must demonstrate structural adequacy. For Part (b) of the question, MHI explains that settlement calculations are based on a "soft soil" site. For Part (c) of the question, MHI states that since the magnitude of the bearing pressures under surrounding structures is less than ½ that under the R/B complex, the effects of these are not considered. MHI points out that the layout of structures surrounding the R/B complex can vary with different sites. As a result, the COL Applicant is responsible to assure that effects of settlement of any surrounding structures do not compromise the structural integrity of the R/B complex or to important safety equipment.

The applicant is requested to provide the following information:

1. In the response(for Part (a) of the question, MHI states that "If the results of the site-specific settlement investigation indicate construction settlements that are larger than those considered during the standard design, or if the site-specific construction sequence is different than the expected construction sequence considered in the standard design, the COL Applicant must demonstrate that the standard design of the basemat reinforcement is sufficient to ensure the structural integrity of the basemat under the site-specific conditions." The staff agrees with MHI that the settlement needs to be checked. Per Subarticles CC-3561 and CC-3566 of ASME Section III, Division 2, the short term and long term settlements should be investigated. However, the staff is not able to find the allowable short term and long term displacements specified in the DCD. The applicant is requested to specify this information in the DCD for which the COL applicant is required to comply.

2. For Part (b) of the response, MHI indicated that the elastic subgrade coefficients of 27.6 lb/in3 and 13.8 lb/in3 are used in the calculations of the immediate settlement and long term settlement, respectively. As it has been discussed in the evaluation to the response to Question 3.8.5-12 of this RAI, these two coefficients are not acceptable to the staff. The applicant is requested to provide the rationale for using these coefficients.
3. For Part (c) of the response, MHI states that "The effects of the nearby structures are not considered in the analyses performed to address the effects of construction settlements on the standard design of the R/B complex common basemat. Since the magnitudes of the bearing pressure under the surrounding foundations are less than half of the bearing pressure under the common basemat of the R/B complex, it is reasonable to expect that for the majority of candidate sites their effect will not be significant." The staff is not convinced by the reason given for not considering the effects of nearby structures. The applicant is requested to provide numerical data to support the statement made above. In addition, the applicant is requested to consider the flip side of their

response, i.e., that the settlement of the surrounding foundations will be influenced by the common basemat because the bearing pressure under the common basemat is twice of the bearing pressure under the surrounding foundation. Is this effect considered for the standard plant design?

Reference: MHI response to RAI 340-2004, dated 7/3/2009, MHI Ref: UAP-HF-09363, ML091900557.

03.08.05-33

In its response to Question 3.8.5-17, MHI presents a formula used for calculating the shear (or sliding) resistance, F_s, along with a range of assumed variables used to calculate F_s.

The staff notices that MHI's explanation of how the shear (sliding) resistance, Fs, is calculated based on an assumed coefficient of friction between the bottom of the foundation basemats and the supporting soil. The resulting value using an angle of internal friction of 35 degrees is 0.7 for the coefficient of friction. However, the bottom of the foundation basemat is not in contact with the soil. It contacts with the fill concrete (see MHI's response to Question 3.8.4-1 of RAI 342-2000); therefore, the friction coefficient should be that of concrete to concrete. The applicant is requested to make this correction and provide the technical basis for the friction coefficient used. If the friction coefficient is different than 0.7, the factor of safety listed in the Table included in the MHI's response to Question 3.8.5-18 of this RAI should be updated.

References:
MHI response to RAI 340-2004, dated 7/3/2009, MHI Ref: UAP-HF-09363, ML091900557
MHI response to RAI 342-2000, dated 7/3/2009, MHI Ref: UAP-HF-09360, ML091900558

03.08.05-34

In its response to Part (a) of Question 3.8.5-19 MHI states that no special measures are taken to prevent concrete cracking at the interface between the 7000 psi and 4000 psi concrete. They will, however, adhere to provisions of American Concrete Institute (ACI) 224R where applicable. MHI claims that by assuring that adequate reinforcement exists at this interface is sufficient to control the cracking. In addition, this area is checked to assure that sufficient margin exists to account for creep and shrinkage stresses. For Part (b) MHI states that at the interface between the concrete governed by ASME Section III, Division 2, and concrete governed by ACI-349, the larger amount of reinforcement required by either code will apply. For Part (c) MHI explains the approach to separating primary and secondary stresses by stating that the primary stress case does not include thermal stress, while the secondary stress case does include thermal stress.

The staff finds MHI's responses for Parts (a) and (b) of the question to be acceptable. This conclusion is based on MHI's statement that they will follow provisions of ACI 224R for the massive concrete pours, and by assuring adequate reserve in the steel reinforcement to resist stresses due to creep and shrinkage, and that reinforcement at the juncture between concrete covered by ASME Code and concrete covered by ACI 349 will be based on the larger values that obtain from each of these codes..

However, the staff finds that MHI's response for Part (c) of the question is not acceptable. The classification of primary and secondary stresses depends on the location and type of stresses. See Table CC-3136.6-1 of ASME Section III Division 2 for more details. The applicant is requested to provide information that addresses the issue of classification of primary and secondary stresses as discussed above.

Reference: MHI response to RAI 340-2004, dated 7/3/2009, MHI Ref: UAP-HF-09363, ML091900557.

03.08.05-35

In its response to Question 3.8.5-22, MHI states that mix designs for any concrete below the foundations of the standard plant are determined by the COL Applicant on a site-specific basis. The DCD will be revised to state the use of "fill" concrete instead of "lean" concrete presently specified. Reference is made to MHI's response to Question 3.8.4-1 of RAI 342-2000 for a detailed description of the fill concrete. MHI states that the DCD will be revised (Revision 2) to indicate fill concrete in lieu of lean concrete, including COL 3.8(23) item that addresses this matter.

MHI's response states that the DCD will be revised to state that fill concrete rather that lean concrete will be used under the basemats for the standard plant design. The staff finds that a description of the fill concrete was given in MHI's response to Question 3.8.4-1 of RAI 342-2000, which response was found acceptable by the staff. However, as noted by the staff in that evaluation, it appeared that a COL item was needed to address the use of this fill concrete, and that MHI needed to add this COL item to the DCD. The applicant is requested to add a COL item to the DCD in which the COL Applicant is assigned the responsibility for the use of the fill concrete.

References:
MHI response to RAI 340-2004, dated 7/3/2009, MHI Ref: UAP-HF-09363, ML091900557
MHI response to RAI 342-2000, dated 7/3/2009, MHI Ref: UAP-HF-09360, ML091900558