RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

12/27/2013

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 1045-7141 REVISION 3**
SRP SECTION:	**03.08.05 – Foundations**
APPLICATION SECTION:	**3.8.5**
DATE OF RAI ISSUE:	**07/08/2013**

QUESTION NO. 03.08.05-51:

On April 3, 2013, the applicant submitted a markup of DCD Tier 2 Section 3.8 to provide updated information related to a seismic design change.

In Subsection 3.8.5.4.2, "Analyses for Basemat Loads during Operation," the fifth paragraph (page 3.8-98) states, "The results of the linear analysis are combined with the non-linear analyses to form the governing load combinations. The results from these analyses include the forces, shears, and moments in the basemat; the bearing pressures under the basemat; and the area of the basemat that is uplifted."

The applicant's method for analyzing the basemat loads during operation is not clear to the staff. The quoted paragraph indicates that there is one linear analysis and multiple non-linear analyses. The applicant is requested to provide the following information:

(1) Describe the linear and non-linear analyses methods and the associated computer codes used.

(2) How was the uplift of the basemat from the soil subgrade treated in the analysis?

(3) Provide an example to describe how the results of the linear analysis are combined with the non-linear analyses to form the governing load combinations, and how the reinforcement of the basemat is designed based on these governing load combinations.

ANSWER:

1) The Computer Code used for the basemat design analyses is ANSYS, Version 13.

   The model used in the analyses to support the basemat design has the same geometry as the ACS-SASSI model used in the Soil-Structure Interaction (SSI) analyses described in US-APWR DCD Chapter 3.7.2. The mesh of the basemat in the ANSYS finite element (FE) model used to design the basemat was enhanced by using 6 layers of elements in the area of the R/B Complex and 12 layers of elements in the pedestal area below the PCCV to increase the resolution in the section being designed. The soil below the basemat is modeled using solid elements and ANSYS surface to surface contact elements are used between the bottom of the basemat and the soil.

The basemat is designed to ASME Section III Division 2, 2001 Edition with addenda through 2003 design code. The design load combinations are identified in ASME Section III, Division 2, Table CC3230-1 and US-APWR DCD Table 3.8.1-2. The Load Cases associated with the Service and Factored loads require that the resulting forces and moments be identified and isolated to an individual load type to allow for the linear combination. This is accomplished by using linear material properties for the soil and concrete elements in the model. The design forces and moments obtained from the basemat linear model include: the associated pretension and pressure, as indicated in Table 1, all of which were applied from the superstructure to the basemat. The surface to surface elements between the soil and bottom of basemat were "bonded" together causing full load transfer without allowing uplift at the bottom of the basemat.

The normal operating and accident thermal was combined into service and emergency load combinations as indicated in Table 1. The thermal load was considered in a linear model that included the superstructure and the basemat. The support of the basemat of the previous mentioned model was modified to where only some of the center nodes at the bottom of the basemat (directly under the center of the PCCV) are fixed and the effects of soil are removed. This is done because the soil may impose artificial tensile forces on the basemat since the basemat and soil elements share bonded contact. This allows the basemat to move freely under the thermal loads while maintaining stability during the analysis. Therefore, more realistic forces induced by the thermal load case are determined and included in the representative load combinations.

The average seismic acceleration used in the analysis was obtained from the ACS-SASSI analyses and represent the average acceleration for each floor elevation in each of the structures common to the basemat. Average seismic accelerations for each elevation were obtained from MUAP-10006 and were applied in each axis at the nodal points in the superstructure; thus an equivalent static seismic force was applied to the basemat through the superstructure. The surface to surface contact elements were compression only elements which allow a gap to develop between the bottom of the basemat and the soil layer. Allowing the gap to develop simulates the effects of the lateral and vertical seismic loads that maximize uplift. The maximum seismically induced, equivalent static forces and moments were included in the load combinations depicted in Table 1.

The analyses were performed using linear material properties. The only non-linear component was the use of surface-to-surface contact elements in the seismic analyses to allow an unrestrained gap to develop between the soil and basemat concrete elements. Displacement was allowed using this approach and the resulting forces and moments were considered in the basemat design.

2) The uplift of the basemat from the soil subgrade was treated in the analysis as follows. The surface-to-surface contact elements used in this model make it possible to perform an uplift analysis. The contact elements used a "target surface" element (TARGE170), and a "contact surface" element (CONTA173) to form a contact pair between the foundation bottom and the top of the soil elements to simulate the separation/contact (uplift) of the foundation. The approach used was to first apply gravity (dead and live loads) and buoyancy loads to the model. The deformed geometry/stress is resumed and seismic induced loads are applied in the second load step using the ANSYS "RESTART" command at the end of the gravity load step (load step 1) to restart the analysis and input seismic loads in load step 2.

Three directional seismic loads, extracted from the SASSI analysis, are applied simultaneously using the Newmark 100-40-40 load combination methodology. A total of 24 load cases are developed by performing all the permutations of directional loads;

specifically, the eight combinations considering the reversal of sign of the seismic input component combined with the three sets of loads considering the 100-40-40 rule. The uplift analysis is made for each of the 24 load combinations.

3) The results of the analysis, including the affects of uplift, are combined into the load combinations presented in Table 1. The load combination that created the largest demand controlled and is included in the design. The 100-40-40 method of combining spatial components of seismic forces for design is used for the direction combination (24 CSDRS permutations) in the analysis of the Reactor Building (R/B) complex basemat. The seismic member forces are enveloped into four seismic cases represented in Table 1 by the "boxed areas". Maximum axial, bending and shear forces are enveloped for In-Plane and Out-of-Plane loading conditions which are considered independently in the design. The following four Force-Moment Interaction cases are considered to develop the governing load combinations.

   i) maximum positive axial force and maximum positive bending moment (Ess ++)
   ii) maximum positive axial force and maximum negative bending moment (Ess +-)
   iii) maximum negative axial force and maximum positive bending moment (Ess -+)
   iv) maximum negative axial force and maximum negative bending moment (Ess --)

   The corresponding out-of-plane shear forces are the shear forces generated from seismic load cases that maximize the total shear force when combined with the shear forces from the other load cases for each load case combination. Based on these governing load combinations, the required longitudinal reinforcement and radial/out-of-plane shear reinforcement is designed per ASME Section III Division 2, 2001 with 2003 addenda.

<u>3.7 and 3.8 Audit Clarification</u>

During the 3.7 and 3.8 Audits in September and November 2013, questions were received probing if different forces, moments, and deflections would be encountered if all loads were considered in non-linear analyses as opposed to linear approach. A separate confirmatory non-linear analysis was performed where all loads were included in the model that included surface-to-surface contact elements. Static loads including, dead, live, prestress, thermal, buoyancy and pressure were sequenced into the analysis as appropriate and results combined into the load combinations controlled by the ASME code. The dynamic seismic loads were obtained by transferring the results from the ACS-SASSI seismic response for two soil profiles, 2032-100 and 270-500 to the ANSYS model. The 100-40-40 approach was used to determine the design forces and moments with consideration to displacements. The basemat design was unaffected without code exceedance. The deflections and loading from the non-linear basemat model was also evaluated in the design of the superstructure above the basemat and the results are discussed in the response to RAI 1044-7140 Question 03.08.04-56.

Table 1: Load Combinations Used for R/B Complex Basemat Design (Approach 3)

Load Case Combination Input (Load Factor)														
		Primary											Secondary	
	Category	D	L	F_i	F_s	F_e	Pt	Pa	Ess ++	Ess +-	Ess -+	Ess --	To	Ta
LCC01	**Test**	1	1	0	1	0	1	0	0	0	0	0	1	0
LCC02	**Construction**	1	1	1	0	0	0	0	0	0	0	0	1	0
LCC03	**Normal**	1	1	0	0	1	0	0	0	0	0	0	1	0
LCC04	**Extreme**	1	1	0	0	1	0	0	1	0	0	0	1	0
LCC05	**Extreme**	1	1	0	0	1	0	0	0	1	0	0	1	0
LCC06	**Extreme**	1	1	0	0	1	0	0	0	0	1	0	1	0
LCC07	**Extreme**	1	1	0	0	1	0	0	0	0	0	1	1	0
LCC08	**Abnormal**	1	1	0	0	1	0	1.5	0	0	0	0	0	1
LCC09	**Abnormal/extreme**	1	1	0	0	1	0	1	1	0	0	0	0	1
LCC10	**Abnormal/extreme**	1	1	0	0	1	0	1	0	1	0	0	0	1
LCC11	**Abnormal/extreme**	1	1	0	0	1	0	1	0	0	1	0	0	1
LCC12	**Abnormal/extreme**	1	1	0	0	1	0	1	0	0	0	1	0	1

Uplift Evaluation

Static Loading (All others)

Where:

LC #	Category	Description
--	D	Dead Load
--	L	Live Load
--	F_i	Prestress (Initial Tensioning)
--	F_s	Prestress (Start-of-operation)
--	F_e	Prestress (End-of-operation)
--	Pt	Test Pressure
--	Pa	Accident Pressure
--	To	Operating thermal
--	Ta	Accident thermal
--	Ess	SSE
LCC01	Test	D + L + F_s + Pt + To
LCC02	Construction	D + L + F_i + To
LCC03	Normal	D + L + F_e + To
LCC04~07	Extreme	D + L + F_e + To + Ess
LCC08	Abnormal	D + L + F_e + 1.5Pa + Ta
LCC09~012	Abnormal/extreme	D + L + F_e + Pa + Ta + Ess

Impact on DCD

Refer to Attachment 1 for changes to Subsection 3.8.5.4.2.

Impact on R-COLA

There is no impact on the R-COLA.

Impact on PRA

There is no impact on the PRA.

Impact on Technical/Topical Report

There is no impact on a Technical/Topical Report.

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

The minimum allowable subgrade bearing capacity of 15,000 psf represents the maximum bearing pressures resulting from static load cases for the R/B complex common basemat, while the minimum allowable dynamic soil bearing capacity of 35,000 psf represents the maximum bearing pressure resulting from Normal plus SSE loads. These bearing pressures envelope the foundation bearing pressures for all other standard plant building structures.

3.8.5.4.2 Analyses for Basemat Loads during Operation

The major seismic category I structures basemat analyses use 3-D ANSYS FE models of the major seismic category I structures~~, which are~~ as described in Subsection 3.7.2.3. ~~Non-linear contact elements are used in the FE model to determine the interaction of the R/B complex basemat with the overlying structures and with the soil subgrade. The model is capable of determining the degree of uplift of the basemat from the soil subgrade in non-linear analyses.~~

The three-dimensional FE model of the basemat includes the structures above the basemat and their effect on the distribution of loads on the basemat. The combined global FE model of the R/B, PCCV, A/B, PS/Bs, and ESWPC including basemat, is presented on Figures 3.8.5-5 through 3.8.5-10.

The analysis considers normal and extreme environmental loads and containment pressure loads. The normal loads include dead loads and live loads. Extreme environmental loads include the SSE.

~~The dead loads and the SSE loads are applied as equivalent static accelerations to the nodes of the FE model. The live loads are applied to the surface of elements as static pressure. The SSE loads are applied as equivalent static loads.~~ The average seismic acceleration from the ACS-SASSI analyses was applied to each node of the FE model which included the dead load, live load as a static pressure, and buoyancy applied to the bottom of the basemat. The resulting equivalent static seismic force was transferred through the structure to the basemat. Surface-to-surface contact elements were included between the soil elements and the bottom of the basemat to allow a gap to develop capturing the vertical and lateral affects of seismically induced uplift in the basemat. The resulting maximum equivalent static forces and moments were in included in the load combinations. For the structural design of the R/B complex basemat concrete and reinforcement, the three directions of the earthquake loading are combined using the Newmark 100-40-40 method.

The results of the linear analysis are combined with the ~~non-linear~~ uplift analyses to form the governing load combinations. The results from these analyses include the forces, shears, and moments in the basemat; the bearing pressures under the basemat; and the area of the basemat that is uplifted. Minimum area of steel reinforcement is calculated from the section forces for the governing load combinations.

~~The required reinforcement for the R/B complex basemat is determined by considering the governing load from the combined linear and non-linear analyses.~~

3.8.5.4.2.1 Global Three-Dimensional FE Modeling of Basemat