RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

12/27/2013

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 340-2004 REVISION 0**
SRP SECTION:	**03.08.05 - Foundations**
APPLICATION SECTION:	**3.8.5**
DATE OF RAI ISSUE:	**04/21/2009**

QUESTION NO. 03.08.05-14:

In DCD Subsection 3.8.5.4.4, the fourth paragraph (Page 3.8-74) states, "Subsequent to the placement of the concrete foundation, walls, and containment internal structure, the basemat is significantly stiffened, minimizing any further tendency of differential settlement."

Placing concrete for walls and containment structures imposes additional loads on the concrete foundation (basemat), and may create additional settlement and differential settlement for the basemat.

The applicant is requested to:

(1) describe its analytical method used to calculate the settlement and differential settlements of the basemat with respect to the proposed construction sequences, and

(2) provide the curves of the basemat settlement vs. different stages of construction, and differential settlements of the basemat vs. different stages of construction, for the four types of soil conditions assumed in the DCD.

Use the curves/data provided in response to (2) above to substantiate the claim that "...the basemat is significantly stiffened, minimizing any further tendency of differential settlement."

ANSWER:

As discussed with the Nuclear Regulatory Commission (NRC) staff during the Design Certification Document (DCD) Tier 2, Section 3.8 Audit conducted on November 4-8, 2013, this answer revises and replaces the previous MHI answer that was transmitted by letter UAP-HF-13064 (ML13107B428). Additionally, as a result of the Public Meeting of October 31st, 2013, the Staff raised a question regarding "dishing" analysis, which is also answered below.

The settlement analysis for US-APWR Standard plant structures is performed in two phases:

<u>Phase 1 - Settlement analysis considering the entire structure:</u>

This phase is discussed below in part (A) of this answer and provided the following results:

1. Time dependent soil deformation moduli for the most deformable generalized layered subgrade profile (270-500), considering both predominantly sand sites and predominantly clay sites. The details of soil modulus calculations, accounting for the effects of primary consolidation (for clays) and viscous deformations (for sands) are presented in the answer to RAI 1045-7141, Question 03.08.05-59.

2. Plant settlements and differential settlements during operation are relevant to lifeline connections and equipment functionality. Details regarding the Finite Element (FE) model used in the analysis, the loads, the method to account for time dependent deformations in a linear elastic analysis, and considerations regarding the construction and the operational life of the plant are presented below, in part (A) of this answer.

Phase 2 - Settlement analysis considering sequential construction

In this phase, the settlements and differential settlements during construction of the plant are calculated considering a number of construction stages and different scenarios that include variations in common construction practice, and effects of reasonably large soil variability in the horizontal direction. Both sand sites and clay sites are considered, with deformation moduli calculated in Phase 1 as the secant equivalent elastic deformation moduli during the construction period. Including a significant part of the subgrade into the FE analysis allows accounting for dishing effects in the basemat.

This phase of settlement calculations will be performed, and final results are not available at this time to answer quantitatively the second part of the RAI question. The methodology proposed by MHI to address sequential construction and its effect on standard plant design is presented in part (B) of ths answer. This analysis will provide the following results:

1. Stresses and bending moments in the basemat and other parts of the structure for each case analyzed. These results will be enveloped over all construction phases and scenarios and reconciled with the values used in design.

2. Curves of the basemat settlements vs. different stages of construction, and differential settlements of the basemat vs. different stages of construction for the most deformable subgrade profile (270-500) to be used for developing a COLA monitoring program.

Part (A) - Phase 1 of settlement analysis, considering the entire structure

The three-dimensional finite element (FE) model developed in ANSYS and used for Phase 1 of settlement analysis includes the Reactor Building (R/B) Complex, the Turbine Building (T/B) and the Access Building (AC/B), placed on an extended volume of subgrade (3000 ft by 2400 ft in a horizontal plane, and 950 ft in depth) - see Figures 1 and 2 of the MHI response to RAI 1045-7141, Question 03.08.05-59. The AC/B is included as an equivalent mat modeling the weight of the structure. The extension of subgrade volume in the horizontal and vertical directions was established from the condition to eliminate any boundary effects on the analysis results. While the dead loads are applied gradually during the “time of construction”, the structures are considered with their full stiffness.

This phase of the settlement analysis considers a generic construction schedule, as follows (Figure 1):

a) **Excavation**. This phase is assumed to be completed in Te = 6 months,

b) **Construction**. The time of construction is taken in the settlement analysis as T_C = 38 months. This represents 44 months from first concrete to fuel filling minus four months for testing (hydro-tests, shakedown, etc.) and an additional two months for major pipe connection lock-in. The reason for excluding 6 months from construction time is explained below.

c) **Operation**. The operation life of the plant is considered T_L - T_C = 60.5 years, representing 40 years (standard plant commission period), plus 20 years (possible life extension), plus six months removed/eliminated from the construction time that are conservatively added to the operation time. T_L represents the total life of the plant, including construction and operation - see Figure 1.

Two categories of settlements are calculated: (1) Short term settlements, at the end of construction, and (2) long term settlements, at the end of the operational life of the plant. The displacements of interest for plant operation and especially for pipe connections are those occurring during operation. Therefore, for the purpose of this calculation, the end of construction is defined as the time when infrastructure and major equipment are in place, but before installing major pipe connections and backfilling around structures, i.e., end of construction in the settlement analysis is taken six months earlier that the actual end of construction.

The loading scenarios used for each structure along with the corresponding settlements are illustrated in Figure 1. There are different sets of loads acting during the life of the plant that contribute to short term and long term settlements:

- Dead Loads, applied during construction, and assumed to increase linearly from zero at the beginning of the construction period to their nominal value at end of construction.

- Live Loads, assumed to act with 25% of their maximum intensity considered for structural design (i.e., long term values), during the operational life of the plant (from end of construction to end of life).

- Weight of the backfill placed around the structures and acting during the operational life of the plant.

- Heave produced by stress reduction due to excavation that reduces settlements for clay soils (materials with large time-dependent deformations), and is accounted for by calculating an equivalent reduction in loads.

Variations in groundwater level including dewatering during construction induce settlement variations. Based on a sensitivity study it was concluded that, for the purpose of settlement calculations, it is conservative to assume the groundwater level below the basemat elevation.

Soil behavior is nonlinear and time dependent. Subgrade settlements consist of immediate settlements that occur at load application and are elastic-plastic, and time dependent settlements that develop in time under constant load (viscous deformations, primary consolidation settlements). To capture this relatively complex behavior with a linear elastic numerical model, the soil deformation moduli used in the model are calculated as secant equivalent elastic moduli at two significant moments in the plant's life: end of construction and end of life. These secant moduli are determined in an iterative process from the condition that the average settlements of each structure at end of life and end of construction obtained from the linear analyses are approximately equal with the corresponding settlements that account for time dependent deformability and are produced after a time T_C (for the construction phase) and after a time T_L (for the entire life of the plant). The method for secant (equivalent elastic) moduli calculation is presented in detail in the answer to RAI 1045-7141, Question 03.08.05-59.

The use of secant moduli for end of construction and end of life is illustrated in Figure 2. These moduli include the effects of both immediate and time dependent deformations produced up to end of construction or end of life and are calculated based on primary consolidation theory and viscous deformation analysis. The total deformations at end of construction at every location in each structure and the subgrade, δ_{EoC}, are calculated in a first three-dimensional FE analysis using secant moduli at end of construction, E_{EoC}, and loading during the construction phase. Similarly, the total deformations at end of life at every location, δ_{EoL}, are calculated in a second three-dimensional FE analysis using secant moduli at end of life, E_{EoL}, and loading during operation phase. The deformations produced during the operation life of the plant are obtained as the difference: $\delta_{EoL} - \delta_{EoC}$.

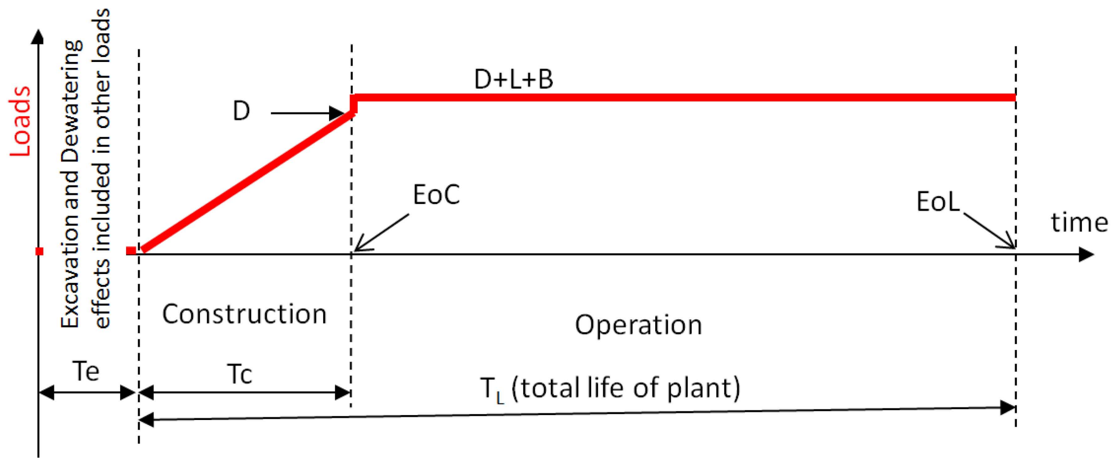

Figure 1. Timeline of Loading for Settlement Analysis. Notations: D = Dead Loads, L = Live Loads, B = Loads from Backfill.

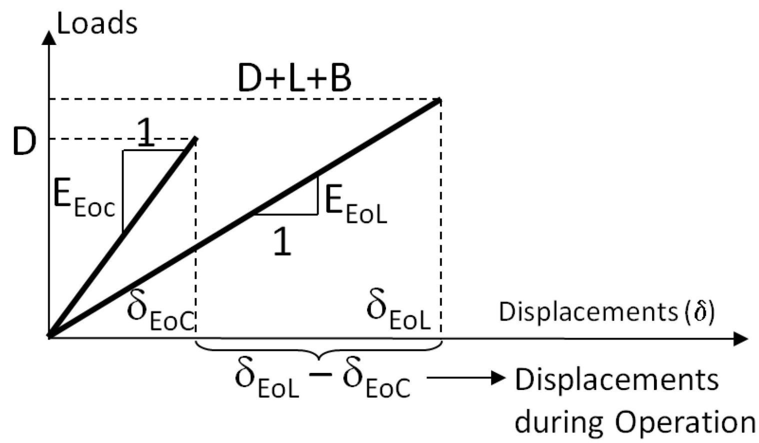

Figure 2. Secant Moduli for Settlement Analysis

The values of settlements and differential settlements calculated for the R/B complex at the end of construction and the end of life in Phase 1 of settlement calculations are listed in Table 1 for two different types of subgrade, namely predominantly sand and predominantly clay soils. Both types of subgrades correspond to the most deformable soil profile considered for the Standard Plant, namely profile 270-500 as identified in Design Control Document (DCD) Table 3.7.1-6.

Table 1. Settlement Analysis - Phase 1: Settlements, Differential Settlements and Tilt for the R/B Complex Placed on the Most Deformable Soil Profile (270-500)

Soil type	Time	Settlement (in)	Differential Settlement (in)(1)	Maximum tilt
Predominantly Sand layers	End of Construction(2)	3.1	2.2	1/2500
	End of Life	3.9	2.5	1/2300
Predominantly Clay layers	End of Construction(2)	6.0	3.8	1/1500
	End of Life	8.4	5.4	1/1065

Notes: (1) Differential settlement across the R/B complex basemat
(2) To be updated in Phase (2)

Part (B) - Phase 2 of settlement analysis, considering sequential construction

Construction sequence (or stages) including various scenarios will be considered, to account for the most demanding loading conditions. These calculations will be performed for the R/B Complex, using ANSYS and the 3D Finite Element (FE) model of the R/B Complex employed for settlement analyses in Phase 1 of the settlement calculations and described in the answer to Part (A) of this question. For each scenario, the construction stages will be added sequentially into the analysis. The main features of this phase of settlement calculations are:

1. Subgrade:
   - The analysis will be performed for the most deformable subgrade profile (270-500) that induces the largest settlements and stresses in the basemat.
   - The subgrade will be represented by continuum finite elements, to ensure capturing dishing and Bousinesque effects. A sufficiently large volume of subgrade will be included in the analysis to avoid any effects of the FE mesh boundaries.
   - Two different soil types will be considered in the upper 500 feet of the subgrade: predominantly granular soil and predominantly cohesive soil.
   - The subgrade moduli during construction will be calculated as described in the answer to RAI 1045-7141, Question 03.08.05-59, accounting for time dependent phenomena (such as primary consolidation and creep).
   - Possible presence of stiff and soft spots in the foundation will be considered in order to maximize the bending moments used for mat design by considering three different scenarios for soil stiffness variation in the horizontal direction.
2. Loads attributable to construction including dead loads, heave due to excavation and construction sequence will be assessed.
3. Construction stages, sequences and scenarios (three soil stiffness scenarios - uniform, soft spot, hard spot - will be considered for each construction stage/scenario):
   - Stage 1: Bottom half of basemat (to elevation -33’-0”) - one stage and one construction scenario (sequences and timing are not important in this stage for stresses and settlements)
   - Stage 2: Upper half of basemat (between elevations -33’-0” and -26’-4”) - 10 sequences (see Figure 3), 3 scenarios (sequentially inward, sequentially outward, and random construction)
   - Stage 3: Superstructure, from elevation -26’-4” to elevation -8’-7” - 4,…,5 sequences, 2 scenarios
   - Stage 4: Superstructure, from elevation -8’-7” to elevation 3’-7” - 4,…,5 sequences, 2 scenarios

- Stages 5 to 9: additional 5 stages (one sequence, one scenario each) to complete construction

4. Expected results:
   - Curves of settlements and differential settlements of the basemat vs. different stages of construction. These curves will be included in the DCD to be used by the COL Applicant for verification purposes in conjunction with predictive calculations associated with the actual construction sequence and with a settlement monitoring program
   - Stresses due to construction developed in the Standard plant basemat and in the Seismic Category I structures (PCCV, CIS, R/B, PS/Bs and ESWPC) - to be included with the stresses used for design

Based on the analysis results, specific COL action items and acceptance criteria will be included in the DCD, as interface considerations between DC and COL.

As a result of the Public Meeting of October 31st, 2013, the following additional question was raised: Has MHI performed or will MHI perform "dishing" analysis for the basemat? If not, why not?

ANSWER: MHI will perform dishing analysis for the basemat. As described before, in Part (B) of the answer, a significant part of the subgrade will be included into the FE analysis domain, with the subgrade represented by continuum finite elements, to ensure capturing dishing effects. The iterative procedure for estimating the secant equivalent elastic moduli mentioned in Part (A) of the answer and presented in detail in the answer to RAI 1045-7141, Question 03.08.05-59, includes the effect of local settlements on the secant modulus values.

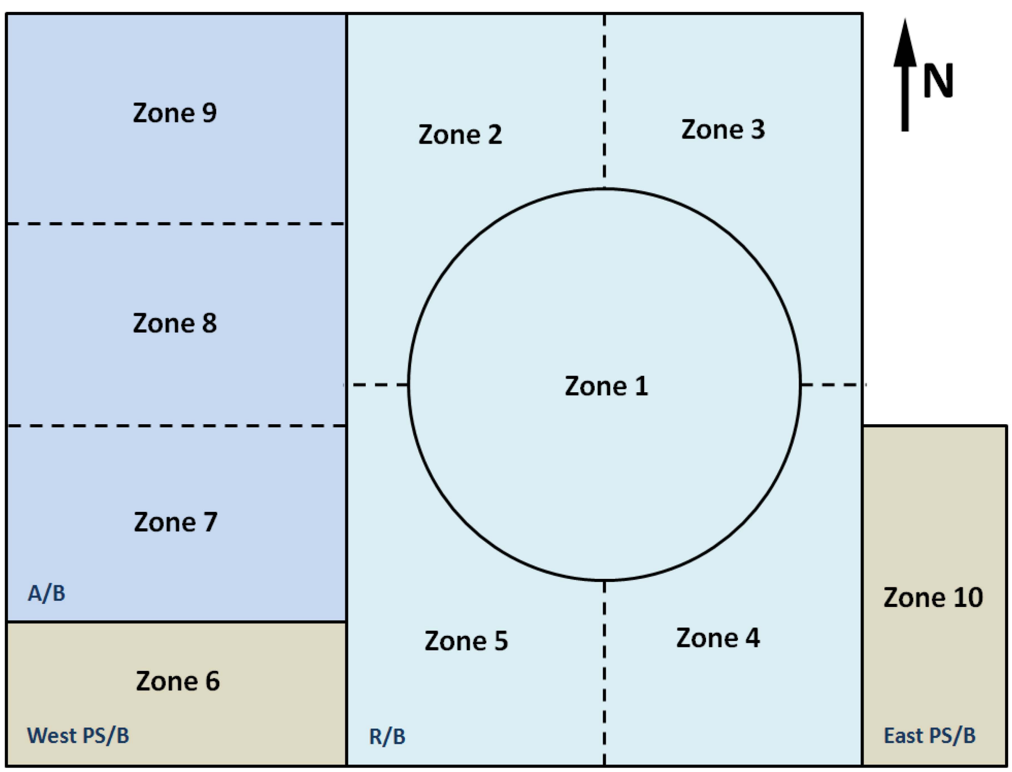

Figure 3. Example of Basemat Concrete Placement Zones (Sequences) between Elevations -33'-0" and -26'-4" (Zone Numbering corresponds to Sequentially Outward Construction)

Impact on DCD

There is no impact on the DCD at this time. The DCD will be updated as necessary, as outlined above, when Phase 2 settlement calculation results are fully available.

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.