RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

3/27/2014

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	NO. 960-6709 REVISION 4
SRP SECTION:	03.07.02 – Seismic System Analysis
APPLICATION SECTION:	3.7.2
DATE OF RAI ISSUE:	09/24/2012

QUESTION NO. 03.07.02-216:

Section 4.0 of MHI's TR MUAP-12002 (R0), "Sliding Evaluation and Results," describes the methodology utilized to perform the sliding stability analyses. To assist the staff in evaluating whether the assumptions and modeling approach are consistent with the guidance in SRP Section 3.8.5; and can predict the magnitude of the sliding response, the staff requests the applicant to provide the following additional information:

a) In Section 4.1, "Assumptions," under Assumption number 1, the applicant stated that sliding is assumed to occur in some cases under safe-shutdown earthquake (SSE) but did not identify those cases. The applicant is requested to identify those cases and provide the basis for the assumption.

b) In Section 4.1, under Assumption number 2, the applicant indicated that it is assumed that a small amount of sliding will not modify the ground motion in the vicinity of the basemat. The applicant is requested to provide a quantitative measure of "small amount of sliding." The applicant also stated that, "this assumption is the accepted industry practice for such analyses." The applicant is requested to provide appropriate basis and references to demonstrate the industry practice for such analyses and that it has been accepted by the staff.

c) Regarding the use of the time histories from the SASSI soil-structure interaction (SSI) analyses and applying them in all three directions, the applicant is requested to provide a technical basis and justification for neglecting the rocking motions in relation to the two horizontal axes.

d) Since the soil ground motions from the SASSI SSI analysis is proposed to be used in the lumped-mass stick model (LMSM) sliding stability analysis, the dynamic characteristics between these two models should be consistent or conservative in the LMSM approach. Therefore, the applicant is requested to explain whether the ground motions from the SASSI SSI analyses to be used as input to the LMSM analyses will be based on the embedment case with no connection between the building side wall foundation and the vertical edge of the side soil or based on the connected case. In addition, the applicant is requested to confirm that the two model dynamic characteristics (SASSI and LMSM) are equivalent or that the more conservative ground motion (side soil/wall connection vs. no side soil/wall connection) will be used.

e) Based on the description presented in Sections 4.2.3 and 4.3 of the TR, the subgrade is modeled as a rigid surface and the basemat is modeled as a rigid surface. Contact elements are used between these two surfaces. The applicant is requested to discuss how the effect of dead weight is included in the nonlinear analysis to consider the potential uplift of the basemat; and to provide a technical basis and justification for the sliding stability model and the analysis results.

f) Assumption 4 in the TR indicates that embedment effects (active and passive pressures) are neglected during sliding. The applicant is requested to explain how the effects of surcharge loads due to adjacent structures will be considered in the sliding stability analyses.

g) The applicant in Assumption 5 stated that the maximum ground water level is considered for the sliding analysis. The applicant is requested to justify this assumption and demonstrate that the maximum ground water level case is conservative and will result in the minimum factor of safety (i.e., maximum seismic sliding force and minimum resistance).

h) Assumption 6 in the TR indicates that, “Dynamic soil pressures acting on basement walls before the initiation of sliding are assumed to be compensated by the difference between static and kinetic friction forces acting at the basemat level.” Section 4.2.4 of the TR also discusses this item; however, it is not clearly explained. Therefore, the applicant is requested to describe this behavior, explain how the effects of these pressures are considered to be compensated by the difference between static and kinetic friction forces, and describe how this assumption is conservative and will be demonstrated, as stated in Section 4.2.4 of the TR.

ANSWER:

As discussed with the Nuclear Regulatory Commission (NRC) staff during the Design Certification Document (DCD) Tier 2, Section 3.7.1, 3.7.2, and 3.7.3 Audit conducted in September 23-27, 2013, this answer revises and replaces part b) to the previous MHI answer that was transmitted by Letter UAP-HF-13096 (ML13135A089).

b) The Standard Review Plan 3.8.5 (September 2013) states in Section II-4-B point 5 that: “If the input motion applied at the foundation of a structural model without the soil is developed from the response of the linear SSI analysis, justification is needed to demonstrate that any minimal sliding or uplift would not affect the assumed seismic input motion taken from the SSI analysis that does not consider any sliding and uplift.” This method (namely using the input motion obtained from SSI analysis in a time history non-linear sliding analysis) is used by MHI to demonstrate sliding stability. It is therefore understood that the NRC staff accepted this method, providing that minimal sliding will not affect this input motion and produce under-conservative results.

Regarding industry acceptance, Reference 1 presents a comprehensive review of the methodologies generally accepted by the industry practice for nonlinear sliding analysis:

1. The decoupled method (e.g. References 2, 3), which uses a dynamic analysis based on displacement continuity (i.e. no sliding allowed) to calculate the equivalent seismic loading throughout the structure, and a second analysis in which the equivalent load time history is used to calculate the seismic induced sliding. In this case, the seismic motion applied to the structure in the second analysis (obtained assuming displacement continuity) may be slightly different from the real motion that may be affected by small sliding.

2. The fully coupled method (e.g. References 4 to 6) that captures in one single analysis the dynamic response of the sliding mass and the nonlinear stick-slip sliding response at the interface with the subgrade. This is the most accurate approach, but involves computational resources that are unfeasible for the structures considered by MHI.

The non-linear sliding analysis used by MHI is a combination of decoupled and fully coupled analyses. The calculation is performed in two steps: The first step, assuming displacement continuity, provides the base input acceleration for the second step. The second step is a coupled analysis, in the sense that the dynamic response of the structure and the nonlinear sliding are captured in a single analysis. It is therefore considered that the method used by MHI is included within the methods accepted by the industry, and it is expected that the results, in terms of sliding, provided by the MHI method would range between the results of a decoupled and a fully coupled analysis.

Regarding the issue of decoupling, resulting in some sliding that may affect the input motion obtained assuming displacement continuity, it will be demonstrated in the remaining of this answer that, for the range of parameters corresponding to the sliding analyses performed by MHI, the decoupled method provides the same, or ever larger sliding, than the coupled method, and therefore the method used by MHI does not produce under-conservative results.

The effect of the methodology for nonlinear sliding analysis on the calculated sliding was investigated by a series of authors. Based on these studies it was concluded that the decoupled approximation provides, in general, conservative results. More recent studies concluded, however, that decoupled analyses may provide non-conservative results for certain situations involving systems with low values of the yield acceleration and high characteristic periods.

Bray and Rathje (2000), Reference 7, present the results of a parametric study on the effect of analysis method on calculated sliding. The study covers a large range of parameters, including:

- Threshold acceleration ratio, k_y/k_{max}, ranging between 0.05 and 0.9, where $k_y g$ is the inertial coefficient corresponding to a pseudo-static factor of safety for sliding equal to one and $k_{max}g$ is the maximum earthquake acceleration in the plane of sliding (g is the acceleration of gravity).

- Period ratio, T_s/T_m ranging between zero and 5, where T_s is the fundamental period of the sliding mass, and T_m is the fundamental period of the earthquake ground motion (defined in equation (1) of Reference 7).

- Total sliding between 0.1cm (0.04in) and 100cm (40in).

The study presented in Reference 7 was originally intended for sliding earth masses. However, the range of parameters addressed in the study is quite large and includes characteristics corresponding to building structures. It will be demonstrated that this range also includes the parameters used in the nonlinear sliding analyses of the US-APWR standard plant structures. Moreover, the nonlinear sliding analysis method used by MHI is a combination of the two methods compared in the study. Therefore this study is relevant for discussing the effect of sliding analysis method on the computational results.

The values corresponding to the parameters used in Reference 7 are discussed below. These values are calculated for the subgrade profile 900-200 and Nahanni acceleration time history - that resulted in the largest sliding for the R/B complex, and for subgrade profile 2032-100 and Hector Mine acceleration time history - that resulted in the largest sliding for the T/B. Both cracked and uncracked sections are considered for the R/B complex. Only the uncracked section is considered here for the T/B - as discussed in Section 5.3.2.3 of Technical Report MUAP 12002, Rev. 1, the uncracked section governs sliding for the T/B.

The parametric study results are presented in terms of these two parameters in Figures 10c and 12a of Reference 7, that are reproduced here as Figures 1 and 2, respectively. The markings in blue indicate results corresponding to the R/B complex with cracked and uncracked section, and the markings in red indicate results corresponding to the T/B.

Figure 1 shows the differences between coupled and decoupled analysis results obtained in the parameter study presented in Reference 7 as a function of the ratio between the dominant period of the structure and the dominant period of the seismic input motion. The markers relevant for US-APWR are the full markers, corresponding to maximum horizontal accelerations (MHA) smaller than 0.5g. For the parameters corresponding to the R/B complex (and indicated by blue arrows) all the results in the parameter study indicate that the decoupled analysis is conservative (i.e., the sliding calculated in a decoupled analysis, $U_{decoupled}$, is larger than the sliding calculated in a coupled analysis, $U_{coupled}$). For the parameters corresponding to the T/B the difference between coupled and decoupled analysis results is about zero.

Figure 2 shows the differences between coupled and decoupled analysis results obtained in the parameter study presented in Reference 7 as a function of the ratio between the threshold acceleration and the maximum horizontal ground acceleration. For the parameters corresponding to the R/B complex (and indicated by a blue arrow) the difference between coupled and decoupled analysis results is about zero. For the parameters corresponding to the T/B, and indicated by a red arrow, all the results in the parameter study indicate that the decoupled analysis is conservative. It can be therefore concluded that, for the cases relevant to US-APWR structures and seismic input accelerations, the decoupled analysis is either slightly conservative or provided close results to the coupled analysis.

For the R/B complex, the parameters relevant to the study and used in Figures 1 and 2 (namely k_y/k_{max} and T_s/T_m) have been calculated for all subgrade profiles and all input acceleration time histories. The ranges of these parameters for the rock profiles (900-200, 900-100 and 2032-100) that dominate sliding are indicated in Figures 1 and 2 by blue shaded areas, and are:

- Between 0.52 and 0.64 for k_y/k_{max}
- Between 0.24 and 0.47 for T_s/T_m

The comparisons presented in Figures 1 and 2 support the conclusion that, for the range of parameters used in the MHI sliding analyses, the decoupled method provides similar or slightly conservative results in terms of sliding as compared to the fully coupled method.

REFERENCES

1. Bray J.D. (2007). Simplified seismic slope displacement procedures. Chapter 14 in *Proc. Earthquake Geotech. Eng., 4th Int. Conf. on Earthquake Geotech. Eng. - Invited Lectures*, K.D. Pitilakis, ed., Vol. 6, Springer, New York, p. 327-353.
2. Makdisi, F. and Seed, H. (1978). Simplified procedure for estimating dam and embankment earthquake-induced deformations, *J. Geotechnical Engineering, ASCE*, 104(7):849-867.
3. Bray J.D., Rathje, E.M., Augello, A.J. and Merry, S.M. (1998). Simplified seismic design procedures for geosynthetic-lined, solid waste landfills. *Geosynthetics International*, 5(1-2):203-235.
4. Chopra, A.K. and Zhang, L. (1991). Earthquake-induced base sliding of concrete gravity dams. *J. Structural Engineering*, *ASCE*, 117(12):3698-3719.
5. Rathje, E.M. and Bray, J.D. (1999). An examination of simplified earthquake-induced displacement procedures for earth structures. *Canadian Geotechnical J.*, 36:72-87.
6. Bray, J.D. and Travasarou, T. (2007). Simplified procedure for estimating earthquake-induced deviatoric slope displacement. *J. Geotechnical and Geoenvironmental Eng., ASCE,* 133(4):381-392.
7. Rathje, E.M. and Bray, J.D. (2000). Nonlinear coupled seismic sliding analysis of earth structures. *J. Geotechnical and Geoenvironmental Eng., ASCE,* 126(11):1002-1014.

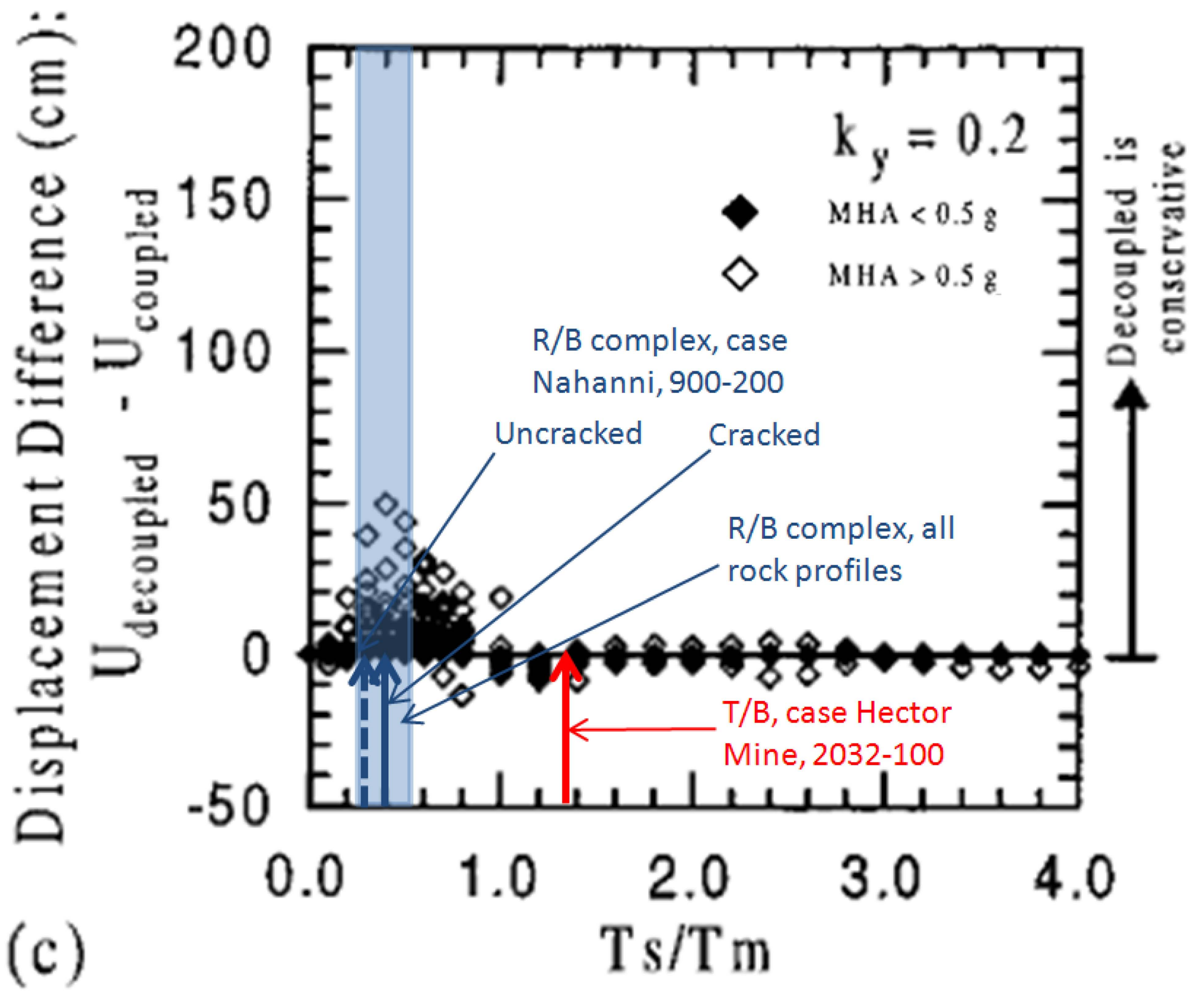

Figure 1. Displacement difference between decoupled and coupled analysis versus T_s/T_m, for k_y = 0.2 (modified after Figure 10c of Reference 7)

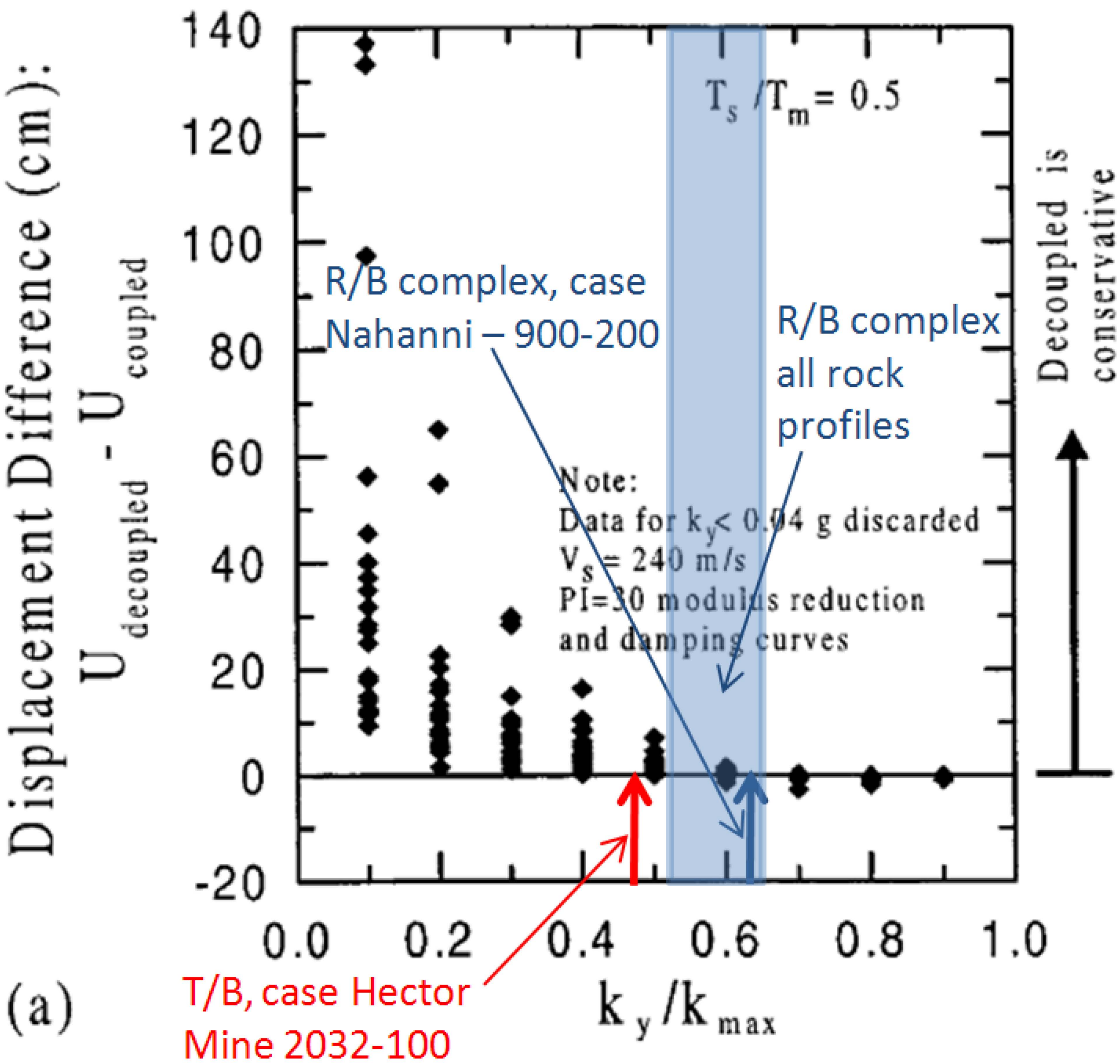

Figure 2. Displacement difference between decoupled and coupled analysis versus k_y/k_{max}, for T_s/T_m = 0.5 (modified after Figure 12a of Reference 7)

Impact on DCD

There is no impact on the DCD.

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 the technical Report. However, the report is being revised per the Seismic Closure Plan to address this issue.

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