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TOKYO, JAPAN

March 30, 2009

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Attention: Mr. Jeffery A. Ciocco

Docket No. 52-021
MHI Ref: UAP-HF-09113

Subject: MHI's Responses to US-APWR DCD RAI No. 212-1950

Reference: 1) "Request for Additional Information No. 212-1950 Revision 1, SRP Section: 03.07.02 – Seismic System Analysis, Application Section: 03.07.02," dated 2/25/2009.

With this letter, Mitsubishi Heavy Industries, Ltd. ("MHI") transmits to the U.S. Nuclear Regulatory Commission ("NRC") a document entitled "Response to Request for Additional Information No. 212-1950, Revision 1."

Enclosed are the responses to 13 RAIs contained within Reference 1. Of the RAIs in Reference 1, 15 will not be answered within this package. They are;

RAI 3.7.2-01, which has a 60-day response time, as agreed to between the NRC and MHI, and will be issued at a later date by a separate transmittal.

RAI 3.7.2-03, which has a 60-day response time, as agreed to between the NRC and MHI, and will be issued at a later date by a separate transmittal.

RAI 3.7.2-05, which has a 60-day response time, as agreed to between the NRC and MHI, and will be issued at a later date by a separate transmittal.

RAI 3.7.2-06, which has a 60-day response time, as agreed to between the NRC and MHI, and will be issued at a later date by a separate transmittal.

RAI 3.7.2-12, which has a 60-day response time, as agreed to between the NRC and MHI, and will be issued at a later date by a separate transmittal.

RAI 3.7.2-13, which has a 60-day response time, as agreed to between the NRC and MHI, and will be issued at a later date by a separate transmittal.

RAI 3.7.2-14, which has a 60-day response time, as agreed to between the NRC and MHI, and will be issued at a later date by a separate transmittal.

RAI 3.7.2-15, which has a 60-day response time, as agreed to between the NRC and MHI, and will be issued at a later date by a separate transmittal.

RAI 3.7.2-16, which has a 60-day response time, as agreed to between the NRC and MHI, and will be issued at a later date by a separate transmittal.

RAI 3.7.2-17, which has a 60-day response time, as agreed to between the NRC and MHI, and will be issued at a later date by a separate transmittal.

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RAI 3.7.2-18, which has a 60-day response time, as agreed to between the NRC and MHI, and will be issued at a later date by a separate transmittal.

RAI 3.7.2-19, which has a 60-day response time, as agreed to between the NRC and MHI, and will be issued at a later date by a separate transmittal.

RAI 3.7.2-20, which has a 60-day response time, as agreed to between the NRC and MHI, and will be issued at a later date by a separate transmittal.

RAI 3.7.2-24, which has a 60-day response time, as agreed to between the NRC and MHI, and will be issued at a later date by a separate transmittal.

RAI 3.7.2-27, which has a 60-day response time, as agreed to between the NRC and MHI, and will be issued at a later date by a separate transmittal.

Please contact Dr. C. Keith Paulson, Senior Technical Manager, Mitsubishi Nuclear Energy Systems, Inc. if the NRC has questions concerning any aspect of this submittal. His contact information is provided below.

Sincerely,

Y. Ogata

Yoshiki Ogata,
General Manager- APWR Promoting Department
Mitsubishi Heavy Industries, LTD.

Enclosure:

1. Responses to Request for Additional Information No. 212-1950, Revision 1

CC: J. A. Ciocco
C. K. Paulson

Contact Information
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Enclosure 1

UAP-HF-09113
Docket No. 52-021

Responses to Request for Additional Information No. 212-1950, Revision 1

March, 2009

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

3/30/2009

US-APWR Design Certification

Mitsubishi Heavy Industries

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SRP SECTION:	**03.07.02 – Seismic System Analysis**
APPLICATION SECTION:	**03.07.02**
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QUESTION NO. RAI 3.7.2-2:

In section 3.7.2.2 of the DCD it is stated that the results obtained from the seismic analysis of the coupled model are reconciled, as necessary, with those results obtained from the current seismic analysis. Provide clarification to this statement and provide details of the various seismic analysis (e.g., current) being referenced.

ANSWER:

The results obtained from comparison of two sets of seismic response analyses form the basis for the seismic design of the Reactor Building (R/B), Prestressed Concrete Containment Vessel (PCCV), Containment Internal Structure and their common basemat foundation. The first set of analyses was performed on the uncoupled model (i.e., "current" as described in Subsection 3.7.2 and Appendix 3H of the DCD). A second set of subsequent analyses was performed on the coupled model and documented in Technical Report MUAP-08005 (R0) "Dynamic Analysis of the Coupled RCL-R/B-PCCV-CIS Lumped Mass Stick Model". The results of the seismic analyses of the uncoupled model serve as the basis for development of the equivalent static seismic design loads for design of the building structural members. For clarity, Subsections 3.7.2.2 and 3.7.2.3.2 of the DCD will be revised to delete the reference to the "current" analysis. The results of the seismic analyses of the coupled model are also used for development of the In-Structure Response Spectra (ISRS) that define the seismic design loads for design of Category I and II subsystems and components as stated in DCD Subsection 3.7.2.5. The ISRS presented in Appendix 3I of the DCD that are obtained from the uncoupled model analyses will be replaced with the ISRS obtained from the analyses of the coupled model that will be provided in response to Question 3.7.2-8 of this RAI.

As described in Section 3.7.2 of the DCD, the seismic responses of the R/B, PCCV and containment internal structure are analyzed using the direct integration time history method, lumped mass stick models and lumped soil-structure interaction parameters to simulate the effects of interaction of the common basemat with the subgrade. The two models used for the seismic response analyses differ in that the stiffnesses of the Reactor Coolant Loop (RCL) are included in the coupled model and excluded from the uncoupled model. The uncoupled model only considers the mass of the RCL that is lumped at the corresponding nodal mass points. Since both the mass and stiffness of the RCL structure contribute to the seismic response, the coupled model provides a better representation of the seismic response of the building by capturing the effects of interaction (coupling) between the RCL structure and the building structures.

Tables 3H.3-1 to 3H.3-3 of DCD Appendix 3H and Tables 8-1 to 8-3 of Technical Report MUAP-08005 provide the fixed base dynamic properties of the uncoupled model and coupled model, respectively. The comparison of the ISRS obtained from the coupled model analyses, presented in Figures 8-1, 9-2 and 8-3 of Technical Report MUAP-08005, with the ISRS obtained from the uncoupled model analysis, presented in Appendix 3I of the DCD, show that the coupling mainly affects the local response of the structures at higher modes of vibration. The results for maximum accelerations and displacements presented in Appendix 3H of the DCD and Technical Report MUAP-08005 show that the effect of RCL coupling on the overall response of the building is not significant.

Therefore, the results of member forces obtained from the uncoupled model analyses are initially used as the basis for development of equivalent static seismic design loads to design the structural members. The magnitudes of the seismic design loads are increased to consider accidental torsion as specified in Subsection 3.7.2.11 of the DCD and also introduce additional margin of safety in the design. The equivalent static seismic design forces are then applied in conjunction with other design loads to a detailed finite element model of the R/B, PCCV and Containment Internal Structure on their common basemat foundation to obtain the design demands for each individual structural member as described in Section 3.8 of the DCD.

The effect of the RCL coupling on the structural members' design is evaluated by comparing seismic design forces used to design the structural members to those enveloped member forces obtained from the coupled model analyses. The comparison of the member forces results obtained from the coupled model analyses and the seismic design forces that are presented in Tables 8-9 and 8-10 of Technical Report MUAP-08005 provides the available design margins. At each floor elevation of the structures, the available design margins at each horizontal direction are compared with the corresponding maximum torsional increase factor for that floor elevation. If the maximum torsional increase factor is higher than the available design margin, the design of the structural members is modified to ensure that all structural members are designed to meet the demands calculated by the coupled model analysis.

Impact on DCD

See Attachment 1 for a mark-up of DCD Tier 2, Section 3.7, Revision 2, changes to be incorporated.

- Delete the first paragraph of Subsection 3.7.2.2 in it's entirety.

- Change the first sentence in the second paragraph of Subsection 3.7.2.2 to: "The seismic analysis and structural design of the R/B, PCCV, and containment internal structure and their common basemat are based on a combined lumped mass stick model consisting of three lumped mass stick models (for each of the three structures) that are all rigidly cross-connected at the surface of the common basemat, as discussed further below in Subsection 3.7.2.3.

- Add the following at the end of second paragraph of Subsection 3.7.2.2: "As discussed in a Technical Report (Reference 3.7-18), seismic analysis of the R/B, PCCV, and containment internal structure and their common basemat is also performed on a coupled model that consists of a detailed RCL lumped mass stick model coupled with a combined R/B-PCCV-containment internal structure lumped mass stick model. The results obtained from the seismic analysis of the coupled model are reconciled, as necessary, with those results obtained from the seismic analysis of the un-coupled model. The seismic analysis of the coupled model is also used to develop ISRS as discussed in Subsection 3.7.2.5."

- Delete the first paragraph of Subsection 3.7.2.3.2 in its entirety.

- Change the second paragraph of Subsection 3.7.2.3.2 to:

  "The seismic analysis and structural design of the R/B, PCCV, and containment internal structure and their common basemat is based on a combined lumped mass stick model consisting of three lumped mass stick models (for each of the three structures) that are all rigidly cross-connected at the surface of the common basemat. Included in this combined model is the calculated mass of the RCL seismic subsystem, which is conservatively rounded up by 20% and distributed proportionately to the appropriate model nodes based on the mass distribution of the RCL system. This is considered a conservative approach for the seismic analysis and design of the R/B, PCCV, and containment internal structure and their basemat because the round-up compensates for uncertainties in the mass distribution and potential effects due to coupling of the RCL subsystem, such as shifts or changes in natural frequency and response modes. Appendix 3H presents the detailed model descriptions, seismic analysis results, and the associated tables and figures that are particular and specific to the uncoupled RCL approach used for the R/B, PCCV, and containment internal structure. Similarly, Appendix 3C presents the analytical methods and modeling approaches used for the uncoupled RCL seismic subsystem analysis. Seismic analysis of the R/B, PCCV, and containment internal structure and their common basemat is also performed using a coupled model that consists of a detailed RCL lumped mass stick model coupled with the combined R/B-PCCV-containment internal structure lumped mass stick model, as documented in a separate Technical Report (Reference 3.7-18). The results obtained from the seismic analysis of the coupled model are reconciled, as necessary, with those results obtained from the seismic analysis of the un-coupled model."

See Attachment 2 for a mark-up of DCD Tier 2, Section 3.7, Revision 2, changes to be incorporated.

- Change Reference 3H-1 in Section 3H.4 of Appendix 3H to the following:

  "3H-1 <u>Dynamic Analysis of the Coupled RCL-R/B-PCCV-Containment Internal Structure Lumped Mass Stick Model</u>, MUAP-08005, Mitsubishi Heavy Industries, Ltd., April 2008."

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

3/30/2009

US-APWR Design Certification
Mitsubishi Heavy Industries
Docket No. 52-021

RAI NO.:	**NO. 212-1950 REVISION 1**
SRP SECTION:	**03.07.02 – Seismic System Analysis**
APPLICATION SECTION:	**03.07.02**
DATE OF RAI ISSUE:	**02/25/09**

QUESTION NO. RAI 3.7.2-4:

SRP Sections 3.7.2.I.2 and 3.7.2.II.2 A and B state that ISRS at support locations of Seismic Category I equipment should be provided. Section 3.7.2.3.10.1 indicates that the in-structure response spectra (ISRS) are extracted from the lumped mass models at arbitrarily selected nodes that represent main floor levels. Provide the criteria used to select the locations of the ISRS shown in Appendices 3H and 3I and References 3.7-18 and 3.7-33. If the ISRS presented are used solely for model validation, provide the ISRS corresponding to Seismic Category 1 equipment support points.

ANSWER:

The ISRS referred to in Section 3.7.2.3.10.1 are extracted from the stick models at lumped mass node points of the main floor levels, and have been presented for purposes of validation of the uncoupled model only, as discussed in the responses to Questions 3.7.2-09 and -10 of this RAI. The ISRS used for the design of seismic Category I equipment are derived from the coupled model at equipment support point locations, and are to be provided as discussed in response to Question 3.7.2-08 of this RAI.

Impact on DCD

There is no impact on the DCD.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

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QUESTION NO. RAI 3.7.2-7:

Section 3.7.2.8 of DCD indicates that structure-to-structure interaction effects will be further addressed if warranted by specific site conditions. Describe the methodology and acceptance criteria that will be used to determine if structure-to-structure interaction analysis is required and how the analysis will be performed if required.

ANSWER:

The total bearing pressure under the common basemat foundation of the R/B, PCCV, and containment internal structure is by far the largest among all of the foundations of the US-APWR standard plant, thus indicating that the seismic responses of the smaller buildings surrounding this foundation will be the most affected by structure-to-structure interaction. The influence that the foundation of the R/B, PCCV, and containment internal structure has on the free-field motion around the building is to be computed by site-specific soil-structure interaction analysis and used to quantify the significance of the structure-to-structure interaction (SSI) effects for particular site-specific conditions. The site-specific SSI analysis of the R/B, PCCV, and containment internal structure on a common mat will provide results for the response of the site in the vicinity of the foundations where other seismic category I and II structures are located. Transfer functions are to be generated that show how the presence of the R/B, PCCV, and containment internal structure foundation affects the free-field motion at locations of other foundations for particular frequencies. The results obtained from the site-specific SSI analysis for 5% damped acceleration response spectra are to be compared with the corresponding foundation input response spectra (FIRS) that define the site-specific design ground motion of the worst affected surrounding building. If the acceleration response spectra calculated from the site-specific SSI analysis of the R/B, PCCV, and containment internal structure on their common mat are significantly different than the corresponding FIRS, then site-specific SSI analysis of the affected building must be performed to address the structure-to-structure interaction. This can be accomplished by including the mass inertia properties of the surrounding buildings into the SSI model.

The above discussion is the intent of DCD COL Item 3.7(10).

Impact on DCD

There is no impact on the DCD.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

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QUESTION NO. RAI 3.7.2-8:

SRP Section 3.7.2 II.3.C (iii) states that local vibration modes should be adequately represented in the dynamic response model in order to ensure that the in-structure response spectra include the additional amplification. Discuss how the spectra (horizontal and vertical) for each of the lumped mass stick models described in the DCD and in References 3.7-18 and 3.7-33 were benchmarked, validated, or otherwise determined to have sufficient resolution to adequately represent the local dynamic response of the structure being modeled.

ANSWER:

ISRS considering local vibration modes and the description of the analysis method will be provided in Revision 2 of the DCD.

Impact on DCD

ISRS which incorporate the effects of local vibration modes and the description of the analysis method are to be provided in DCD Tier 2, Section 3.7, Revision 2.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

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QUESTION NO. RAI 3.7.2-9:

Section 3.7.2.5 of the DCD indicate that the ISRS for the Seismic Category 1 structures and design spectra for the RCL system are required to be developed from a coupled model of the RCL-R/B-PCCV-CIS. However, it appears that the spectra that form the basis for the standard plant design are from Appendix 3I of the DCD, which is based on an uncoupled model rather than from the results of the coupled model that are documented in the technical report MAUP-08005, April 2008 (Ref. 3.7-18). Describe the role of the two models and how the results (forces, displacements, accelerations, ISRS) from each of the models were used in the US-APWR standard plant design. Clarify whether the coupled or uncoupled model is the basis for the seismic analysis and design of the standard plant.

ANSWER:

The two models used for the seismic response analyses differ in that the stiffness of the Reactor Coolant Loop (RCL) is included in the coupled model and excluded from the uncoupled model that only considers the mass of the RCL that is lumped at the corresponding nodal mass points. Since both the mass and stiffness of the RCL structure are relatively significant, the coupled model provides a better representation of the seismic response of the building and forms the basis for the seismic design of the Reactor Building (R/B), Prestressed Concrete Containment Vessel (PCCV), Containment Internal Structure and their common basemat foundation.

The seismic analyses of the coupled model, documented in Technical Report MUAP-08005 (R0) "Dynamic Analysis of the Coupled RCL-R/B-PCCV-CIS Lumped Mass Stick Model", are used for development of the In-Structure Response Spectra (ISRS) that define the seismic design loads for design of Category I and II subsystems and components. The ISRS presented in Appendix 3I of the DCD that are obtained from the uncoupled model analyses will be replaced with the ISRS obtained from the analyses of the coupled model as discussed in the response to RAI 3.7.2-8. Further discussion of the ISRS used for design of SSCs is provided in the responses to questions 3.7.2-4 3.7.2-8, 3.7.2-10, and 3.7.2-11 of this RAI. The envelope of the maximum displacements results listed in Tables 8-11 to 8-14 that are obtained from the seismic response analyses of the coupled model for the four generic site conditions, are adopted as the maximum displacements used for the design of the plant.

Impact on DCD

Refer to Impact on DCD for Questions RAI 3.7.2-2 and RAI 3.7.2-8 of this RAI for changes that are applicable to this response.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

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QUESTION NO. RAI 3.7.2-10:

Section 3.7.2.5 of the DCD indicates that the ISRS for the Seismic Category I structures and design spectra for the RCL system are to be developed from a coupled model of the RCL-R/B-PCCV-CIS. Appendix 3I of the DCD describes the uncoupled lumped mass stick model of the RCL-R/B-PCCV-CIS and Ref. 3.7-18 in the DCD describes the coupled lumped mass stick model of the RCL-R/B-PCCV-CIS. Describe the criteria used to support the conclusion in Section 9.0 of the technical report for coupled model, MAUP-08005, April 2008 (Ref. 3.7-18) that no significant differences were observed in the results between the coupled RCL-R/B-PCCV-CIS model and the uncoupled R/B complex model. It is noted that in some cases, the spectral accelerations from the coupled model are higher than those from the uncoupled model (which appears to have been used as the design basis). For example, the ISRS at the frequency of 10 Hz in the north-south direction at PCCV (El 50'-2") has a peak value of 1.9g and 1.3g from the coupled and uncoupled model respectively. This difference of 46% at the frequency of design interest is significant. Provide a comparison of the ISRS from the coupled and uncoupled models. From this comparison, provide justification for the ISRS selected for the standard plant design basis.

ANSWER:

The values obtained from the RCL coupled lumped mass stick model define the basis for design of the seismic Category I SSCs because the RCL coupled lumped mass stick model provides a more accurate representation of the actual dynamic properties of the structures. ISRS are obtained from the coupled model which have peak values at higher frequencies that are lower than those obtained from the uncoupled model, but these differences are not more than 15%. The differences are due to local coupling effects on the dynamic properties of the structures at higher modes of vibrations that do not have a significant effect on the overall response of the building.

The peak value of the ISRS for the PCCV N-S direction at frequencies above 10 Hz is 1.9 g for the RCL coupled lumped mass stick model (MUAP-08005, Figure 8-1, Sheet 2 of 33), and 1.7 g for the RCL uncoupled lumped mass stick model (DCD Appendix 3I, Revision 1, Figure 3I-1, Sheet 2 of 31) respectively. This difference indicates the local coupling effect that influenced the response of PCCV structure at the higher second mode of vibration defined at the frequency of 12.9 Hz as shown in Table 8.2 of MUAP-08005 and Table 3H.3-2 of DCD Appendix 3H.

The analysis of the coupled lumped mass stick model also yielded lower peak values of the ISRS representing the response of containment internal structure in the N-S direction at a frequency close to 9 Hz. For example, MUAP-08005 Figure 8-1, Sheet 19 of 33 shows for the coupled model an approximately 12% smaller peak value at a frequency of 9 Hz than that for the uncoupled lumped mass stick model presented in Appendix 3I, Figure 3I-1, Sheet 18 of 31, of DCD Revision 1. This difference reflects the local effect of coupling on the dynamic properties of the containment internal structure that can also be observed by comparing the results from the fixed base analyses of the coupled model presented in Table 8-3 of MUAP-08005 and Table 3H.3-3 of DCD Appendix 3H. Similar to the PCCV, the coupling with the RCL affects the higher second mode of vibration of the containment internal structure lumped mass stick model.

Impact on DCD

There is no impact on the DCD.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

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QUESTION NO. RAI 3.7.2-11:

Section 3.7.2.5 of the DCD indicates that the ISRS for the Seismic Category 1 structures and design spectra for the RCL system are to be developed from a coupled model of the RCL-R/B-PCCV-CIS. Table 3H.3-4 of the DCD and Table 8-4 of Ref. 3.7-18 show differences in the modal properties for the coupled and uncoupled lumped mass stick models of the R/B-PCCV-CIS for the case of soil with a 6,500 ft/s shear wave velocity (the last two rows of the Tables show different frequencies and participation factors). Explain how the results from these two tables are used and what impact the differences will have on the ISRS for the US-APWR standard plant design.

ANSWER:

Table 3H.3-4 of the DCD and Table 8-4 of Technical Report MUAP-08005 (R0) summarize the results from the modal analysis of the uncoupled and coupled models with linear and rotational springs attached to the common basemat foundation representing the lumped soil-structure interaction (SSI) stiffness of various supporting subgrades. As described in DCD 3.7.2.1, the direct integration time history analyses performed on the coupled and uncoupled models to obtain the seismic response of the Reactor Building (R/B), Prestressed Concrete Containment Vessel (PCCV), Containment Internal Structure does not actually use the results of the modal analyses. The direct integration method does not require decoupling of the differential equations of motion as with the mode superposition method and thus does not rely on the results of the modal analysis as an input. Therefore, the tables that list the frequencies and modal participation factors for the modes characterizing the response of the basemat foundation serve solely as indicators of the possible effects of different SSI stiffness on the dynamic properties of the combined dynamic system. Attachment 3I of the DCD and Figures 8-1, 8-2 and 8-3 of Technical Report MUAP-08005 present the ISRS obtained from the coupled model and uncoupled model analyses, respectively. The comparison of the ISRS results obtained from the two analyses at locations that are most sensitive to SSI effects do not indicate any significant differences in the response of the basemat.

The modal participation factors listed in Table 8-4 of Technical Report MUAP-08005 quantify the significance of the particular mode of vibration on the response of the system in specific direction. The effects of the modes representing the torsional response of the multi-degree system are small and difficult to quantify their significance based on the modal participation factors. The torsional modes of response are also difficult to detect if they couple with horizontal response and. The values presented in Table 3H.3-4 of the DCD and Table 8-4 of Technical Report MUAP-08005 only provide reference values.

The ISRS results obtained from the uncoupled model analyses and coupled model analyses for locations RE01, CV01 and CIS01 are not significantly different. Therefore, these ISRS representing the response of the building at locations that are close to the basemat suggest that there are no significant differences in the response of the basemat. The ISRS developed from the two sets of analyses for locations RE04, RE41, RE42 and FH06 representing the response of the North and South portions of the R/B also are almost identical and indicate no differences in the torsional response of the basemat.

Impact on DCD

There is no impact on the DCD.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

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QUESTION NO. RAI 3.7.2-21:

In Tier 1 Table 2.1-1 and Tier 2 Table 2.0-1 of the DCD, it specifies maximum ground water level is 1ft below plant grade; however the SSI analysis discussed in section 3.7.2.4 is based on four soil profiles that are all linear elastic half-space uniform dry materials (no layer and water table considered). Provide justification for not considering soil layering and location of water table in the SSI analysis.

Also, clarify the last paragraph in Section 3.7.2.4 of the DCD. What model is used for SSI analysis that takes into account the site-specific conditions? What does the lumped parameter model consists of - a stick model of a building on layered soil media, or a stick model that uses lumped impedance parameters for the soil? If it is the former, how are the damping characteristics of the layered media compared to impedance function values?

ANSWER:

Frequency-dependent SSI effects such as soil layering, water table depth and foundation embedment, is accounted for in the SSI analysis by the complex response method and sub-structuring technique utilized in the ACS-SASSI program. As described in Subsection 3.7.2.4.1, the COL Applicant verifies the standard design by comparing the site-specific SSI analysis results for the in-structure response spectra (ISRS) at lumped mass locations with the corresponding standard design ISRS presented in Appendix 3I of the DCD.

The site-specific SSI validation analyses use a model of standard plant structures supported by a flexible foundation resting on a layered subgrade. A three-dimensional model, consisting of beam and shell finite elements representing the structures and solid finite elements representing the soil, is used to determine the dynamic properties of the below grade portion of the building embedded in layers of soil. The lumped mass stick model that extends above plant grade, which is also used for the standard design analysis, is imported into the ACS-SASSI to represent the above grade portion of the building. To assure the proper comparability, the site-specific verification SSI analyses must use the same verified and validated lumped mass stick models as those used for the US-APWR standard design certification process. The SSI analysis uses site-specific profiles of stiffness and damping properties of the subgrade materials that are compatible with the strains generated by the site-specific design earthquake

The variations of site properties considered in the standard design by the four general subgrade conditions documented in DCD Section 3.7.2.4 are deemed sufficient to account for the uncertainties introduced in calculations of the seismic response of the structures due to the water table depth. The four profiles, which are all linear elastic half-space models, represent a range of properties that could actually consist of dry materials or materials with a water table present. For example, the shear wave velocity (V_s) and Poisson's ratio (ν) of the lower bound ("soft soil") general subgrade condition and upper bound ("hard rock") general subgrade condition have corresponding P-wave velocity values which envelope the value for the P-wave velocity in water, 5,000 ft/s. In any case, it is required that the depth of the water table must be considered on a site-specific basis when developing the P-wave velocities of the submerged subgrade materials, as described in Section 3.7.2.4.1.

Provided that the site-specific SSI analysis demonstrates that the response of the four standard plant profiles envelopes the site-specific SSI responses and in-structure response spectra, then it can be concluded that the standard plant design is conservative for use at a specific site. Historically, only a site-specific SSI analysis would have been required. Further, it is not necessary to consider soil layering (or damping characteristics) in the standard plant analysis because of the site-specific commitment to confirm conservatism of the responses in the COLA. The requirement for ACS-SASSI analysis of the R/B-PCCV-containment internal structure on a common mat, in order to address site-specific conditions, is covered by COL Item 3.7(25) and the requirement to address/consider site-specific conditions is also collectively addressed by COL Items 3.7(2), 3.7(20) 3.7(22), and 3.7(23).

Impact on DCD

There is no impact on the DCD.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

3/30/2009

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 212-1950 REVISION 1**
SRP SECTION:	**03.07.02 – Seismic System Analysis**
APPLICATION SECTION:	**03.07.02**
DATE OF RAI ISSUE:	**02/25/09**

QUESTION NO. RAI 3.7.2-22:

The last two paragraphs of Section 3.7.2.4.1 of the DCD describe a criterion under which a fixed-base analysis is acceptable per ASCE 4-98. The staff has not reviewed and endorsed ASCE 4-98 for this application. Currently this ASCE standard is under revision. Provide bases and technical justification for the criterion. Discuss how the proposed criterion meets the provision of SRP Section 3.7.2.II.4 for assuming a fixed-base condition.

ANSWER:

Section 3.7.2.4.1 provides requirements for site-specific soil-structure interaction (SSI) analyses to be performed by the COL Applicant. Since the staff has not reviewed and endorsed ASCE 4-98 with respect to the criterion for performing a fixed-base analysis, for this application the DCD will be revised to delete the ASCE 4-98 criterion and replace it with the criterion given in SRP 3.7.2.II.4 for fixed base analysis.

Impact on DCD

See Attachment 1 for the mark-up of DCD Tier 2, Subsection 3.7, Revision 2, changes to be incorporated.

- Replace the last two paragraphs of Section 3.7.2.4.1 with the following:

  "In accordance with SRP 3.7.2 (Reference 3.7-16), Section II.4, fixed base response analysis can be performed if the basemats are supported by subgrades having a shear wave velocity of 8,000 ft/s or higher, under the entire surface of the foundation."

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

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QUESTION NO. RAI 3.7.2-23:

In Section 3.7.1.1 of the DCD it is stated that the essential service water pipe tunnel (ESWPT), the power source fuel storage vaults (PSFSVs), and the ultimate heat sink related structures (UHSRS) are Seismic Category I buildings and structures, but are not included as part of the standard plant. Provide a detailed description of the seismic input, modeling procedure, and seismic analysis methods for each of the structures in order to review their adequacy in accordance with the SRP section 3.7.2 guidelines.

ANSWER:

The ESWPT, PSFSVs, and UHSRS configuration, orientation, and layout, and their interfaces with the standard plant, are greatly dependent on site-specific parameters such as the site-specific source of plant cooling water, depth of bedrock (if not a soil site), depth of embedment, depth of foundation with respect to other structures, and tornado loadings. The configuration, orientation, and layout may differ greatly among COLA plants. For example, a lake or bay may be used instead of an ultimate heat sink basin structure. Provision is made in the DCD to accommodate the interface of these structures with the standard plant where such interface locations are well-defined. For example, DCD Sections 3.7.2.8 and 3.7.3.7 describe the interface of the ESWPT with standard plant structures. However, because the exact configuration, orientation, and layout of the ESWPT, PSFSV, and UHSRS are greatly dependent on site conditions, the Tier 2 DCD therefore specifies, in various COL items in Sections 3.7 and 3.8, that these structures are to be designed by the COL Applicant on a site-specific basis. COL Item 3.7(21) is a general requirement which obligates the COL Applicant to perform the seismic design of these structures. COL Items 3.8(15) and 3.8(19) are also general requirements that obligate the COL applicant to perform the structural and seismic design of the ESWPT, PSFSVs, and UHSRS. COL Items 3.7(5), 3.7(24), and 3.7(30) provide requirements for the COL Applicant with respect to seismic input, including development/verification of seismic input motion. COL Items 3.7(3), 3.7.3(4), 3.7(10), 3.7(22), and 3.7(26) provide requirements for the COL Applicant with respect to seismic analysis methods and modeling, including requirements for soil structure interaction and structure-to-structure interaction analysis. The detailed descriptions of the seismic input, modeling procedure, and seismic analysis methods for the ESWPT, PSFSVs, and UHSRS are provided and documented by the COL Applicant for each new US-APWR reactor on a site-specific basis in the respective COLA. For example, the seismic input, modeling procedure, and seismic analysis methods for the ESWPT, PSFSVs, and UHSRS are described in detail in the COLA for new US-APWR Units 3 and 4 at Comanche Peak. It is therefore anticipated that the NRC review of the adequacy of each of those structures in accordance with SRP Section 3.7.2 guidelines with respect to seismic input, modeling procedure, and seismic analysis methods, will be performed on a site-specific basis during the NRC review of the respective COLA.

Impact on DCD

There is no impact on the DCD.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

3/30/2009

US-APWR Design Certification
Mitsubishi Heavy Industries
Docket No. 52-021

RAI NO.:	**NO. 212-1950 REVISION 1**
SRP SECTION:	**03.07.02 – Seismic System Analysis**
APPLICATION SECTION:	**03.07.02**
DATE OF RAI ISSUE:	**02/25/09**

QUESTION NO. RAI 3.7.2-25:

Provide a list of the buildings and structures that will be analyzed for site-specific soil-structure interaction effects and indicate the method of SSI analysis for each –finite element or impedance approach.

ANSWER:

The following buildings and structures will be analyzed for site-specific soil-structure interaction effects, with method of SSI analysis as noted.

Building/Structure and Seismic Classification	Method of Site-Specific SSI Analysis/Remarks	Basis for Response
Reactor Building, PCCV, and containment internal structure on a common foundation basemat (seismic Category I)	SASSI Finite Element A site-specific SSI analysis is required unless otherwise justified by the COL Applicant.	DCD Tier 2 Subsection 3.7.2.4.1 and COL Item 3.7(25)
Power Source Buildings (PS/Bs) (seismic Category I)	No site-specific SSI analysis is required unless the COL Applicant determines based on site-specific conditions that structure-to-structure interaction needs to be included in the seismic response analysis. See also the response to Question 3.7.2-7 of RAI 212-1950. In the case that site-specific SSI is determined to be	DCD Tier 2 Subsection 3.7.2.3.3, COL Item 3.7(10), and MHI Document MUAP-08002 Rev. 0

	necessary, the method of site-specific SSI analysis is to be determined by the COL Applicant.	
Essential Service Water Pipe Tunnel (ESWPT) (seismic Category I)	SASSI Finite Element	The SASSI finite element method is required by DCD Tier 2 Subsection 3.7.2.8.3. See also Section 3.7 COL Items 3.7(26) and 3.7(10).
Power Source Fuel Storage Vaults (PSFSVs) (seismic Category I)	The method of site-specific SSI analysis is to be determined by the COL Applicant.	DCD Tier 2 Section 3.7, and COL Items 3.7(26) & 3.7(10)
Ultimate Heat Sink Related Structures (UHSRS) (seismic Category I)	The method of site-specific SSI analysis is to be determined by the COL Applicant.	DCD Tier 2 Section 3.7, and COL Items 3.7(26) & 3.7(10)
Auxiliary Building (seismic Category II)	No site-specific SSI analysis is required unless the COL Applicant determines based on site-specific conditions that structure-to-structure interaction needs to be included in the seismic response analysis. See also the response to Question 3.7.2-7 of RAI 212-1950. In the case that site-specific SSI is determined to be necessary, the method of site-specific SSI analysis is to be determined by the COL Applicant.	DCD Tier 2 Section 3.7, and COL Items 3.7(26) & 3.7(10)
Turbine Building (seismic Category II)	No site-specific SSI analysis is required unless the COL Applicant determines based on site-specific conditions that structure-to-structure interaction needs to be included in the seismic response analysis. See also the response to Question 3.7.2-7 of RAI 212-1950. In the case that site-specific SSI is determined to be necessary, the method of site-specific SSI analysis is to be	DCD Tier 2 Section 3.7, and COL Items 3.7(26) & 3.7(10)

	determined by the COL Applicant.	

See also the response to Question 3.7.2-23 of this RAI for further information regarding site-specific SSI analyses of the ESWPT, PSFSVs, and UHSRS.

Impact on DCD

There is no impact on the DCD.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

3/30/2009

US-APWR Design Certification
Mitsubishi Heavy Industries
Docket No. 52-021

RAI NO.:	**NO. 212-1950 REVISION 1**
SRP SECTION:	**03.07.02 – Seismic System Analysis**
APPLICATION SECTION:	**03.07.02**
DATE OF RAI ISSUE:	**02/25/09**

QUESTION NO. RAI 3.7.2-26:

Section 3.7.2.7 of the DCD presents equations for two grouping methods for combining modal responses in a response spectrum method of analysis. However, the nomenclature and equations in the DCD appear inconsistent with those in RG 1.92, Rev. 1 and Rev. 2. Demonstrate that the equations given in the DCD are equivalent to those in RG 1.92, or else explain the differences between the approaches and provide justification for the proposed approach.

ANSWER:

It is the intent of the US-APWR DCD to always meet the requirements of RG 1.92 Revision 2 or Revision 1 (where permitted by Revision 2) for combining modal responses. As stated in the third paragraph of Section 3.7.2.7, when response spectra methods of analysis are used, the combination of modal responses is done by one of the methods in Regulatory Guide 1.92 Revision 2 or by the 10% grouping method (as contained in Revision 1 of RG 1.92 and as permitted in Revision 2 of RG 1.92). In some applications, the more conservative methods contained in Revision 1 of RG 1.92 are also used as permitted in Revision 2 of RG 1.92.

The two grouping method equations in DCD Section 3.7.2.7 for combining modal responses will be revised in DCD Revision 2 to be consistent with regulatory positions C1.2.1 and C1.2.2 of the RG 1.92 Revision 1.

Impact on DCD

See Attachment 1 for the mark-up of DCD Tier 2, Subsection 3.7, Revision 2, changes to be incorporated.

- Change the fourth paragraph in Subsection 3.7.2.7 to the following:

  "For the grouping method, the total unidirectional seismic response for subsystems is obtained by combining the individual modal responses using the SRSS method for frequencies spaced more than 10%."

- Change the sixth paragraph in Subsection 3.7.2.7 to the following:

  "The combined total response for systems having such closely spaced modal frequencies is obtained by adding to the SRSS of all modes the product of the responses of the modes in each group of closely spaced modes."

- Change the equation under seventh paragraph of Subsection 3.7.2.7 to the following:

$$R^2 = \sum_{k=1}^{N} R_k^{\,2} + \sum_{q=1}^{P} \sum_{l=i}^{j} \sum_{m=i}^{j} \left| R_{lq} \cdot R_{mq} \right| \qquad l \neq m$$

- Change the definitions of variables for the equation under seventh paragraph of Subsection 3.7.2.7 to the following:

R	=	total unidirectional response
R_k	=	the peak value of the response due to the kth mode
R_{lq}, R_{mq}	=	are the modal responses, R_l and R_m within the q^{th} group
N	=	total number of modes considered
P	=	number of groups of closely spaced modes
i	=	lowest modal number associated with group q of closely spaced modes
j	=	highest modal number associated with group q of closely spaced modes

- Change the first sentence of the eighth paragraph in Subsection 3.7.2.7 to the following: "Alternatively, a more conservative ten percent grouping method can be used in the seismic response spectra analyses."

- Change the equation under eighth paragraph of Subsection 3.7.2.7 to the following:

$$R^2 = \sum_{k=1}^{N} R_k^{\,2} + 2\sum \left| R_i R_j \right| \qquad i \neq j$$

- Change the definitions of variables for equation under the eighth paragraph of Subsection 3.7.2.7 to the following:

  "The second summation is to be done on all i and j modes whose frequencies are closely spaced to each other."

- Change the ninth paragraph in Subsection 3.7.2.7 to the following:

  "All terms for the modal combination remain the same as defined above."

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

3/30/2009

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 212-1950 REVISION 1**
SRP SECTION:	**03.07.02 – Seismic System Analysis**
APPLICATION SECTION:	**Section 3.7.2**
DATE OF RAI ISSUE:	**02/25/09**

QUESTION NO. RAI 3.7.2-28:

Based on the information in Section 3.7.2.12 of the DCD, it appears that the DC Applicant may have misinterpreted the intent of SRP Section 3.7.2.II.12. The SRP acceptance criteria state that if both the time history analysis method and the response spectrum analysis method are used to analyze an SSC, the peak responses obtained from these two methods should be compared, to demonstrate approximate equivalency between the two methods. The DC Applicant should clearly state whether any SSCs are analyzed using both the time history method and the response spectrum method, and document the comparisons of the two methods.

ANSWER:

The US-APWR standard plant building structures are dynamically analyzed using only the time history method of analysis. Therefore, comparison of the responses between the response spectrum method and the time history method is not applicable.

Impact on DCD

See Attachment 1 for a mark-up of DCD Tier 2, Section 3.7, Revision 2, changes to be incorporated.

- Change the last sentence in the second paragraph of Subsection 3.7.2.12 to: "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, is not applicable."

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

This completes MHI's responses to the NRC's questions.

Analyses of seismic category I and II subsystems are primarily performed using equivalent static load analysis or modal response spectra analysis. The input seismic loads are defined by ISRS that are obtained from the time history analyses of the major seismic category I buildings and structures. Seismic subsystems are discussed in Subsection 3.7.3, and the modal response spectra and equivalent static load analysis methods are discussed in Subsection 3.7.3.1.

Seismic anchor motions are taken into consideration for all seismic analysis methods used in the design of seismic category I and seismic category II SSCs. All analysis approaches have been based on linear elastic analysis of SSCs, with allowable stresses within the elastic limits for seismic loads and load combinations as delineated in Section 3.8. Except in limited cases where permitted by code, inelastic behavior is not considered for seismic loads and load combinations in performing the plant design, however, limited inelastic and nonlinear behavior for seismic loading conditions may be used for site-specific COL designs, future operability analyses or as-built evaluations, as permitted in SRP 3.7.2 (Reference 3.7-16). Nonlinear and inelastic behavior is considered for certain loads and load combinations involving impact and impulsive loading, as discussed in Subsection 3.8.4.

3.7.2.2 Natural Frequencies and Responses

~~As discussed further below in Subsection 3.7.2.3, the seismic analysis and design of the R/B, PCCV, and containment internal structure and their common basemat are based on a coupled model that consists of a detailed RCL lumped mass stick model coupled with a combined R/B-PCCV-containment internal structure lumped mass stick model. The seismic analysis of the RCL-R/B-PCCV-containment internal structure coupled model is the subject of a Technical Report (Reference 3.7-18). The results obtained from the seismic analysis of the coupled model are presented in the report and reconciled, as necessary, with those results obtained from the current seismic analysis.~~

The ~~current~~ seismic analysis and structural design of the R/B, PCCV, and containment internal structure and their common basemat are based on a combined lumped mass stick model consisting of three lumped mass stick models (for each of the three structures) that are all rigidly cross-connected at the surface of the common basemat, as discussed further below in Subsection 3.7.2.3. The natural frequencies and modal responses for the combined R/B-PCCV-containment internal structure model (which includes the masses of the RCL system but is not coupled with the RCL lumped mass stick model) are presented in Appendix 3H. As discussed in a Technical Report (Reference 3.7-18), seismic analysis of the R/B, PCCV, and containment internal structure and their common basemat is also performed on a coupled model that consists of a detailed RCL lumped mass stick model coupled with a combined R/B-PCCV-containment internal structure lumped mass stick model. The results obtained from the seismic analysis of the coupled model are reconciled, as necessary, with those results obtained from the seismic analysis of the un-coupled model. The seismic analysis of the coupled model is also used to develop ISRS as discussed in Subsection 3.7.2.5.

It should be noted that the results obtained from the seismic analysis of the lumped mass stick models are obtained considering the potential effects of SSI. The site-independent SSI analyses, which are discussed further in Subsection 3.7.2.4, consider four generic subgrade conditions: (1) soft soil with shear wave velocity V_s = 1,000 ft/s, (2) rock (medium 1) with V_s = 3,500 ft/s, (3) rock (medium 2) with V_s = 6,500 ft/s, and (4) hard rock with V_s = 8,000 ft/s (fixed base condition is assumed).

Since there will not be any seismic category I SSCs contained within seismic category II buildings, the development of ISRS is not necessary.

Using the computer program NASTRAN (Reference 3.7-20), detailed FE models are developed for the major seismic category I and seismic category II structures, primarily to be utilized as static analysis models for structural design based on loads and load combinations as described in Section 3.8. However, the NASTRAN FE models are also used for validation of the dynamic lumped mass stick models and the seismic analysis results, as discussed later in this section. Final results obtained from analysis of the NASTRAN FE models are validated by comparison to the results of separate ANSYS (Reference 3.7-21) FE model analyses.

3.7.2.3.2 R/B, PCCV, and Containment Internal Structure Lumped Mass Stick Models

~~The seismic analysis and design of the R/B, PCCV, and containment internal structure and their common basemat are based on a model that consists of a detailed RCL system lumped mass stick model coupled with a combined R/B-PCCV-containment internal structure lumped mass stick model. The seismic analysis of the RCL-R/B-PCCV-containment internal structure coupled model is addressed in a separate Technical Report (Reference 3.7-18). The results obtained from the seismic analysis of the RCL-R/B-PCCV-containment internal structure coupled model are compared to the current seismic analysis of the R/B, PCCV, and containment internal structure and their common basemat and design adjustments due to the reconciliation are made, as necessary, and addressed in the Technical Report.~~

The ~~current~~ seismic analysis and structural design of the R/B, PCCV, and containment internal structure and their common basemat is based on a combined lumped mass stick model consisting of three lumped mass stick models (for each of the three structures) that are all rigidly cross-connected at the surface of the common basemat. Included in this combined model is the calculated mass of the RCL seismic subsystem, which is conservatively rounded up by 20% and distributed proportionately to the appropriate model nodes based on the mass distribution of the RCL system. This is considered a conservative approach for the seismic analysis and design of the R/B, PCCV, and containment internal structure and their basemat because the round-up compensates for uncertainties in the mass distribution and potential effects due to coupling of the RCL subsystem, such as shifts or changes in natural frequency and response modes. Appendix 3H presents the detailed model descriptions, seismic analysis results, and the associated tables and figures that are particular and specific to the uncoupled RCL approach ~~currently~~ used for the R/B, PCCV, and containment internal structure. Similarly, Appendix 3C presents the analytical methods and modeling approaches ~~currently~~ used for the uncoupled RCL seismic subsystem analysis. Seismic analysis of the R/B, PCCV, and containment internal structure and their common basemat is also performed using a coupled model that consists of a detailed RCL lumped mass stick model coupled with the combined R/B-PCCV-containment internal structure lumped mass stick model, as documented in a separate Technical Report (Reference 3.7-18). The results obtained from the seismic analysis of the coupled model are reconciled, as necessary, with those results obtained from the seismic analysis of the un-coupled model.

and comparison with the corresponding results from site-independent analyses. The COL Applicant is to verify that the results of the site-specific SSI analysis for the broadened ISRS and basement walls lateral soil pressures are enveloped by the US-APWR standard design.

The analyses use input soil properties derived from geotechnical investigations of the site that are compatible to the strains generated in the subgrade by the input design earthquake. The uncertainties and variations of the subgrade properties are considered using the methodology previously described for the development of the strain-compatible site profiles for the site-specific SSI analysis of the major seismic category I structures. The control motions are developed from site-specific FIRS that are described in Subsection 3.7.1.1 and applied to the models at the bottom of the basemat.

In accordance with Section 1.2 of RG 1.61 (Reference 3.7-15), the lower OBE damping values in Table 3.7.3-1(b) are assigned to the structural model used for development of ISRS if the site-specific SSE is not large enough to use the damping values and Table 3.7.3-1(a), and OBE design loads. ISRS do not need to be generated for seismic category II buildings and structures which do not contain or support safety-related SSCs, such as the T/B and A/B.

Simplified SSI modeling approaches, such as a lumped parameter model, can be employed for the site-specific seismic response analyses of seismic category I and II buildings and structures that are not part of the US-APWR standard design if it is demonstrated that for the specific site conditions the following applies:

- The basemats are much stiffer than the supporting subgrade
- The SSI impedance functions remain relatively constant in the range of frequencies important for the design
- The consideration of basemat embedment yields conservative results

In accordance with SRP 3.7.2 (Reference 3.7-16), Section II.4, fixed base response analysis can be performed if the basemats are supported by subgrades having a shear wave velocity of 8,000 ft/s or higher, under the entire surface of the foundation. ~~In accordance with Subsection 3.3.1.1 of ASCE 4-98 (Reference 3.7-9), fixed base response analysis can be performed if the basemats are supported by subgrades that meet the following condition.~~

~~The frequency of the system consisting of subgrade stiffness (SSI impedance) and the combined lumped mass inertia of the whole super-structure and the basemat (i.e., by assuming the super-structure and the basemat are absolutely rigid) are twice the frequency obtained from the fixed base modal analysis of the superstructure.~~

3.7.2.5 Development of Floor Response Spectra

ISRS for the major seismic category I structures as well as design spectra for the RCL system are required to be developed from the results of the site-independent seismic analysis of the coupled RCL-R/B-PCCV-containment internal structure lumped mass stick model described in Subsection 3.7.2.3 by using direct integration time history analysis method as described in Subsection 3.7.2.1, and by capturing SSI effects for all four generic soil conditions as discussed in Subsection 3.7.2.4. The statistically or stresses in the member. 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.

3.7.2.7 Combination of Modal Responses

As previously discussed, the seismic responses of the major seismic category I structures lumped mass stick models are obtained utilizing the direct integration method of time history analyses. As described in Subsection 3.7.2.1, the damping matrix is not proportional to the stiffness and mass matrix of the combined soil-structure model, so the decomposition of the equations of motion in generalized coordinates is not possible. Therefore, the response of the major seismic category I structures are obtained directly by integrating the equations of motions presented in Equation 3.7.2-1 without performing modal decomposition and subsequent modal superposition.

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. In modal superposition, only modes with frequencies less than the frequencies defining the ZPA response participate in the modal solution. The modal contribution of the residual rigid response for modes with frequencies greater than ZPA frequency is accounted for by using the missing mass method. As permitted by RG 1.92, Rev.2 (Reference 3.7-27), the missing mass contribution, scaled to the instantaneous input acceleration, is treated as an additional mode in the algebraic summation of modal responses at each time step. The missing mass contribution is considered for all DOF.

When the response spectra method of analysis is used (see Subsection 3.7.3.1 for a discussion of response spectra methods of analysis), modal responses have been combined by one of the RG 1.92, Rev.2 (Reference 3.7-27), methods, or by the 10% grouping method described below. In some applications, the more conservative modal combination methods contained in Rev.1 of RG 1.92 (Reference 3.7-28) are also used, as permitted in Revision 2 of RG 1.92 (Reference 3.7-27).

For the ~~10%~~ grouping method, the total unidirectional seismic response for subsystems is obtained by combining the individual modal responses using the SRSS method for frequencies spaced more than 10%.

For subsystems having modes with closely spaced frequencies, this method is modified to include the possible effect of these modes. The groups of closely spaced modes are chosen so that the differences between the frequencies of the first mode and the last mode in the group do not exceed 10% of the lower frequency.

The combined total response for systems having such closely spaced modal frequencies is obtained by adding to the SRSS of all modes the product of the responses of the modes in each group of closely spaced modes ~~times appropriate coupling factors~~.

This can be represented mathematically as follows:

$$\cancel{R_T^2 = \sum_{i=1}^{N} R_i^2 + 2\sum_{j=1}^{S}\sum_{k=Mj}^{Nj-1}\sum_{\ell=k+1}^{Nj} R_k R_\ell \varepsilon_{k\ell}}$$

$$\underline{R^2 = \sum_{k=1}^{N} R_k^{\ 2} + \sum_{q=1}^{P}\sum_{l=i}^{j}\sum_{m=i}^{j}\left|R_{lq} \cdot R_{mq}\right| \qquad l \neq m}$$

where

R_T = total unidirectional response

$\underline{R_k}$ = <u>the peak value of the response due to the kth mode</u>

$\cancel{R_i}$ $\underline{R_{lq,}\ R_{mq}}$ = ~~absolute value of response of mode I~~ <u>are the modal responses, R_l and R_m within the q^{th} group</u>

N = total number of modes considered

~~S~~ $\underline{P}$ = number of groups of closely spaced modes

~~M_j~~ $\underline{i}$ = lowest modal number associated with group ~~j~~ <u>q</u> of closely spaced modes

~~N_j~~ $\underline{j}$ = highest modal number associated with group ~~j~~ <u>q</u> of closely spaced modes

~~ε_{kl} = coupling factor, defined as follows:~~

$$\cancel{\varepsilon_{k\ell} = \left(1 + \frac{(w'_k - w'_\ell)^2}{(\beta'_k w_k + \beta'_\ell w_\ell)^2}\right)^{-1}}$$

~~and,~~

$$\cancel{w'_k = w_k\left[1 - (\beta_k)^2\right]^{1/2}}$$

$$\cancel{\beta'_k = \beta_k + \frac{2}{w_k t_d}}$$

~~where~~

~~ω_k = frequency of closely spaced mode k~~

~~β_k = fraction of critical damping in closely spaced mode k~~

~~t_d = duration of the earthquake~~

Alternatively, a more conservative <u>ten percent</u> grouping method can be used in the seismic response spectra analyses. The groups of closely spaced modes are chosen so that the difference between two frequencies (the first and last mode in a group) is no greater than 10%. Therefore,

$$\cancel{R_T^2 = \sum_{i=1}^{N} R_i^2 + 2\sum \varepsilon_{kl} R_k R_l}$$

$$R^2 = \sum_{k=1}^{N} R_k^{\ 2} + 2\sum |R_i R_j| \qquad i \neq j$$

The second summation is to be done on all i and j modes whose frequencies are closely spaced to each other.

~~where~~

~~ω_k = first circular frequency in the group~~

~~ω_l = last circular frequency in the group~~

All ~~other~~ terms for the modal combination remain the same as defined above.

The 10% grouping method is more conservative than the grouping method because the same mode can appear in more than one group.

For the seismic response spectra analysis, the ZPA cut-off frequency is 50 Hz. High frequency or rigid modes must be considered using the static ZPA method, the left-out force method as described in Subsection 3.7.2.7 below, or the Kennedy Missing Mass method contained in Revision 2 of RG 1.92 (Reference 3.7-27).

3.7.2.7.1 Left-Out-Force Method (or Missing Mass Correction for High Frequency Modes)

The left-out-force method is based on the Left-Out-Force Theorem. This theorem states that for every time history load, there is a frequency, f_r, called the "rigid mode cutoff frequency" above which the response in modes with natural frequencies above f_r will very closely resemble the applied load at each instant of time. These modes are called "rigid modes." The formulation follows and is based on the method used in the computer program PIPESTRESS (Reference 3.7-29). The left-out-force method is not used for seismic analysis of the major seismic category I structures; however, it may be used for other seismic category I and II systems and subsystems.

The left-out-force vector for time history analyses, { Fr }, is calculated based on lower modes:

$$\{ Fr \} = [\, 1 - \sum M\, e_j\, e_j^T \,]\, f(t)$$

where

f (t) = the applied load vector

M = the mass matrix

e_j = the eigenvector

Note that $\sum$ only represents the flexible modes, not including the rigid modes.

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The torsional effect is included in accordance with SRP 3.7.2 Section II (Reference 3.7-16) in the design of all seismic category I and II structures by use of the following process:

- The horizontal mass properties, center of rigidity, and the corresponding nodal accelerations, are computed in order to determine the inertial torsional moments. These computations are performed separately for each floor elevation of the building lumped mass stick models that are used for seismic analysis, which are described in Subsection 3.7.2.3. ~~Computation of the horizontal mass properties on each floor elevation of the building lumped mass stick models, and the corresponding nodal accelerations.~~
- The accidental torsional moments are computed by determining an additional building torsion equal to story shear force with a moment arm of +/- 5% of the plan dimension of the floor perpendicular to the direction of the applied motion. This computation is performed for both horizontal directions. ~~Computation of the accidental eccentricity by determining the distance between the center of mass at each floor with respect to its center of rigidity, computed separately for each floor level, as required by ASCE 4 (Reference 3.7-9) Subsection 3.1.1(d).~~
- The accidental torsional moments due to eccentricities of the masses at each floor elevation are assumed to act in the same direction on each structure unless otherwise demonstrated in the seismic analysis. Both positive and negative accidental torsional moments ~~values~~ are considered in the design of building structures in order to capture worst case effects.
- The accidental torsional moment is combined with the inertial torsional moment. This is computed conservatively so that the combined torsional moment is additive for each floor elevation. The combined torsional moment is distributed to the resisting structural elements in proportion to their relative stiffnesses.

~~For member design only, an additional building torsion (accidental torsion) equal to story shear force with a moment arm of 5% of the plan dimension of the floor perpendicular to the direction of the applied motion, as stipulated in ASCE 4-98 (Reference 3.7-9) Subsection 3.1.1 (e), is applied in the resultant force calculations. As explained in ASCE 4-98 Subsection 3.3.1.2 (a), this accounts for effects of non-vertically incident or incoherent waves.~~

The methods and approaches used to capture torsional effects in seismic category I buildings are described further in Subsection 3.7.2.3.

3.7.2.12 Comparison of Responses

The major seismic category I structures are analyzed using time history analysis methods.

As described in Subsection 3.7.1.1, the time history analyses are based on design ground motion time histories which have been artificially synthesized and meet the requirements of “Acceptance Criteria, Design Time History Option 1: Single Set of Time Histories, Approach 2”, NUREG-0800, SRP 3.7.1, Section II (Reference 3.7-10). ~~As required by Approach 2, the response spectra obtained from the artificial ground motion time histories have been compared with the target response spectra to assure that the~~

~~spectra derived from the time histories match/envelope the CSDRS with an approximate mean based fit.~~ 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.

3.7.2.13 Methods for Seismic Analysis of Dams

The US-APWR standard plant design does not include dams. It is the responsibility of the COL Applicant to perform any site-specific seismic analysis for dams that may be required.

3.7.2.14 Determination of Dynamic Stability of Seismic Category I Structures

Based on NUREG-0800, SRP 3.8.5 (Reference 3.7-34), for all structures, for load combinations involving SSE loads, a minimum factor of safety of 1.1 against overturning and sliding under the worst condition of loading is provided. If an OBE value is chosen to be greater than 1/3 of the site-specific SSE for the design of site-specific seismic category I structures, then load combinations involving the site-specific OBE must have a minimum factor of safety of 1.5 against overturning and sliding.

The US-APWR standard plant design is based on the assumption, as discussed in Chapter 2, that there is no potential for liquefaction of the supporting media. In order to verify the dynamic stability of US-APWR standard plant and site-specific seismic category I structures, site-specific investigations are performed of the supporting media as described in Subsection 2.5.4.8 to verify that there is no potential for liquefaction. 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.

3.7.2.15 Analysis Procedure for Damping

The analysis procedure of damping in the various elements of the soil-structure system model has been discussed in Subsections 3.7.1.2, 3.7.2.3, and 3.7.2.4.

3.7.3 Seismic Subsystem Analysis

This section addresses seismic analysis of civil structure-related seismic category I subsystems, which are analyzed in accordance with NUREG-0800, SRP 3.7.3 (Reference 3.7-35). The civil structure-related subsystems are accounted for in the global seismic models of the seismic category I building structures described in Subsection 3.7.2.3 by considering the mass and mass distribution of the subsystems in the models. However, seismic analysis of the subsystems has generally been performed separately because the subsystems do not contribute to the building stiffness and because the seismic responses of the buildings (ISRS as discussed in Subsection 3.7.2.5) serve as the seismic design input motion for the subsystems. SSCs that are seismically analyzed as civil structure-related subsystems include:

- Structures such as miscellaneous steel platforms, stairs, and walkways.
- Structures such as reinforced masonry block walls and enclosures.

Figure 3H.3-3 presents the comparison between results obtained for the containment internal structure from the lumped mass stick model versus those obtained from the detailed FE model with respect to static deformations. The comparison shows the correlation of the stiffness properties of the two models.

Figure 3H.3-4 presents the comparison between the 5% damping ISRS obtained for the containment internal structure at various locations and elevations from the fixed-base lumped mass stick model, versus those obtained from the fixed-base FE model. The comparison shows the correlation of the dynamic responses obtained from the two models.

Table 3H.3-10 presents the results of the PS/B time history analyses by using the methodology described in Subsection 3.7.2.

Tables 3H.3-11 through 3H.3-14 provide resulting maximum displacement at various mass nodes for shear wave velocities.

3H.4 REFERENCES

3H-1 Dynamic Analysis of the Coupled RCL-R/B-PCCV-Containment Internal Structure Lumped Mass Stick Model, MUAP-08005, Mitsubishi Heavy Industries, Ltd., April 2008 ~~MHI Technical Report, Later~~.

3H-2 Seismic Analysis of Safety-Related Nuclear Structures. American Society of Civil Engineers, ASCE 4-98, Reston, Virginia, 2000.

3H-3 Combining Responses and Spatial Components in Seismic Response Analysis. Regulatory Guide 1.92, Rev. 2, U.S. Nuclear Regulatory Commission, Washington, DC, July 2006.

3H-4 Investigation of Out-of-Plane Flexibility of Floor Slabs with Respect to Development of ISRS, MHI Technical Report, Later.