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TOKYO, JAPAN

May 7, 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-09188

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.

2) "MHI's Responses to US-APWR DCD RAI No. 212-1950, UAP-HF-09113, dated 3/30/2009.

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

Enclosed are the responses to the remaining 15 RAIs contained within Reference 1. Thirteen additional RAI responses contained within Reference 1 were previously provided in Reference 2.

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

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NRO

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Enclosure 1

UAP-HF-09188
Docket No. 52-021

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

May, 2009

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

5/07/2009

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 3.7.2-1:

The seismic analysis methods described in section 3.7.2.1 of the DCD state that the methods conform to the requirements of SRP Subsections 3.7.1 and 3.7.2 and generally to industry standard ASCE 4-98. The staff has not reviewed and endorsed ASCE 4-98 for this application. Currently this ASCE standard is under revision. The applicant need to provide justification independent of ASCE 4-98 in all instances where this standard is relied upon as the basis for seismic analysis. The lumped mass stick models described in Section 3.7.2.1 of the DCD use frequency-independent impedance functions for the half-space modeling of the soil media. The SRP acceptance criteria 3.7.2.II.4 state that for the half-space modeling of the soil media, the lumped parameter (soil spring) method and the compliance function method are acceptable provided that frequency variation and layering effects are incorporated. Provide justification including studies and test data for using frequency-independent impedance functions for the half-space modeling of the soil media.

ANSWER:

References to ASCE 4-98 in Sections 3.7 and 3.8 of the DCD and related Chapter 3 Appendices were reviewed. For each instance where ASCE 4-98 was referenced, ASCE 4-98 was either maintained through justification by supporting references or discussion, replaced with an alternate reference or standard, or deleted. The results of this review, including justifications and discussion, are provided in Table 1 below. Changes to be made within the DCD as a result of this review are identified in the DCD Impact of this RAI response. Justification for using frequency-independent impedance functions for the half space modeling is provided in Table 1, Item No. 3.

TABLE 1
Question RAI 3.7.2-01

ASCE 4-98 References with DCD Sections 3.7 and 3.8

Item No.	Use of ASCE 4-98 in DCD Tier 2, Revision 1	Maintain, Replace, or Delete ASCE 4-98 as Reference?	If ASCE 4-98 to be Replaced, Name of the Alternate Standard, Reference or Methodology	Remarks
1	Subsection 3.7.1.1, Site-Specific GMRS, second paragraph: If materials are present at the site in which the initial (small strain) shear velocity is less than 3,500 ft/s [which corresponds to rock material for the purpose of defining input motion in accordance with Section 1.2 of ASCE 4-98 (Reference 3.7-9)], the site response analysis has to address probable effects of non-linearity of the subgrade materials.	Delete	Not Applicable	Reference to ASCE 4-98 is to be deleted during DCD Revision 2 in response to RAI 211-1946, Question RAI 3.7.1-4.
2	Subsection 3.7.1.2, first paragraph: The specified damping coefficients are in accordance with RG 1.61 (Reference 3.7-15), ASCE 4-98 (Reference 3.7-9), and are based on consideration of the material, load conditions, and type of construction used in the structural system.	Delete	Not Applicable	Reference to ASCE 4-98 is to be deleted during DCD Revision 2 in response to RAI 211-1946, Question RAI 3.7.1-5.
3	Subsection 3.7.1.3, third paragraph: Six sets of two parameters, one for stiffness and one for damping, are developed in accordance with Subsection 3.3.4.2 of ASCE 4-98 (Reference 3.7-9) to represent the properties of the SSI in each one of the six degrees of freedom (DOFs) that describe the three dimensional vibrations of the rigid basemat.	Maintain	Not Applicable	The stiffness and damping parameters of ASCE 4-98 referenced in DCD Subsection 3.3.4.2 are in accordance with "Vibrations of Soils and Foundations" (Reference 1). Reference 1 is an industry standard in use for several years at several operating nuclear power plants. Reference 1 has also been cited in the US NRC Generic Letter, GL 80-109 (Reference 2) that contains the report on 'SSRT Guideline for SEP Soil-Structure Interaction Review'. The chairman of the SSRT

Item No.	Use of ASCE 4-98 in DCD Tier 2, Revision 1	Maintain, Replace, or Delete ASCE 4-98 as Reference?	If ASCE 4-98 to be Replaced, Name of the Alternate Standard, Reference or Methodology	Remarks
				(Senior Seismic Review Team) committee was Prof. N. M. Newmark. The SSRT members prepared the guideline. The use of ASCE 4-98 stiffness and damping parameters based upon Reference 1 can be considered analogues to simplified dynamic method discussed in NRC GL 80-109 (Reference 2). It may be noted that the generic site (i.e. site-independent condition) considers uniform, elastic-half space as explained in DCD Subsection 3.7.1.3. According to Section 10.5 of Reference 1, spring constant formulas provided in Tables 10.13 and 10.14 are based upon the theory of elasticity. Further, authors of Reference 1 state, *"These formulas apply for situations corresponding to rigid block or mat foundations with shallow embedments"*. However, the issue of embedment is more fully described in response to RAI #212-1950 Revision 1, Question RAI 3.7.2-20. The formulation of damping parameters for a problem of rigid mat resting on uniform, elastic-half space are provided in Chapter 7 of Reference 1, and are summarized in Table A-2 of the reference. From the above discussion, it follows that for uniform, elastic, half-space type site conditions, stiffness and damping parameters of ASCE 4-98 are applicable, have sound mathematical basis, and have been used in operating nuclear power plants. In this approach of seismic analysis, conservatisms are added in

Item No.	Use of ASCE 4-98 in DCD Tier 2, Revision 1	Maintain, Replace, or Delete ASCE 4-98 as Reference?	If ASCE 4-98 to be Replaced, Name of the Alternate Standard, Reference or Methodology	Remarks
				computing responses; that is, consideration is given to variation in soil properties, enveloping responses for four different site conditions, and broadening and smoothing the ISRS over four different site conditions. In addition, the COL Applicant performs site-specific analysis, as required under *COL 3.7(3)* as described in DCD Subsection 3.7.2.4.1, to confirm that site-specific responses are enveloped by the standard design. The site-specific seismic analysis, in accordance with DCD Subsection 3.7.2.4, needs to consider local soil conditions, embedment effects, and perform frequency-dependent (SASSI) analysis.
4	<u>Subsection 3.7.2.1, first paragraph:</u> The methods used for the seismic analysis of the US-APWR seismic category I systems conform to the requirements of SRP Subsections 3.7.1 (Reference 3.7-10) and 3.7.2 (Reference 3.7-16) and generally to the analysis requirements of Section 3.2 of ASCE 4-98 (Reference 3.7-9).	Delete	Not Applicable	SRP Subsections 3.7.1 and 3.7.2 suffice and provide the basis for seismic analysis of the US-APWR seismic category I structures. The reference to ASCE 4-98 is extraneous, and is to be deleted during Revision 2 of the DCD.
5	<u>Subsection 3.7.2.1, second paragraph:</u> The stiffness and damping properties of the subgrade are modeled using the lumped parameter approach developed in accordance with Subsection 3.3.4.2 of ASCE 4-98 (Reference 3.7-9).	Maintain	Not Applicable	Refer to item #3 for justification.
6	<u>Subsection 3.7.2.1, eighth paragraph:</u> The lumped SSI parameters are calculated from the formulas given in ASCE 4-98, Subsection 3.3.4 (Reference 3.7-9) that are based on closed form	Maintain	Not Applicable	Refer to item #3 for justification.

Item No.	Use of ASCE 4-98 in DCD Tier 2, Revision 1	Maintain, Replace, or Delete ASCE 4-98 as Reference?	If ASCE 4-98 to be Replaced, Name of the Alternate Standard, Reference or Methodology	Remarks
	solutions for vibrations of a rigid basemat resting on elastic-half space. The values of the lumped parameters for damping in the horizontal direction are conservatively reduced to 60% of the values calculated from the formulas of ASCE 4-98 (Reference 3.7-9) unless an applicable justification based on site-specific conditions is applied.			
7	Subsection 3.7.2.1, tenth paragraph: As an alternative option for seismic category I systems and subsystems, it is also acceptable to utilize the composite modal damping method associated with the modal superposition of time history analysis when the equations of motion can be decoupled, as discussed in Subsection 3.2.2.2 of ASCE 4-98 (Reference 3.7-9).	Replace	SRP 3.7.2, Section II.13	Replace reference to ASCE 4-98 with SRP 3.7.2 (Reference 3.7-16), Section II.13 during Revision 2 of the DCD.
8	Subsection 3.7.2.3.1, second paragraph: The procedures used for development of analytical models for seismic analysis are consistent with the procedures and guidelines of Chapter 3 of ASCE 4-98 (Reference 3.7-9) and SRP 3.7.2, Section II.3 (Reference 3.7-16).	Delete	Not Applicable	SRP 3.7.2, Section II.3 suffices and provides the basis for seismic analysis of the US-APWR seismic category I structures. The reference to ASCE 4-98 is extraneous, and is to be deleted during Revision 2 of the DCD.
9	Subsection 3.7.2.3.2, fifth paragraph: The lumped parameter coefficients representing the stiffness and the damping properties of the SSI, are developed in accordance with ASCE 4-98 (Reference 3.7-9), Table 3.3-3, as discussed in Subsection 3.7.2.4.	Maintain	Not Applicable	Refer to item #3 for justification.

Item No.	Use of ASCE 4-98 in DCD Tier 2, Revision 1	Maintain, Replace, or Delete ASCE 4-98 as Reference?	If ASCE 4-98 to be Replaced, Name of the Alternate Standard, Reference or Methodology	Remarks
10	<u>Subsection 3.7.2.3.3, second paragraph:</u> The lumped parameter coefficients representing the stiffness and the damping properties of the SSI, are developed in accordance with ASCE 4-98 (Reference 3.7-9), Table 3.3-3, as discussed in Subsection 3.7.2.4.	Maintain	Not Applicable	Refer to item #3 for justification.
11	<u>Subsection 3.7.2.3.7, third paragraph:</u> Generally, in accordance with ASCE-4 (Reference 3.7-9) Subsection C3.1.8.3, if the shear wall has no flange elements at its ends, the shear area is equal to the total web area divided by 1.2.	Maintain	Not Applicable	For use of this methodology and the factor "1.2", ASCE 4-98 cites the reference of *J. A. Blume, N. M. Newmark and L. H. Corning, "Design of Multistory Reinforced Concrete Buildings for Earthquake Motions"* (Reference 3). This is a standard industry reference, and the authors of the book are prominent in the field of earthquake engineering. Prof. Newmark was Head of the Civil Engineering Department at the University of Illinois, and a recognized leader in earthquake engineering.
12	<u>Subsection 3.7.2.4, first paragraph:</u> In accordance with the requirements of SRP 3.7.2, Section II.4 (Reference 3.7-16), and following the standards specified by ASCE 4-98, Section 3.3 (Reference 3.7-9), SSI effects are considered in the seismic response analysis of all major seismic category I and seismic category II buildings and structures that are part of the US-APWR standard and non-standard plant.	Delete	Not Applicable	SRP 3.7.2, Section II.4 suffices and provides the basis for the procedures used in the seismic analysis. The reference to ASCE 4-98 is extraneous, and is to be deleted during Revision 2 of the DCD.

Item No.	Use of ASCE 4-98 in DCD Tier 2, Revision 1	Maintain, Replace, or Delete ASCE 4-98 as Reference?	If ASCE 4-98 to be Replaced, Name of the Alternate Standard, Reference or Methodology	Remarks
13	<u>Subsection 3.7.2.4, second paragraph:</u> The lumped parameters representing the stiffness and damping properties of the SSI are calculated from the formulas presented in Table 3.3-3, Subsection 3.3.4.2 of ASCE 4-98 (Reference 3.7-9).	Maintain	Not Applicable	Refer to item #3 for justification.
14	<u>Subsection 3.7.2.4, third paragraph:</u> The ratio of basemat depth-to-equivalent-radius for the R/B-PCCV basemat is less than 0.3 (the embedded depth is 38'-10"), which indicates a shallow embedment basemat for purposes of SSI as defined in ASCE 4-98, Subsection 3.3.4.2 (Reference 3.7-9).	Maintain	Not Applicable	Justification of the acceptability of current seismic methodology for shallow embedments and a clarification to the DCD is provided in response to Question RAI 3.7.2-20.
15	<u>Subsection 3.7.2.4, last paragraph:</u> Using a lumped parameter model, SSI damping is based on the characteristics of the site-specific subgrade conditions, not to exceed the values specified by the ASCE 4-98 code (Reference 3.7-9).	Delete	Not Applicable	The sentence is to be deleted during DCD Revision 2 in response to RAI 205-1584, Question RAI 3.9.2-11.
16	<u>Subsection 3.7.2.4.1, fifth paragraph:</u> In accordance with Subsection 3.3.17 of ASCE 4-98 (Reference 3.7-9), the LB and UB values for initial soil shear modulii (Gs) are established as follows: $G_s^{(LB)} = \frac{G_s^{(BE)}}{(1+C_v)}$ and $G_s^{(UB)} = G_s^{(BE)} \quad (1+C_v)$ where Cv is a variation factor. ASCE 4-98 (Reference 3.7-9) mandates that value of Cv must be greater than 0.5. When insufficient data are available to address uncertainties in properties of deep soil layers, Cv must be greater than 1.0.	Replace	SRP 3.7.2, Section II (Refer to bullet #5 under Specific Guidelines for SSI Analysis)	Replace references to ASCE 4-98 (Reference 3.7-9) with SRP 3.7.2 (Reference 3.7-16) Section II during Revision 2 of the DCD.

Item No.	Use of ASCE 4-98 in DCD Tier 2, Revision 1	Maintain, Replace, or Delete ASCE 4-98 as Reference?	If ASCE 4-98 to be Replaced, Name of the Alternate Standard, Reference or Methodology	Remarks
17	<u>Subsection 3.7.2.4.1, next to last paragraph:</u> 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.	Replace	SRP 3.7.2, Section II.4	The response to RAI 212-1950, Revision 1, Question RAI 3.7.2-22 replaces the reference to Subsection 3.3.1.1 of ASCE 4-98 (Reference 3.7-9) with SRP 3.7.2 (Reference 3.7-16), Section II.4
18	<u>Subsection 3.7.2.8, fifth paragraph:</u> This is acceptable and in accordance with ASCE 4-98 (Reference 3.7-9) Subsection 3.3.1.5 and the related commentary in Subsection C3.3.1.5, provided that local effects such as at below-grade walls are taken into consideration (discussed further below).	Delete	Not Applicable	The sentence is to be deleted during DCD Revision 2 in response to RAI 212-1950, Question RAI 3.9.2-24.
19	<u>Subsection 3.7.2.8, sixth paragraph:</u> In accordance with the requirements of Subsections 3.3.1.5 and 3.5.3 of ASCE 4-98 (Reference 3.7-9), the structural design of US-APWR seismic category I structures accounts for the local effects on below-grade exterior walls that are due to the interaction with adjacent structures.	Maintain	Not Applicable	The reference to ASCE 4-98 is kept because computation of dynamic lateral earth pressures in accordance with ASCE 4 is permitted as described in SRP 3.8.4 Section II.4.H. Refer to the response provided for Question RAI 3.7.2-24 for clarifications made to this paragraph.
20	<u>Subsection 3.7.2.11, second bullet of second paragraph:</u> 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).	Delete	Not Applicable	In response to Question RAI 3.7.2-27, the reference to ASCE 4 is to be deleted and discussion is to be expanded on torsional effects using a computational methodology consistent with SRP 3.7.2 during Revision 2 of the DCD.
21	<u>Subsection 3.7.2.11, third paragraph:</u> 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	Delete	Not Applicable	In response to Question RAI 3.7.2-27, the reference to ASCE 4 is to be deleted and discussion is to be expanded on torsional effects using a computational methodology

Item No.	Use of ASCE 4-98 in DCD Tier 2, Revision 1	Maintain, Replace, or Delete ASCE 4-98 as Reference?	If ASCE 4-98 to be Replaced, Name of the Alternate Standard, Reference or Methodology	Remarks
	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.			consistent with SRP 3.7.2 during Revision 2 of the DCD.
22	Subsection 3.7.3.1.2, third bullet of first paragraph: In accordance with ASCE 4-98, Subsection 3.2.5.2 (Reference 3.7-9), for cantilever beams with uniform mass distribution, the equivalent-static-load base shear is determined using the peak acceleration, and the base moment is determined using the peak acceleration times a factor of 1.1.	Maintain	Not Applicable	Justification to maintain factors cited in ASCE 4-98 and a clarification to the DCD is provided in response to RAI 213-1951, Revision 1, Question RAI 3.7.3-3.
23	Subsection 3.7.3.3, first paragraph: The damping values are based on RG 1.61 (Reference 3.7-15) and ASCE Standard 4-98 (Reference 3.7-9).	Delete	Not Applicable	RG 1.61 suffices and provides the basis for the damping values used in the seismic analysis. The reference to ASCE 4-98 is extraneous, and is to be deleted during Revision 2 of the DCD.
24	Subsection 3.7.3.9, last paragraph: The hydrodynamic loads due to seismic sloshing are considered in the design of these structures as part of the seismic loading and are calculated in accordance with ASCE 4-98, Subsection 3.5.4 (Reference 3.7-9).	Replace	SRP 3.7.3, Section II.14	The DCD is to be changed during Revision 2 to reference the provisions of SRP 3.7.3 (Reference 3.7-35), Section II.14 and the guidance of ASCE 4-98, Subsection 3.5.4 (Reference 3.7-9).
25	Subsection 3.8.3.4.2, first paragraph: ASCE 4-98 Subsection 3.5.4.3, states "The fluid slosh height may be determined based upon the assumption of a rigid tank shell."	Replace	DCD Subsection 3.7.3.9	The DCD is to be changed during Revision 2 to include a reference Subsection 3.7.3.9, since it refers to SRP 3.7.3, Section II.14. The reference to ASCE 4-98 is maintained for guidance in the calculation of slosh height considering a rigid tank shell, since it is a conservative simplifying assumption.

Item No.	Use of ASCE 4-98 in DCD Tier 2, Revision 1	Maintain, Replace, or Delete ASCE 4-98 as Reference?	If ASCE 4-98 to be Replaced, Name of the Alternate Standard, Reference or Methodology	Remarks
26	<u>Subsection 3.8.4.2, fifth bullet:</u> • ASCE 4-98, Seismic Analysis of Safety-Related Nuclear Structures and Commentary on Seismic Analysis of Safety-Related Nuclear Structures, American Society of Civil Engineers, 1998 (Reference 3.8-34).	Delete	Not Applicable	This bullet containing ASCE 4-98 as an applicable code and standard is to be deleted during Revision 2 of the DCD. ASCE 4-98 is maintained as Reference 3.8-34 when applicable.
27	<u>Subsection 3.8.4.3.2, first paragraph:</u> Hydrodynamic loads due to seismic sloshing are calculated per ASCE Standard 4-98 (Reference 3.8-34), and included in earthquake load E_s.	Replace	DCD Subsection 3.7.3.9	The DCD is to be changed during Revision 2 to reference DCD Subsection 3.7.3.9, which maintains a reference to ASCE 4-98, Subsection 3.5.4 (Reference 3.7-9) for guidance.
28	<u>Subsection 3.8.4.4.3, sixth paragraph:</u> Lateral earth pressure is calculated in accordance with ASCE 4-98 (Reference 3.8-34) for both active and passive earth pressures.	Maintain	Not Applicable	Use of ASCE 4 to calculate dynamic lateral earth pressures is permitted by SRP 3.8.4 II.4.H. Commentary Section C3.5.3.2 of ASCE 4-98 provides standard industry references as the basis of the approach that is presented in the standard. These references are: *J. H. Wood, "Earthquake-Induced Soil Pressures to Structures", EERI 73-05, California Institute of Technology, Pasadena, Ca., 1973 and H. B. Seed and R. V. Whitman, "Design of Earth Retaining Structures for Dynamic Loads", ASCE Specialty Conference on Lateral Stresses and Earth Retaining Structures, June 1970* (References 4 and 5 below). Since, the methodology presented is the standard industry practice to calculate earth pressures, ASCE 4-98 is considered justifiable. Hence, no change to the DCD is needed. Related Question 3.8.4-16 in RAI 342-2000

Item No.	Use of ASCE 4-98 in DCD Tier 2, Revision 1	Maintain, Replace, or Delete ASCE 4-98 as Reference?	If ASCE 4-98 to be Replaced, Name of the Alternate Standard, Reference or Methodology	Remarks
				on this DCD text regarding passive earth pressures will be addressed by the response to Question 3.8.4-16 in RAI 342-2000.
29	Subsection 3.8.5.2, third bullet of second paragraph: • ASCE 4-98, Seismic Analysis of Safety-Related Nuclear Structures and Commentary, American Society of Civil Engineers, 1998 (Reference 3.8-34)	Delete	Not Applicable	This bullet containing ASCE 4-98 as an industry standard is to be deleted during Revision 2 of the DCD. ASCE 4-98 is maintained as Reference 3.8-34 when applicable.
30	Subsection 3.8.5.4.1, fifth paragraph: The foundation depth-to-equivalent-radius ratio for the R/B-PCCV basemat is less than 0.3, which indicates a shallow embedment foundation for purposes of SSI as defined in ASCE 4-98, Subsection 3.3.4.2 (Reference 3.8-34).	Maintain	Not Applicable	Justification of the acceptability of current seismic methodology for shallow embedments and a clarification to the DCD is provided in response to RAI 212-1950 Revision 1, Question RAI 3.7.2-20.
31	Appendix 3H Section 3H.2 The SSI lumped parameter coefficients are computed for each of the three flexible generic subgrade conditions using the formulas and general approaches given in American Society of Civil Engineers (ASCE) 4 (Reference 3H-2), discussed in further detail in Subsection 3.7.2.4.	Maintain	Not Applicable	Refer to item #3 for justification.

References

1. F. E. Richart, R. D. Woods and J. R. Hall, "Vibrations of Soils and Foundations", Prentice-Hall, Inc. 1970.
2. US NRC GL 80109 dated December 15, 1980, "Guidelines for SEP Soil-Structure Interaction Reviews" and its enclosure "SSRT Guidelines for SEP Soil-structure Interaction Review" by N. M. Newmark, dated December 8, 1980.
3. J. A. Blume, N. M. Newmark and L. H. Corning, "Design of Multistory Reinforced Concrete Buildings for Earthquake Motions"
4. J. H. Woods, "Earthquake-Induced Soil Pressures to Structures", EERI 73-05, California Institute of Technology, Pasadena, Ca., 1973
5. H. B. Seed and R. V. Whitman, "Design of Earth Retaining Structures for Dynamic Loads", ASCE Specialty Conference on Lateral Stresses and Earth Retaining Structures, June 1970.

Impact on DCD

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

- (Item 1) Refer to RAI 211-1946, Question RAI 3.7.1-4 for deletion of reference to ASCE 4-98 in the second paragraph of Subsection 3.7.1.1, Site-Specific GMRS.

- (Item 2) Refer to RAI 211-1946, Question RAI 3.7.1-5 for deletion of reference to ASCE 4-98 in the first paragraph of Subsection 3.7.1.2.

- (Item 4) Change the first sentence of the first paragraph in Subsection 3.7.2.1 to the following: "The methods used for the seismic analysis of the US-APWR seismic category I systems conform to the requirements of SRP Subsections 3.7.1 (Reference 3.7-10) and 3.7.2 (Reference 3.7-16)."

- (Item 7) Change the last sentence of the tenth paragraph in Subsection 3.7.2.1 to the following: "As an alternative option for seismic category I systems and subsystems, it is also acceptable to utilize the composite modal damping method associated with the modal superposition of time history analysis when the equations of motion can be decoupled in accordance with SRP 3.7.2 (Reference 3.7-16), Section II.13."

- (Item 8) Change the first sentence of the second paragraph in Subsection 3.7.2.3.1 to the following: "The procedures used for development of analytical models for seismic analysis are consistent with the procedures and guidelines of SRP 3.7.2, Section II.3 (Reference 3.7-16)."

- (Item 12) Change the first sentence of the first paragraph in Subsection 3.7.2.4 to the following: "In accordance with the requirements of SRP, Section II.4 (Reference 3.7-16), SSI effects are considered in the seismic response analysis of all major seismic category I and seismic category II buildings and structures that are part of the US-APWR standard and non-standard plant."

- (Item 14) Refer to Question RAI 3.7.2-20 for clarifications of the reference to ASCE 4-98 in the third paragraph of Subsection 3.7.2.4.

- (Item 15) Refer to RAI 205-1584, Question RAI 3.9.2-11 for deletion of reference to ASCE 4-98 in the last paragraph of Subsection 3.7.2.4.

- (Item 16) Change the fifth sentence of the fifth paragraph in Subsection 3.7.2.4.1 to the following: "In accordance with the specific guidelines for SSI analysis contained in Section II.4 of SRP 3.7.2 (Reference 3.7-16), the LB and UB values for initial soil shear modulii (G_s) are established as follows:"

- (Item 16) Replace the last two sentences of the fifth paragraph in Subsection 3.7.2.4.1 with the following: "For well investigated sites, the C_v should be no less than 0.5. For sites that are not well investigated, the C_v for shear modulus shall be at least 1.0."

- (Item 17) Refer to the response previously submitted for RAI 212-1950, Question RAI 3.7.2-22, for replacement of reference to ASCE 4-98 in the next-to-last paragraph of Subsection 3.7.2.4.1.

- (Item 18) Refer to Question RAI 3.7.2-24 for deletion of reference to ASCE 4-98 in the fifth paragraph of Subsection 3.7.2.8.

- (Item 19) Refer to Question RAI 3.7.2-24 for clarifications of the reference to ASCE 4-98 in the sixth paragraph of Subsection 3.7.2.8.

- (Item 20) Refer to Question RAI 3.7.2-27 for deletion of reference to ASCE 4-98 in the second bullet in the second paragraph of Subsection 3.7.2.11.

- (Item 21) Refer to Question RAI 3.7.2-27 for deletion of reference to ASCE 4-98 in the third paragraph of Subsection 3.7.2.11.

- (Item 22) Refer to RAI 213-1951 Revision 1, Question RAI 3.7.3-3, for related clarifications in Subsection 3.7.3.1.2.

- (Item 23) Change the fourth sentence of the first paragraph in Subsection 3.7.3.3 to the following: "The damping values are based on RG 1.61 (Reference 3.7-15)."

- (Item 24) Change the first sentence of the last paragraph in Subsection 3.7.3.9 to the following: "Hydrodynamic loads including sloshing loads on these liquid-retaining vessels are determined using methods that conform to the provisions of Subsection II.14 of SRP 3.7.3 (Reference 3.7-35) and the guidance of ASCE 4-98, Subsection 3.5.4 (Reference 3.7-9)."

See Attachment 3 for a mark-up of DCD Tier 2, Section 3.8, Revision 2, changes to be incorporated.

- (Item 25) Replace the paragraph in Subsection 3.8.3.4.2 with the following:

  "The vertical and lateral pressures of liquids inside containment are treated as dead loads. Structures supporting fluid loads during normal operation and accident conditions are designed for the hydrostatic as well as hydrodynamic loads as discussed in Subsection 3.7.3.9. The hydrodynamic analyses take into account the flexibility of walls in considering fluid-structure interaction. Sloshing height, however, is calculated using a conservative simplified assumption of a rigid tank shell in accordance with guidance provided in ASCE 4-98 (Reference 3.8-34), Subsection 3.5.4.3."

- (Item 26) Delete the fifth bullet of the first paragraph in Subsection 3.8.4.2 in its entirety.

- (Item 27) Change the fourth sentence in Subsection 3.8.4.3.2 to the following: "Hydrodynamic loads due to seismic sloshing are determined as discussed in Subsection 3.7.3.9, and included in earthquake load E_s."

- (Item 29) Delete the third bullet of the second paragraph in Subsection 3.8.5.2 in its entirety.

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 3.7.2-3:

Section 3.7.2.3.10 of the DCD addresses the validation of various lumped mass stick models. The lumped mass models are nominally validated by comparing static deformations and ISRS at arbitrarily selected nodal locations from the lumped mass models to those from more detailed distributed mass models. In order to verify if the dynamic properties of the stick model conform to those of the detailed finite element model, in accordance with the SRP Section 3.7.2.II.A.iv, provide comparisons of natural frequencies, mode shapes, modal participation factors and total seismic response obtained from the two models by using the identical seismic input motion.

ANSWER:

Further comparison of the dynamic properties between the R/B-PCCV-containment internal structure lumped mass stick models and the detailed finite element model will be provided in DCD Revision 2.

Impact on DCD

DCD Revision 2 will incorporate additional information with respect to validation of the US-APWR lumped mass stick models.

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 3.7.2-5:

It is stated in Section 3.7.2.8 of the DCD that the phenomenon of structure-to-structure interaction through the soil is neglected in the soil-structure interaction (SSI) analysis and instead the variations of the site properties considered by the four general subgrade conditions are deemed sufficient to address the uncertainties related to possible structure-to-structure interaction effects. Provide justification for this position other than the reference to ASCE 4-98.The staff has not reviewed and endorsed ASCE 4-98 for the SSI application. Currently this ASCE standard is under revision.

ANSWER:

The standard design of the US APWR seismic Category I structures, systems, and components (SSCs) is based on simple soil structure interaction (SSI) models of rigid foundations resting on the surface of elastic-half space that neglect the effects of interaction with the surrounding buildings through the subgrade. Besides the geometry of the foundation and the weight of the building, the effects of structure-to-structure interaction on the seismic responses depend on site-specific conditions that can vary significantly from site to site, such as plant layout, soil properties and layering, and depth of the water table. In view of the potential variation in such parameters, the DCD statement that "the four general subgrade conditions are deemed sufficient to address uncertainties related to possible structure-to-structure interaction effects" is applicable only for purposes of generic standard plant design. This statement is required to be validated by the COL Applicant considering site-specific conditions as required by DCD COL item 3.7(10).

To clarify this requirement, Subsection 3.7.2.8 is to be revised during Revision 2 of the DCD to state that structure-to-structure interaction is not considered for the purposes of the seismic analyses of the four generic site profiles for the standard plant. The reference to ASCE 4-98 for the SSI application is also deleted as addressed in the response to question RAI 3.7.2-24 of this RAI.

As discussed in the response to question RAI 3.7.2-7 of this RAI, the results of the site-specific SSI analyses of the reactor building, prestressed concrete containment vessel, and containment internal structure are used to assess the effects of structure-to-structure interaction on the seismic response of the category I SSCs. If the results indicate that the structure-to-structure interaction is important for specific site conditions, the structure-to-structure interaction has to be included in the models used for the site-specific SSI analyses.

Impact on DCD

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

- Change the first sentence of the fifth paragraph in Subsection 3.7.2.8 to the following: "With respect to the coupling of the dynamic responses of adjacent structures through the soil, the phenomenon of structure-to-structure interaction is neglected in the SSI analyses for the standard plant discussed in Subsection 3.7.2.4."

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 3.7.2-6:

Section 3.7.2.8 of the DCD addresses the interaction of non-category I structures with Category I SSCs in accordance with Section 3.7.2.II.8 of the SRP. It is indicated in the DCD that the maximum displacements of the T/B and A/B have been calculated in order to determine the minimum size of the expansion joints between adjacent buildings. Clarify whether the maximum displacements calculated in analysis of the T/B and A/B include SSI effects, or whether the maximum displacements are determined from fixedbase models. Also, provide a detailed description of the analyses for the ESWPT, (SC I), the T/B, and A/B (SC II) and the AC/B (NS) structures.

ANSWER:

The dynamic analyses of the T/B and A/B are performed using time history analyses of lumped mass stick models as described in Subsection 3.7.2 of the DCD. The maximum displacements calculated in the analyses of the T/B and A/B account for SSI effects through the use of soil springs representing generic soil conditions. The maximum computed displacements envelope those obtained from fixed-base analyses.

Detailed descriptions of the seismic analyses for the T/B, A/B, and AC/B will be provided in separate technical reports.

Regarding the ESWPT, provision is made in the DCD to accommodate the interface of this structure with the standard plant. DCD Subsections 3.7.2.8 and 3.7.3.7 describe the interface of the ESWPT with standard plant structures. The exact configuration, orientation, and layout of the ESWPT are dependent on site conditions. The seismic analysis of the ESWPT is the responsibility of the COL Applicant as specified in various COL items in Sections 3.7 and 3.8 of the DCD. The requirement for the COL Applicant to provide detailed description of the design of the ESWPT is discussed further in the response previously provided for Question 3.7.2-23 of this RAI 212-1950.

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 3.7.2-12:

In Section 3.2.2.7 of the DCD, for the seismic response spectra analysis, three methods are proposed for calculating residual rigid response - the static ZPA method, the missing mass method, and the left-out-force method. SRP Section 3.7.2 II.7 references RG 1.92 regarding acceptable methods for calculating residual rigid response. The first two methods above are acceptable according to RG 1.92, but the third method above has not been reviewed and accepted by the staff in RG 1.92, or in the SRP. Provide a comparison of the responses calculated from the left-out-force method with the other two acceptable methods and demonstrate that the results are conservative in comparison with the other two accepted methods.

ANSWER:

The left-out-force (LOF) method considers the residual rigid response in the same manner as other methods accepted by RG 1.92.

As described in DCD Subsection 3.12.3.2.4, the LOF method is used by the PIPESTRESS computer program for analyzing most of the piping systems. PIPESTRESS uses the LOF method in order to calculate the effect of the high frequency rigid modes as described in the "PIPESTRESS Theory Manual" (DCD Reference 3.12-14) and the "Outline of Dynamic Analysis for Piping Systems" (DCD Reference 3.12-15). In addition, Subsection 3.12.5.6 of NUREG-1793 accepts the LOF method used in PIPESTRESS.

Therefore, additional comparison of the responses calculated from the LOF method with the other two methods is not necessary.

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 3.7.2-13:

It is stated in Section 3.7.2.8 of the DCD that dynamic increases in seismic lateral earth pressure on below-grade exterior walls were accounted for in the design of the USAPWR Seismic Category I structures by applying conservative maximum static and dynamic lateral pressure profiles in accordance with ASCE 4-98. The staff has not reviewed and endorsed ASCE 4-98 for this application. Currently this ASCE standard is under revision. Describe the pressure distribution profiles and the application of these pressure profiles to below-grade exterior walls in the seismic models, and what models are affected. Explain the basis for determining the lateral pressure distribution profiles to be conservative.

ANSWER:

As described in Subsection 3.8 of the DCD, the design of the below-grade walls of the US-APWR seismic category I buildings is based on the results of static analyses performed on detailed finite element models. The static and seismic design earth pressure loads are applied on these detailed finite element models in conjunction with other design loads to obtain structural and stability demands. The earth pressure loads are applied to all below-grade exterior walls that are in contact with embedment soil. The earth pressure loads are applied along the whole embedment height of the walls conservatively assuming that during an earthquake there is no separation between the walls and the soil. Hydrostatic design loads due to ground water are applied on the below-grade exterior walls that are separated from other structures with expansion joints sized to prevent contact between the buildings. The hydrostatic pressures are applied at elevations below the nominal water table elevation specified in Table 2.0-1 of the DCD at 1 foot below the nominal plant grade.

The design lateral earth pressure loads are calculated using the following conservatively selected material properties for the embedment soil:

Total unit weight γ_t = 130 pcf

Unit weight of the water γ_w = 62.4 pcf

Poisson's Ratio $\nu = 0.35$

Coefficient for earth pressure at rest $K_0 = 0.5$

Since the foundations of the US-APWR plant will be embedded in granular backfill, the above input soil properties provide upper bound estimates of the soil unit weight that result in a conservative estimate of the static and dynamic earth pressures. Furthermore, the calculations of the soil pressures conservatively assume the dry unit weight of the soil to be identical to the total unit weight.

The following earth pressure design loads are applied on the below grade exterior walls in contact with soil:

1. Static earth pressure (p_0) that is due to the weight of the soil is calculated as a function of depth (z) as follows:

   - above water table (z = 0 to 1 ft per DCD Table 2.0-1) $p_0 = \gamma_t z K_0$

   - below water table (z from z_1 = 1 ft to embedment depth H) $p = (\gamma_t - \gamma_w) z K_0$

   where: γ_t is the total weight of the soil, γ_w is the unit weight of water, K_0 is the coefficient of earth pressure at rest, and z_1 is the depth of groundwater table..

2. Static surcharge pressure (p_s) due to live load (p_L) on the ground surface that is applied along the height of the wall as uniform load with magnitude $p_s = p_L K_0$.

3. Hydrostatic pressure (p_w) from the ground water that is applied on the wall below the water table elevation ($z = z_1$ to H) as triangular load with magnitude

   $$p_w = \gamma_w (z - z_1)$$

4. Seismic earth pressures due to the design ground motion and the interaction of the foundation with the surrounding soil are calculated using the dynamic earth pressures distributions presented in Figure 3.5-1 of ASCE 4-98. The presented pressure distribution curves for Poisson ratio of $\nu = 0.3$ and $\nu = 0.4$ are linearly interpolated to obtain a pressure distribution for soil with $\nu = 0.35$. Using a peak ground acceleration of 0.3g and total weight of the soil γ_t = 130 pcf, the lateral seismic earth pressures at selected depths are calculated as shown in the tables below.

Figure 3.5-1 of ASCE 4-98 is based on the results of a numeral study conducted by J. H. Wood, "Earthquake Induced Soil Pressures on Structures" Report EERL 73-05 (1973), California Institute of Technology. The soil pressures are obtained from a model consisting of a cantilever representing the stiffness of the wall and a linear elastic shear beam representing the far field action of the embedment both bounded by a rigid foundation that is subjected to a ground motion. Linear springs connect the shear beam with the cantilever beam representing the stiffness of the wall (as shown in the figure below). Subsequent numerical studies of the state of the art that were conducted on more realistic models of cylindrical foundation embedded in a semi infinite visco-elastic stratum of soil (Veletsos and Younan "Dynamic Soil Pressures on Vertical Walls", SOA15, Proceedings from Third International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, April 2-27 1993, Volume III, St Louis) have demonstrated the conservatism of the Wood's solution. The models used in the referenced two studies neglected to consider the flexibility of the subgrade and the non-linear behavior of the soil, which resulted in overestimated wall pressures.

Seismic Earth Pressure Distribution on Reactor Building Subgrade Exterior Walls

Depth (ft)	Y/H*	Pressure Distribution $\sigma_0/\gamma H$ for 1g			Seismic Earth Pressure (psf)
		ν = 0.3*	ν = 0.4*	ν = 0.35**	
0.00	1.0	1.073	1.073	1.073	1625
7.77	0.8	1.182	1.255	1.218	1844
15.53	0.6	1.118	1.209	1.164	1763
23.30	0.4	0.955	1.064	1.009	1528
31.06	0.2	0.682	0.791	0.736	1115
38.83	0.0	0.218	0.345	0.282	427

* Values taken from ASCE 4-98, Figure 3.5-1

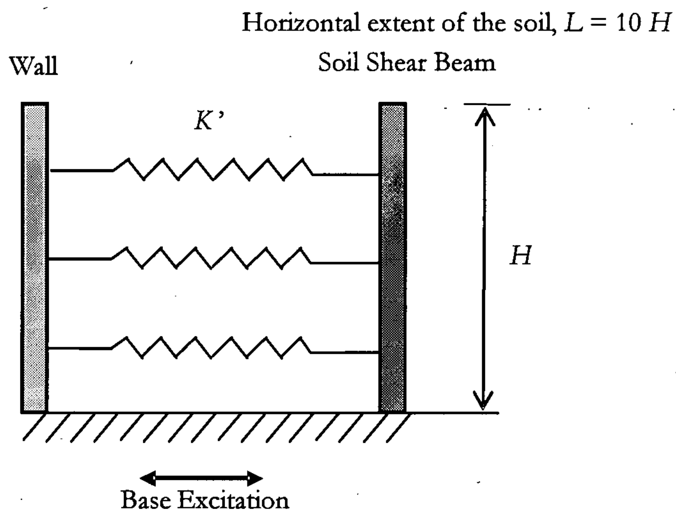
** Interpolated values

Seismic Earth Pressure Distribution on Power Source Building Subgrade Exterior Walls

Depth (ft)	Y/H*	Pressure Distribution $\sigma_0/\gamma H$ for 1g			Seismic Earth Pressure (psf)
		ν = 0.3*	ν = 0.4*	ν = 0.35**	
0.00	1.0	1.073	1.073	1.073	1559
7.45	0.8	1.182	1.255	1.218	1769
14.90	0.6	1.118	1.209	1.164	1691
22.35	0.4	0.955	1.064	1.009	1466
29.80	0.2	0.682	0.791	0.736	1069
37.25	0.0	0.218	0.345	0.282	410

* Values taken from ASCE 4-98, Figure 3.5-1

** Interpolated values



Model for Calculation of Dynamic Earth Pressures (Wood 1973)

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 3.7.2-14:

It is stated in Section 3.7.2.4.1 of the DCD and in COL action item COL 3.7(23) that the lateral soil pressures on the basement walls determined from a site-specific SSI analysis will be verified to be enveloped by the US-APWR standard design. However, the only SSI models described in the DCD have a basemat resting on the surface of a uniform elastic half-space exclusive of any basement walls. Describe how the lateral soil pressures on the basement walls calculated from a site-specific SSI analysis will be compared to those from the US-APWR standard design.

ANSWER:

As described in Subsection 3.7.2.4.1, the certified standard design is validated by performing site-specific SSI analyses that use the ACS-SASSI computer program to obtain the seismic response of category I systems and structures when subjected to the site-specific design ground motion. The ACS-SASSI program utilizes the complex response method and sub-structuring technique to solve in the frequency domain for the seismic response of the structure supported by either a surface or embedded flexible foundation. The models used for site-specific SSI analysis of US-APWR seismic category I systems use shell and solid finite elements to represent the dynamic properties of the below-grade portion of the building embedded in horizontally infinite layers of soil.

Solid elements representing the soil around the basement walls are added to the structural model to allow calculation of dynamic soil pressures. The stiffness and damping properties assigned to the elements correspond to the strain-compatible properties of the embedment soil layer. The soil elements provide the stresses in the soil in contact with the walls at the centroid of each fill element. The orientation of the stresses is with respect to the global axes of the SASSI model. The normal stresses (σ_{xx} or σ_{yy}) in the fill elements act in the direction normal to the basement walls (*x* or *y* direction), and represent the magnitude of the lateral dynamic soil pressures. For the *x* direction, the corresponding shear stresses τ_{xz} and τ_{xy} represent the tangential dynamic soil pressures in the vertical (*z*) direction and horizontal (*y*) direction, respectively. For the *y* direction, the corresponding shear stresses τ_{yz} and τ_{yx} represent the tangential dynamic soil pressures in the vertical (*z*) direction and horizontal (*x*) direction, respectively.

The SASSI results for peak soil pressures due to each direction of input motion are combined by the square root of sum of the squares (SRSS) method. The results obtained from SASSI analyses of each soil case are enveloped. If the site-specific conditions are such that foundation embedment is below the water table, the dynamic water pressures are added to the lateral dynamic soil pressures as described in the response to question RAI 3.7.2-13. These site-specific seismic earth pressures are compared with the corresponding values of dynamic soil pressures obtained for the standard plant design using ASCE 4-98 methodology as described in the response to question RAI 3.7.2-13. As stated by COL item 3.7(23), the COL Applicant is to verify that the magnitude of the seismic earth pressures used in the standard design envelopes the site-specific seismic earth pressures obtained from the SASSI analysis, in order to demonstrate the validity of the US-APWR standard design.

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 3.7.2-15:

The SRP acceptance criteria 3.7.2 II.9 states that the effects of potential concrete cracking on structural stiffness should be specifically addressed when determining the effects of parameter variations on floor response spectra. Describe how and where the effect of potential concrete cracking is accounted for in the determination of floor spectra.

ANSWER:

The effects of potential concrete cracking on structural stiffnesses are considered in the development of local vibration modes for the ISRS. As discussed in the previous response to Question 3.7.2-8 of this RAI 212-1950, ISRS considering local vibration modes and the description of the analysis method will be provided in Revision 2 of the DCD.

Impact on DCD

As part of the previous response to Question 3.7.2-8 of this RAI 212-1950, the effects of potential concrete cracking on structural stiffnesses are considered in the development of local vibration modes for the ISRS to be provided in Revision 2 of 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 3.7.2-16:

Provide a listing or table indicating which analysis method is used for each of the Seismic Category I, Seismic Category II, and non-seismic SSCs, or justify why such a description is not provided in the DCD. SRP Subsections 3.7.2 II.1 through 3.7.2.II.14 provide acceptance criteria for the seismic system analysis, but the acceptability of the SSCs cannot be evaluated without descriptions of the methodologies used. It is noted that the applicant has provided such information in Table 3.7.2-1 of the DCD for a subset of the structures. It is stated in Sections 3.7.2.8.2 and 3.7.2.8.4 that the design of the turbine building (T/B) and Auxiliary building (A/B) are based on a seismic dynamic analysis using a three-dimensional lumped mass model. Provide detailed description of these models and analysis results.

ANSWER:

The organization and content of the US-APWR DCD are intended to conform to the provisions of SRP 3.7.2 and RG 1.206. The analysis methods used for each of the US-APWR standard plant seismic category I, seismic category II, and non-seismic buildings are presently described in the DCD. Further explanation of how the seismic analysis methods of seismic category I, seismic category II, and non-seismic buildings are presently described in the DCD is outlined below. Detailed descriptions of the seismic models and analysis results for the A/B and T/B will be provided in separate technical reports as stated in the response to Question RAI 3.7.2-6.

Subsection 3.7.2 in the US-APWR DCD provides information on the methods used for seismic system analysis, where systems are defined, in accordance with SRP 3.7.2, as structures analyzed in conjunction with their foundations and supporting media. This information is described in the DCD for seismic category I structures, and as noted in the question, is also summarized for seismic category I systems in Table 3.7.2-1. However, analysis methods for seismic category II and non-seismic systems are also presently addressed in the DCD. On page 3.7-12 of Revision 1 of the DCD, Subsection 3.7.2 identifies that the seismic responses for seismic category II structures are obtained from SSI time history analyses of lumped mass stick models with frequency independent lumped parameter constants representing the stiffness and damping properties of the subgrade. On page 3.7-12, DCD Subsection 3.7.2 provides a further summary description of the overall seismic analysis process for these structures. Subsections

3.7.2.1 and 3.7.2.3 also describe the analysis and modeling methods, respectively, used for the seismic analyses. DCD Subsection 3.7.2.8 provides further information on seismic design of seismic category II (A/B, T/B) and non-seismic (AC/B) structures with respect to the potential for interaction with seismic category I structures. The seismic analysis method for the non-seismic AC/B system is in accordance with the International Building Code as stated in DCD Subsection 3.7.2.8.1.

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 3.7.2-17:

Model properties and seismic analysis results for lumped mass stick models are presented in Appendix 3H of the DCD. Dynamic responses from the lumped mass stick and finite element distributed mass models have been compared. However, it is not clear what data are being presented, how the data are being used, what acceptance criteria apply for the comparisons, and what conclusions are drawn. For example, in subsection 3H.3 of the appendix it is stated that comparison is made with responses obtained from the frequency domain time history analysis of the fixed base detailed finite element model. Provide the details and technical basis of the frequency domain time history analysis method. SRP Subsections 3.7.2.II.1 and 3.7.2.II.3 contain guidelines for determining if lumped mass models have sufficient degrees of freedom to properly capture the dynamic response of the structure of interest and if acceptable modeling procedures are employed. Describe how the lumped mass and distributed mass models meet the guidelines in the SRP Subsection 3.7.2.II.3C. Provide a clear explanation of the purpose of the Appendix 3H, data presented therein, conclusions drawn, and the technical basis for the conclusions.

ANSWER:

Further information on the validation comparison between the dynamic responses of the lumped mass stick models and finite element distributed mass models will be provided in DCD Revision 2, including description of the frequency domain time history analysis of the fixed base detailed finite element model.

Impact on DCD

DCD Revision 2 will incorporate additional information on the validation comparison between the dynamic responses of the lumped mass stick models and finite element distributed mass models, including description of the frequency domain time history analysis of the fixed base detailed finite element model.

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 3.7.2-18:

Section 2.3.1 of the technical report 'Enhanced Information for PS/B design' (Reference 3.7-33) describes the criteria for determining if the lumped mass stick models of the PS/B have adequate degrees of freedom. SRP Section 3.7.2 II.1.A.iv provides guidelines for determining whether a lumped mass model has adequate degrees of freedom for dynamic modeling. Provide the basis of the statement that additional DOFs do not result in more than a 10% increase in response, and describe how the proposed criteria that additional DOFs equals or exceeds twice the number of modes with frequencies less than 33 Hz meet the intent of SRP Section 3.7.2 II.1.A.iv. If the highest structural frequency is limited to 33 Hz, explain how the high frequency responses will be captured. Also, provide a comparison of seismic responses from the lumped mass stick model of the PS/B and the distributed mass finite element model.

ANSWER:

The seismic design of the PS/B will be based on time history analysis of the PS/B finite element model which meets the dynamic analysis criteria of SRP 3.7.2, Section II.1.A. Further details will be provided in Revision 1 of the MHI Technical Report MUAP-08002, "Enhanced Information for PS/B Design."

Impact on DCD

The DCD will be updated accordingly in Revision 2 to address changes in Technical Report MUAP-08002.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

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DATE OF RAI ISSUE:	**02/25/09**

QUESTION NO. RAI 3.7.2-19:

In Section 3.7.2.3.1 of the DCD it is stated that the NASTRAN finite element models are used for validation of the dynamic lumped mass stick models and the NASTRAN results are validated by comparison to the results of separate ANSYS finite element model analyses. Provide results and details of the NASTRAN and ANSYS validations. Describe how the various finite element models that were developed for validation meet the guidelines of SRP Sections 3.7.2.II.3.C.ii and iii.

ANSWER:

To verify whether the dynamic properties of the NASTRAN FE model conform to those of the ANSYS FE model, the 5% damping ISRS are calculated at several node points in both models that represent main floor levels. The points selected for validation are shown in Figures 19.1 and 19.2 (below) and Tables 19.1 and 19.2 (below) which are the same points selected in Subsection 3.7.2.3.10 of the DCD.

Figures 19.3 and 19.4 illustrate the comparisons of ISRS for the NASTRAN and ANSYS R/B FE models. It can be recognized that the ISRS evaluated by the NASTRAN FE model correlate well with those of the ANSYS FE model.

Further results and details of the NASTRAN and ANSYS FE model validations will be provided in Revision 2 of the DCD, including demonstration that the mesh sizes conform to the guidelines of SRP Section 3.7.2.II.3.C.ii.

As stated in the response to question RAI 3.7.2-8 of this RAI, ISRS which incorporate the effects of local vibration modes will be provided in Revision 2 of the DCD. The revision will meet the guidelines of SRP Section 3.7.2.II.3.C.iii.

Table 19.1 Selected Point for ISRS evaluation in R/B

	NORTH-EAST	SOUTH-EAST	SOUTH-WEST	NORTH-WEST	
	11-A	11-L	1-L	4-A	1-A
RF3	200704			200271	
RF2	240854			240775	
RF1		231495	231151		
RF	240556	230814	230603	240282	220305
4F	183521	183564	182492	182727	182447
3F	163278	163321	162208	162446	162163
2F	142744	142787	141593	141838	141548

Table 19.2 Selected Point for ISRS evaluation in C/S

EL.	Position 1	Position 2	Position 3	Position 4	Position 5
138'7"	21003	21005			
96'7"			17215	17271	
75'5"		16003	16003	16071	16026
49'2"		14503	14503	14571	14526
35'7"		13503	13503	13571	13526
23'7"		12503	12503	12571	12526

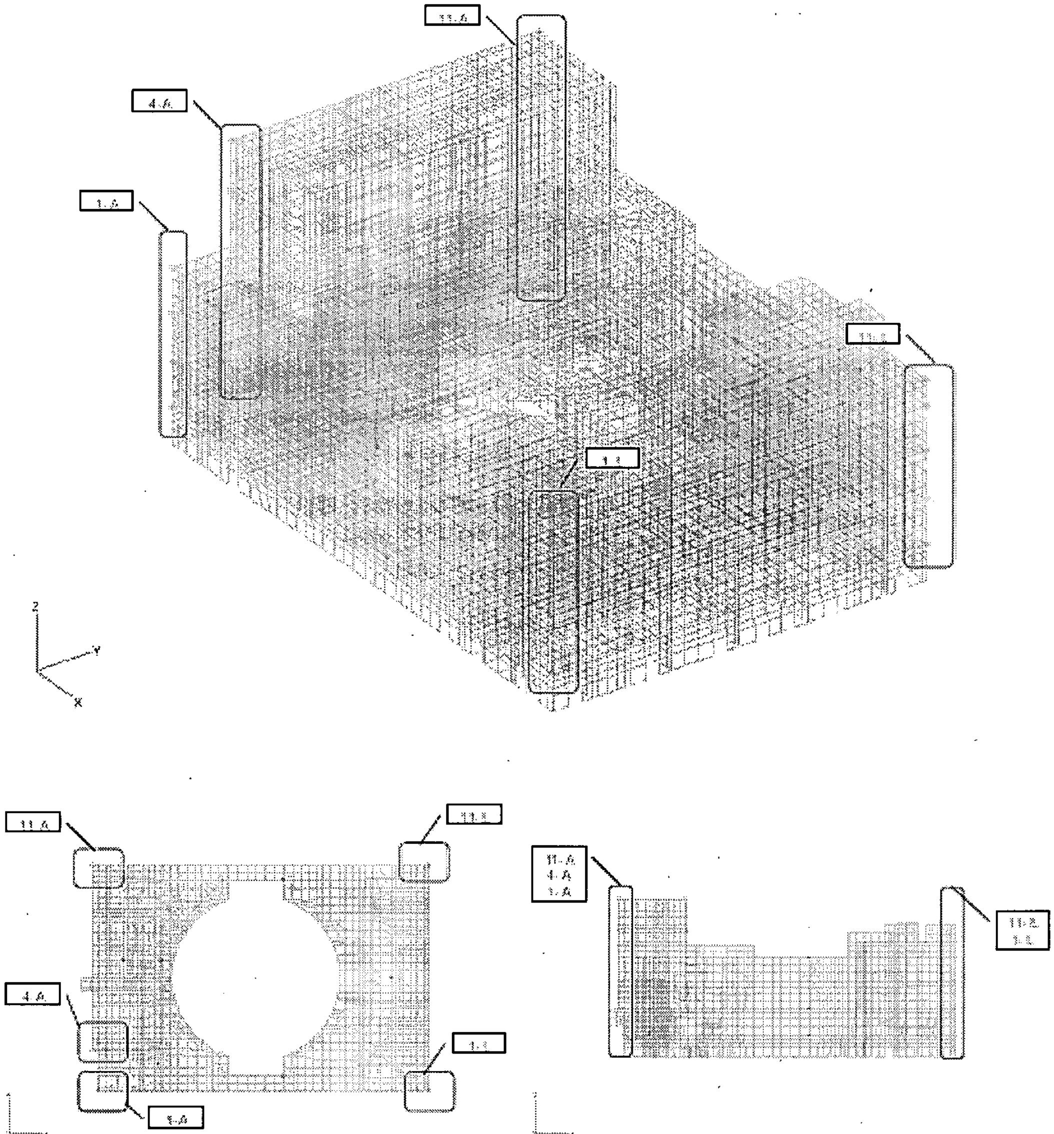

Fig.19.1 Fixed-Base FE Model of R/B

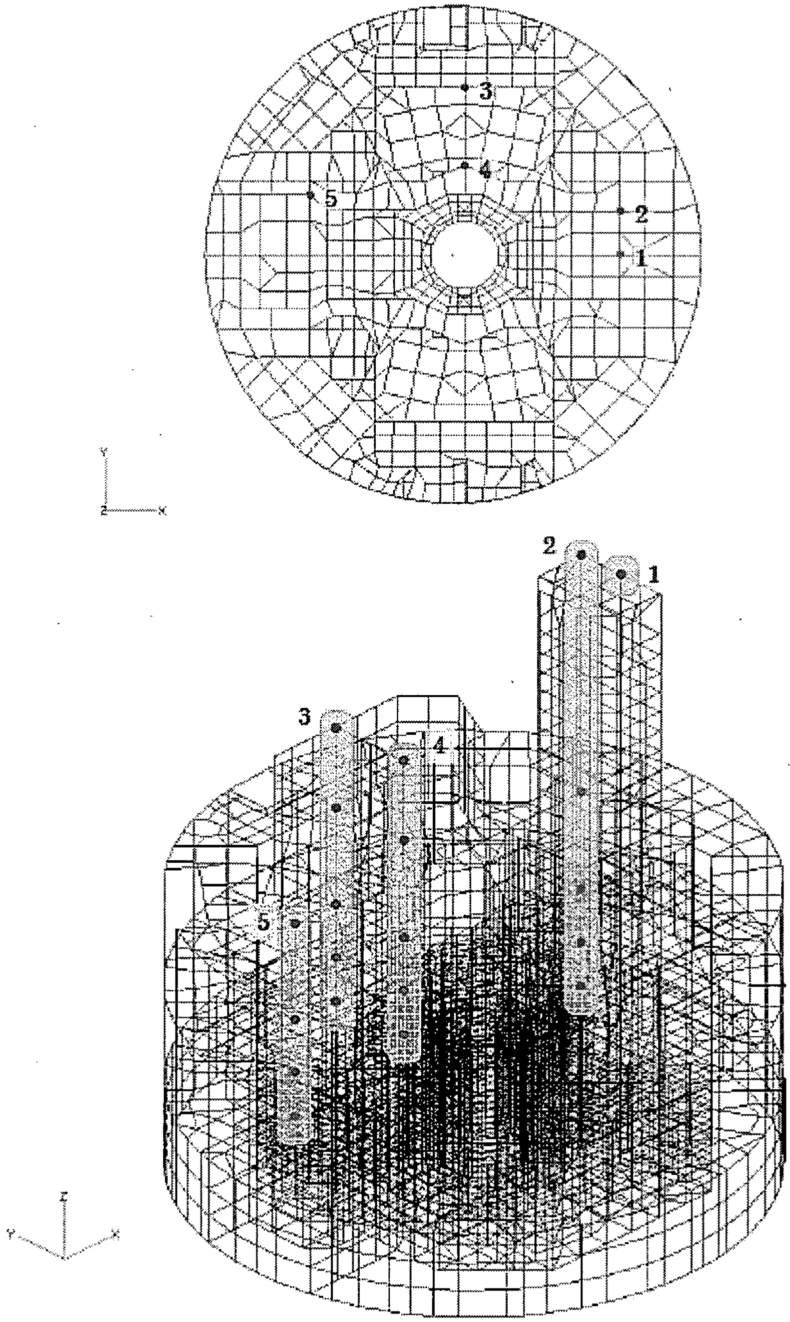

Fig.19.2 Fixed-Base FE Model of CIS

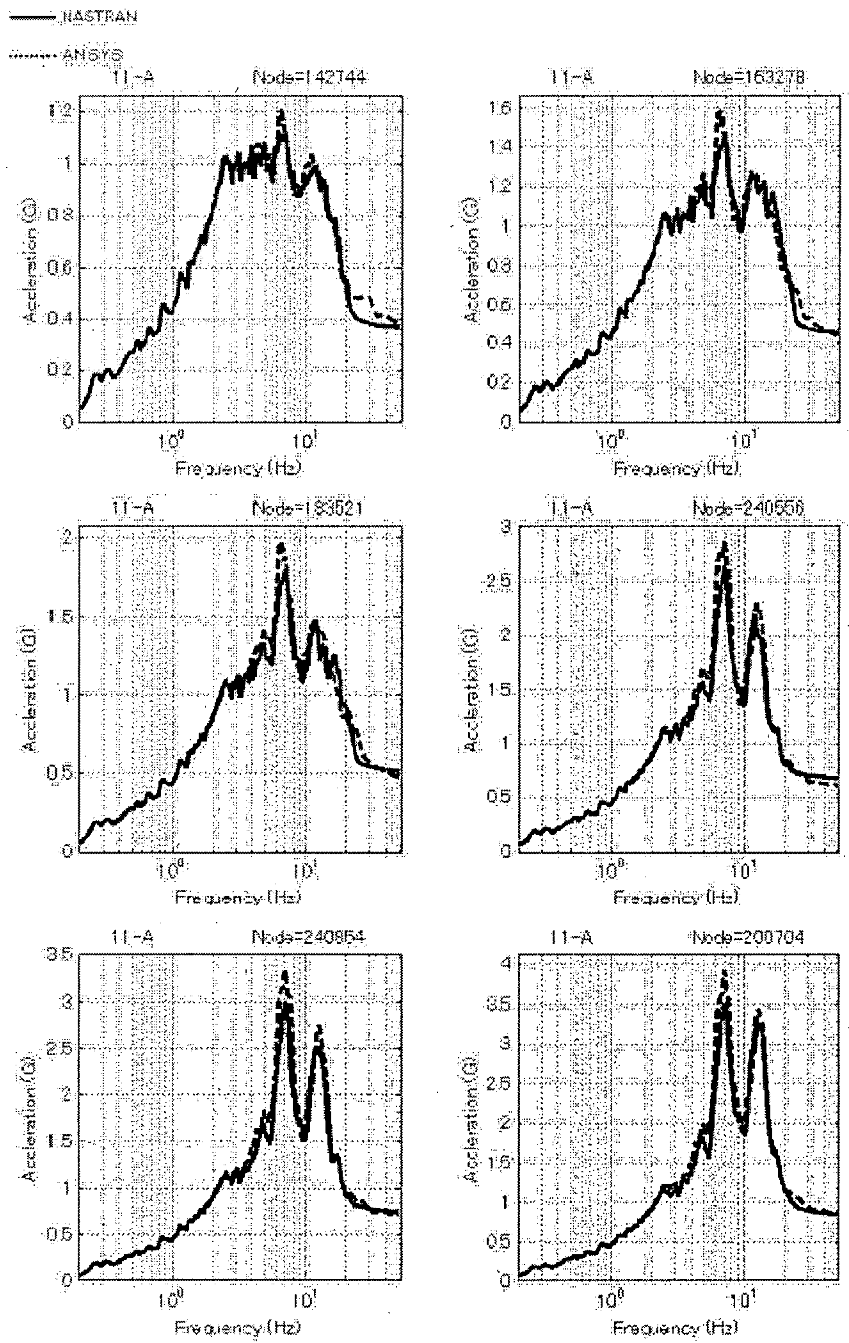

Fig.19.3 Comparison of ISRS for NASTRAN and ANSYS FE R/B models (EW Direction)
(Sheet 1 of 5)

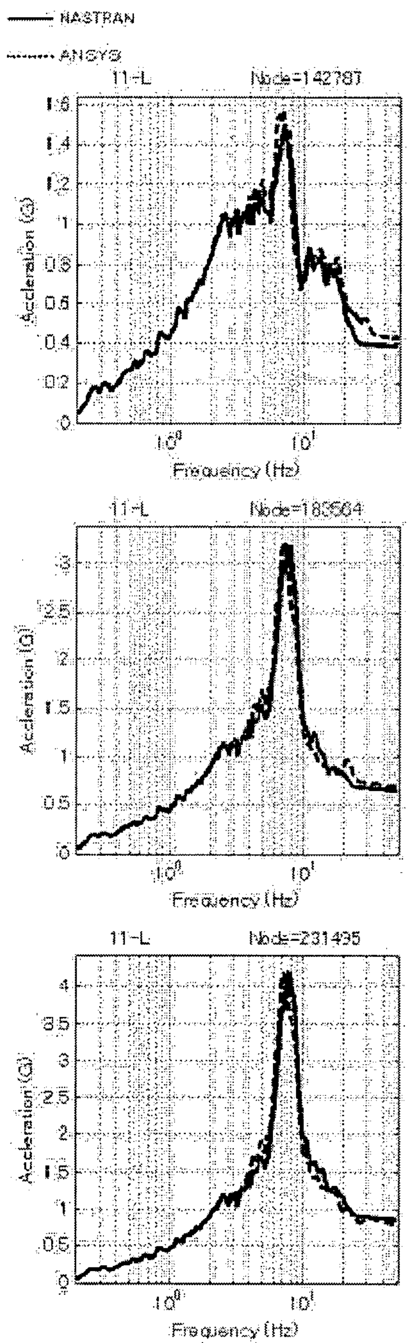

Fig.19.3 Comparison of ISRS for NASTRAN and ANSYS FE R/B models (EW Direction)
(Sheet 2 of 5)

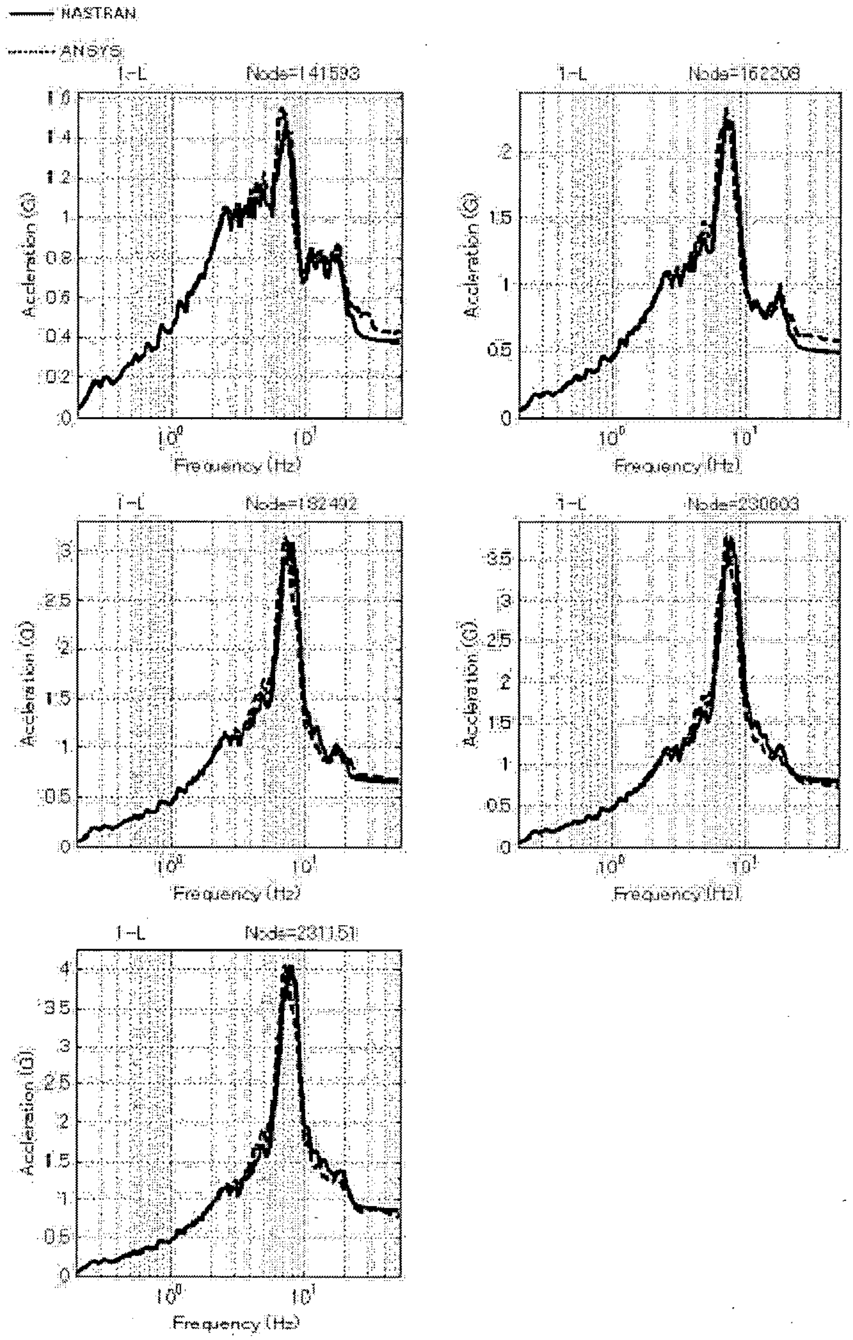

Fig.19.3 Comparison of ISRS for NASTRAN and ANSYS FE R/B models (EW Direction)
(Sheet 3 of 5)

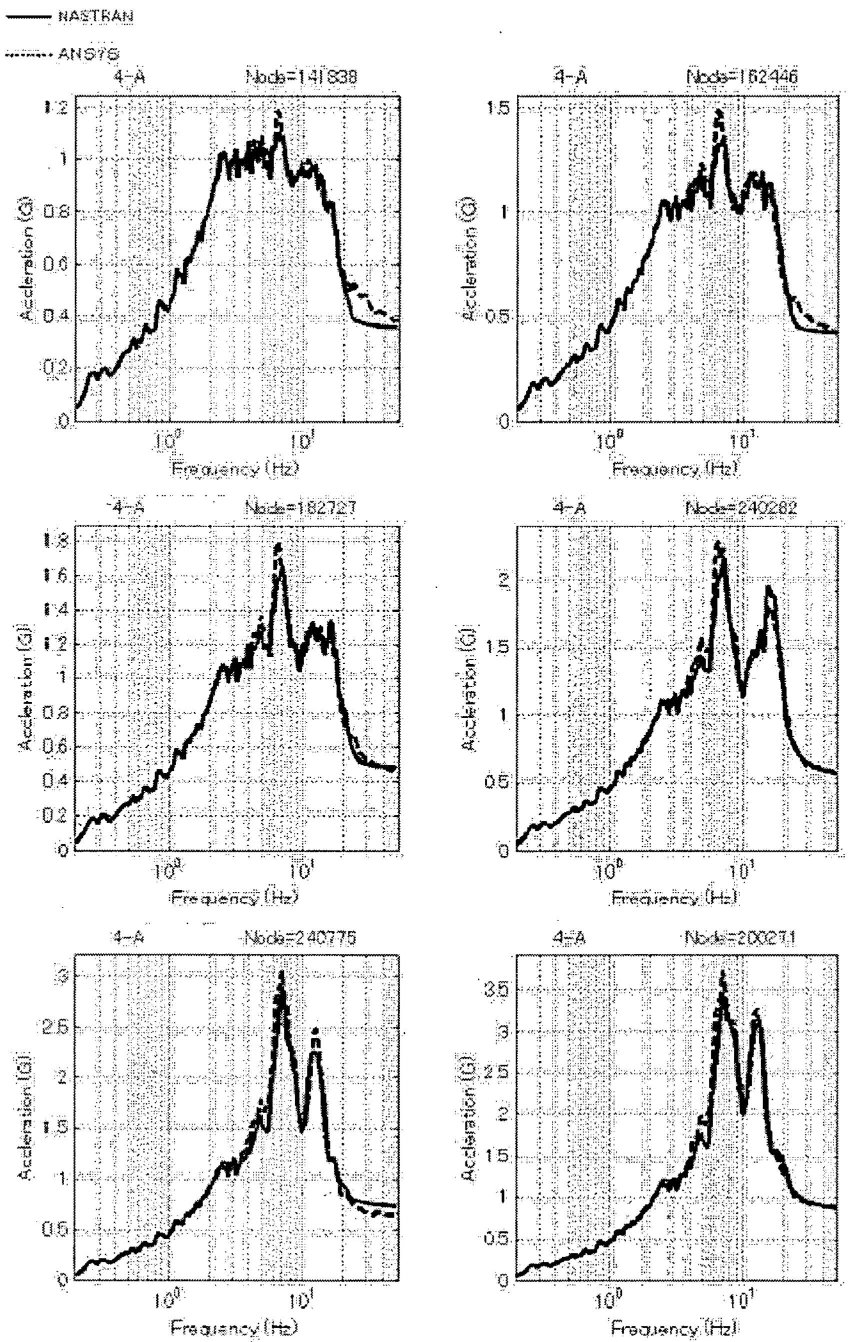

Fig.19.3 Comparison of ISRS for NASTRAN and ANSYS FE R/B models (EW Direction)
(Sheet 4 of 5)

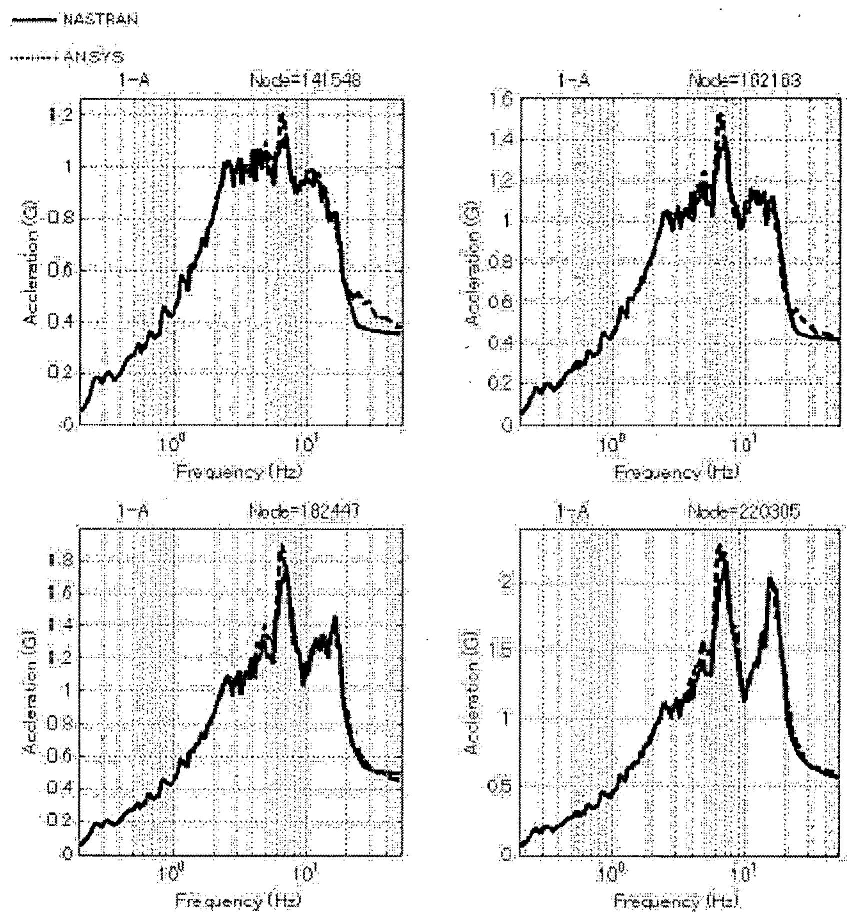

Fig.19.3 Comparison of ISRS for NASTRAN and ANSYS FE R/B models (EW Direction)
(Sheet 5 of 5)

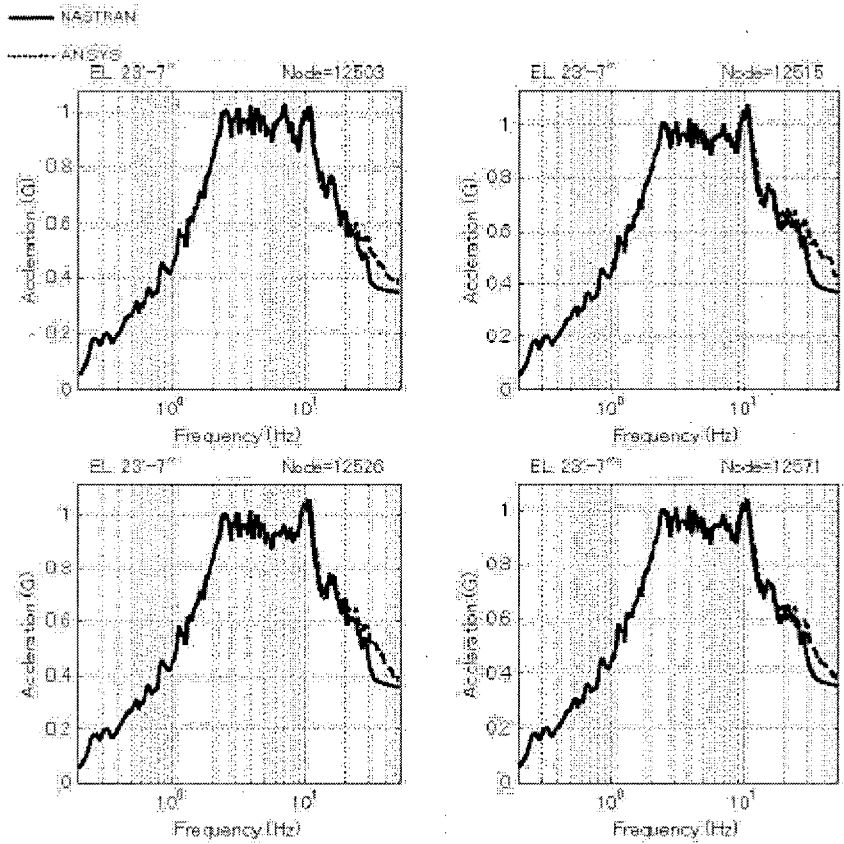

Fig.19.4 Comparison of ISRS for NASTRAN and ANSYS FE CIS models (EW Direction)

(Sheet 1 of 5)

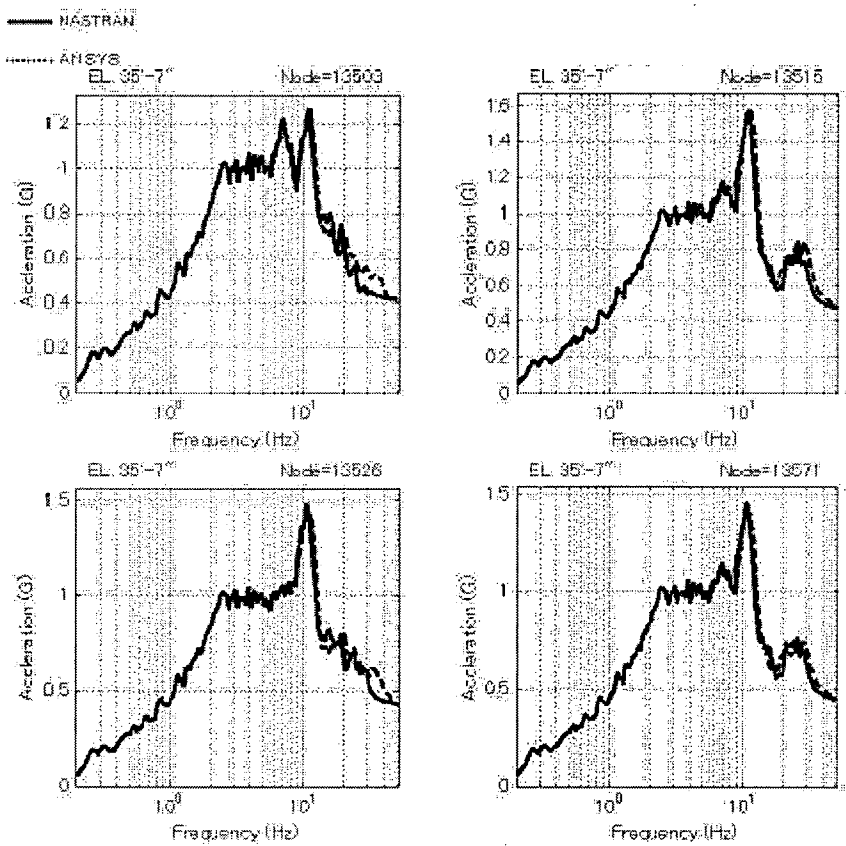

Fig.19.4 Comparison of ISRS for NASTRAN and ANSYS FE CIS models (EW Direction)
(Sheet 2 of 5)

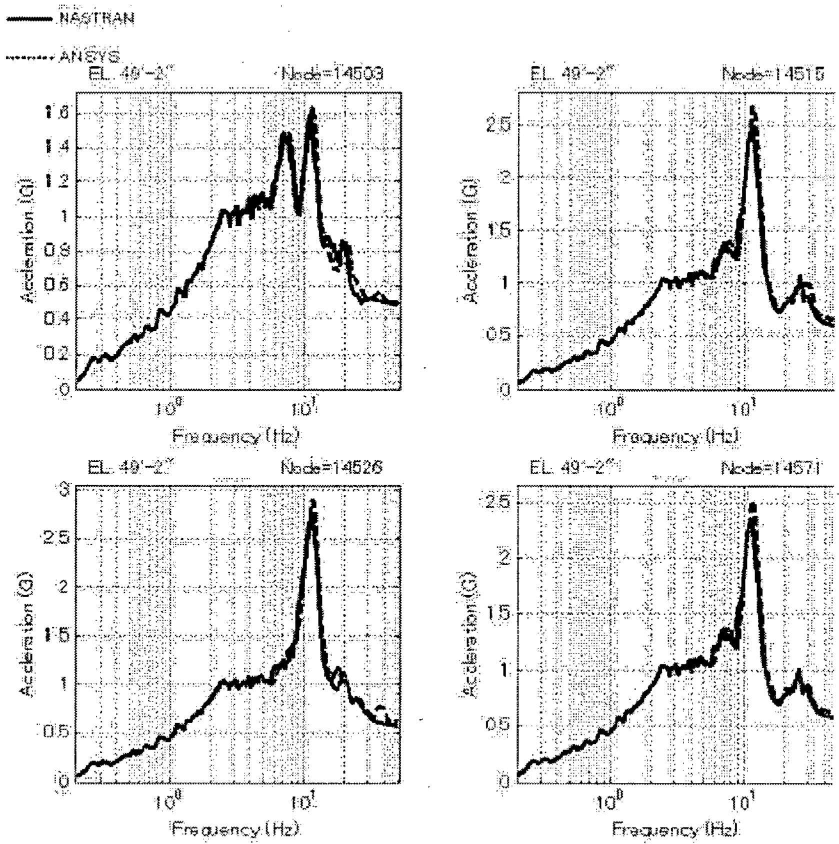

Fig.19.4 Comparison of ISRS for NASTRAN and ANSYS FE CIS models (EW Direction)
(Sheet 3 of 5)

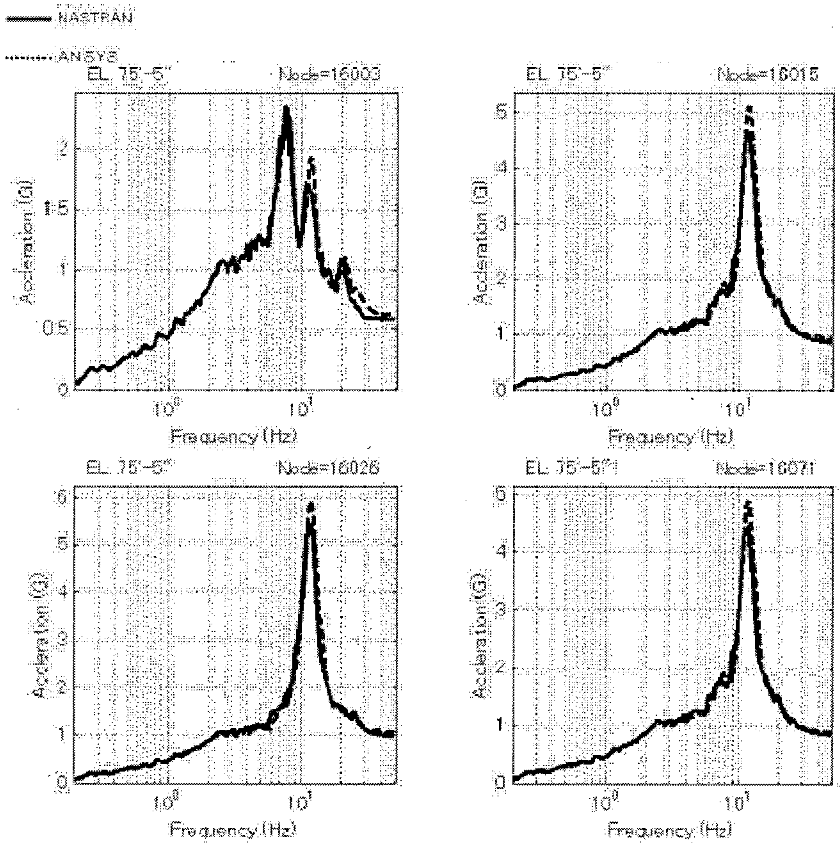

Fig.19.4 Comparison of ISRS for NASTRAN and ANSYS FE CIS models (EW Direction)
(Sheet 4 of 5)

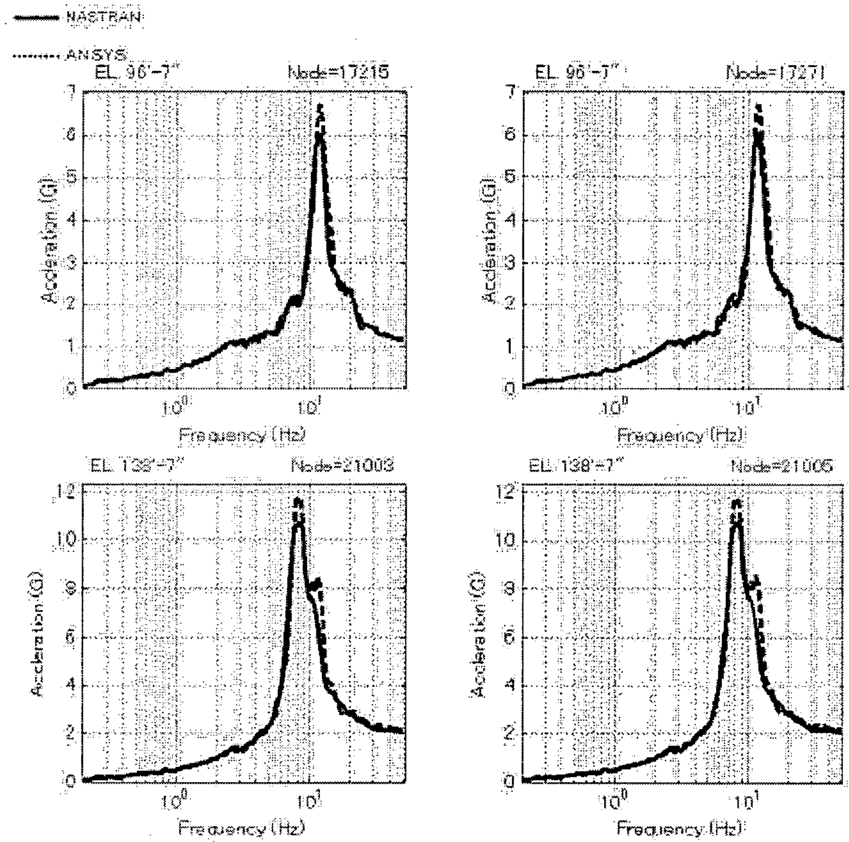

Fig.19.4 Comparison of ISRS for NASTRAN and ANSYS FE CIS models (EW Direction)
(Sheet 5 of 5)

Impact on DCD

Further results and details of NASTRAN and ANSYS FE model validations will be provided in Revision 2 of the DCD. The response previously submitted for RAI 212-1950, Question RAI 3.7.2-8, states the ISRS, considering local vibration modes, will be provided in Revision 2 of the DCD.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

5/07/2009

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 3.7.2-20:

Section 3.7.2.4 of the DCD states that the SSI analysis conservatively neglects the effects of embedment of the common R/B and PCCV basemat. The natural frequency of the structure is sensitive to the embedment effect and the seismic response of subsystem and equipment can be lower or higher depending on the seismic input ground motion and the frequency of subsystem or equipment of interest. Provide a technical basis including studies or test data to demonstrate that neglecting the effects of embedment results in conservative results.

ANSWER:

The word "conservatively" was intended to indicate that no credit was taken in the standard plant analyses for any reduction in the amplitude of the response due to embedment in the subgrade or backfill materials. It is acknowledged that embedment of a structure, even a shallow embedment, can affect the frequency of response. These considerations are evaluated on a site-specific basis for the R/B-PCCV on their common basemat. The third paragraph of Subsection 3.7.2.4 will be revised during Revision 2 of the DCD to clarify the discussion of embedment, and similar text in DCD Subsection 3.8.5.4.1 is to be revised to delete the word "conservatively".

The variations of site properties considered in the standard design by the four general subgrade conditions are deemed sufficient to envelope the variations of the seismic response due to the effects of the foundation embedment. COL item 3.7(25) requires the COL Applicant to verify the applicability of the standard design by performing site-specific soil-structure interaction (SSI) analyses. The site-specific SSI analyses must address the effects of the foundation embedment among the other site-specific factors as described in Subsection 3.7.2.4 and as collectively required by several COL items including, but not limited to, COL items 3.7(4), 3.7(10), 3.7(20), 3.7(22) and 3.7(23).

The "Handbook of Impedance Functions" (J. G. Sieffert and F. Cevaer, Quest Editions ISBN 2-908261-32-4) compiles solutions from a number of studies for impedance functions of circular and rectangular foundations supported by an elastic half space in Chapters 2 and 3, respectively. Tables 2.5, 2.6 and 3.5 within this publication present the solutions for frequency independent (static) stiffness coefficients of circular and square embedded foundations resting on elastic half space or elastic layer supported by elastic half-space. The following expression taken from Table 3.5 quantifies the increase of the frequency independent SSI stiffness of square foundation with footprint dimension (*B*) as a function of foundation embedment depth (*D*):

Vertical stiffness increase	$0.47\ D/B - 0.05\ (D/B)^2$
Horizontal stiffness increase	$1.13\ D/B - 0.16\ (D/B)^2$
Rocking stiffness increase	$0.98\ D/B - 1.13\ (D/B)^2$

Referring to Table 3.7.1-3 of the DCD, the ratio between the embedment depth (38.83 ft) and the smaller footprint dimension (210 ft) of the R/B and PCCV common foundation is 18.5%. When this value is substituted in the equations presented above, it can be seen that the increase in the SSI stiffness due to embedment is 8.5% in the vertical direction, 14.2% in rocking and 20.3% in the horizontal direction. Since frequency is proportional to the square root of the stiffness, this indicates that the effect on the natural frequencies of vibration of the overall SSI system due to embedment will be less than 10%.

The graphs in Sections 3 of Chapters 2 and 3 provide comparison of the complex SSI impedance as a function of frequency for foundations with different ratios of embedment depth and footprint dimensions. The graphs show that both the stiffness and the damping, represented by the real and imaginary part of the impedance functions, increase with the embedment of the foundation. The overall dissipation of energy in the system also increases due to the material damping of the embedment soil. The comparison of the solutions for SSI impedance of surface and embedded circular foundations provided in the figures in Section 2 of Chapter 3 show that the effects of the embedment are small for circular foundations with a ratio between the depth of the foundation and its footprint radius of 25%. Since the ratio between the embedment depth (38.83 ft) and the equivalent radius (143.7 ft) of the common foundation of the reactor building complex is about 27%, this serves as an indication of the relatively small effect of the embedment on the seismic response of the building.

Besides the stiffness and damping of the SSI system, the embedment also affects the kinematics of the SSI due to scattering of the incoming seismic waves from the foundation. The studies on the kinematic SSI effects that have been conducted by analyzing the response of mass-less foundations have shown that the kinematic interaction is less significant for shallower foundations with low embedment ratio.

The discussion above indicates that the embedment does not significantly affect the natural frequencies of the overall SSI system and that these effects are small enough to be covered by the variations of subgrade stiffness considered in the standard design seismic response analyses. The increased SSI damping due to the embedment reduces the response of the PCCV, RB and containment internal structure at resonant frequencies. Therefore, the standard design that is based on analyses of surface foundations in general envelopes the variations in the seismic response due to the embedment effects. Nevertheless, the effects of the embedment on the standard seismic design are verified on a site-specific basis by performing SSI analyses on models that consider the foundation embedment, site-specific soil properties, the water table elevation and the characteristics of the site-specific ground motion.

Impact on DCD

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

- Change the third paragraph of Subsection 3.7.2.4 to the following:

"The ratio of basemat depth-to-equivalent-radius for the R/B-PCCV basemat is approximately 0.27. ASCE 4-98 Subsection 3.3.4.2 (Reference 3.7-9) considers that a basemat depth-to-equivalent-radius ratio of less than 0.3 is an indication of a shallow embedment foundation, for which effects of the embedment on the seismic response of the building are generally not significant. SSI analysis performed as part of the site-independent US-APWR standard plant design neglects the effects of embedment of the common R/B and PCCV basemat. Therefore, the R/B-PCCV seismic models are not coupled with any subgrade or backfill material at the sides of the basemat or along the faces of below-grade exterior walls, and no credit is taken in the seismic analysis for reduction in amplitude of the response due to foundation embedment in the subgrade or backfill materials. Embedment effects, including shifts in the structural frequencies, are considered to be small enough to be enveloped by the variations of subgrade stiffness considered in the standard design seismic response analyses of a surface foundation. However, the effects of the embedment are required to be analyzed on a site-specific basis as discussed in Subsection 3.7.2.4.1 to confirm suitability of the design."

See Attachment 3 for a mark-up of DCD Tier 2, Section 3.8, Revision 2, changes to be incorporated.

- Change the third sentence of the last paragraph of Subsection 3.8.5.4.1 to the following: "Therefore, the R/B-PCCV seismic models are not coupled with any subgrade or backfill material at the sides of the basemat or along the faces of below-grade exterior walls, and no credit is taken in the seismic analysis for restraint due to the presence of these materials."

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

5/07/2009

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 3.7.2-24:

Section 3.7.2.8 of the DCD states that for the purposes of site-specific SSI analysis and for subgrade dynamic bearing capacity confirmation, it is acceptable to use maximum pressure distributions below the basemats of adjacent structures. Provide bases and technical justification for the position and describe how such pressure distributions will be determined and applied in an analysis.

ANSWER:

Seismic earth pressures for the design of the US-APWR standard plant are determined using analysis methods provided in ASCE 4-98. Seismic earth pressures for site-specific SSI analysis of seismic category I building structures are determined using dynamic finite element analyses with the computer program SASSI. The responses to questions RAI 3.7.2-13 and RAI 3.7.2-14 of this RAI provide further explanation to determine the seismic earth pressures for standard plant design and site-specific design, respectively.

To clarify the determination of pressure distributions, the fifth and sixth paragraphs of Subsection 3.7.2.8 will be changed during DCD Revision 2, including the deletion of statements to use maximum pressure distributions below the basemats of adjacent structures.

Refer also to the response to question RAI 3.7.2-5 for additional discussion and changes to Subsection 3.7.2.8 related to this question.

Impact on DCD

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

- Change the fifth paragraph of Section 3.7.2.8 to the following:

"With respect to the coupling of the dynamic responses of adjacent structures through the soil, the phenomenon of structure-to-structure interaction is neglected in the SSI analyses for the standard plant discussed in Subsection 3.7.2.4. Instead, the variations of site properties considered by the four general subgrade conditions are deemed sufficient to address the uncertainties related to possible structure-to-structure interaction effects on the overall seismic response results. It is the responsibility of the COL Applicant to further address structure-to-structure interaction if the specific site conditions can be important for the seismic response of particular US-APWR seismic category I structures, or may result in exceedance of assumed pressure distributions used for the US-APWR standard plant design."

- Change the sixth paragraph of Section 3.7.2.8 to the following:

"Maximum lateral earth pressure due to the backfill, surcharge due to live load or adjacent basemat bearing pressures, groundwater, and other such static-load effects on below-grade exterior walls are discussed in Section 3.8. The design of below-grade exterior walls for US-APWR seismic category I structures takes into account any dynamic increases of these loads due to a seismic event. This is accomplished through the use of conservative maximum static and dynamic lateral pressure distribution profiles developed using analysis methods provided in Section 3.5.3 of ASCE 4-98 (Reference 3.7-9)."

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

5/07/2009

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 3.7.2-27:

In Section 3.7.2.11 of the DCD, clarify the second bulleted item. It seems to state that the eccentricities between the mass centers and centers of rigidities for each floor are included to account for accidental torsion. However, the methodology is consistent with determining the torsional effects due to the known asymmetries in the distribution of mass and stiffness of the building rather than accidental torsion as implied in the DCD.

ANSWER:

The intention of the US-APWR DCD is to consider torsional effects in accordance with the recommendations outlined in Section 3.7.2.II.11 of SRP 3.7.2. The applicant's interpretation of Section 3.7.2.II.11, which is implemented in the design, is as follows:

The torsional effects in a building structure can come from two parts. First, torsional effects are due to the general layout of the building, which cause eccentricities between the center of mass and center of rigidities, and these eccentricities vary from floor elevation to floor elevation. These eccentricities cause torsional effects and as per Section 3.7.2.II.11, it is acceptable to account for these torsional effects by performing dynamic analysis that incorporates those torsional degrees of freedom. Second, torsional effects are due to consideration of accidental torsion, where an additional eccentricity of +/- 5 percent of the maximum building dimension is used for both horizontal directions. The effects of responses from these two parts are combined in the building structure designs.

Section 3.7.2.11 of the US-APWR DCD will be clarified and revised as provided in Attachment 1. The design will be reviewed to assure that the above interpretation is properly implemented in the design.

Impact on DCD

See Attachment 1 (which was submitted with partial RAI response in Transmittal Letter UAP-HF-09113, and is reattached for reference) for the mark-up of DCD Tier 2, Subsection 3.7, Revision 2, changes to be incorporated.

- Change the first bullet of second paragraph in Subsection 3.7.2.11 to the following:
    - "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."
- Change the second bullet of second paragraph in Subsection 3.7.2.11 to the following:
    - "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."
- Change the third bullet of second paragraph in Subsection 3.7.2.11 to the following:
    - "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 are considered in the design of building structures in order to capture worst case effects."
- Add the following as the fourth bullet of second paragraph in Subsection 3.7.2.11:
    - "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."
- Delete the third paragraph in Subsection 3.7.2.11 in its entirety.

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.

ATTACHMENT 1
to RAI 212-1950

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

Discussed in Subsection 3.7.3 are the seismic analyses applicable to seismic category I civil structure subsystems housed within or supported by the major seismic category I structures. Seismic and dynamic qualification of mechanical and electrical equipment and subsystems performed by testing is discussed in Section 3.10 and Appendix 3D. Mechanical subsystems include mechanical equipment, piping, vessels, tanks, heat exchangers, valves, and instrumentation tubing and tubing supports. The seismic analysis of mechanical subsystems is addressed in Sections 3.9 and 3.12. The mass inertia properties of the major civil structural, mechanical, and all other seismic subsystems are accounted for in the seismic system analyses, as explained further in Subsection 3.7.2.3.

3.7.2.1 Seismic Analysis Methods

The methods used for the seismic analysis of the US-APWR seismic category I systems conform to the requirements of SRP Subsections 3.7.1 (Reference 3.7-10) and 3.7.2 (Reference 3.7-16) ~~and generally to the analysis requirements of Section 3.2 of ASCE 4-98 (Reference 3.7-9)~~. Table 3.7.2-1, as updated by the COL Applicant to include site-specific seismic category I structures, presents a summary of dynamic analysis and combination techniques including types of models and computer programs used, seismic analysis methods, and method of combination for the three directional components for the seismic analysis of the US-APWR standard plant seismic category I buildings and structures.

The seismic response of the major seismic category I and seismic category II structures of the US-APWR is obtained from site-independent analyses that use the direct integration time history method. Three-dimensional lumped mass stick models are used to represent the mass inertia, stiffness, and damping properties of the buildings, structures, and basemats. The stiffness and damping properties of the subgrade are modeled using the lumped parameter approach developed in accordance with Subsection 3.3.4.2 of ASCE 4-98 (Reference 3.7-9). The case when the seismic category I system is founded on hard rock is also considered by using stick models fixed at the base. The analyses of all of the systems are performed for three orthogonal (two horizontal and one vertical) components of site-independent design earthquake ground motion.

The response of a multi-DOF linear system subjected to seismic excitation is generally represented by the following differential equation of motion:

$$[M]\ddot{\vec{x}} + [C]\dot{\vec{x}} + [K]\vec{x} = [M]\,\vec{u}_b\,\ddot{u}_g \qquad \text{(Eq. 3.7.2-1)}$$

where

$[M]$ = the (nxn) mass matrix of the dynamic system

$[C]$ = the (nxn) damping matrix of the dynamic system

$[K]$ = the (nxn) stiffness matrix of the dynamic system

$\vec{x}$ = the (nx1) column vector of relative displacements

$\dot{\vec{x}}$ = the (nx1) column vector of relative velocities

ATTACHMENT 2
to RAI 212-1950

$$\left[\vec{\phi}\right]^T \cdot [M] \cdot \left[\vec{\phi}\right] = [I]$$ (where [*I*] is an identity matrix)

The natural frequencies and the normalized mode shape matrix are obtained from the modal analysis of the combined soil-structure system.

The stiffness weighted modal damping ratio h_j of the j^{th} mode is obtained from the following equation:

$$h_j = \frac{\vec{\phi}_j^{\,T}\left[\overline{K}\right]\vec{\phi}_j}{\vec{\phi}_j^{\,T}\left[K\right]\vec{\phi}_j} \qquad \text{(Eq. 3.7.2-4)}$$

where

$[K]$ = the stiffness matrix of the combined soil-structure system composed as shown in Equation (3.7.2-2)

$\vec{\phi}_j$ = the j^{th} normalized mode shape vector

$\left[\overline{K}\right] = \sum [k_i] \cdot \xi_i$ = the modified stiffness matrix constructed from the products of the element stiffness matrices $[k_i]$ and the applicable damping ratio ξ_i. To be noted is that the damping ratio for the soil spring is set to zero, which means no material damping is assumed by the soil.

The stiffness matrix [K_C] and the damping matrix [C_C], representing the dynamic properties of the subgrade, are constructed from the lumped SSI parameters. The lumped SSI parameters are calculated from the formulas given in ASCE 4-98, Subsection 3.3.4 (Reference 3.7-9) that are based on closed form solutions for vibrations of a rigid basemat resting on elastic-half space. The values of the lumped parameters for damping in the horizontal direction are conservatively reduced to 60% of the values calculated from the formulas of ASCE 4-98 (Reference 3.7-9) unless an applicable justification based on site-specific conditions is applied.

The damping matrix of the combined soil-structure dynamic system [*C*] is non-proportional to the stiffness and the mass inertia of the dynamic system and as such prevents the decoupling of the differential equations of motion (Equation 3.7.2-1) into generalized coordinates. Therefore, the solution for the dynamic response of the soil-structure system is obtained from a time domain analysis that uses a direct integration method. The implicit integration technique is adopted based on Newmark β method (β=0.25, γ=0.5). The time step of integration (Δt) is set to 0.001 sec, which is verified to be small enough such that the use of $1/2\Delta t$ time step does not change the value of calculated response by more than 10%.

The above-described method utilizing direct integration for time history analysis is used for the analysis of the R/B-PCCV-containment internal structure on their common basemat. As an alternative option for seismic category I systems and subsystems, it is also acceptable to utilize the composite modal damping method associated with the modal superposition of time history analysis when the equations of motion can be decoupled~~, as discussed in Subsection 3.2.2.2 of ASCE 4-98 (Reference 3.7-9)~~ in accordance with SRP 3.7.2 (Reference 3.7-16), Section II.13.

Subsection 3.7.2.5 discusses development of ISRS based on the results of the site-independent seismic analyses for the US-APWR standard plant.

3.7.2.3 Procedures Used for Analytical Modeling

3.7.2.3.1 General Discussion of Analytical Models

The procedures used for analytical modeling of the major standard plant seismic category I and seismic category II structures are discussed herein.

The procedures used for development of analytical models for seismic analysis are consistent with the procedures and guidelines of ~~Chapter 3 of ASCE 4-98 (Reference 3.7-9) and~~ SRP 3.7.2, Section II.3 (Reference 3.7-16). Structural element mass and stiffness characteristics, as well as load and tributary masses, and damping characteristics, are incorporated into the models.

The models used for seismic analysis are developed by discretization of the mass inertia and stiffness properties of the dynamic system, such that the mass inertia of the system is lumped at distinct characteristic nodes, which are interconnected by a network of stiffness elements. The mass is lumped in selected nodes in a way that provides an adequate representation of the mass distribution considering the high-stress concentration points of the system. In general, lumped mass inertia is assigned at the selected locations in all six DOF corresponding to translations along three orthogonal axes, and rotations about these axes. The number of DOF should be reduced by the number of constraints, where applicable.

When the subsystem analysis is performed, reduced DOFs can be used to represent the dynamic behavior at locations needed for equipment qualification, provided that they can provide an adequate and conservative prediction of the response of the equipment.

The seismic analyses of the US-APWR standard plant are performed on three-dimensional lumped mass stick models representing the major seismic category I and seismic category II structures. The basic dimensions of these buildings and structures as considered in the seismic analyses are presented in the general arrangement drawings in Section 1.2. The models consider all six DOF (three rotational and three translational) and incorporate mass and stiffness eccentricities to assure that torsional and rocking/swaying effects, and any cross-directional coupling, are captured. Torsional and rocking/swaying effects are also captured at the basemat/subgrade interface through the use of lumped SSI parameters for all six DOF. The frequency independent lumped parameter formulation and methodology for calculation of lumped stiffness and damping coefficients is addressed in detail in the SSI analysis discussion in Subsection 3.7.2.4.

It is the responsibility of the COL Applicant to develop analytical models appropriate for the seismic analysis of buildings and structures that are designed on a site-specific basis including, but not limited to, the following:

- PSFSVs (seismic category I)
- ESWPT (seismic category I)
- UHSRS (seismic category I)

iii) Comparison of ISRS

Comparisons of ISRS are made between the three-dimensional stick model and the FE model at various points in various elevations as previously discussed.

3.7.2.3.11 Equivalent Masses due to Dead and Live Loads

In the design of seismic category I and seismic category II buildings and structures, dead loads and various portions of live loads are treated as equivalent masses for consideration in the global seismic analysis models. For example, 25% of the design floor live loads during normal operation (ASCE 7, Subsection 12.7.2 [Reference 3.7-24]) or 75% of the roof snow load, whichever is applicable depending on the specific location in the building or structure, have been considered in computing tributary mass at node points in the seismic models. This is consistent with SRP 3.7.2, Section II.3(d) (Reference 3.7-16). For the containment operating deck in the PCCV, the design floor live load for maintenance and refueling is 950 lb/ft^2 and the floor live load for normal operation is 200 lb/ft^2. Therefore, 50 lb/ft^2 (25% of 200 lb/ft^2) has been used as an equivalent live load (mass) for the seismic analysis models.

Equivalent dead loads used in the seismic analysis models also include the weight of SSCs not specifically identified or included as dead loads in the models such as the weight of minor piping systems, cables and cable trays, ducts, and all related supports. Similarly, equivalent live loads include fluid contained within the minor piping and equipment under operating conditions. The weight of permanently attached tanks (uniformly distributed over the room floor area) is included as equivalent dead load (mass) in the seismic models. For the seismic analysis models, an equivalent dead load of a minimum of 50 lb/ft^2 uniform load is applied to cover these conditions. This is consistent with SRP 3.7.2, Section II(3)(d) (Reference 3.7-16).

For floors with a significant number of small pieces of equipment (e.g., electrical cabinet rooms), their total weight divided by the floor area that effectively supports the equipment within the room, plus an additional 50 lb/ft^2, is used as the equivalent dead load.

The equivalent dead loads (mass) are appropriately increased in areas such as main piping corridors, and cable tray and HVAC ductwork runs where such loads exceed the value of 50 lb/ft^2.

3.7.2.4 Soil-Structure Interaction

In accordance with the requirements of SRP 3.7.2, Section II.4 (Reference 3.7-16), ~~and following the standards specified by ASCE 4-98, Section 3.3 (Reference 3.7-9),~~ SSI effects are considered in the seismic response analysis of all major seismic category I and seismic category II buildings and structures that are part of the US-APWR standard and non-standard plant. The SSI analyses use the lumped mass stick models that are described above in Subsection 3.7.2.3 to represent the dynamic properties of the super-structures. In the case of the SSI lumped parameter analysis of the R/B-PCCV-containment internal structure, a site-specific SSI analysis is also performed using the computer program SASSI (Reference 3.7-17) in order to confirm that site-specific effects are enveloped by the standard design.

The site-independent SSI analyses of US-APWR standard plant are performed by assuming an absolutely rigid basemat that rests on uniform linear-elastic half-space. A viscous damping represents the dissipation of energy in the elastic-half space that is due to radial damping in the subgrade media. This assumption allows the use of simple closed solutions in terms of frequency-independent lumped parameters that describe the stiffness and the dissipation of energy in the SSI system in the six DOF. Three DOF represent the translations of the basemat in two orthogonal horizontal directions and in the vertical direction. Two DOF represent the rocking of the basemat about two horizontal axes, and one rotational DOF describes the torsional vibrations of the basemat. The lumped parameters representing the stiffness and damping properties of the SSI are calculated from the formulas presented in Table 3.3-3, Subsection 3.3.4.2 of ASCE 4-98 (Reference 3.7-9). The values of the lumped SSI parameters for damping in two horizontal translational DOF are conservatively set at 60% of the theoretical dashpot values obtained from formulas in Table 3.3-3.

The ratio of basemat depth-to-equivalent-radius for the R/B-PCCV basemat is ~~less than 0.3 (the embedded depth is 38'-10"), which indicates a shallow embedment basemat for purposes of SSI as defined in ASCE 4-98, Subsection 3.3.4.2 (Reference 3.7-9)~~ approximately 0.27. ASCE 4-98 Subsection 3.3.4.2 (Reference 3.7-9) considers that a basemat depth-to-equivalent-radius ratio of less than 0.3 is an indication of a shallow embedment foundation, for which effects of the embedment on the seismic response of the building are generally not significant. SSI analysis performed as part of the site-independent US-APWR standard plant design ~~conservatively~~ neglects the effects of embedment of the common R/B and PCCV basemat. Therefore, the R/B-PCCV seismic models are not coupled with any subgrade or backfill material at the sides of the basemat or along the faces of below-grade exterior walls, and no credit is taken in the seismic analysis for ~~restraint due to the presence of these materials~~ reduction in amplitude of the response due to foundation embedment in the subgrade or backfill materials. Embedment effects, including shifts in the structural frequencies, are considered to be small enough to be enveloped by the variations of subgrade stiffness considered in the standard design seismic response analyses of a surface foundation. However, the effects of the embedment are required to be analyzed on a site-specific basis as discussed in Subsection 3.7.2.4.1 to confirm suitability of the design.

The use of frequency independent SSI impedance parameters is based on the assumption that the subgrade conditions are relatively uniform up to a depth of one equivalent basemat diameter below the bottom of the basemat of the major seismic category I structures. Dry soil conditions are assumed in order to simplify the analysis. The following values for shear wave velocity V_s, density γ and Poisson's ratio ν are assigned to the uniform elastic half-space to simulate the general subgrade conditions:

- Soft soil site, V_s = 1,000 ft/s, γ = 110 pcf, ν = 0.40
- Rock site (Medium 1), V_s = 3,500 ft/s, γ = 130 pcf, ν = 0.35
- Rock site (Medium 2), V_s = 6,500 ft/s, γ = 140 pcf, ν = 0.35
- Hard rock site, V_s = 8,000 ft/s, γ = 160 pcf, ν = 0.30

A fixed base analysis considers the hard rock case listed above. The values used for the soil shear wave velocities are considered to be compatible to the strain level corresponding to the site-independent SSE. Table 3.7.2-3 summarizes the US-APWR the subgrade properties by using at least three sets of site profiles that represent the best estimate, lower bound, and upper bound (BE, LB, and UB for equations, respectively) soil and rock properties. If sufficient and adequate soil investigation data are available, the LB and UB values of the initial (small strain) soil properties are established to cover the mean plus or minus one standard deviation for every layer. In accordance with Subsection 3.3.17 of ASCE 4-98 (Reference 3.7-9) the specific guidelines for SSI analysis contained in Section II.4 of SRP 3.7.2 (Reference 3.7-16), the LB and UB values for initial soil shear modulii (G_s) are established as follows:

$$G_s^{(LB)} = \frac{G_s^{(BE)}}{(1+C_v)} \quad \text{and} \quad G_s^{(UB)} = G_s^{(BE)} \ (1+C_v)$$

where C_v is a variation factor. ASCE 4-98 (Reference 3.7-9) mandates that value of C_v must be greater than 0.5. When insufficient data are available to address uncertainties in properties of deep soil layers, C_v must be greater than 1.0. For well investigated sites, the C_v should be no less than 0.5. For sites that are not well investigated, the C_v for shear modulus shall be at least 1.0.

The SSI analysis must use stiffness and damping properties of the subgrade materials that are compatible with the strains generated by the site-specific design earthquake (SSE or/and OBE). The soil properties may be considered strain-independent for subgrade materials with initial shear wave velocities of 3,500 ft/s or higher. The COL Applicant is to institute dynamic testing to evaluate the strain-dependent variation of the material dynamic properties for site materials with initial shear wave velocities below 3,500 ft/s. If the strains in the subgrade media are less than 2%, the strain compatible properties can be obtained from equivalent linear site-response analyses using soil degradation curves. Degradation curves that are published in literature can be used after demonstrating their applicability for the specific site conditions. The strain-compatible soil profiles for the site-specific verification SSI analyses of the major seismic category I structures can be obtained from the results of the site response analyses that are performed to calculate site-amplification factors for the development of GMRS, as described in Subsection 3.7.1.1.

The depth of the water table must be considered when developing the P-wave velocities of the submerged subgrade materials. Significant variations in the water table elevation and significant variations of the subgrade properties in the horizontal direction are addressed by using additional sets of site profiles.

To assure the proper comparability, the site-specific verification SSI analyses must use the same verified and validated lumped mass stick models of the building super-structure as those used for the US-APWR standard plant design. FE analyses are employed to evaluate the flexibility of the basemat and the embedded portion of the building. The floor slabs located at and above the ground surface are assumed absolutely rigid. In order to verify the converted structural model, a site-specific SSI analysis is performed with hard rock site profile that simulates fixed base conditions. The results of the SSI analysis with hard rock site profile are to match closely with the results from the analysis of fixed base stick model. In accordance with requirements of 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 as complex damping.

In the response spectra analysis, the low frequency modes are combined by one of the modal combination methods in accordance with RG 1.92, Rev.2 (Reference 3.7-27) as discussed above. For each support level, there is a pseudo-load vector or left-out-force vector in the X, Y, and Z directions.

These left-out-force vectors are used to generate left-out-force solutions which are multiplied by a scalar amplitude equal to a magnification factor specified by the user. This factor is usually the ZPA of the response spectra for the corresponding direction. The resultant low frequency responses are combined by the SRSS with the high frequency responses (rigid modes results).

3.7.2.8 Interaction of Non-Seismic Category I Structures with Seismic Category I Structures

The locations of all major buildings within the power block are shown on the general arrangement drawings in Section 1.2.

Seismic category II structures have been analyzed for the same seismic loads and using the same seismic analysis methods described for seismic category I SSCs in Subsection 3.7.2.1 to verify that they will not collapse or adversely interfere with seismic category I SSCs or adversely affect the MCR occupants. Seismic category II is defined in Section 3.2. By definition, seismic category II structures are designed to retain their position to the extent necessary to assure that they will not impact the function or integrity of seismic category I SSCs.

NS structures have been located such that, in case of their collapse or failure, they do not have the potential to impact seismic category I SSCs, either directly or indirectly.

NS structures that are not located beyond the range of impact are isolated by heavy concrete walls from seismic category I SSCs.

With respect to the coupling of the dynamic responses of adjacent structures through the soil, the phenomenon of structure-to-structure interaction is neglected in the SSI analyses <u>for the standard plant</u> discussed in Subsection 3.7.2.4. Instead, the variations of site properties considered by the four general subgrade conditions are deemed sufficient to address the uncertainties related to possible structure-to-structure interaction effects on the overall seismic response results. ~~Also, for purposes of site-specific SSI analysis as described in Subsection 3.7.2.4 and for subgrade dynamic bearing capacity confirmation, maximum anticipated vertical and lateral pressure distributions below adjacent structure's basemats are to be used. This is acceptable and in accordance with ASCE 4-98 (Reference 3.7-9) Subsection 3.3.1.5 and the related commentary in Subsection C3.3.1.5, provided that local effects such as at below-grade walls are taken into consideration (discussed further below).~~ It is the responsibility of the COL Applicant to further address structure-to-structure interaction if the specific site conditions can be important for the seismic response of particular US-APWR seismic category I structures, or may result in exceedance of assumed pressure distributions used for the US-APWR standard plant design.

~~In accordance with the requirements of Subsections 3.3.1.5 and 3.5.3 of ASCE 4-98 (Reference 3.7-9), the structural design of US-APWR seismic category I structures accounts for the local effects on below-grade exterior walls that are due to the interaction~~

with adjacent structures. Maximum lateral earth pressure due to the backfill, surcharge due to live load or adjacent basemat bearing pressures, groundwater, and other such static-load effects on below-grade exterior walls are discussed in Section 3.8. The design of below-grade exterior walls for US-APWR seismic category I structures takes into account any dynamic increases of these loads due to a seismic event. This is accomplished through the use of conservative maximum static and dynamic lateral pressure distribution profiles on exterior below-grade walls developed using analysis methods provided in Section 3.5.3 of ASCE 4-98 (Reference 3.7-9).

The COL Applicant is to assure that the design or location of any site-specific seismic category I SSCs, for example buried yard piping or duct banks, will not expose those SSCs to possible impact due to the failure or collapse of non-seismic category I structures, or with any other SSCs that could potentially impact, such as heavy haul route loads, transmission towers, non safety-related storage tanks, etc. Alternately, site-specific seismic category I SSCs are designed for impact loads due to postulated failure of the non-seismic category I SSCs.

Following is a discussion of major structures in the power block area with respect to potential interaction with seismic category I structures.

3.7.2.8.1 AC/B

The AC/B is structurally designed as a NS structure on reinforced concrete foundation located at the west side of the A/B (seismic category II). The AC/B is not located adjacent to any seismic category I SSCs. If the AC/B were to fail or collapse, it could impact the A/B which is a seismic category II structure. AC/B is smaller, shorter, and much less massive than the reinforced concrete A/B. In the unlikely event of impact, there would not be sufficient kinetic energy transfer to cause the A/B to displace beyond acceptable limits. Specifically, the A/B would not displace enough to impact the R/B, PS/Bs, or any other seismic category I SSCs.

The design philosophy of the AC/B is stated as follows.

- The seismic design is in accordance with the International Building Code (Reference 3.7-30) with an Importance Factor of 1.0.
- The structure is designed in accordance with applicable building codes.

3.7.2.8.2 T/B

The T/B is structurally designed as seismic category II, such that its integrity will not be impacted by a design basis seismic event; that is the T/B will not fail or collapse due to seismic loading. The T/B is located on the south sides of the R/B and the PS/Bs, and is separated from these structures with an expansion joint at all above-grade interface locations. The expansion joints are sized prevent contact between buildings, even if the maximum translational and rotational displacements due to a seismic loading (and other loading) were to occur. The minimum sizes of expansion joints must be obtained by considering, at all potential contact locations, the absolute summation of the T/B deflection and the adjacent structures' deflection (R/B, PS/Bs, and ESWPT) obtained from the response spectra or time history analysis results for those structures. The

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3.7.3.2 Procedures Used for Analytical Modeling

Seismic subsystems are defined as those systems that are not analyzed in conjunction with basemats and subgrade, as previously discussed in Subsection 3.7.2. The procedures used for analytical modeling of subsystems may be the same as those used for the major seismic category I and II building structures described previously in Subsection 3.7.2.3. These procedures include the use of mathematical computer models comprised of nodes and elements used to represent connections and members. The models are sufficiently detailed to represent the overall structural and seismic response. Depending on the complexity of the seismic subsystem, structure, or component being analyzed, detailed member design may be performed by hand calculations using the results of the overall building structural and seismic analyses. Alternatively, the computer model may be sufficiently detailed to be used for the design calculation of the individual members.

3.7.3.3 Analysis Procedure for Damping

Energy dissipation within a structural system is represented by equivalent viscous dampers in the mathematical model. The damping coefficients used are based on the material, load conditions, and type of construction used in the structural system. The SSE damping values to be used in the dynamic analysis for various seismic category I and II subsystems and their related supports are shown in Table 3.7.3-1(a). The damping values are based on RG 1.61 (Reference 3.7-15) ~~and ASCE Standard 4-98 (Reference 3.7-9)~~. The damping value of conduit, empty cable trays, and their related supports is similar to that of a bolted structure, namely 7% of critical. The damping value of filled cable trays and supports increases with increased cable fill and level of seismic excitation. The use of higher damping values for cable trays with flexible support systems (e.g., rod-hung trapeze systems, strut-hung trapeze systems, and strut-type cantilever and braced cantilever support systems) is permissible, subject to obtaining NRC review for acceptance on a case-by-case basis.

For subsystems that are composed of different material types, the composite modal damping approach with either the weighted mass or stiffness method is used to determine the composite modal damping value. Alternately, the minimum damping value may be used for these systems.

Composite modal damping for coupled building and piping systems is used for piping systems that are coupled to the RCL and the containment internal structure. Alternatively, Rayleigh damping with direct integration may be used. Seismic analysis of the RCL is addressed in a separate Technical Report (Reference 3.7-18), and piping systems coupled to the RCL are also addressed therein.

Piping systems are analyzed for SSE using 4% damping. Alternatively, frequency-dependent damping values may be utilized as noted and described in Tables 3.7.3-1(a) and 3.7.3-1(b). The seismic analysis of piping and other mechanical subsystems is addressed in further detail in Sections 3.9 and 3.12.

3.7.3.4 Three Components of Earthquake Motion

For seismic category I subsystems, the three components of earthquake motion are considered in the same manner as described in Subsection 3.7.2.6.

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SASSI analysis with the exception that no stick model is required. Instead, plate elements are to be directly included to represent the tunnel in the SASSI model.

3.7.3.8 Methods for Seismic Analysis of Category I Concrete 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.

3.7.3.9 Methods for Seismic Analysis of Aboveground Tanks

It is the responsibility of the COL Applicant to design seismic category I below- or above-ground liquid-retaining metal tanks such that they are enclosed by a tornado missile protecting concrete vault or wall, in order to confine the emergency gas turbine fuel supply.

The other seismic category I liquid-retaining vessels utilized in the design are reinforced concrete vessels whose walls and floors form part of the building structural framework, including the following:

- Spent fuel pit, located in the R/B with top of vessel at level 4F
- Refueling cavity, located in PCCV with top of vessel at level 4F
- Fuel transfer canal, which connects the spent fuel pit and refueling cavity
- Cask washdown pit located in the R/B with top of vessel at level 4F
- Cask loading pit and fuel inspection pit located in the R/B and connected to the spent fuel pit with a canal, with tops of vessels at level 4F
- New fuel storage pit located in the R/B with top of vessel at level 4F
- Refueling water storage pit, located in PCCV below level 2F

~~The hydrodynamic loads due to seismic sloshing are considered in the design of these structures as part of the seismic loading and are calculated in accordance with~~ Hydrodynamic loads including sloshing loads on these liquid-retaining vessels are determined using methods that conform to the provisions of Subsection II.14 of SRP 3.7.3 (Reference 3.7-35) and the guidance of ASCE 4-98, Subsection 3.5.4 (Reference 3.7-9). The horizontal response analysis considers both the impulsive mode (in which a portion of the water moves in unison with the tank wall) and the horizontal sloshing convective mode. The seismic sloshing analysis also considers potential slosh heights with respect to the potential of creating flooding, which is discussed in Section 3.4.

3.7.4 Seismic Instrumentation

The proposed seismic instrumentation program for the US-APWR is in accordance with NUREG-0800, SRP 3.7.4 (Reference 3.7-39) and all aspects of 10 CFR 50, Appendix S (Reference 3.7-7), which requires that "suitable instrumentation must be provided so that the seismic response of nuclear power plant features important to safety can be evaluated promptly after an earthquake." Appendix S of 10 CFR 50 (Reference 3.7-7)

t = thickness of SC module
t_s = thickness of plate on each face of SC module

3.8.3.4.2 Hydrodynamic Analyses

The vertical and lateral pressures of liquids inside containment are treated as dead loads. Structures supporting fluid loads during normal operation and accident conditions are designed for the hydrostatic as well as hydrodynamic loads as discussed in Subsection 3.7.3.9. ~~ASCE 4-98 Subsection 3.5.4.3., states "The fluid slosh height may be determined based upon the assumption of a rigid tank shell."~~ The hydrodynamic analyses take into account the flexibility of walls in considering fluid-structure interaction. Sloshing height, however, is calculated using a conservative simplified assumption of a rigid tank shell in accordance with guidance provided in ASCE 4-98 (Reference 3.8-34), Subsection 3.5.4.3.

3.8.3.4.3 Thermal Analyses

The RWSP water and containment operating atmosphere's temperature is considered stable. The operating thermal load for each concrete member is calculated as the average and gradient based on this condition. The stress analysis is carried out by inputting these loads into the corresponding part of R/B whole FE model. The normal thermal stresses for design are calculated in accordance with Appendix A of ACI 349 (Reference 3.8-8). The analysis reduction factor and modeling methods are shown in Table 3.8.3-3 and Table 3.8.3-4.

The RWSP water and containment atmosphere are subject to temperature transients in the event of a LOCA as described in Subsection 3.8.3.3. The accident temperature transients result in a nonlinear temperature distribution within the members. Temperatures within the concrete members are calculated in a unidimensional heat flow analysis. The accident thermal load (average and equivalent linear gradients) is calculated from this analysis, at selected times during the transient.

The stress analysis is carried out by inputting the accident thermal load into the corresponding part of R/B whole FE model, as well as other parts. The stresses of containment are used for containment design. Though the stresses of containment internal structure are also obtained at the same time, since these self-limiting stresses are released in ultimate condition under such as extreme and abnormal load conditions, they are not taken into account in calculation of required reinforcement steel.

Thermal transients for the DBAs are described in Section 6.3.

3.8.3.4.4 Design Procedures

The concrete members of the containment internal structure are designed by the strength method, as specified in the ACI "Code Requirements for Nuclear Safety-Related Structures", ACI-349 (Reference 3.8-8).

The primary and secondary shield walls, RWSP, refueling cavity, and other structural walls are designed using SC modules. SC modules are designed as reinforced concrete structures in accordance with the requirements of ACI-349 (Reference 3.8-8), as supplemented in the following paragraphs.

- ACI 318-99, Building Code Requirements for Structural Concrete, American Concrete Institute, 1999 (Reference 3.8-32).
- ACI 349-01, Code Requirements for Nuclear Safety-Related Concrete Structures, American Concrete Institute, 2001 (Reference 3.8-8).
- ANSI/AISC N690-1994, Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities, including Supplement 2 (2004), American National Standards Institute/American Institute of Steel Construction, 1994 & 2004 (Reference 3.8-9).
- ANSI/ANS-57.7 Design Criteria for an Independent Spent Fuel Storage Installation (Water Pool Type), American National Standards Institute/American Nuclear Society, 1997 (Reference 3.8-33).
- ~~ASCE 4-98, Seismic Analysis of Safety-Related Nuclear Structures and Commentary on Seismic Analysis of Safety-Related Nuclear Structures, American Society of Civil Engineers, 1998 (Reference 3.8-34).~~
- ASCE 7-05, Minimum Design Loads for Buildings and Other Structures, American Society of Civil Engineers, 2005 (Reference 3.8-35).
- ASCE 37-02, Design Loads on Structures During Construction, American Society of Civil Engineers, 2002 (Reference 3.8-36).
- ASME BPVC-III, Rules for Construction of Nuclear Facility Components - Section III Division 1 - Subsection NF - Supports, American Society of Mechanical Engineers, 2001 Edition through the 2003 Addenda (Reference 3.8-2).
- ASME NQA-2-1983, Quality Assurance Requirements for Nuclear Power Plants, with ASME NQA-2a-1985, Addenda to ASME NQA-2-1983, American Society of Mechanical Engineers (Reference 3.8-37).
- Specification for the Design of Cold-Formed Steel Members. 1996 Edition and Supplement No 1, American Iron and Steel Institute, July 30, 1999 (Reference 3.8-38).
- ACI-304R, Guide for Measuring, Mixing, Transporting, and Placing Concrete, American Concrete Institute, 2000 (Reference 3.8-39).

Appendix 3A, Section 3A.2, lists the applicable codes, standards and specifications for HVAC ducts and duct supports. Appendix 3F, Section 3F.2, lists the applicable codes, standards and specifications for conduit and conduit supports. Appendix 3G, Section 3G.2, lists the applicable codes, standards and specifications for cable trays and cable tray supports.

3.8.4.3 Loads and Load Combinations

Loads considered in the design are listed below. Not all loads listed are necessarily applicable to all structures and their elements. The loads for which each structure is designed are dependent on the applicable conditions.

The COL Applicant is to identify any applicable externally generated loads. Such site-specific loads include those induced by floods, potential non-terrorism related aircraft crashes, explosive hazards in proximity to the site, and projectiles and missiles generated from activities of nearby military installations. Loads that are due to malevolent vehicle assault, aircraft impact, and accidental explosion are taken as W_t in load combination 5 in accordance with RG 1.142 (Reference 3.8-19), Regulatory Position 7. Externally generated loads are not normally postulated to occur simultaneously with abnormal plant loads; however, the applicable loads and the related load combinations are determined on a case-by-case basis.

3.8.4.3.1 Dead Loads (D)

Dead loads are taken as the weight of all permanent construction/installations including fixed equipment and tanks. Uniform and/or concentrated dead loads are generally utilized for design of individual members. Equivalent dead loads are used during global analyses as conservative uniform load allowances of minor equipment and distribution systems, including small bore piping.

3.8.4.3.1.1 Dead Loads (Uniform and/or Concentrated)

Dead loads include the weight of structures such as slabs, roofs, decking, framing (beams, columns, bracing, and walls), and the weight of permanently attached major equipment, tanks, machinery, cranes, elevators, etc. The deadweight of equipment is based on its bounding operating condition including the weight of fluids. In addition, permanently attached non-structural elements such as siding, partitions, and insulation are included. Dead loads of cranes and elevators do not include the rated capacity lift or impact.

3.8.4.3.1.2 Equivalent Dead Load (Uniform)

Equivalent dead load includes the weight of minor equipment not specifically included in the dead load defined in Subsection 3.8.4.3 and the weight of piping, cables and cable trays, ducts, and their supports. It also includes fluid contained within the piping and minor equipment under operating conditions. Floors are checked for the actual equipment loads. To account for permanently attached small equipment, piping, ductwork and cable trays, a minimum equivalent dead load of 50 lb/ft^2 is applied. Where piping, ductwork, or cable trays are supported from platforms or walkway beams, actual loads may be determined and used in lieu of a conservative loading.

For floors with a significant number of small pieces of equipment (e.g., electrical cabinet rooms), the equivalent dead load is determined by dividing the total equipment weight by the floor area that effectively supports the equipment within the room, plus an additional 50 lb/ft^2.

3.8.4.3.2 Liquid Loads (F)

The vertical and lateral pressures of liquids are treated as dead loads except for external pressures due to ground water which are treated as live loads. The effects of buoyancy and flooding on SSCs are considered, where applicable. Structures supporting fluid loads during normal operation and accident conditions are designed for the hydrostatic as well as hydrodynamic loads. Hydrodynamic loads due to seismic sloshing are determined as discussed in Subsection 3.7.3.9 ~~calculated per ASCE Standard 4-98 (Reference 3.8-34)~~, and included in earthquake load E_s. For the purposes of evaluating flotation in Subsection 3.8.5.3, F_b is the buoyant force of the design-basis flood or high ground water table, whichever is greater.

The bottom layer of basemat reinforcement is arranged in a rectangular grid. The basemat also consists of a top layer of reinforcement, and vertical shear reinforcement.

3.8.5.1.3 Site Specific Structures

Other non-standard seismic category I plant buildings and structures of the US-APWR are designed by the COL Applicant based on site-specific subgrade conditions.

3.8.5.2 Applicable Codes, Standards and Specifications

The following industry codes, standards and specifications are applicable for the design, construction, materials, testing and inspections of the PCCV basemat. Pressure retention requirements of the vessel are in accordance with the guidance from SRP 3.8.1. (Reference 3.8-7).

- Rules for Construction of Nuclear Facility Components, Division 2, Concrete Containments, Section III, American Society of Mechanical Engineers, 2001 Edition through the 2003 Addenda (hereafter referred to as ASME Code). (Reference 3.8-2).

  Note: Articles CC-1000 through CC-6000 of Section III, Division 2 are acceptable for the scope, material, design, construction, examination, and testing of concrete containments of nuclear power plants subject to the regulatory positions provided by RG 1.136 (Reference 3.8-3).

The following industry standards are applicable for the design and construction of seismic category I basemats not required as a pressure retention boundary. Other codes, standards and specifications applicable to materials, testing and inspections are provided in Subsections 3.8.4.6 and 3.8.4.7.

- ACI 349-01, Code Requirements for Nuclear Safety-Related Concrete Structures, American Concrete Institute, 2001 (Reference 3.8-8)
- RG 1.142, Rev. 2, Safety-Related Concrete Structures for Nuclear Power Plants (Other Than Reactor Vessels and Containments), U.S. Nuclear Regulatory Commission, Washington, DC, November 2001. (Reference 3.8-19)
- ~~ASCE 4-98, Seismic Analysis of Safety-Related Nuclear Structures and Commentary, American Society of Civil Engineers, 1998 (Reference 3.8-34)~~

3.8.5.3 Loads and Load Combinations

Loads and load combinations are discussed in detail in Subsections 3.8.1.3 and 3.8.4.3. The containment design pressure P_d of 68 psi is included as an accident pressure in these load cases. Other load combinations applicable to the design of the basemat include acceptance criteria for overturning, sliding, and flotation as detailed in Table 3.8.5-1. The non-ASME portion of the basemat is designed in accordance with ACI-349 (Reference 3.8-8) and the provisions of RG 1.142 (Reference 3.8-19), where applicable. The reinforced concrete basemat for the PCCV and enveloped containment internal structure are designed in accordance with ASME Code Section III, Division 2,

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The foundation depth-to-equivalent-radius ratio for the R/B-PCCV basemat is less than 0.3, which indicates a shallow embedment foundation for purposes of SSI as defined in ASCE 4-98, Subsection 3.3.4.2 (Reference 3.8-34). Embedment effects on the R/B and PCCV SSI analysis are neglected in the US-APWR standard plant design in obtaining the soil impedance functions. Therefore, ~~conservatively,~~ the R/B-PCCV seismic models are not coupled with any subgrade or backfill material at the sides of the basemat or along the faces of below-grade exterior walls, and no credit is taken in the seismic analysis for restraint due to the presence of these materials. Subsequently, there are no explicit requirements for shear wave velocity or other material characteristics requirements for the subgrade and/or backfill materials present on the sides of the basemat and R/B below-grade exterior walls. Subsection 3.7.2.4 provides additional discussion on the SSI analysis.

3.8.5.4.2 Analyses for Loads during Operation

The major seismic category I structures basemat analyses use 3-dimensional NASTRAN FE models of the major seismic category I structures, which are described in Subsection 3.7.2.3. Soil springs are assigned in the model to determine the interaction of the basemat with the overlying structures and with the subgrade. The model is capable of determining the possibility of uplift of the basemat from the subgrade during postulated SSE events. The vertical spring at each node in the analytical model act in compression only. The horizontal springs are active when the vertical spring is in compression and inactive when the vertical spring lifts off. Horizontal bearing reactions on the side walls below grade are conservatively neglected for the analysis of the basemat. However, horizontal forces are considered in the analysis of the wall.

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

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

Dead loads are applied as inertia loads. Live loads and the SSE loads are applied as concentrated loads on the nodes. The SSE loads are applied as equivalent static loads using the assumption that while the maximum response from one direction occurs, the responses from the other two directions are 40% of the maximum. Combinations of the three directions of the SSE are considered.

Linear analyses are performed for all specified load combinations assuming that the soil springs can not take tension. The results of the linear cases are then used to select critical load cases for non-linear analyses. The results from these analyses include the forces, shears, and moments in the basemat; the bearing pressures under the basemat; and the area of the basemat that is uplifted. Minimum area of steel reinforcement is calculated from the section forces for the most critical load combinations.

The required reinforcement steel for the portion of the basemat under the R/B (other than PCCV) is determined by considering the reinforcement envelope for the full non-linear iteration of the most critical load combinations.