**MITSUBISHI HEAVY INDUSTRIES, LTD.**
**16-5, KONAN 2-CHOME, MINATO-KU**
**TOKYO, JAPAN**

April 3, 2012

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-12083

**Subject:** MHI's Responses to US-APWR DCD RAI No. 894-6270 Revision 3 (SRP 03.08.03)

**Reference:** 1) "Request for Additional Information No. 894-6270 Revision 3, SRP Section: 03.08.03 - Concrete and Steel Internal Structures of Steel or Concrete Containments," dated January 25, 2012.

With this letter, Mitsubishi Heavy Industries, Ltd. ("MHI") transmits to the U.S. Nuclear Regulatory Commission ("NRC") a document entitled "Response to Request for Additional Information No. 894-6270, Revision 3."

Enclosed is the response to the RAIs contained within Reference 1.

As indicated in the enclosed materials, this document contains information that MHI considers proprietary, and therefore should be withheld from public disclosure pursuant to 10 C.F.R. § 2.390 (a)(4) as trade secrets and commercial or financial information which is privileged or confidential. A non-proprietary version of the document is also being submitted with the information identified as proprietary redacted and replaced by the designation "[ ]".

This letter includes a copy of the proprietary version of the RAI response (Enclosure 2), a copy of the non-proprietary version of the RAI response (Enclosure 3), and the Affidavit of Yoshiki Ogata (Enclosure 1) which identifies the reasons MHI respectfully requests that all material designated as "Proprietary" in Enclosure 2 be withheld from disclosure pursuant to 10 C.F.R. § 2.390 (a)(4).

Please contact Joseph Tapia, General Manager of Licensing Department, 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,
Director- APWR Promoting Department
Mitsubishi Heavy Industries, LTD.

D081
NRO

Enclosures:

1. Affidavit of Yoshiki Ogata
2. Response to Request for Additional Information No. 894-6270, Revision 3 (proprietary)
3. Response to Request for Additional Information No. 894-6270, Revision 3 (non-proprietary)

CC: J. A. Ciocco
J.Tapia

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Docket No. 52-021
MHI Ref: UAP-HF-12083

# ENCLOSURE 1

## MITSUBISHI HEAVY INDUSTRIES, LTD.

## AFFIDAVIT

I, Yoshiki Ogata, state as follows:

1. I am Director, APWR Promoting Department, of Mitsubishi Heavy Industries, LTD ("MHI"), and have been delegated the function of reviewing MHI's US-APWR documentation to determine whether it contains information that should be withheld from public disclosure pursuant to 10 C.F.R. § 2.390 (a)(4) as trade secrets and commercial or financial information which is privileged or confidential.

2. In accordance with my responsibilities, I have reviewed the enclosed document entitled "Responses to Request for Additional Information No. 894-6270, Revision 3," dated April 2012, and have determined that portions of the document contain proprietary information that should be withheld from public disclosure. All pages contain proprietary information as identified with the label "Proprietary" on the top of the page, and the proprietary information has been bracketed with an open and closed bracket as shown here "[ ]". The first page of the document indicates that all information identified as "Proprietary" should be withheld from public disclosure pursuant to 10 C.F.R. § 2.390 (a)(4).

3. The information identified as proprietary in the enclosed documents has in the past been, and will continue to be, held in confidence by MHI and its disclosure outside the company is limited to regulatory bodies, customers and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and is always subject to suitable measures to protect it from unauthorized use or disclosure.

4. The basis for holding the referenced information confidential is that it describes the unique design and methodology developed by MHI as it provides the analytical and testing basis for the qualification of steel concrete modules.

5. The referenced information is being furnished to the Nuclear Regulatory Commission ("NRC") in confidence and solely for the purpose of information to the NRC staff.

6. The referenced information is not available in public sources and could not be gathered readily from other publicly available information. Other than through the provisions in paragraph 3 above, MHI knows of no way the information could be lawfully acquired by organizations or individuals outside of MHI.

7. Public disclosure of the referenced information would assist competitors of MHI in their design of new nuclear power plants without incurring the costs or risks associated with the design of the subject systems. Therefore, disclosure of the information contained in the referenced document would have the following negative impacts on the competitive position of MHI in the U.S. nuclear plant market:

   A. Loss of competitive advantage due to the costs associated with the development of the unique design parameters.

   B. Loss of competitive advantage of the US-APWR created by the benefits of the steel concrete module design.

I declare under penalty of perjury that the foregoing affidavit and the matters stated therein are true and correct to the best of my knowledge, information and belief.

Executed on this 3rd day of April, 2012.

Y. Ogata

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

Enclosure 3

UAP-HF-12083
Docket No. 52-021

# Response to Request for Additional Information No. 894-6270, Revision 3

April, 2012

(Non-Proprietary)

# RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

**4/2/2012**

**US-APWR Design Certification**

**Mitsubishi Heavy Industries**

**Docket No. 52-021**

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|---|---|
| **RAI NO.:** | **NO. 894-6270 REVISION 3** |
| **SRP SECTION:** | **03.08.03 – Concrete and Steel Internal Structures of Steel or Concrete Containments** |
| **APPLICATION SECTION:** | **3.8.3** |
| **DATE OF RAI ISSUE:** | **1/25/2012** |

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**QUESTION NO. RAI 03.08.03-56:**

The Executive Summary of MHI Technical Report MUAP-11018-P (R0), page vii, states "However, some aspects of SC specific behavior can cause slight deviations from RC behavior. For example: ... (iii) The steel reinforcement ratios for SC walls are much higher (about 2-4%)." Since this range of steel ratios for SC members is very high, the staff requests that the applicant explain what is the technical basis for accepting these higher values. In addition, the staff requests that the applicant provide sufficient test data to show that the steel-concrete (SC) composite member performance is equal to or better than reinforced concrete (RC) members. This should be demonstrated by comparison of performance parameters that include stiffness, ultimate strength, cyclic behavior, and ductility in all member directional loadings (i.e., membrane, bending, shear in and out of plane, and combination of these loadings).

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**ANSWER:**

The technical basis for accepting the higher reinforcement ratio (2-4%) is that these ratios are representative of typical SC designs and specimens that have been tested and included in the experimental database for developing the design criteria. SC walls cannot be made with lower reinforcement ratios because of the minimum plate thickness requirements associated with local bending due to concrete hydrostatic pressure during casting. Finally, the steel faceplate thickness is also governed by local buckling requirements, which have been described in Technical Report MUAP-11019 Chapter 2.2. As shown there, the steel plate thickness has been designed to achieve yielding before local buckling under applied compressive loads. This results in larger steel plate thickness, and consequently higher reinforcement ratios.

ACI 349-06 limits steel reinforcement ratio for flexural and compression members in Sections 10.3.5 and 10.9.1. For compression members, area of longitudinal reinforcement is limited to a maximum of $0.08*A_g$, which exceeds the maximum reinforcement ratio used in the US-APWR SC walls. In terms of the flexural member limitation inherent in Section 10.3.5, MUAP-11019 Section 5.2.2 explains that this limit does not apply to SC walls because they are doubly reinforced with equal steel plate area and strength on both the compression and tension faces. Because of the balance of tension and compression reinforcement in the SC walls, the limiting concrete compressive strain (0.003) cannot be reached before the tension reinforcement has yielded except under very large axial compression values.

The SC walls in the US-APWR CIS have reinforcement ratios between [ ] The reinforcement ratios used in the tests range from [ ] which covers the range of values used in the US-APWR. This is illustrated in the experimental database table submitted in response to Question 03.08.03-45 in RAI 858-6126. Thus, the technical basis for accepting these higher reinforcement ratios are: (i) practical considerations of steel plate stiffness for resisting concrete casting hydrostatic pressure, (ii) prevention of yielding before local buckling, and (iii) range of reinforcement ratios used in the experimental database.

In response to the second request in this RAI question for test data demonstrating equal or better performance of SC walls vs. RC walls, the experimental database prepared for RAI 858-6126 has been augmented to include a detailed discussion of the experimental findings pertaining to SC performance relative to RC performance. This discussion will be provided along with the experimental database tables in an appendix to MUAP-11005.

**Impact on DCD**

There is no impact on the DCD.

**Impact on R-COLA**

There is no impact on the R-COLA.

**Impact on S-COLA**

There is no impact on the S-COLA.

**Impact on PRA**

There is no impact on the PRA.

**Impact on Technical Report:**

There is no impact on the Technical Report.

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4/2/2012

**US-APWR Design Certification**

**Mitsubishi Heavy Industries**

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| **RAI NO.:** | **NO. 894-6270 REVISION 3** |
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**QUESTION NO. RAI 03.08.03-57:**

The Executive Summary of MHI Technical Report MUAP-11018-P (R0), page vii, (as well as other sections of the report), presents a table which summarizes the equations for stiffness developed for SC Category 1 and RC members for load condition A - seismic plus operating thermal loading (Ess+To) and different equations for load condition B - seismic plus accident thermal loading (Ess+Ta).

1.The stiffness and damping values for each of these load conditions are developed separately depending on the level of cracking that would occur for the applicable load combination. Because predicting the level of cracked concrete is uncertain and because concrete cracking may occur for some of the loading conditions, all of the loads and load combinations should be analyzed for the range of uncracked and cracked conditions.

Based on the MUAP-11013 report, it appears that the enveloping approach (for the two levels of cracking) is being utilized for developing the US-APWR in-structure response spectra (ISRS). However, it is not clear to the staff whether the enveloping approach is also being utilized for developing member forces for design. Therefore, the staff requests that the applicant clarify whether (1) for seismic loading, the stiffness values (and damping values) corresponding to load condition A and the stiffness values (and damping values) corresponding to load condition B for all members are analyzed; (2) the same approach is also used for the other loads that appear in the various load combinations for design; (3) then, for each load combination used to design the RC and SC members, total member forces are determined separately for the two levels of stiffness conditions, and the envelope of these two cases is used for the design of the members. If different levels of cracking are used for various members or regions in the model within a loading condition, then also clarify how the effects of reduced stiffness values (and corresponding damping values) due to cracking of the concrete will be considered in the finite element model. For example, explain whether each finite element in the seismic SSI models and design models is checked for stress levels and the corresponding stiffness values and damping values are used based on the stress level, or a single stiffness value and a single damping value are used for all finite elements within the SC category and RC type members based on the load condition A or B being evaluated. If it is the latter, provide the basis for this approach.

2. Loading condition A provides the stiffness equations for shear and flexure. Explain why the equations for in-plane membrane are not provided. Also, provide the basis for the stiffness values being used for the in-plane membrane direction.

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**ANSWER:**

1. We would like to clarify that: (1) for seismic analysis of the CIS, the stiffness values (and damping values) corresponding to load condition A and the stiffness values (and damping values) corresponding to load condition B are analyzed for all members in the CIS; (2) the same approach is also used for the other loads that appear in the design load combinations stated in Table 3.8.4-3 of the DCD, such as dead (D), live (L), accident pressure ($P_a$), etc.; (3) then, for each load combination used to design the RC and SC members in the CIS, total member forces are determined separately for the two levels of stiffness conditions, and the envelope of these two cases is used for the design of the members.

The application of the stiffness and damping values to the analysis models has been described in Chapter 8.0 of MUAP-11018. As explained, linear elastic finite element models are used for conducting the SSI analyses and the subsequent structural analysis for determining design forces. This is consistent with industry practice given the limitations of SSI computer programs etc. The structural properties (elastic modulus E', wall thickness t') of the walls in the LEFE models are calibrated to match the target in-plane shear stiffness and flexural stiffness values in Table 7-1 for the walls.

The target values are selected based on an engineering evaluation of the state of the entire walls (not individual finite elements) for different loading conditions. The extent of cracking in the SC walls of category 1, 2, and 3 was evaluated for loading condition A using preliminary analysis results as explained in Section 5.0. The focus of this evaluation was categorization of the complete wall (not individual finite elements) as 'cracked' or 'uncracked'. The basis of this approach has been presented in detail in Sections 5.1, 5.2, and 5.3, where each wall was evaluated on a holistic basis using preliminary analysis results. Once an SC wall or RC slab is deemed 'cracked' in shear or flexure then corresponding stiffness and damping values are used for the entire wall or slab.

For example, this approach is illustrated in terms of the in-plane shear stiffness of the Category 1 walls. Table 5-1 summarizes the effective in-plane shear stiffness evaluated for each of the SC walls under loading condition A. [

] Corresponding uncracked and cracked damping values of[ ]were then used for all Category 1 walls under conditions A and B, respectively.

2. The in-plane membrane stiffness modeled by the LEFE model of the CIS has been discussed in detail in Section 4.1.6 and then in Section 8.2 of MUAP-11018.

There are three structural stiffnesses (in-plane shear, flexure, and axial) that can be considered when developing the LEFE model of the CIS. And, there are three material and structural properties that can potentially be adjusted in the elastic models (elastic modulus E', section thickness t', and poisson's ratio $\nu$) to match the three stiffnesses. However, the poisson's ratio $\nu$ was assumed to have the value for concrete $\nu_c$ because adjusting it could have unintended repercussions on the structural behavior of the model by: (i) influencing the transverse displacements and their interactions with the surrounding walls, components etc., and (ii) modifying dynamic characteristic of wave travel speeds in SSI analyses.

This leaves only two properties (elastic modulus E', and section thickness t') that can be adjusted to match the target stiffnesses. We chose to match the in-plane shear stiffness and the flexural stiffness because those are much more relevant to overall structural behavior of the SC walls. The axial stiffness is not directly controlled in the calibration of the E' and t' properties, given its limited impact on the seismic response of a heavy shear wall structure like the CIS. Instead, the E' and t' properties calibrated to achieve the more important shear and flexural stiffness terms are further evaluated to check the reasonableness of the resulting axial stiffness values for both conditions (A and B). This evaluation is described in Section 8.2, and in the calculations and comparisons shown in Appendix G.

As described in Section 8.2 and calculated in Appendix G, the as-modeled axial stiffness values for condition A were very close to the uncracked axial stiffness of the composite SC section [ ] which is quite reasonable. [

]This was further evaluated numerically in Table 8-1, which shows the as-modeled axial stiffness for condition B to be about [

]that is used for RC walls based on recommendations of ACI 349.1R. Please see also the graphical comparison of the calibrated axial stiffness values vs. RC stiffness values that is provided in the response to question 03.08.03-63.

**Impact on DCD**

There is no impact on the DCD.

**Impact on R-COLA**

There is no impact on the R-COLA.

**Impact on S-COLA**

There is no impact on the S-COLA.

**Impact on PRA**

There is no impact on the PRA.

**Impact on Technical Report:**

There is no impact on the Technical Report.

4/2/2012

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

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| APPLICATION SECTION: | 3.8.3 |
| DATE OF RAI ISSUE: | 1/25/2012 |

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**QUESTION NO. RAI 03.08.03-58:**

The Executive Summary of MHI Technical Report MUAP-11018-P (R0), presents two tables on page viii, which indicates that the flexural stiffness (EcIct) of Category I SC walls under loading condition A is the same as that under loading condition B. Several places of the report explain that, with the lower load condition A, this is due to the fact that SC walls tend to crack early in flexure due to locked in shrinkage strains and lower degree of composite action. Section 5 of the report, which was intended to evaluate stiffness and damping for load condition A, does not provide an evaluation for SC Category 1 flexural stiffness. Therefore, the applicant is requested to provide the technical justification for the use of EcIct for loading condition A and to demonstrate that the values of the SC member flexural stiffness for load conditions A and B are the same.

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**ANSWER:**

The CIS consists of SC walls acting primarily as shear walls under seismic loading. The in-plane shear stiffness of SC walls is very important for modeling the structural behavior (stiffness and damping) of the CIS. The flexural stiffness of SC walls is relevant, but not significant for modeling the structural behavior of the CIS.

As explained in Section 4.1.5 and Appendix E of MUAP-11018, the 'theoretically calculated' uncracked composite flexural stiffness is not exhibited experimentally by SC walls because: (i) the bond between the steel faceplates and concrete infill is discrete (not continuous like RC) and involves some local deformation or slip at the shear connector before engaging fully, and (ii) there are locked-in shrinkage strains in the concrete. The appropriate flexure stiffness for condition A is $E_cI_{ct}$, because no other flexural stiffness is manifest consistently in SC walls.

For loading condition B, experimental results of unrestrained specimens subjected to nonlinear thermal gradients show extensive through section cracking, and that the local section flexural stiffness is equal to that of the steel section alone ($E_sI_s$). This has been shown experimentally and analytically in Varma et al. [1,2,3] It is important to note however that this is the local section stiffness (EI value) for unrestrained SC sections free to crack and expand.

In the CIS, the SC walls will be restrained at the base and at several locations along the height by other walls and RC slabs. These restraints will cause axial compression, and close or limit concrete cracking in these regions. Using a flexural stiffness of $E_sI_s$ that represents unrestrained specimens free to crack extensively would be inappropriate for the whole wall. The local section flexural stiffness of the SC walls will vary between $E_sI_s$ and $E_cI_{ct}$ depending on the thermal gradient (which changes over time), and the degree of thermal restraint over the expanse of the wall.

Given the fact that the flexural stiffness of SC walls is relevant, but not significant for modeling the structural behavior of CIS, and given the results discussed in Section 4.1.5 and Appendix E, it is appropriate to model the wall flexural stiffness for condition B using $E_cI_{ct}$. Any other EI value would require significant calibration to nonlinear models in order to be accurate for the corresponding specific thermal gradient and restraint condition. This would make LEFE models and analyses almost impossible to use for LRFD. ACI 349.1R also provides users with similar refrains from trying to 'accurately' model concrete cracking due to thermal loading, and instead suggests using a smeared reduction of 50% of $E_cI_g$ for accident thermal analyses.

**Impact on DCD**

There is no impact on the DCD.

**Impact on R-COLA**

There is no impact on the R-COLA.

**Impact on S-COLA**

There is no impact on the S-COLA.

**Impact on PRA**

There is no impact on the PRA.

**Impact on Technical Report:**

There is no impact on the Technical Report.

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1 Booth, P., Varma, A.H., Malushte, S.R., and W. Johnson. "Experimental Behavior of Composite Sandwich Walls for Nuclear Facilities." Transactions of the Annual Structural Mechanics in Reactor Technology Conference (SMiRT19), Paper #H01/4, Toronto, Canada.

2 Varma, A.H., Malushte, S.R., Sener, K.C., and P. Booth. "Analysis and Design of Modular Composite Walls for Combined Thermal and Mechanical Loading." Transactions of the Annual Structural Mechanics in Reactor Technology Conference (SMiRT20), Paper #1820, 9-14 August 2009, Espoo, Finland.

3 Varma, A.H., Malushte, S.R., Sener, K.C., Booth, P. and K. Coogler. "Steel-Plate Composite (SC) Walls: Analysis and Design Including Thermal Effects." Transactions of the Annual Structural Mechanics in Reactor Technology Conference (SMiRT21), Paper #761, 6-11 November 2011, New Delhi, India.

## RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

**4/2/2012**

**US-APWR Design Certification**

**Mitsubishi Heavy Industries**

**Docket No. 52-021**

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|---|---|
| **RAI NO.:** | **NO. 894-6270 REVISION 3** |
| **SRP SECTION:** | **03.08.03 – Concrete and Steel Internal Structures of Steel or Concrete Containments** |
| **APPLICATION SECTION:** | **3.8.3** |
| **DATE OF RAI ISSUE:** | **1/25/2012** |

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**QUESTION NO. RAI 03.08.03-59:**

The Executive Summary of MHI Technical Report MUAP-11018-P (R0), first table on page viii, shows that for loading condition A, the uncracked shear stiffness and the cracked flexural stiffness are being utilized for SC Category 1 members. According to ASCE 43-05, which is referenced and shown in Table 4-1 (page 4-15), if walls are cracked, then both the flexural and shear stiffnesses should use a factor of 0.5. Explain why the shear stiffness is based on uncracked properties while cracked stiffness is assumed for flexural behavior. This same issue appears in the second table on page ix for RC Category 4; however, the uncracked and cracked conditions in this case appear for loading condition B.

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**ANSWER:**

As explained in Section 4.1.5, experiments on full-scale SC specimens subjected to out-of-plane flexure indicate that the theoretically calculated 'cracked' composite stiffness is observed immediately upon application of loads that induce flexural stresses. The theoretically calculated 'uncracked' composite flexure stiffness is not observed. The reasons for this behavior are discussed in detail in Section 4.1.5. They include: (i) locked-in shrinkage strains in the concrete, (ii) discrete nature of bond between the steel and concrete core, and (iii) slight flexibility of the shear studs or connectors connecting the steel faceplates and concrete.

For condition A, the in-plane shear stiffness of the SC walls in the CIS was evaluated as explained in Section 5.1 using the design force demands calculated using results from preliminary seismic and structural analyses of the CIS as follows:

Table 4-1, which lists the ASCE 43-05 values for RC walls and slabs, was referenced in Section 4.3 (page 4-7) while discussing the stiffness of category 4 and 5 reinforced concrete structures. Since the ASCE 43-05 stiffness values are for typical RC walls and slabs, their application to SC walls must be considered carefully and judiciously. As discussed in Sections 4.1 and 5.1, SC-specific values were assigned to the category 1 SC walls after assessment of the forces and moments induced by loading condition A. [

] The SC-specific values assigned are tabulated vs. the ASCE 43-05 reinforced concrete stiffness values in the executive summary (page ix), but the tables are given for comparison purposes only, in order to illustrate the general similarities in the values, as well as the slight differences that result from capturing composite SC-specific behavior.

The out-of-plane flexural stiffness values of the category 4 RC slabs subjected to loading condition B were explained in Section 6.5. Please note that the ASCE 43-05 recommendations are for seismic loading condition A only. They are not necessarily meant for accident thermal + seismic loading condition B.

As explained in Section 6.5, the category 4 reinforced concrete slabs are exposed to accident thermal loading on both faces. The effects of combined accident thermal loading, pressure, and seismic loading were evaluated using: (i) results from preliminary analysis, (ii) principal moment calculated in the slabs, and (iii) cracking moments calculated using Equations 5-3 and 5-4. The results of this evaluation were summarized in Figure 6-5, which shows that the slab is subjected to significant thermally induced flexure and associated concrete cracking. The primary dynamic response of interest for the RC slabs in the US-APWR CIS is out-of-plane flexure, and the presence of significant thermally induced cracking justified the used of cracked flexural stiffness for the category 4 slabs under condition B.

The in-plane shear stiffness was assumed to be uncracked because: (i) in-plane shear force demands are much lower than the cracking threshold for RC slabs as mentioned on page 5-3, (ii) concrete is an anisotropic material, which means that cracking in flexure does not necessarily translate into cracking for in-plane shear, and (iii) out-of-plane flexure rather than in-plane shear is the primary dynamic response for the RC slabs in the CIS.

**Impact on DCD**

There is no impact on the DCD.

**Impact on R-COLA**

There is no impact on the R-COLA.

**Impact on S-COLA**

There is no impact on the S-COLA.

**Impact on PRA**

There is no impact on the PRA.

**Impact on Technical Report:**

There is no impact on the Technical Report.

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4/2/2012

**US-APWR Design Certification**

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| **DATE OF RAI ISSUE:** | **1/25/2012** |

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**QUESTION NO. RAI 03.08.03-60:**

The Executive Summary of MHI Technical Report MUAP-11018-P (R0), second table on page viii, provides the stiffness values for the SC and RC members. Explain why the shear stiffness value for the SC Category 1 wall under loading condition B, is smaller than that of the RC wall, considering the higher reinforcement ratio in the SC wall. Also, provide the specific reinforcement ratio for the RC wall used in the table, and explain what equations are used for calculating the reinforcement ratios for both SC and RC members in this report.

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**ANSWER:**

The referenced table compares the in-plane shear stiffness of SC walls with that of an equivalent RC wall for loading condition B, which is accident thermal + seismic loading. It is important to note that ASCE 43-05 focuses primarily on seismic loading condition (A), and it recommends the in-plane shear stiffness value of 0.5 $G_cA_g$ for RC walls cracked due to seismic loading (not due to thermal loading). The recommended in-plane shear stiffness value (0.5 $G_cA_g$) is independent of the reinforcement ratio or distribution (bond parameter), which indicates that it is a general and approximate equation for RC shear walls cracked in shear due to seismic loading. The accuracy of this equation ($0.5G_cA_g$) for modeling the in-plane shear stiffness of RC shear walls cracked due to thermal loading is unclear. ACI 349.1R does not recommend it directly, but mentions that reductions of about 50% in the gross stiffness are generally used to account for thermal cracking effects.

The shear stiffness equation for SC walls subjected to loading condition B is based on mechanics based models and some experimental validation discussed in Appendix D. This equation is a function of the reinforcement ratio, and is appropriate for SC walls with adequate composite action between the steel plates and concrete infill achieved using the shear connector requirements of technical report MUAP-11019 Chapter 2 [

]

There is little correlation between the in-plane shear stiffness equation given for SC walls subjected to loading condition B, and that typically assumed for RC walls cracked due to accident thermal loading. The comparisons were provided in the executive summary for information purposes, and to show that the values are close to (in the neighborhood of) each other. The reason that the stiffness of SC walls is slightly lower than that calculated using $0.5G_cA_g$ is incidental. It could have been higher for a slightly different reinforcement ratio.

The reinforcement ratio in the RC walls used for the comparison is irrelevant because it does not feature in the stiffness equation ($0.5\ G_cA_g$). [

]

**Impact on DCD**

There is no impact on the DCD.

**Impact on R-COLA**

There is no impact on the R-COLA.

**Impact on S-COLA**

There is no impact on the S-COLA.

**Impact on PRA**

There is no impact on the PRA.

**Impact on Technical Report:**

There is no impact on the Technical Report.

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## RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

**4/2/2012**

**US-APWR Design Certification**

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### QUESTION NO. RAI 03.08.03-61:

The Executive Summary of MHI Technical Report MUAP-11018-P (R0), first table on page viii, indicates that the damping ratios of SC Category 1 walls under loading condition A and B are 4% and 5%, respectively. According to the report, the 5% damping ratio is based on test results of the 1/10th scale test. Since the 1/10th scale test is for the entire CIS structure which includes various SC category types, not just the SC Category 1 walls, the staff requests that the applicant provide additional justification/test data to justify the use of the 4% and 5% damping ratios for the SC Category 1 walls used in the US-APWR Containment Internal Structure (CIS).

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### ANSWER:

As mentioned in the report Section 7.0, uniform damping ratios of 4 and 5% were used for the CIS subjected to loading condition A and loading condition B, respectively. Individual damping ratios were not used for the different structure categories (1-6). Instead, uniform damping values were used for all structural components of the CIS, which were conservatively determined based on the category-specific values in Table 7-1.

Additional justification for the damping values used for the CIS is as follows:

For the limited stress levels associated with operating basis earthquakes, typical steel frame structures are typically assigned a damping ratio of 3%, and concrete structures are assigned a damping ratio of 4%. [

]

For the higher stresses or cracking levels typically associated with safe shutdown earthquakes, steel frame structures are typically assigned a damping ratio of 4%, and concrete structures are assigned a damping ratio of 7%. [

]

In addition to the evaluation of SC damping in the 1/10th scale experiment, the relative damping ratios of SC and RC structures have been investigated experimentally by Kim et al.[1] Kim et al. conducted free vibration tests of equivalent SC and RC wall specimens to compare their relative damping values. The damping values were determined using experimental measurements and the logarithmic decrement method. Figure 1, which is extracted from Kim et al. summarizes the key experimental data from the tests. In this figure, RC-S and SC-S are squat shear walls governed by shear behavior, and RC-M and SC-M are taller walls governed by flexure behavior.

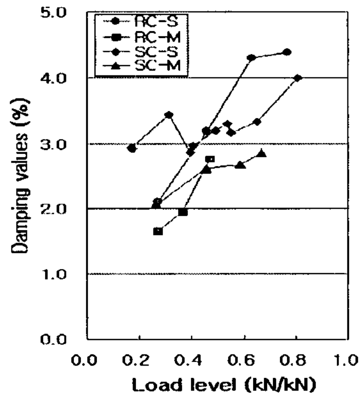


Figure 1. Damping ratios of SC and RC walls (Kim et al. 2009)

As shown in Figure 1, increasing loading results in more damping due to concrete cracking. The damping ratios for SC are slightly lower than those of equivalent RC systems. It is important to note that the experimental damping values for both SC and RC systems are anticipated to be lower than in an actual structure, because the tests involved isolated structures with no non-structural attachments, equipment, or piping, and the specimens were subjected to free vibration from various starting points associated with different levels of loading (and cracking).

**Impact on DCD**

There is no impact on the DCD.

**Impact on R-COLA**

There is no impact on the R-COLA.

**Impact on S-COLA**

There is no impact on the S-COLA.

**Impact on PRA**

There is no impact on the PRA.

**Impact on Technical Report:**

There is no impact on the Technical Report.

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1 Kim, W., Lee, S.J., Jung, R.Y., and M. Kim. "Damping Values for Seismic Design of Nuclear Power Plant SC Structures." Transactions of the Annual Structural Mechanics in Reactor Technology Conference (SMiRT20), Paper #1697, 9-14 August 2009, Espoo, Finland.

## RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

**4/2/2012**

**US-APWR Design Certification**

**Mitsubishi Heavy Industries**

**Docket No. 52-021**

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|---|---|
| **RAI NO.:** | **NO. 894-6270 REVISION 3** |
| **SRP SECTION:** | **03.08.03 – Concrete and Steel Internal Structures of Steel or Concrete Containments** |
| **APPLICATION SECTION:** | **3.8.3** |
| **DATE OF RAI ISSUE:** | **1/25/2012** |

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**QUESTION NO. RAI 03.08.03-62:**

For damping, MHI Technical Report MUAP-11018-P (R0) also references MHI Technical Report MUAP-10002-P (R0). Page 2-2 of MHI Technical Report MUAP-10002-P (R0) indicates that, in the test model, a significant portion of the steel plates on both surfaces were connected by web plates. The staff's understanding is that this web plate method will not be used in the design of the US-APWR SC structures. In addition, MHI Technical Report MUAP-11013-P (R1), page 1-2, indicates that the SC wall anchorage details of the 1/10th test model are different from those proposed for the US-APWR SC structures. Provide an explanation of the effects of the above construction differences, and any others that may exist, on the damping ratio.

---

**ANSWER:**

(a)

(b)

Figure 2: Comparison of secondary shield wall construction showing web plates. a) Plan view of actual US-APWR CIS; b) Plan view of $1/10^{th}$ scale test model.

Per the presented discussion it is concluded that construction differences between the 1/10$^{th}$ scale test and the actual structure are insignificant in terms of their effect on damping ratio.

[ ]

**Impact on DCD**

There is no impact on the DCD.

**Impact on R-COLA**

There is no impact on the R-COLA.

**Impact on S-COLA**

There is no impact on the S-COLA.

**Impact on PRA**

There is no impact on the PRA.

**Impact on Technical Report:**

There is no impact on the Technical Report.

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**QUESTION NO. RAI 03.08.03-63:**

The Executive Summary of MHI Technical Report MUAP-11018-P (R0), page ix, presents a table which summarizes the equations developed for SC Categories 2 & 3 for load condition A ($E_{ss}$+$T_o$) and different equations for load condition B ($E_{ss}$+$T_a$). The technical basis for using RC equations for the SC Categories 2 & 3 does not appear to be adequate. For example, the SC to RC flexural ratio from the table on page viii of the technical report is 1.34, which shows that an SC member 48 inches thick is much stiffer than the corresponding RC member. Therefore, explain why would a 56 inch thick SC Category 2 member have the same stiffness as an RC member.

---

**ANSWER:**

Based on interaction with the NRC (shortly before MUAP 11018 was submitted), we did not implement our original plan. Instead in MUAP 11019, we conservatively utilized ACI 349-06 based RC design approaches for both Category 1 and 2 SC walls. MUAP 11019 does not distinguish between the design of category 1 and 2 SC walls, and we are confident and comfortable with this design approach because it has several conservatisms built in; for example: [

]

Based on interaction with the NRC, there were two choices for the stiffness and damping of category 2 SC walls: [

]

The tables in the executive summary and Chapter 7 of MUAP 11018 were developed to illustrate the proximity of the SC-specific equations and RC stiffness values. The following figures further illustrate this comparison of SC-specific equations and RC stiffness values for SC walls with reinforcement ratios between [ ] These comparisons apply to both the category 1 and 2 SC walls. [

]

[

]

Figure 3(a) presents the variation of the normalized shear stiffness with respect to the reinforcement ratio for condition A (operating thermal + seismic). The SC-specific equation accounts for composite action by estimating the in-plane shear stiffness as a function of the steel reinforcement ratio ($G_sA_s+G_cA_c$), whereas the RC equation just assumes it to be equal to $G_cA_g$ (independent of the reinforcement ratio). [

]

Figure 3(b) presents the variation of the normalized shear stiffness with respect to the reinforcement ratio for condition B (accident thermal + seismic). [

] It is important to note that $0.5G_cA_g$ was provided by ASCE 43-05 for walls cracked due to seismic loading. It is assumed for RC walls cracked initially by accident thermal loading in the absence of better information and based on the suggestion provided in ACI 349.1R Section 1.4. It is only a reasonable engineering estimate of the in-plane shear stiffness of RC walls cracked due to accident thermal loading, not an accurate one. [

]

Figure 3: Comparison of normalized stiffness (SC-specific stiffness divided by RC stiffness per ASCE 43-05) vs. reinforcement ratio.

Figure 3(c) presents the variation of the normalized flexural stiffness with respect to the reinforcement ratio for condition A (operating thermal + seismic). [

]

Figure 3(d) presents the variation of the normalized flexural stiffness with respect to the reinforcement ratio for condition B (accident thermal + seismic). [

]

[

] It is only a reasonable engineering estimate of the flexural stiffness of RC walls cracked due to accident thermal loading, not an accurate one.

Figures 3(e) and 3(f) present the variation of normalized in-plane axial stiffness with respect to reinforcement ratio for loading conditions A and B, respectively. As discussed in the response to part 2 of question 03.08.03-57, the SC axial stiffness has been calculated based on the values of modulus of elasticity (E) and section thickness (t) that are calibrated to achieve the in-plane shear and out-of-plane flexural stiffness assigned for the given loading condition. The condition A RC stiffness is taken as $E_cA_g$ based on ASCE 43-05 Table 3-1, and the condition B RC stiffness is taken as $0.5E_cA_g$ based on ACI 349.1R Section 1.4.

[

]

In summary, SC-specific stiffness equations have been used in the US-APWR seismic analyses for the Category 1 SC walls, based upon the available research that confirms the composite response of these structures. RC stiffness equations from ASCE 43-05 have been used for the Category 2 walls, for which the fully composite response has not been ascertained. It has been demonstrated that for the typical reinforcement ratios used in the US-APWR, the RC equations result in reasonably similar stiffness values to those obtained with the SC-specific equations, even though the RC equations are generalized and do not account for reinforcement ratio. Given this similarity, as well as the limited proportion of Category 2 walls [ ] and the intent to perform bounding analyses with both uncracked and cracked stiffness terms, the use of the [ ] for the Category 2 walls is considered a reasonable engineering approach.

**Impact on DCD**

There is no impact on the DCD.

**Impact on R-COLA**

There is no impact on the R-COLA.

**Impact on S-COLA**

There is no impact on the S-COLA.

**Impact on PRA**

There is no impact on the PRA.

**Impact on Technical Report:**

The calculations supporting the charts presented in Figure 3 will be added as an appendix to TR MUAP-11018.

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**QUESTION NO. RAI 03.08.03-64:**

The Executive Summary of MHI Technical Report MUAP-11018-P (R0), first table on page ix, indicates a damping ratio of 7% for SC Category 2 walls under loading condition B. The damping ratio is higher than the 5%, shown in the first table on page viii, for SC walls under loading condition B. Since the SC Category 2 member is still an SC type member, provide the technical basis for using a higher damping value. Generally, the damping value should be determined based on the stress level not the thickness of the section.

---

**ANSWER:**

The damping ratio employed in the condition B analysis was 5%. As mentioned earlier, a constant damping value of 5% was used for all parts of the structure in both the SSI analyses for generation of in-structure response spectra, and the subsequent response spectrum analyses for generation of member forces for design. The tabulated values for the individual structure categories are consistent with the stiffness equations assigned for the given loading condition, and are presented only to illustrate the conservatism of the constant 5% damping ratio used throughout the structure in the analyses.

**Impact on DCD**

There is no impact on the DCD.

**Impact on R-COLA**

There is no impact on the R-COLA.

**Impact on S-COLA**

There is no impact on the S-COLA.

**Impact on PRA**

There is no impact on the PRA.

**Impact on Technical Report:**

There is no impact on the Technical Report.

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**QUESTION NO. RAI 03.08.03-65:**

The Executive Summary of MHI Technical Report MUAP-11018-P (R0), page x, indicates that the stiffness and damping values for SC Category 6 steel structures with non-structural concrete infill are based on the stiffness of the steel structure alone. The mass of the non-structural concrete infill is included in the models. Provide a technical basis for only including the steel stiffness properties of this Category 6 structure. Even though the concrete is considered to be "nonstructural," it may provide some stiffness to the members. Therefore, the potential range of stiffness values for such members should be considered or an acceptable technical basis needs to be provided for totally neglecting the stiffness contribution from the concrete.

---

**ANSWER:**

The concrete mass is not composite with the steel plates or members of the category 6 structures. Since there are no shear connectors, it is reasonable to assume no force transfer between the steel and the concrete of these structures. Due to this reason, there will be no stiffness contribution of the concrete mass to the overall structure. Only the mass of the concrete is included in the analysis.

**Impact on DCD**

There is no impact on the DCD.

**Impact on R-COLA**

There is no impact on the R-COLA.

**Impact on S-COLA**

There is no impact on the S-COLA.

**Impact on PRA**

There is no impact on the PRA.

**Impact on Technical Report:**

There is no impact on the Technical Report.

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**QUESTION NO. RAI 03.08.03-66:**

Section 4.1 of MHI Technical Report MUAP-11018-P (R0), which describes how the in-plane shear stiffnesses for SC Category 1 walls are determined is extremely important. The uncracked and cracked in-plane shear stiffnesses for SC members are derived analytically. These equations rely on the combined monolithic behavior of the steel faceplates and concrete as if they act as an integrally connected unit, which is a key assumption. For the uncracked stiffness equation, reference is made to the Ozaki et al. testing. The referenced paper/report could not be located in the technical report(s). The staff requests that that applicant provide the test report/information along with a summary demonstrating its applicability (e.g., specimen configuration and design detail) to the SC members used in the US-APWR design and adequacy of its results.

For the cracked stiffness equation, reference is made to Appendices A through C, which derive the equations. These derivations are very complex with several assumptions. The equations have some parameters that are difficult to quantify (i.e., tensile strength of concrete and shrinkage strains), and therefore, the equations are calibrated to match experimental test data which makes the equations empirical. The staff requests that that applicant identify the test report used to calibrate the equations and provide the test report/information along with a summary demonstrating its applicability to the SC members used in the US-APWR design and adequacy of its results.

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**ANSWER:**

The requested Ozaki paper is not provided as an attachment to this RAI response due to the restriction of the copy right. The requested Ozaki paper is available at the web site at http://www.sciencedirect.com/

In addition, a tabular comparison of the experimental specimen configuration and design details to the SC members in the US-APWR was provided in the response to question

03.08.03-45 under RAI 858-6126. These comparative tables will also be provided within the aforementioned new appendix to MUAP-11005.

The calibration of the cracked SC stiffness equations is performed in the paper entitled, "Steel-Plate Composite (SC) Walls: Analysis and Design Including Thermal Effects[1]". The tests evaluated in this paper are also included in the comparison of all SC-related tests to the US-APWR SC geometries provided in the new appendix to MUAP-11005.

**Impact on DCD**

There is no impact on the DCD.

**Impact on R-COLA**

There is no impact on the R-COLA.

**Impact on S-COLA**

There is no impact on the S-COLA.

**Impact on PRA**

There is no impact on the PRA.

**Impact on Technical Report:**

There is no impact on the Technical Report.

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[1] Varma, A.H., Malushte, S.R., Sener, K.C., Booth, P. and K. Coogler. "Steel-Plate Composite (SC) Walls: Analysis and Design Including Thermal Effects." Transactions of the Annual Structural Mechanics in Reactor Technology Conference (SMiRT21), Paper #761, 6-11 November 2011, New Delhi, India.