RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

12/27/2013

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 1040-7139 REVISION 3**
SRP SECTION:	**03.08.01 – Concrete Containment**
APPLICATION SECTION:	**3.8.1**
DATE OF RAI ISSUE:	**07/01/2013**

QUESTION NO. 03.08.01-21:

On April 3, 2013, the applicant submitted a markup of DCD Tier 2 Section 3.8 to provide updated information related to a seismic design change.

In Subsection 3.8.1.4.2.1, "Concrete Cracking Consideration," the last paragraph (Page 3.8-13) states, "The PCCV [prestressed concrete containment vessel] shell is evaluated for a condition in which the liner is heated as a result of a LOCA [loss of coolant accident] while the concrete maintains a normal operating temperature gradient. The difference in temperature induces a compressive stress and strain in the liner plate. This condition is defined as the liner plate spike load."

The applicant is requested to describe (1) the result of the evaluation on the PCCV due to the liner plate spike load, (2) how the concrete cracking was considered in the evaluation, and (3) the changes of the PCCV design as a result of the liner plate spike load.

This answer supplements the previous MHI answer that was transmitted by letter UAP-HF-13193 (ML13228A271) on August 2, 2013. The supplemental response presented below was discussed with the Nuclear Regulatory Commission (NRC) staff during the Design Certification Document (DCD) Tier 2, Section 3.8 Audit conducted during the week of November 4, 2013.

ANSWER:

(1) Describe the result of the evaluation on the PCCV due to the liner plate spike load:

Sample evaluation results on the PCCV (prestressed concrete containment vessel) due to the liner plate spike load are show in Table 1. A final DCR (demand capacity ratio) of less than 1.0 indicates that the evaluated concrete section meets all code requirements. The final DCRs from Table 1 show that current PCCV design is adequate.

Element #216 is located in the PCCV dome, while element #3019 is located midheight of the PCCV cylinder.

Corresponding evaluation results of the same elements and same loadings without liner plate spike loads are presented in Table 2. Load combination 15 (LC15 in Table 1) corresponds to load combination 8 (LC8 in Table 2), Load combination 16 (LC16 in Table 1) corresponds to load combination 12 (LC12 in Table 2). LC8 and LC12 consider accidental thermal operation condition along with other applicable loads.

LC15 and LC16 consider liner plate spike load of accidental thermal condition on top of normal operation thermal condition along with the loads considered in LC8 and LC12.

Load combination 8 is load combination 1.0D+1.0L+1.0F+1.0G+1.5Pa+1.0Ta+1.0Ra from DCD Table 3.8.1-2.

Load combination 12 is load combination 1.0D+1.0L+1.0F+1.0G+1.0Pa+1.0Ta+1.0Ess+1.0Ra+1.0Rr from DCD Table 3.8.1-2.

Load combination 15 represents 1.0D+1.0L+1.0F+1.0G+1.5Pa+1.0To+1.0Ra+Liner Plate Spike Load.

Load combination 16 represents 1.0D+1.0L+1.0F+1.0G+1.0Pa+1.0To+1.0Ess+1.0Ra+1.0Rr+LinerPlateSpikeLoad.

From corresponding DCR comparisons from Table 1 and Table 2, liner plate spike loads induce tensile stresses in the concrete section. This can be seen by reviewing the DCRs associated with the outside face reinforcing steel (So) values for the membrane plus bending loading conditions. The outside face reinforcing steel exhibits reductions in compressive stress in terms of reduced DCRs due to liner plate spike loads.

Table 1: PCCV Section Verification Summary Sample due to Liner Plate Spike Loading

Table 2: PCCV Section Verification Summary Sample without Liner Plate Spike Loading

Table 3: Property Description for Table 1 and Table 2

Property	Description
a	Distance to Neutral Axis (dependent on section cracking condition)
Crack	Depth of Cracking from Face (dependent on section cracking condition)
f'c	Concrete compressive DCR
S	Reinforcing Steel DCR
So	Outside Reinforcing Steel DCR
Si	Inside Reinforcing Steel DCR
S_tie	Shear Tie DCR

(2) Describe how the concrete cracking was considered in the evaluation:

The following example is provided to show how concrete cracking in the PCCV cylindrical section is considered. The stress across a concrete section is calculated as an un-cracked section initially and then the stress due to concrete cracking is calculated to adjust the concrete section given the effects of the cracked concrete behavior.

The example presented herein is an example of a PCCV concrete section when subjected to a thermal gradient with reinforcement provided on both faces and concrete cracking is considered. PCCV concrete section evaluation due to liner plate spike load uses the same approach.

Given: b = 12” t = 42”

$A's$ = 2 in² ΔT = 100°F Linear

As = 2 in² Ec = 3 x10^6 psi

n = 10 a = 6.0 x 10^{-6} (for concrete and steel)

Nomenclatures:

a is coefficient of thermal expansion (°F^{-1})

$A's$ is inside steel area (in^2)

As is outside steel area (in^2)

t is concrete section height (in.)

ΔT is thermal gradient (Degree F)

Ec is modulus of elasticity for concrete (psi)

Es is modulus of elasticity for steel (30 x 10^6 psi)

fs is tension reinforcing Steel Stress (psi)

$f's$ is compression reinforcing Steel Stress (psi)

n is modular ratio of reinforcing and concrete (Es/Ec)

σc is uncracked concrete stress (psi)

σ' is cracked concrete stress (psi)

Assumptions:

- The coefficient of thermal expansions for the reinforcing steel and concrete are equal to each other.
- Free axial expansion.

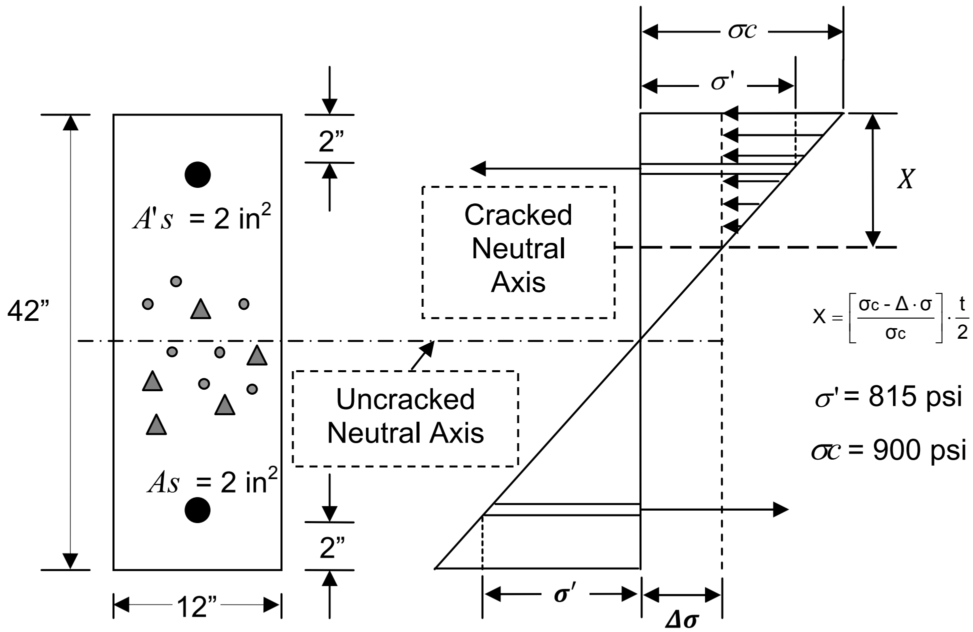

Figure 1 Section View and Stresses

Force Equilibrium

Uncracked concrete stress, σc:

$$\sigma c = \frac{1}{2} aEc\Delta T = 900 psi$$

Cracked concrete stress at rebar location, σ':

$$\sigma' = \sigma c\left(\frac{\frac{t}{2} - 2''}{\frac{t}{2}}\right)$$

= 900 ((21-2)/21) = 814.3 psi, use σ' = 815 psi

Force Equilibrium to Solve for Change in Stress, $\Delta\sigma$:

Resultant Reinforcing Tension – Initial Concrete Compression Force + Concrete Compression Reduction = 0

$$[Asfs-(A's)(f's)]-\frac{\sigma c}{2}\left(\frac{t}{2}\right)b+\frac{\Delta\sigma b}{2}\left[\frac{t}{2}+\frac{t}{2}\left(\frac{\sigma c-\Delta\sigma}{\sigma c}\right)\right]=0$$

The term $[Asfs-(A's)(f's)]$ is adjusted due to stress shift where reinforcing steel stress in tension is subtracted by the amount of reinforcing steel stress in compression and is calculated as follows:

$$[Asfs-(A's)(f's)]=\left[As(\sigma'+\Delta\sigma)n-A's(\sigma'-\Delta\sigma)(n-1)\right]$$

Therefore, the change in stress, $\Delta\sigma$ is calculated as shown below.

$$2.0(815+\Delta\sigma)10-2.0(815-\Delta\sigma)(10-1)-\frac{900}{2}(21)(12)+\Delta\sigma\frac{12}{2}(21+21\frac{900-\Delta\sigma}{900})=0$$

$\Delta\sigma=511.9\,psi$, use $\Delta\sigma=512\,psi$

The tension and compression reinforcement along with the concrete compression stress are adjusted with the $\Delta\sigma$ value calculated previously to account for concrete cracking condition. The tension and compression reinforcement and concrete compression stress are adjusted as follows:

Adjusted Tension Reinforcing Steel Stress, fs

$$fs=(\sigma'+\Delta\sigma)n$$

= (815 + 512)10 = 13,270 psi

Adjusted Compression Reinforcing Steel Stress, $f's$

$$f's=(\sigma'-\Delta\sigma)(n-1)$$

= (815 – 512)(10-1) = 2,727 psi

Adjusted Compression Concrete Stress, fc

$$fc=(\sigma c-\Delta\sigma)$$

= (900 – 512) = 388 psi

Due to the effects of concrete cracking have on the cross section, the neutral axis is shifted to reflect such conditions. The cracked neutral axis is therefore calculated as follows.

Cracked Neutral Axis, X

$$X=\left(\frac{\sigma c-\Delta\sigma}{\sigma c}\right)\frac{t}{2}=\left(\frac{388}{900}\right)21=9.05in$$

(3) Describe the changes of the PCCV design as a result of the liner plate spike load:

There is no change of the current PCCV design as a result of the liner plate spike load.

Supplemental Answer:

Section 3.8 Audit Open Item 21A: Per RBF-13-05-205-002 & Revised RAI 490-3732, Question 03.08.01-9, what is the methodology used for implementing the factored loads analysis and design for containment per the ASME SEC III, Division 2 code, Article CC-3500? And revise 03.08.01-21.

Factored Load Design used to design the PCCV is in accordance with ASME Section III Division 2, Subsection CC-3511.1, 2001 Edition with addenda through 2003. Subsection CC-3511.1(c) which states that the stress in the concrete reinforcement below 0.9 F_y is determined by the modulus of elasticity of the reinforcement (E_s) times the steel strain (ε).

ASME Section III Division 2, Subsection CC-3422.1(b) identifies that the allowable stress in the reinforcement for resisting purposes shall not exceed 0.9 F_y. The relationship between stress and limit strain is identified in the Response to RAI 490-3732 Question 03.08.01-9 and it was established that the relationship between stress and strain is linear. The following relationships are offered to describe how the code was considered in the factored load design:

$\varepsilon_s = \frac{\sigma}{Es}$ *Where*: ε_s = Steel Strain; σ = Steel Stress; and E_s= Modulus of Elasticity

$\sigma_{allowable} = 0.9\ F_y$ Subsection CC-3422.1(b)

$\varepsilon_{allowable} = 0.9\ \varepsilon_y$ Linear Relationship between Stress and Strain

$\varepsilon_{allowable} = \frac{\sigma allowable}{Es} = \frac{0.9\ Fy}{Es}$ (*Note: Using substitution of 1st and 2nd equations*)

Setting E_s = 29,000 ksi and F_y = 60 ksi for steel concrete reinforcement

$\varepsilon_{allowable} = \frac{0.9\ (60\ ksi)}{29{,}000\ ksi} = 0.00186\ {}^{in}/_{in}$

Limit Strain is identified in ASME Section III Division 2, Subsection CC-3420, specifically Table CC-3421-1, which defines that the maximum allowable primary-plus-secondary membrane and compressive stress of 0.85 f'_c correspond to a limit strain of 0.002 in/in. Also, Subsection CC-3422.1(b) sets the stress limit in the rebar to be 0.9 F_y and the linear relationship requires the strain limit to also to be limited to 0.9 ε_y. The Factored Load methodology used in the design maintains the strain limits to be within code allowables for both concrete and steel. Therefore, the methodology balances the reinforcement stress and strain such that if the rebar meets either the stress or strain criteria, it satisfies the code for both stress and strain.

Impact on DCD

There is no impact on the DCD.

Impact on R-COLA

There is no impact on the R-COLA.

Impact on PRA

There is no impact on the PRA.

Impact on Technical/Topical Report

There is no impact on the Technical/Topical Report.

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