SUPPLEMENTAL RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

12/27/2013

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 490-3732 REVISION 0**
SRP SECTION:	**03.08.01 – Concrete Containment**
APPLICATION SECTION:	**3.8.1**
DATE OF RAI ISSUE:	**11/23/2009**

QUESTION NO. 03.08.01-09:

In its response for Part (a) of Question 3.8.1-9, MHI states that thermal forces and moments are reduced according to the concrete cracking depth during the post-processing of the global FE model analysis results. The reduction is based on redistribution of section forces and moments that occurs from the concrete cracking.

For Part (b) of the question MHI explains that the depth of concrete cracking is calculated by determining the neutral axis of the cross-section of the member, along with consideration of strain compatibility among the concrete, liner, tendons, and steel reinforcement. A summary description of the stress verification methodology is presented in this response, including simplified examples to demonstrate the methodology.

The staff finds that MHI's response does not clearly indicate how thermal forces and moments are reduced according to the concrete cracking depth. In MHI's response, a notation, σc1, is used to denote the extreme fiber stress of the concrete; however, in the example given at the end, an additional notation, σc2, is introduced without any explanation. MHI is requested to clarify this confusion. Also, MHI is requested to provide a calculation example that is taken from the US-APWR design, and that will have numerical results clearly showing the amount of reduction in forces and moments and the concrete cracking depth.

This answer supplements the previous MHI answer that was transmitted by letter UAP-HF-13154 (ML13199A062) on July 8, 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:

This response replaces the previous response submitted via MHI letter UAP-HF-10033 dated February 4, 2010 (ML100430768).

Due to changes in the US-APWR prestressed concrete containment vessel (PCCV) analysis and design approach, the variable, σc2, is no longer applicable. As before, the reduction is based on redistribution of section forces and moments that occurs from the concrete cracking. Concrete is considered to crack when the section is subject to tension and the neutral axis is shifted.

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.

Given:	b	= 12”	t	= 42”
	$A's$	= 2 in²	ΔT	= 100°F Linear
	As	= 2 in²	Ec	= 3 x10^6 psi
	n	= 10	α	= 6.0 x 10^{-6} (for concrete and steel)

Nomenclatures:

α 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 (°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.

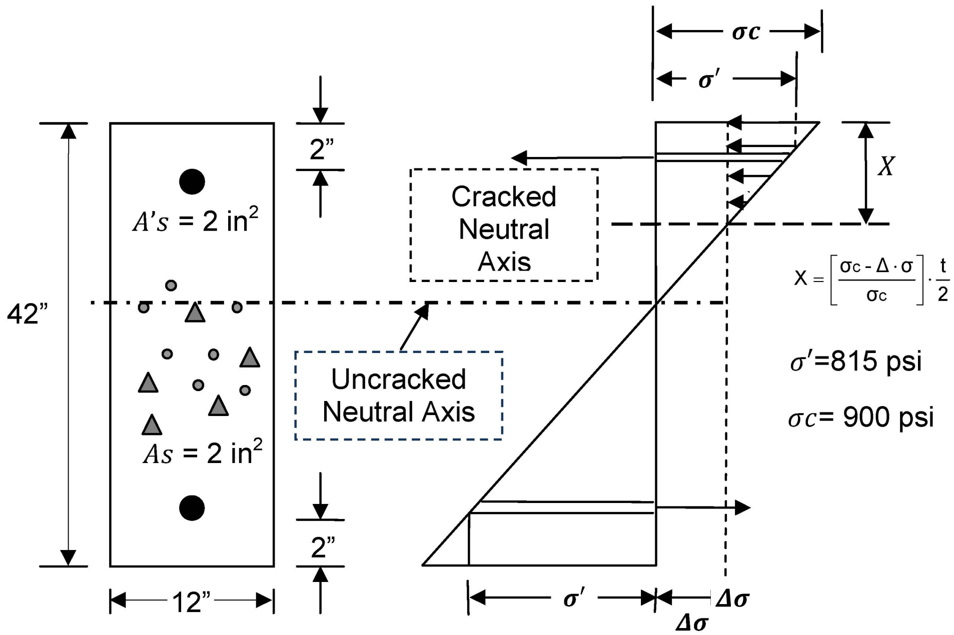

Figure 1 Section View and Stresses

Uncracked concrete stress, σc:

$$\sigma c = \frac{1}{2}\alpha E c \Delta T = 900\, psi$$

Cracked concrete stress at rebar location, σ':

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

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

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

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

$$Asfs - \frac{\sigma c}{2}\left(\frac{t}{2}\right)b + \frac{\Delta\sigma b}{2}\left[\frac{t}{2} + \frac{t}{2}\left(\frac{\sigma c - \Delta\sigma}{\sigma c}\right)\right] = 0$$

The term $Asfs$ 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:

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

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

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

$\Delta\sigma = 511.9\ psi$, 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

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

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

Adjusted Compression Reinforcing Steel Stress, $f's$

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

$f's$ = (815 – 512)(10-1) = 2,727 psi

Adjusted Compression Concrete Stress, fc

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

fc = (900 – 512) = 388 psi

The addition of compression reinforcing has increased the stress in the tensile reinforcing from 12,860 psi to 13,270 psi due to the compression reinforcing expanding from the applied thermal gradient. If the gradient is applied over a long period of time, the concrete section will creep in the compressive zone, relieving concrete stress, but increasing the compression reinforcing steel stress. The tensile reinforcing stress can be calculated by adjusting the outside reinforcing modular ratio, n.

$$f's = 2727\frac{(2n - 1)}{(n - 1)} = 2727\frac{(19)}{9} = 5{,}757\ psi$$

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

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

Supplemental Answer:

Section 3.8 Audit Open Item 15D: For factored load design in accordance with ASME Section III, Div. 2, what relationship is assumed between the concrete stress distribution and the concrete strain?

The relationship between the concrete compressive stress distribution and the concrete strain is linear and assumed to be represented by a triangle as allowed by ASME Section III Division 2, Subsection CC-3511.1(e), 2001 Edition with Addenda through 2003. Additional guidance regarding this linear relationship and the specific usage of triangles is provided in the Commentary for ASME Section III Division 2, Subsection CC-3511.1(e), July 2012 where the use of triangles is considered representative for this application and is specifically allowed in the later edition.

The resulting stresses using this approach are compared to the stress limits defined 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. Code compliance is provided as follows:

PCCV (Concrete Design Strength, f'_c = 7,000 psi)

$$E_c = 57{,}000(f'_c)^{0.5} = \frac{57{,}000(7{,}000)^{0.5}}{1000} = 4{,}769\ ksi$$

$$\varepsilon_c = \sigma_{allowable} / E_c = \frac{0.85(7\ ksi)}{4{,}769\ ksi} = 0.00125\frac{in}{in} < 0.002\ o\mathrm{k}$$

Basemat (Concrete Design Strength, f'_c = 5,000 psi)

$$E_c = 57{,}000(f'_c)^{0.5} = \frac{57{,}000(5{,}000)^{0.5}}{1000} = 4{,}031\ ksi$$

$$\varepsilon_c = \sigma_{allowable} / E_c = \frac{0.85(5\ ksi)}{4031\ ksi} = 0.00105\frac{in}{in} < 0.002\ o\mathrm{k}$$

The methodology is allowed by code with the resulting strain being 63% and 53% of the code strain limit for PCCV and Basemat, respectively.

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 a Technical/Topical Report.

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