December 4, 2012

MEMORANDUM TO: Kriss M. Kennedy, Director
Division of Reactor Projects
Region IV

FROM: Sher Bahadur, Deputy Director **/RA/**
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

SUBJECT: FINAL RESPONSE TO TASK INTERFACE AGREEMENT 2011-008, SAN ONOFRE NUCLEAR GENERATING STATION USE OF AMERICAN CONCRETE INSTITUTE REPORTS FOR EVALUATIONS RELATED TO STEAM GENERATOR REPLACEMENT CONTAINMENT RESTORATION

By letter dated May 3, 2011 (Agencywide Documents Access and Management System Accession No. ML12025A073), the U.S. Nuclear Regulatory Commission, Region IV Office, requested technical assistance from the Office of Nuclear Reactor Regulation (NRR) in determining if the San Onofre Nuclear Generating Station (SONGS) licensee is in compliance with its Final Safety Analysis Report (FSAR) commitments and requirements. For Units 2 and 3, the licensee performed calculations and evaluations of the structural integrity of the restored containment building following steam generator replacement (SGR). During an inspection of the SONGS Unit 3 SGR, three calculations were reviewed in conjunction with the inspection-referenced models and equations from American Concrete Institute (ACI) technical reports ACI 209R-92 and ACI 224.2R-92. The inspectors identified that these two ACI reports were not referenced in the licensee's concrete construction code of record (ACI 318-71), and were also not referenced in the licensee's FSAR. This concern was characterized as unresolved item 05000362/2010009-01.

Region IV requested NRR assistance to address the above concern by providing answers to the five questions stated in the Task Interface Agreement, which are reproduced in the enclosed evaluation. The NRR staff position is documented in the enclosed evaluation.

Enclosure:
As stated

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TASK INTERFACE AGREEMENT 2011-008

SAN ONOFRE NUCLEAR GENERATING STATION USE OF AMERICAN CONCRETE INSTITUTE REPORTS FOR EVALUATIONS RELATED TO STEAM GENERATOR REPLACEMENT CONTAINMENT RESTORATION

1.0 INTRODUCTION

By letter dated May 3, 2011 (Agencywide Documents Access and Management System Accession No. ML12025A073), the U.S. Nuclear Regulatory Commission (NRC), Region IV Office, requested technical assistance from the Office of Nuclear Reactor Regulation (NRR) in determining if the San Onofre Nuclear Generating Station (SONGS) licensee is in compliance with its Final Safety Analysis Report (FSAR) commitments and requirements (Reference 1). For Units 2 and 3, the licensee performed calculations and evaluations of the structural integrity of the restored containment building following steam generator replacement (SGR). During an inspection of the SONGS Unit 3 SGR, three calculations were reviewed in conjunction with the inspection-referenced models and equations from technical reports American Concrete Institute (ACI) 209R-92 and ACI 224.2R-92. The inspectors identified that these two ACI reports were not referenced in the licensee’s concrete construction code of record, which is ACI 318-71, and were also not referenced in the licensee’s FSAR. This concern was characterized as unresolved item 05000362/2010009-01.

Region IV requested NRR assistance to address the above concerns by providing answers to the following Task Interface Agreement (TIA) questions:

1. Is the application of methods in report ACI 209R-92 for predicting the time-dependent creep, shrinkage, and elastic modulus characteristics of concrete technically acceptable for the restoration evaluation of the SONGS (Units 2 and 3) post-tensioned concrete containments following SGR?

2. If the application of the methods in ACI 209R-92, described in 1 above, is acceptable for the SONGS (Units 2 and 3) containment evaluation, should the licensee address the statement in Section 1.1 of the report with regards to special structures, such as containments, that may require further considerations which are not within the scope of the report in order to justify a sound basis of its use?

3. Is the application of the method in Section 4.1, “Axial stiffness of one-dimensional members,” of report ACI 224.2R-92, to model a reduced sectional stiffness to account for the effects of concrete cracking under factored design basis load combinations technically acceptable, and consistent with the safety analysis methods in the Updated FSAR (UFSAR), for the restoration evaluation of the SONGS (Units 2 and 3) post-tensioned concrete containments following SGR?

ENCLOSURE

4. Does the use of the models and methodology for calculations pertaining to the cracked section contained in ACI 224.2R-92 represent a “Departure From A Method of Evaluation Described in the FSAR,” as defined in Nuclear Energy Institute (NEI) 96-07, Revision 1, Sections 3.4 and 4.3.8, described below and thus should have been evaluated in a Title 10 of the *Code of Federal Regulations* (10 CFR) 50.59 evaluation?

   NEI 96-07, Revision 1, Section 3.4:
   “Departure from a method of evaluation described in the FSAR means (ii) changing from a method described in the FSAR to another method unless that method has been approved by NRC for the intended application.”

   NEI 96-07, Revision 1, Section 4.3.8:
   “…..the following changes are considered a departure from a method of evaluation described in the UFSAR: - Use of new or different methods of evaluation that are not approved by NRC for the intended application.”

5. If the methods in both the ACI reports are appropriate for use in this situation, were the methods and equations associated with them used correctly with the appropriate assumptions and inputs in support of the design basis evaluation of the restored SONGS (Units 2 and 3) containments following SGR?

2.0 BACKGROUND

During the SGR inspection at SONGS Unit 3, the inspectors observed that equations and models from ACI 209R-92, “Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures,” and ACI 224.2R-92, “Cracking of Concrete Members in Direct Tension,” were used in calculations.

ACI 209R-92 was referenced in the following three calculations reviewed by the inspectors as part of the inspection:

- Section 8.2.2 of Calculation No. C-257-01.04.05, “Evaluation of Restored Containment – Concrete Modular Ratio,” which is part of Engineering Change Package (ECP) No. 061200409-6, Revision 0, uses equations from ACI 209R-92 to calculate creep and shrinkage of the existing concrete, and in Section 8.2.4 to calculate prediction estimates for creep and shrinkage for the new concrete to be used for restoring the SGR opening.

- Section 7.1.2 of Calculation No. C-257-01.04.06, “Evaluation of Restored Containment: End-of-Life Analysis,” which is part of ECP No. 061200409-6, Revision 0, and 061200409-7, Revision 0, uses equations from ACI 209R-92 to calculate an effective modulus of elasticity for determining stresses resulting from prestressing loads.

- Section 8.1.1 of Calculation No. C-257-01.04.06 was revised with Engineering Change Notice (ECN) No. D0020134. This revision, which has the same calculation number and title, still uses equations from ACI 209R-92 to calculate an effective modulus of elasticity for determining stresses resulting from prestressing loads; however, in this revision, these equations are referenced.

Section 1.1 in ACI 209R-92 states, in part, the following:

> "These direct solution methods predict the response behavior at an arbitrary time step with a computational effort corresponding to that of an elastic solution. They have been reasonably well substantiated for laboratory conditions and are intended for structures designed using the ACI 318 Code. They are not intended for the analysis of creep recovery due to unloading, and they apply primarily to an isothermal and relatively uniform environment. Special structures, such as nuclear reactor vessels and containments, bridges or shells of record spans, or large ocean structures, may require further considerations which are not within the scope of this report."

ACI 224.2R-92 was referenced in one of the calculations reviewed by the inspectors as part of the inspection. Calculation No. C-257-01.04.06 was revised with ECN No. D0020134 and uses ACI 224.2R-92 as a reference. Section 7.2.2 of the previous revision of this calculation (referred to as Calc. No. C-257-01.04.06, ECP No. 061200409-6, Revision 0, and 061200409-7, Revision 0) concluded that additional steel reinforcement (rebar) was "required in the restored concrete area to compensate for the loss of concrete compressive stresses." Figure 9 in that revision provided the proposed steel reinforcement detail.

As a result of constructability reviews, the calculation was revised as part of ECN No. D0020134. Section 8.1.1.2, of this revision uses equations from ACI 224.2R-92 to calculate a reduced concrete sectional stiffness, which is detailed in Appendix H of the calculation. Section 8.1.2.7 of the revised calculation concludes that "no additional reinforcement is required," which is depicted in Figure 12 in that section.

The introductory commentary in ACI 224.2R-92 begins by stating, "This report is concerned with cracking in reinforced concrete caused primarily by direct tension rather than bending." Additionally, Chapter 1, states, in part, "This report deals specifically with cracking in members subjected to direct tension." The approach and equations from this report that were used in the revised calculation are from Section 4.1, titled, "Axial stiffness of one-dimensional members." This section of the ACI report provides a method for estimating the reduced stiffness in the post-cracking range for a one-dimensional member and is based on a symmetrical reinforced concrete member loaded in tension. This report also includes ACI 209R as a reference.

The inspectors could not find any reference, endorsement, or review of ACI 209R-92 or ACI 224.2R-92 by the NRC. The licensee's FSAR did not reference these ACI reports. The licensee's code of record for concrete construction is ACI 318-71, which issued in 1971 pre-dates these reports issued in 1992, therefore, they are not referenced in that code.

Additionally, Section 8.1.2.6 of the revised calculation (ECN No. D0020134) states, in part, the following:

> "For membrane forces only at service loads, UFSAR requires that concrete shall not develop any tensile stress to prevent concrete cracking. Due to large loss of concrete compressive stress, tensile stress up to 0.13 ksi may occur in the concrete within the opening area. However, this level of tensile stress is acceptable for the following reasons: (1) the tensile stress level will not cause concrete cracking, (2) this occurs at a local area, and (3) it has been calculated with various conservative assumptions as discussed below."

Licensee Position

Based on discussions of the Region IV inspectors with the licensee, their position is that ACI 209R-92 and ACI 224.2R-92 are both acceptable and appropriate to use for analysis of the nuclear containment structures. The summary of this position is provided below:

ACI 209R-92:

The ACI 209R report is a widely recognized guidance document that provides a simple, yet reasonably accurate methodology for estimating creep and shrinkage design values. For the SONGS containment structure, the use of such estimated values have been further justified and validated by comparison to long term creep and shrinkage test results performed on the actual concrete mix used to restore the temporary construction opening.

ACI 224.2R-92:

The SONGS Units 2 and 3 UFSAR describes methods of evaluation for the containment structure in subsection 3.8.1.4, "Design and Analysis Procedures." Consideration of concrete cracking in the development of analytical models is explicitly described: "assumptions as to material properties, including the effects of creep, shrinkage, and cracking on concrete, are used in design." Furthermore, UFSAR 3.8.1.4, states that details concerning various phases of the engineering work involved in executing the design of a containment structure are contained in Bechtel Topical Report BC-TOP-5, "Prestressed Concrete Nuclear Reactor Containment Structures," Revision 1. This report implies that consideration of concrete cracking is a necessary equilibrium check of the analytical model, using results from intermediate analysis steps. Where results indicate local tensile stresses in elements representing concrete, the elements in question should be considered subject to cracking. In that case, the local element properties should be adjusted by reducing the stiffness of the affected elements using techniques that are appropriate for the type of analytical model. This adjustment redistributes internal forces, at which point the final concrete and steel stresses can be determined.

For the Steam Generator Replacement Project (SGRP), a new paragraph 3.8.1.4.1.2D, "Temporary Construction Opening for SGRP," was added to UFSAR 3.8.1.4. The new paragraph 3.8.1.4.1.2D, describes the new containment analysis, contained in calculation C-257-01.04.06 that was performed to demonstrate that the restored temporary construction opening for SGRP would satisfy design requirements. A 10 CFR 50.59 evaluation was performed for this activity that explicitly addressed whether the new analysis involves a departure from approved methods of evaluation. Since the new analysis employs a new computer program, ANSYS, which is not included in BC-TOP-5, and the analytical model uses shell elements rather than various solid element types described in BC-TOP-5, a baseline comparison was performed. The baseline comparison demonstrated that the new computer software and new analytical model produce results that are essentially the same as those from the previous containment analysis. Based on this baseline comparison, the 10 CFR 50.59 evaluation concluded that the new analysis does not involve a departure from UFSAR-described methods of evaluation. With respect to concrete cracking, the new analysis considers that the activity of removing and replacing the concrete within the construction opening, by itself, significantly redistributes internal forces in the concrete at this location. This redistribution of internal forces influences crack development, an effect that should be considered in the analysis to be consistent with the UFSAR-described methods of evaluation summarized above. ACI

224.2R expressions were used to adjust the local element properties by reducing stiffness to account for concrete cracking. Appendix H of calculation C-257-01.04.06 demonstrated that use of ACI 224.2R expressions is an appropriate technique, considering the type of analytical model used in the analysis. This technique does not replace or revise any of the provisions of ACI 318-71 that are applied to the design of the containment structure. Therefore, use of ACI 224.2R as a model refinement technique is encompassed by the 10 CFR 50.59 evaluation's conclusion that the new analysis does not involve a departure from approved methods of evaluation.

Recommended Actions by Region IV

As stated above, Section 1.1 of ACI 209R-92 has a statement regarding special structures, such as nuclear containment structures possibly requiring other considerations that are not part of the scope of ACI 209R. The licensee should have performed an evaluation to verify that the report and the equations derived therein are applicable to the SONGS containment structure despite the statement in the report, and all considerations have been taken into account. Additionally, the licensee’s response that testing was performed to validate the ACI 209R estimates that were calculated does not address the calculations used in the evaluation of the existing concrete, for which core testing was not performed.

The region has reviewed the licensee’s 10 CFR 50.59 evaluation described in its position above, and has determined that the evaluation justified the use of the computer program ANSYS in lieu of SAP for the local analysis but did not address the differences between the iterative methods used with the original design calculations and the new methods, models, and equations as presented in the ACI 224.2R-92 report. The inspectors believe that the licensee should have performed a 10 CFR 50.59 evaluation for the new methodology and type of analysis. This evaluation should consider that ACI 224.2R was developed to evaluate cracking in members from direct tension across the entire member, and this does not appear to relate specifically to this type of post-tensioned structure due to other stresses from bending or flexure. Additionally, some evaluation or justification should be documented to explain why the equations and models derived in Section 4.1 for one-dimensional members are adequate to use for this complex system.

Section 8.1.2.6 of the revised calculation (ECN No. D0020134), which is stated in the background section above, indicates that the tensile stress may exceed the UFSAR requirement. The licensee should have evaluated this UFSAR deviation in a 10 CFR 50.59 evaluation.

3.0 EVALUATION

Question 1:

Is the application of methods in report ACI 209R-92 for predicting the time-dependent creep, shrinkage, and elastic modulus characteristics of concrete technically acceptable for the restoration evaluation of the SONGS (Units 2 and 3) post-tensioned concrete containments following SGR?

Response:

Yes, when project-specific test data is not available at the time of design.

ACI 209R-92 is a recognized guidance report that presents simplified and unified methods for predicting time-dependent variation of creep, shrinkage, and temperature effects (material response and structural response) for design of reinforced and prestressed concrete structures. The report states that the methods presented have been reasonably well substantiated for laboratory conditions based on a significant amount of laboratory measured data under steady environmental and loading conditions. The report is generally consistent with ACI 318, "Building Code Requirements for Structural Concrete," which is the construction code-of-record (ACI 318-71) for SONGS Unit 2 and Unit 3 (Reference 2), and includes material indicated in the Code, but not specifically defined therein.

The SONGS Unit 2 and Unit 3 containments are post-tensioned prestressed concrete structures. Section 18.6 of ACI 318-71 lists the sources of loss of prestress to be considered in prestressed concrete design, without defining methods for computing those losses. This list includes time-dependent losses from creep and shrinkage of concrete. Therefore, if project-specific test data is not available at the time of design, it is acceptable to use the methods and equations in ACI 209R to estimate the time-dependent variation of loss of prestress due to creep and shrinkage of concrete and to determine the shrinkage strain and effective elastic modulus of concrete (which is a function of time-dependent creep coefficient) for the end-of-life structural analysis models and evaluation of the restored SONGS containments, following SGR. It should be noted that this acceptability is subject to the limitations and conditions of applicability provided in ACI 209R and additional considerations (described in the response to Question 2) for special structures such as nuclear reactor containments.

SONGS Calculation No. C-257-01.04.05, "Evaluation of Restored Containment – Concrete Modular Ratio" (Reference 3), and Calculation No. C-257-01.04.06 (ECN No. D0020134), "Evaluation of Restored Containment – End-of-Life Analysis" (Reference 4), used equations from ACI 209R-92 to develop design prestressing forces and material property (creep, shrinkage, effective modulus) inputs to the ANSYS finite element model for containment restoration analysis as follows:

(a) Equations (2-8) and (2-9) in ACI 209R-92 were used to estimate the time-dependent variation of creep and shrinkage, respectively, in the existing concrete and the new concrete used for restoration of the SGR construction opening. These equations were used to predict the prestress losses in the post-tensioning tendons due to creep and shrinkage of the concrete to enable the determination of prestressing forces for design. Values of creep and shrinkage strain used in these equations for existing concrete were taken from the original calculations and were based on tests of original concrete at the time of construction. Values of creep and shrinkage strain used for new concrete in the SGR construction opening area were based on ACI 209R-92. These losses along with other prestress losses are used to predict the variation of tendon forces with time from the time of restoration to the end-of-life of the containments and to determine the design prestressing forces to be used in the end-of-life analysis.

(b) Equations (3-1) and (5-1) in ACI 209R-92 were used to estimate the effective/age-adjusted effective modulus of elasticity of the new concrete, a function of the time-dependent creep coefficient, to account for creep in the finite element model for end-of-life structural response evaluation. The effective modulus of elasticity (the more conservative of the estimates obtained using Equations 3-1 and 5-1) is used as input in the containment finite element model to capture the creep-adjusted effect due to prestressing forces on the stiffness of new concrete. In addition, the shrinkage effect on the stress distribution is considered in the finite element model by modeling the shrinkage strain (estimated using Equation 2-9 of ACI 209R-92) of the new concrete as an input.

The creep and shrinkage estimates used for existing (original) concrete were extrapolated (for 60-year end-of-life analysis) from numbers used in original calculations, which were based on tests on original concrete (Refer to Section 5.1 of Calculation C-257-01.04.05 (Reference 3)).

Question 2:

If the application of the methods in ACI 209R-92, described in Question 1 above, is acceptable for the SONGS (Units 2 and 3) containment evaluation, should the licensee address the statement in Section 1.1 of the report with regards to special structures, such as containments, that may require further considerations which are not within the scope of the report in order to justify a sound basis of its use?

Response:

Yes, as described below.

The NRC staff position in NUREG-0800, "Standard Review Plan [(SRP)]," Section 3.8.1 (Revisions 1, 2, and 3) "Concrete Containment," paragraph II.4.D, related to acceptance criteria for design and analysis procedures with regard to creep and shrinkage of concrete states that: "Creep and shrinkage of concrete should be established by tests performed on the concrete to be used in the containment structure or from data obtained on completed containments constructed of the same kind of concrete. In establishing these values, the analysis should consider the differences in the environment between the test samples and the actual concrete in the structure." Further, it is recognized that each of the factors (concrete creep and shrinkage, steel relaxation) affecting the time-dependent characteristics of tendon forces are subject to variations. Therefore, for applications such as nuclear containment structures including modifications involving SGR construction openings, it is recommended that estimates of time-dependent prestress losses from creep and shrinkage of concrete using applicable equations in ACI 209R-92 should be subject to the following additional considerations. The staff evaluation of whether the licensee included these considerations in its containment restoration calculations is also discussed with each consideration.

(1) The potential variations in time-dependent prestress losses from creep and shrinkage of concrete as well as relaxation of prestressing steel should be accounted for by developing a tolerance band of upper-bound lower-bound curve of predicted prestressing forces with time using a method such as recommended in Regulatory Guide (RG) 1.35.1, "Determining Prestressing Forces for Inspection of Prestressed Concrete Containments." The tendon prestressing forces used in design shall not exceed the lower-bound predicted forces.

From Section 8.3.2.5 of Calculation C-257-01.04.05 (Reference 3), the NRC staff finds that the licensee did consider a tolerance band consistent with RG 1.35.1 for the new concrete properties to account for variations in prestress losses and considered lower-bound prestress force values in the structural evaluations. Therefore, the NRC staff concludes that the licensee included the above consideration in its calculations.

(2) The estimated values of concrete creep and shrinkage using provisions/equations in ACI 209R is further validated and its impact on the containment evaluation reconciled by comparison to long term creep and shrinkage test results performed on the actual concrete mix used in the actual construction under environmental and loading conditions similar to those expected in the field to the extent possible.

In its position on the use of ACI 209R, the licensee stated, in part, that the use of ACI 209R-92 estimated values for creep and shrinkage has been further justified and validated for SONGS by comparison to long term creep and shrinkage test results performed on the actual concrete mix used to restore the temporary construction opening. In its request for additional information (RAI) 1 in Reference 5, the NRC staff requested the licensee to provide the above stated comparison of the concrete properties (creep, shrinkage, and elastic modulus) obtained from tests of the actual concrete mix used in the SGR construction opening to those used in the analysis based on ACI 209R-92, and address the impact of the differences, if any, on the containment restoration evaluation. In its response to RAI 1 in Reference 6, the licensee provided the comparison of concrete properties (i.e., creep coefficient, shrinkage strain, and elastic modulus) from tests of the new concrete mix used for containment restoration and the values used in the end-of-life analysis based on estimates using ACI 209R-92. The licensee stated that the test values of creep coefficient and shrinkage strain, and elastic modulus from tests were found to be higher by 27 percent and 85 percent respectively, than the values estimated using ACI 209R-92. The licensee stated that the total change (increase) in prestress losses using test data of creep and shrinkage for the new concrete mix used in the containment opening restoration, in comparison to losses calculated based on ACI 209R recommendations, was less than 1 ksi and therefore, negligible in comparison to the estimated average tendon stress at end of life of the order of 170 ksi (from Tables 16 and 17 of Reference 3). Further, the licensee stated that the modulus of elasticity of new concrete determined by testing was about 3 percent higher than the calculated value that was used in the analysis. Hence, the licensee concluded that the difference in values of creep, shrinkage and elastic modulus of new concrete obtained by testing and that which was used in the analysis has a negligible impact on the design. The licensee also confirmed that the environmental difference between the test samples and the actual concrete was minimal. As discussed in the response to Question 1, the creep and shrinkage values used for existing concrete were numbers used in original calculations which were based on creep tests on original concrete.

Based on the response to RAI 1, the NRC staff finds that the licensee addressed and reconciled the differences between the test values of creep and shrinkage of the new concrete from that used in the calculations to predict prestress losses in the tendons (i.e., the application of ACI 209R-92 described in subparagraph (a) in the response to TIA Question 1). Further, the case using the lower-bound value of reduced effective stiffness in a bounding approach to account for concrete cracking in the SGR opening area (discussed in response to TIA Question 5) factors the impact of the increased values of creep coefficient, shrinkage strain, and elastic modulus obtained by testing on the results of the finite element analysis for end-of-life (i.e., the application of ACI 209R-92 described in subparagraph (b) in the response to Question 1). Therefore, the NRC staff concludes that the licensee included the above additional consideration in its calculations.

(3) The predicted variation of tendon forces with time based on all calculated prestress losses, including ACI 209R-based estimates of time-dependent losses such as creep and shrinkage of concrete and relaxation of tendon steel, are subject to periodic verification based on measured lift-off forces of a sample of tendons of each type used on the containment structure.

The NRC staff finds that this consideration is satisfied by SONGS since operating reactors with post-tensioned containments are required to perform periodic tendon surveillance as part of the containment inservice inspection program in accordance with American Society of Mechanical Engineers (ASME) Code Section XI, Subsection IWL, pursuant to 10 CFR 50.55a.

Based on the above discussion, the NRC staff finds that the licensee has satisfied the additional considerations in (1) through (3) above in applying ACI 209R-92. Therefore, the NRC staff concludes that the licensee has addressed the statement in Section 1.1 of the ACI 209R-92 report, with regards to special structures, such as containments, that may require further considerations which are not within the scope of the report, for the end-of-life structural evaluation of the SONGS containments.

Question 3:

Is the application of the method in Section 4.1, "Axial stiffness of one-dimensional members," of report ACI 224.2R-92, to model a reduced sectional stiffness to account for the effects of concrete cracking under factored design basis load combinations technically acceptable, and consistent with the safety analysis methods in the UFSAR, for the restoration evaluation of the SONGS (Units 2 and 3) post-tensioned concrete containments following SGR?

Response:

Yes, subject to proper implementation of the appropriate method in Section 4.1 of ACI 224.2R-92 (Reference 7) and using a bounding approach to account for the simplifying assumptions/approximations and expected variations of the cracking stiffness. Note that the licensee's implementation of the method is evaluated in detail in the response to TIA Question 5.

The ACI 224.2R-92 technical report (Reference 7) discusses methods for estimating post-cracking axial stiffness of concrete in direct tension. In Appendix H of Calculation No. C-257-01.04.06 (Reference 4), a method based on equations 4.12 and 4.13 of the ACI 224.2R-92 report was used to estimate a reduced concrete sectional stiffness to account for cracking in the restored SGR opening area, in the ANSYS finite element model, based on linear elastic behavior using thin shell elements, for the end-of-life evaluation of the restored SONGS containments. It is technically acceptable to apply the method using equations 4.12 and 4.13 in Section 4.1 of ACI 224.2R-92 report, concerning the axial stiffness due to cracking of one-dimensional reinforced concrete members in direct tension, to estimate an approximate reduced concrete axial stiffness to account for cracking of the SONGS end-of-life evaluation following restoration of the SONGS prestressed reinforced concrete containments based on the reasons below.

(a) The prestressing forces are modeled as a load and the cross-sectional area of the prestressing tendons are included in the calculation of effective stiffness of the member using equations 4.12 and 4.13 of ACI 224.2R-92, applicable to reinforced concrete members in direct tension. This is confirmed in the licensee's response to RAIs 2 and 3 in Reference 6. Therefore, the prestressed (post-tensioned) containment structure can be essentially considered as a reinforced concrete structure.

(b) Review of Sections 8.1.2.1, 8.1.2.2, and Table 6 of the SONGS containment restoration end-of-life analysis calculation (Reference 4) indicate that only the factored load combinations (LCs) III, IV, and VI presented below (see UFSAR Section 3.8.1.3.2 for definition of loads in the load combinations) produce large membrane tensile forces in the SGR construction opening area that could cause through-wall cracking of concrete.

LC III (Abnormal Case): $D + F + T_A + 1.5P$
LC IV (Abnormal/Severe Environmental Case): $D + F + T_A + 1.25P \pm 1.25E$
LC VI (Abnormal/Extreme Environmental Case): $D + F + T_A + P \pm E'$

All of the above three LCs include internal accident pressure loads (P); and LCs IV and VI include seismic loads (E (OBE) and E' (SSE). It should be noted that only factored load combinations including internal accident pressure (P) may cause membrane cracking of concrete. The internal pressure load primarily causes membrane (axial) tension in the hoop (horizontal) and meridional (vertical) directions of the cylindrical shell. The results in Table 6 of Reference 4 indicates that the seismic loads (E & E') in LCs IV and VI also primarily cause membrane (axial) tension and membrane compression in the meridional (vertical) direction. The uncracked analysis results for the SGR construction opening area in Table 6 of Reference 4 indicates that load combinations excluding internal pressure do not result in membrane tension forces and do not cause membrane cracking of concrete. Thus, it can be concluded that it is the membrane (axial) forces that are the primary cause of through-wall cracking expected for LCs III, IV, and VI with the accident pressure being the primary governing load. Therefore, under these load conditions, it is reasonable to approximate the effect of cracking on the response of the containment under these load combinations primarily as one dimensional (axial or membrane) in each of the hoop and vertical directions.

The method used in Reference 4, based on ACI 224.2R, to develop the input to the finite element analysis model to account for concrete cracking, is consistent with the intent of the safety analysis techniques in the UFSAR, the original design calculation (Reference 8) and the NRC staff position (in RG 1.136 and SRP Section 3.8.1 in NUREG-0800 with regard to consideration of the effects redistribution of forces due to concrete cracking for the following reasons.)

(i) The design and analysis procedures used in original design of the SONGS containments are described in UFSAR Section 3.8.1.4 and the original design calculation (Reference 8). UFSAR Section 3.8.1.4 states that improved assumptions as to material properties, including the effects of creep, shrinkage, and cracking on concrete, are used in design. The overall analysis of the containment, given the application of axisymmetric loads, was performed considering it to be an axisymmetric structure using the bilinear-elastic finite element computer program FINEL (which is currently obsolete). The computer model consisted of quadrilateral or triangular elements of the following materials: concrete, liner plate, reinforcing steel, and soil, and is shown in UFSAR Figure 3.8-14. The computer program accounted for concrete cracking by using an incremental and iterative approach. This was done by using incremental loads and a series of successive elastic iterations (to achieve the desired convergence) in which the stiffness matrix of the cracked elements is modified (by reducing the concrete modulus of elasticity to a small value) to account for the effect of cracking of each element. The procedure is detailed in Subsection 7.2.1 of BC-TOP-5, Revision 1 (Reference 9), which is referenced in the UFSAR with regard to design and analysis procedures. It should be noted that only factored load combinations including internal pressure could cause cracking of concrete in the SONGS containments.

(ii) In the Reference 4 containment restoration calculation following SGR, the licensee applied the method based on equations 4.12 and 4.13 of Section 4.1 of ACI 224.2R-92 to approximate an effective (reduced) tensile membrane (axial) stiffness $(E_cA)_{eff}$ for use as input to the SONGS containment restoration ANSYS finite element analysis model using thin shell elements (note that the ANSYS shell element model does not include the reinforcement, the liner plate and soil). This reduced axial stiffness is used to account for the effects of concrete cracking in the approximately 30 ft x 30 ft SGR construction opening area under factored design basis LCs III, IV, and VI, described earlier, that include accident pressure loading. The initial ANSYS uncracked analysis determined that the SGR opening area was subject to concrete cracking under these factored load combinations. Basically, the approach used is to write the effective stiffness, $(EA)_e$, of the cracked region in terms of the modulus of elasticity of concrete, E_c, and an effective cross sectional area, A_e, of concrete (i.e., E_cA_e). This approach is analogous to the effective moment of inertia concept for evaluation of deflections incorporated in ACI 318. The concept of gradual reduction in stiffness due to progressive cracking is well illustrated in Figure 4-1 of ACI 224.2R-92 by considering the relationship between the tensile load and the average strain in both the uncracked and cracked states. The so obtained effective stiffness (E_cA_e) when divided by the uncracked stiffness (E_cA_g, where A_g is the uncracked gross cross sectional area of concrete) gives a ratio which when multiplied by E_c, gives a reduced (effective) concrete modulus of elasticity (E_{cr}) that is used as input to the finite element model to be representative of the cracking stiffness. As explained in the licensee's response to RAI 8 in Reference 6, this reduced modulus of elasticity input in the model automatically approximates the reduced tensile membrane stiffness, the reduced flexural stiffness, and the reduced shear stiffness since the formulation of these stiffnesses in the element/global stiffness matrices in the finite element model are a function of the concrete modulus of elasticity (and Poisson's ratio (ν_c) for shear stiffness only). Thus, the simplified concept used to model cracking in the finite element model using a reduced elastic modulus in the cracked areas, determined based on a previous uncracked analysis, is analogous to a similar approach used in the original FINEL analysis using an iterative process. It should be noted that the method of overall containment structural analysis under design loads, incorporating cracking effects, used in both the Reference 8 original design calculation (using FINEL computer code) and the Reference 4 SGR containment restoration calculation (using ANSYS computer code) is the finite element method based on elastic theory.

(iii) The NRC has endorsed in RG 1.136, with regulatory positions, the 2001 Edition with 2003 addenda of the ASME Code, Section III, Division 2, "Code for Concrete Containments." The provisions stipulated in sub-article CC-3300 of the code with regard to design analysis procedures for consideration of concrete cracking are:

CC-3310 General, in part states: "…In the design of local sections, consideration shall be given to the redistribution of moments and forces in a statically indeterminate structure because of cracking of the concrete, and to the stiffening effect of buttresses or other integral portions of the containment."

CC-3320 Shells, subparagraph (a) states: "Containments are normally thin shell structures. Elastic behavior shall be the accepted basis for predicting internal forces, displacements, and stability of thin shells. Effects of reduction in shear stiffness and tensile membrane stiffness due to cracking of the concrete shall be considered in methods for predicting maximum strains and deformations of the containment. Equilibrium check of internal forces and external loads shall be made to ensure consistency of results."

The above Code provisions specify consideration to be given to the effects of concrete cracking under design loads in the structural analysis. From the above Code provisions, it should be further noted that while elastic shell behavior is the accepted basis of overall structural analysis, the Code does not prescribe specific analytical procedures to satisfy the requirement for consideration of the effects of concrete cracking in the analysis, but leaves the choice of reasonable analytical techniques to the qualified analyst/design engineer.

The review guidance in the current SRP, NUREG-0800, Section 3.8.1, "Concrete Containment," paragraph II.4.D acceptance criteria with regard to techniques for consideration of cracking of concrete states, in part, that: "With improvements in the development of computer programs for analysis of concrete structures, the evaluation of concrete cracking can be analyzed directly within the finite element model. Alternatively, additional analyses can treat the effect of concrete cracking by determining the response of the containment to variation in the stiffness characteristics of the containment shell (e.g., shear stiffness and tensile membrane stiffness reduction)…."

The NRC staff notes that the licensee's approach for the restored SONGS containments using ACI 224.2R equations would fall in the latter category of alternative additional analyses by varying the stiffness characteristics from a best-estimate to treat the effect of concrete cracking in the above staff review guidance. To avoid a number of iterative analyses, the licensee's approach was to perform an initial uncracked analysis for the load combinations based on which cracked or uncracked stiffness properties were assigned to various elements based on their anticipated stress state. The licensee also explained its considerations of the effect of cracking on the axial, flexural and shear stiffnesses in its response to RAI 8 in Reference 6.

Question 4:

Does the use of the models and methodology for calculations pertaining to the cracked section contained in ACI 224.2R-92 represent a “Departure From A Method of Evaluation Described in the FSAR” as defined in NEI 96-07, Revision 1, Sections 3.4 and 4.3.8 described below and thus should have been evaluated in a 10 CFR 50.59 evaluation?

NEI 96-07, Revison 1, Section 3.4:
“Departure from a method of evaluation described in the FSAR means (ii) changing from a method described in the FSAR to another method unless that method has been approved by NRC for the intended application.”

NEI 96-07, Revision 1, Section 4.3.8:
“…the following changes are considered a departure from a method of evaluation described in the UFSAR: - Use of new or different methods of evaluation that are not approved by NRC for the intended application.”

Response:

No. However, a different 10 CFR 50.59 issue was identified as discussed below.

The NRC staff evaluated the licensee’s 10 CFR 50.59 against NRC requirements and guidance documents. Specifically, 10 CFR 50.59 provides a means for licensees to make changes in the facility as described in the FSAR (as updated). The regulation at 10 CFR 50.59(c)(2)(viii) requires that licensees obtain a license amendment pursuant to 10 CFR 50.90 prior to implementing a proposed change if the change would result in a departure from a method of evaluation described in the FSAR (as updated) used in establishing the design bases or in the safety analyses. The regulation at 10 CFR 50.59 a(2) states, “Departure from a method of evaluation described in the FSAR (as updated) used in establishing the design bases or in the safety analyses” means (i) changing any of the elements of the method described in the FSAR (as updated) unless the results of the analysis are conservative or essentially the same; or (ii) changing from a method described in the FSAR to another method unless that method has been approved by NRC for the intended application. NEI 96-07, Revision 1, “Guidelines for 10 CFR 50.59 Implementation” was endorsed in NRC RG 1.187, “Guidance for Implementation of 10 CFR 50.59, Changes, Tests, and Experiments,” dated November 2000, as acceptable guidance for complying with the provisions of 10 CFR 50.59. Section 3.10, “Methods of Evaluation,” states, “Definition: Methods of evaluation means the calculational framework used for evaluating behavior or response of the facility or structures, systems, and components.”

The NRC staff evaluated the licensee’s use of equations from ACI 224.2R-92 used to evaluate cracking and whether this constituted a change in the method of evaluation from ACI 318-71 that the licensee should have addressed in its 10 CFR 50.59 evaluation. Section 2 of this TIA states that the licensee’s position is that ACI 224.2R expressions were used to adjust the local element properties by reducing stiffness to account for concrete cracking, that Appendix H of

Calculation C-257-01.04.06 demonstrated that use of ACI 224.2R expressions is an appropriate technique, and that this technique does not replace or revise any of the provisions of ACI 318-71 that are applied to the design of the containment structure. Therefore, the licensee’s position is that the use of ACI 224.2R as a model refinement technique is encompassed by the 10 CFR 50.59 evaluation's conclusion that the new analysis does not involve a departure from approved methods of evaluation.

The NRC staff evaluated the use of ACI 224.2R-92 against 10 CFR 50.59(c)(2)(viii), which requires that licensees obtain a license amendment pursuant to 10 CFR 50.90 prior to implementing a proposed change if the change would result in a departure from a method of evaluation described in the FSAR (as updated) used in establishing the design bases or in the safety analyses. Specifically, the SONGS 2 and 3 UFSAR Section 3.8.1.5, “Structural Acceptance Criteria,” states, “Similar to the original containment structure evaluation, the provisions of the ASME Section III, Division I and ACI 318-71 codes are used to evaluate the containments’ structural integrity following restoration of the SGRP temporary construction opening.” The licensee’s update to the FSAR to reflect the restoration of the temporary containment opening did not add a specific reference to ACI 224.2R-92 which is acceptable based on the above response to Question 3 which states that the method used in Appendix H of Calculation No.C-257-01.04.06 (Reference 4), a method based on equations 4.12 and 4.13 of the ACI 224.2R-92 to develop the input to the finite element analysis model to account for concrete cracking, is consistent with the intent of the safety analysis techniques in the UFSAR, the original design calculation (Reference 8), and the NRC staff position (in RG 1.136 and SRP Section 3.8.1 in NUREG-0800) with regard to consideration of the effects of redistribution of forces due to concrete cracking.

NEI 96-07, Revision 1, Section 4.3.8 states “By way of contrast, the following changes are not considered departures from a method of evaluation described in the UFSAR: Departures from methods of evaluation that are not described, outlined or summarized in the UFSAR (such changes may have been screened out as discussed in Section 4.2.1.3).” Therefore, the NRC staff found it acceptable that the licensee’s 10 CFR 50.59 evaluation did not specifically address ACI 224.2R-92. However, the NRC staff identified a different 10 CFR 50.59 issue that is described as follows:

<u>Change in Method of Evaluation from SAP to ANSYS</u>

The NRC staff evaluated the change in the method of evaluation from SAP, the finite element program the FSAR described was used to analyze large penetration openings, to ANSYS, the finite element program which the update to the FSAR describes was used to analyze the restored temporary construction opening. Specifically, the SONGS 2 and 3 UFSAR describes methods of evaluation for the containment structure in subsection 3.8.1.4, "Design and Analysis Procedures.” For the SGRP, a new paragraph 3.8.1.4.1.2D, “Temporary Construction Opening for SGRP,” was added to UFSAR 3.8.1.4 which states, “The containment structure is reanalyzed for the effects of the creation and closure of the temporary construction opening. This re-analysis of the containment is performed using the methods for evaluating large penetration openings contained in Reference 8. [Reference 8 is BC-TOP-5, Rev. 1, “Prestressed Concrete Nuclear Reactor Containment Structures,” December 1972.]. The analysis is performed with the ANSYS finite-element computer program.”

The licensee’s 10 CFR 50.59 evaluation states that even though the concrete and tendons are ultimately restored, the temporary SGR opening introduces a permanent, non-symmetric redistribution of prestress loads similar to, although not as pronounced as, a large penetration opening. To evaluate the permanent effects of the temporary SGR containment opening, a three-dimensional containment structural analysis was performed utilizing the ANSYS finite element analysis computer program. UFSAR 3.8.1.4.1.2.B, “Large Penetration Openings,” states, “The stresses at the opening are predicted by an analysis performed using Bechtel’s computer program SAP, described in appendix 3C, section 3C.5, which is capable of performing a static analysis of linear elastic three-dimensional structures utilizing the finite-element method.“

The NRC staff evaluated the use of ANSYS in lieu of SAP for the local analysis of the temporary SGR construction opening against 10 CFR 50.59 a(2) which states, “Departure from a method of evaluation described in the FSAR (as updated) used in establishing the design bases or in the safety analyses means (i) changing any of the elements of the method described in the FSAR (as updated) unless the results of the analysis are conservative or essentially the same; or (ii) changing from a method described in the FSAR to another method unless that method has been approved by NRC for the intended application.” The licensee’s 10 CFR 50.59 evaluation stated that “In using ANSYS in lieu of SAP for the local analysis of the temporary SGR construction opening, we changed elements of the approved method of evaluation for the Containment structure, but did not use an entirely new method altogether.” Accordingly, the licensee’s 10 CFR 50.59 evaluation described the results of example runs with each method and demonstrated the results were essentially the same as the basis for concluding that ANSYS did not involve a departure of the method of evaluation.

The NRC staff evaluated the licensee’s 10 CFR 50.59 evaluation against 10 CFR 50.59(d)(1) which states, “The licensee shall maintain records of changes in the facility, of changes in procedures, and of tests and experiments… . These records must include a written evaluation which provides the bases for the determination that the change, test, or experiment does not require a license amendment… .” The NRC staff also evaluated the use of ANSYS in lieu of SAP for the local analysis of the temporary SGR construction opening against NEI 96-07, Revision 1, Section 3.10 definition which states, “Definition: Methods of evaluation means the calculational framework used for evaluating behavior or response of the facility or structures, systems, and components.” The NRC staff determined SAP and ANSYS each met this definition of method of evaluation and as such, the change in the FSAR from SAP to ANSYS constituted a change from a method described in the FSAR to another method. These two methods were used to establish the design basis of containment. As a result, the written evaluation required by 10 CFR 50.59(d)(1) was inadequate in that it did not provide an adequate basis for the determination that the change does not require a license amendment because the basis for whether the change involves a departure for the method of evaluation failed to evaluate the use of ANSYS in lieu of SAP against 10 CFR 50.59a(2)(ii) “changing from a method described in the FSAR to another method unless that method has been approved by NRC for the intended application.”

Question 5:

If the methods in both the ACI reports are appropriate for use in this situation, were the methods and equations associated with them used correctly with the appropriate assumptions and inputs in support of the design basis evaluation of the restored SONGS (Units 2 and 3) containments following SGR?

Response:

A. Application of ACI 209R-92:

Yes.

B. Application of ACI 224.2R-92:

Yes, with the quality-related observations noted below under "NRR Staff Evaluation."

The design of the SONGS Unit 2 and Unit 3 post-tensioned concrete containments is described in Section 3.8.1, "Concrete Containment," of the UFSAR (Reference 2). The design basis loading conditions and loading combinations are tabulated on page 3.8-21 in Section 3.8.1.5, "Structural Acceptance Criteria," of the UFSAR. The limits for allowable stresses and strains in concrete, reinforcement, and the liner for the different loading conditions are provided in UFSAR Table 3.8-1. In UFSAR Section 3.8.1.5, it is stated that the acceptance margins in the structural acceptance criteria will be compatible with the provisions of ASME Section III, Division 1, 1971 Edition with 1972 Addenda for liner and ACI 318-71 codes. The design for service load conditions is based on working stress method and that for factored load conditions is based on the strength design method of ACI 318-71 (Reference 10).

In Section 8.1.1.2 of Reference 4, the licensee described its approach to address cracked conditions of the containment which, in part, states that: "…because of reduction of prestressing forces at the opening area [due to redistribution of dead load and prestress during creation and restoration of the opening], tensile cracking may occur at the opening area before the rest of the structure for short-term loads [accident pressure, earthquake]. When sections crack locally, the concrete stiffness reduces and, thus, the local cracked sections will attract less force. Therefore, the opening area can be modeled with reduced section stiffness for short-term loads (accident pressure, earthquake) when the cracking is expected. The factored load combinations (LC) that may induce tensile cracking at the opening area are identified [LCs III, IV and VI]."

In the Reference 4 calculation, the licensee used an approximate method based on equations 4.12 and 4.13 in Section 4.1 of ACI 224.2R-92 (Reference 7) to estimate the reduced effective axial stiffness of the restored SGR construction opening area in the post-cracking range. This reduced effective stiffness, modeled as a reduced value of the concrete elastic modulus (E_c), was used as an input to the ANSYS finite element shell model of the restored containment for end-of-life analysis to account for, in an approximate way, the redistribution of forces and moments due to cracking under the factored load combinations involving short-term loads (accident pressure (P) and earthquake loads (E or E')). The licensee documented its implementation of the method using equations 4.12 and 4.13 (reproduced below) of ACI 224.2R, to arrive at a reduced axial stiffness of $0.4E_cA_g$ for modeling the opening area that is subjected to cracking under the above mentioned short-term loads in Appendix H of Reference 4. The rest of the structure is modeled using an uncracked stiffness of 1.0 E_cA_g. Since Appendix H of Reference 4 was very limited in the details provided with regard to implementation of the ACI 224.2R method, the licensee further explained its implementation of the method in responses to RAIs 2 through 6 and 8 in Reference 6.

$P = E_cA_e \square_m$ (Equation 4.12 of ACI 224.2R)

where:

P is the axial (membrane) tensile force (load) causing an axial post-cracking strain $\square_m$,

E_c is the concrete modulus of elasticity (4415 ksi used for SONGS restoration concrete), and A_e is the effective (reduced) cross-sectional area due to cracking and defined as below.
$A_e = A_g (P_{cr}/P)^3 + A_{cr}[1-(P_{cr}/P)^3]$ (Equation 4.13 of ACI 224.2R)

where:

A_g = gross cross-sectional area; $A_{cr} = n A_s$ (n = ratio of modulus of elasticity of steel to that of concrete = (E_s/E_c), E_s is modulus of elasticity of [reinforcing] steel); and A_s is area of tension reinforcement [and should also include prestressing steel for prestressed concrete].

The term A_g in Equation 4.13 is replaced by the transformed area (A_t) to include the contribution of reinforcing [and prestressing] steel to the uncracked system. [$A_t = A_g + (n-1)A_s$].

P_{cr} is axial force (load) at which concrete cracking occurs (typically calculated using tensile strength of concrete as 4sqrt(f'_c) if test data is not available, which is what the licensee did based on its response to RAI 3(c) in Reference 6; f'_c = concrete compressive strength = 6000 psi for SONGS).

In its response to RAIs 3(a) and 3(b) in Reference 6, the licensee stated that the cross-sectional area of the unbonded tendons were included in the calculation of parameters A_g, A_s, and A_{cr}. Also, the gross cross-sectional area, A_g, was replaced with transformed area, A_t, to include the contribution of both the bonded reinforcing steel and the unbonded prestressing steel in the post-tensioned prestressed concrete containment.

Figure 4.1 of ACI 224.2R (reproduced as Figure H.1 in Reference 4 calculation) illustrates the relationships between load and axial strain from equations 4.12 and 4.13. It indicates that the cross-sectional stiffness starts to reduce gradually once the axial load exceeds the tensile cracking capacity. The reduction of concrete stiffness depends on the severity of cracking, which is presented in terms of axial strain.

In Appendix H of the Reference 4 calculation, the best-estimate value of reduced sectional stiffness was determined by a parametric study using the mathematical algorithm below:

(1) A reduced stiffness value was assumed for the SGR opening area, $(E_cA_e)_{ANSYS}$, in the ANSYS model and the finite element analysis was conducted for LC III, considering it to be the worst-case for cracking. As a simplifying assumption, the same value of reduced stiffness was assumed in both the hoop and vertical directions.

(2) Axial strains ($\square_m$) in the vertical and hoop directions were obtained from the ANSYS results.

(3) The corresponding ACI 224.2R reduced stiffness values, $(E_cA_e)_{ACI224}$, were then calculated in the hoop and vertical directions by solving equations 4.12 and 4.13 for A_e using the axial strains ($\square_m$) obtained from the ANSYS results.

(4) The above steps were repeated for various assumed reduced stiffness values (i.e., data points were generated for $(E_cA_e)_{ANSYS}/E_cA_g$ values of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, and 0.7).

(5) To determine convergence of the ANSYS and ACI 224.2R based results, the parametric study results for the hoop and vertical directions were plotted using normalized non-dimensional parameter, $(E_cA_e)_{ANSYS}/E_cA_g$, along the x-axis and normalized non-dimensional parameter, $(E_cA_e)_{ACI\ 224}/(E_cA_e)_{ANSYS}$, along the y-axis. A curve based on the average of the results in the hoop and vertical direction was also plotted, which was then assessed for convergence using the criteria in Step 6 below. A horizontal line representing the ratio $(E_cA_e)_{ACI\ 224}/(E_cA_e)_{ANSYS} = 1.0$ was drawn to represent a perfect agreement (convergence) between the ANSYS and ACI 224.2R based results.

(6) Convergence Criteria Used: From the plot in Step 5 above, the value(s) of $(E_cA_e)_{ANSYS}/E_cA_g$ on the x-axis that corresponds to the intersection of the "average" curve and the horizontal line through $(E_cA_e)_{ACI\ 224}/(E_cA_e)_{ANSYS} = 1.0$ was determined by the licensee to be the converged (best-estimate) reduced stiffness ratio. The plot of the results of the parametric study for load combination III is shown as Figure H.2 (reproduced below) in Appendix H of Reference 4. The Figure showed convergence (using the above criteria based on the average curve) at the effective stiffness values of $0.4E_cA_g$ and $0.7E_cA_g$. The licensee used the value of $0.4E_cA_g$ as the reduced effective stiffness in the opening area and implemented it by using $0.4E_c$ as the input concrete elastic modulus value for the cracked SGR construction opening area in the ANSYS finite element model for each of the three LCs (III, IV, and VI) that could cause cracking.

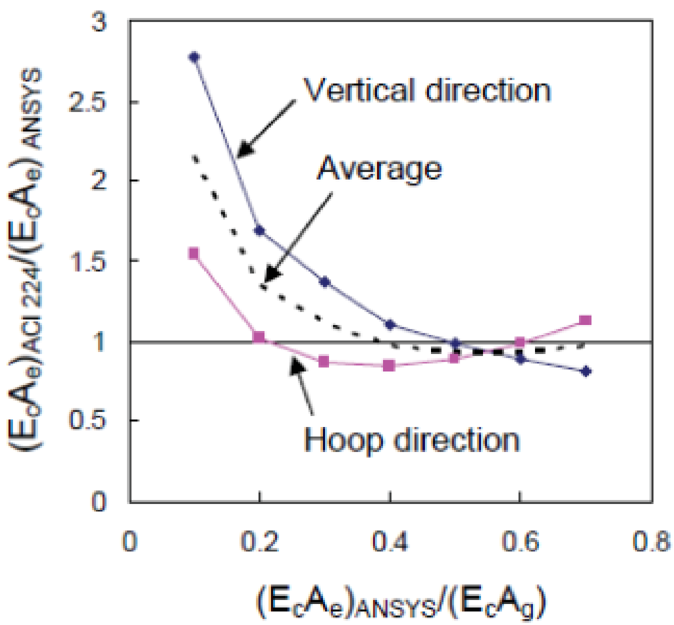

Figure H.2 – Convergence of Sectional Stiffness between ANSYS and ACI 224: Load Combination III

In its responses to RAIs 6, 5, and 4, the licensee explained its reasoning for the convergence criteria, and the use of $0.4E_cA_g$ as the reduced effective stiffness due to cracking in both the vertical and hoop directions for all the three LCs (III, IV, VI) that could cause cracking. The licensee stated that the Reference 4 calculation provides a supplemental local analysis that accounts for redistribution of stresses in the areas within and surrounding the restored SGR opening area. The licensee stated that it considered the existing surrounding area to be critical in the post-restoration structural integrity evaluation and LC III was most critical with regard to cracking in the opening area. The licensee stated that the correct value of effective stiffness may vary depending on the direction and the LCs used. The licensee's critical design goal was to maximize the redistribution of the forces to the existing containment area surrounding the SGR opening area to assure design adequacy in case the stiffness is reduced due to cracking in the opening repair area. The greater the reduction in the effective stiffness value in the opening area, the greater the redistribution of forces to the surrounding area. Therefore, the licensee used the value of $0.4E_cA_g$ as the lower-bound value of reduced effective stiffness in the opening area to maximize redistributed forces (upper-bound) in the surrounding area for design evaluation.

NRR Staff Evaluation:

Based on the response to RAIs 3(a), 3(b), and 3(c) in Reference 6 and Appendix H of Reference 4, the NRC staff finds that the licensee used the appropriate inputs in the application of equations 4.12 and 4.13 of ACI 224.2R-92 to the containment restoration analysis. The NRC staff also found that the data points, using the above algorithm, for the vertical and hoops direction curves in Figure H.2 of Reference 4 (also reproduced here on previous page) were appropriately generated for the vertical and horizontal directions. However, the NRC staff has the following quality-related observations in the implementation of the method.

The NRC staff finds that the convergence criteria used in Step 6 of the above described algorithm, based on the average curve, to determine the best-estimate reduced stiffness to be rather arbitrary and not a mathematical convergence of the algorithm used. Further, the criteria does not seek to satisfy nor does the converged solution so-obtained satisfy the simplifying assumption/approximation that the effective (reduced) stiffness in the vertical and hoop directions are equal, that forms the basis of the ANSYS analyses in the parametric study from which the values of strain, ε_m, in the vertical and hoop directions are obtained. Therefore, the NRC staff position is that a mathematically converged solution for reduced effective axial stiffness values based on ACI 224.2R should also result in the values of $(E_cA_e)_{ACI\ 224}$ being equal for both hoop and vertical directions and should be a necessary condition in the convergence criteria.

Considering the data and assumptions in Figure H.2 of Reference 4, the NRC staff observes that the rational mathematical convergence criteria to be used to determine the converged value (best-estimate) of reduced effective axial stiffness between ANSYS parametric study and ACI 224.2R-estimated values should be the value of $(E_cA_e)_{ANSYS}$ for which:

$$[(E_cA_e)_{ACI\ 224} / (E_cA_e)_{ANSYS}]_{Hoop} = [(E_cA_e)_{ACI\ 224} / (E_cA_e)_{ANSYS}]_{Vertical} = 1\ (\pm 10\%)$$

This criterion mathematically satisfies the converged ACI 224.2R-based solution and the assumption in the ANSYS parametric analysis in that the effective stiffnesses in the two directions are equal. The NRC staff recognizes that these ratios for the two directions are not expected to converge exactly to 1 because of the simplifying assumptions and approximations in the 1-dimensional ACI 224.2R method relative to the 3-dimensional ANSYS parametric analyses, but would be approximately close to 1 (±10 percent commonly accepted) if the ACI 224.2R model is appropriate for the application. If not, the ACI 224.2R-based equations are not appropriate to model reduced axial stiffness of concrete due to cracking in a complex 3-dimensional structure. Using the above criterion with reference to Figure H.2 on page 84 of Reference 4 (also reproduced on previous page), the staff observes that the converged value (best-estimate) of reduced effective axial stiffness for LC III would be the value corresponding to the intersection of the vertical and hoop curves.

The licensee's implementation of the appropriate ACI 224.2R-based method (described previously) to account for concrete cracking involved the following simplifying assumptions and approximations which may be reasonable, but have an impact on the level of cracking that could be expected in the SGR opening area. Hence, the NRC staff position is that a bounding approach (using both lower-bound and upper-bound values from best-estimate) is in order for the reduced concrete stiffness in the opening area for the treatment of cracking to account for the variation of cracking stiffness on the analytical results. (Note that the licensee's analysis considered only a lower-bound value of effective cracking stiffness).

(a) The reduced effective axial stiffness (E_cA_e or $(E_cA_e)_{ANSYS}$) values due to cracking are assumed to be equal for the hoop and vertical directions.

(b) The same value of reduced concrete section stiffness (A_eE_c) of $0.4E_cA_g$ was used in the model for each of LCs III, IV, and VI for which cracking is expected. This assumes that the axial strains and the extent of concrete cracking, and therefore the sectional stiffness, is the same for all LCs regardless of the magnitude of the forces due to applied loads in the different LCs.

(c) The entire opening area is considered to be cracked and to the same extent for each of the three LCs, and lack of the incremental loading and iterative analysis approach used in original design to accounting for cracking.

(d) The prestressing forces used in the end-of-life analysis is conservatively taken as the lower-bound minimum design prestressing force. The actual prestressing forces in the hoop and vertical directions would be higher (to a varying degree) than the minimum design prestressing force assumed in the end-of-life evaluation during the period between completion of restoration of containment opening following SGR and end-of-life. This could result in a lesser degree of cracking under the critical LCs if accident pressure and seismic loads occur between the time of containment restoration to the end-of-life.

(e) Liner not included in the model.

(f) Expected variations in material properties

The NRR staff agrees and accepts the $0.4E_cA_g$ value used by the licensee as a lower-bound value of effective stiffness that maximizes the redistribution of forces due to cracking to the surrounding area and would be the conservative or controlling case for design evaluation of the areas surrounding the opening. However, the NRC staff observes that the controlling case for design evaluation of the SGR opening area itself would be based on an upper-bound value of effective stiffness in the opening area that would minimize the redistribution of forces due to cracking providing upper-bound design forces for the opening area under the critical load combinations. The NRC staff independently evaluated the safety-significance of the two quality-related observations in the next paragraph and did not identify a safety concern. However, the NRC staff recommends that a design evaluation based on reasonable upper-bound value from the best-estimate (factoring the staff observation on convergence criteria) of effective cracking stiffness for the SGR opening area also be addressed in order to demonstrate that upper-bound design forces and moments in the SGR opening area itself meets the acceptance criteria described in Section 3.8.1 and Table 3.8-1 of the UFSAR.

The NRR staff did not identify a safety concern, due to the observations identified above in the implementation of the method to account for cracking, as explained below.

The NRR staff conservatively considered the uncracked analysis (axial stiffness of $1.0E_cA_g$) results in Table 6 of Reference 4 as the upper-bound design forces for the SGR opening area for the LCs III, IV, and VI that could cause concrete cracking. The NRC staff notes that if these forces and moments are plotted on the Interaction Diagrams for the opening area in Figure 9 and Figure 10 of Reference 4, the acceptance criteria based on Table 3.8-1 of the UFSAR would not be met. Therefore, for a general overall safety assessment, in RAI 7 (Reference 5), the staff requested the licensee to provide the maximum stress and strain information assuming that the forces and moments at the concrete sections expected to be cracked (i.e., SGR opening area), obtained on the basis of the uncracked ANSYS analysis, are reacted entirely by the combination of unbonded prestressing tendons and bonded reinforcing steel, for each of the hoop and vertical directions for the critical load combinations in the SONGS containment EOL analysis. The NRC staff request was based on the provision in CC-3423, “Tendon System Stresses,” of ASME Code, Section III, Division 2, which the NRC has endorsed in RG 1.136. The intent of sub-paragraph CC-3423 is to permit an increase in tendon stress that could be utilized when the applied loads cause tensile strain in the tendons. It is noted that this acceptance criteria for capacity of tendon under design loads is not included in ACI 318-71 code and the acceptance criteria for stresses and strain described in Section 3.8.1 (Table 3.8-1) of the SONGS UFSAR.

In its response to RAI 7 in Reference 6, the licensee provided the requested maximum stress and strain information for critical LCs. These are reproduced in columns 2 and 3 of the Table 1 below. Columns 4 and 5 in Table 1 below were included by the NRC staff to enable comparison of the stresses and strains to applicable acceptance criteria.

Table 1: Maximum Stresses and Strains in Opening Area for Critical Load Combinations Based on Uncracked Analysis

	Vertical	**Hoop**	**Allowable stresses and strains**	**Source of Criteria for Allowables**
Maximum tensile stress in the prestressing tendons	183 ksi	177 ksi	$0.9f_{py}$ = 0.9 x 0.85 x 270 = 207 ksi (Note 2)	CC-4423 of Ref. 14 (See Note 3)
Maximum tensile stress in the reinforcement for the primary forces	47 ksi	52 ksi	$0.9f_y$ = 54 ksi	Table 3.8-1 of UFSAR
Maximum tensile stress and the maximum strain in the bonded reinforcement for the combined primary and secondary forces	51 ksi 1745×10^{-6} in/in	48 ksi 1655×10^{-6} in/in	$0.9f_y$ = 54 ksi NA	Table 3.8-1 of UFSAR
Maximum stress and strain in the liner	-22 ksi -775×10^{-6} in/in	24 ksi = $f_{y,liner}$ 2207×10^{-6} in/in	NA $\pm 5000 \times 10^{-6}$ in/in	 Table 3.8.1 of UFSAR

<u>Notes</u>:
1. (+) Tension; (-) Compression; $f_{y,liner}$ = yield strength of liner
2. f_{py} = yield strength of prestressing strands = $0.85f_u$ (conservatively) = 0.85 x 270 = 230 ksi, for ASTM A416 Grade 270 strands (UFSAR Section 3.8.1.6).
3. This criterion is not included the acceptance criteria for stress and strain in Table 3.8-1 of the UFSAR.

Based on the results in Table 1, the NRC staff finds that the maximum stresses and strains in the rebar and liner for the conservative upper-bound solution meet the criteria in the SONGS UFSAR Table 3.8-1 and the maximum stress in the tendon meets the criteria in the 2001 Edition with 2003 addenda of the ASME Code, Section III, Division 2, “Code for Concrete Containments,” which the NRC has endorsed in RG 1.136. Therefore, there is reasonable assurance that the containment structural integrity will be maintained under critical design basis LCs and, hence, the NRC staff did not identify a safety concern.

4.0 CONCLUSION

Based on its review of TIA 2011-008, the NRR staff concludes the following:

1. Subject to the additional considerations described in the response to TIA Question 2, it is technically acceptable, and consistent with the intent of the containment design basis in Section 3.8.1 of the UFSAR, to apply data and equations in technical report ACI 209R-92 in the SONGS Unit 2 and 3 containment restoration end-of-life evaluation to generate material property inputs for time-dependent creep, shrinkage, and effective modulus to: (i) estimate prestress losses to determine design prestressing forces and (ii) model the effect of creep and shrinkage in the ANSYS finite element analysis model. Refer response to TIA Question 1 for explanation.

2. The licensee has addressed the statement in Section 1.1 of the ACI 209R-92 report, with regards to special structures, such as containments, that may require further considerations outside the report. Refer to the response to TIA Question 2 for explanation.

3. Subject to using a bounding implementation approach, it is technically acceptable to apply the method using equations 4.12 and 4.13 in Section 4.1, "Axial stiffness of one-dimensional members," of technical report ACI 224.2R-92, to estimate a reduced sectional stiffness for use as input to the ANSYS finite element analysis model to approximately account for the effects of concrete cracking under factored design basis LCs for the post-SGR restoration evaluation of the SONGS (Units 2 and 3) post-tensioned containments. The NRC staff observes that a bounding approach based on lower-bound and upper-bound values of reduced stiffness would account for simplifying assumptions and approximations, and expected variations in the reduced concrete stiffness due to cracking under design loads and load combinations. This application is consistent with the intent of the safety analysis techniques in Section 3.8.1 of the UFSAR and the NRC staff position in RG 1.136 and SRP 3.8.1 with regard to consideration of the effects redistribution of forces and moments due to concrete cracking. Refer to the response to TIA Question 3 for explanation.

4. The NRC staff determined that both ANSYS and SAP meet the definition noted in NEI 96-07, Revision 1, Section 3.10 which states, Methods of evaluation means the calculational framework used for evaluating behavior or response of the facility or an SSC." As such, the change in the FSAR from SAP to ANSYS constituted a change from a method described in the FSAR to another method. The licensee's 10 CFR 50.59 written evaluation was inadequate regarding whether the change involves a departure for the method of evaluation in that it failed to evaluate the use of ANSYS in lieu of SAP against 10 CFR 50.59a(2)(ii) "changing from a method described in the FSAR to another method unless that method has been approved by NRC for the intended application."

5. The ACI 224.2R method and its associated equations were implemented appropriately in support of the design basis evaluation of the restored SONGS containments, with two noted quality-related observations. These observations are with respect to: (i) mathematical convergence criteria used for the ACI 224.2R best-estimate of reduced stiffness, and (ii) with regard to upper-bound value of reduced effective stiffness due to cracking (licensee analysis was based only on a lower-bound value) in the opening area to ensure a bounding approach for the structural evaluation that meets the acceptance criteria in UFSAR Section 3.8.1 and Table 3.8-1. Refer to the response to TIA Question 5 for explanation.

6. The NRR staff did not identify an apparent safety concern based on an independent overall staff assessment that partly included acceptance criteria for increased allowable tendon stress under design load combinations from ASME Code Section III, Division 2, which is not included in the acceptance criteria in Table 3.8-1 of the SONGS UFSAR. It is recommended that the NRR staff's quality-related observations in Item 5 above be addressed as part of the licensee's quality assurance process for design.

5.0 REFERENCES

1. TIA 2011-008, dated May 3, 2011, Request for Technical Assistance-San Onofre Nuclear Generating Station Use of American Concrete Institute (ACI) Reports for Evaluations Related to Steam Generator Replacement Containment Restoration (ADAMS Accession No. ML111230851).

2. SONGS UFSAR, Amended April 2009, Section 3.8.1 "Concrete Containment."

3. Calculation No. C-257-01.04.05, "Evaluation of Restored Containment-Concrete Modulus Ratio," SONGS Unit 2 and Unit 3, which is part of Engineering Change Package (ECP) No. 061200409-6, Revision 0.

4. Calculation No. C-257-01.04.06, ECN/Prelim CCN No. D0020134, "Evaluation of Restored Containment: End-of-Life Analysis," SONGS Unit 2 and Unit 3.

5. Letter dated October 14, 2011 from J.R. Hall (NRC) to P.T. Deitrich (SCE) regarding SONGS Units 2 and 3-Request for Additional Information Regarding Use of American Concrete Institute (ACI) Reports for Restoration of Unit 3 Containment, ADAMS Accession No. ML112660460.

6. Letter dated December 28, 2011, from Richard J. St. Onge (SCE) to NRC, Docket Nos. 50-361 and 50-362, Response to Request for Additional Information Regarding Use of American Concrete Institute (ACI) Reports for Restoration of Unit 3 Containment, San Onofre Nuclear Generating Station, Units 2 and 3. (ADAMS Accession No. ML11364A045)

7. ACI 224.2R-92 (Reapproved 2004), Cracking of Concrete Members in Direct Tension.

8. Calculation C-257-1.04, Revision 1, Containment Shell Analysis- FINEL Computer Analysis, SONGS Unit 2 and Unit3 (Original design calculation)

9. BC-TOP-5, Revision 1, Prestressed Concrete Nuclear Reactor Containment Structures, Bechtel Power Corporation, December 1972.

10. ACI 318-71, Building Code Requirements for Reinforced Concrete (with Commentary)

11. Calculation No. C-257-01.04.06, "Evaluation of Restored Containment: End-of-Life Analysis," SONGS Unit 2 and Unit 3, which is part of ECP No. 061200409-6, Revision 0 and 061200409-7, Revision 0.

12. ACI 209R-92 (Reapproved 1997), Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures.

13. Topical Report BC-TOP-5A, Revision 3 (February 1975), Prestressed Concrete Nuclear Reactor Containment Structures, Bechtel Power Corporation, San Francisco, CA.

14. ASME Section III, Division 2, Code for Concrete Containments, 2001 Edition with 2003 Addenda.

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