UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

June 4, 1992

Docket No. 50-206

Mr. Harold B. Ray
Senior Vice President
Southern California Edison Company
Irvine Operations Centre
23 Parker Street
Irvine, California 92718

Dear Mr. Ray:

SUBJECT: SAFETY EVALUATION FOR THE BUCKLING ANALYSIS OF THE SAN ONOFRE 1 CONTAINMENT, SEP TOPIC III-7.B (TAC NO. M65867)

In 1981 and 1982, Lawrence Livermore National Laboratory (LLNL) conducted a safety review of the San Onofre, Unit 1, containment structure and issued a report of its findings on July 23, 1982. The report recommended that a further detailed study was needed to reach a final conclusion about possible containment shell buckling under certain loading conditions. On September 21, 1982, the NRC requested Southern California Edison (SCE) to refine the buckling analysis of the combined seismic and LOCA loads on the San Onofre 1 containment shell. SCE responded on March 30, 1984, with the results of a buckling analysis that was generally qualitative in nature and a second submittal on September 26, 1991, that was more quantitative and specific to the San Onofre 1 containment. These submittals have now been reviewed by the staff. Our review of the analysis provided to date indicates that the calculated factor of safety against buckling is less than recommended by the design codes. However, this reduction in margin by itself does not indicate that the containment structure is inadequate. The staff needs the results of comprehensive analyses for all the applicable geometric and loading conditions to judge the overall acceptability of the San Onofre 1 containment structure. A copy of our Safety Evaluation is attached.

Since permanent shutdown of Unit 1 is contemplated at the conclusion of the current Cycle 11 fuel cycle, a requirement for additional analysis is suspended at this time. However, since the anticipated shutdown is not definite, please respond to this letter with a commitment and schedule to perform the indicated analysis in the event that this shutdown does not occur as presently planned.

If you have any questions, please contact me at (301) 504-1367 or John O. Bradfute at (301) 504-1381.

Sincerely,

Original signed by

George Kalman, Senior Project Manager
Project Directorate V
Division of Reactor Projects III/IV/V
Office of Nuclear Reactor Regulation

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Enclosure:
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cc w/enclosure:
See next page

Mr. Harold B. Ray
Southern California Edison Company

San Onofre Nuclear Generating Station, Unit No. 1

cc:
Mr. Phil Johnson
U.S. Nuclear Regulatory Commission
Region V
1450 Maria Lane, Suite 210
Walnut Creek, California 94596

Mr. Robert G. Lacy
Manager, Nuclear Department
San Diego Gas & Electric Company
P. O. Box 1831
San Diego, California 92112

Resident Inspector/San Onofre NPS
c/o U.S. Nuclear Regulatory Commission
P. O. Box 4329
San Clemente, California 92674

Mayor
City of San Clemente
100 Avenida Presidio
San Clemente, California 92672

Chairman, Board of Supervisors
County of San Diego
1600 Pacific Highway, Room 335
San Diego, California 92101

Regional Administrator, Region V
U.S. Nuclear Regulatory Commission
1450 Maria Lane, Suite 210
Walnut Creek, California 94596

Mr. Hank Kocol
Radiologic Health Branch
State Department of Health Services
Post Office Box 942732
Sacramento, California 94234

Mr. Don J. Womeldorf
Chief, Environmental Management Branch
California Department of Health Services
714 P Street, Room 616
Sacramento, California 95814

Mr. Richard J. Kosiba, Project Manager
Bechtel Power Corporation
12440 E. Imperial Highway
Norwalk, California 90650

SAFETY EVALUATION OF BUCKLING ANALYSIS
AT SAN ONOFRE UNIT 1 CONTAINMENT

STRUCTURAL AND GEOSCIENCES BRANCH

1.0 BACKGROUND

As a part of the Systematic Evaluation Program (SEP), Lawrence Livermore National Laboratory (LLNL) conducted a safety evaluation of the San Onofre Nuclear Generating Station Unit 1 (SONGS 1) containment structure for the Nuclear Regulatory Commission (NRC) during the period of 1981-1982. LLNL analyzed the SONGS 1 containment structure for the combined effect of dead load, safe shutdown earthquake (SSE) load, and the pressure and thermal loads generated by either a loss of coolant accident (LOCA) or a main steam line break (MSLB).

LLNL submitted a report with its findings, conclusions and recommendations to NRC on July 23, 1982 (Reference 1). LLNL concluded that all the calculated stresses were within those allowed by the 1980 edition of the ASME Boiler and Pressure Vessel Code, Section III, Subsection NE for Class MC components, except for the case of membrane stress under dead load plus pressure load. Nevertheless, LLNL concluded that the containment was acceptable for that loading condition since the containment sphere was previously tested under that particular load combination (dead load plus pressure load).

However, LLNL identified a rather high compressive hoop stress (27,500 psi) of the sphere in the sand filled transition zone due to the thermal condition induced by a postulated MSLB. LLNL recommended that a further detailed study was needed to reach a final conclusion about possible shell buckling since there was no simple method that could accurately predict the critical buckling stress in that region (Reference 1).

NRC staff agreed with above LLNL recommendation and concluded that a more detailed analysis of the SONGS 1 containment with consideration of design factors (i.e., shell imperfection, nonsymmetrical SSE load, and other factors stated in Reference 2) was needed to determine the adequacy of the containment structure to resist the combined seismic and LOCA loads.

In the September 21, 1982 NRC letter, NRC requested the Southern California Edison (SCE) Company to provide a more refined analysis, particularly buckling analysis, of the SONGS 1 containment structure under the combined seismic and LOCA loads (Reference 2). SCE responded to the NRC request on March 30, 1984 with the results of a buckling analysis (Reference 3). However, rather than being a detailed, comprehensive analysis, the SCE analysis provided only qualitative discussion as a means of demonstrating the adequacy of containment's resistance to buckling. Subsequently, seven years later on September 26, 1991, SCE submitted a buckling analysis that was specific to the SONGS 1 containment, but the analysis was for the containment structure subjected to thermal load only (Reference 4). Our evaluation of the latest SCE submittal is provided below.

2.0 EVALUATION

The buckling analysis of the SONGS 1 containment structure performed by SCE is done by using the three dimensional, nonlinear, large deformation finite element analysis computer program, ANSYS. The analysis was performed on vertical sectors of the spherical shell under the thermal load only. Hoop stress in the shell and its displacement were calculated at different temperatures up to metal temperature of 400°F.

SCE presented a hoop stress-temperature relationship. This relationship is linear initially, then it becomes nonlinear at 295°F, which slightly exceeds the maximum postulated shell temperature of 280°F. Maximum stress is reached at 340°F, then the stress decreases as the metal temperature reaches 400°F. Figure 2.4 of the submittal (Reference 4) shows the hoop stresses of 0 psi, 26,000 psi, 28,500 psi and 30,500 psi approximately at 70°F, 280°F, 295°F and 340°F, respectively.

SCE concluded that the buckling will not occur under the postulated thermal loading condition since the analysis results indicate that the hoop stress at metal temperature of 280°F does not exceed the hoop stress at the temperature of 340°F. SCE defined a margin based on stress-free metal temperature of 70°F as:

$$\text{Margin} = \frac{340°F-70°F}{280°F-70°F} = 1.28,$$

and concluded that the SONGS 1 containment structure has a margin of safety against buckling.

The staff reviewed the SCE buckling analysis and identified several discrepancies in the analysis. Section 2.1 provides the staff's overall evaluation on the SCE response in compliance with the NRC request and the SCE analysis conclusion. Sections 2.2 through 2.6 provide the staff's specific evaluations on the parameters of SCE used in its buckling analysis including: (1) analytical assumptions, (2) modeling of material, (3) boundary conditions and (4) input parameters used in the analysis.

Based on the review the staff concludes that SCE has not provided an adequate analysis of the SONGS 1 containment against buckling. Section 3.0 provides the overall staff conclusion.

2.1 Overall Evaluation

(1) In the September 21, 1982 NRC letter, NRC requested SCE to perform a more refined, detailed buckling analysis of the SONGS 1 containment structure under seismic and LOCA loads. However, the SCE analysis contained a buckling analysis for the thermal load only. The SCE response, therefore, does not comply with the previous NRC request.

(2) The margin of the safety against buckling has been defined by SCE based on temperature and it does not have a strong physical rationale for the instability margin. SCE should define a margin of the safety based on buckling load since a buckling phenomenon is viewed, in general, as collapse at the maximum point in a load vs. deflection curve. The critical buckling load is not given in the submittal. However, if the staff assumes that the critical buckling stress is the hoop stress of 30,500 psi at the metal temperature of 340°F as shown in Figure 2.4 of Reference 4, then a margin of 1.17 should be calculated as follows:

$$\text{Margin} = \frac{\text{Critical buckling stress}}{\text{stress at } 280°\text{F}} = \frac{30{,}500 \text{ psi}}{26{,}000 \text{ psi}} = 1.17.$$

SCE concluded that no buckling problem will occur at 280°F based on the calculated margin of safety.

The relationship shown in Figure 2.4 of Reference 4 is a phenomenon for a structure subjected to uniform thermal load in axisymmetrical analysis. However, if the structure is subjected to nonuniform and/or nonsymmetrical load such as combined seismic and LOCA loads, and if imperfection of the spherical shell is considered in the analysis, then a lower buckling load could be reached. Since SCE did not consider both cases of the shell imperfection and the nonsymmetrical combined loads (SSE load plus LOCA load), the staff is dubious about the reliability of and the validity of SCE's buckling stress selection of 30,500 psi at the metal temperature of 340°F and the corresponding calculated margin of the safety.

Considering the Design Factors required by ASME code, Section III and Code Case N-284 as shown in the table below, and incompleteness of the SCE buckling analysis as discussed above, the buckling analysis submitted by SCE is judged unacceptable.

ASME Design Factor

Service Level	Subsection NE-3222	Case N-284
Level A	3.0	2.0
Level B	3.0	2.0
Level C	2.5	1.67
Level D	2.0	1.34

2.2 Estimation of Sand Properties

In the comparison study between the results of the LLNL study and ANSYS analysis, SCE modeled the sand in the transition zone as a homogeneous and isotropic material with an estimated Young's modulus of 48,600 psi. This modulus used in the analysis is somewhat higher compared to a sand modulus commonly used in geotechnical engineering practice: 1,400 psi-3,500 psi for loose sand and 7,000 psi-12,000 psi for dense sand (Reference 5). To cover possible uncertainty involved in modeling the sand, LLNL increased the sand modulus of 48,600 psi by 100% and decreased the modulus by 50% in its analysis to get higher and lower estimated values. The staff views that this would be a reasonable approach to cover possible uncertainty of sand modeling for bounding calculations and feels that the SCE analysis should have been done by using values for Young's modulus based on tests and upper and lower bounding values to account for uncertainty. The most critical stress values from these sand modulii should have been then used in the assessment of the containment structure. Thus, the SCE approach of using a single high value of the Young's modulus is deficient.

2.3 Linear Spring Model for Sand

In the final analysis, SCE used a linear spring model for the sand-filled transition zone in order to reduce computation time. An apparent Young's modulus of 78,000 psi for the sand was calculated, and this value was used in the spring model to represent the stiffness of the sand.

To use a spring model in a finite element analysis is a practice to simplify a model and to reduce computation time, and this modeling technique can be used as long as valid justifications are provided. However, the assumption made by SCE in the derivation of the apparent Young's modulus is not acceptable. SCE assumed that the sand undergoes strain changes in only one (x-) direction, and no strain changes in other two (y- and z-) directions under any given loading condition. It is known that sand undergoes strain changes in all three (x-, y- and z-) directions, therefore, the SCE's uniaxial strain assumption for the sand contradicts with the real soil behavior and represents another deficiency in the analysis.

In general, the variation of sand stiffness does not affect the membrane shell stresses much, but it affects significantly the bending resultants, especially the bending resultants under an SSE load. SCE analysis does not recognize the sensitivity of shell stress as to the variations of the sand stiffness, and does not adequately model the sand-filled transition zone.

The staff believes that the proper modeling of sand and adequate representation of boundary condition in the analysis are essential to obtain valid analysis results.

2.4 Containment Imperfection

In reality, a large containment structure is not a perfect sphere, therefore, a buckling analysis should include an imperfection sensitivity study using imperfection tolerances in accordance with the ASME Boiler and Pressure Vessel Code.

The SCE buckling analysis was based on the assumption that the SONGS 1 containment is a perfect sphere. In view of the capacity reduction factor adopted by the ASME Code, the staff feels that the SCE buckling analysis should have included an imperfection sensitivity study. The buckling load should be determined at an imperfection amplitude, which should be within the maximum permissible deviation allowed by ASME Boiler and Pressure Vessel Code, Section III, Subsection NE, Article NE 4221.

2.5 Service Loadings

SCE analyzed the SONGS 1 containment subjected to only thermal load under the assumptions that external load, dead weight, and SSE load are not critical. However, a containment would be very susceptible to buckling under SSE load in combination with other loads. SCE has not demonstrated the adequacy of SONGS 1 containment capacity against buckling under all applicable loading conditions.

2.6 Design Calculations

(1) SCE ignored the effects of penetrations, hatches and other types of structural discontinuities in the spherical shell,

i.e., the spherical shell is assumed as a continuous shell without discontinuities and of uniform thickness. SCE should have provided the basis to establish that the penetrations do not weaken the strength of the containment, i.e., that the strength of a penetrated containment shell is at least equal to that of an unpenetrated shell.

(2) The SONGS 1 spherical shell thickness varies between 1.02 inches at the top and 1.034 inches at the bottom. SCE performed the buckling analysis using the uniform thickness of 1.034 inches. SCE could have used the true geometry or 1.02-inch thickness of the containment to produce conservative results.

(3) SCE did not provide justifications for using linear strain hardening assumption in the plastic region and the ultimate strain of 0.215.

3.0 CONCLUSION

The staff reviewed the SCE buckling analysis, and concluded that SCE has not established the adequacy of the SONGS 1 containment shell against buckling due to the accident and extreme environmental loading conditions, therefore, it is not acceptable. The basis for the staff conclusion is delineated in the above evaluation.

4.0 REFERENCE

1. Lo, Ting-Yu, "Systematic Evaluation Program Structural Review of the San Onofre Nuclear Generating Station Unit 1 Containment Structure Under Combined Loads," Lawrence Livermore National Laboratory Report UCID 19141, May, 1982.

2. Letter from W. Paulson, NRC to R. Dietch, SCE dated September 21, 1982. Subject: SEP Topic III-7.B, Design Codes, Design Criteria and Load Combinations-San Onofre 1.

3. Letter from M. O. Medford, SCE to D. M. Crutchfield, NRC, Buckling Analysis for the Reactor Containment, March 30, 1984.

4. Letter from R. M. Rosenblum, SCE to NRC, Docket No. 50-206, Containment Structure Buckling Analysis, SEP Topic III-7.B San Onofre Nuclear Generating Station Unit 1, September 26, 1991.

5. Bowles, J. E., "Foundation Analysis and Design," McGraw-Hill Book Company, Fourth Edition, 1988.