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SYSTEMATIC EVALUATION PROGRAM
STRUCTURAL REVIEW OF THE SAN ONOFRE NUCLEAR GENERATION STATION
UNIT 1 CONTAINMENT STRUCTURE UNDER COMBINED LOADS;

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MASTER

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ABSTRACT

This report is a structural assessment of the containment structure of the San Onofre Nuclear Generation Station Unit 1, performed for the Nuclear Regulatory Commission as part of the Systematic Evaluation Program (SEP). The SEP is a plant-by-plant reassessment of the safety of 11 operating nuclear reactors that received construction permits between 1956 and 1967. Many safety criteria have changed since these plants were licensed. The purpose of the SEP is to develop a current, documented basis for the safety of older facilities.

The San Onofre assessment focused on the overall structural integrity of the containment structure under a safe shutdown earthquake and a postulated design basis accident. The safe shutdown earthquake was represented by the Housner Spectra, scaled to 0.67 g peak ground acceleration. The postulated design basis accident was either a loss of coolant accident or a main steam line break. No structural details, such as the equipment hatch and personnel air lock, or other penetrations, were evaluated. In accordance with the intent of the SEP, current licensing criteria were used as scales to assess the safety margins of the containment structure, but the containment structure was not evaluated to demonstrate compliance with these criteria.

Several combined stresses were evaluated for their adherence to the 1980 edition of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code allowables. All the calculated stress intensities were found to be acceptable according to this code except the general primary membrane stress due to combined dead and pressure loads under level A service limits. Because the containment structure was previously tested under combined dead and pressure loads for a higher peak pressure than the one used here, this study concluded that it was acceptable.

The compressive hoop stress of the containment structure in the sand filled transition zone was found to be rather high, due to the thermal load induced by a postulated main steam line break. Further detailed study is needed to reach a final conclusion about possible shell buckling in the circumferential direction.

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24

CONTENTS

Abstract	iii
List of Figures	vi
List of Tables	viii
Preface	xi
1. Introduction	1
2. Description of the Containment Structure	3
3. Loads and Load Combinations	5
3.1. Dead Load	5
3.2. Seismic Loads	5
3.3. Design Basis Accident Loads	5
3.4. Load Combinations	6
4. Analysis of the Containment Structure	12
4.1. Material Properties	12
4.2. Modeling	13
4.3. Results of the Analysis	13
5. Summary and Conclusions	17
References	36

LIST OF FIGURES

1.	Horizontal safe shutdown earthquake	2
2.	Schematic drawing of the San Onofre Nuclear Generation Station Unit 1 containment structure	4
3.	Containment pressure during a loss of coolant accident due to a double-ended pump suction break	10
4.	Containment temperature during a loss of coolant accident due to a double-ended pump suction break	10
5.	Containment pressure during a main steam line break	11
6.	Containment temperature during a main steam line break	11
7.	Finite-element model of the containment structure showing (a) the overall containment structure and (b) detail of the sand filled transition zone	25
8.	Stresses or force/moment resultants of a shell	26
9.	Results of the analyses using dead load and the higher estimate of the static sand stiffness	27
10.	Results of the analyses using a peak metal temperature of 268 °F and the higher estimate of the static sand stiffness	28
11.	Results of the analyses using an internal pressure of 1.0 psi and the higher estimate of the static sand stiffness	29
12.	Results of the analyses using dead load plus peak pressure load and the higher estimate of the static sand stiffness	30
13.	Results of the analyses using dead load plus thermal load plus pressure load and the higher estimate of the static sand stiffness	31
14.	Results of the analyses using dead load and the lower estimate of the dynamic sand stiffness	32

15. Results of the analyses using a peak metal temperature of 268 °F and the lower estimate of the dynamic sand stiffness	33
16. Results of the analyses using an internal pressure of 1.0 psi and the lower estimate of the dynamic sand stiffness	34
17. Results of the analyses using dead load plus peak pressure load and the lower estimate of the dynamic sand stiffness	35

LIST OF TABLES

1.	Membrane and bending stresses caused by the safe shutdown earthquake	8
2.	Peak containment pressure and temperature caused by design basis accidents	9
3a.	Maximum general primary membrane stress (P_m) for the level A service limits	18
3b.	Assessment based on the stress intensity of Table 3a	18
4a.	Maximum local membrane stress (P_L) for the level A service limits	19
4b.	Assessment based on the stress intensity of Table 4a	19
5a.	Maximum primary general or local membrane stress plus primary bending stress ($P_L + P_b$) for the level A service limits	20
5b.	Assessment based on the stress intensity of Table 5a	20
6a.	Maximum primary general or local membrane stress plus secondary stress intensity ($P_L + P_b + Q$) for the level A service limits	21
6b.	Assessment based on the stress intensity of Table 6a	21
7a.	Maximum general primary membrane stress (P_m) for the level C service limits	22
7b.	Assessment based on the stress intensity of Table 7a	22
8a.	Maximum local membrane stress (P_L) for the level C service limits	23
8b.	Assessment based on the stress intensity of Table 8a	23
9a.	Maximum primary general or local membrane stress plus primary bending stress ($P_L + P_b$) for the level C service limits	24

9b. Assessment based on the stress intensity of

Table 9a	24
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PREFACE

This report is part of the Systematic Evaluation Program (SEP) being conducted by the Nuclear Regulatory Commission (NRC). The SEP is a plant-by-plant reassessment of the safety of 11 operating nuclear reactors that received construction permits between 1956 and 1967. Many safety criteria have changed since these plants were licensed. The purpose of the SEP is to develop a current, documented basis for the safety of older facilities.

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1. INTRODUCTION

As part of the Systematic Evaluation Program (SEP), Lawrence Livermore National Laboratory (LLNL) is conducting a safety evaluation of some older operating nuclear power plants for the Nuclear Regulatory Commission (NRC). This report presents the LLNL assessment of the safety margins of the San Onofre Unit 1 containment structure to withstand the combined effects of a safe shutdown earthquake (SSE) and a design basis accident (DBA). The effect on containment due to a DBA alone was also evaluated. The DBA was either a loss of coolant accident (LOCA) or a main steam line break (MSLB).

The SSE was represented by the Housner spectra, scaled to 0.67 g peak ground acceleration in the horizontal direction (Fig. 1). The vertical spectra were equal to two-thirds of the horizontal spectra. The seismic analysis of the containment structure was previously performed by the Bechtel Power Corporation.¹ The stresses due to the SSE at two representative locations in the containment structure are available in Ref. 2.

The thermal and pressure loads due to a DBA were based on an NRC review of transmittals by the licensee.³

Since we focused on the overall structural integrity, no details, such as the equipment hatch and personnel air lock or other penetrations, were evaluated. We assumed that the thickening around the penetration is strong enough to negate the discontinuity effect of the penetration. Hence, we developed an axisymmetric shell-of-revolution finite-element model to represent the containment structure.

In accordance with the intent of the SEP, the structural review was not conducted to demonstrate compliance with the current licensing criteria, such as the Standard Review Plan and the Regulator Guide. They were used only as scales to assess the safety margin of the containment structure.

Fig. 1. Horizontal safe shutdown earthquake.

2. DESCRIPTION OF THE CONTAINMENT STRUCTURE

The San Onofre Unit 1 containment structure (Fig. 2) is a spherical shell with an inside diameter of 140 ft and a thickness of slightly greater than 1 in. The shell extends 40 ft below grade and is supported by a concrete cradle, which is a spherical segment with its rim extending only a few inches above the ground surface. A sand filled transition zone around the sphere is provided between the concrete cradle and the free-standing steel shell. This sand filled cavity is approximately 6 ft deep and an average of 2 ft across from top to bottom. It provides a stiffness transition to reduce stress concentration in the steel shell.

Inside the containment sphere is the concrete reactor building, which provides support and shielding for a three-loop PWR nuclear steam supply system (NSSS). The main function of the containment sphere is to contain any possible release of radioactive material from the NSSS. Therefore, it is an airtight steel vessel. The equipment hatch and personnel air lock are the major containment penetrations. Other penetrations are much smaller.

The containment sphere was originally designed for a peak internal pressure of 46.4 psig and a peak temperature of 271.2 °F.⁴ Assuming the stress free temperature of the sphere is 71.2 °F, the maximum temperature rise is, therefore, 200 °F. The containment sphere was also designed to withstand an internal vacuum of 2.0 psig to cover possible extreme ambient weather conditions. It was designed to the requirements of 1963 edition of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code.

Fig. 2. Schematic drawing of the San Onofre Nuclear Generation Station Unit 1 containment structure.

3. LOADS AND LOAD COMBINATIONS

Only loads affecting overall integrity of the structure were considered in this analysis. These were the dead load, the seismic loads, and the pressure and thermal loads due to a postulated DBA.

3.1 DEAD LOAD

The dead load was generated by multiplying the steel weight density (0.284 lb/in³) by the containment steel volume.

3.2 SEISMIC LOADS

Bechtel Power Corporation¹ performed the seismic analysis of the containment structure. The horizontal SSE seismic input was the Housner response spectra normalized to 0.67 g peak ground acceleration. The vertical response spectra were two-thirds of the horizontal spectra. The stresses due to the SSE at two locations in the containment structure were taken from Ref. 2 and are shown in Table 1. Aside from the locations close to the penetrations, these two locations, at the northern or southern most points of the sphere along the horizontal loop direction, were considered to be typical. They were also considered to be the most critically stressed areas of the sphere. The location representative of the continuous shell is at a 31-ft elevation, and the location representing the gross structural discontinuity at grade is at a 20-ft elevation. Since the shell was considered to be axisymmetric in this study, these stress results were used to represent any location in the horizontal hoop direction at the same elevation.

3.3 DESIGN BASIS ACCIDENT LOADS

The licensee has performed the mass and energy analyses of the containment pressure and temperature responses due to both a LOCA and an MSLB. References 5-9 document the results of these analyses. LLNL reviewed these analyses for the NRC as part of the SEP.³ The design basis LOCA was a double-ended cold leg (pump suction) break at 102% of full power. The

resulting post-LOCA pressure and containment atmosphere temperature profile are shown in Figs. 3 and 4.

The licensee presented four cases of MSLB.⁷ Table 2 summarizes the peak values of containment pressure, containment atmosphere temperature, and containment metal temperature due to LOCA and MSLB cases.

The four MSLB cases showed almost the same peak containment atmosphere temperatures, which all exceeded the peak LOCA temperature by a substantial margin. Case 3 had a higher peak metal temperature than case 1. Cases 3 and 4 had higher pressure responses than the LOCA and cases 1 and 2. The peak pressure of 52.2 psig for case 3 was only slightly less than 53.0 psig for case 4.

Case 3 pressure and temperature transients were selected for our assessment purposes because of their high peak values and the closeness of peak pressure and peak temperature on the time scale. In addition, this case was based on nominal and better estimated blowdown data as stated in Ref. 7. The pressure and temperature profiles of case 3 are shown in Figs. 5 and 6. The peak metal temperature was used, and the peak pressure and peak metal temperature were assumed to occur at the same time.

3.4 LOAD COMBINATIONS

We used the load combinations specified under level A and level C service limits of the Standard Review Plan, Section 3.8.2.¹⁰ The stress intensity limits specified in this Plan are consistent with those of ASME Code, Section III, Division 1, Subsection NE, 1980 edition. The peak stresses due to dead, seismic, and DBA loads were combined algebraically with the worst combination of signs possible. Our load combinations were:

$$\text{Level A service limits} = D + T_a + P_a,$$

$$\text{Level C service limits} = D + T_a + P_a + E',$$

where

D = Dead load,

P_a = Pressure load generated by the postulated pipe break accident,

T_a = Thermal load under thermal conditions generated by the postulated pipe break accident,

E' = Load generated by the SSE.

The live load was neglected because it was considered insignificant; the pipe reactions were not considered, since they are localized loads.

Table 1. Membrane and bending stresses caused by a safe shutdown earthquake. Stresses are measured in psi.

Location	<u>Membrane stress resultants</u>			<u>Bending stress resultants</u>		
	Hoop or longitudinal	Meridional	Shear	Hoop or longitudinal	Meridional	Shear
<u>Continuous shell</u>						
	1172.0	1483.0	1517.1	115.1	33.5	4.1
<u>Gross structural discontinuity at grade</u>						
	2034.4	6685.2	1849.3	7921.7	2404.3	25.8

Table 2. Peak containment pressure and temperature caused by design basis accidents. The mass/energy release assumptions for MSLB cases 1 and 3 are based on better estimates. Those for cases 2 and 4 are based on standard calculation procedures.

Mass/energy release assumptions	LOCA	Main steam line break accident			
		1	2	3	4
Reactor power (%)	102	100	103	0	0
Peak pressure (psig)	49.4	48.4	50	52.2	53.0
Peak atmosphere temperature (°F)	291	405	406	403	404
Peak metal temperature (°F)	Not available	239	Not available	268	Not available

Fig. 3. Containment pressure during a loss of coolant accident due to a double-ended pump suction break.

Fig. 4. Containment temperature during a loss of coolant accident due to a double-ended pump suction break.

Fig. 5. Containment pressure during a main steam line break.

Fig. 6. Containment temperature during a main steam line break.

4. ANALYSIS OF THE CONTAINMENT STRUCTURE

4.1 MATERIAL PROPERTIES

The containment shell material was supplied to the ASME specification SA-212, Grade B Fire Box Quality produced to SA-300 specification. This corresponds to current ASME Specification SA-516, Grade 70 Plate Material.¹ The 1980 edition of the ASME code appendices specify the following material properties corresponding to the peak sphere metal temperature of 268 °F:

- Minimum yield strength, $S_y = 34,000$ psi,
- Minimum ultimate tensile strength, $S_u = 70,000$ psi,
- Allowable stress intensity, $S_{mc} = 19,250$ psi,
- Design stress intensity, $S_{m1} = 22,700$ psi,
- Young's modulus, $E = 29.2 \times 10^6$ psi,
- Coefficient of thermal expansion, $\alpha = 6.14 \times 10^{-6}$ in/in/ °F.

Bechtel Power Corporation² studied documented test data consisting of 12 tensile strength tests that included welds as well as the material itself. These test data indicate that the S_u of the sphere material exceeds the code specification considerably. A statistical approach was used to establish the S_u . Its value was selected as 78,572 psi to ensure that 95% of the statistical strength values would exceed the S_u with a 90% confidence level. This value is about 1,800 psi less than the minimum of the 12 test values, but it exceeds the ASME code specified value of 70,000 psi by 12%. The calculated S_{mc} is 21,600 psi. The S_y used in Bechtel's analysis of the containment sphere was 38,000 psi.⁷

The Poisson's ratio and density for steel were assumed to be 0.3 and 0.284 lb/in³, respectively. The sand in the transition zone was assumed to have the following best-estimate material properties¹¹:

- Young's modulus, E
Static = 48,600 psi (or 7,000 ksf),
Dynamic = 20,800 psi (or 3,000 ksf),
- Poisson's ratio = 0.35.

Both steel and sand were assumed homogeneous and isotropic.

4.2 MODELING

An axisymmetric finite-element model was constructed to analyze the containment structure using the MODSAP computer program. The steel sphere was modeled by 83 shell-of-revolution finite elements. Twenty-four solid-of-revolution finite elements were used to simulate the sand filled transition zone. In the meridional direction the length of the elements in the sand filled transition zone and the region right above grade were made relatively small compared to the rest of the shell in order to capture the bending behavior of the shell in this region. This decision was made as the result of a sensitivity study of finite-element mesh sizes in this region. Figure 7 shows the finite-element model, with the detail of the sand filled transition zone. We believed that the sand close to the surface was not capable of developing the full stiffness. Hence, we arbitrarily reduced the Young's moduli for the top three layers of finite elements to $1/6E$, $3/6E$ and $5/6E$, respectively.

4.3 RESULTS OF ANALYSIS

To cover possible uncertainty involved in modeling the sand, including the reduction of stiffness for the top three sand layers, the Young's moduli were increased by 100% and reduced by 50% to get higher and lower estimate values. The analyses were done using these estimated values together with the best-estimate sand stiffness. The most critical stress values from these three sand stiffnesses were then used in the assessment of the containment structure.

Two sets of finite-element analyses were performed: one for each of the service levels considered. For level C service limits, the Young's modulus corresponding to the dynamic condition for the sand fill was used since the load combination included the dynamic load of the SSE. The static Young's modulus was used for level A service limits.

Each set of finite-element analyses included three computer runs using the best estimate, higher estimate, and lower estimate of the sand stiffness. The two extreme cases are the lower estimate case of dynamic sand stiffness, which has the lowest sand Young's modulus, and the upper estimate case of

static sand stiffness, which has the highest sand Young's modulus. The notations and sign conventions for the stresses or force/moment resultants of a shell are shown in Fig. 8. The results for the analyses are presented in Figs. 9-17. The abscissa indicates the location on the spherical shell along its meridional direction. This is represented by the angle ϕ , measuring from the vertical axis as shown in Fig. 7a. The ordinate represents the response quantities, such as the force/moment resultants or the normal stresses.

Figures 9-11 are the force/moment resultants due to the dead load, the peak thermal load, and the pressure load of 1.0 psi using the higher estimated sand stiffness. Figure 12 shows the normal stresses at the mid-surface and the two extreme fibres of the steel shell for combined dead and peak pressure loads. Figure 13 shows the normal fibre stresses for combined dead load, peak thermal load, and peak pressure load.

Corresponding results (except for those of Fig. 13) using the lower estimated sand stiffness are shown in Figs. 14-17. The results presented in these two sets of figures allow one to get a measure of the sensitivity of shell stresses to the possible variations in sand stiffness because the results of other cases are bounded by these two extreme cases.

In general, the variation of sand stiffness affects the shell stress distribution in the sand filled zone and the area immediately above it. As one would expect, it has little effect on the stresses far away from the sand filled transition zone. Neither does it affect the membrane stresses much. However, it does have a significant effect on the bending resultants (M_s , M_θ), especially on the bending resultants close to the gross structural discontinuity at grade.

The capability of the containment sphere to withstand the postulated DBA and the combined effect of a DBA and SSE was assessed based on the criteria specified by the ASME code and the Standard Review Plan as stated in Section 3.4. Tables 3-6 present the assessment for level A service limits; Tables 7-9 show the assessment for level C service limits.

To measure the structural integrity of the containment structure under various loads or load combinations, the term Safety Margin (SM) was adopted from Ref. 1. The SM is defined as the ratio of the allowable stress intensity limit specified by the code to the calculated stress intensity. The larger

the SM, the better the structure is able to withstand the specified loads. The "a" part of Tables 3-9 show the stresses due to various loads and load combinations, along with the maximum stress intensity for the specific load combinations. The "b" part of each table presents the SM based on the metal strengths established by Bechtel or specified by the ASME code.

In these tables all SMs are greater than 1.0 except for the case of maximum general primary membrane stress (P_m) under level A service limits for a dead load plus pressure load combination. In this case the SM values are equal to 0.94 and 0.84 for metal strength established by Bechtel and specified by the code, respectively. The structure is not necessarily unsafe when SM values are lower than 1.0. However, it does indicate that the strength of the containment sphere is lower than the code requirements. The containment was previously tested under 53.4 psig.⁷ This test pressure is higher than the peak pressure used in this study. Therefore, we considered the SM values of 0.94 and 0.84 acceptable even though they are lower than 1.0.

Figures 10 and 15 indicate that the containment sphere is under very high compressive hoop stress in the sand filled transition zone due to the postulated MSLB thermal condition. The peak hoop stress is 27,500 psi at the fixed location. It maintains a rather high stress level throughout the sand filled zone and drops off sharply above grade level. The buckling of the shell under this high compressive hoop stress is a very complicated problem, and there is no simple method that can predict accurately the critical buckling stress.

Nevertheless, two extreme cases of critical buckling loads were calculated. One approach was based on ASME code buckling stress for a uniform external pressure on a spherical shell. This buckling stress was calculated at 1100 psi. Another approach was based on the local circumferential buckling of a uniformly heated thin cylindrical shell with a rigid bulkhead.¹² The predicted buckling stress for this case was 262,800 psi, which is well beyond the elastic range. These two cases do not reflect the true condition at the sand zone but rather comprise upper and lower bounds.

The pressure load applied at the same time as the thermal load provides some stabilizing effect, in addition to that provided by the rigid restraint at the base of the sand filled zone. Unlike some of the boiling water reactor (BWR) drywells, which also have a sand filled transition zone at the base, the

San Onofre Unit 1 containment sphere does not have concrete backing inside in this region. The top of the concrete base of the reactor building stops at the bottom elevation of the sand filled cavity. Inward buckling of the steel shell is possible under the high thermal condition caused during a DBA. However, further detailed study is needed to assess the safety margin of the containment sphere in this area.

5. SUMMARY AND CONCLUSIONS

The containment sphere of the San Onofre Nuclear Generation Station Unit 1 was analyzed for the combined effect of dead load, SSE loads, and the pressure and thermal loads generated by either a LOCA or an MSLB.

The combined stresses were evaluated according to the 1980 edition of the ASME Boiler and Pressure Vessel Code, Section III Subsection NE for Class MC components. All the calculated stress intensities are within those allowed by the code, except for the case of general primary membrane stress (P_m) under level A service limits. The SMs for this case are 0.94 and 0.84 for metal strength established by Bechtel and specified by the code, respectively. Since the containment sphere was previously tested under that particular load combination (dead load plus pressure load) for an even higher pressure (53.4 psig), the containment is considered acceptable for that condition.

The compressive hoop stress of the sphere in the sand filled transition zone is rather high (27,500 psi) due to the thermal condition induced by a postulated MSLB case. Since there is no simple method that can accurately predict the critical buckling stress in that region, further detailed study is needed to reach a final conclusion about possible shell buckling in the circumferential direction.

Table 3a. Maximum general primary membrane stress (P_m) for the level A service limits. Measurements were taken in psi a few ft above grade.

Load	Meridian (σ_s)	Hoop (σ_θ)	Shear (τ)
Dead, D	-400	488	0
Pressure, P_a	21,924	22,493	0
Sum, $D + P_a$	21,524	22,981	0
Maximum stress intensity = 22,981			

Table 3b. Assessment based on the stress intensity of Table 3a.

Assessment	Bechtel	ASME
Allowable stress intensity limit (psi) ^a	21,600	19,250
Safety margin	0.94	0.84

^a $1.0 \times S_{mc}$

Table 4a. Maximum local membrane stress (P_L) for the level A service limits. Measurements were taken in psi at grade elevation.

Load	Meridian (σ_s)	Hoop (σ_θ)	Shear (τ)
Dead, D	-403	-24	0
Pressure, P_a	21,924	10,750	0
Sum, D + P_a	21,521	10,726	0
Maximum stress intensity = 21,521			

Table 4b. Assessment based on the stress intensity of Table 4a.

Assessment	Bechtel	ASME
Allowable stress intensity limit (psi) ^a	32,400	28,875
Safety margin	1.50	1.34

^a $1.5 \times S_{mc}$.

Table 5a. Maximum primary general or local membrane stress plus primary bending stress ($P_L + P_b$) for the level A service limits. Measurements were taken in psi a few ft above grade.

Load	Meridian (σ_s)	Hoop (σ_θ)	Shear (τ)
Dead plus pressure, D + P _a	26,779	22,780	0
Maximum stress intensity = 26,779			

Table 5b. Assessment based on the stress intensity of Table 5a.

Assessment	Bechtel	ASME
Allowable stress intensity limit (psi) ^a	32,400	28,875
Safety margin	1.21	1.08

^a $1.5 \times S_{mc}$.

Table 6a. Maximum primary general or local membrane stress plus secondary stress intensity ($P_L + P_b + Q$) for the level A service limits. Measurements were taken in psi at grade elevation.

Load	Meridian (σ_s)	Hoop (σ_θ)	Shear (τ)
Dead plus pressure plus thermal, $D + P_a + T_a$	54,170	-1,980	0
Maximum stress intensity = 56,150			

Table 6b. Assessment based on the stress intensity of Table 6a.

Assessment	Bechtel	ASME
Allowable stress intensity limit (psi) ^a	76,400 ^b	68,100
Safety margin	1.36	1.21

^a $3.0 \times S_{m1}$.

^b No S_{m1} was given in Refs. 2 and 7, since the 1974 edition of the ASME code was used in Bechtel's study. The S_{m1} for material property established by Bechtel was assumed to be

$$\left(\frac{S_{m1}}{S_{mc}} \right)_{ASME} \times \left(S_{mc} \right)_{Bechtel}.$$

Table 7a. Maximum general primary membrane stress (P_m) for the level C service limits. Measurements were taken in psi a few ft above grade.

Load	Meridian (σ_s)	Hoop (σ_θ)	Shear (τ)
Dead, D	-400	489	0
Pressure, P_a	21,924	22,483	0
<u>SSE, E'</u>	<u>6,685</u>	<u>2,034</u>	<u>1,849</u>
Sum, $D + P_a + E'$	28,209	25,006	1,849

Maximum stress intensity = 29,050

Table 7b. Assessment based on the stress intensity of Table 7a.

Assessment	Bechtel	ASME
Allowable stress intensity limit (psi) ^a	38,000	34,000
Safety margin	1.31	1.17

^a The larger of $1.25 S_{mc}$ and S_y .

Table 8a. Maximum local membrane stress (P_L) for the level C service limits. Measurements were taken in psi at grade elevation.

Load	Meridian (σ_s)	Hoop (σ_θ)	Shear (τ)
Dead, D	-406	41	0
Pressure, P_a	21,924	12,082	0
SSE, E'	<u>6,685</u>	<u>2,034</u>	<u>1,849</u>
Sum, $D + P_a + E'$	28,203	14,157	1,849

Maximum stress intensity = 28,440

Table 8b. Assessment based on the stress intensity of Table 8a.

Assessment	Bechtel	ASME
Allowable stress intensity limit (psi) ^a	57,000	51,000
Safety margin	2.00	1.79

^a The larger of $1.8 S_{mc}$ and $1.5 S_y$.

Table 9a. Maximum primary general or local membrane stress plus primary bending stress ($P_L + P_b$) for the level C service limits. Measurements were taken in psi at grade elevation.

Load	Meridian (σ_s)	Hoop (σ_θ)	Shear (τ)
Dead plus pressure, $D + P_a$	31,758	13,680	0
SSE load, E'	<u>6,685</u>	<u>2,034</u>	<u>1,849</u>
Sum, $D + P_a + E'$	38,443	15,714	1,849
Maximum stress intensity = 38,592			

Table 9b. Assessment based on the stress intensity of Table 9a.

Assessment	Bechtel	ASME
Allowable stress intensity limit (psi) ^a	57,000	51,000
Safety margin	1.48	1.32

^a The larger of $1.8 S_{mc}$ and $1.5 S_y$.

Fig. 7. Finite-element model of the containment structure showing (a) the overall containment structure and (b) detail of the sand filled transition zone.

Fig. 8. Stresses or force/moment resultants of a shell.

Fig. 9. Results of the analyses using dead load and the higher estimate of the static sand stiffness. (a) shows force resultants and (b) shows moment resultants.

Fig. 10. Results of the analyses using a peak metal temperature of 268 °F and the higher estimate of the static sand stiffness. (a) shows force resultants and (b) shows moment resultants.

Fig. 11. Results of the analyses using an internal pressure of 1.0 psi and the higher estimate of the static sand stiffness. (a) shows force resultants and (b) shows moment resultants.

Fig. 12. Results of the analyses using dead load plus peak pressure load and the higher estimate of the static sand stiffness. (a) shows meridional normal stresses and (b) shows hoop normal stresses.

Fig. 13. Results of the analyses using dead load plus thermal load plus pressure load and the higher estimate of the static sand stiffness. (a) shows meridional normal stresses and (b) shows hoop normal stresses.

Fig. 14, Results of the analyses using dead load and the lower estimate of the dynamic sand stiffness. (a) shows force resultants and (b) shows moment resultants.

Fig. 15. Results of the analyses using a peak metal temperature of 268 °F and the lower estimate of the dynamic sand stiffness. (a) shows force resultants and (b) shows moment resultants.

Fig. 16. Results of the analyses using an internal pressure of 1.0 psi and the lower estimate of the dynamic sand stiffness. (a) shows force resultants and (b) shows moment resultants.

Fig. 17. Results of the analyses using dead load plus peak pressure load and the lower estimate of the dynamic sand stiffness. (a) shows meridional normal stresses and (b) shows hoop normal stresses.

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