52-003

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

September 29, 1995

APPLICANT: Westinghouse Electric Corporation

FACILITY: AP600

SUBJECT: SUMMARY OF MEETING ON THE ANALYSIS AND DESIGN OF THE WESTINGHOUSE AP600 CONTAINMENT VESSEL

On August 30 and 31, 1995, representatives of the Nuclear Regulatory Commission (NRC) and Ames Laboratory, NRC consultant, met with representatives of the Westinghouse Electric Corporation (Westinghouse) and Chicago Bridge and Iron Company (CBI), Westinghouse consultant, to discuss the analysis and design of the Westinghouse AP600 containment vessel and review related draft safety evaluation report (DSER) open items (OI). The meeting was held at the CBI office in Plainsfield, Illinois. Attachment 1 is a list of attendees and Attachment 2 is the meeting agenda.

CBI presented the Westinghouse response to NRC concerns identified in several of the open items. Attachment 5 is the CBI discussion materials (overhead slides). CBI presented results from the Containment Vessel Design Report on the effects of large penetrations on buckling. CBI made several copies of the Containment Vessel Design Report (MV50 S3R 005), Revision 0 available for NRC review. Ames Laboratory presented confirmatory analysis results on containment vessel buckling performance. Attachment 6 is the Ames Laboratory presentation material. During the meeting, the results of the analysis were compared to CBI results and were found to be similar. Further, it was noted that differences in the results were, at least in part, due to differences in input parameters and models. Westinghouse and the NRC agreed to run the same input parameters on both organization's models and on one model by both organizations.

Containment vessel performance beyond design basis was also discussed. The NRC staff expressed concern over the Westinghouse use of the von Mises failure criteria combined with the median yield strength. NRC and Westinghouse agreed that a 10 percent increase on the median yield strength was acceptable. NRC cited the example of an actual test where failure occurred before von Mises failure criterion was reached. However, discussions will continue on the use of the von Mises criteria. Failure modes for the containment vessel top head were discussed. The NRC staff questioned that only one failure mode was addressed in the standard safety analysis report (SSAR). Westinghouse stated that other failure modes were analyzed but only discussed the dominant mode in the SSAR. Westinghouse agreed to expand the SSAR discussion to include the other failure modes.

Pertinent open items and new requests for additional information (RAIs) were reviewed. New Probabilistic Risk Assessment Chapter 42 RAIs were transmitted to Westinghouse in a letter dated August 4, 1995. A revision of these RAIs was faxed to Westinghouse on August 29, 1995, and later sent in an individual

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letter. A clarification to one RAI was faxed to Westinghouse on September 18, 1995. The revised RAIs and clarification are given as Attachment 3. Progress was made towards the resolution of the open items. The status of open items and new RAIs are given as Attachment 4.

As a result of the meeting, the items listed below were considered by the staff as major action items needed for issue resolution. Items 1 - 3 should be added to the open item tracking system database. Actions in items 4 - 7 are included in existing open items.

1. Westinghouse will revise SSAR Section 3.8.2.4.1.1 to include the consideration of the vertical component of earthquake motions.

2. Westinghouse should provide a similar table as SSAR Table 3.7.2-14 to describe the models and associated analysis methods that were used for analyzing each portion of containment vessel.

3. Westinghouse will verify the adequacy of seismic input motions (horizontal and vertical) provided to NRC for confirmatory analyses.

4. Westinghouse will review NUREG/CR-4209 and references cited in DSER and respond to the staff later regarding the combined use of von Mises yield criterion and mean strength material for cylindrical portion.

5. The NRC staff will review N-284, Revision 1 and the ASME confirmation of AP600 interpretation. This item involves the factor of safety for equipment hatches for deterministic ASME Service Level C criteria.

6. The NRC staff will review the test data used to generate lower bound curve in N-284, generate a 50 percent curve and compare with 150 percent critical pressure (P_{cr}). This item involves the use of the 150 percent P_{cr} derived from the lower bound curve in N-284 for equipment hatches.

7. The staff proposed the revision on SSAR 3.8.2.4.2 such that the best estimate pressure calculations would move to Chapter 42 of the Probabilistic Risk Assessment Report (PRA).

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Office of Nuclear Reactor Regulation

Docket No. 52-003

Attachments: As stated

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AP600 CONTAINMENT VESSEL
AUGUST 30 AND 31, 1995
BETWEEN THE NRC AND WESTINGHOUSE
MEETING PARTICIPANTS

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THOMAS CHENG	NRC/NRR/ECGB
SEUNG LEE	NRC/NRR/ECGB
DIANE JACKSON	NRC/NRR/PDST
FOUAD FANOUS	AMES LABORATORY/NRC CONSULTANT
LOWELL GREIMANN	AMES LABORATORY/NRC CONSULTANT
AYMANN KHDIL	AMES LABORATORY/NRC CONSULTANT
SHERIF SAFAR	AMES LABORATORY/NRC CONSULTANT
RICHARD ORR	WESTINGHOUSE
DON LINDGREN	WESTINGHOUSE
THOMAS AHL	CHICAGO BRIDGE AND IRON CO(CBI)/ WESTINGHOUSE CONSULTANT
RAJ DESHMUKH	CBI/WESTINGHOUSE CONSULTANT
DONALD HORACEK	CBI/WESTINGHOUSE CONSULTANT
DALE SWANSON (PART-TIME)	CBI/WESTINGHOUSE CONSULTANT
CLARENCE MILLER (PART-TIME)	CBI/WESTINGHOUSE CONSULTANT

Attachment 1

MEETING AGENDA
ANALYSIS AND DESIGN OF THE AP600 CONTAINMENT VESSEL
AUGUST 30 AND 31, 1995
CBI OFFICES, PLAINFIELD, ILLINOIS

1.	Introductory remarks	R. Orr / T. Cheng	9.00 am
2.	Design criteria for containment vessel	R. Orr	9.15 am

- OI 3.8.2.2-1 ASME NE 1992
- OI 3.8.2.3-1 Load combinations
- OI 3.8.2.4-2 Dynamic analyses
- OI 3.8.2.4-4 Eccentric masses
- OI 3.8.2.4-6 Thermal loads due to passive cooling
- OI 3.8.2.4-14 Buckling due to passive cooling thermal loads
- OI 3.8.2.4-7 Wind and tornado loads

3.	Containment vessel design report	T.Ahl	10.00 am

- OI 3.8.2.4-5 Thermal stresses at base
- OI 3.8.2.4-8 CBI computer codes
- OI 3.8.2.4-12 Stress analyses
- OI 3.8.2.4-13 Vessel deflections
- OI 3.8.2.4-16 Buckling analyses

4.	Effect of large penetrations on buckling	D. Horacek	10.30 am

- OI 3.8.2.4 - 9, 10 and 14

5.	NRC Confirmatory analyses	Ames Lab	11.00 am
6.	NRC Revie of AP600 Calculations	pm 8/30 and 8/31	
7.	Containment Performance beyond the design basis	R .Orr S. Lee	8.00 am 8/31

- OI 3.8.2.4 -19 Best estimate material properties
- OI 3.8.2.4 -25 Failure mechanism for top head
- OI 3.8.2.4 -26 Best estimate capacity for equipment hatch
- OI 3.8.2.4 -30 Service Level C capacity for equipment hatch

8.	Status of Open Items	R. Orr T. Cheng	10.00 am 8/31

- Meeting 3/28/94 Open items 457-469
- Meeting 7/5/94 NRC letter 8/23/94
- DSER Open Items within Design Basis (3.8.2.1-1 thru 3.8.2.4-16)
- DSER Open Items beyond Design Basis (3.8.2.1-17 thru 3.8.2.4-31)
- RAIs - PRA Chapter 42 - 8/4/95

9.	Meeting summary		3.00 pm

Attachment 2

Request for Additional Information For AP600 Containment
Conditional Containment Failure Probability (CCFP) Calculations

1. In Chapter 42 of PRA SSAR, Rev. 4, the mean failure pressure is mentioned for each failure mode. As stated in DSER, the staff recommended the best estimate pressure be median for containment CCFP calculation. (If lognormal distribution is used, the mean is median times $\exp(\beta^2/2)$ where β is logarithmic standard deviation.) For the failure pressure estimates, the staff is not in a position to accept the 32 percent increase using both von Mises criterion and mean yield strength of SA537 Class 2 material. See Open Items 3.8.2.4-19 and 19.2.6.2-3.

- A comparison between experimental and theoretical yield stresses in Engineering Design, Faupel, J.H., pp. 249-258, John Wiley & Sons, 1964 shows that the von Mises yield criterion does not always give a 15 percent higher yield stress than that obtained from the maximum shear stress criterion,

- The material test data uses only 122 specimen and they are neither exactly the same as the SA 537, Class 2 material nor as-built material,

- In "Comparisons of Analytical and Experimental Results from Pressurization of a 1:8 - Scale Steel Containment Model," Clauss, D.B. and Horschell, D.S., Proceedings 8th Intl. Conf. on SMiRT, August 19 - 23, 1985, and NUREG/CR-4209, the measured yield pressure was reported 15 percent less than that predicted yield pressure (r = 84", t = 0.197", σ_y = 57.1 ksi, P = $\sigma_y t/r$ = 134 psig) using MARC FEM code with large displacement, nonlinear material property obtained from standard uniaxial tensile tests (test coupons were machined from remnants and cutouts for the penetrations), and von Mises yield criterion due to (1) strain rate effects (5 percent reduction), (2) Bauschinger effect (5 to 10 percent reduction) referring to the phenomenon whereby the yield stress in tension or compression is reduced if the material has been previously yielded in the opposite sense (when the plates comprising the cylinder were rolled into the cylindrical shape, the internal surface underwent compressive yielding and internal pressurization results in tensile yielding in the cylinder), and (3) difficulties in applying uniaxial data to multiaxial strain states,

- From an American Iron and Steel Institute (AISI) survey of test results for thousands of individual product samples, it has been found that strength levels vary as much as 20 percent from the certified material test reports (CMTR) test values. It has been the staff's position that minimum specified strength values (e.g., ASME Code minimum strength values) should be used as the basis for allowable stresses as described in the letter from G. Bagchi and C. Cheng to J. Stolz, Subject: Review of Oyster Creek Drywell Containment Structural Integrity, dated June 14, 1990.

2. In Section 42.2, is lognormal distribution applicable for the 16-ft and 25-ft equipment hatches? Due to their convexity, these are under compression when subjected to containment internal pressure as mentioned, further justification is necessary for these equipment hatches.

3. In Section 42.3.1, Ref. 42-1 did not provide data showing that the actual yield strength of containment construction materials could be 12 to 22 percent higher than the specified minimum material strength. The range is 2.5 to 22 percent in Table 1. Also, there is no data for SA537, Class 2 material in Ref. 42-1.

4. In Section 42.4, provide uncertainties for geometric properties (as-built condition) and residual stress for buckling of knuckle area and equipment hatch covers. Imperfection for internal pressure is insensitive, however, for external pressure, it should be significant. (from N-284, capacity reduction factor is considered for imperfection and plasticity of nonlinear material properties.)

5. In Section 42.4.1, how is the COV of 0.1 derived from Ref. 42-1? The Table 4 of Ref. 42-1 shows only the thickness of 1-1/4" thickness (mean = 1.277", σ = 0.012", COV = 0.01) and it assumes normal distribution, not lognormal distribution. Also, this COV of 0.01 represents the uncertainty for geometric properties, not modeling error. The Ref. 42-1 shows the modeling error COV of 0.144 from $(0.12^2 + 0.08^2)^{1/2}$ in Table 7. The COV for all practical purposes of modeling error which should include nonsymmetric features such as penetrations and other reinforced openings, longitudinal stringers, etc. as well as circumferential variations in thickness, ring and stringer sizes, amount of reinforcing steel, and shell imperfection is 0.12 (Ref. 42-2). The staff believes that the use of the COV of 0.1 results in unconservative CCFP calculation. See Open Items 3.8.2.4-21 and 19.2.6.3-1.

6. In Section 42.4.2, provide mean (median) failure pressures with modeling and material uncertainties for crown yield, knuckle area yield, and knuckle area buckling. Imperfection uncertainty is insignificant due to internal pressure buckling (See N-284).

   How is 192 psig derived in knuckle area? Is it 146*1.15*1.15?

   How is 144 psig derived for ellipsoidal head buckling failure mode in Table 42-1? It is not given in SSAR. Is it derived from 174 x 138/166?

   For the ellipsoidal head, there are two possible failure modes, i.e., asymmetric buckling (P_{cr}) and plastic collapse (P_c). Therefore, the plastic collapse pressure information should be considered in SSAR.

7. In Section 42.4.3, Westinghouse increases 50 percent critical pressure for the best estimate failure pressure based on N-284 curve which was derived from lower bound of tests. However, there was only one test performed for AP600 containment configuration (M_i = 14.5). Therefore, it is believed that 50 percent curve from tests might be appropriate use for

AP600 containment. (N-284 does not provide 50 percent and upper bound curves.) Are test data in N-284 applicable to AP600? They seem to be stiffened spheres.

Also, in NUREG/CR-4209 and -4137, equipment hatch has critical pressure of 3,000 psig and the predicted response of the cover and tensioning ring was elastic up to 360 psig. In this case, only up to 12 percent of critical pressure is elastic. After that, equipment hatch cover will experience plastic deformation. Therefore, Westinghouse's claim that the failure pressure is 150 percent of critical pressure is questionable. See Open Items 3.8.2.4-26 and 19.2.6.3-6.

Equipments hatches are subjected to external pressure, not internal pressure.

8. In Section 42.5, provide the sample CCFP calculations for head at 100 psig. You have constructed the containment failure probability distribution for a particular failure mode by first developing the failure distribution assuming only random error and then developing another distribution assuming only subjective error. The staff believes this method may not be conservative in comparison with the combination of random and subjective errors ($\beta_c^2 = \beta_{material}^2 + \beta_{modelling}^2$) in the left tail region.

9. In Section 42.6, what is the definition of mean internal pressure? Should it be median pressure? See Open Items 3.8.2.4-27 and 19.2.6.3-7.

10. In Table 42-1, does "Structural" under COV heading imply "Material"?

11. In Table 42-2, 50 percent failure pressure for head seems to be around 156 psig. Where does this pressure come from?

12. In Section 42.4, coefficient of variation, not coefficient of variance, should be used.

13. In SSAR Subsection 3.8.2.4.2.5, EPAs to be used will be one of those tested by Sandia in NUREG/CR-5334:

    D.G. O'Brien: 182.8°C (361°F) and 1,068.7 kPa (155 psia) for 10 days,
    Westinghouse: 204.4°C (400°F) and 517.1 kPa (75 psia) for 10 days,
    Conax: 371.1°C (700°F) and 930.8 kPa (135 psia) for 10 days

    If Westinghouse EPAs will be used for AP600, they do not satisfy ASME Service Level C limits (90 psig at 400°F). Also, in fragility curve, the dominant failure mode is cylindrical shell with 138 psig at 400°F. Therefore, if they are used, they control the whole design both in deterministic and probabilistic. The fragility curve for EPAs should be provided.

14. In Section 42.4, if the bellow capacity is 90 psig at 400°F, what is probability of failure beyond this pressure? Westinghouse should provide the mean (or median) failure pressure, and uncertainties of geometric properties, modeling, and material for complete CCFP calculations.

15. In Section 3.8.2.4.2.2, the maximum deflection at crown is 15.9" at 174 psig and corresponding strain is 2.5 percent. Therefore, radius is 15.9/0.025 = 636". Where does this radius come from? The radius, R_s, is 1,347.5".

Open Item Status on
Containment Vessel design of AP600 Standard Plant
August 30 and 31, 1995

The status flag given is the NRC status for the open item. If two status flags are given, it is the Westinghouse status/NRC status, as agreed upon in the meeting.

OI No.	DSER OI No.	Status and Action detail
461	3.8	Closed - In Revision 3 of SSAR Section 3.8.2.1.1, Westinghouse increased the thickness of the containment vessel from 1.625 inches to 1.75 inches for providing margin in the event of corrosion in the embedment transition region. In addition, Westinghouse committed in SSAR Section 3.8.2.6 that the containment vessel is coated with an inorganic zinc coating, except for those portions (both outside and inside) fully embedded in concrete and the inside of the vessel below the operating floor and up to eight feet above the operating floor also has a phenolic top coat. This satisfies the staff's concern regarding possible corrosion of containment shell.
463	3.8	Action NRC - Because the SRP did not provide guidelines for combining the SSE load with wind and tornado loads, the staff agreed to develop its position for the resolution of this issue.
466	3.8	Closed - This issue is to be resolved as part of OI 3.8.2.3-1.
467	3.8	Closed - This issue is resolved under OI 3.7.2.3-8.
677	3.8.2.2-1	Action Westinghouse - Westinghouse agreed to provide written response to identify the differences between the 1992 edition of the ASME code and the 1989 edition of the ASME code, and submit an analysis of these differences for the staff review and acceptance.
678	3.8.2.3-1	Action Westinghouse - Westinghouse should make decision how the SSAR is to be revised in combining the external pressure (3 psig) and the SSE loads.
680	3.8.2.4-2	Resolved - Westinghouse demonstrated that the results based on the equivalent static analysis with the acceleration profile (plot of the maximum acceleration at each lumped mass location) as input are more conservation than

those based on dynamic analysis. In addition, Westinghouse committed, in SSAR Section 3.8.2, Revision 3, that local analyses are performed for the responses of local masses using floor response spectra at appropriate elevation of the containment vessel as input motions. Also, the results obtained from the staff's independent analyses confirm that Westinghouse's demonstration is reasonable.

681	3.8.2.4-3	Action Westinghouse - Westinghouse agreed to expand SSAR Section 3.8.2.4.1.2 to include (1) detailed description of methods to be used for the dynamic analysis of local masses, (2) the approach for analyzing the buckling potential of the containment shell adjacent to local masses, and (3) methods for evaluating the compressive strength of the containment shell in the vicinity of local masses. This open item is resolved pending Westinghouse submittal.
682	3.8.2.4-4	Action NRC - In determining the buckling potential of the containment shell in the region of large penetrations and polar crane support, NRC will compare shell stresses, including the consideration of eccentricities due to concentrated masses, calculated by Westinghouse with those obtained from the staff's confirmatory analyses.
683	3.8.2.4-5	Resolved - The staff reviewed Westinghouse's calculation of the thermal stress analyses and buckling evaluation for the containment shell near the base, and found that the method used and results obtained are reasonable. This conclusion was confirmed by the comparison of results by Westinghouse with those from the staff's confirmatory analysis. Therefore, this open item is resolved.
684	3.8.2.4-6	Resolved - The resolution of this open item is to be addressed in Section 6 of this SER and this issue is considered resolved.
685	3.8.2.4-7	Resolved - The wind and tornado pressure loads for the design of containment vessel are defined in Revision 2 of SSAR Section 3.3.
686	3.8.2.4-8	Action Westinghouse/Action NRC - The staff review of the validation package of CBI in-house computer code E0781B found that only simple problems were used to validate this computer program. The staff agreed to provide the containment shell model used for the independent confirmatory analysis to Westinghouse for validating this code.
687	3.8.2.4-9	Resolved - This open item is considered resolved as a result of OI 3.8.2.4-3.
688	3.8.2.4-10	Resolved - This open item is considered resolved as a result of OI 3.8.2.4-3.

690	3.8.2.4-12	Resolved - The staff reviewed Westinghouse's containment vessel design report for all combined load conditions, and found that the results obtained met code requirements. This conclusion was also confirmed by the comparison of results by Westinghouse with those from the staff's confirmatory analysis.
691	3.8.2.4-13	Resolved - This open item is considered resolved as a result of OI 3.8.4.1-2.
692	3.8.2.4-14	Resolved - This open item is considered resolved as a result of OI 3.8.2.4-3.
693	3.8.2.4-15	Resolved - As discussed in the resolution status of OI 3.8.2.4-6, the verification of the containment temperature distribution during the passive cooling process will be addressed in Section 6 of the FSER. From the close comparison of results from its confirmatory analysis with those obtained from the thermal stress analysis performed by Westinghouse, the staff found that the boundary conditions defined by Westinghouse are reasonable.
694	3.8.2.4-16	Resolved - From its review of the containment vessel design report and the comparison of results from the independent confirmatory analysis with those documented in the design report, the staff found that the containment vessel does possess enough margin to resist combined load conditions from buckling.
696	3.8.2.4-18	Resolved
697	3.8.2.4-19	Resolved/Resolved - Subsumed by new RAI #1 received in the meeting on 8/30-31/95 (DSER Chapter 19/ PRA Chapter 42).
698	3.8.2.4-20	NRR/SCSB will review the containment leakage of 0.12 percent at design basis conditions in PRA Chapter 42.
699	3.8.2.4-21	Closed/Resolved
700	3.8.2.4-22	Closed/Resolved - PRA Chapter 42 was revised to adapt lognormal distribution for CCFP.
701	3.8.2.4-23	Resolved
702	3.8.2.4-24	Resolved - Subsumed by new RAI #1 received in the meeting on August 30 and 31, 1995 (DSER Chapter 19/ PRA Chapter 42).
703	3.8.2.4-25	Resolved/Resolved - Subsumed new by RAI #6 received in the meeting on August 30 and 31, 1995, (DSER Chapter 19/ PRA Chapter 42).

704	3.8.2.4-26	Action NRC - The staff will review the test data used to generate the lower bound curve in N-284, generate a 50 percent curve, and compare it with 150 percent P_{cr} (criteria pressure).
705	3.8.2.4-27	Closed/Resolved - PRA Chapter 42 was revised to describe the mathematical construction of the overall cumulative failure probability curve.
706	3.8.2.4-28	Resolved/Action Westinghouse - Westinghouse will clarify in SSAR/PRA to state that the failure mode of the containment bellows is tied to the cylindrical portion failure mode.
708	3.8.2.4-30	The NRC staff will review N-284, Revision 1 and the ASME confirmation of AP600 interpretation.
709	3.8.2.4-29	Resolved - superseded by new RAI #13 received in the meeting on 8/30-31/95 (DSER Chapter 19/ PRA Chapter 42).
1888	3.8.2.4-1	Resolved/Action Westinghouse - Westinghouse will revise SSAR 3.8.6.1 to change "ultimate capacities" to "ultimate pressure capacities" to demonstrate ASME Level C and ultimate capacity.
1471	19.2.6.2-2	Resolved
1472	19.2.6.2-3	Resolved/Resolved - Subsumed by new RAI #1 received in the meeting on August 30 and 31, 1995 (DSER Chapter 19/ PRA Chapter 42).
1473	19.2.6.2-4	NRR/SCSB will review the containment leakage of 0.12 percent at design basis conditions in PRA Chapter 42.
1474	19.2.6.3-4	Closed/Resolved
1475	19.2.6.3-2	Closed/Resolved - PRA Chapter 42 was revised to adapt lognormal distribution for CCFP.
1476	19.2.6.3-3	Resolved
1477	19.2.6.3-4	Resolved - Subsumed by new RAI #1 received in the meeting on August 30 and 31, 1995, (DSER Chapter 19/ PRA Chapter 42).
1478	19.2.6.3-5	Resolved/Resolved - Subsumed new by RAI #6 received in the meeting on August 30 and 31, 1995, (DSER Chapter 19/ PRA Chapter 42).

1479 19.2.6.3-6 Action NRC - The staff will review the test data used to generate the lower bound curve in N-284, generate a 50 percent curve, and compare it with 150 percent P_{cr} (criteria pressure).

1480 19.2.6.3-7 Closed/Resolved - PRA Chapter 42 was revised to describe the mathematical construction of the overall cumulative failure probability curve.

1482 19.2.6.3-9 Resolved/Action Westinghouse - Westinghouse will clarify in SSAR/PRA to state that the failure mode of the containment bellows is tied to the cylindrical portion failure mode.

1485 19.2.6.4-3 Action NRC - The NRC staff will review N-284, Revision 1 and the ASME confirmation of AP600 interpretation.

1486 19.2.6.4-4 Resolved - Subsumed by new RAI #13 received in the meeting on 8/30-31/95 (DSER Chapter 19/ PRA Chapter 42).

1975 19.2.6.4-1 Resolved/Action Westinghouse - Westinghouse will revise SSAR 3.8.6.1 to change "ultimate capacities" to "ultimate pressure capacities" to demonstrate ASME Level C and ultimate capacity.

RAI#1 Action Westinghouse - Westinghouse will review NUREG/CR-4209 and referenced cited in DSER and respond to the NRC. Westinghouse shall justify additional yield using von Mises; Westinghouse can use 10 percent increase on median yield strength for best estimate failure pressure.

RAI#2 Action Westinghouse - Westinghouse will revise SSAR to clarify configuration due to internal pressure.

RAI#3 Action Westinghouse - Westinghouse will review Reference 42-1 and change the range of tested minimum material strength, accordingly.

RAI#4 Action Westinghouse - Westinghouse will revise SSAR to describe (1) the Coefficients of Variation (COVs) of material and modeling uncertainties are enough to drive containment fragility curve and (2) insignificance of geometric properties uncertainties in buckling of equipment hatches.

RAI#5 Action Westinghouse - Westinghouse will review Reference 42-1 and change the range of tested minimum material strength, accordingly.

RAI#6 Action Westinghouse - Westinghouse will revise PRA Chapter 42.4.2 to clarify the pressures and will revise SSAR 3.8.2.4.2.2 to clarify the failure mode at the knuckle region is buckling rather than top yield or axisymmetric plastic collapse.

RAI#7 Action NRC - The NRC staff will review the test data used to generate the lower bound curve in N-284, generate a 50 percent curve, and compare it with the critical pressure, P_{cr}. The staff reviewed CBI calculation (MV50, S3R002, Rev. V) to confirm the elastic range of equipment hatches.

RAI#8 Action Westinghouse - Westinghouse will respond later.

RAI#9 Action Westinghouse - Westinghouse will respond later.

RAI#10 Action Westinghouse - Westinghouse will revise the COV heading in Table 42-1.

RAI#11 Action Westinghouse - Westinghouse will check 50 percent pressure for the head portion.

RAI#12 Action Westinghouse - Westinghouse will use the term "coefficient of variation."

RAI#13 Action Westinghouse - Westinghouse will revise SSAR 3.8.6.1 to change "ultimate capacities" to "ultimate pressure capacities" to demonstrate ASME Level C and ultimate capacity.

RAI#14 Action Westinghouse - Westinghouse will clarify in SSAR/PRA to state that the failure mode of the containment bellows is tied to the cylindrical portion failure mode.

RAI#15 Resolved - Westinghouse revised the radius, R_s is derived from the deformed shape.

WESTINGHOUSE AND CHICAGO BRIDGE AND IRON COMPANY
PRESENTATION MATERIAL
FOR THE MEETING ON THE
AP600 CONTAINMENT VESSEL DESIGN

AUGUST 30 AND 31, 1995

Attachment 5

1992 ASME SECTION III, SUBSECTION NE CODE CHANGES RELATIVE TO 1989 CODE

LOCATION	ADDENDUM	BRIEF DESCRIPTION OF CHANGE
Fig. NE-1132.2-1 through -3	A90	Applies to Jurisdictional Boundary[a].
NE-2121	A90 and A91	Permitted Material Specifications Tables NE-2121(a)-1 and -2 are new[a].
NE-2190	A90	Nonpressure-Retaining Material[a].
NE-2420(2)(f)	A91	Required tests[a].
NE-2510	A90	Pressure Retaining Material - Examined and Repaired[a].
NE-3112.4	A91	Allowable Stress Intensity and Stress Values - Reference to Table I-10.0 changed to Table I-7.0[a].
NE-3122	A91	Cladding[a].
NE-3122.4(a), (b)	A91	Integrally Clad Plate[a].
Table NE-3132-1	A89 and A90	Dimensional Standards[a].
NE-3133.2	A91	Nomenclature, S - Reference to Table I-10 changed to Table I-7[a].
NE-3133.6(a)	A91	Reference to Table I-10.0 changed to Table I-7.0[a].
NE-3134.6	A91	Reference to Table I-10.0 changed to Table I-7.0[a].
NE-3227.1(1)	A91	Reference to Table I-10.2 changed to Table I-7.2[a].
NE-3231	A91	Reference to Table I-10.3 changed to Table I-7.3[a].
NE-3232	A91	Reference to Table I-10.3 changed to NE-3231(a) [a].
NE-3232.1 and .2	A91	Reference Table I-10.3 changed to I-7.3[a].
NE-3324.8(c)	A91	Reference Table I-10.0 changed to I-7.0[a].
NE-3325.1	A91	Reference Table I-10.0 changed to I-7.0[a].
NE-3338.1	A90	Pressure Stresses in Openings for Fatigue Evaluation under operating Conditions[a].
NE-3366.2	A91	Design Requirements - Reference Table I-10.0 changed to I-7.0[a].
NE-4335.1(c)	A89	Impact Tests of Weld Material[a].
Table NE-4622.7(b)-1	A90	Footnotes[a].
NE-7xxx	A91	Minor Changes that do not affect the design of the Containment Vessel.

[a]This does not affect the Containment Vessel design.

Table 3.8.2-1

LOAD COMBINATIONS AND SERVICE LIMITS FOR CONTAINMENT VESSEL

Load Description		Load Combination and Service Limit										
		Test	Des.	Des.	A	A	A	C	C	C	C	D
Dead	D	x	x	x	x	x	x	x	x	x	x	x
Live	L	x	x	x	x	x	x	x	x	x	x	x
Wind	W				x							
SSE	E_s							x	x			x
Tornado	W_t									x		
Test pressure	P_t	x										
Test temperature	T_t	x										
Operating pressure	P_o				x				x	x		
Design pressure	P_d		x			x		x				x
External pressure (2.5 psid)	P_e			x			x					
External pressure (3.0 psid)	P_e										x	
Normal reaction	R_o			x	x		x		x	x	x	
Normal thermal	T_o			x	x		x		x	x	x	
Accident thermal reactions	R_a		x			x		x				x
Accident thermal	T_a		x			x		x				x
Accident pipe reactions	Y_r											x
Jet impingement	Y_j											x
Pipe impact	Y_m											x

Notes:

1. Service limit levels are per ASME-NE.
2. Where any load reduces the effects of other loads, that load shall be taken as zero, unless it can be demonstrated that the load is always present or occurs simultaneously with the other loads.

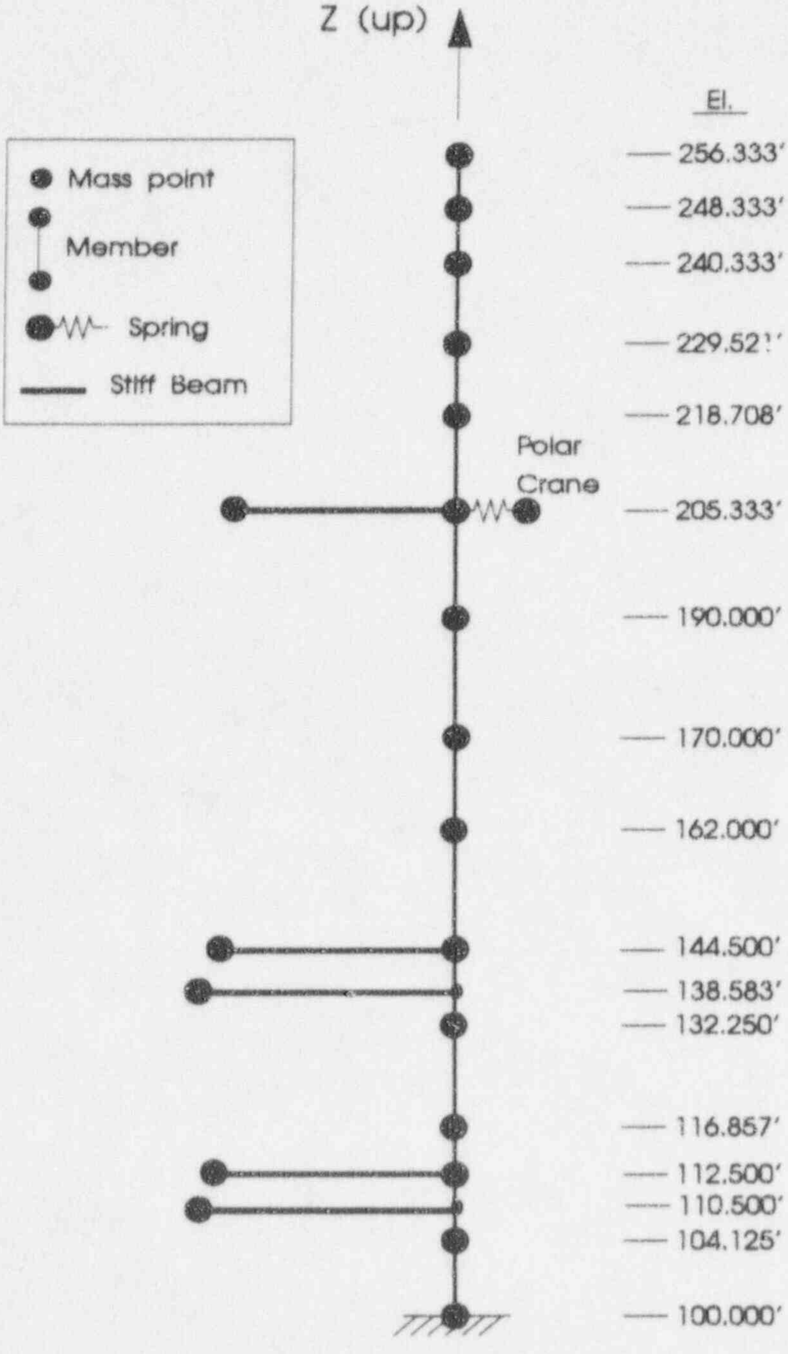


Figure 3.7.2-5
Steel Containment Vessel Lumped Mass Stick Model

Table 3.7.2-6 (Sheet 1 of 3)

MAXIMUM ABSOLUTE NODAL ACCELERATION (ZPA) STEEL CONTAINMENT VESSEL

HARD ROCK SITE CONDITION

Elevation (ft)	Maximum Absolute Nodal Acceleration, ZPA (g.)					
	N-S Direction		E-W Direction		Vertical Direction	
256.33	0.87		1.15		1.30	
248.33	0.85		1.11		1.04	
240.33	0.82	(0.85)	1.07	(1.07)	0.92	(0.93)
229.52	0.73		1.02		0.81	
218.71	0.73		0.96		0.77	
205.33	0.69	(0.71)	0.89	(0.89)	0.75	(0.78)
205.33 (Polar Crane)	1.82		1.09		1.17	
190.00	0.64		0.80		0.71	
170.00	0.55		0.66		0.65	
162.00	0.51	(0.51)	0.60	(0.60)	0.62	(0.65)
144.50	0.41		0.48		0.55	
132.25	0.36		0.39		0.50	
116.86	0.33	(0.33)	0.34	(0.34)	0.43	(0.44)
112.50	0.32		0.33		0.41	
104.13	0.31		0.31		0.37	
100.00	0.30		0.30		0.32	

Note:

1. Enveloped response results at the north and west edge nodes of the structure are shown in parentheses. This is the maximum value of the response at any of these edge nodes.

Table 3.7.2-6 (Sheet 2 of 3)

MAXIMUM ABSOLUTE NODAL ACCELERATION (ZPA) STEEL CONTAINMENT VESSEL

SOFT ROCK SITE CONDITION

Elevation (ft)	Maximum Absolute Nodal Acceleration, ZPA (g.)					
	N-S Direction		E-W Direction		Vertical Direction	
256.33	0.66		0.90		0.78	
248.33	0.64		0.86		0.63	
240.33	0.63	(0.63)	0.83	(0.83)	0.57	(0.57)
229.52	0.61		0.78		0.49	
218.71	0.59		0.74		0.46	
205.33	0.56	(0.57)	0.67	(0.67)	0.45	(0.47)
205.33 (Polar Crane)	1.31		1.15		1.10	
190.00	0.54		0.59		0.44	
170.00	0.47		0.49		0.39	
162.00	0.45	(0.45)	0.45	(0.45)	0.41	(0.44)
144.50	0.40		0.38		0.37	
132.25	0.37		0.34		0.37	
116.86	0.35	(0.35)	0.33	(0.33)	0.36	(0.41)
112.50	0.34		0.31		0.36	
104.13	0.32		0.31		0.35	
100.00	0.31		0.31		0.34	

Note:

1. Enveloped response results at the north and west edge nodes of the structure are shown in parentheses. This is the maximum value of the response at any of these edge nodes.

Table 3.7.2-6 (Sheet 3 of 3)

MAXIMUM ABSOLUTE NODAL ACCELERATION (ZPA)
STEEL CONTAINMENT VESSEL

SOFT-TO-MEDIUM STIFF SOIL CONDITION

Elevation (ft)	Maximum Absolute Nodal Acceleration, ZPA (g.)					
	N-S Direction		E-W Direction		Vertical Direction	
256.33	0.47		0.63		0.69	
248.33	0.45		0.61		0.57	
240.33	0.43	(0.44)	0.59	(0.59)	0.51	(0.53)
229.52	0.41		0.56		0.45	
218.71	0.38		0.53		0.42	
205.33	0.35	(0.37)	0.49	(0.49)	0.42	(0.50)
205.33 (Polar Crane)	0.69		1.12		1.35	
190.00	0.34		0.44		0.41	
170.00	0.31		0.38		0.41	
162.00	0.30	(0.30)	0.36	(0.36)	0.40	(0.48)
144.50	0.29		0.31		0.40	
132.25	0.28		0.32		0.39	
116.86	0.27	(0.28)	0.30	(0.30)	0.38	(0.44)
112.50	0.27		0.30		0.38	
104.13	0.26		0.29		0.38	
100.00	0.26		0.29		0.37	

Note:

1. Enveloped response results at the north and west edge nodes of the structure are shown in parentheses. This is the maximum value of the response at any of these edge nodes.

Containment Vessel Wind Loads

SSAR 3.3

The development of loads on the air baffle due to the design wind and tornado (W_W) are described in the test reports (References 3, 4, and 5). Models of the AP600 were tested in a wind tunnel and subjected to representative wind profiles. Pressures were measured on each side of the baffle, and the differential pressures were normalized to the input wind velocity. The pressure coefficients are applied to the effective dynamic pressure for the design wind and the tornado to obtain the wind loads across the baffle.

- Wind conditions result in a pressure reduction in the annulus between the shield building and the containment vessel as well as above the containment dome. This reduced pressure is equivalent to an increase in containment internal pressure and is within the normal operating range for containment pressure (–0.2 to 1.0 psig).

- Wind conditions result in a small wind load across the containment vessel. This is maximum opposite the air intakes where positive pressures occur on the windward side and negative pressures occur on the leeward side. Lateral loads on the containment vessel are developed in Reference 5.

Design Specification

Design wind (to be used in the Service Level A load combination)

Reduction in external pressure = 0.9 psi.
Pressure amplitude on cylindrical portion (n = 1 harmonic)
= 8.1 pounds per square foot.
Pressure amplitude on top head below elevation 236′ (n = 1 harmonic)
= 14.8 pounds per square foot.

Tornado (to be used in the Service Level C load combination)

Reduction in external pressure = 3.0 psi.
Pressure amplitude on cylindrical portion (n = 1 harmonic)
= 17.3 pounds per square foot.
Pressure amplitude on top head below elevation 236′ (n = 1 harmonic)
= 31.7 pounds per square foot.

3. WCAP-13323-P and WCAP-13324-NP, "Phase II Wind Tunnel Testing for the Westinghouse AP600 Reactor," June 1992.
4. WCAP-14068-P, Phase IVA Wind Tunnel Testing for the Westinghouse AP600 Reactor, May, 1994
5. WCAP-14169-P, Phase IVA Wind Tunnel Testing for the Westinghouse AP600 Reactor, Supplement 1 Report, September,1994

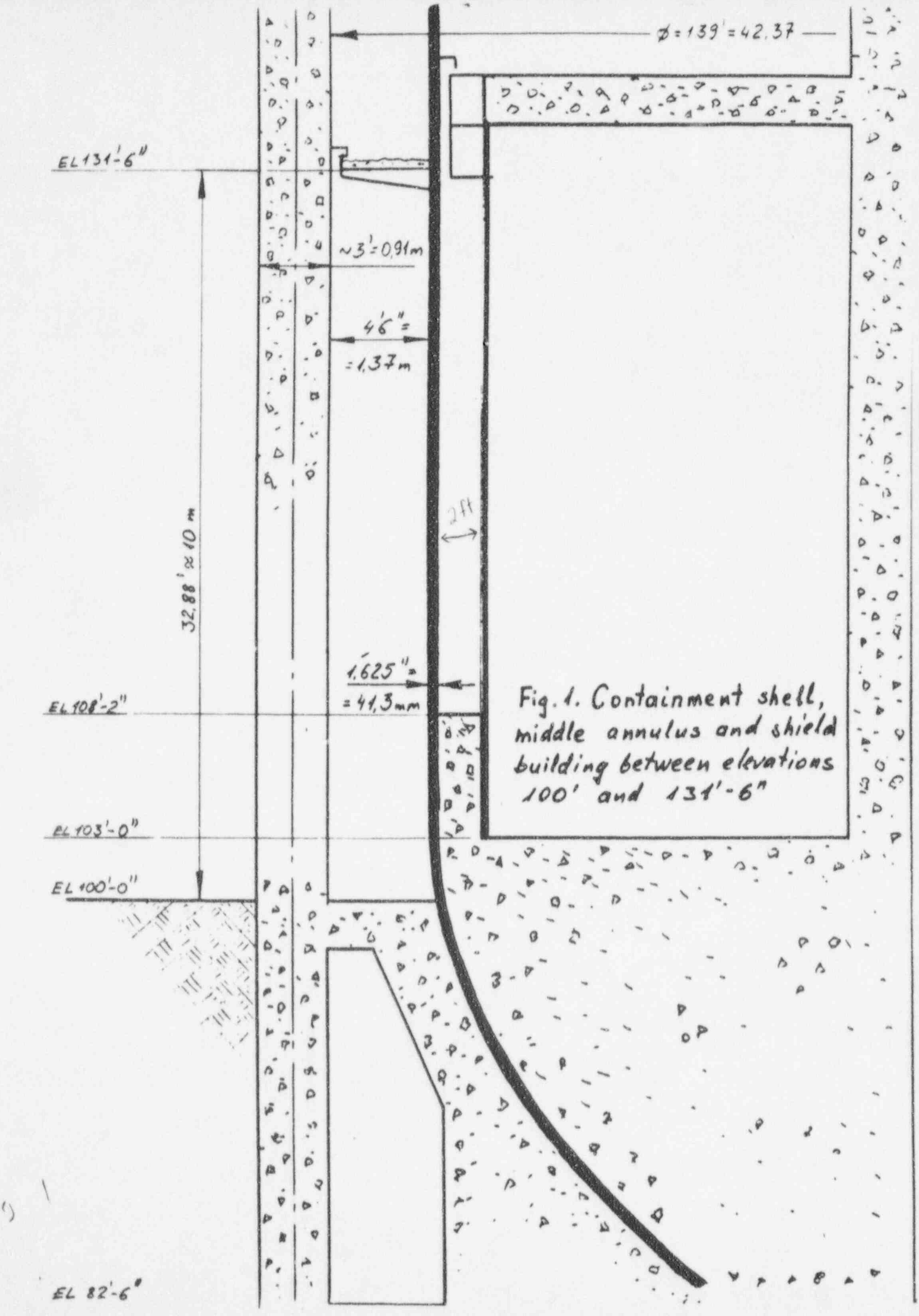
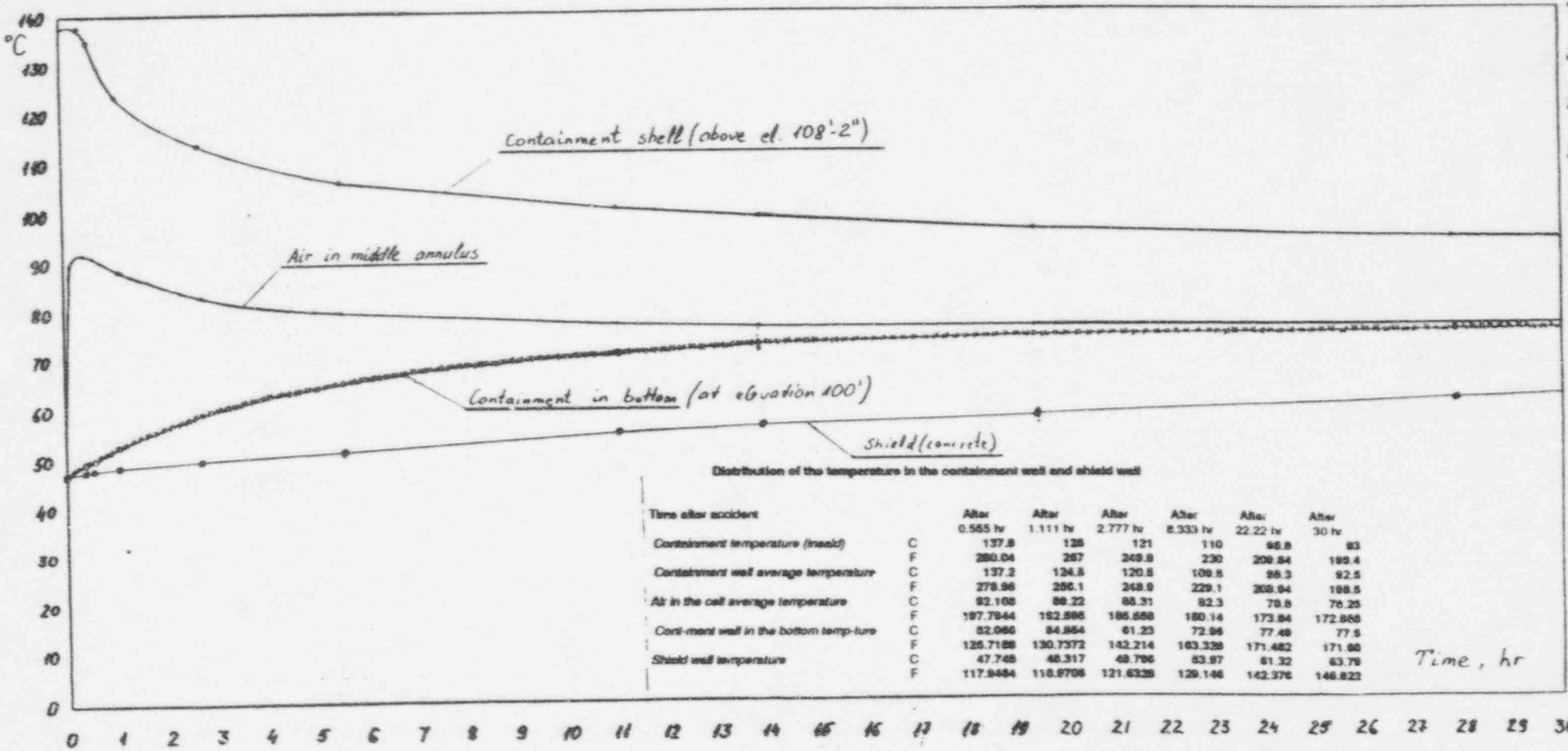


Fig. 1. Containment shell, middle annulus and shield building between elevations 100' and 131'-6"

PRELIMINARY

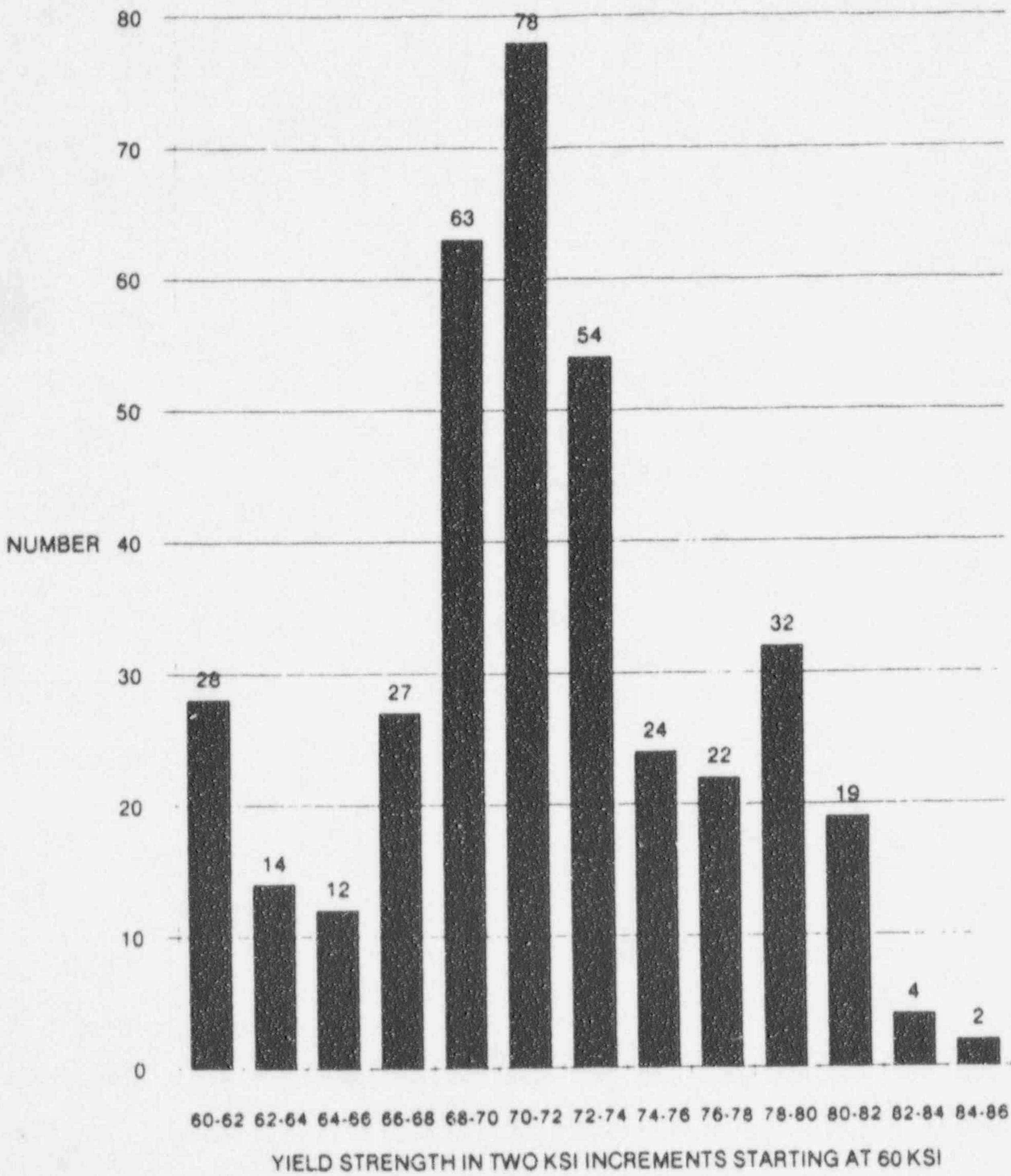


Distribution of the temperature in the containment wall and shield wall

Time after accident		After 0.555 hr	After 1.111 hr	After 2.777 hr	After 8.333 hr	After 22.22 hr	After 30 hr
Containment temperature (inside)	C	137.8	125	121	110	98.8	93
	F	280.04	257	249.8	230	209.84	199.4
Containment wall average temperature	C	137.2	124.5	120.5	109.5	98.3	92.5
	F	278.96	256.1	248.9	229.1	208.94	198.5
Air in the cell average temperature	C	92.108	89.22	85.31	82.3	78.8	78.25
	F	197.7944	192.596	186.658	180.14	173.84	172.868
Cont-ment wall in the bottom temp-ture	C	52.066	54.854	61.23	72.96	77.49	77.5
	F	125.7188	130.7372	142.214	163.328	171.482	171.66
Shield wall temperature	C	47.748	48.317	49.796	53.97	61.32	63.79
	F	117.9464	118.9706	121.6328	129.146	142.376	146.823

Fig. 7. Temperatures of the containment shell, air in middle annulus and shield building after accident

SA537 CL 2 ACTUAL YIELD STRESS HISTOGRAM



RSQ 11/15/91 TJA 11/19/91

RESULTS (CONTINUED)

of 146 psig. It is interesting to observe that we get $p_Y = \frac{2}{\sqrt{3}} \times \frac{\sigma_Y \times t}{R} = \frac{2}{\sqrt{3}} \times \frac{60000 \times 1.625}{780} = 144.3$ psig – see sheet 2-7 of Task #2 for this formula which is based on von Mises yielding criterion. 'BOSOR5' also uses this criterion. Yield of the knuckle region started at 152 psig.

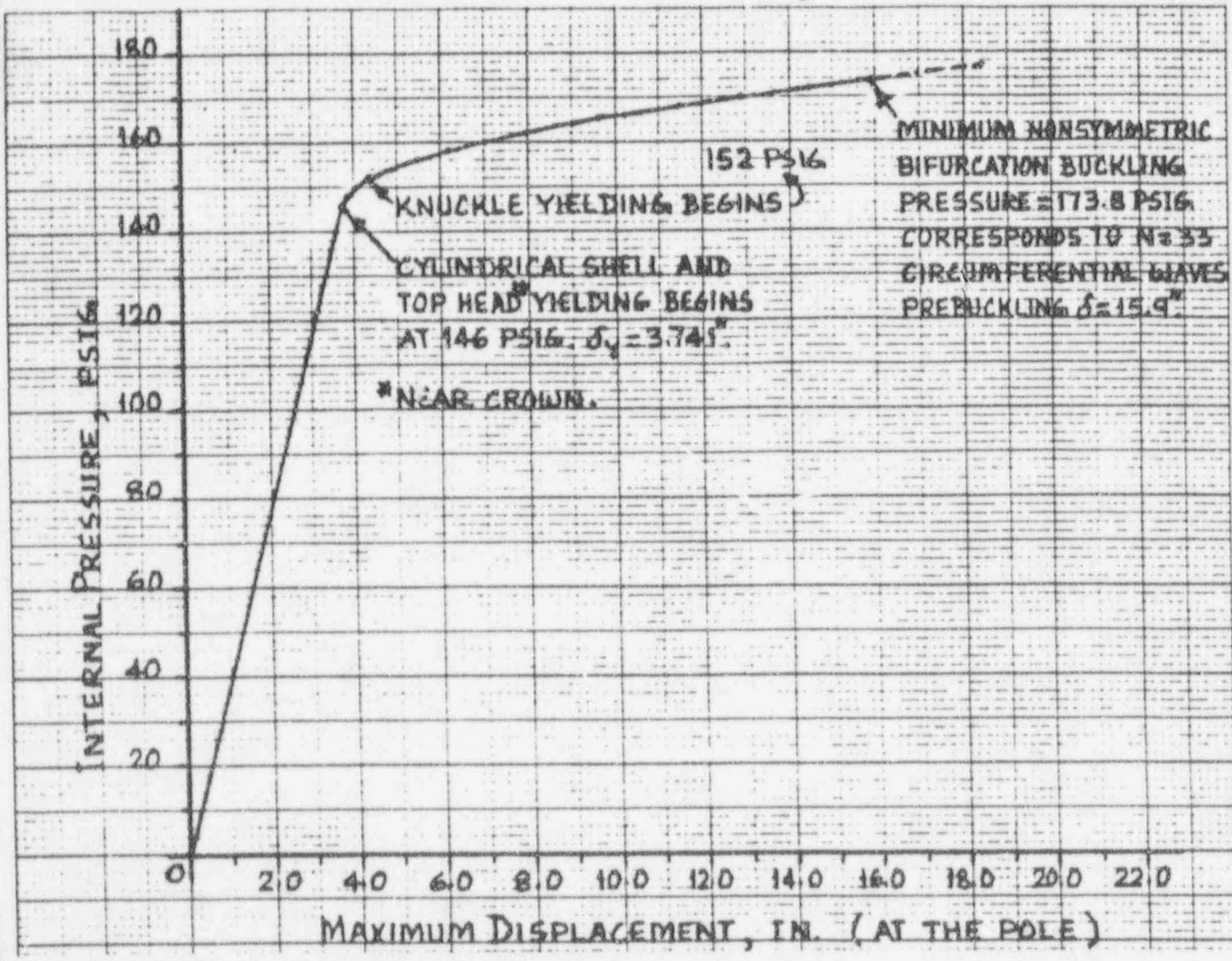


FIG. 3.5: INTERNAL PRESSURE – MAXIMUM DISPLACEMENT CURVE

SUBJECT	OFFICE	REVISION		REFERENCE NO
BUCKLING CAPACITY EVALUATION TASK #3, CBI PHASE 3 STUDY AP600, WESTINGHOUSE	CBI NOE-A			902657
	MADE BY RSQ / VERIFIED BY TJA	MADE BY	VERIFIED BY	SHT 3-10 OF
	DATE 12/18/91 / DATE 2/18/92	DATE	DATE	

902657: BUCKLING OF TOP HEAD 12/17/91
DEFORMED STRUCTURE
LOAD STEP 42. LOAD = 1.738E+02 PRESTRESS
PSIG

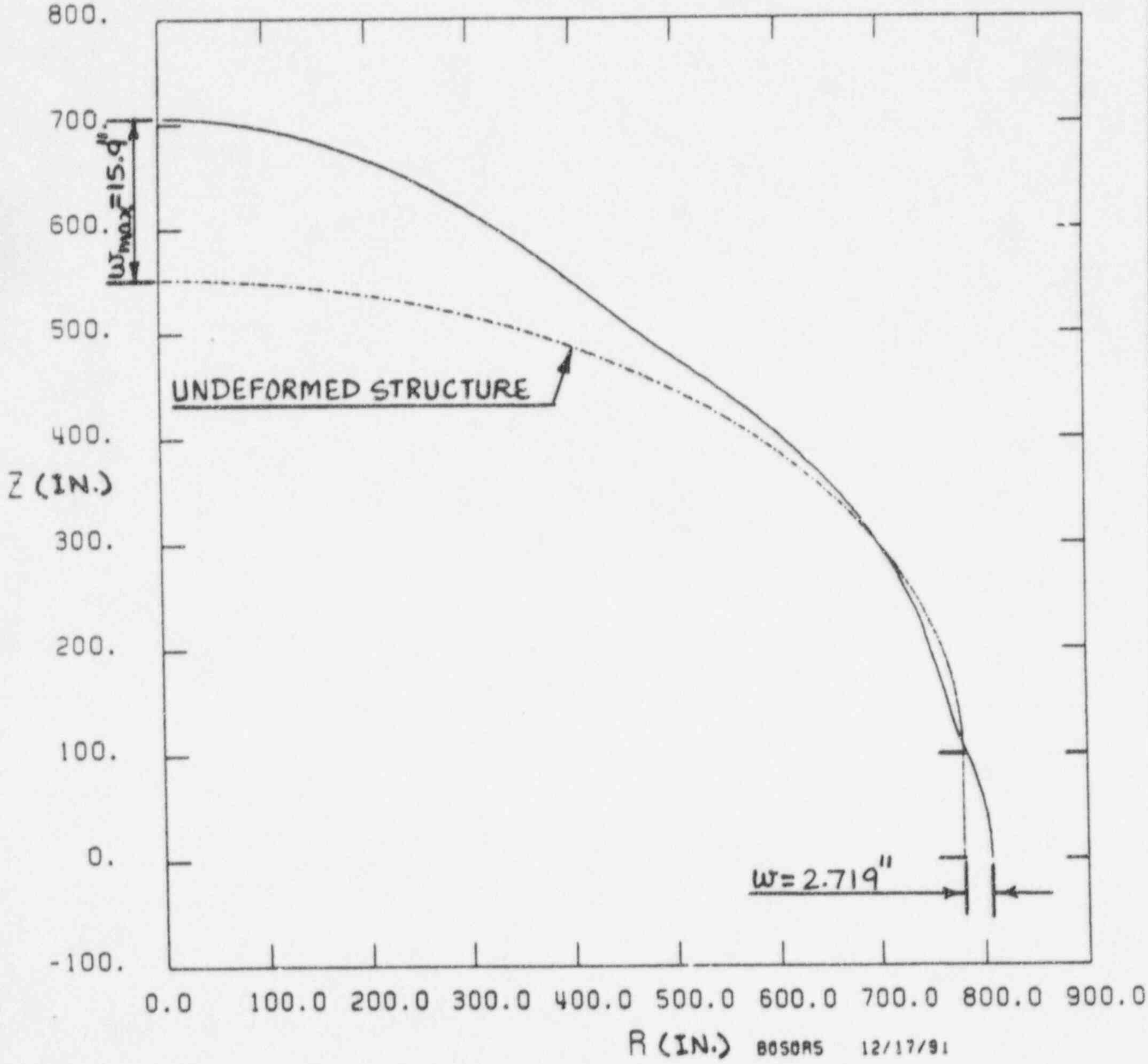


FIG. 3-6: PREBUCKLING DISPLACEMENTS AT $P_{cr\,MIN}$=173.8 PSIG (BOSOR5)

SUBJECT	OFFICE		REVISION		REFERENCE NO
BUCKLING CAPACITY EVALUATION	CBI NOE-A				902657
TASK #3, CBI PHASE 3 STUDY	MADE BY RSD	VERIFIED BY TJA	MADE BY	VERIFIED BY	3-12 SHT ___ OF ___
AP600, WESTINGHOUSE	DATE 12/17/91	DATE 2/18/92	DATE	DATE	

902657: BUCKLING OF TOP HEAD 12/17/91

DEFORMED STRUCTURE

BUCKLE MODE. N = 33, LOAD = 1.738E+02 PSIG = $P_{cr\,MIN}$

WAVES (MIN.)

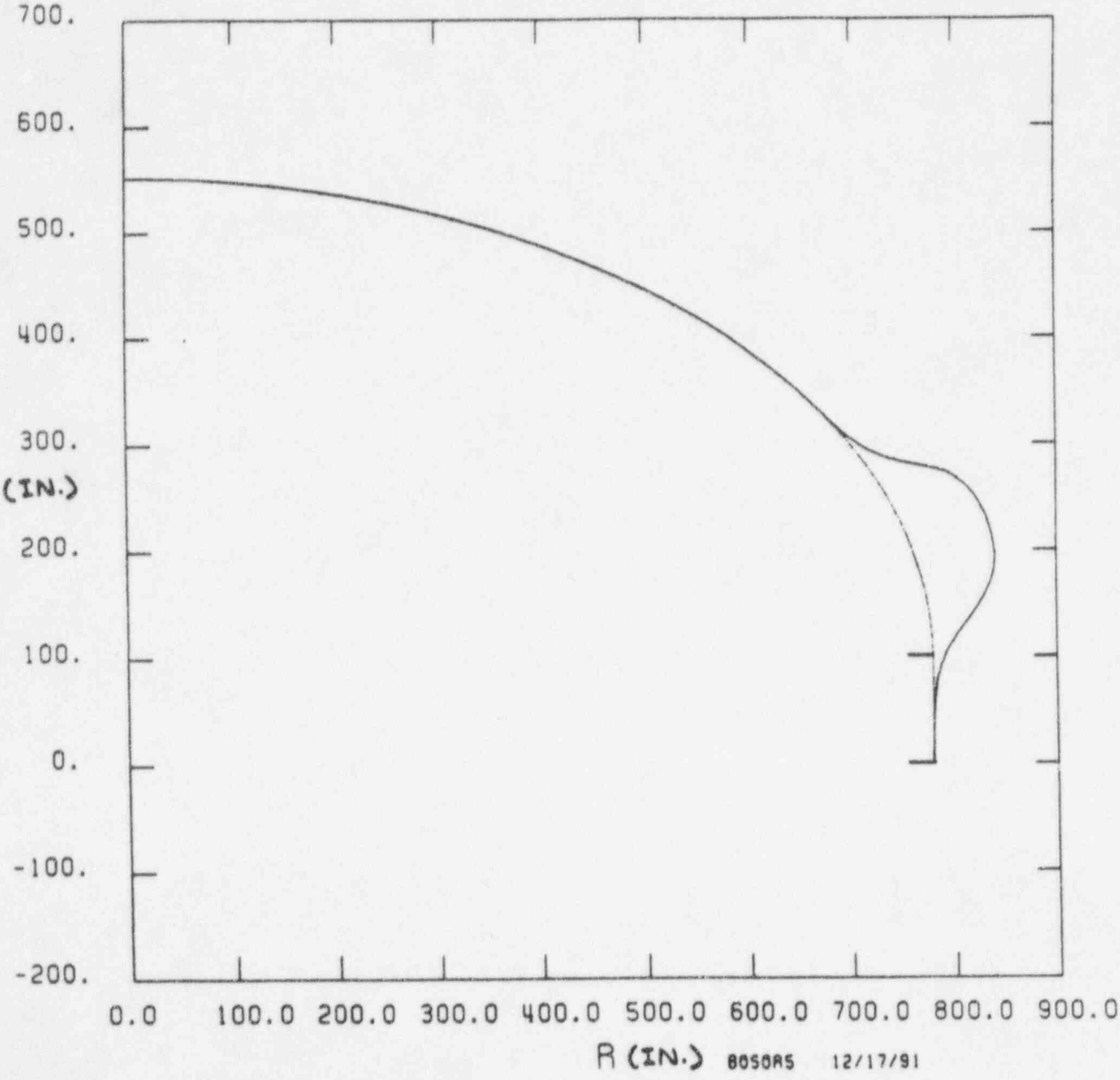


FIG. 3-7 : CRITICAL BUCKLING MODE FOR AP600 TOP HEAD (BOSOR 5)

SUBJECT	OFFICE		REVISION		REFERENCE NO
BUCKLING CAPACITY EVALUATION	CBI NOE-A				902657
TASK # 3, CBI PHASE 3 STUDY	MADE BY RSD	VERIFIED BY TJA	MADE BY	VERIFIED BY	SHT 3-13 OF
AP600, WESTINGHOUSE	DATE 12/17/91	DATE 2/18/92	DATE	DATE	

Printed in USA

GO 64A AUG 8

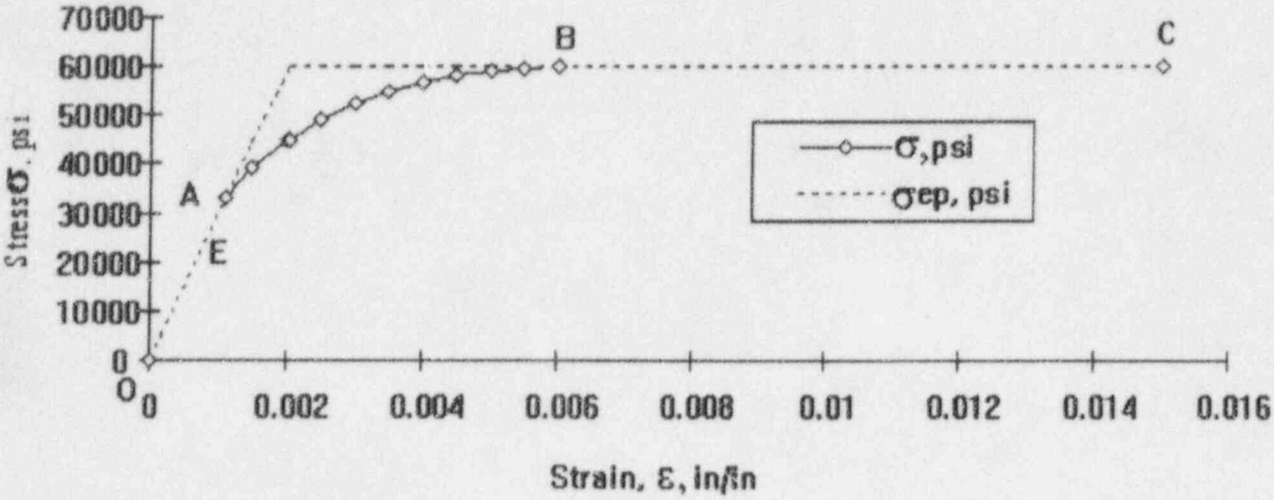


Figure 220.8-1

Stress-Strain Curve

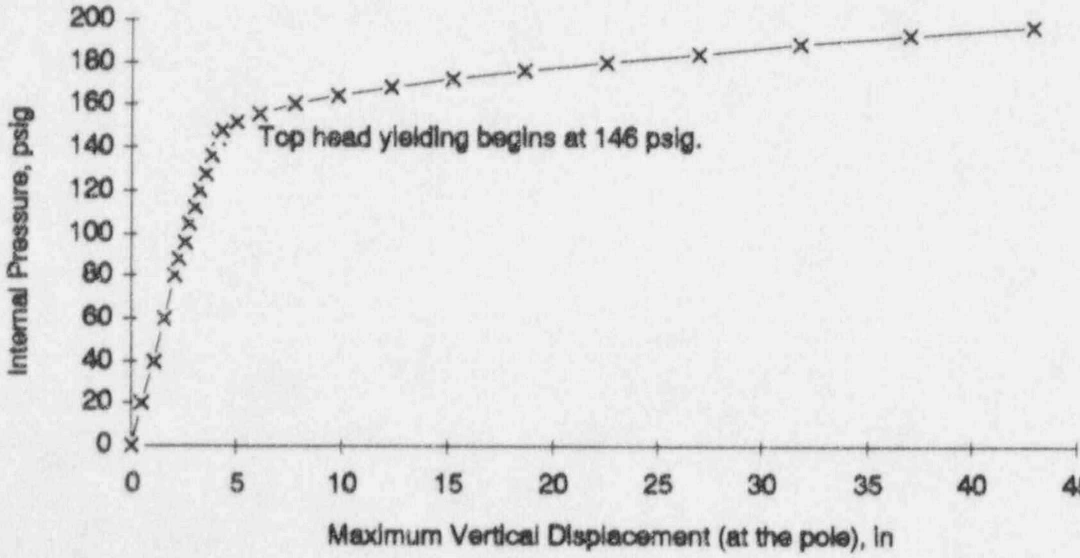
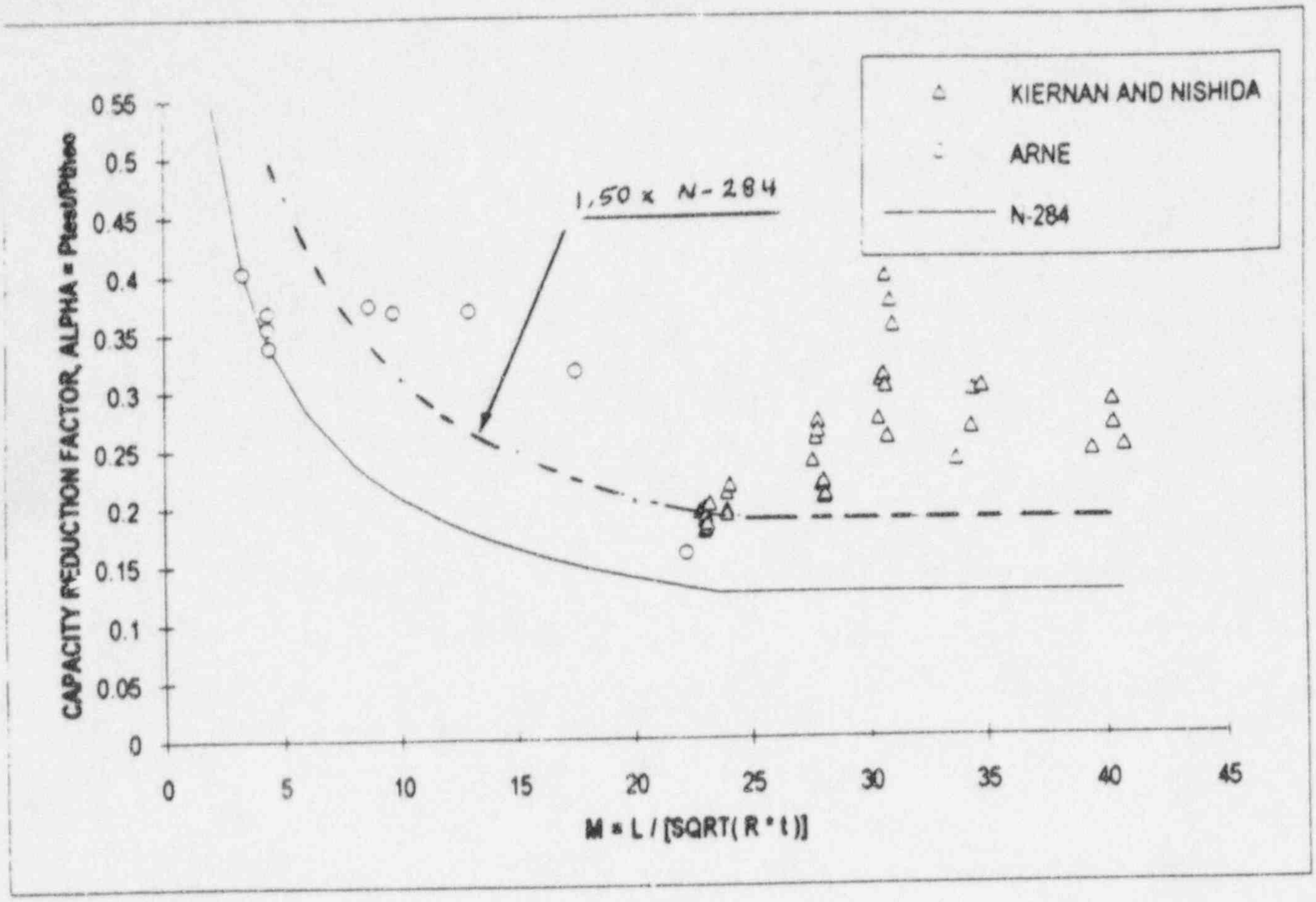


Figure 220.8-2

Internal Pressure - Maximum Displacement Curve



COMPARISON OF CAPACITY REDUCTION FACTORS FOR
THE 'KIERNAN AND NISHIDA' AND 'ARNE' TESTS WITH N-284

RAI 220.32

CONTAINMENT VESSEL DESIGN REPORT

AP600 DOCUMENT NO.
MV50 S3R 005, REV. 0

SECTION S

Linear Bifurcation Buckling Effects of Large ASME Reinforced Openings

PRELIMINARY

See next page, "Document Control Log Sheet" and the Index for the contents and the revision status of this Section.

of 1 to 10. Classical buckling solutions from "Theory of Elastic Stability," by Timoshenko and Gere for similar, but simpler, geometry were used as a guide. The critical load levels are the product of the unit load values and the calculated eigenvalues.

The base of the model is fully restrained to represent the embedment condition. (Concrete on inside from El. 100'-0 to El. 107'-2 is ignored in the analysis.) The vertical edges of the model are restrained using symmetry conditions. The top edge of the model, above the stiffener at El. 131'-9, is restrained radially using a uniform radial displacement (specified below) and all rotations are fixed to preclude buckling at the top of the model.

The radial restraint was set to match the uniform radial growth of the 1.625" thick shell due to each loading. The value used with the external pressure loading is $\Delta r = -0.159"$ and the value used with the axial loading is $\Delta r = 0.079"$.

RESULTS

The calculated theoretical critical linear bifurcation buckling loads are summarized in Table 2. Results are presented for six cases; two for the external pressure loading and four for the axial compression loading. The reason for presenting the additional axial pressure cases is to demonstrate the level of sensitivity this case had relative to the amount of shell included in the analysis.

TABLE 2: CALCULATED THEORETICAL CRITICAL LINEAR BIFURCATION BUCKLING LOAD

Model	External Pressure [on a Closed Vessel] (psi)	Axial Compression (ksi)
Unpenetrated Shell	15.38	37.64
Penetrated Shell	16.05	35.80
Unpenetrated Shell*	N/A	38.24
Penetrated Shell*	N/A	36.16

* Prior to extending model in circumferential and vertical directions.

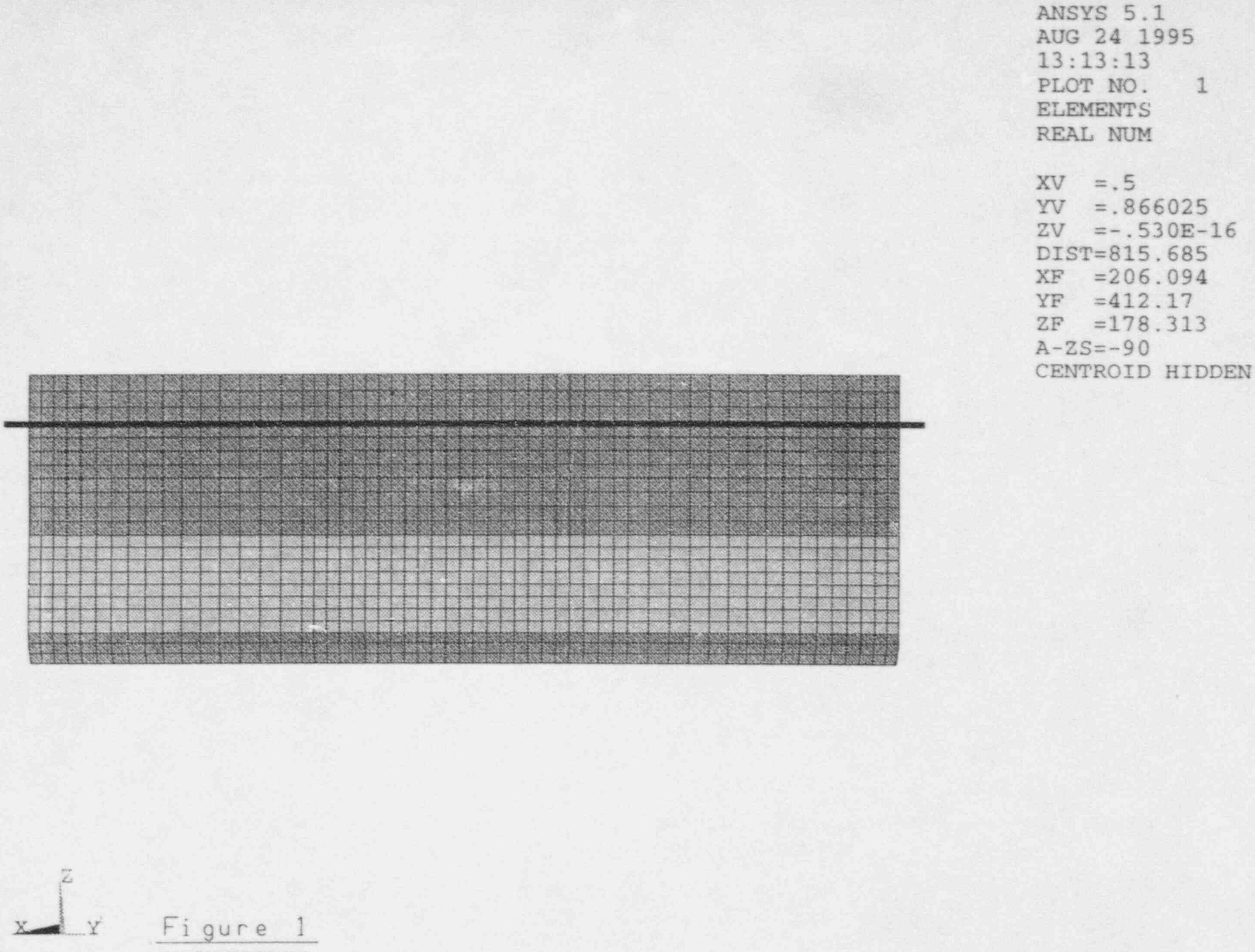


Figure 1

Unpenetrated Shell Model

ANSYS 5.1
AUG 24 1995
12:18:39
PLOT NO. 1
ELEMENTS
REAL NUM

XV =.458656
YV =.888645
ZV =.605E-15
DIST=811.085
XF =206.094
YF =412.17
ZF =178.313
A-ZS=-90
CENTROID HIDDEN

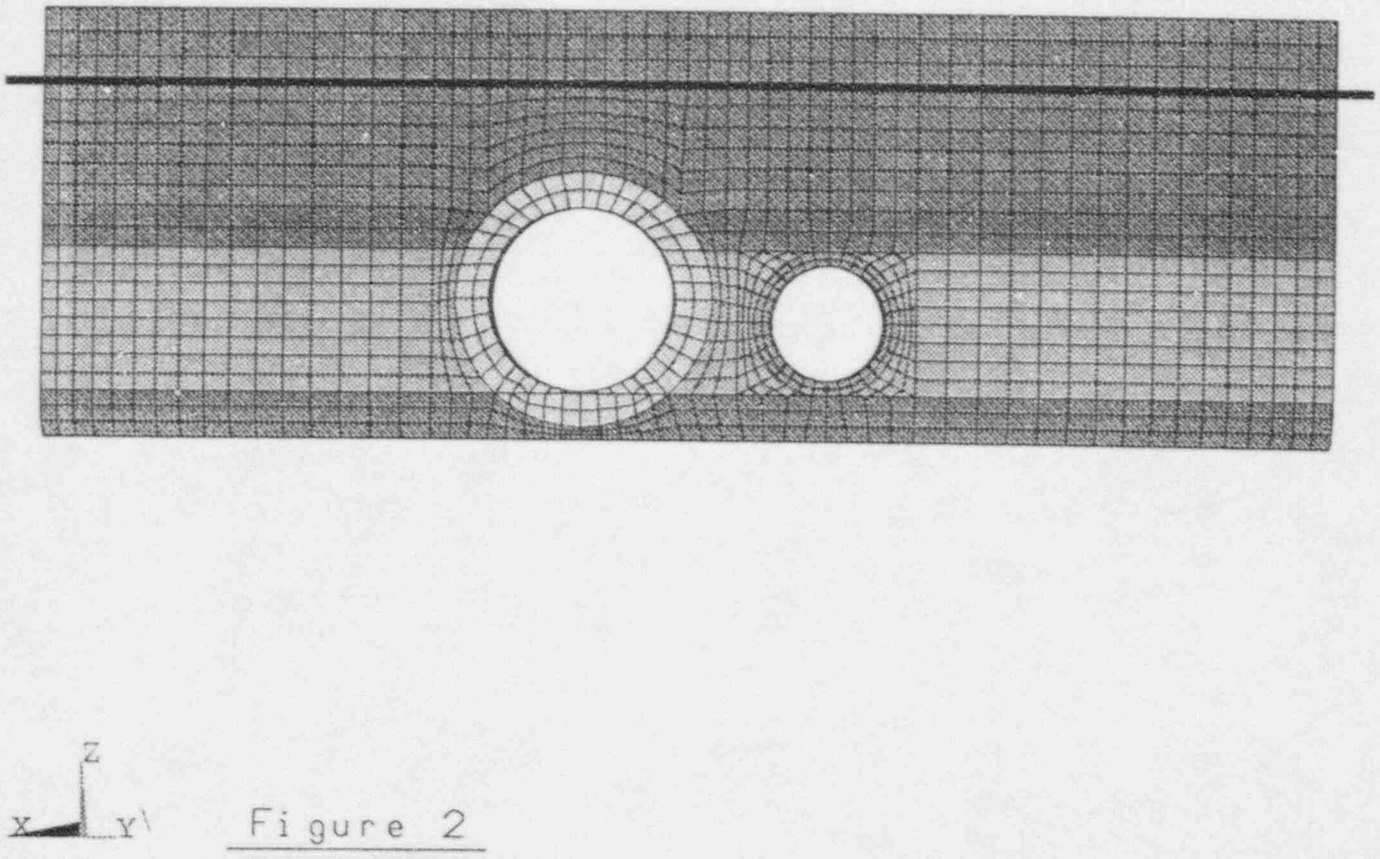


Figure 2

Penetrated Shell Model

ANSYS 5.1
AUG 24 1995
13:20:16
PLOT NO. 2
DISPLACEMENT
STEP=1
SUB =1
FACT=1.046
RSYS=1
DMX =1

*DSCA=60
XV =.5
YV =.866025
ZV =-.530E-16
DIST=834.518
XF =188.692
YF =412.196
ZF =178.313
A-ZS=-90
CENTROID HIDDEN

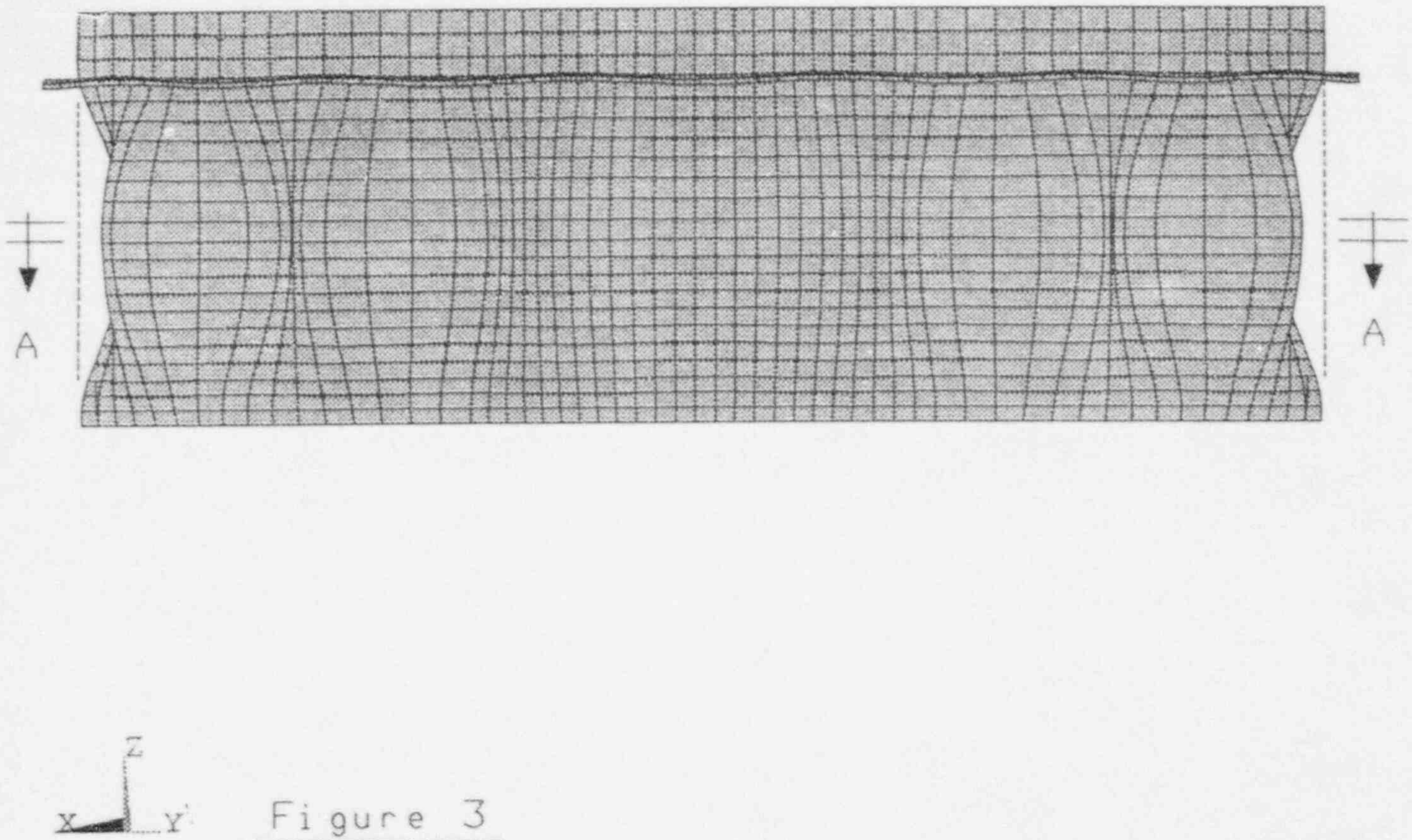


Figure 3

Unpenetrated Shell w/ 14.7 psi External Pressure

Section A-A

Figure 4

Unpenetrated Shell w/ 14.7 psi External Pressure

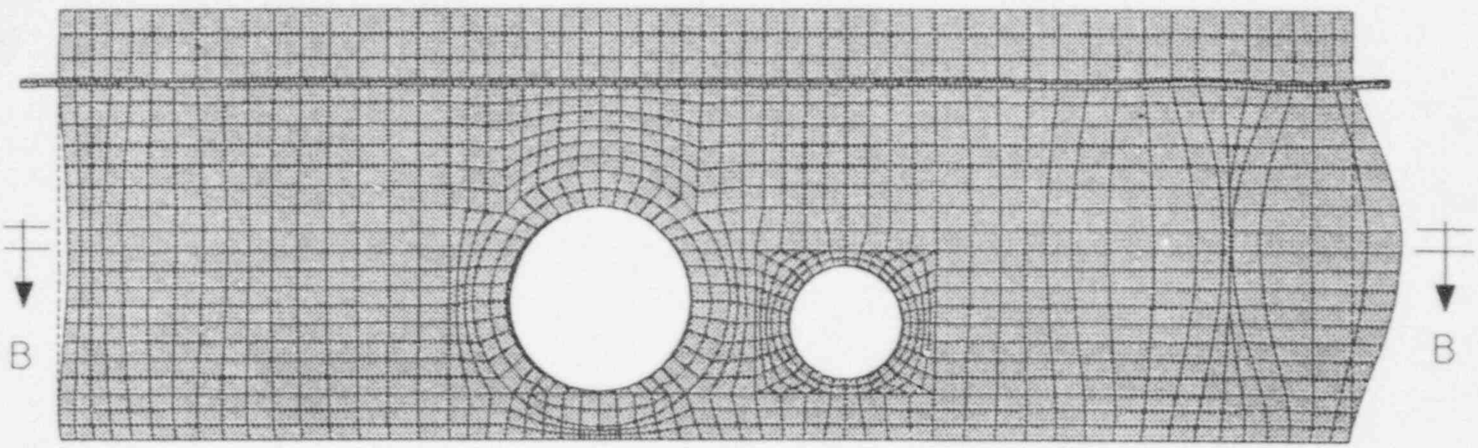
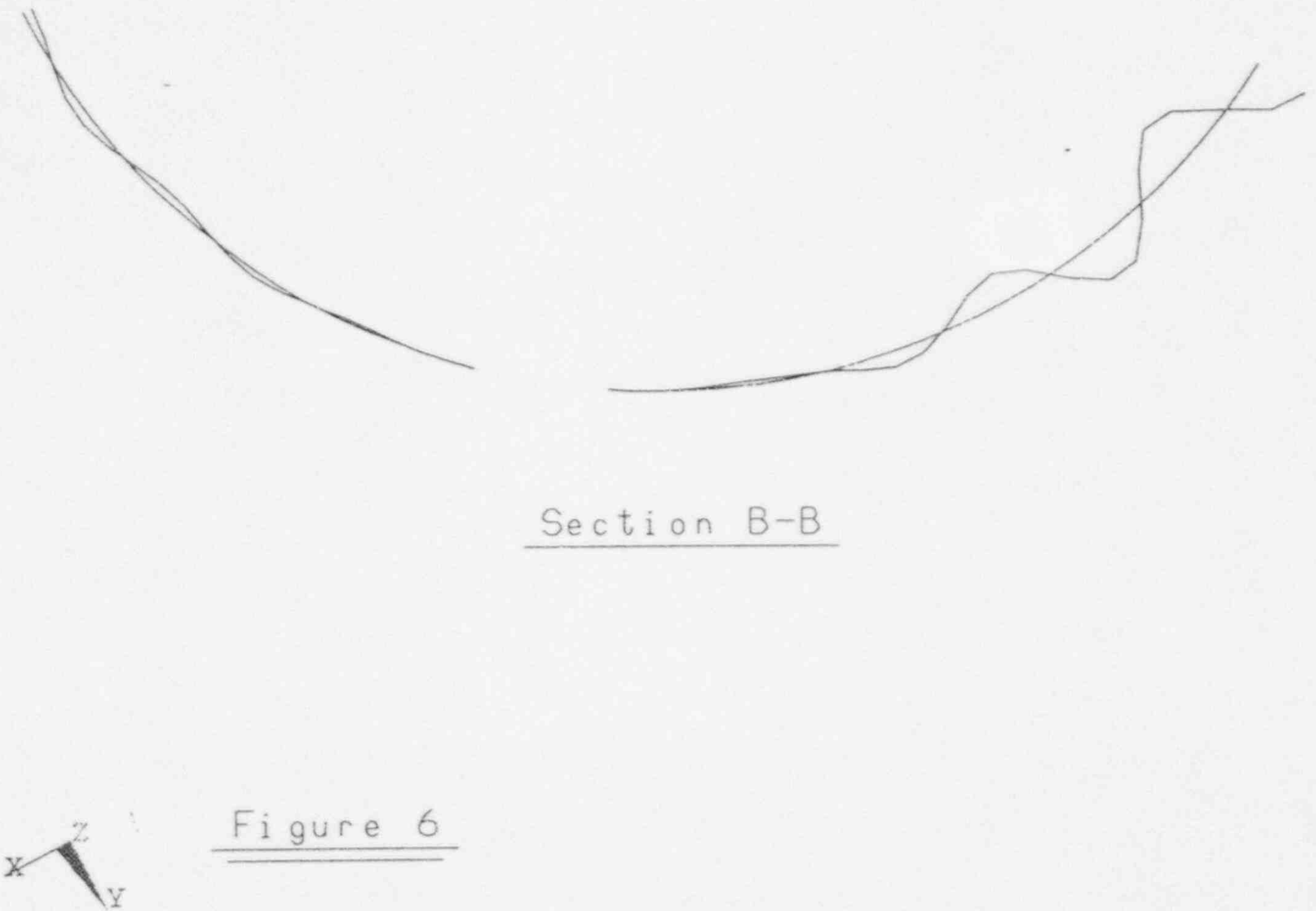


Figure 5

Penetrated Shell w/ 14.7 psi External Pressure



Section B-B

Figure 6

Penetrated Shell w/ 14.7 psi External Pressure

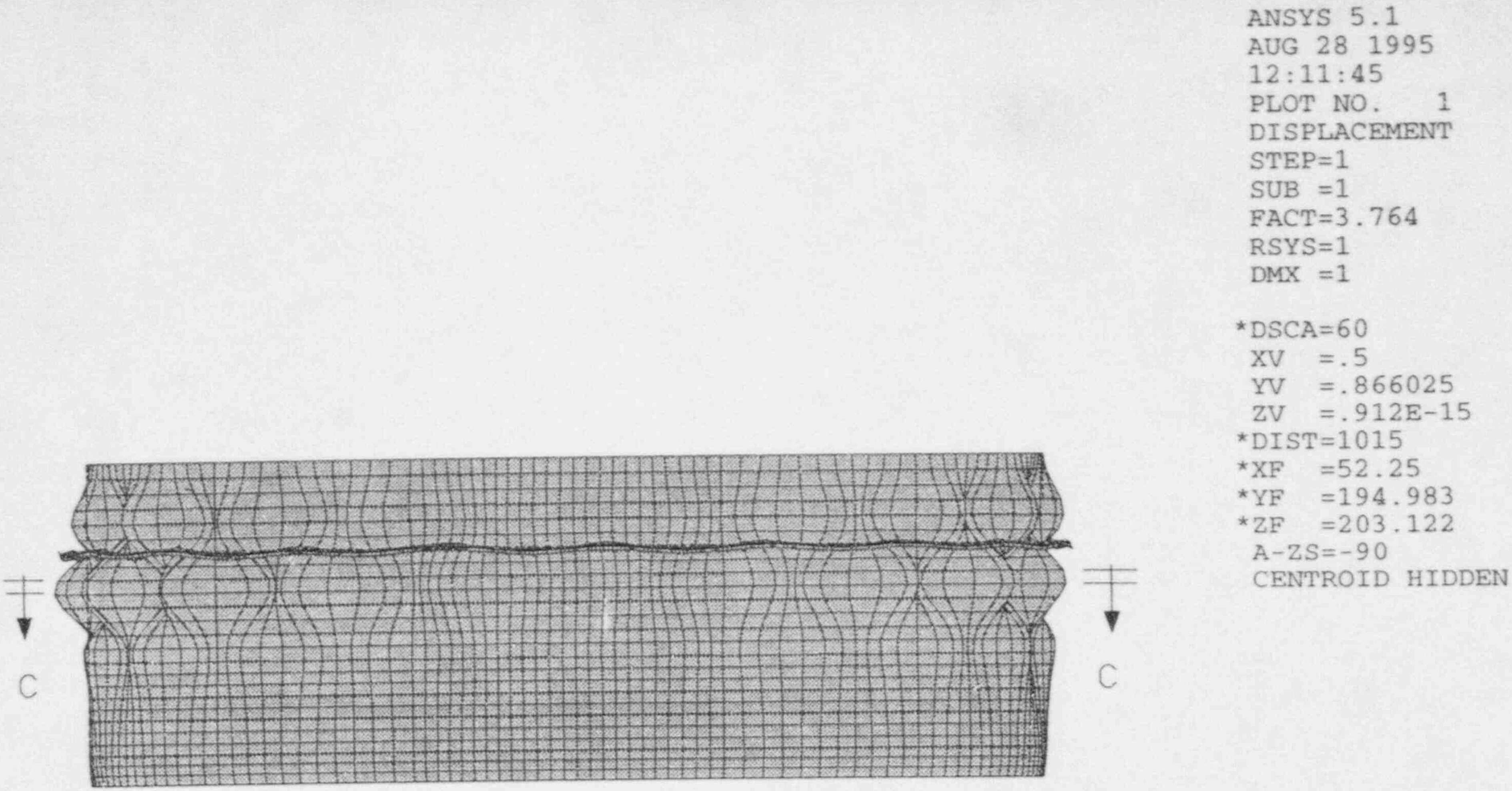


Figure 7

Unpenetrated Shell w/ 10 ksi Axial Load

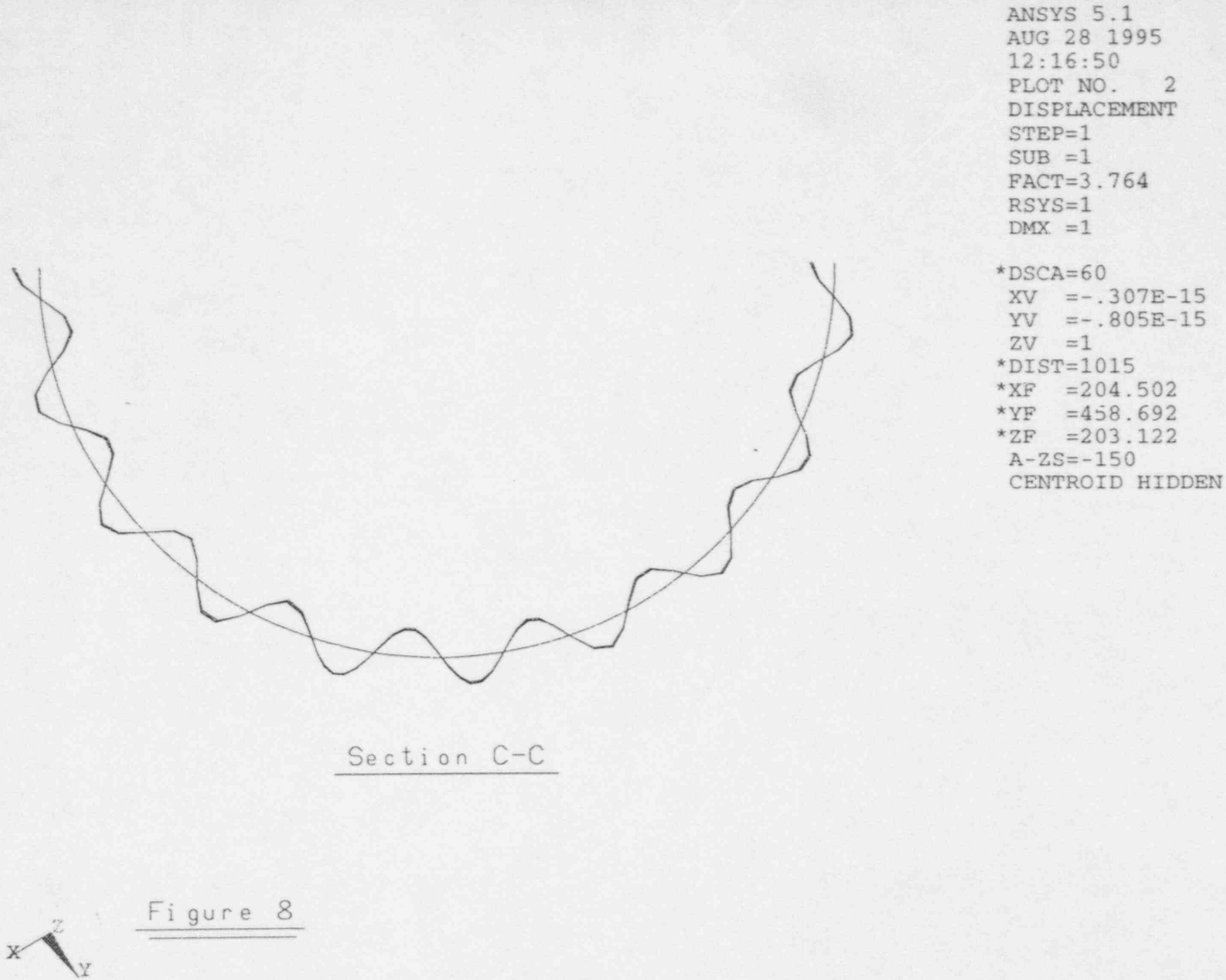


Figure 8

Unpenetrated Shell w/ 10 ksi Axial Load

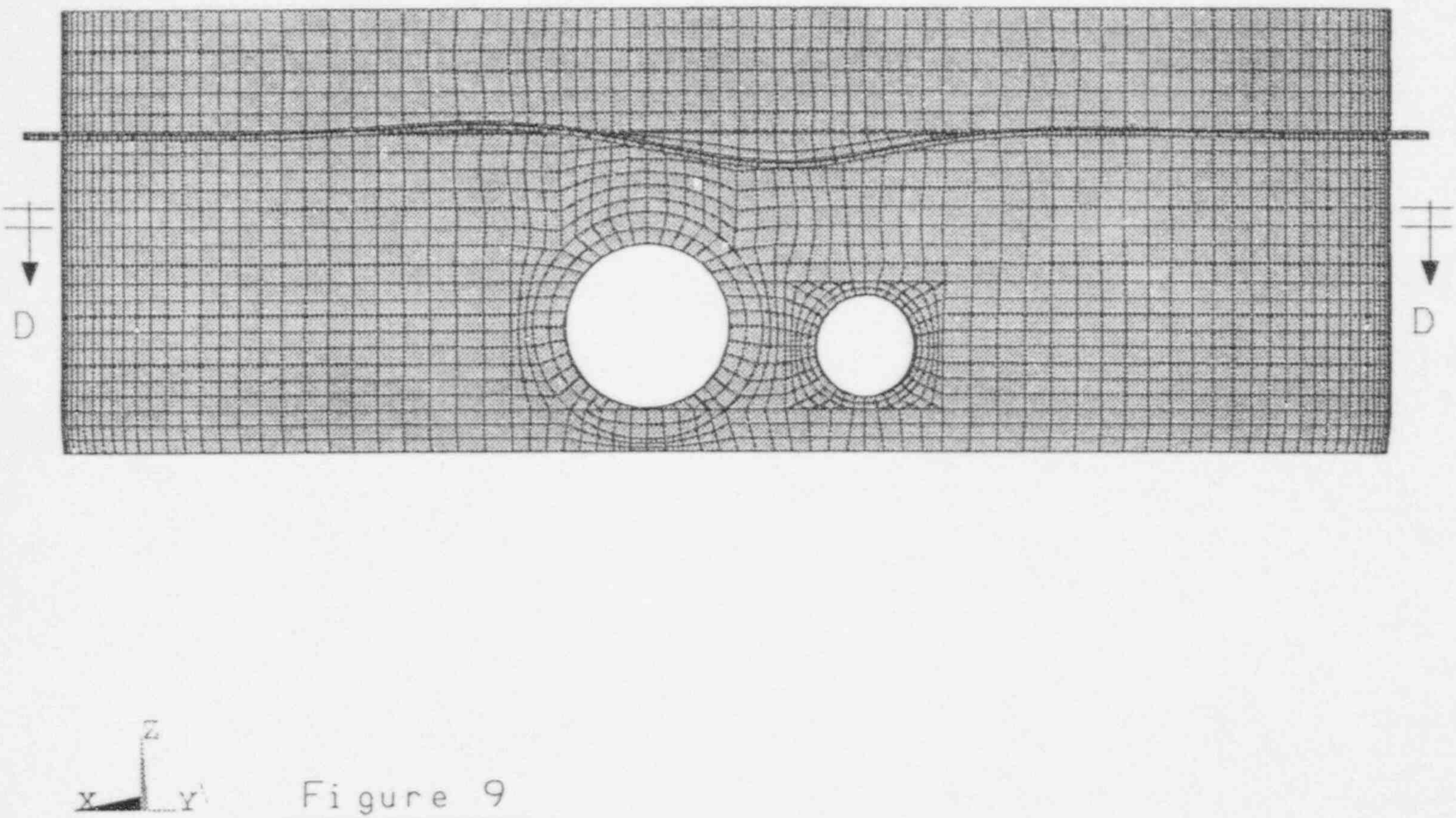
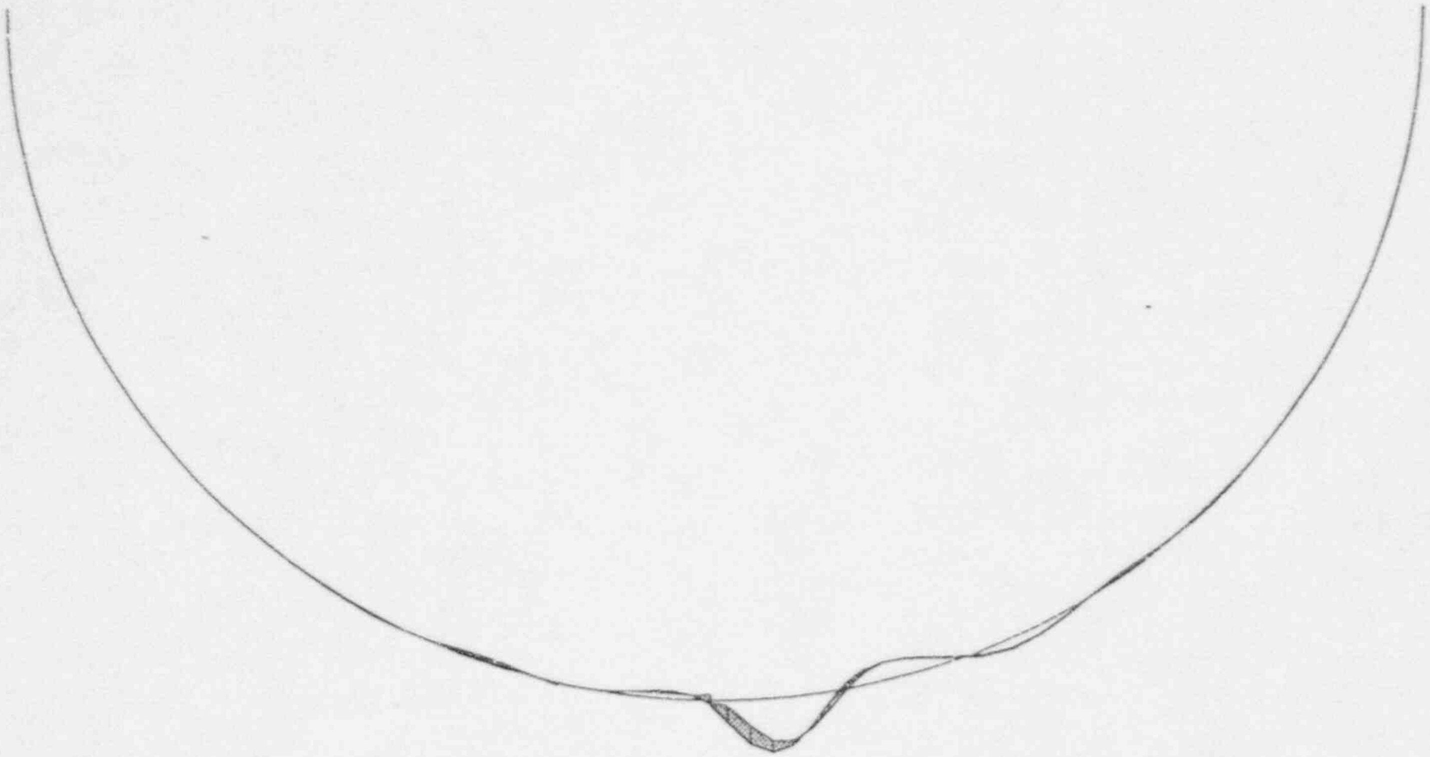


Figure 9

Penetrated Shell w/ 10 ksi Axial Load



ANSYS 5.1
AUG 24 1995
09:32:37
PLOT NO. 2
DISPLACEMENT
STEP=1
SUB =1
FACT=3.58
RSYS=1
DMX =1

*DSCA=60
XV =-.688E-16
YV =-.274E-16
ZV =1
*DIST=856.516
*XF =231.199
*YF =401.258
*ZF =217.391
A-ZS=-150
CENTROID HIDDEN

Section D-D

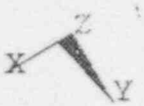


Figure 10

Penetrated Shell w/ 10 ksi Axial Load

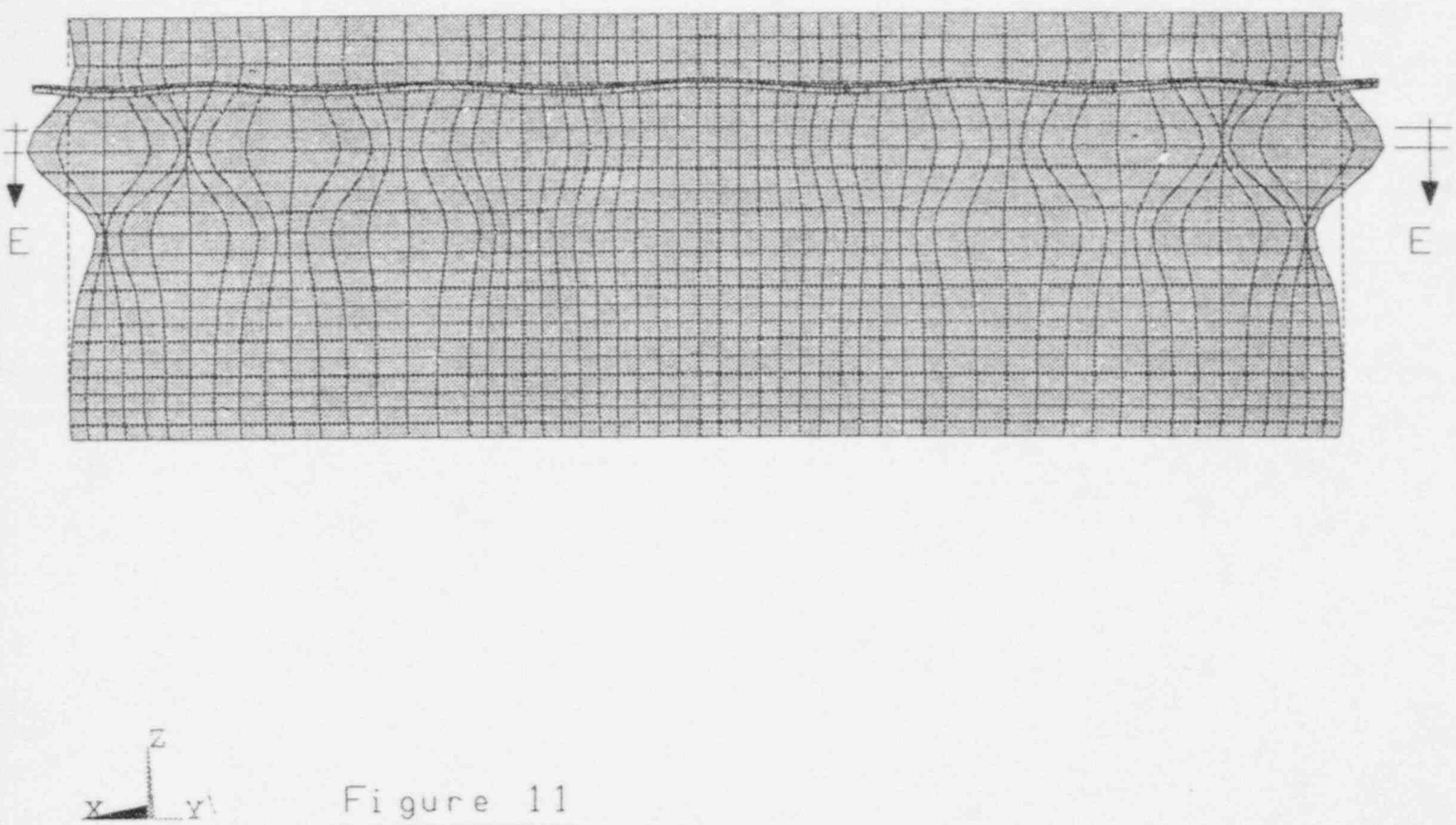
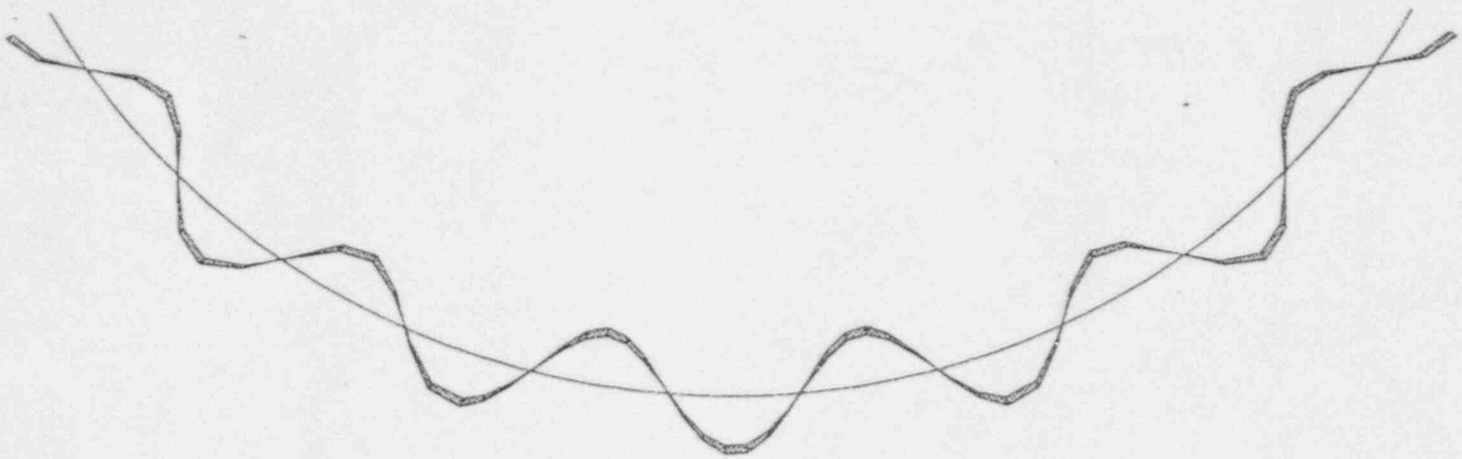


Figure 11

Unpenetrated Shell w/ 10 ksi Axial Load



Section E-E

Figure 12

Unpenetrated Shell w/ 10 ksi Axial Load

PRELIMINARY

AP600

CONTAINMENT VESSEL DESIGN REPORT

AP600 DOCUMENT NO.: MV50 S3R 005, REV. 0, AUGUST 30, 1995

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	DATE / DATE	DATE	DATE	

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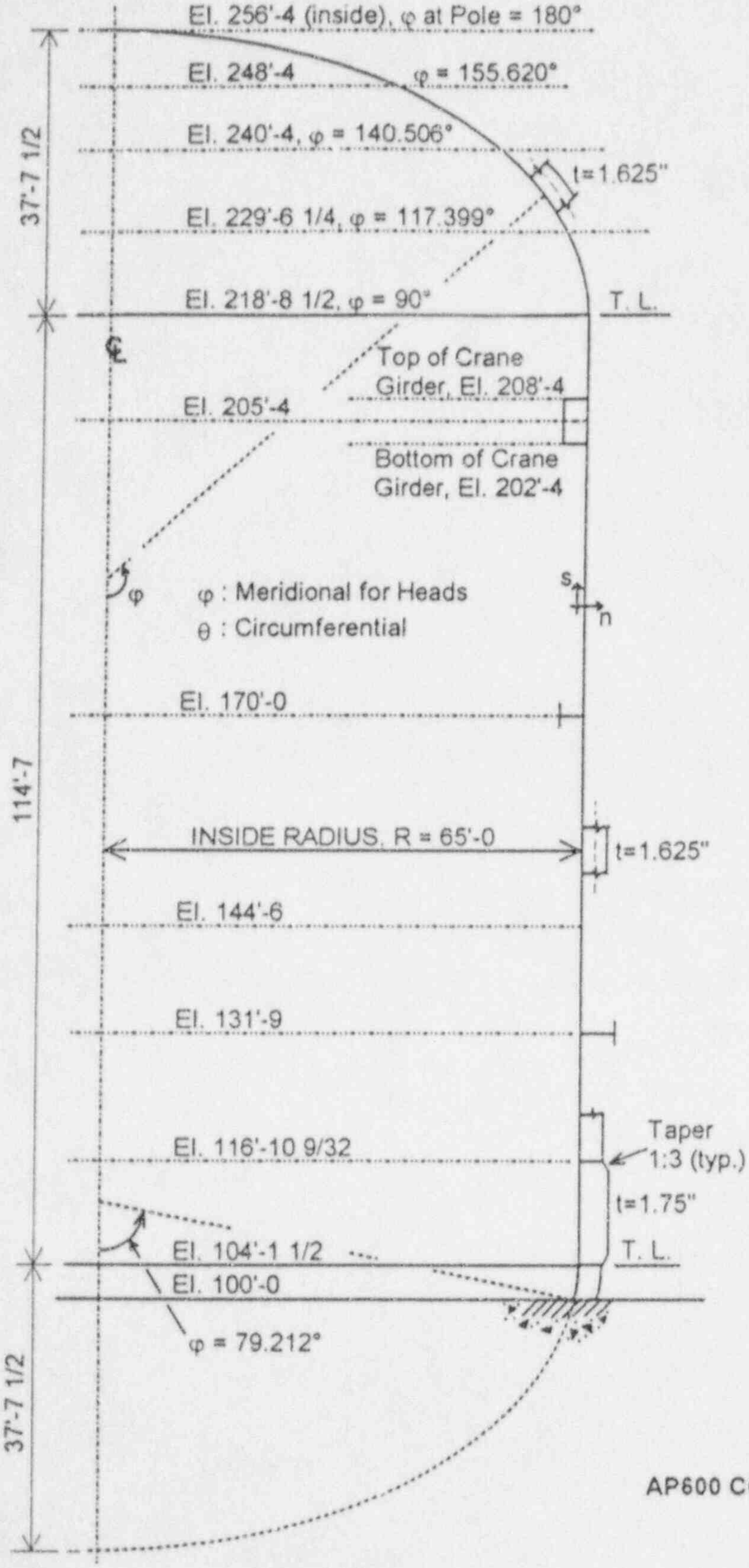


FIGURE 1

AP600 CONTAINMENT VESSEL

PRELIMINARY

TABLE 6A: SUMMARY OF MEMBRANE STRESSES AT EL. 144'-6

σ_φ, σ_θ, $\tau_{\varphi\theta}$: Meridional, circumferential, tangential shear stress, respectively. Stresses are in ksi.

Load Description	ID	σ_φ	σ_θ	$\tau_{\varphi\theta}$	Stress Type	Ref. Calc.
DL 'CV + Polar Crane Parked' (at $\theta_L = 0°$)[a]	DP	-0.81	0.00	0.00	P_M	G.7A
Design internal pressure (45 psig)	P_i	10.80	21.60	0.00	P_M	G.3
Design external pressure (3 psig, scaled from P_i)	P_e	-0.72	-1.44	0.00	P_M	$\propto P_i$
'+' Operating pressure (1 psig, scaled from P_i)	P_{+o}	0.24	0.48	0.00	P_M	$\propto P_i$
'-' Oper. pressure (-0.2 psig, scaled from P_i)	P_{-o}	-0.05	-0.10	0.00	P_M	$\propto P_i$
Axisymmetric operating thermal load (at $\theta = 180°$)	T_o	0.00	0.00	0.00	$P_M + Q$	G.4
Axisymmetric design thermal load (at $\theta = 180°$)	T_a	0.00	0.00	0.00	$P_M + Q$	G.4
Wind load	W	0.19	0.46	0.00	P_M	G.6
Tornado differential pressure load	W_t	0.66	1.51	0.00	P_M	G.6
SSE 'CV + Polar Crane Parked' Combinations[a]:						
W4R3 in Table 5B of G.7B	$\pm E_sP1$	-1.53	0.29	0.45	P_M	G.7B
W5R6 in Table 5B of G.7B	$\pm E_sP2$	1.53	-0.29	-0.45	P_M	G.7B
W3T3 in Table 5A of G.7B	$\pm E_sP3$	-0.73	0.1	1.33	P_M	G.7B

LC No.	Load Combination (LC)	σ_φ	σ_θ	$\tau_{\varphi\theta}$	Stress Type	Condition
D1.1	$DP + P_i + T_a$	9.99	21.60	0.00	$P_M + Q$	Design
D1.2	$DP + P_i$	9.99	21.60	0.00	P_M	Design
D1.3	$DP + T_a$	-0.81	0.00	0.00	$P_M + Q$	Design
D2.0	$DP + P_e + T_o$	-1.53	-1.44	0.00	P_M	Design
LA1.1	$DP + P_i + T_a$ (Same as D1.1)	9.99	21.60	0.00	$P_M + Q$	Level A
LA1.2	$DP + P_i$ (Same as D1.2)	9.99	21.60	0.00	P_M	Level A
LA1.3	$DP + T_a$ (Same as D1.3)	-0.81	0.00	0.00	$P_M + Q$	Level A
LA2.0	$DP + P_e + T_o$ (Same as D2.0)	-1.53	-1.44	0.00	P_M	Level A
LA3.1	$DP + W + P_{+o} + T_o$	-0.38	0.94	0.00	P_M	Level A
LA3.2	$DP - W + P_{-o} + T_o$	-1.05	-0.56	0.00	P_M	Level A
LC1.1.1	$DP + P_i + T_a + E_sP1$ (=LA1.1 + E_sP1)	8.46	21.89	0.45	$P_M + Q$	Level C
LC1.2.1	$DP + P_i - E_sP1$ (=LA1.2 - E_sP1)	8.46	21.89	0.45	P_M	Level C
LC1.3 1	$DP + T_a + E_sP1$ (=LA1.3 + E_sP1)	-2.34	0.29	0.45	$P_M + Q$	Level C
LC2.0.1	$DP + P_e + T_o + E_sP1$ (=LA2.0 + E_sP1)	-3.06	-1.15	0.45	P_M	Level C
LC3.1	$DP + W_t + P_{+o} + T_o$	0.09	1.99	0.00	P_M	Level C
LC3 2	$DP - W_t + P_{-o} + T_o$	-1.52	-1.61	0.00	P_M	Level C
LC2.0.2	$DP + P_e + T_o + E_sP2$ (=LA2.0 + E_sP2)	0.00	-1.73	-0.45	P_M	Level C
LC2.0.3	$DP + P_e + T_o + E_sP3$ (=LA2.0 + E_sP3)	-2.26	-1.34	1.33	P_M	Level C

[a]Stresses due to eccentricity of masses are not included.

PRELIMINARY

TABLE 6B: MEMBRANE STRESS INTENSITY EVALUATION AT EL. 144'-6

Allowable Stresses, σ_A:

Design and Level A Service Stress Intensity Limit for Local membrane, P_M = $1.0S_{mc}$ = 22.00 ksi

Level C Service Stress Intensity Limit for Local membrane, P_M = $1.0S_y$ = 52.76 ksi

$P_M + Q$ = Not Applicable (NA). (Evaluation required only for $P_L + P_b + Q$.)

σ_φ, σ_θ, $\tau_{\varphi\theta}$: Meridional, circumferential, tangential shear stress, respectively.

Principal Stresses

$\sigma_1 = 0.5 \times (\sigma_\varphi + \sigma_\theta) + 0.5 \times \mathrm{sqrt}[(\sigma_\varphi - \sigma_\theta)^2 + 4 \times (\tau_{\varphi\theta})^2]$,

$\sigma_2 = 0.5 \times (\sigma_\varphi + \sigma_\theta) - 0.5 \times \mathrm{sqrt}[(\sigma_\varphi - \sigma_\theta)^2 + 4 \times (\tau_{\varphi\theta})^2]$,

$\sigma_3 = 0$.

Stress intensity, σ_{INT} = Maximum of absolute of: $(\sigma_1 - \sigma_2)$, $(\sigma_2 - \sigma_3)$, and $(\sigma_3 - \sigma_1)$

Stresses are in ksi.

LC No.	Condition	Stress Type	σ_φ	σ_θ	$\tau_{\varphi\theta}$	σ_1	σ_2	σ_{INT}	σ_A	Status
D1.1	Design	$P_M + Q$	9.99	21.60	0.00	21.60	9.99	21.60	NA	NA
D1.2	Design	P_M	9.99	21.60	0.00	21.60	9.99	21.60	22.00	OK
D1.3	Design	$P_M + Q$	-0.81	0.00	0.00	0.00	-0.81	0.81	NA	NA
D2.0	Design	P_M	-1.53	-1.44	0.00	-1.44	-1.53	1.53	22.00	OK
LA1.1	Level A	$P_M + Q$	9.99	21.60	0.00	21.60	9.99	21.60	NA	NA
LA1.2	Level A	P_M	9.99	21.60	0.00	21.60	9.99	21.60	22.00	OK
LA1.3	Level A	$P_M + Q$	-0.81	0.00	0.00	0.00	-0.81	0.81	NA	NA
LA2.0	Level A	P_M	-1.53	-1.44	0.00	-1.44	-1.53	1.53	22.00	OK
LA3.1	Level A	P_M	-0.38	0.94	0.00	0.94	-0.38	1.32	22.00	OK
LC1.1.1	Level C	$P_M + Q$	8.46	21.89	0.45	21.91	8.44	21.91	NA	NA
LC1.2.1	Level C	P_M	8.46	21.89	0.45	21.91	8.44	21.91	52.76	OK
LC1.3.1	Level C	$P_M + Q$	-2.34	0.29	0.45	0.36	-2.41	2.78	NA	NA
LC2.0.1	Level C	P_M	-3.06	-1.15	0.45	-1.05	-3.16	3.16	52.76	OK
LC3.1	Level C	P_M	0.09	1.99	0.00	1.99	0.09	1.99	52.76	OK
LC2.0.2	Level C	P_M	0.00	-1.73	-0.45	0.11	-1.84	1.95	52.76	OK
LC2.0.3	Level C	P_M	-2.26	-1.34	1.33	-0.39	-3.21	3.21	52.76	OK

PRELIMINARY

TABLE 6C: MEMBRANE STRESS BUCKLING EVALUATION AT EL. 144'-6

σ_φ, σ_θ, $\tau_{\varphi\theta}$: Meridional, circumferential, tangential shear stress, respectively.

Design and Level A Service Allowable Compressive Stresses based on N-284: (in ksi)

$\sigma_{xA} = 4.51$, $\sigma_{rA} = 1.86$ $\sigma_{hA} = 1.78$ $\sigma_{\tau A} = 4.59$

Level C Service Allowable Compressive Stresses based on N-284 (1.2 times the above): (in ksi)

$\sigma_{xA} = 5.41$ $\sigma_{rA} = 2.23$ $\sigma_{hA} = 2.14$ $\sigma_{\tau A} = 5.51$

Factors defined in N-284 as: $K = \sigma_\varphi / \sigma_\theta$ and $K_s = 1 - (\tau_{\varphi\theta} / \sigma_{\tau A})^2$

Interaction Equations:

Axial Compression Plus Hoop Compression

If $K < 0.5$, $IEV = \sigma_\theta / [\, \sigma_{ra} - 2^*\sigma_x{}^*\{\, \sigma_{rA} / \sigma_{hA} - 1 \,\}] \le IEVA = 1.0$ (a)

If $K > 0.5$, $IEV = [\, \sigma_\varphi - 0.5^*\sigma_{ha} \,] / [\sigma_{xA} - 0.5^*\sigma_{hA} \,] + (\, \sigma_\theta / \sigma_{hA} \,)^2 \le IEVA = 1.0$ (b)

Axial Compression Plus Shear

$IEV = \sigma_\varphi / \sigma_{xA} + (\, \tau_{\varphi\theta} / \sigma_{\tau A} \,)^2 \le IEVA = 1.0$ (c)

Hoop Compression Plus Shear

$IEV = \sigma_\theta / \sigma_{rA} + (\, \tau_{\varphi\theta} / \sigma_{\tau A} \,)^2 \le IEVA = 1.0$ (d)

Axial Compression Plus Hoop Compression Plus Shear

Substitute $K_s\,\sigma_{xA}$, $K_s\,\sigma_{rA}$, and $K_s\,\sigma_{hA}$ for σ_{xA}, σ_{rA}, and σ_{hA}, respectively, in the first two equations above.

Stresses are in ksi.

LC No.	Condition	σ_φ	σ_θ	$\tau_{\varphi\theta}$	K	K_s	IEV	IEVA	Status	Equation
D1.1	Design	9.99	21.60	0.00	NA	1.00	0.00	1.00	OK	σ's in tension
D1.2	Design	9.99	21.60	0.00	NA	1.00	0.00	1.00	OK	σ's in tension
D1.3	Design	-0.81	0.00	0.00	NA	1.00	0.18	1.00	OK	(c)
D2.0	Design	-1.53	-1.44	0.00	1.06	1.00	0.83	1.00	OK	(b)
LA1.1	Level A	9.99	21.60	0.00	NA	1.00	0.00	1.00	OK	σ's in tension
LA1.2	Level A	9.99	21.60	0.00	NA	1.00	0.00	1.00	OK	σ's in tension
LA1.3	Level A	-0.81	0.00	0.00	NA	1.00	0.18	1.00	OK	[illegible]
LA2.0	Level A	-1.53	-1.44	0.00	1.06	1.00	0.83	1.00	OK	(b)
LA3.1	Level A	-0.38	0.94	0.00	NA	1.00	0.08	1.00	OK	(c)
LC1.1.1	Level C	8.46	21.89	0.45	NA	0.99	0.08	1.00	OK	$\tau_{\varphi\theta} < \sigma_{\tau A}$
LC1.2.1	Level C	8.46	21.89	0.45	NA	0.99	0.08	1.00	OK	$\tau_{\varphi\theta} < \sigma_{\tau A}$
LC1.3.1	Level C	-2.34	0.29	0.45	NA	0.99	0.44	1.00	OK	(c)
LC2.0.1	Level C	-3.06	-1.15	0.45	2.66	0.99	0.76	1.00	OK	(c)
LC3.1	Level C	0.09	1.99	0.00	NA	1.00	0.00	1.00	OK	σ's in tension
LC2.0.2	Level C	0.00	-1.73	-0.45	0.00	0.99	0.78	1.00	OK	(d)
LC2.0.3	Level C	-2.26	-1.34	1.33	1.69	0.94	0.75	1.00	OK	(b)

TABLE 3A: SUMMARY OF MEMBRANE STRESSES AT EL. 100'-0 (BASE)

σ_φ, σ_θ, $\tau_{\varphi\theta}$: Meridional, circumferential, tangential shear stress, respectively. Stresses are in ksi.

Load Description	ID	σ_φ	σ_θ	$\tau_{\varphi\theta}$	Stress Type	Ref. Calc.
DL 'CV + Polar Crane Parked' (at θ_L = 0°)[a]	DP	-0.91	-0.27	0.00	P_L	G.7A
Design internal pressure (45 psig)	P_i	10.83	3.25	0.00	P_L	G.3
Design external pressure (3 psig, scaled from P_i)	P_e	-0.72	-0.22	0.00	P_L	$\propto P_i$
'+' Operating pressure (1 psig, scaled from P_i)	P_{+o}	0.24	0.07	0.00	P_L	$\propto P_i$
'-' Oper. pressure (-0.2 psig, scaled from P_i)	P_{-o}	-0.05	-0.01	0.00	P_L	$\propto P_i$
Axisymmetric operating thermal load (at θ = 180°)	T_o	0.00	0.00	0.00	$P_L + Q$	G.4
Axisymmetric design thermal load (at θ = 180°)	T_a	0.30	-36.90	0.00	$P_L + Q$	G.4
Wind load	W	0.31	0.09	0.00	P_L	G.6
Tornado differential pressure load	W_t	0.94	0.28	0.00	P_L	G.6
SSE 'CV + Polar Crane Parked' Combinations[a]:						
W3R4 in Table 3C of G.7B	$\pm E_sP1$	-2.99	-0.90	-0.57	P_L	G.7B
N3R3 in Table 3A of G.7B	$\pm E_sP2$	-2.66	-0.8	0.66	P_L	G.7B
W3T3 in Table 3A of G.7B	$\pm E_sP3$	-1.24	-0.37	1.65	P_L	G.7B

LC No.	Load Combination (LC)	σ_φ	σ_θ	$\tau_{\varphi\theta}$	Stress Type	Condition
D1.1	$DP + P_i + T_a$	10.22	-33.92	0.00	$P_L + Q$	Design
D1.2	$DP + P_i$	9.92	2.98	0.00	P_L	Design
D1.3	$DP + T_a$	-0.61	-37.17	0.00	$P_L + Q$	Design
D2.0	$DP + P_e + T_o$	-1.63	-0.49	0.00	P_L	Design
LA1.1	$DP + P_i + T_a$ (Same as D1.1)	10.22	-33.92	0.00	$P_L + Q$	Level A
LA1.2	$DP + P_i$ (Same as D1.2)	9.92	2.98	0.00	P_L	Level A
LA1.3	$DP + T_a$ (Same as D1.3)	-0.61	-37.17	0.00	$P_L + Q$	Level A
LA2.0	$DP + P_e + T_o$ (Same as D2.0)	-1.63	-0.49	0.00	P_L	Level A
LA3.1	$DP + W + P_{+o} + T_o$	-0.36	-0.11	0.00	P_L	Level A
LC1.1.1	$DP + P_i + T_a + E_sP1$ (=LA1.1 + E_sP1)	7.23	-34.82	-0.57	$P_L + Q$	Level C
LC1.2.1	$DP + P_i - E_sP1$ (=LA1.2 - E_sP1)	12.91	3.88	0.57	P_L	Level C
LC1.3.1	$DP + T_a + E_sP1$ (=LA1.3 + E_sP1)	-3.60	-38.07	-0.57	$P_L + Q$	Level C
LC2.0.1	$DP + P_e + T_o + E_sP1$ (=LA2.0 + E_sP1)	-4.62	-1.39	-0.57	P_L	Level C
LC3.1	$DP + W_t + P_{+o} + T_o$	0.27	0.08	0.00	P_L	Level C
LC2.0.2	$DP + P_e + T_o + E_sP2$ (=LA2.0 + E_sP2)	-4.29	-1.29	0.66	P_L	Level C
LC2.0.3	$DP + P_e + T_o + E_sP3$ (=LA2.0 + E_sP3)	-2.87	-0.86	1.65	P_L	Level C

[a]Stresses due to eccentricity of masses are not included.

PRELIMINARY

TABLE 3E: INSIDE SURFACE STRESS INTENSITY EVALUATION AT EL. 100'-0 (BASE)

Allowable Stresses, σ_A:

Design and Level A Service Stress Intensity Limit for Local membrane, P_L = $1.5S_{mc}$ = 33.00 ksi

Level C Service Stress Intensity Limit for Local membrane, P_L = $1.5S_y$ = 79.14 ksi

$P_L + Q$ = Not Applicable (NA). (Evaluation required only for $P_L + P_b + Q$.)

σ_φ, σ_θ, $\tau_{\varphi\theta}$: Meridional, circumferential, tangential shear stress, respectively.

Principal Stresses

$\sigma_1 = 0.5 \times (\sigma_\varphi + \sigma_\theta) + 0.5 \times \text{sqrt}[(\sigma_\varphi - \sigma_\theta)^2 + 4 \times (\tau_{\varphi\theta})^2]$,

$\sigma_2 = 0.5 \times (\sigma_\varphi + \sigma_\theta) - 0.5 \times \text{sqrt}[(\sigma_\varphi - \sigma_\theta)^2 + 4 \times (\tau_{\varphi\theta})^2]$,

$\sigma_3 = 0$.

Stress intensity, σ_{INT} = Maximum of absolute of: $(\sigma_1 - \sigma_2)$, $(\sigma_2 - \sigma_3)$, and $(\sigma_3 - \sigma_1)$

Stresses are in ksi.

LC No.	Condition	Stress Type	σ_φ	σ_θ	$\tau_{\varphi\theta}$	σ_1	σ_2	σ_{INT}	σ_A	Status
D1.1	Design	$P_L + P_b + Q$	64.81	-17.51	0.00	64.81	-17.51	82.32	NR	
D1.2	Design	$P_L + P_b$	-2.39	-0.71	0.00	-0.71	-2.39	2.39	33.00	OK
D1.3	Design	$P_L + P_b + Q$	71.02	-15.65	0.00	71.02	-15.65	86.67	NR	
D2.0	Design	$P_L + P_b$	4.23	1.27	0.00	4.23	1.27	4.23	33.00	OK
LA1.1	Level A	$P_L + P_b + Q$	64.81	-17.51	0.00	64.81	-17.51	82.32	80.00	Not OK
LA1.2	Level A	$P_L + P_b$	-2.39	-0.71	0.00	-0.71	-2.39	2.39	33.00	OK
LA1.3	Level A	$P_L + P_b + Q$	71.02	-15.65	0.00	71.02	-15.65	86.67	80.00	Not OK
LA2.0	Level A	$P_L + P_b$	4.23	1.27	0.00	4.23	1.27	4.23	33.00	OK
LA3.1	Level A	$P_L + P_b$	4.97	1.50	0.05	4.97	1.50	4.97	33.00	OK
LC1.1.1	Level C	$P_L + P_b + Q$	77.57	-13.68	-0.57	77.57	-13.68	91.26	NR	
LC1.2.1	Level C	$P_L + P_b$	-15.15	-4.54	0.57	-4.51	-15.18	15.18	79.14	OK
LC1.3.1	Level C	$P_L + P_b + Q$	83.78	-11.82	-0.57	83.78	-11.82	95.61	NR	
LC2.0.1	Level C	$P_L + P_b$	16.99	5.10	-0.57	17.02	5.08	17.02	79.14	OK
LC3.1	Level C	$P_L + P_b$	7.65	2.30	0.11	7.65	2.30	7.65	79.14	OK
LC2.0.2	Level C	$P_L + P_b$	15.57	4.67	0.66	15.61	4.63	15.61	79.14	OK
LC2.0.3	Level C	$P_L + P_b$	9.52	2.86	1.65	9.91	2.48	9.91	79.14	OK

PRELIMINARY

TABLE 3C: MEMBRANE STRESS BUCKLING EVALUATION AT EL. 100'-0 (BASE)

σ_{φ}, σ_{θ}, $\tau_{\varphi\theta}$: Meridional, circumferential, tangential shear stress, respectively.

Principal Stresses

$\sigma_1 = 0.5 \times (\sigma_{\varphi} + \sigma_{\theta}) + 0.5 \times \text{sqrt}[(\sigma_{\varphi} - \sigma_{\theta})^2 + 4 \times (\tau_{\varphi\theta})^2]$,

$\sigma_2 = 0.5 \times (\sigma_{\varphi} + \sigma_{\theta}) - 0.5 \times \text{sqrt}[(\sigma_{\varphi} - \sigma_{\theta})^2 + 4 \times (\tau_{\varphi\theta})^2]$,

$\sigma_3 = 0.$

σ_L = Larger compression of σ_1 and σ_2

σ_S = Smaller Compression of σ_1 and σ_2 (if tension use zero value)

Design and Level A Service Allowable Compressive Stresses based on N-284, FS = 2:

When $\sigma_{\varphi} > \sigma_{\theta}$: σ_{1A} = 3.66 ksi, σ_{2A} = 6.39 ksi.

When $\sigma_{\varphi} < \sigma_{\theta}$: σ_{1A} = 10.67 ksi, σ_{2A} = 2.19 ksi.

Level C Service Allowable Compressive Stresses based, FS = 1.67 (1.2 times the above values):

When $\sigma_{\varphi} > \sigma_{\theta}$: σ_{1A} = 4.39 ksi, σ_{2A} = 7.67 ksi.

When $\sigma_{\varphi} < \sigma_{\theta}$: σ_{1A} = 12.80 ksi, σ_{2A} = 2.63 ksi.

Interaction Equation: $IEV = [(\sigma_L - \sigma_S)/\sigma_{1A}] + [\sigma_S/\sigma_{2A}] \le IEVA = 1.0$

Stresses are in ksi.

LC No.	Condition	σ_1	σ_2	σ_L	σ_S	IEV	IEVA	Status	Remarks
D1.1	Design	10.22	-33.92	-33.92	0.00	BSR5	NA	OK	See Sec. H
D1.2	Design	9.92	2.98	0.00	0.00	0.00	1.00	OK	σ's in tension
D1.3	Design	-0.61	-37.17	-37.17	-0.61	BSR5	NA	OK	See Sec. H
D2.0	Design	-0.49	-1.63	-1.63	-0.49	0.39	1.00	OK	
LA1.1	Level A	10.22	-33.92	-33.92	0.00	BSR5	NA	OK	See Sec. H
LA1.2	Level A	9.92	2.98	0.00	0.00	0.00	1.00	OK	σ's in tension
LA1.3	Level A	-0.61	-37.17	-37.17	-0.61	BSR5	NA	OK	See Sec. H
LA2.0	Level A	-0.49	-1.63	-1.63	-0.49	0.39	1.00	OK	
LA3.1	Level A	-0.11	-0.36	-0.36	-0.11	0.09	1.00	OK	
LC1.1.1	Level C	7.24	-34.83	-34.83	0.00	BSR5	NA	OK	See Sec. H
LC1.2.1	Level C	12.95	3.84	0.00	0.00	0.00	1.00	OK	σ's in tension
LC1.3.1	Level C	-3.59	-38.08	-38.08	-3.59	BSR5	NA	OK	See Sec. H
LC2.0.1	Level C	-1.29	-4.72	-4.72	-1.29	0.95	1.00	OK	
LC3.1	Level C	0.27	0.08	0.00	0.00	0.00	1.00	OK	σ's in tension
LC2.0.2	Level C	-1.15	-4.43	-4.43	-1.15	0.90	1.00	OK	
LC2.0.3	Level C	0.07	-3.80	-3.80	0.00	0.86	1.00	OK	

PRELIMINARY

NRC AND AMES LABORATORY
PRESENTATION MATERIAL
FOR THE MEETING ON THE
AP600 CONTAINMENT VESSEL DESIGN

AUGUST 30 AND 31, 1995

Attachment 6

STRESS AND BUCKLING ANALYSIS OF AP600 STEEL CONTAINMENT VESSEL

Work performed by
Ames Laboratory, ISU
Ames, IA

Presented to:
NRC
Westinghouse
Chicago Bridge & Iron

August 30-31, 1995

AXISYMMETRIC ANALYSIS

a. BOSOR MODEL

b. LOAD COMBINATIONS AS PER S.R.P. 3.8.2

c. LOADS and STRESS ANALYSIS

1. Dead Load
2. External and Internal Pressure
3. Crane Loads
4. Wind and Tornado Loads
5. Temperature
6. Seismic Loads
7. ASME Code Checks

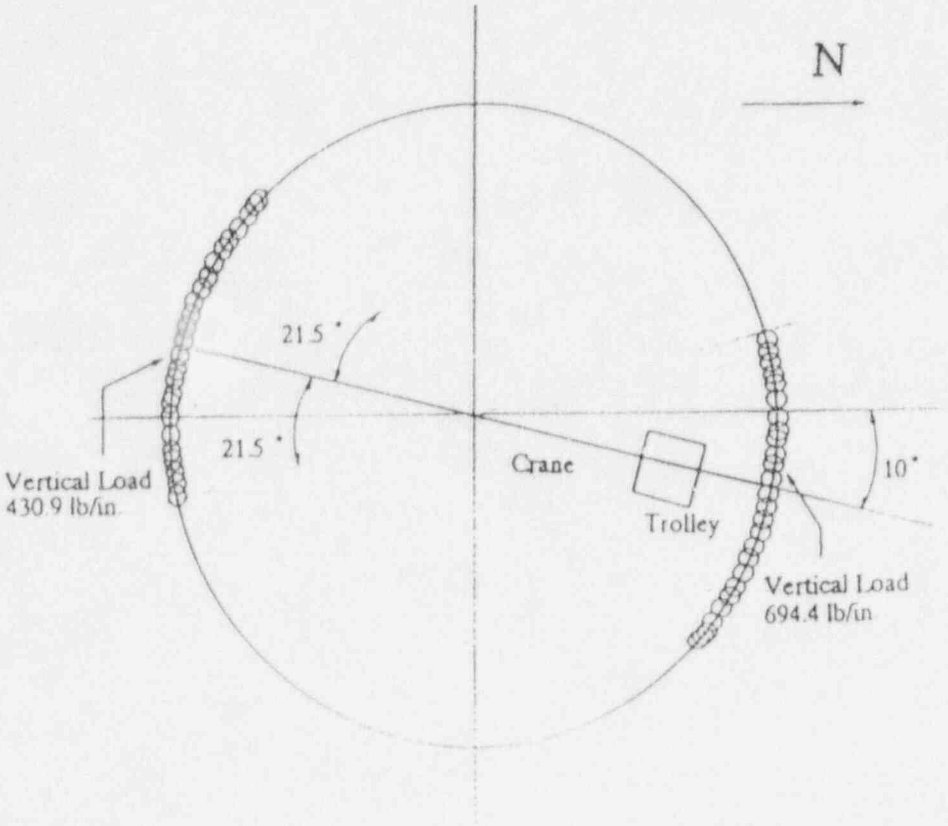
d. BUCKLING ANALYSIS

1. Load Cases as per S.R.P. 3.8.2
2. Seismic Limit Analysis

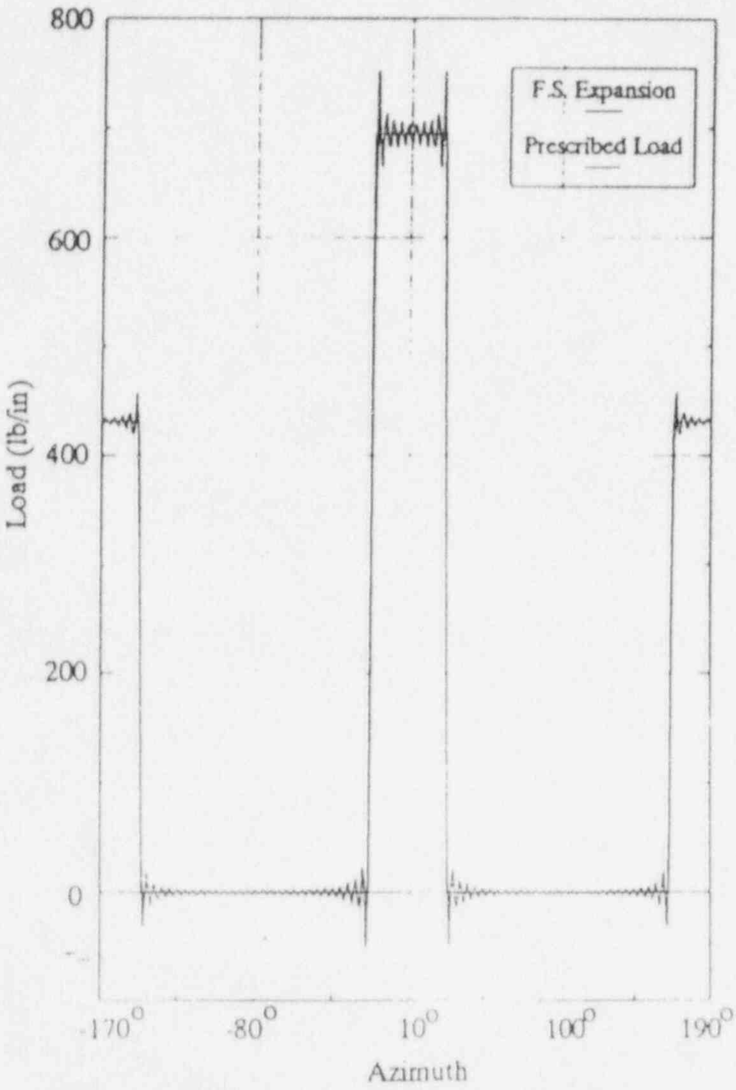
BOSOR MODEL

- STRESS ANALYSIS
  - PERFECT SHELL
  - 25 SHELL SEGMENTS
  - FIXED BASE
- MODAL ANALYSIS
  - PERFECT SHELL
  - MASS OF THE ATTACHMENTS
    a. Air Baffle
    b. Walkways
    c. Cable Trays
    d. Equipment Hatches
    e. Personnel Airlocks
    f. HVAC Ducts
    g. Containment Recirculation Unit
    h. Crane D.L.

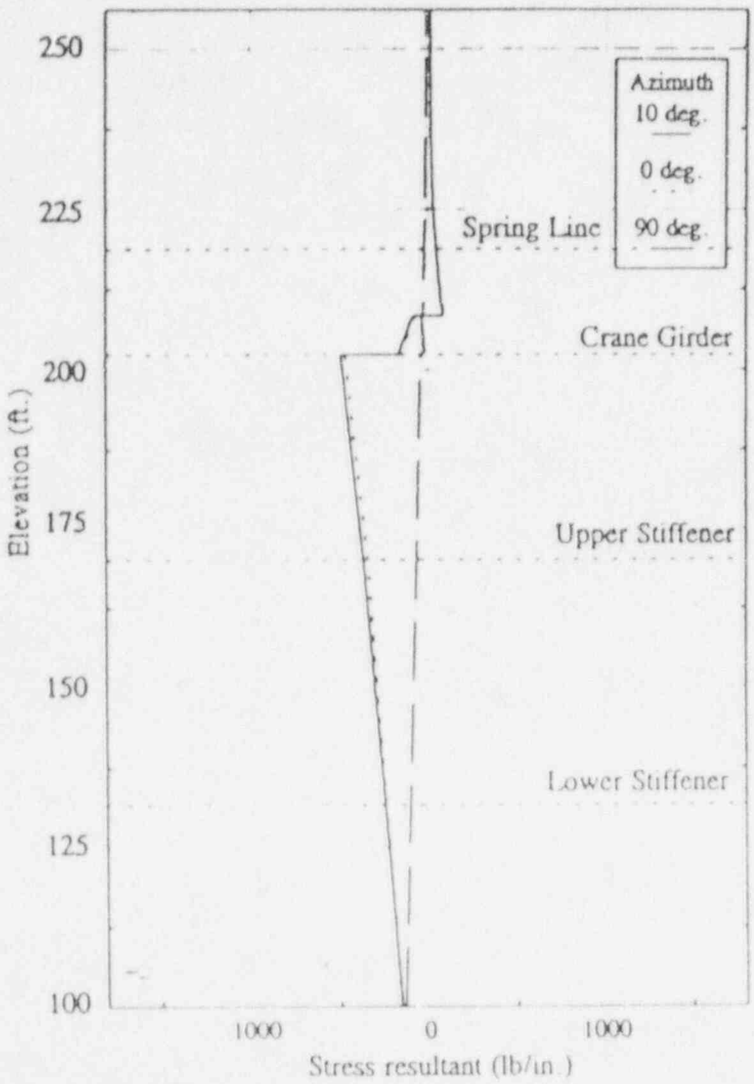
Plan View Of The Containment with Trolley Parked For Plant Operating Condition.



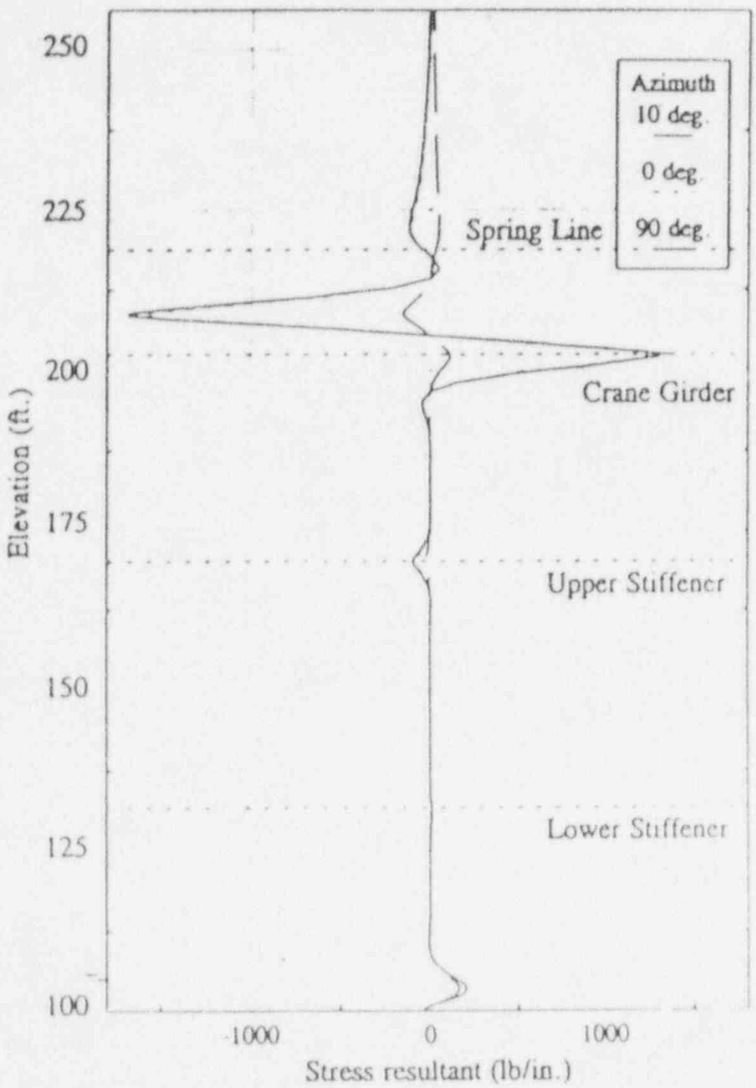
Comparison Of The Prescribed Crane Loading and Fourier Series (F.S.) Expansion.



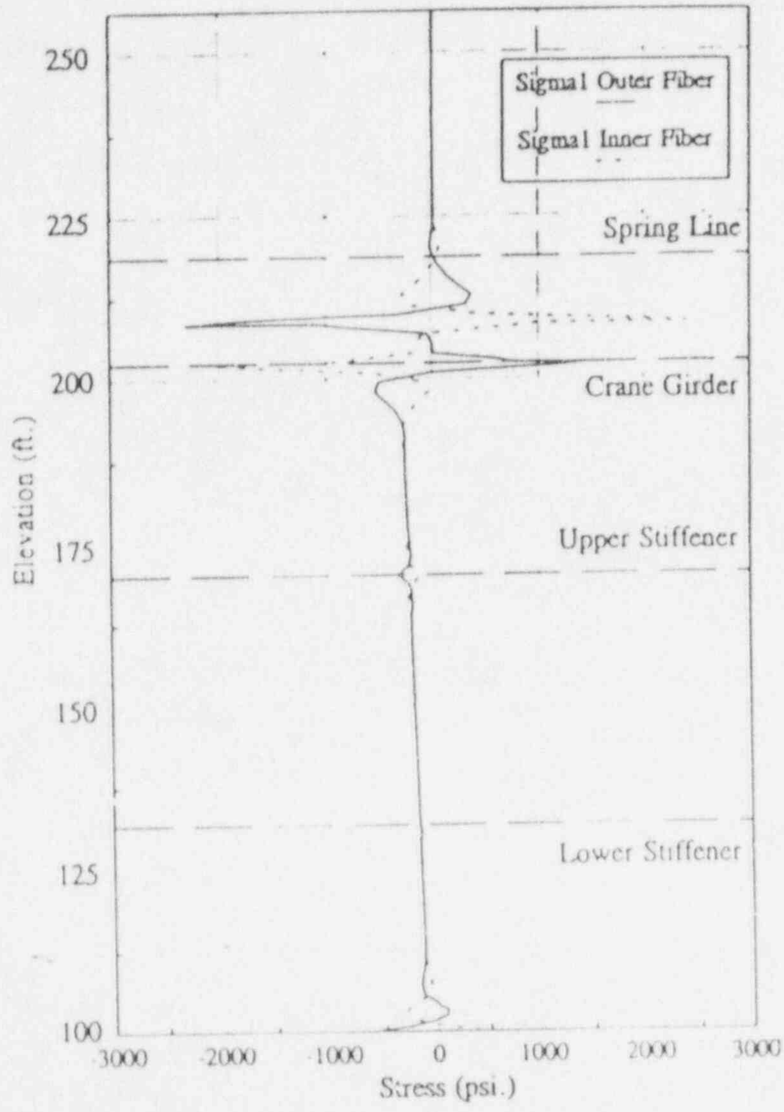
Comparison Of Meridional (N_1) Stress Resultants Due To Crane Dead Load.



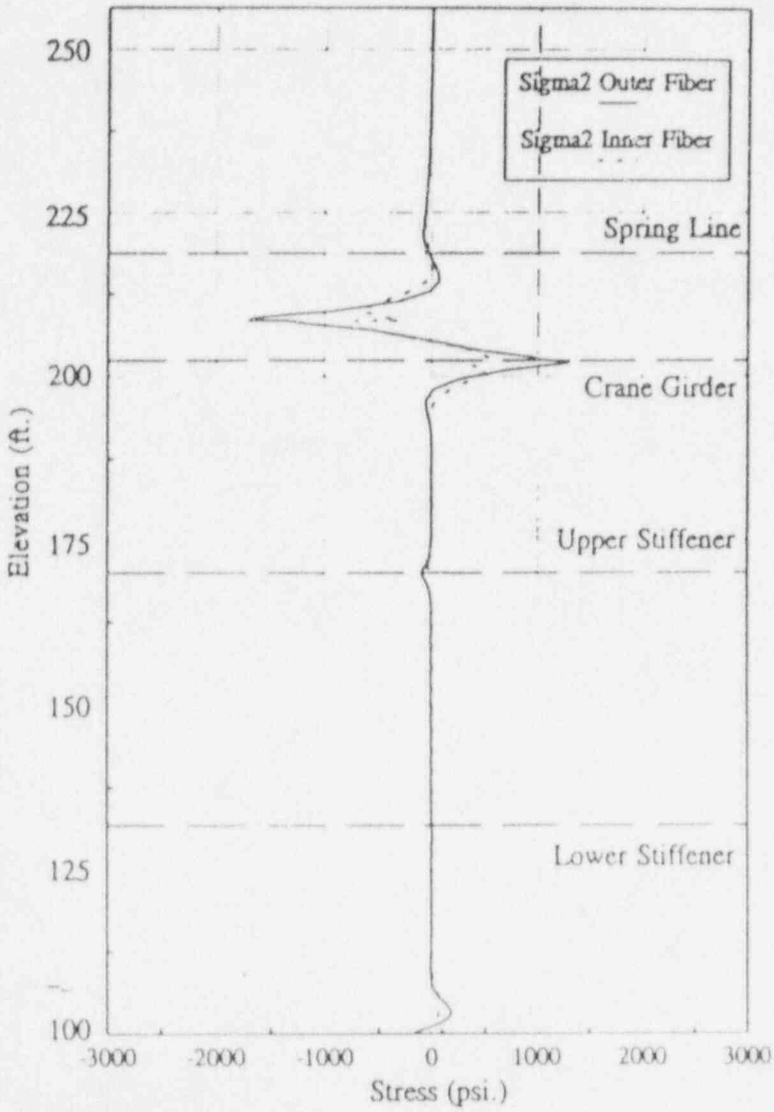
Comparison Of Circumferential (N_2) Stress Resultants Due To Crane Dead Load.



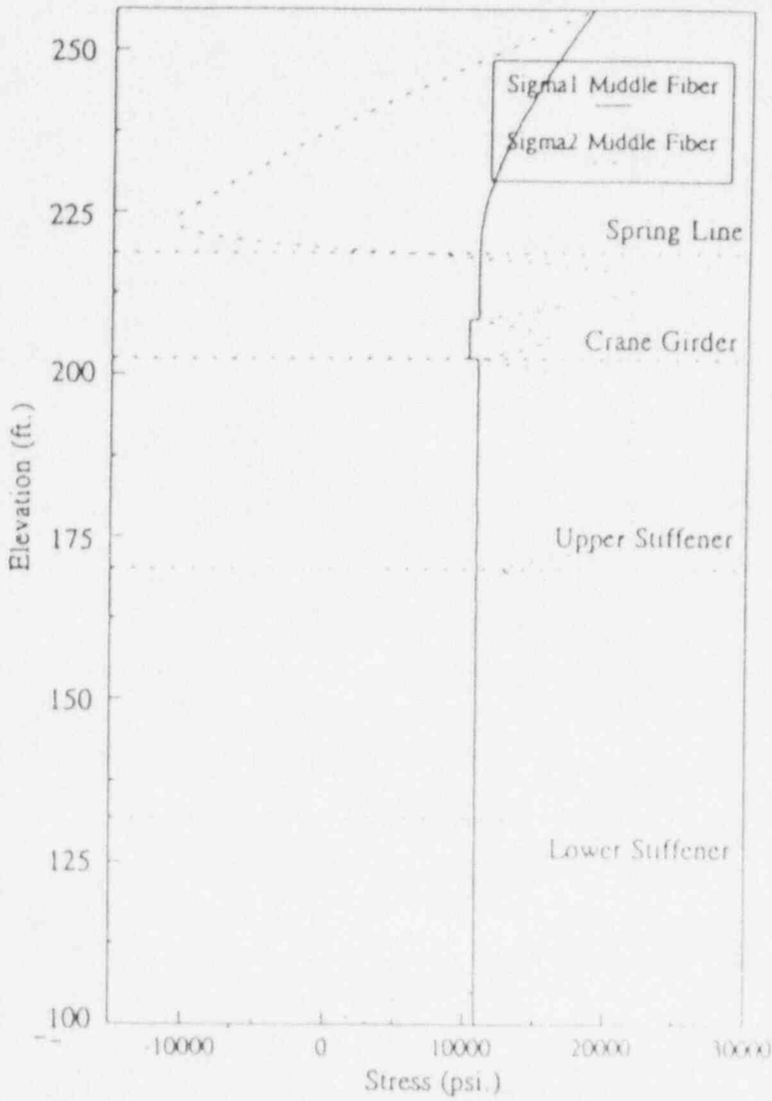
Extreme Fiber Meridional ($Sigma_1$) Stresses Due To Crane Dead Load.



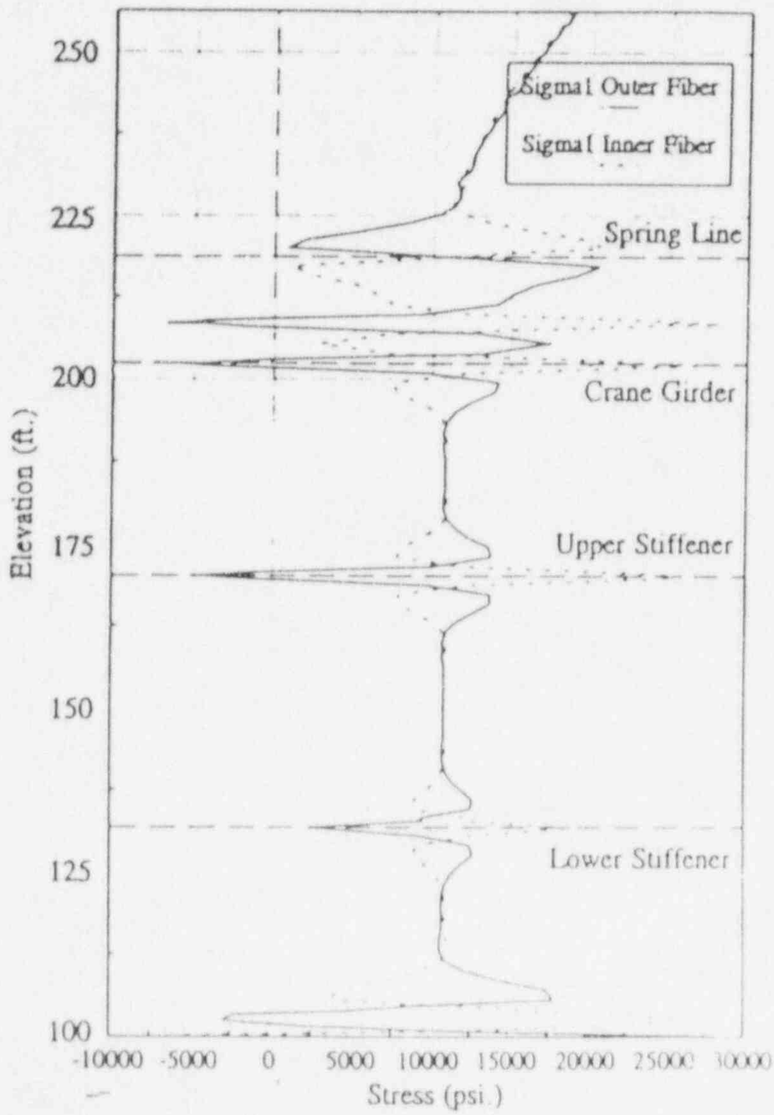
Extreme Fiber Circumferential ($Sigma_2$) Stresses Due To Crane Dead Load.



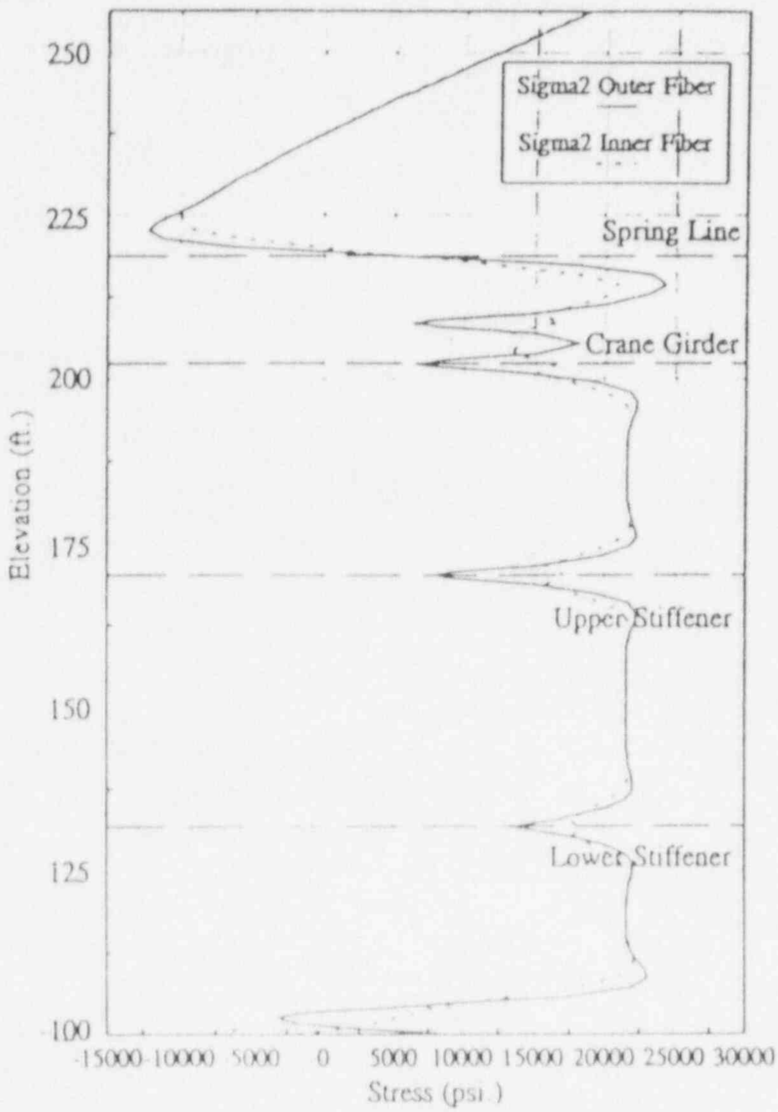
Meridional ($Sigma_1$) and Circumferential ($Sigma_2$) Stresses Internal Pressure = 45 psig



Extreme Fiber Meridional ($Sigma_1$) Stresses
Internal Pressure of 45 psig



Extreme Fiber Circumferential ($Sigma_2$) Stresses
Internal Pressure of 45 psig



TEMPERATURE LOADS ON THE CONTAINMENT

Shell Temperature

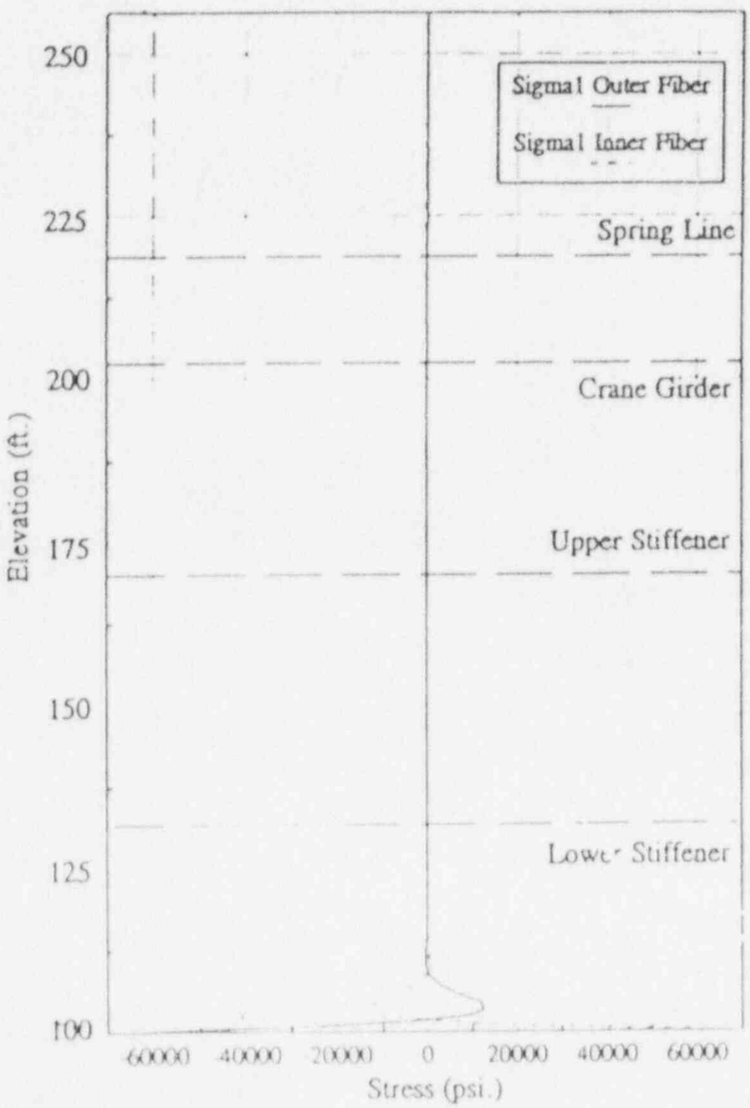
- Case 1: Uniform Temperature 280°F
- Case 2: Striping Case (a)
- Case 3: Striping Case (b)

*<u>References:</u>

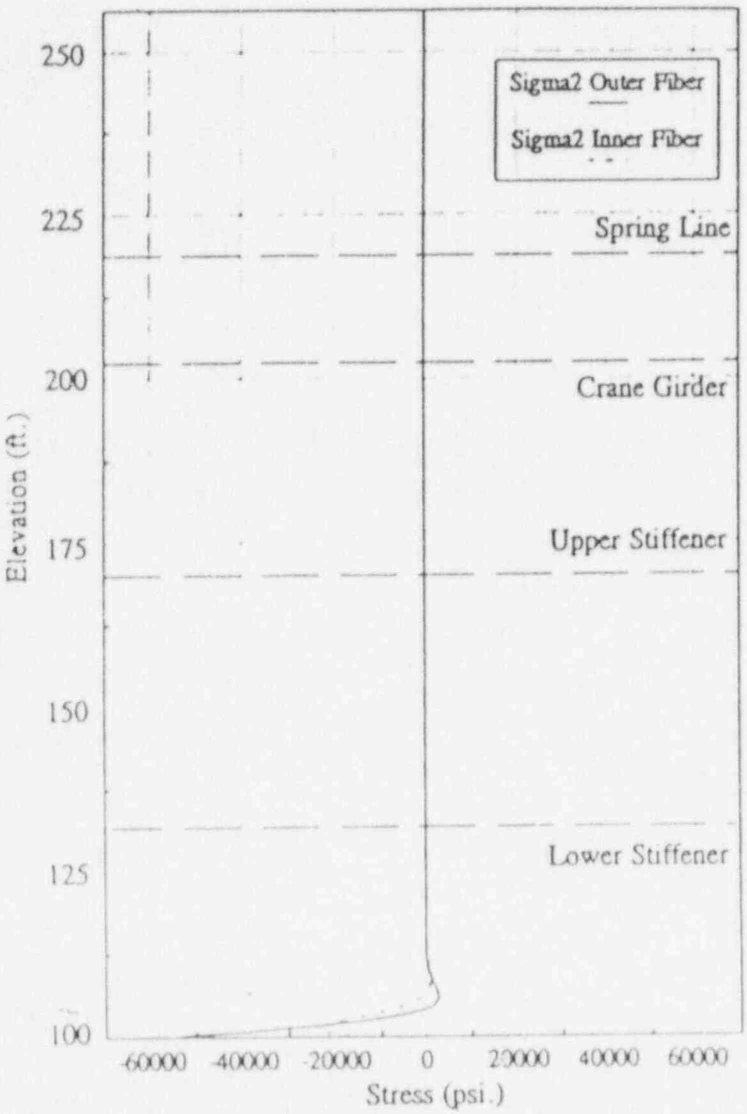
Gilmore, J. E., "AP600 Passive Containment Cooling System -- Phase II -- Test Data Report," WCAP-12396, March 1992.

McDermott, D., "Passive Containment Cooling System," Presented to NRC and Ames Laboratory Personnel, March 28, 1994.

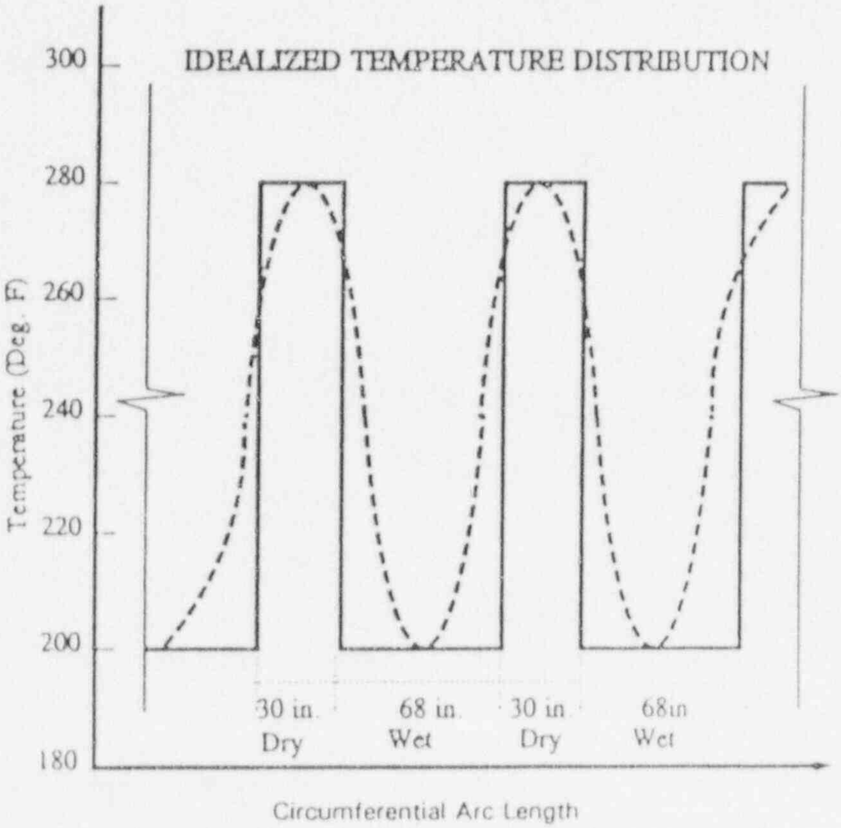
Extreme Fiber Meridional (Sigma$_1$) Stresses due to Case 1 Temperature Loading



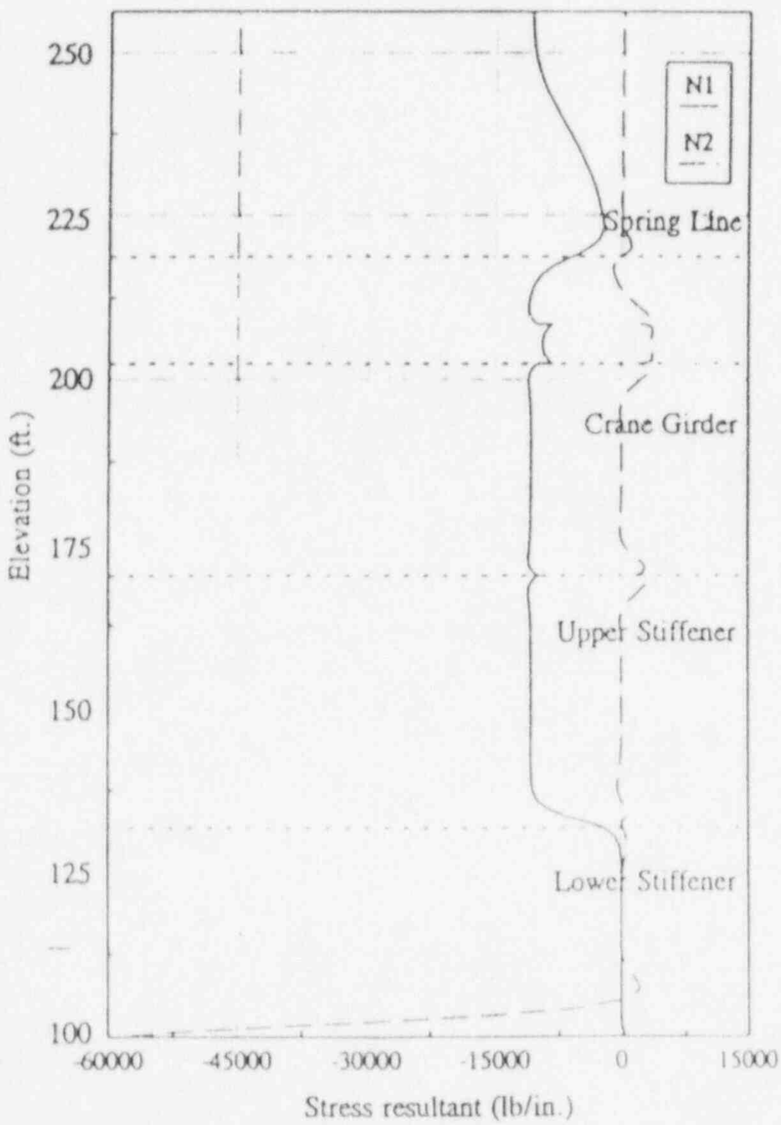
Extreme Fiber Circumferential (Sigma$_2$) Stresses due to Case 1 Temperature Loading



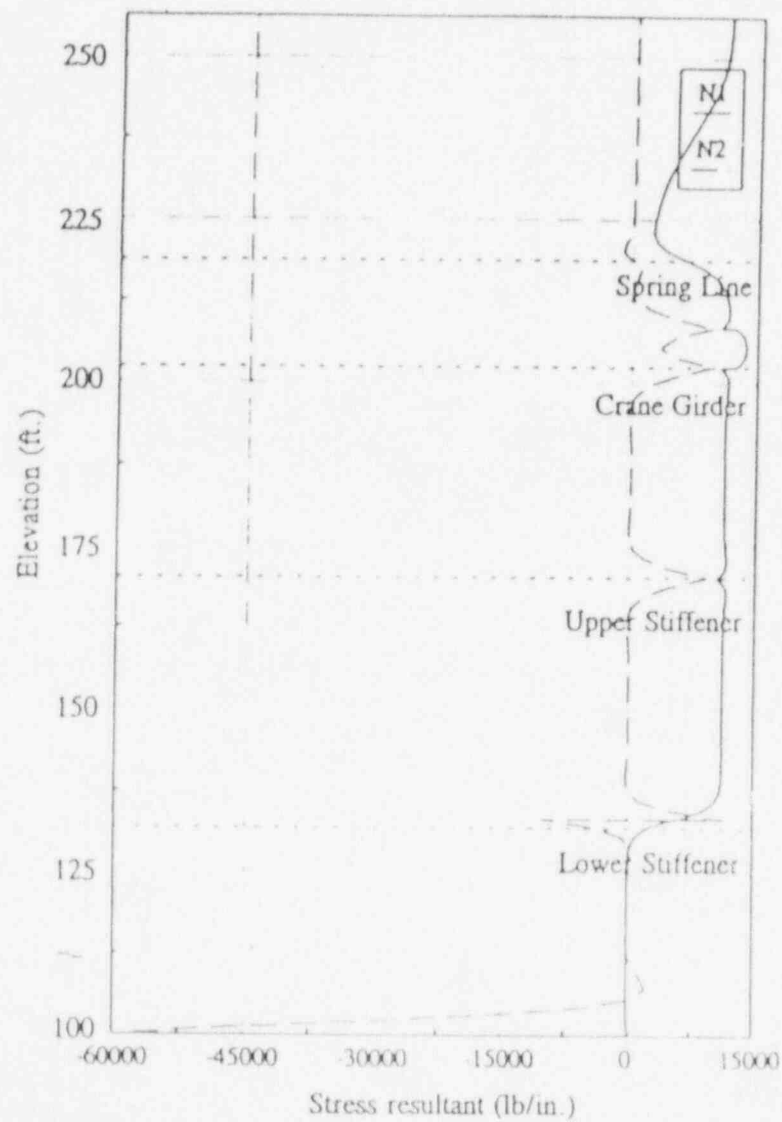
Case 2 Temperature Loading Above Elevation 132'3"



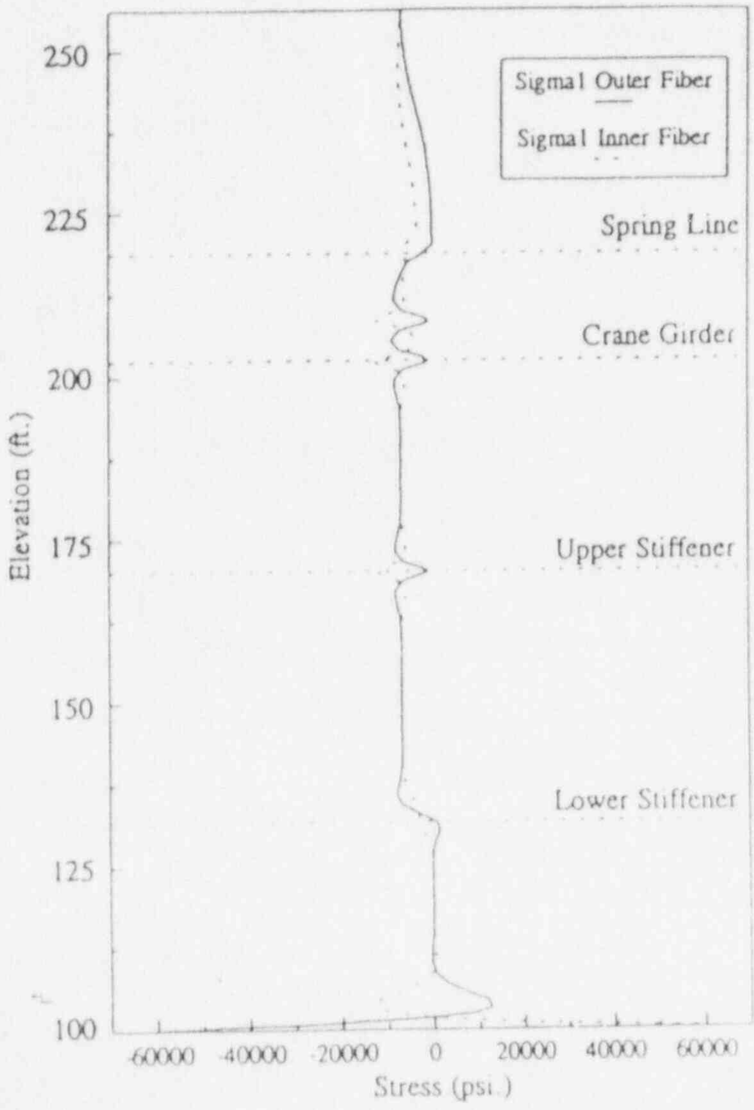
Meridional (N_1) and Circumferential (N_2) Stress Resultants due to Case 2 Temperature Loading (Dry Zone)



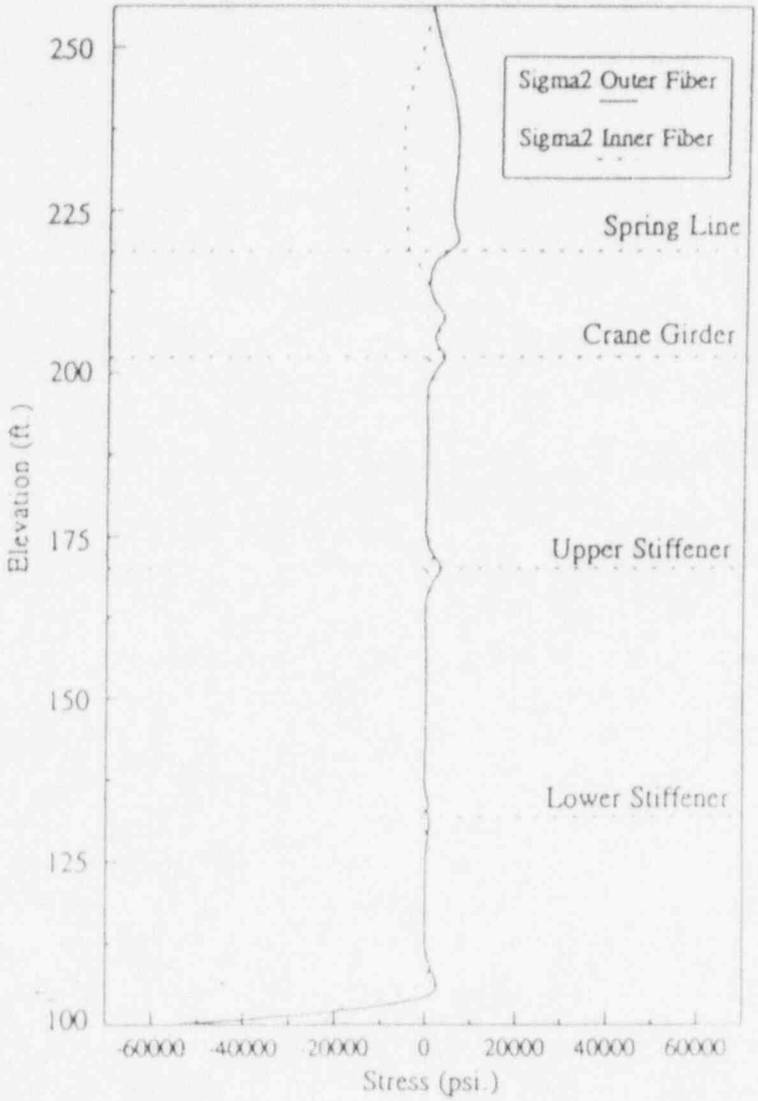
Meridional (N_1) and Circumferential (N_2) Stress Resultants due to Case 2 Temperature Loading (Wet Zone)



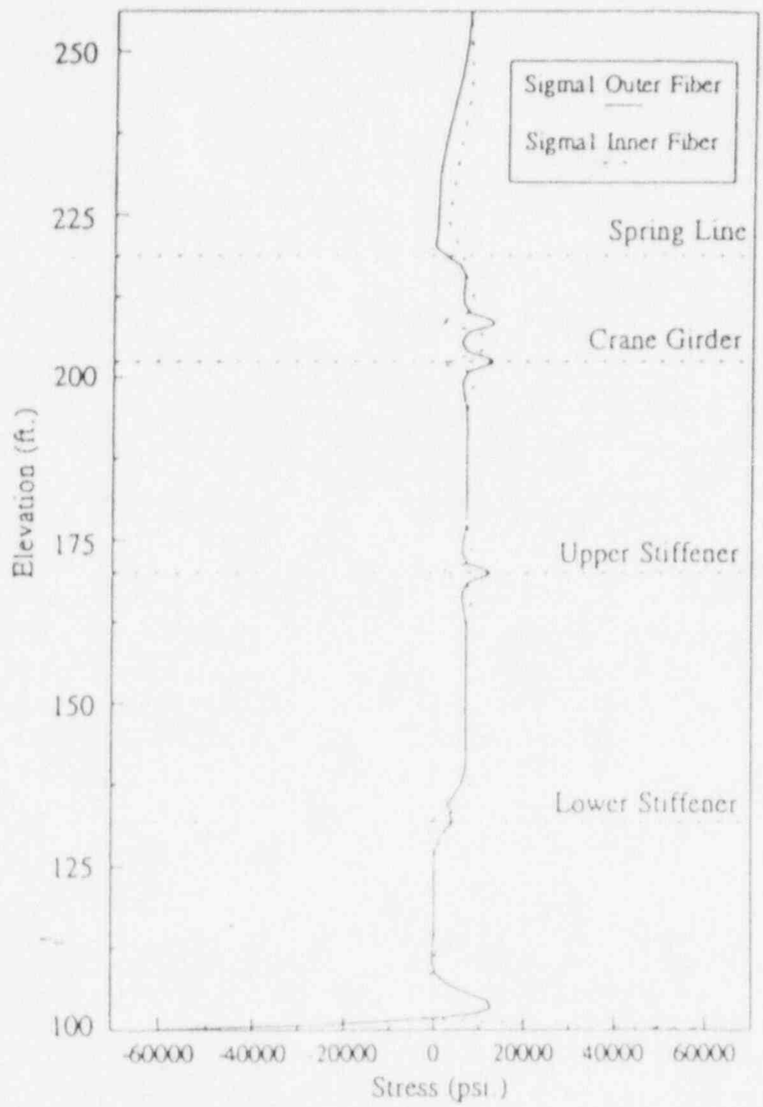
Extreme Fiber Meridional (Sigma$_1$) Stresses due to Case 2 Temperature Loading (Dry Zone)



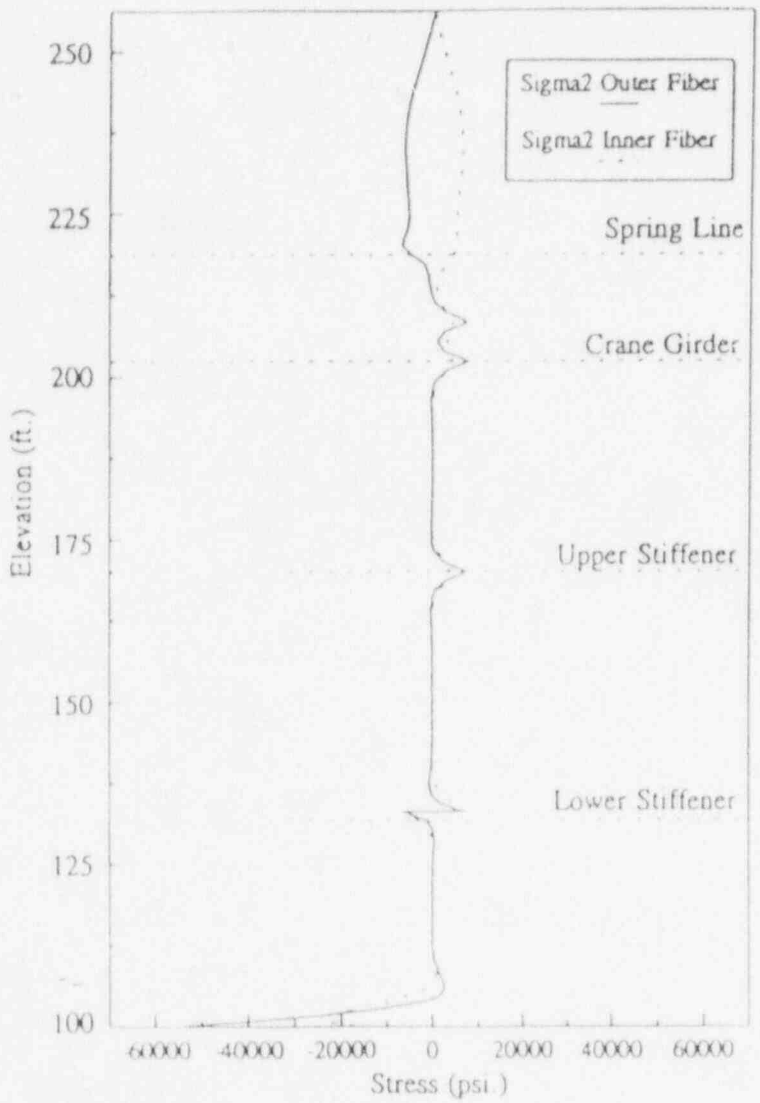
Extreme Fiber Circumferential ($Sigma_2$) Stresses due to Case 2 Temperature Loading (Dry Zone)



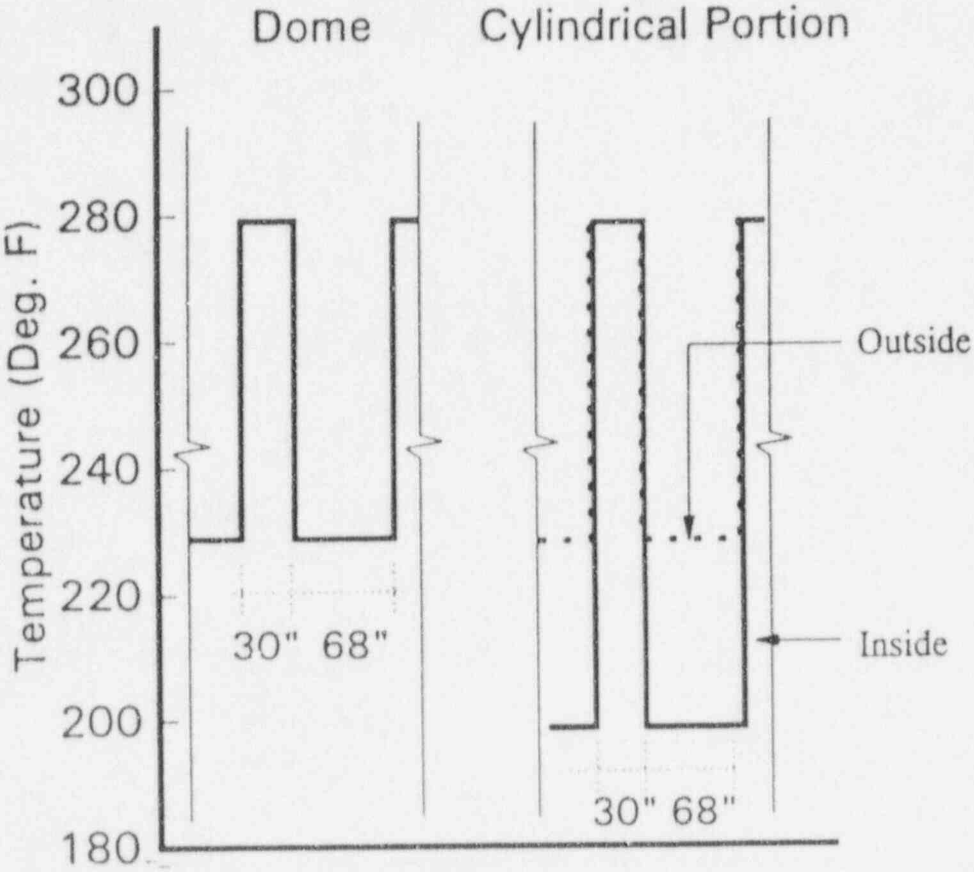
Extreme Fiber Meridional ($Sigma_1$) Stresses due to Case 2 Temperature Loading (Wet Zone)



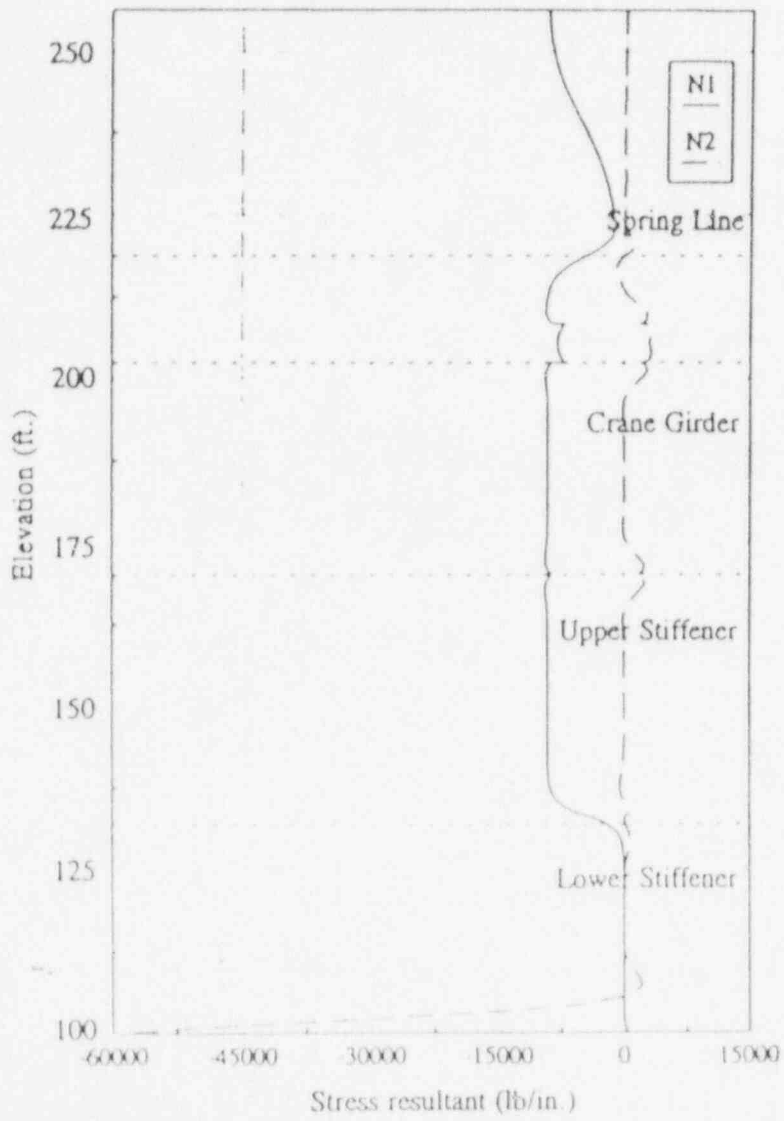
Extreme Fiber Circumferential (Sigma$_2$) Stresses due to Case 2 Temperature Loading (Wet Zone)



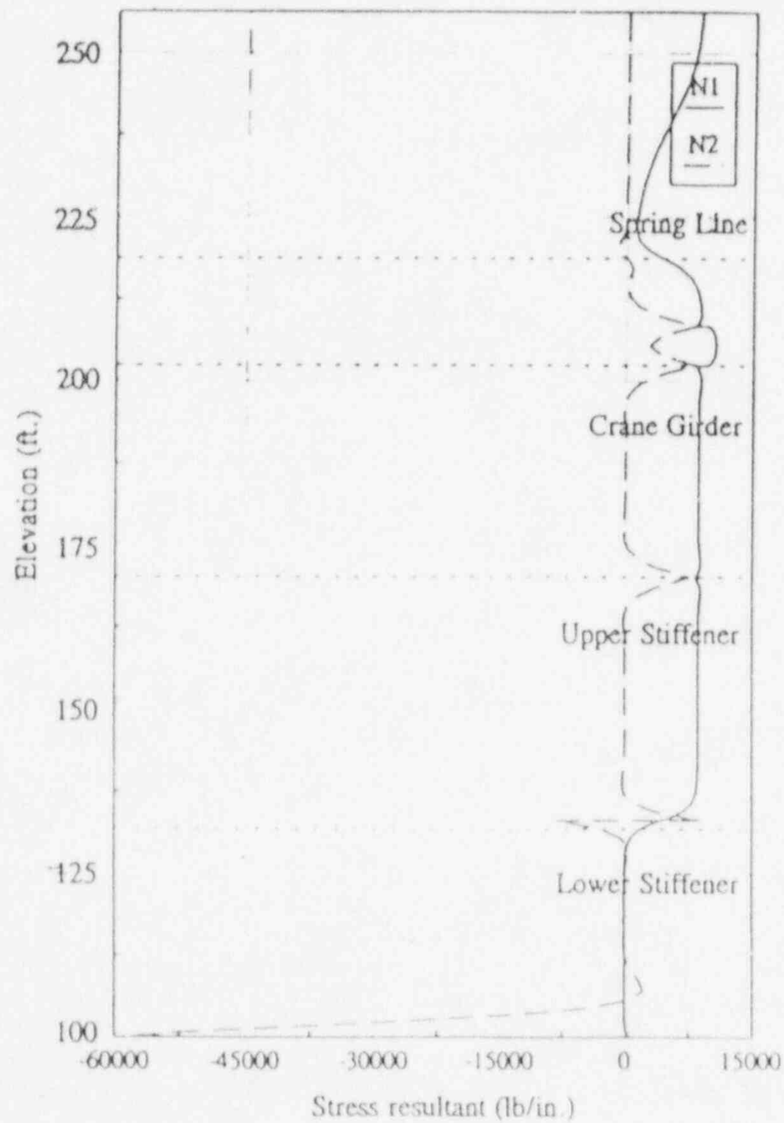
Case 3 Temperature Loading Above Elevation 132' 3"



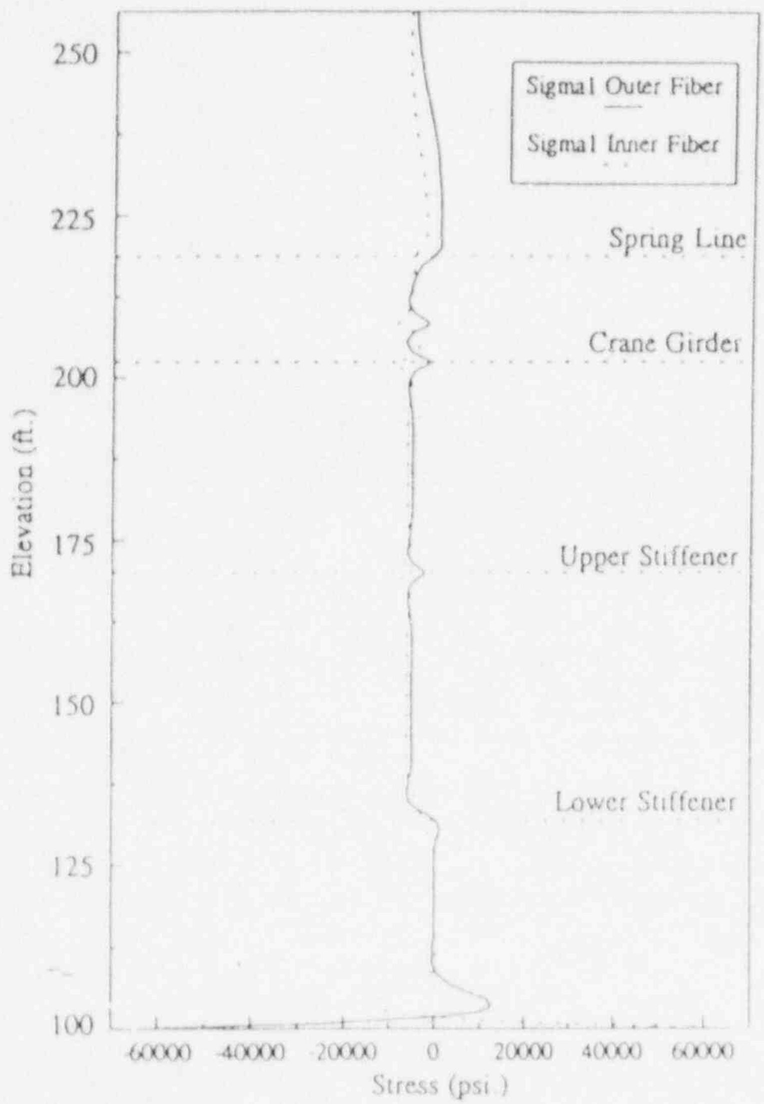
Meridional (N_1) and Circumferential (N_2) Stress Resultants due to Case 3 Temperature Loading (Dry Zone)



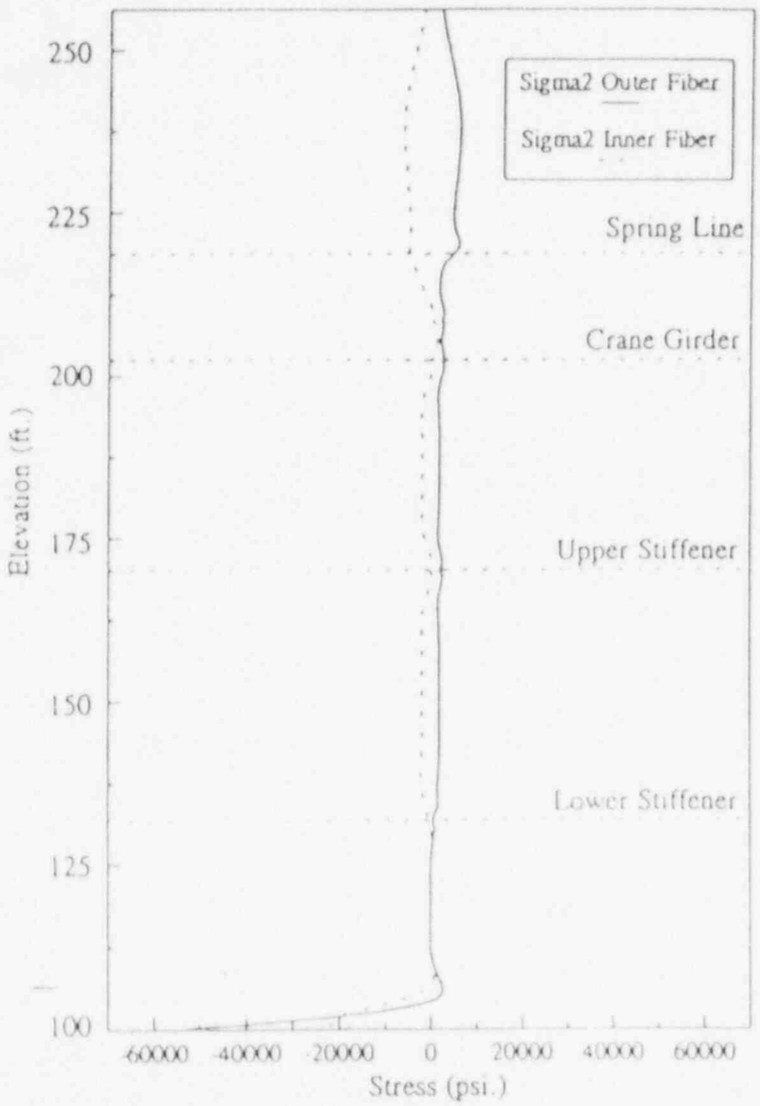
Meridional (N_1) and Circumferential (N_2) Stress Resultants due to Case 2 Temperature Loading (Wet Zone)



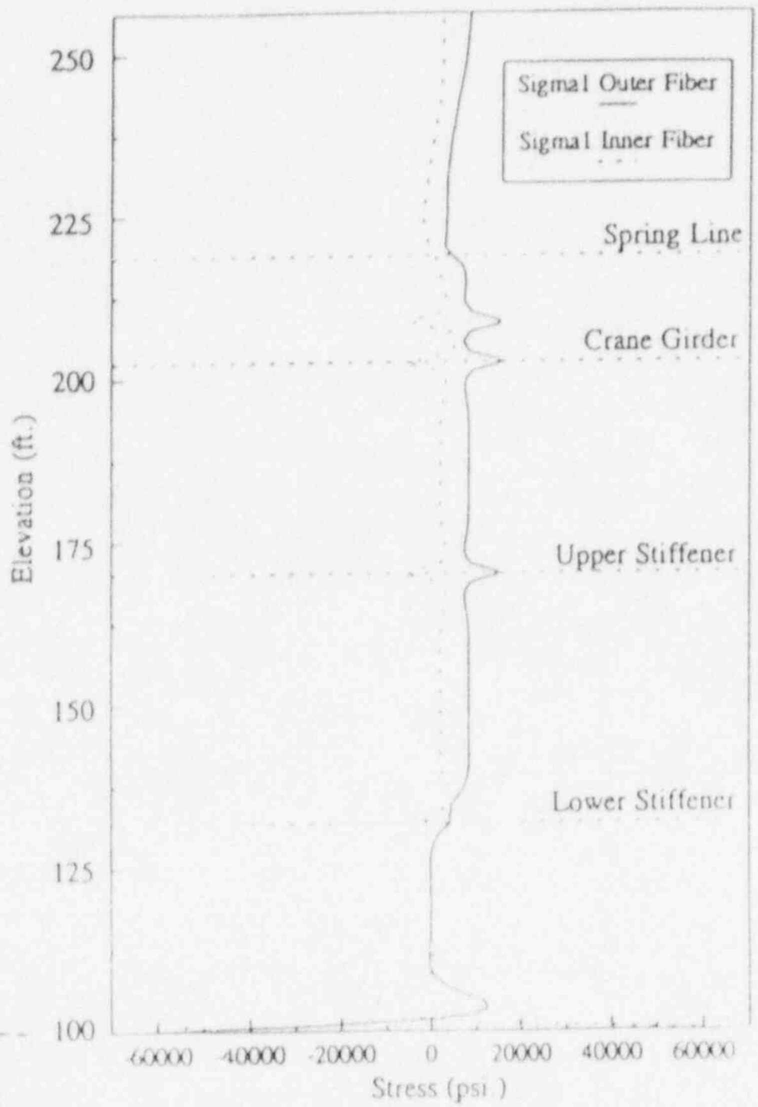
Extreme Fiber Meridional ($sigma_1$) Stresses due to Case 3 Temperature Loading (Dry Zone)



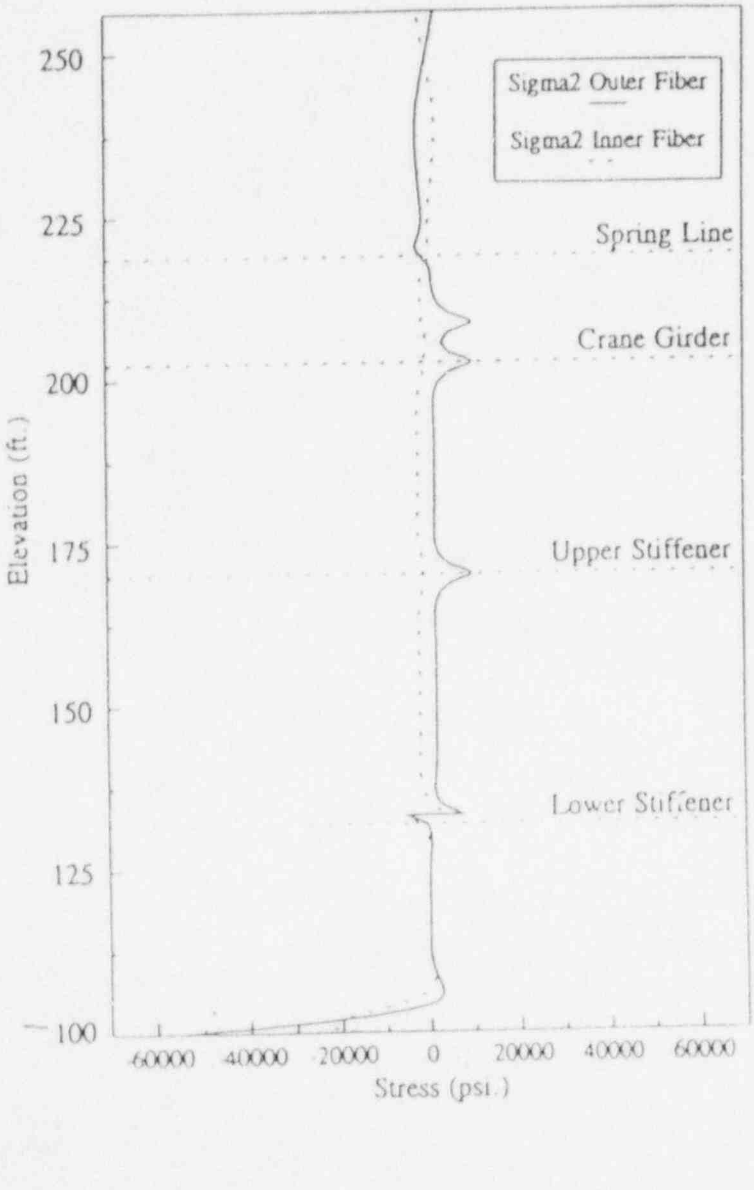
Extreme Fiber Circumferential ($Sigma_2$) Stresses due to Case 3 Temperature Loading (Dry Zone)



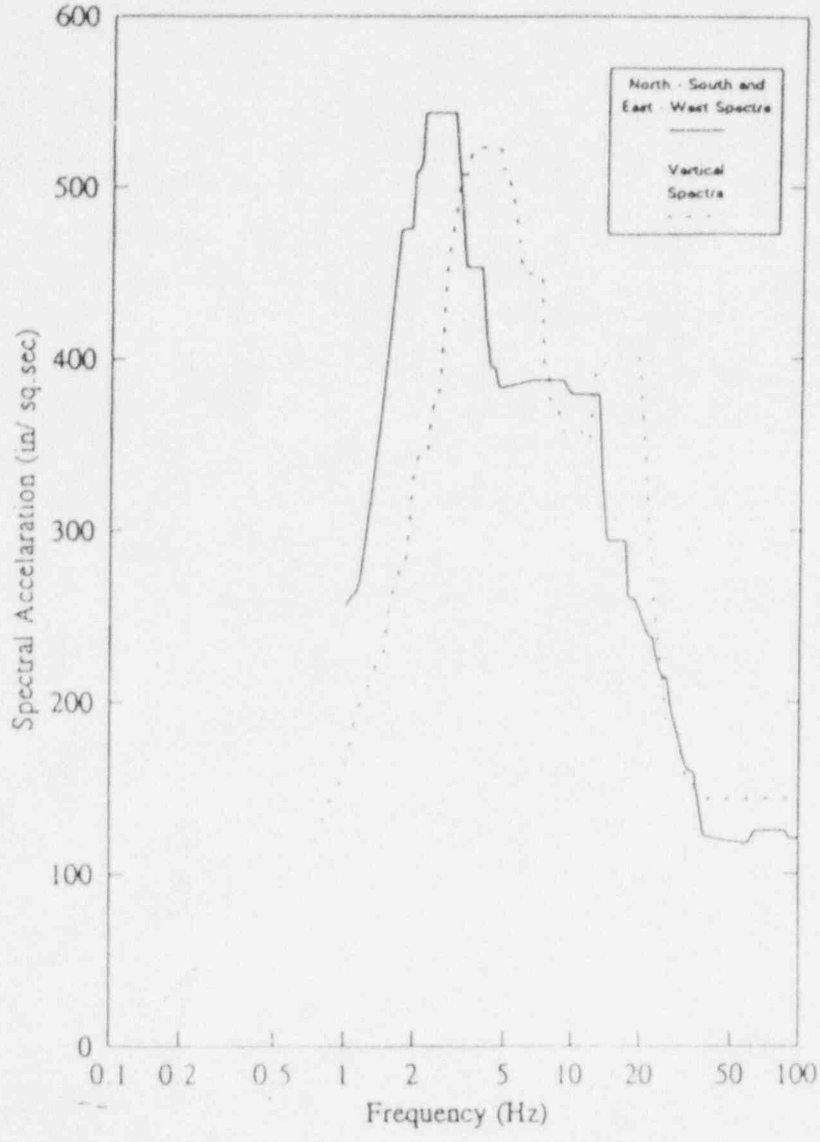
Extreme Fiber Meridional (Sigma$_1$) Stresses due to Case 3 Temperature Loading (Wet Zone)



Extreme Fiber Circumferential (Sigma$_2$) Stresses due to Case 3 Temperature Loading (Wet Zone)



S.S.E. Response Spectrum (4% Damping)

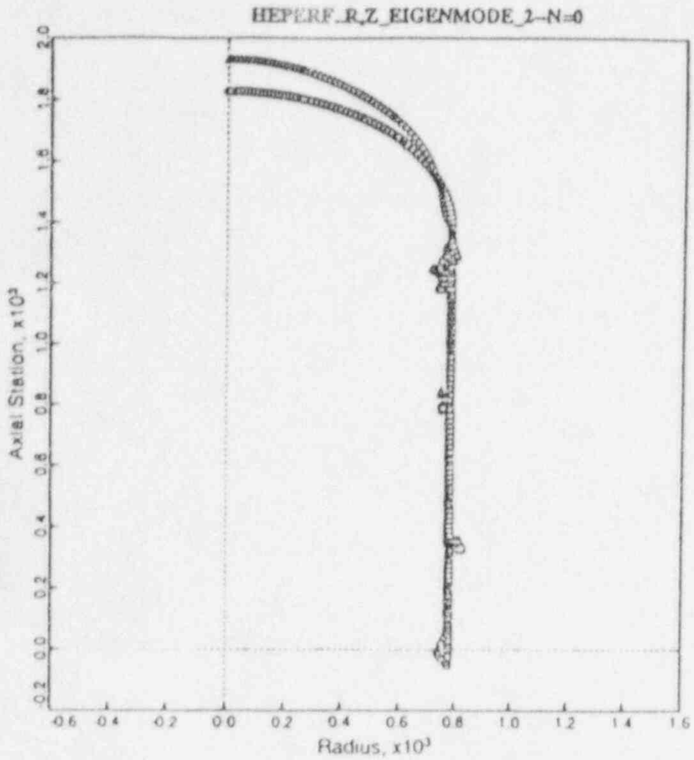


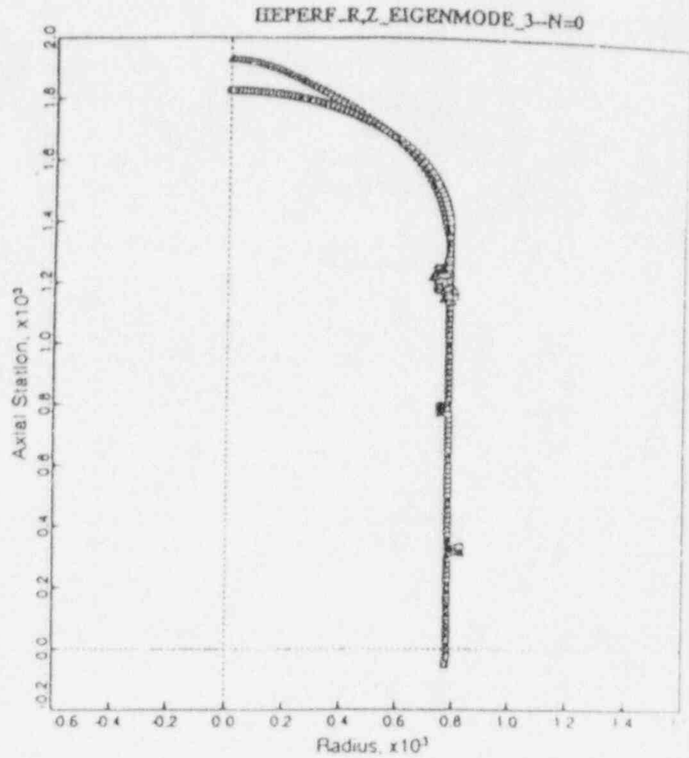
Effective Modal Mass Computation - Perfect Shell (Vertical Modes)

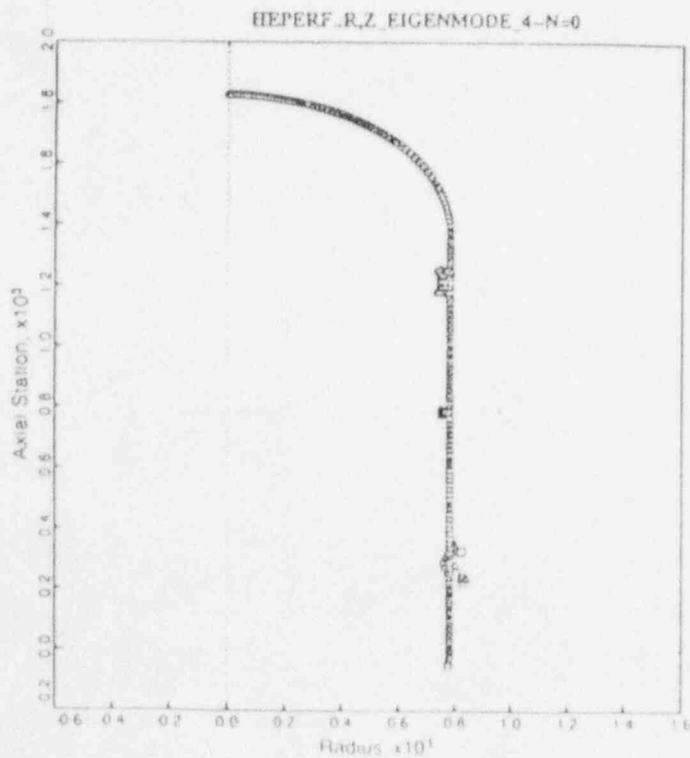
Mode	Frequency (Hz)	Generalized Mass (GM)	Participation Factor, Γ	Effec. Mass ($GM * \Gamma^{(2)}$)	% of Total Mass
1	13.61	9597.0	0.0	0.0	0.0
2	16.16	3314.0	1.956	12679.20	71.63
3	21.82	479.2	0.651	203.20	1.15
4	23.04	254.0	0.819	170.30	0.96
5	23.64	1251.0	0.032	1.30	0.01
6	23.66	46.2	0.541	13.53	0.08
7	24.44	112.6	1.084	132.31	0.75
8	24.72	244.8	0.496	60.22	0.34
9	25.53	89.6	0.834	62.30	0.35
10	26.52	113.7	1.282	186.90	1.06

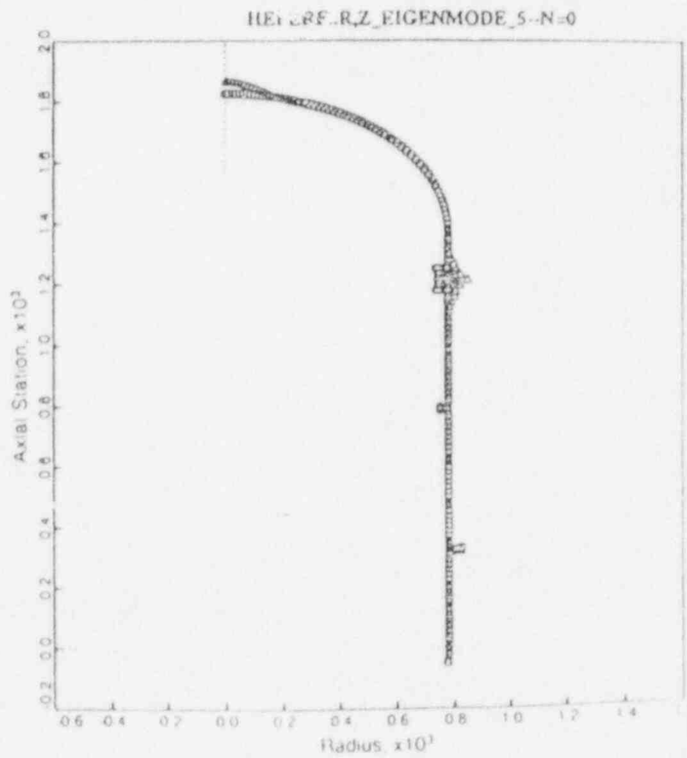
- Total mass = 17720 $lb.sec^2/in.$

VERTICAL MODES (N=0)





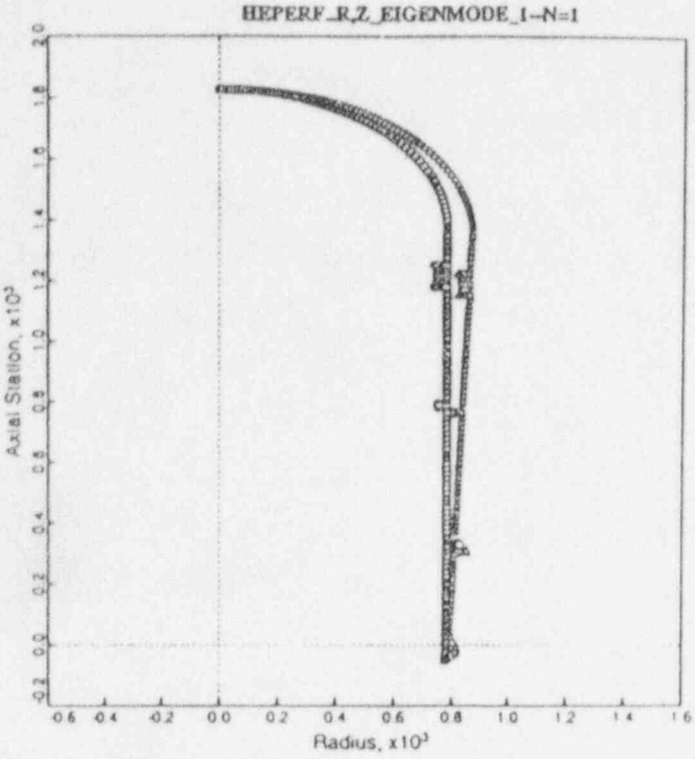


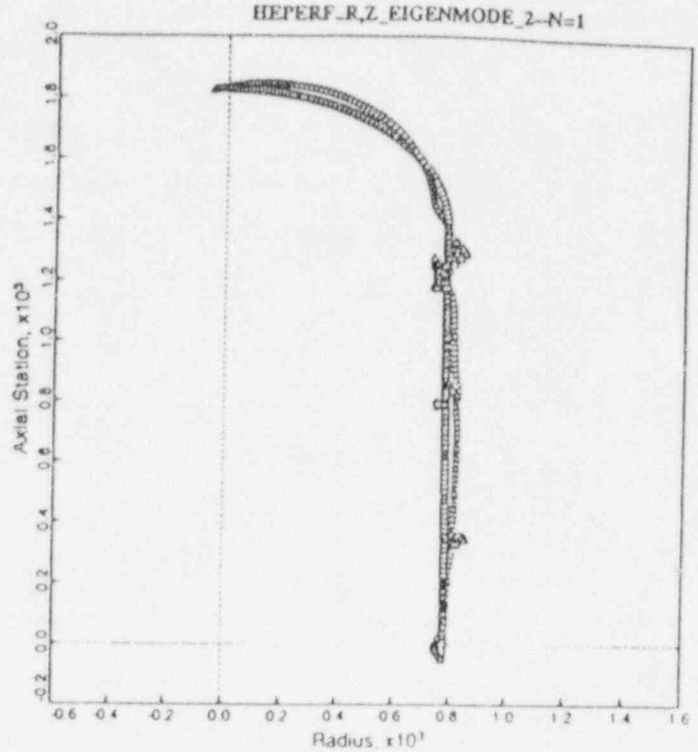


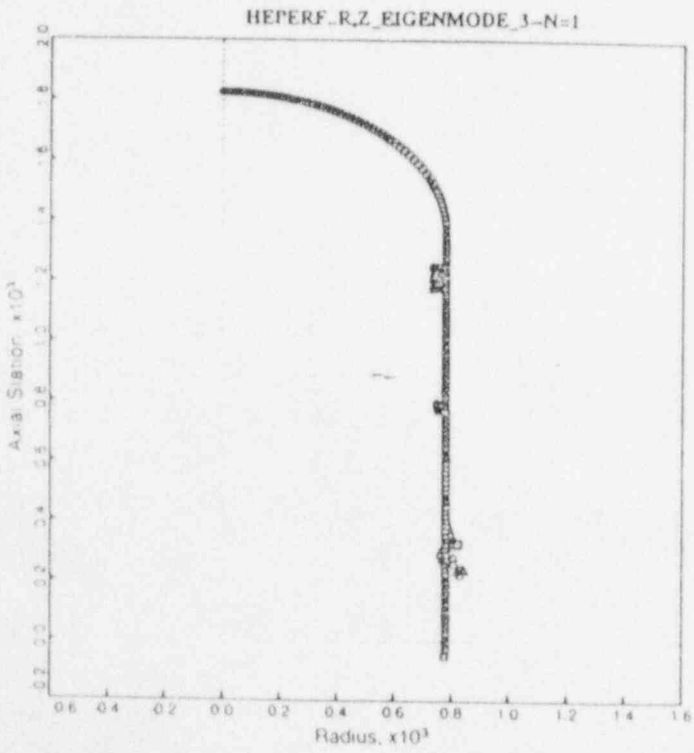
Effective Modal Mass Computation - Perfect Shell (Horizontal Modes)

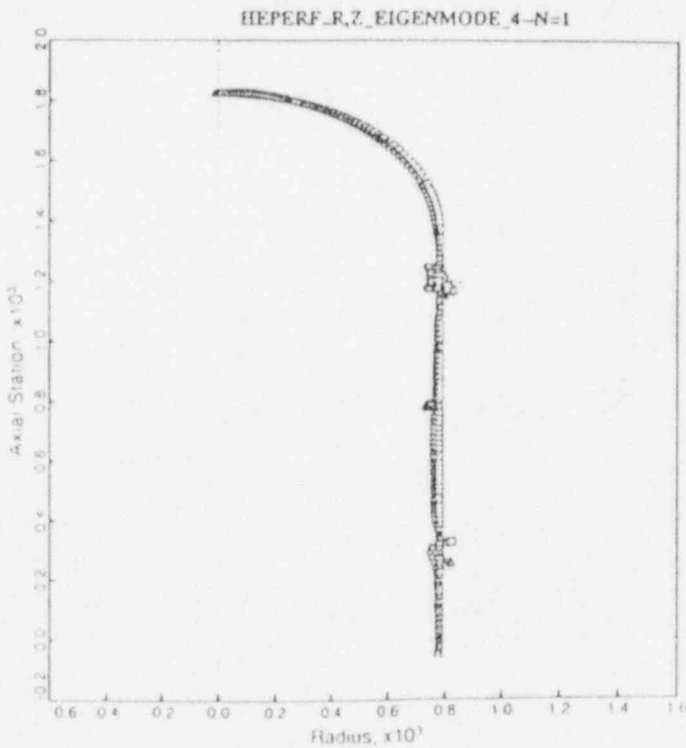
Mode	Frequency (Hz)	Generalized Mass (GM)	Participation Factor, Γ	Effec. Mass ($GM * \Gamma^{(2)}$)	% of Total Mass
1	6.77	7411.0	1.356	13626.90	76.98
2	19.31	3420.0	0.702	1686.80	9.53
3	23.13	140.7	0.880	108.88	0.62
4	23.62	971.5	0.563	307.72	1.74
5	23.97	67.3	0.019	0.02	0.00
6	24.47	204.2	1.085	240.39	1.36
7	24.76	139.0	0.168	3.90	0.02
8	25.00	150.6	1.046	164.80	0.93
9	25.68	143.2	0.400	22.90	0.13
10	26.72	149.4	0.322	15.50	0.09

VIBRATION MODES (N=1 or N=-1)

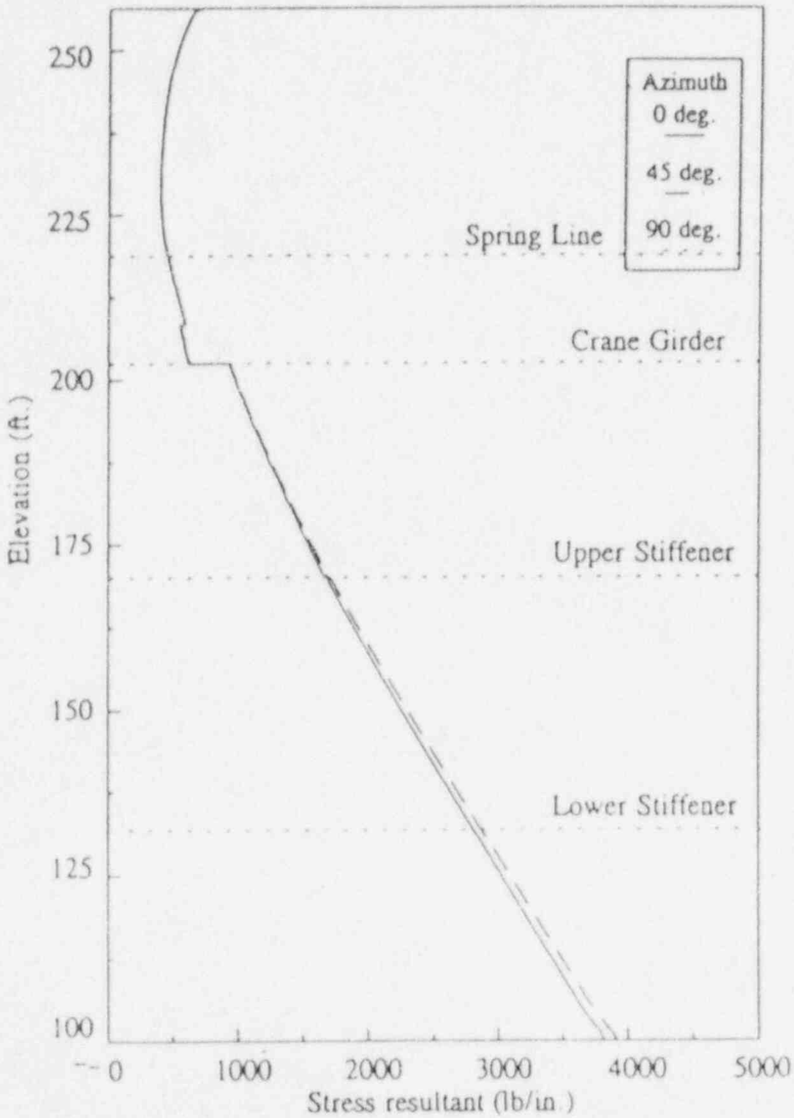




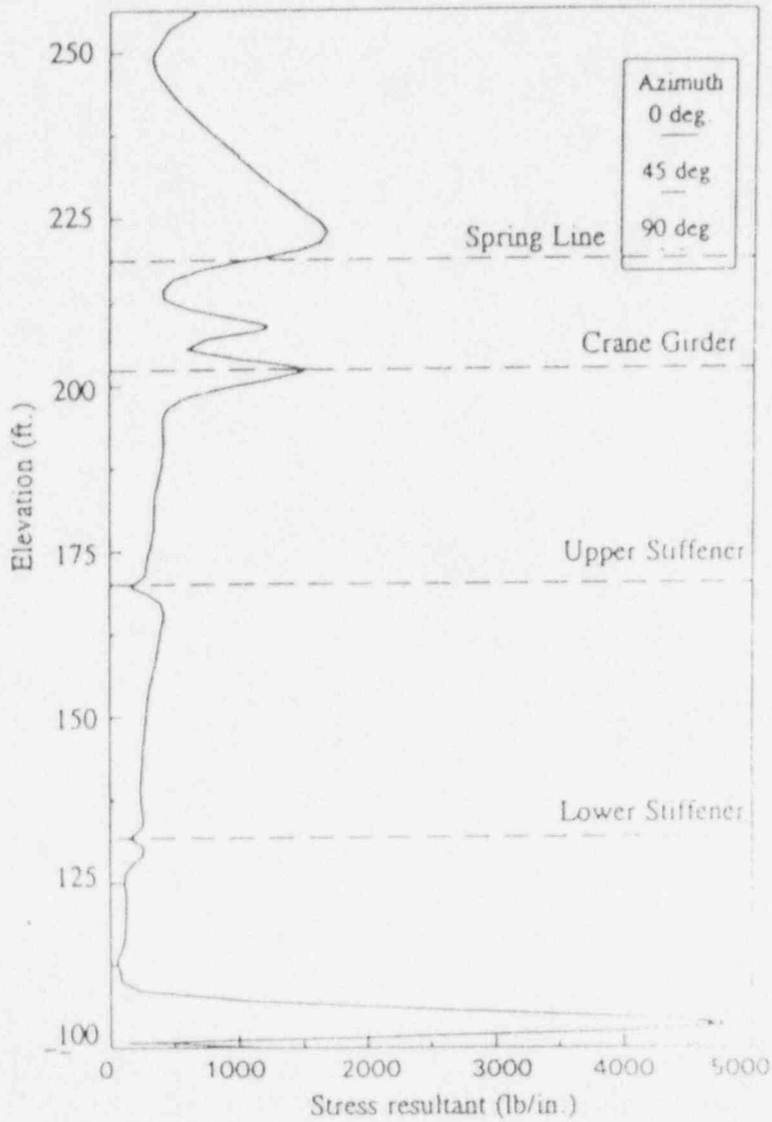




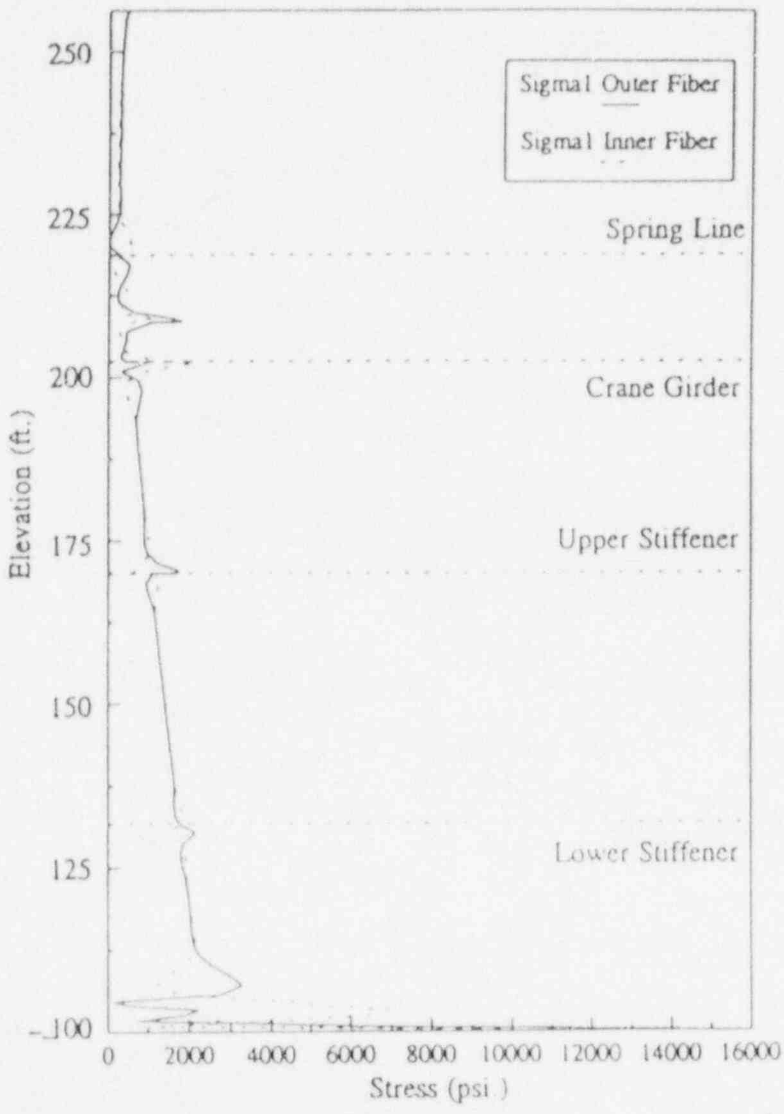
S.R.S.S. Meridional (N_1) Stress Resultants



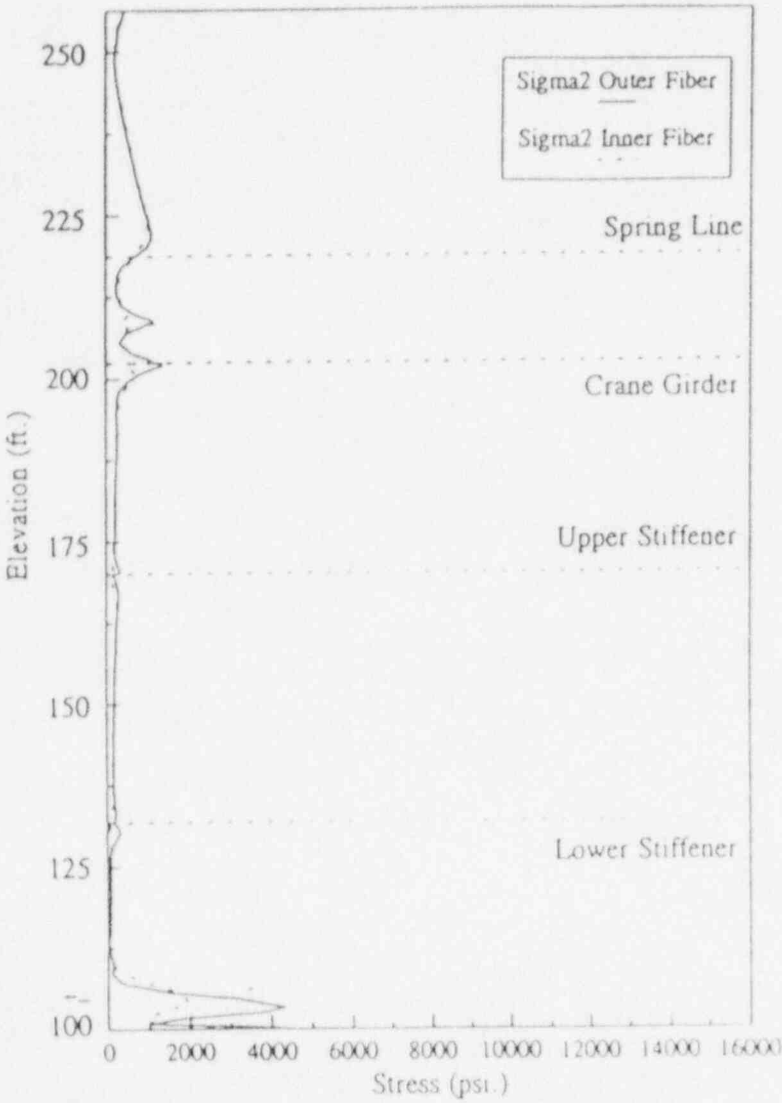
S.R.S.S. Circumferential (N_2) Stress Resultants



Extreme Fiber SRSS Meridional ($Sigma_1$) Stresses



Extreme Fiber SRSS Circumferential ($Sigma_2$) Stresses



WIND LOADS ON THE CONTAINMENT

- Loads to be considered above Elevation 142 ft.
- Wind Pressure Computed Using Measured Pressure Coefficients.

$$p_r = C_p \, p_{roof}$$

$$p_{roof} = 0.5 \, \rho \, v^2$$

Where p_r = Computed Wind Pressure

p_{roof} = Dynamic Wind Pressure at Roof Height

ρ = Air density

v = Mean hourly wind speed equivalent to design wind velocity

- Case 1: Design Wind @ 110 mph

p_{roof} = 38.2 psf (1)

- Case 2: Tornado Wind @ 300 mph

p_{roof} = 116.0 psf (1)

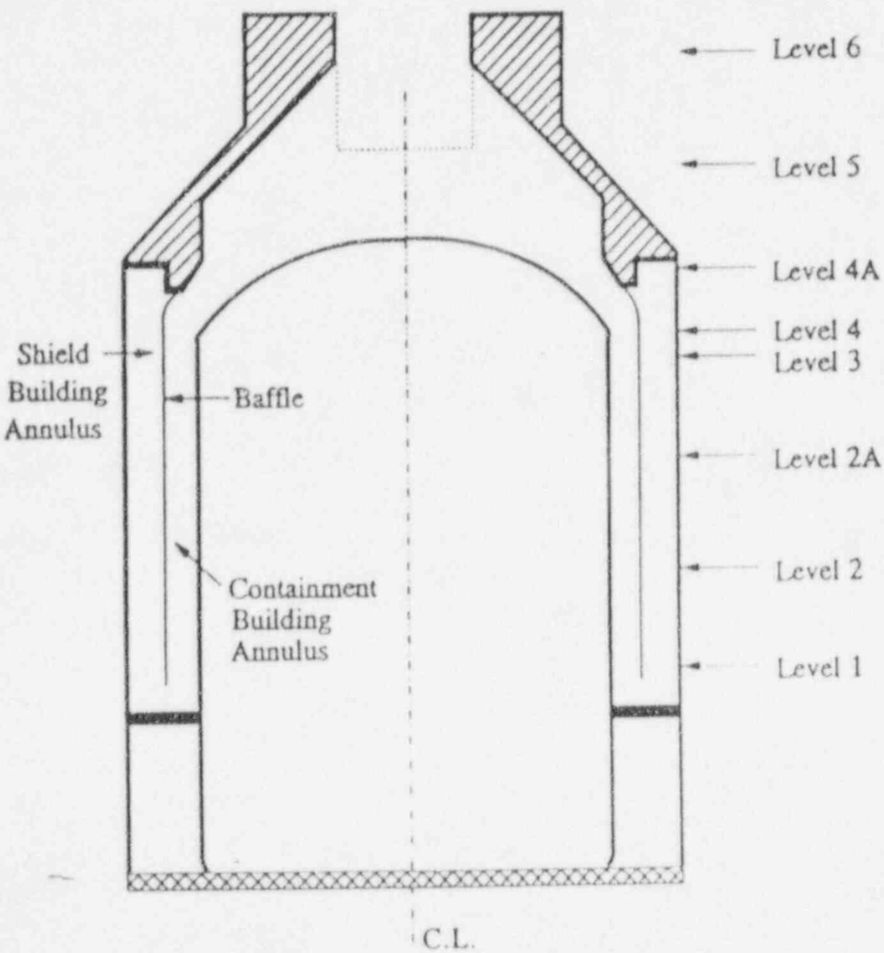
Idealized Suction and Lateral Load Cases from C_p measured per [2]

*References:

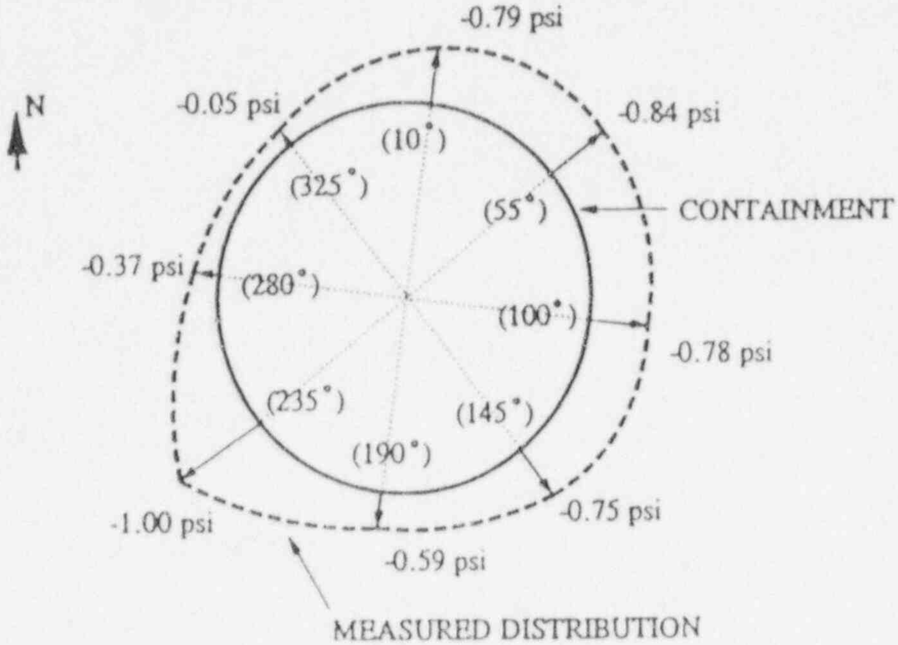
(1) Lyth, G. R. and Surry, D., "Phase II Wind Tunnel Testing for the Westinghouse AP600 Reactor," Report No. WCAP-13323, May 1992.

(2) Lyth, G. R., Surry, D., "Phase IVa Wind Tunnel Testing for the Westinghouse AP600 Reactor," Report No. 14068, 1994.

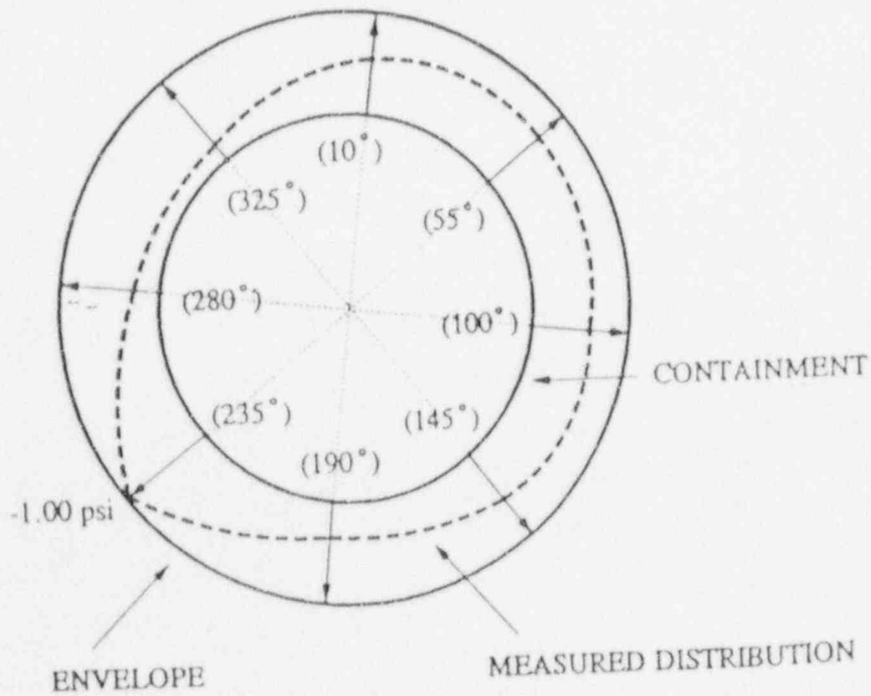
Cross Sectional Elevation of AP600 Containment Indicating Location of Instrumentation for Wind Pressure Coefficient Measurement



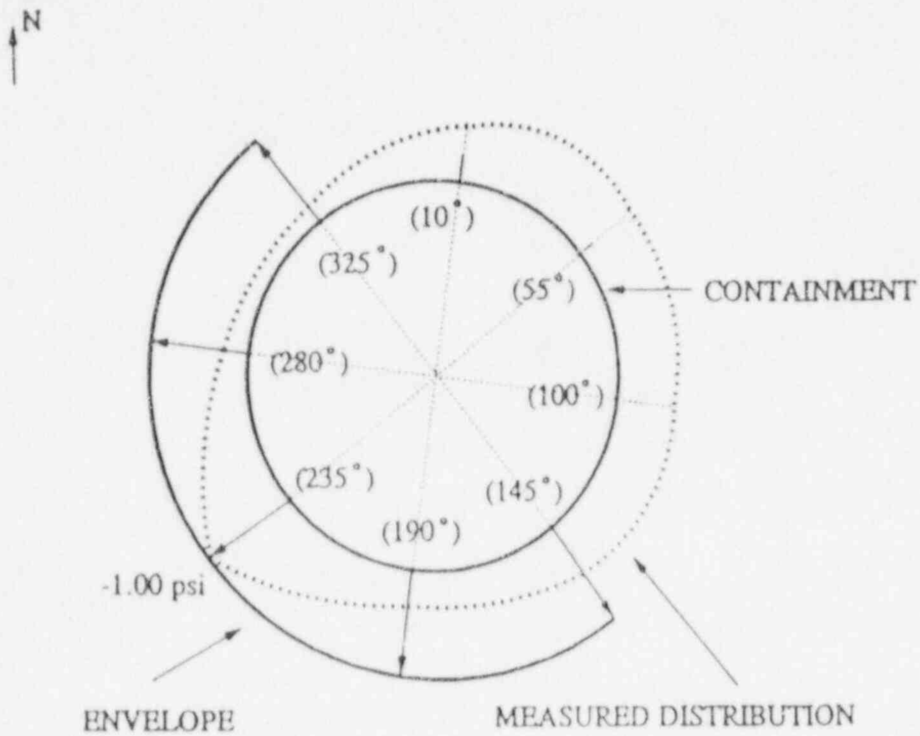
Pressure Distribution Corresponding to Measured Minimum Pressure Coefficients



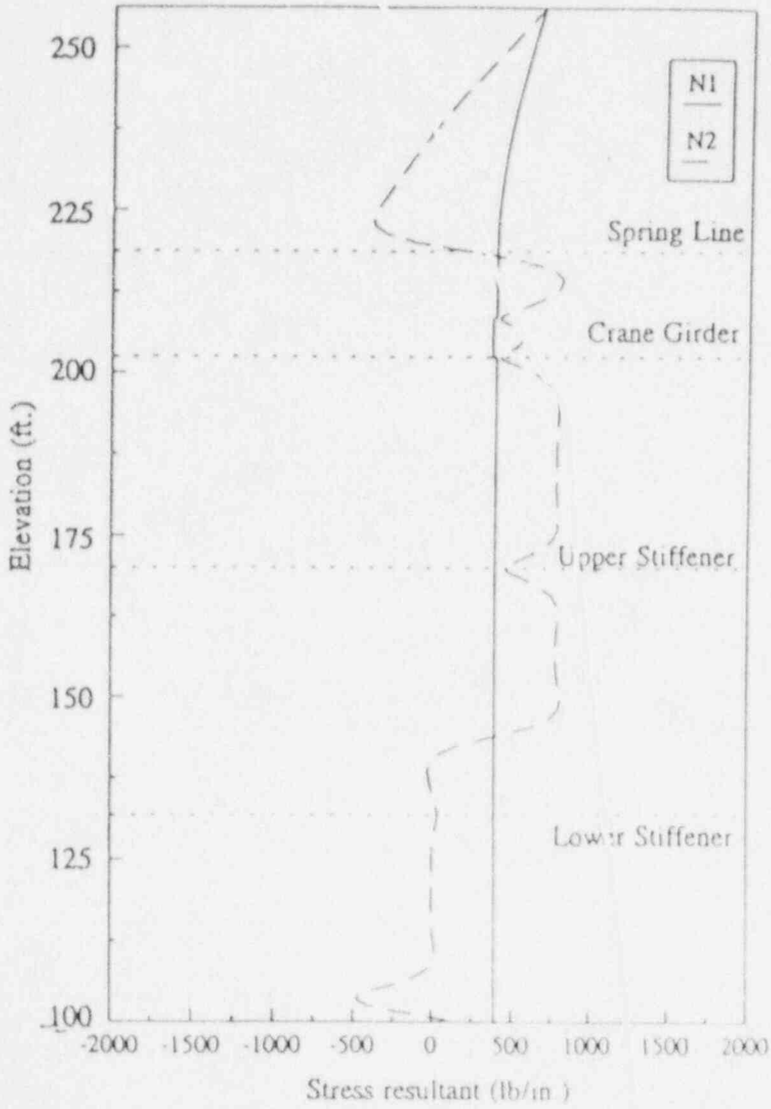
Enveloped Pressure Distribution (Uniform Suction)



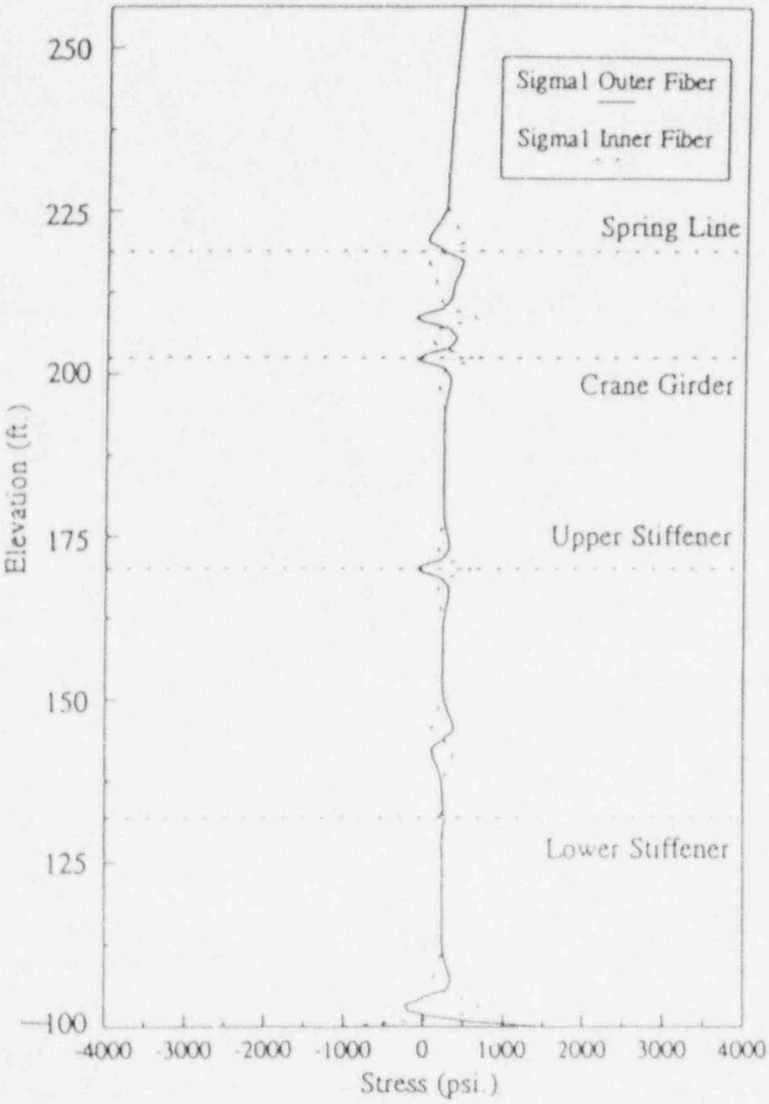
Enveloped Pressure Distribution (Lateral Load)



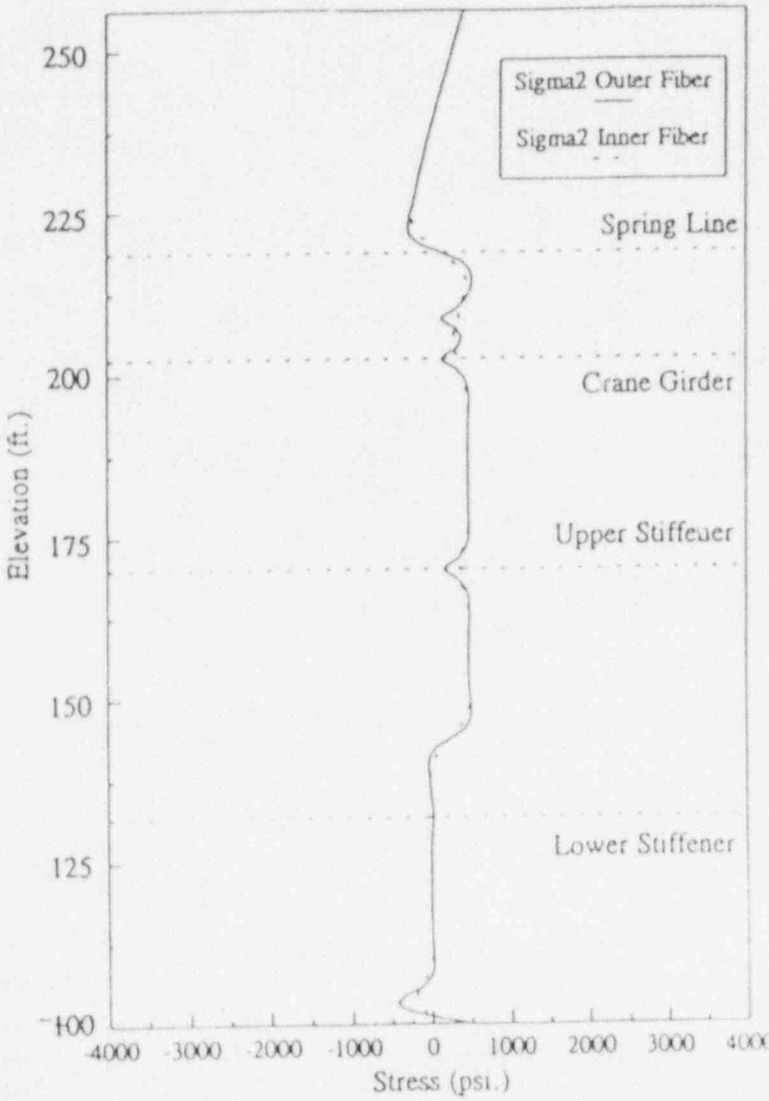
Meridional (N_1) and Circumferential (N_2) Stress Resultants due to Uniform Wind Suction of 1.0 psi



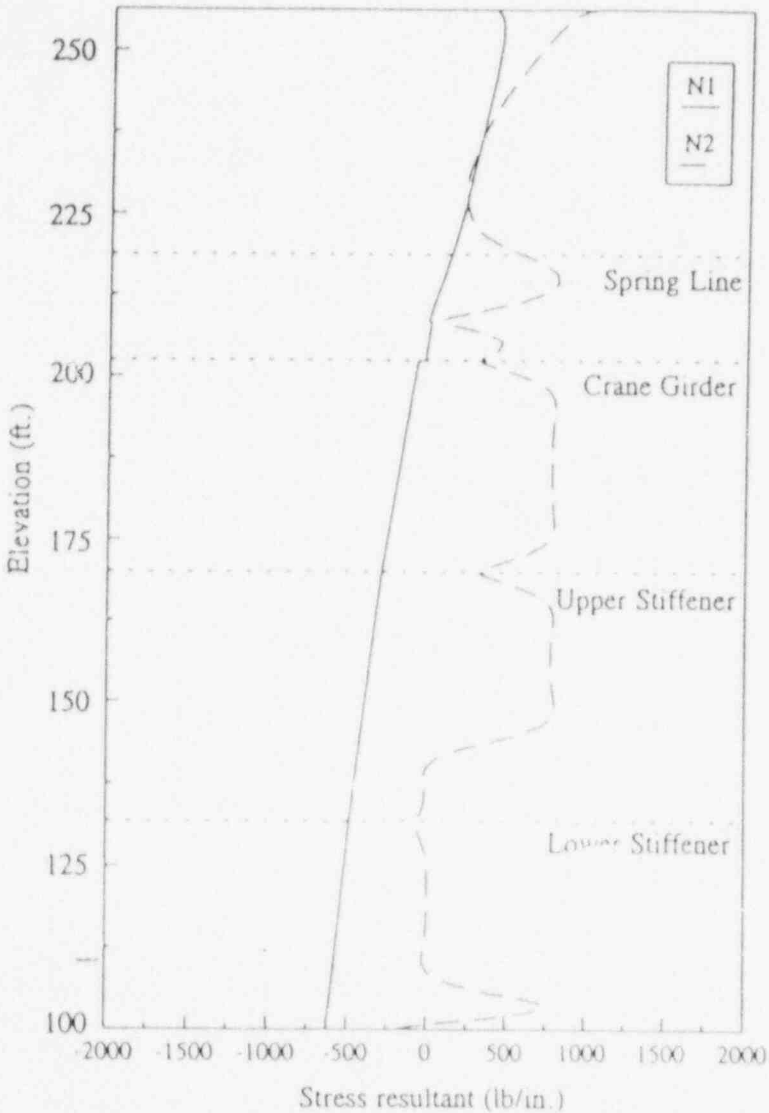
Extreme Fiber Meridional (Sigma$_1$) Stresses due to Uniform Wind Suction of 1.0 psi



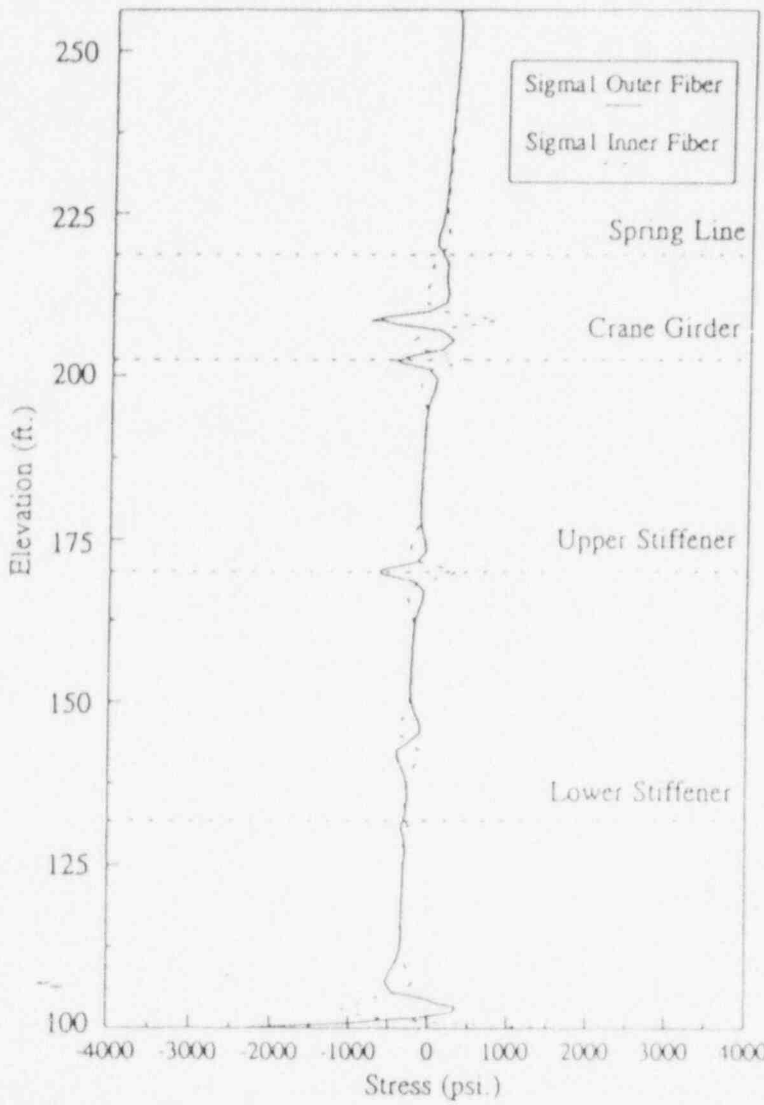
Extreme Fiber Circumferential ($Sigma_2$) Stresses due to Uniform Wind Suction of 1.0 psi



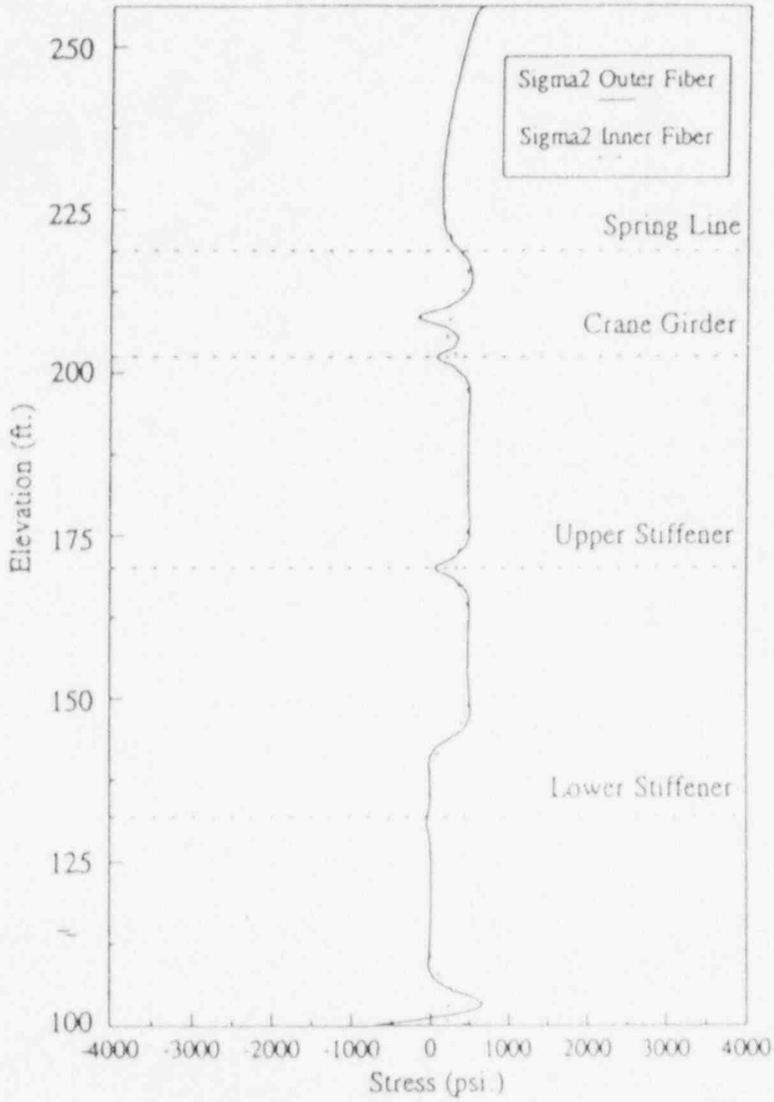
Meridional (N_1) and Circumferential (N_2) Stress Resultants due to Enveloped Lateral Load (1.0 psi) on the 235° Azimuth



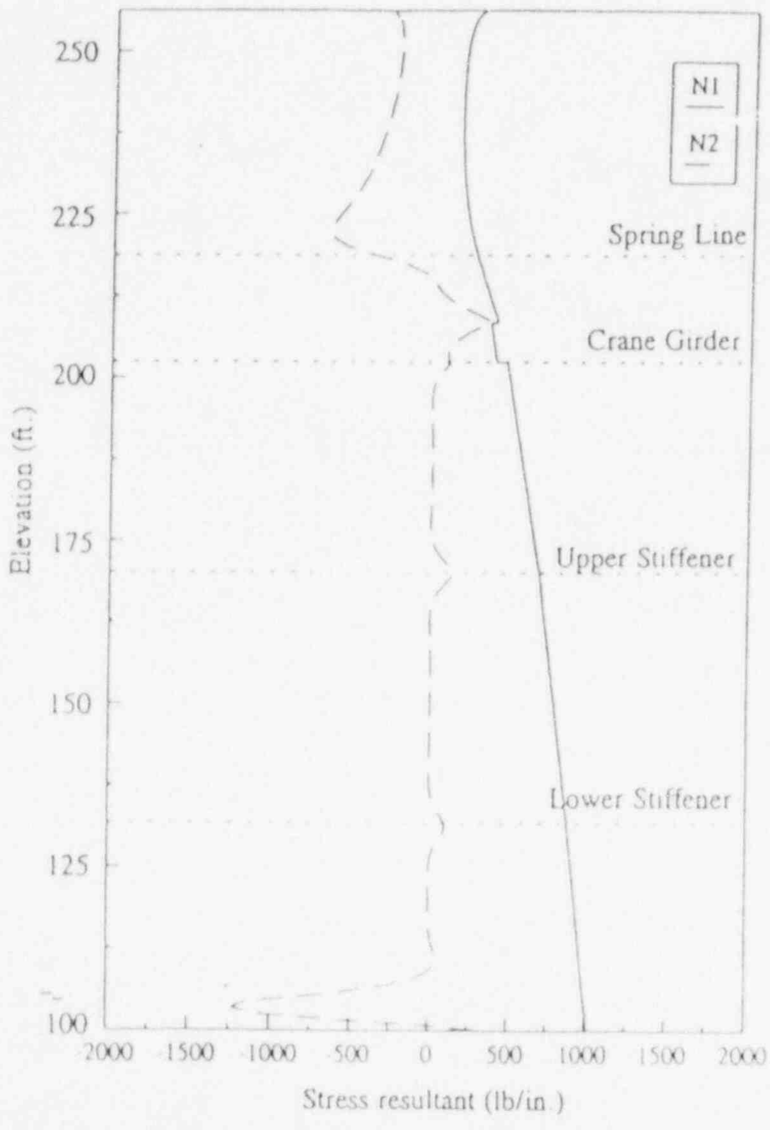
Extreme Fiber Meridional ($Sigma_1$) Stresses due to Enveloped Wind Lateral Load (1.0 psi) on the 235° Azimuth



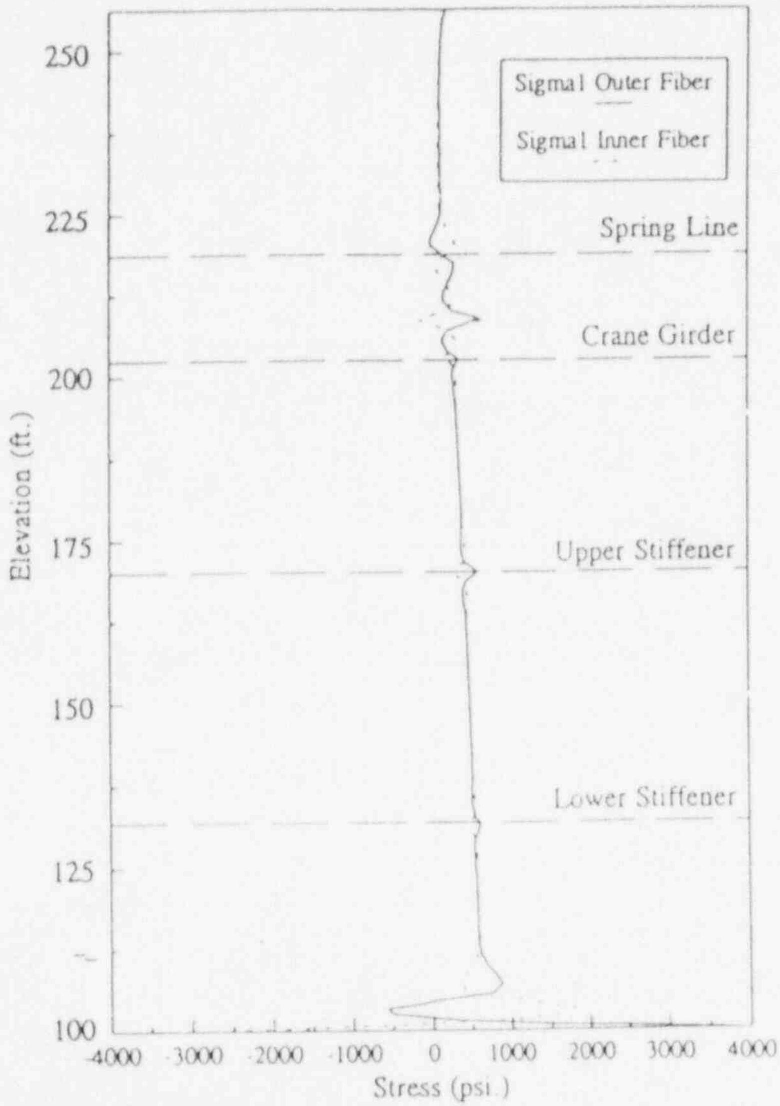
Extreme Fiber Circumferential ($Sigma_2$) Stresses due to Enveloped Wind Lateral Load (1.0 psi) on the 235° Azimuth



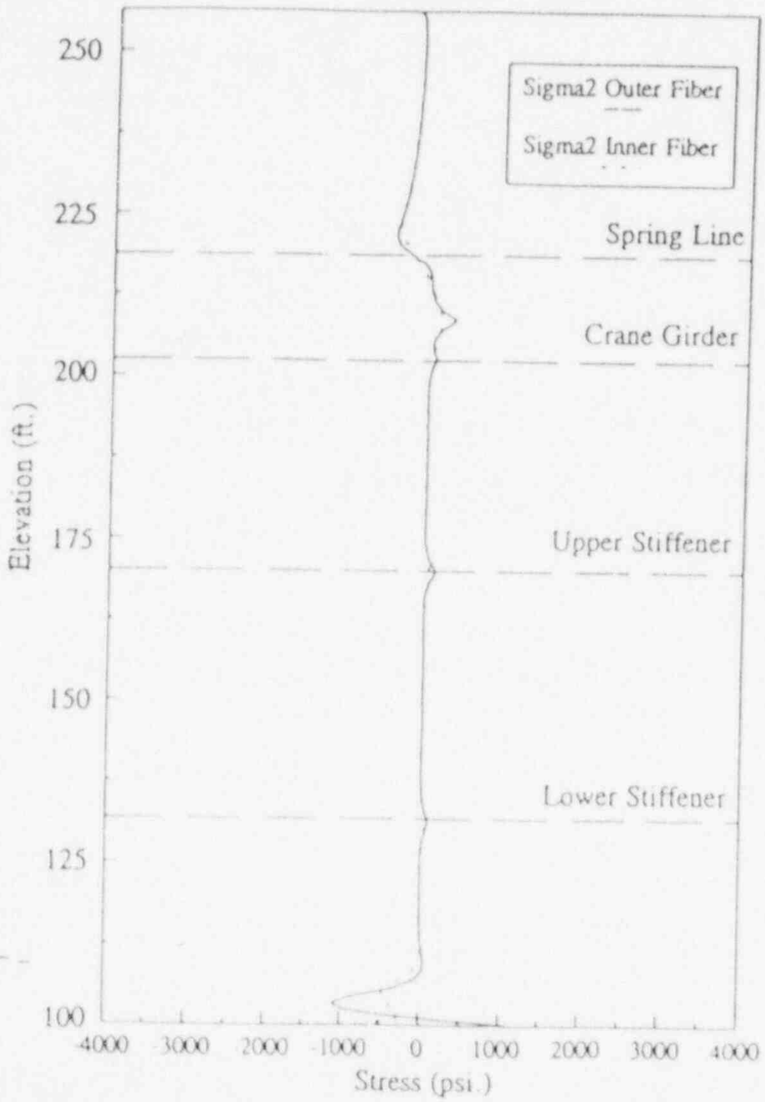
Meridional (N_1) and Circumferential (N_2) Stress Resultants due to Enveloped Lateral Load (1.0 psi) on the 55° Azimuth



Extreme Fiber Meridional ($Sigma_1$) Stresses due to Enveloped Wind Lateral Load (1.0 psi) on the 55° Azimuth



Extreme Fiber Circumferential ($Sigma_2$) Stresses due to Enveloped Wind Lateral Load (1.0 psi) on the 55° Azimuth



Maximum Stresses in the Containment

Load Case	Meridional Stresses				Circumferential Stresses			
	Outer Fiber (psi)	El. (ft.)	Inner Fiber (psi)	El. (ft.)	Outer Fiber (psi)	El. (ft.)	Inner Fiber (psi)	El. (ft.)
Dead Load (D)	-4,950	100	3,330	100	-1,490	100	1,000	100
Crane Load (L)	-2,300	208.4	2,410	208.4	-1,720	208.4	-719	208.4
P_o = 45.0 psig	28,200	100	28,300	208.4	24,300	214.3	22,100	111.6
Wind @ 110 mph-Suction	1,480	100	-999	100	539	214.3	491	150.5
Wind @ 110 mph-Lateral Load Azimuth 235°	-2,380	100	1,600	100	-713	100	603	256
Wind @ 110 mph-Lateral Load Azimuth 55°	3,860	100	-2,600	100	1,160	100	-781	100
T_a = 280°F	-62,100	100	62,600	100	-54,300	100	-24,300	100.8
S.S.E.*	15,023	100	10,202	100	4,507	100	3,060	100

*Max. Shear: 1,573 psi (outer fiber elev. 100.8 ft.) And 1,571 psi (inner fiber, elev. 100 ft.)

STRESS COMBINATION

Load Combinations as per S.R.P 3.8.2

ASME Limits	Design Conditions		Level A			Level C and Level D			
Load Combinations as per S.R.P 3.8.2*	DG1	DG2	OC1	DBA1	DBA2	OC2	OC3	DBA3	DBA4
Dead Load (D)	X	X	X	X	X	X	X	X	X
Live Load (L)	X	X	X	X	X	X	X	X	X
Operating conditions:									
P_o = 1.0 psig T_o = 120°F			X			X	X		
Wind @ 110 mph			X						
Accident Conditions:									
P_a = 45 psig T_a = 280°F*	X			X				X	
P_a = -2.5 psid T_a = 120°F		X			X				
P_a = -3.0 psid T_a = 120°F									X
S.S.E						X		X	X
W_T @ 300 mph							X		

* DG1 = Design Conditon 1; DG2 = Design Condition 2; OC1 = Operating Condition 1; OC2 = Operating Condition 2; OC3 = Operating Condition 3; DBA1 = Design Basis Accident 1; DBA2 = Design Basis Accident 2; DBA3 = Design Basis Accident 3; DBA4 = Design Basis Accident 4.

* Includes temperature profiles Case 1, Case 2 and Case 3.

Load Combinations as per S.R.P 3.8.2

ASME Limits	Design Conditions		Level A			Level C and Level D			
Load Combinations as per S.R.P.3.8.2*	DG1	DG2	OC1	DBA1	DBA2	OC2	OC3	DBA3	DBA4
Dead Load (D)	X	X	X	X	X	X	X	X	X
Live Load (L)	X	X	X	X	X	X	X	X	X
Operating conditions:									
P_o = 1.0 psig T_o = 120°F			X			X	X		
Wind @ 110 mph			X						
Accident Conditions:									
P_a = 45 psig T_a = 280°F*	X			X				X	
P_a = -2.5 psid T_a = 120°F		X			X				
P_a = -3.0 psid T_a = 120°F									X
S.S.E						X		X	X
W_T @ 300 mph							X		

* DG1= Design Conditon 1; DG2 = Design Condition 2; OC1 = Operating Condition 1; OC2 = Operating Condition 2; OC3 = Operating Condition 3; DBA1= Design Basis Accident 1; DBA2 = Design Basis Accident 2; DBA3 = Design Basis Accident 3; DBA4 = Design Basis Accident 4.

* Includes temperature profiles Case 1, Case 2 and Case 3.

Design Conditions

SRP Reference Number	Load Combination	Design Allowable Stress Intensity Limit			Maximum Calculated Stress	
		Type	Limit	Value (psi)	Value (psi)	Elev. (ft)
(ii)	DG1	P_m	1.0 S_{mc}	22,000	22,596*	+214
(ii)	DG2	P_m	1.0 S_{mc}	22,000	2,457	+103

*Can be classified as P_L

Level A Service Limits

SRP Reference Number	Load Combination	Design Allowable Stress Intensity Limit			Maximum Value as per Stress Analysis	
		Type	Limit	Value	Value (psi)	Elev. (ft)
(iii)(a)(1)	OC1	P_m	1.0 S_{mc}	22,000	2,683	+104
(iii)(a)(1)	OC1	P_L+P_b+Q	3.0 S_{ml}	80,100	21,894	+100
(iii)(a)(2)		Not applicable				
(iii)(a)(3)						
(iii)(a)(3)	DBA1	P_m	1.0 S_{mc}	22,000	22,596*	+214
(iii)(a)(3)						
(iii)(a)(3)	DBA1	P_L+P_b+Q	3.0 S_{ml}	80,100	77,517	+100
	DBA2	P_m	1.0 S_{mc}	22,000	2,457	+103
	DBA2	P_L+P_b+Q	3.0 S_{ml}	80,100	21,405	+100

*Can be classified as P_L

Level C Service Limits

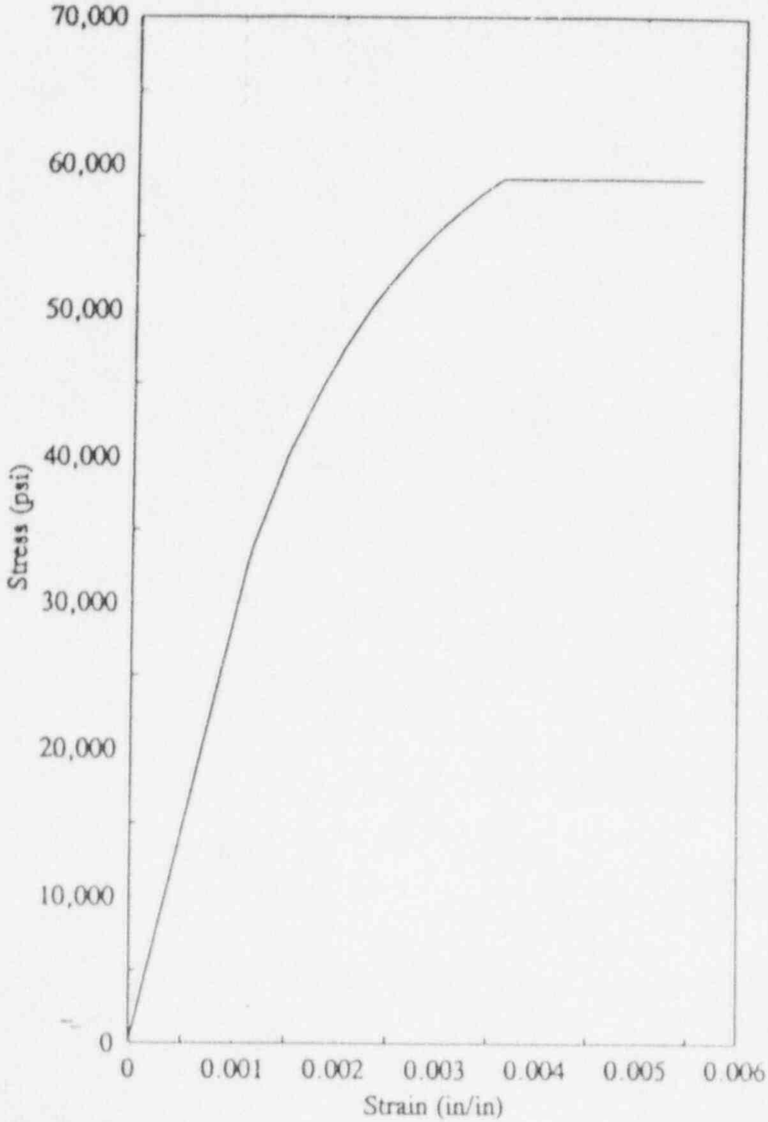
SRP Ref. Number	Load Combination	Design Allowable Stress Intensity Limit (psi)			Maximum Value as per Stress Analysis	
		Type	Limit	Value (psi)	Value (psi)	Elev (ft)
(iii)(c)(2)	OC2	P_m	1.0 S_y	59,000	12,799	100
(iii)(c)(2)	OC3	P_m	1.0 S_y	59,000	4,433	103
(iii)(c)(1)	DBA3	P_m	1.0S_y	52,760	22,878	214
(iii)(c)(1)	DBA4	P_m	1.0S_y	59,000	13,454	100

Level D Service Limits

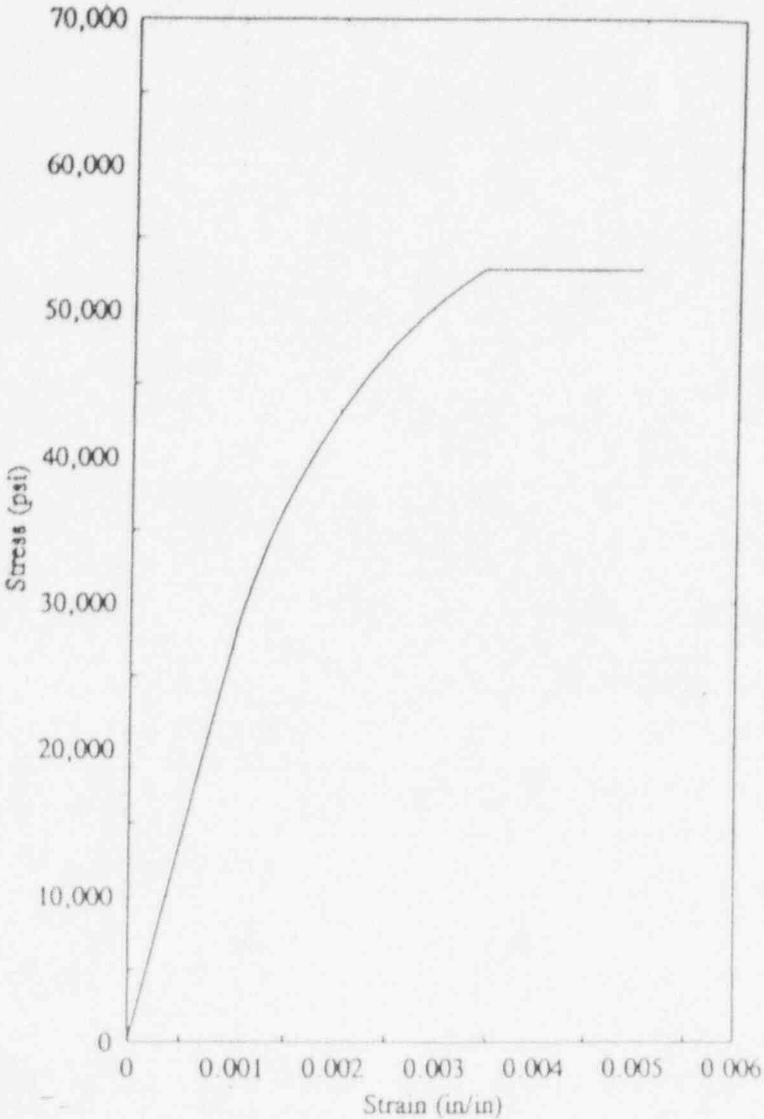
SRP Ref Number	Load Combination	Design Allowable Stress Intensity Limit (psi)			Maximum Value as per Stress Analysis	
		Type	Limit	Value (psi)	Value (psi)	Elev (ft)
(iii)(d)(1)	DBA3	P_m	S_f	47,600	22,878	214
(iii)(d)(1)	DBA4	P_m	S_f	47,600	13,454	100

BUCKLING ANALYSIS

Stress Strain Curve for Temperature of 120°F (Curve A)

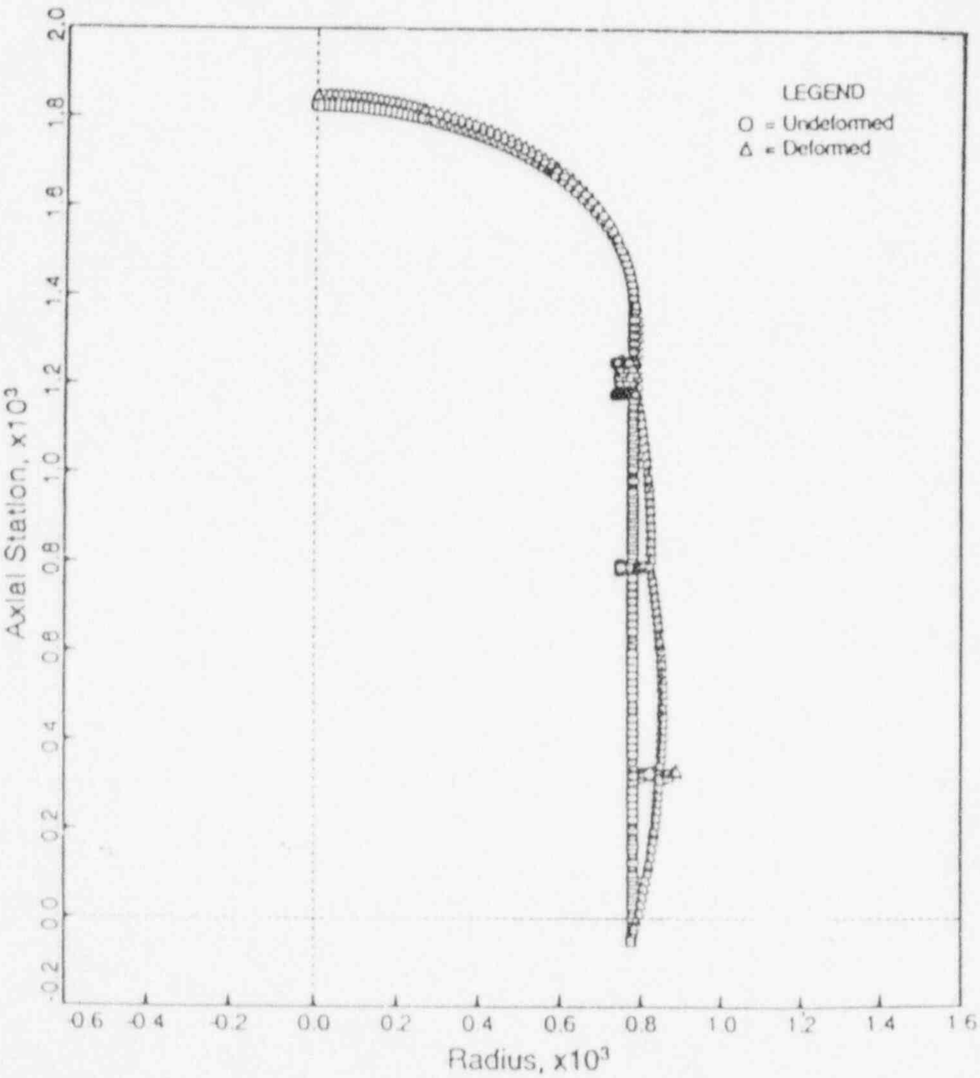


Stress Strain Curve for Temperature of 280°F (Curve B)



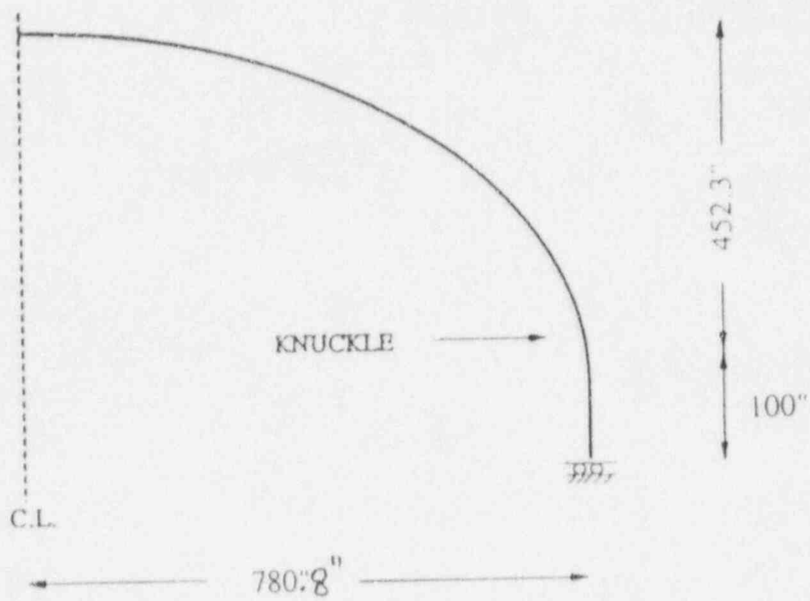
DEFORMED SHAPE OF THE CONTAINMENT

- Load Combination: Design Condition 1 or Design Basis Accident 1
- Loading: Dead Load and Crane Load
  Internal Pressure of 45 psi
  Uniform Temperature of 280°F
- Material: Stress Strain - Curve B
- Geometry: Perfect



- Factor of Safety, λ: 3.10 and was associated with gross tensile yield in the cylinder

Axisymmetric Model of the Top Ellipsoidal Head



Pressure Only (Elastic-Plastic, Perfect)

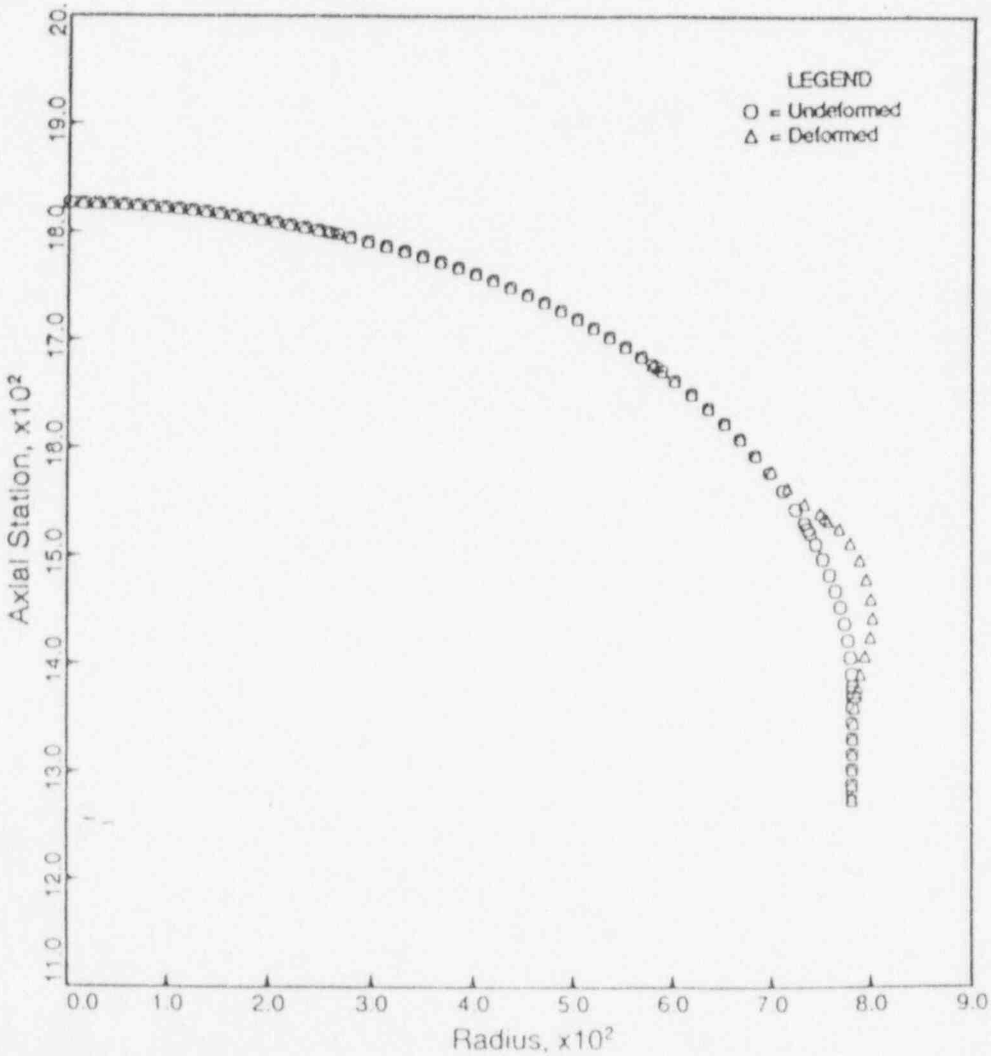
Ames Lab	171 psig
CB&I	174 psig

BUCKLED SHAPE OF THE TOP ELLIPSOIDAL HEAD

- **Load Combination**: Design Condition 1 or Design Basis Accident 1
- **Loading:** Dead Load

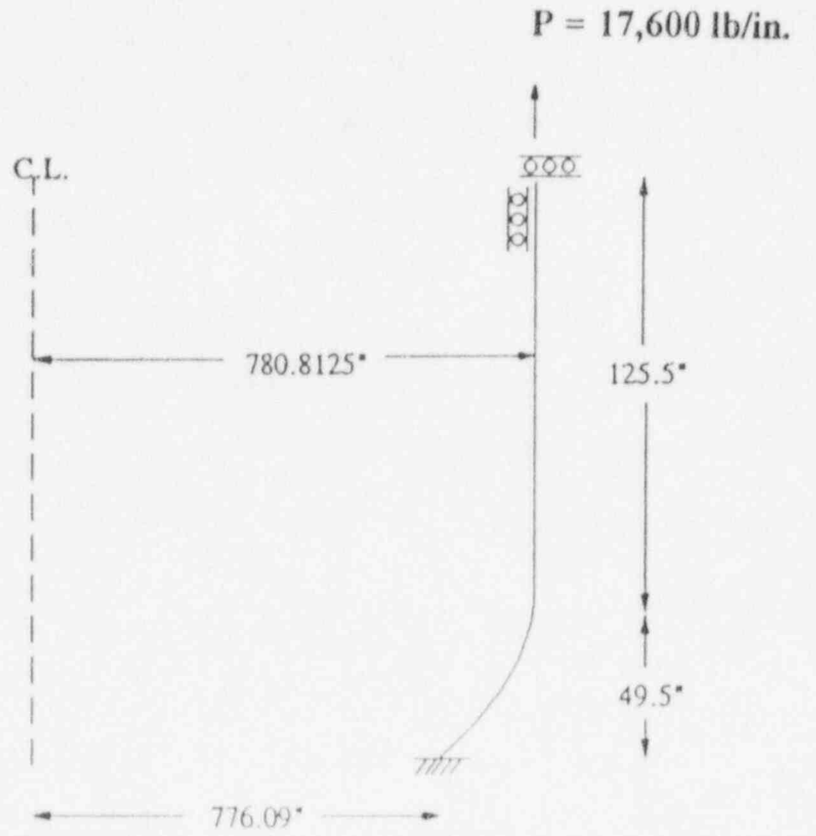
  Internal Pressure of 45 psi

  Uniform Temperature of 280 °F
- **Material:** Stress Strain Curve - Curve B
- **Geometry:** Imperfect, K = 13.5, n = 35



- **Factor of Safety, λ**: 3.52
- **Failure Mode**: Buckle formation in the Compressive Zone

Axisymmetric Model of the Bottom Ellipsoidal Head
(Note: Radial Dimension is Distorted)

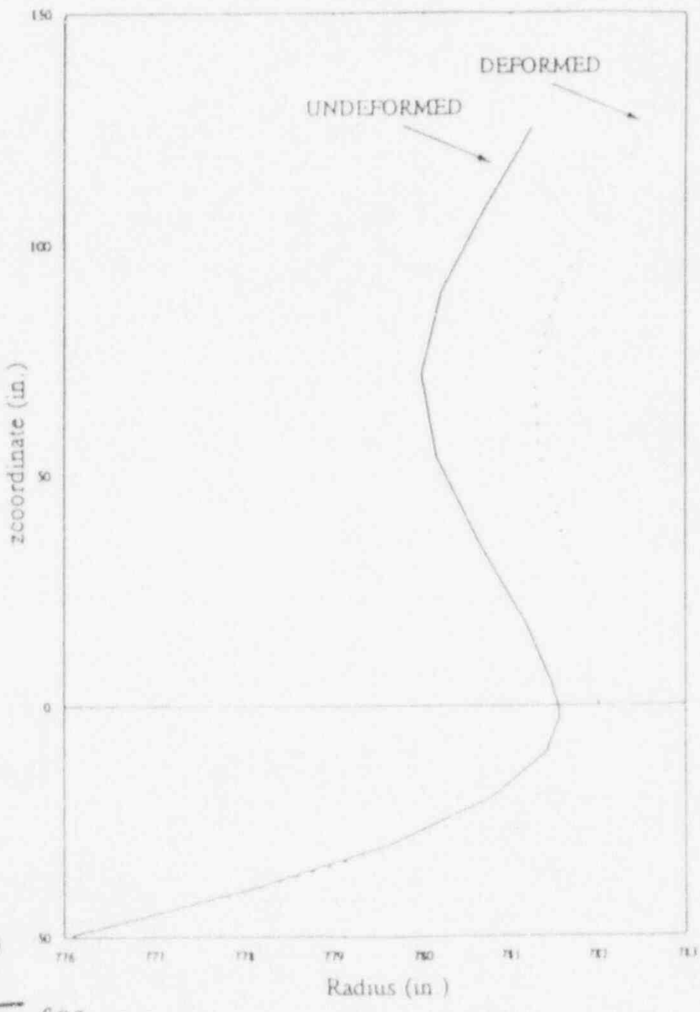


DEFORMED SHAPE OF THE CONTAINMENT

- **Load Combination**: Design Condition 1 or Design Basis Accident 1
- **Objective**: Assess Performance of Bottom Ellipsoidal Head
- **Loading**: Dead

  Internal Pressure of 45 psi

  Uniform Temperature of 280°F
- **Material**: Stress Strain - Curve B
- **Geometry**: Imperfect, K = 4.5



- **Factor of Safety, λ**: 4.90

  ~~(CB&I, λ = 6.00)~~ CBI did temp. only
- **Failure Mode**: Gross Tensile Yield at Base

SUMMARY - DESIGN CONDITION 1 or DBA 1

- LOADS

  DEAD LOAD

  LIVE LOAD

  INTERNAL PRESSURE 45 psi

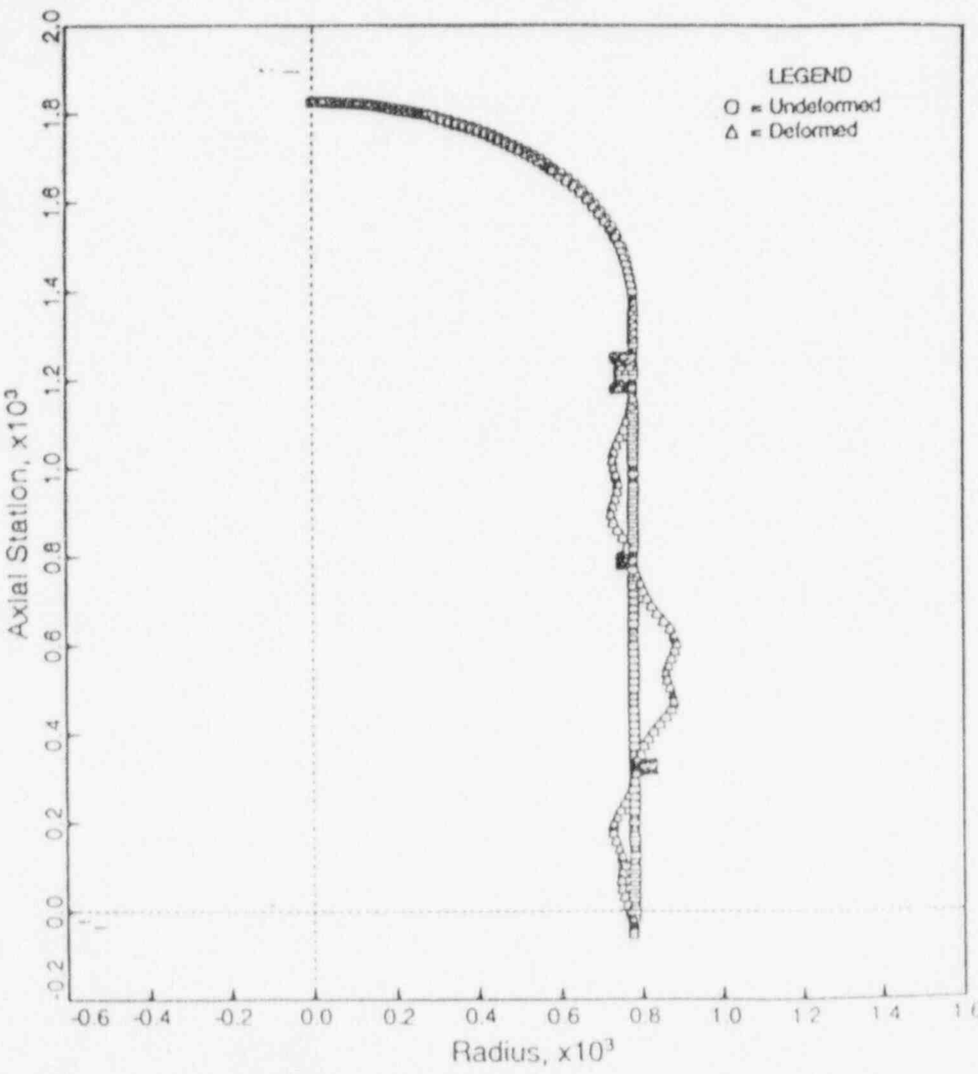
  TEMPERATURE 280°F

- FACTORS OF SAFETY

  1. Overall Failure of the Containment = 3.10
  2. Failure of the Upper Ellipsoidal Head = 3.52
  3. Failure of the Lower Ellipsoidal Head = 4.90

DEFORMED SHAPE OF THE CONTAINMENT

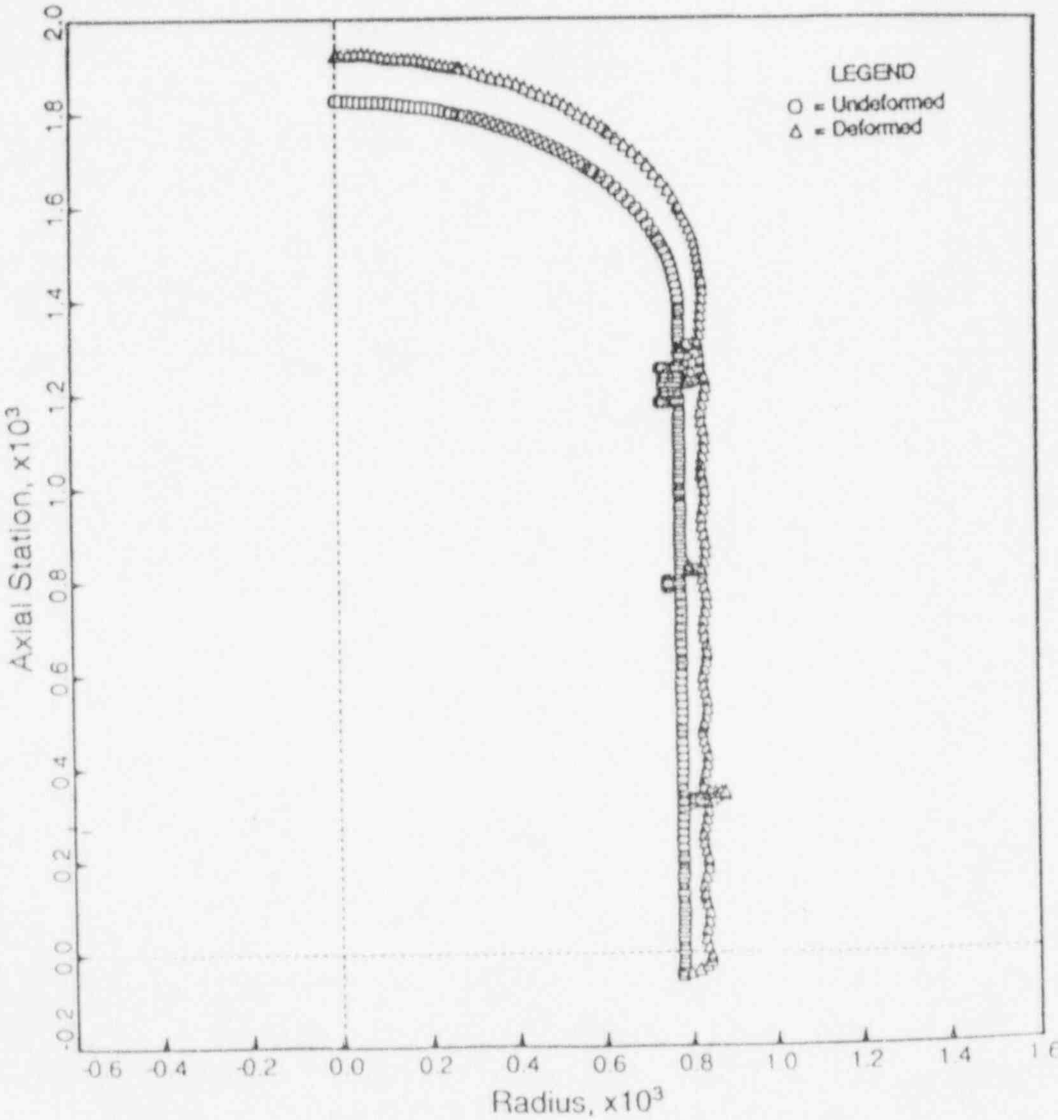
- **Load Combination: Design Condition 2 or Design Basis Accident 2**
- **Loading: Dead Load and Crane Load, External Pressure of 2.5 psi and Uniform Temperature of 120°F**
- **Material: Stress Strain - Curve A**
- **Geometry: Imperfect, K = 4**



- **Failure Mode: Buckling Between Upper and Lower Heads**
- **No. of Circumferential Waves: 14**
- **Factor of Safety, λ: 3.03**

DEFORMED SHAPE OF THE CONTAINMENT

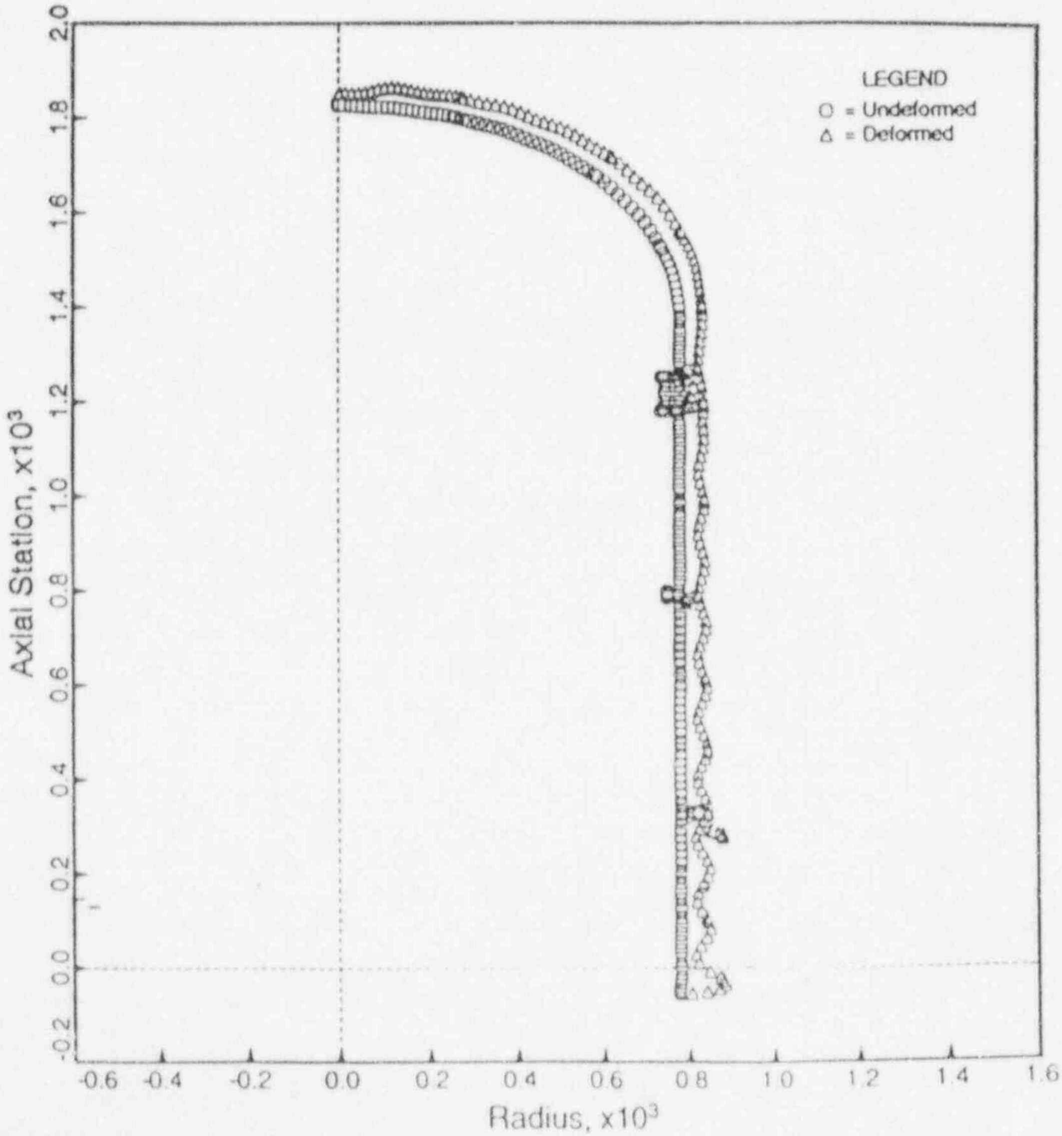
- **Load Combination: Operating Condition 1**
- **Loading:** **Dead Load and Crane Load, Internal Pressure of 1.0 psi, and Uniform Temperature of 120°F**
  Lateral Load due to Operating Wind @ 110 mph
- **Material:** **Stress Strain Curve - Curve A**
- **Geometry:** **Imperfect, K = 3.0**



- **Failure Mode: Gross Yield at Base, Factor of Safety, λ: 7.10**

DEFORMED SHAPE OF THE CONTAINMENT

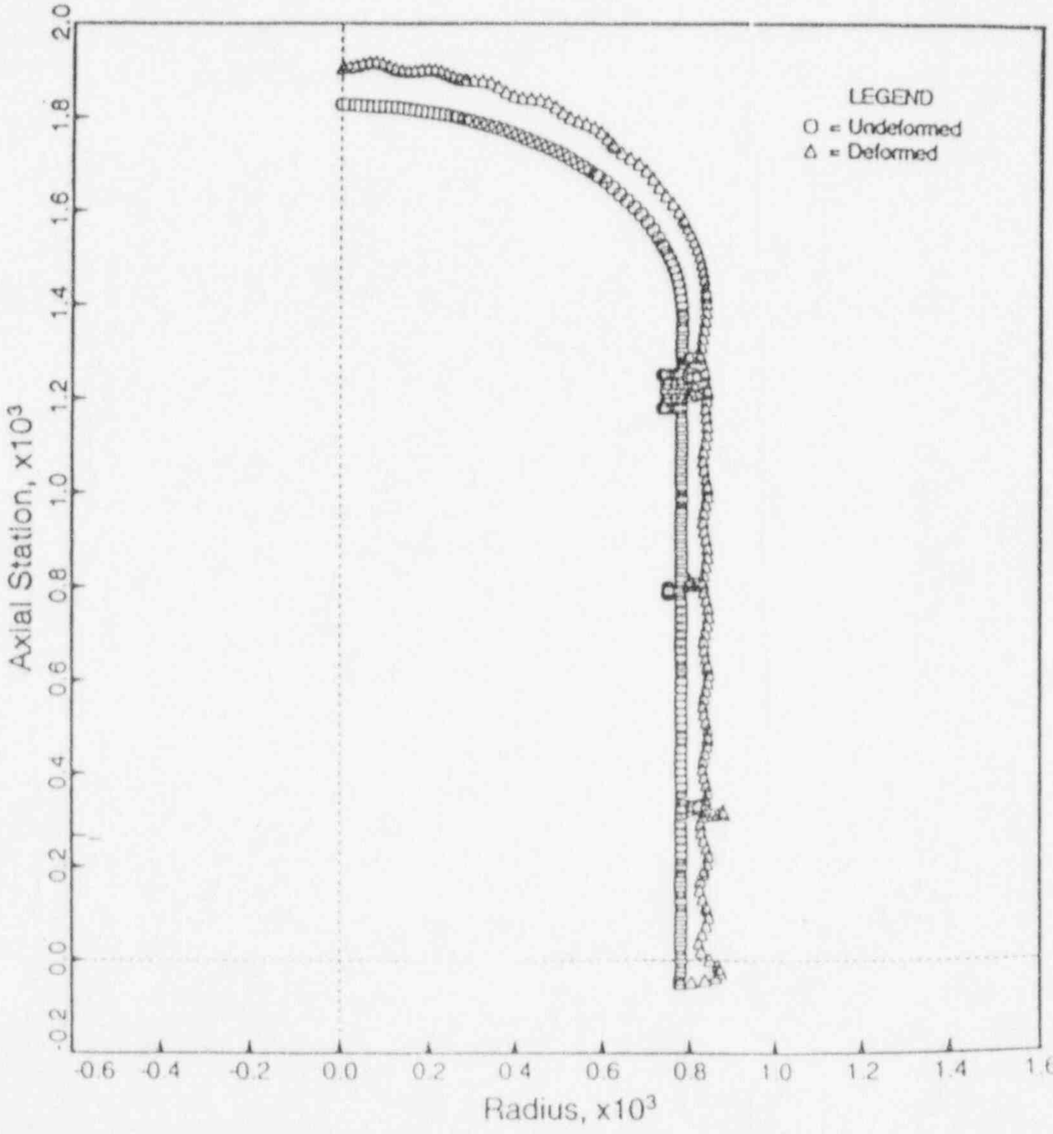
- **Load Combination**: Operating Condition 2
- **Loading**: Dead Load and Crane Load, Internal Pressure of 1.0 psi, Uniform Temperature of 120°F and SSE
- **Material**: Stress Strain Curve - Curve A
- **Geometry**: Imperfect, K = 3.5



- **Failure Mode**: Gross Yield at Base
- **Factor of Safety, λ**: 3.80

DEFORMED SHAPE OF THE CONTAINMENT

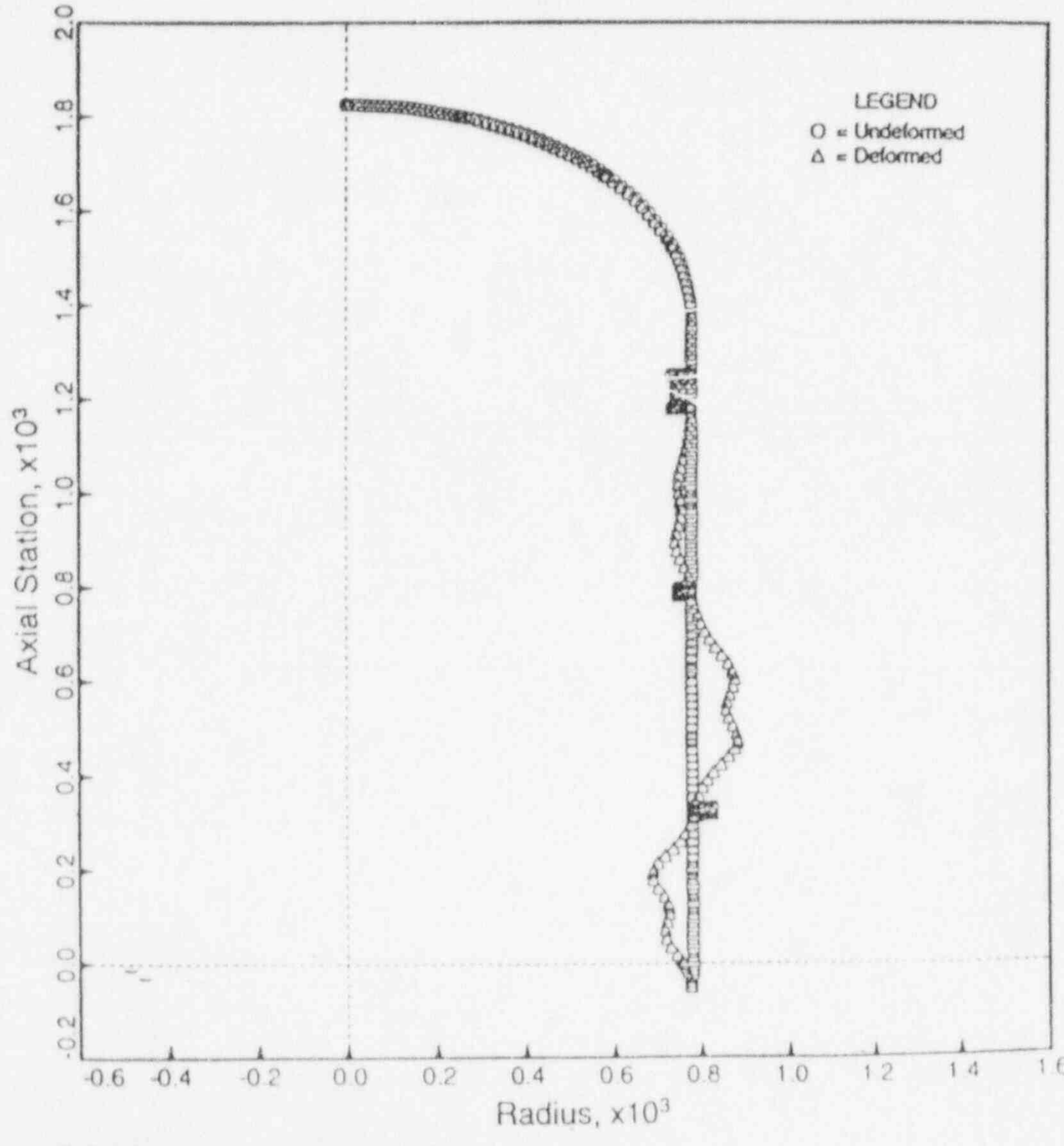
- **Load Combination**: Operating Condition 3
- **Loading**: Dead Load and Crane Load, Internal Pressure of 1.0 psi, Uniform Temperature of 120°F, and Lateral Load Due to Tornado @ 300 mph
- **Material**: Stress Strain Curve - Curve A
- **Geometry**: Imperfect, K = 3.5



- **Failure Mode**: Gross Yield at Base, **Factor of Safety**, λ: 5.20

BUCKLED SHAPE OF THE CONTAINMENT

- **Load Combination: Design Basis Accident 4**
- **Loading: Dead Load and Crane Load, External Pressure of 3.0 psi, Uniform Temperature of 120°F and SSE**
- **Material: Stress Strain Curve - Curve A**

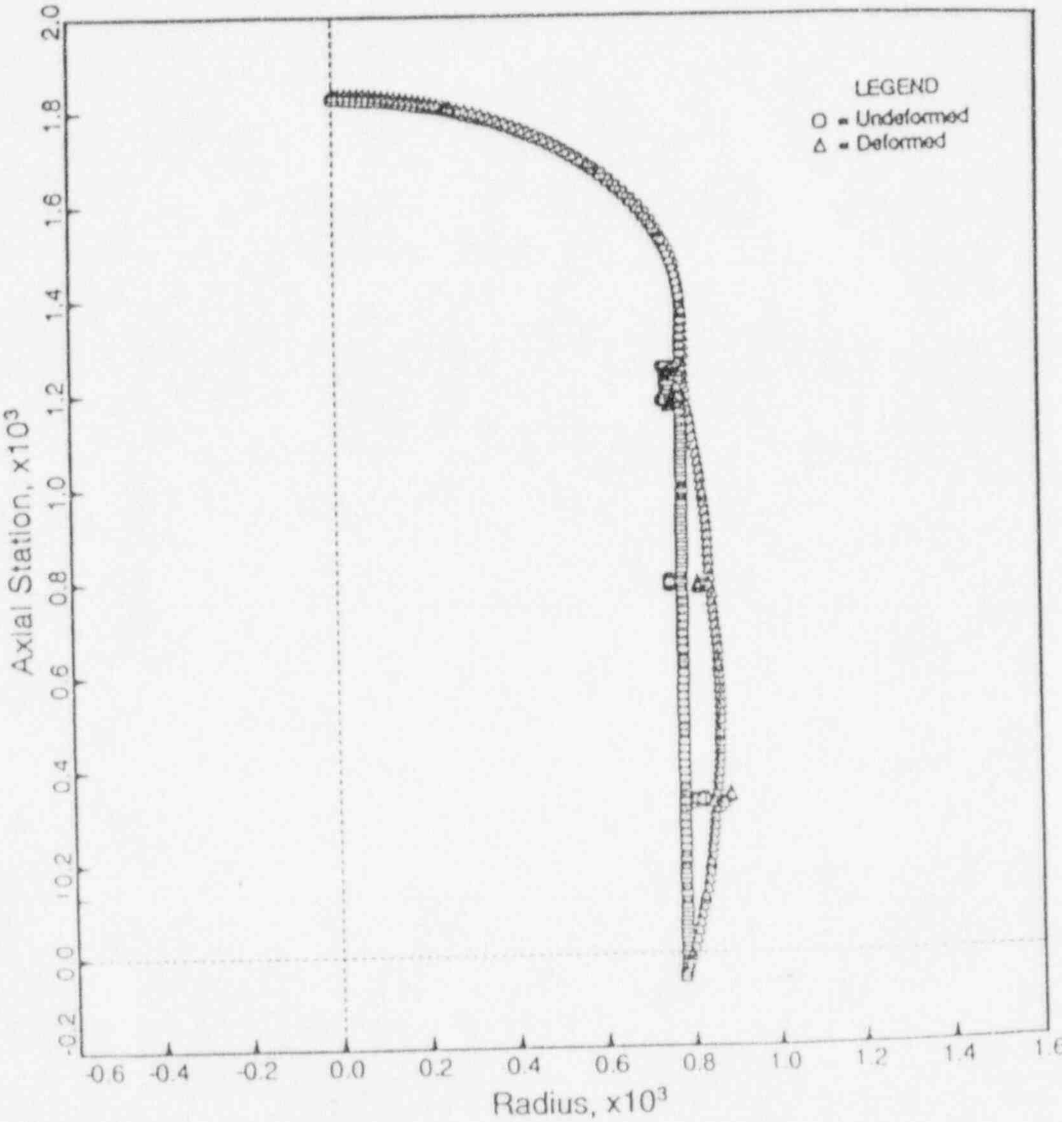


- **Failure Mode: Between Stiffeners**

  No. of Circumferential Waves: 13
- **Factor of Safety, λ: 2.02**

DEFORMED SHAPE OF THE CONTAINMENT

- **Load Combination**: **Design Basis Accident 3**
- **Loading:** **Dead Load and Crane Load, Internal Pressure of 45 psi, Uniform Temperature of 280°F, and SSE**
- **Material:** **Stress Strain Curve - Curve B**
- **Geometry:** **Imperfect, K = 3.5**



- **Failure Mode**: **Gross Yield at Base**
- **Factor of Safety, λ**: **3.20**

BUCKLING FACTORS OF SAFETY

S.R.P. Reference Number	Load Combination	Factor of Safety	Buckling Location
DESIGN CONDITIONS			
(ii)	DG1	3.10	General tenile yield in the Cylinder
(ii)	DG2	3.03	Buckling between upper and lower stiffeners
LEVEL A SERVICE LIMITS			
(iii)(a)(1)	OC1	7.10	Gross Yield near the base
(iii)(a)(2)	Not applicable		-
(iii)(a)(3)	DBA1	3.10	General tensile yield in the Cylinder
(iii)(a)(3)	DBA2	3.03	Buckling between upper and lower stiffeners
LEVEL C SERVICE LIMITS			
(iii)(c)(1)	DBA3	3.20	Gross yield at base
(iii)(c)(1)	DBA4	2.02	Between base and lower stiffener
(iii)(c)(2)	OC2	3.80	Gross yield near the base
(iii)(c)(2)	OC3	5.20	Gross yield near the base
LEVEL D SERVICE LIMITS			
(iii)(d)(1)	DBA3	3.20	Gross yield at base
(iii)(d)(1)	DBA4	2.02	Between base and lower ring

SEISMIC LIMIT ANALYSIS

- **LOADING AND SOLUTION PROCEDURE**

Buckling Load = D+ αE

Where:

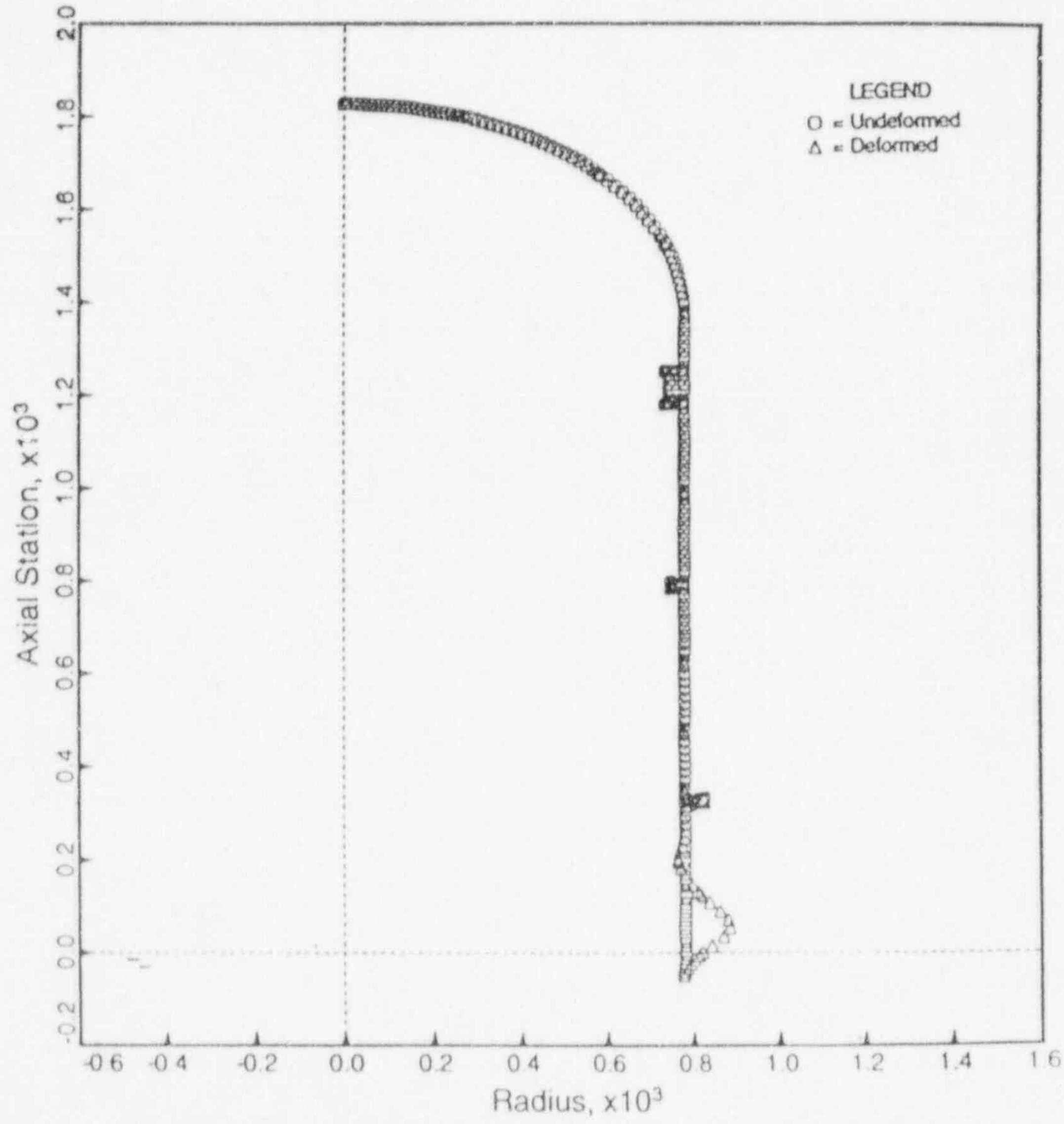
α = Buckling Load Multiplier

D = Dead Load

E = Seismic Loads

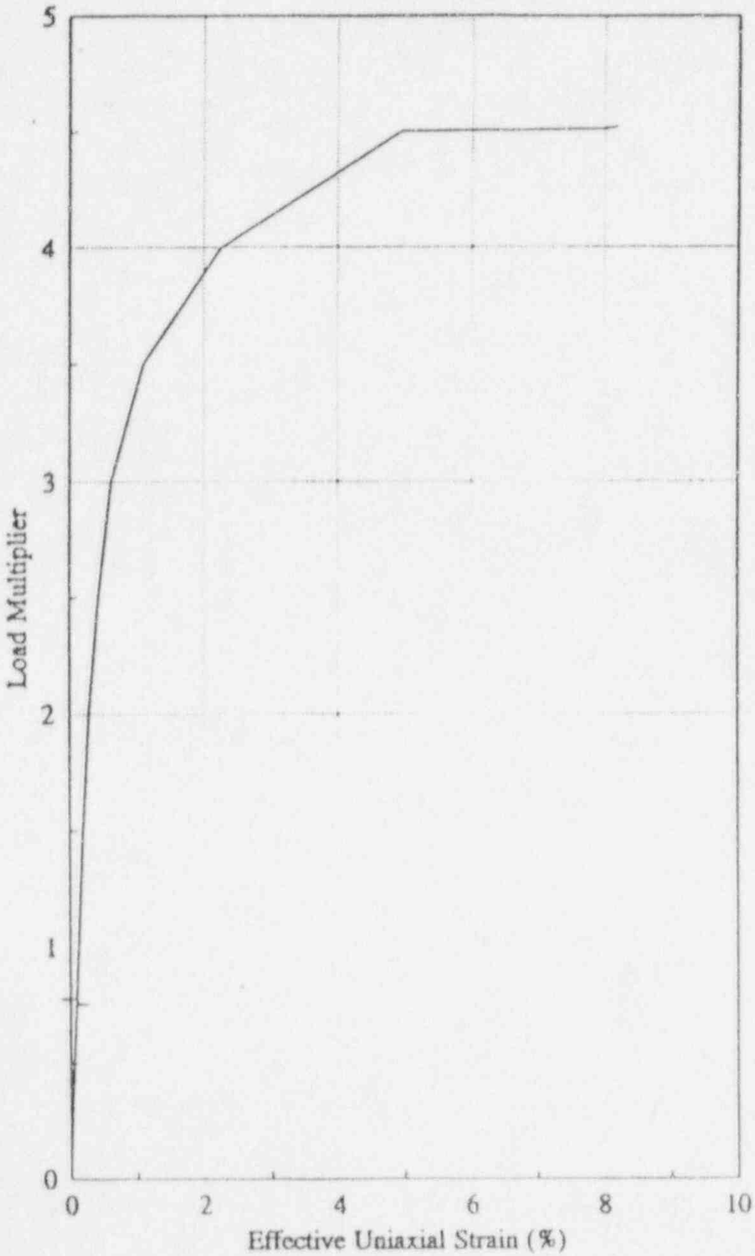
BUCKLED SHAPE OF THE CONTAINMENT

- Load Combination: Seismic Limit Analysis
- Loading: Dead Load and Crane Load and SSE
- Material: Effective Stress Strain Curve
- Geometry: Imperfect, K = 4.0



- Seismic Load Factor, α: 4.67
- Failure Mode: Local, Between Lower Stiffener and Base, n=13

Variation of Effective Uniaxial Strain With Load Multiplier (Seismic Limit Loading)



SUMMARY OF BUCKLING ANALYSIS

- Design Conditions and Level A Service Limits:

  Controlling Load Case: Design Basis Accident 2

  Loading: Dead Load and Crane Load
  External Pressure of 2.5 psi
  Uniform Temperature of 120°F

  Factor of Safety, λ: 3.03

  Satisfies ASME Section NE 3222.2 and ASME Code Case N-284

- Level C Service Limits:

  Controlling Load Case: Design Basis Accident 4

  Loading: Dead Load and Crane Load
  External Pressure of 3.0 psi
  Uniform Temperature of 120°F
  Safe Shutdown Earthquake

  Factor of Safety, λ: 2.02

  Satisfies Reg. Guide 1.57 (F.S. = 2) and ASME Code Case N-284 (F.S. = 1.67)
  Does not Satisfy ASME Section NE 3222.2 (F.S. = 2.5)

- Level D Service Limits:

Controlling Load Case: Design Basis Accident 4

Satisfies ASME Section NE 3222.2, Reg. Guide 1.57 and ASME Code Case N-284

- Seismic Limit Analysis:

Loading: Dead Load and Crane Load

Safe Shutdown Earthquake

Seismic Load Factor, α = 4.67

3D ANALYSIS OF AP600

PART I : MESH PARAMETERS

PART II : MODE FREQUENCY ANALYSIS

PART III : RESPONSE SPECTRUM ANALYSIS

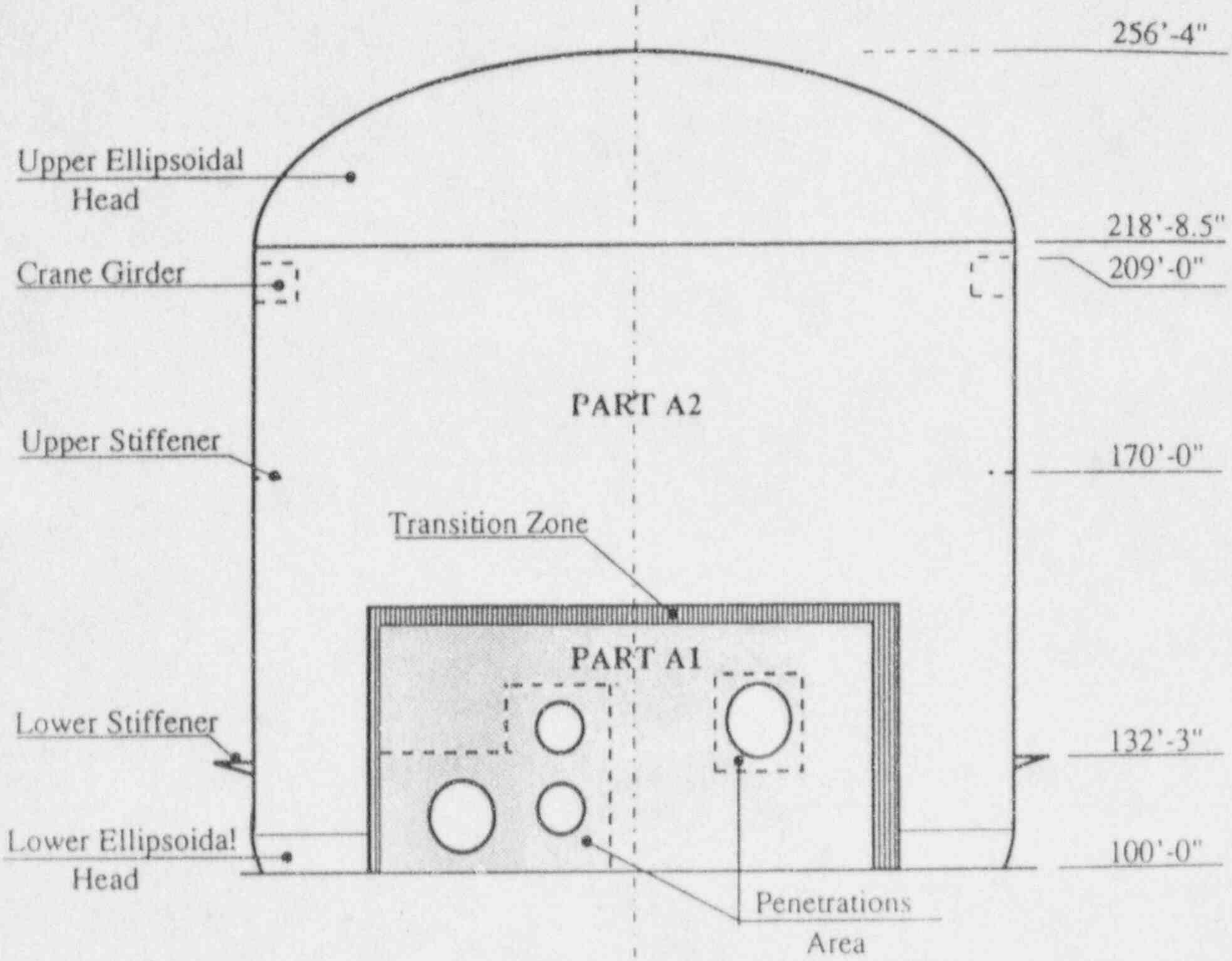
PART IV : BUCKLING ANALYSIS

PART V : ASYMMETRIC TEMPERATURE ANALYSIS

PART I: MESH PARAMETERS

A. Mesh Guidelines:

- Discretization of AP600



Elevation View of AP600 Steel Containment

B. Cylindrical Containment:

Elements Size:

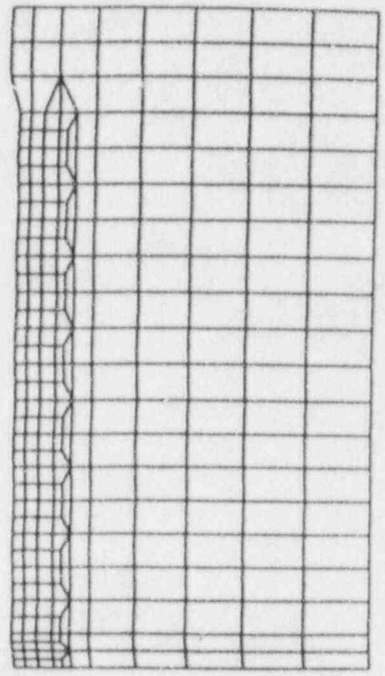
Part A1: $0.375\sqrt{rt}$ x $0.75\sqrt{rt}$

Part A2: $0.75\sqrt{rt}$ x $1.50\sqrt{rt}$

Transition Zone:

S8R5 (Quadrilateral Elements)

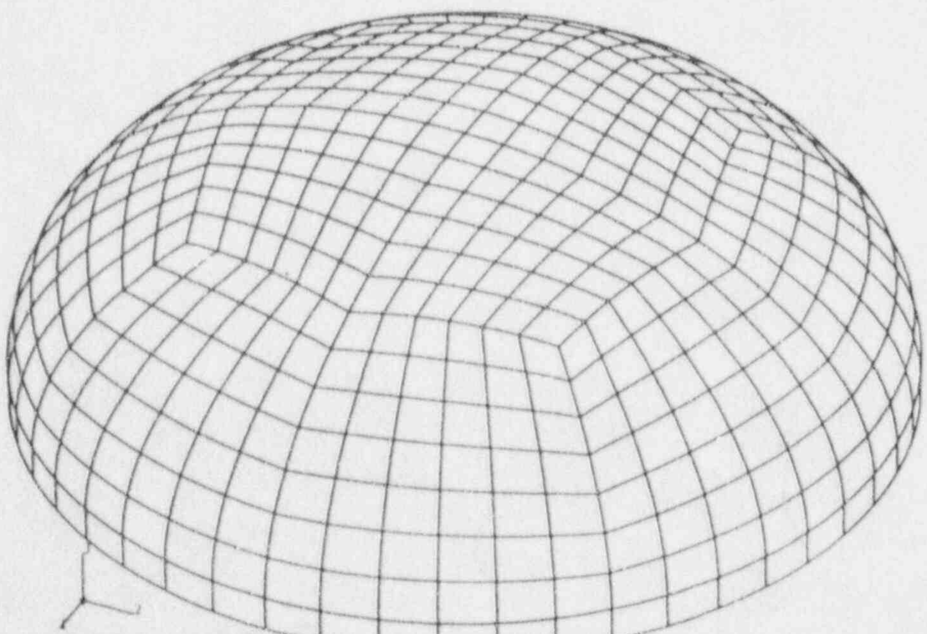
STRI65 (Triangular Elements)



Cylinderical Portion

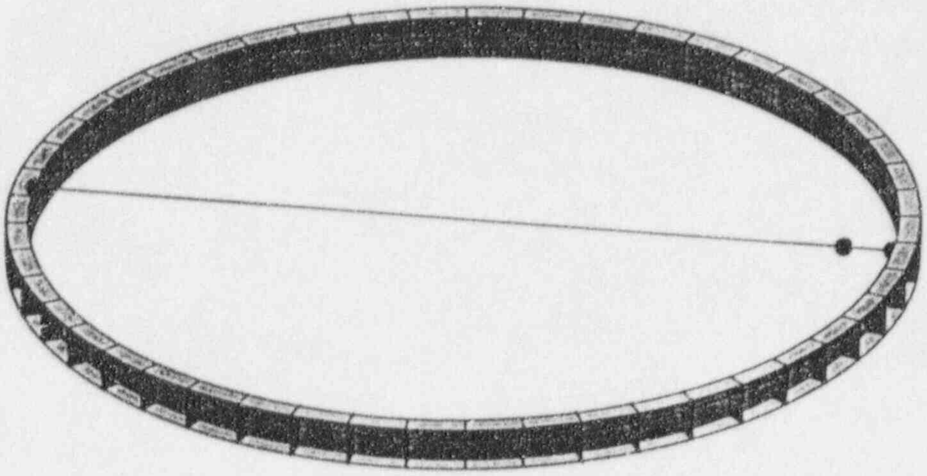
C. Ellipsoidal Head:

Elements Size: $2.10\sqrt{rt}$ x $1.50\sqrt{rt}$

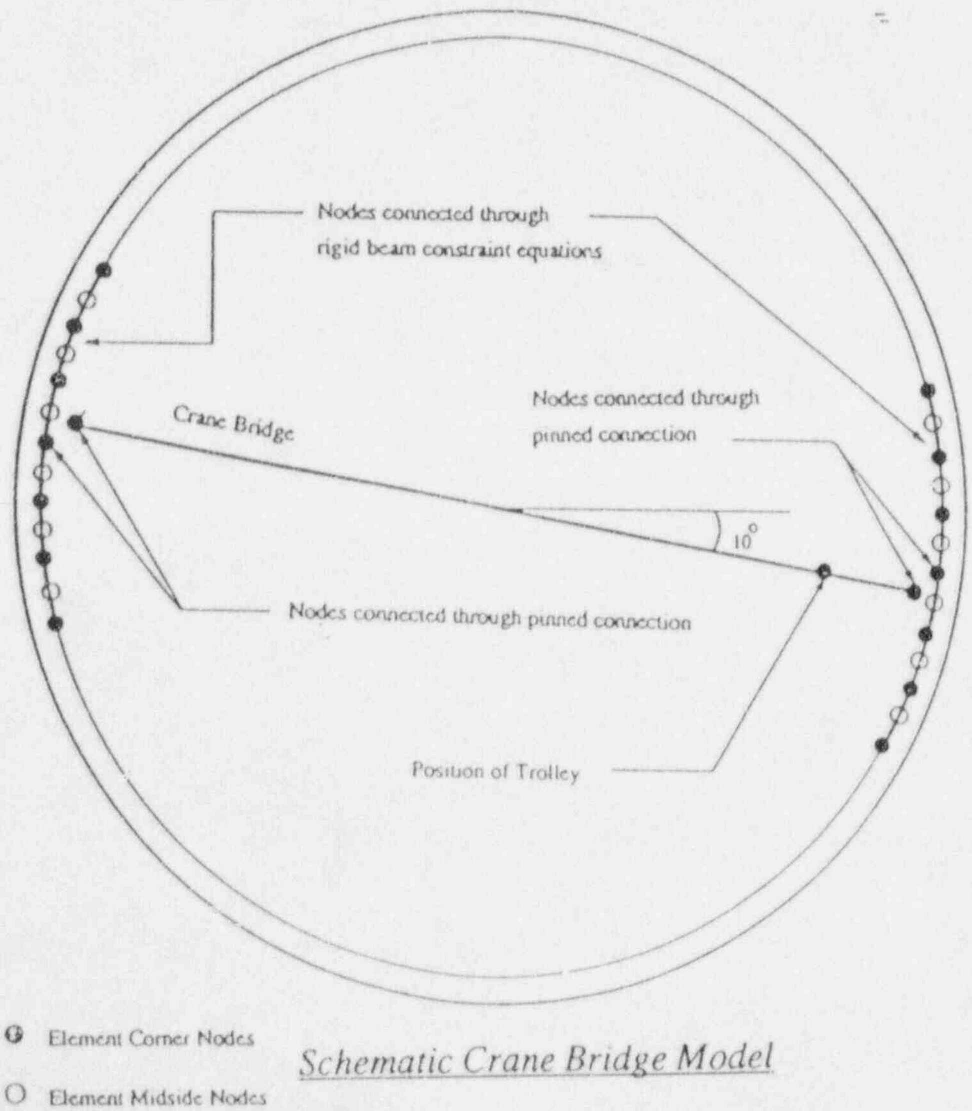


Ellipsoidal Head

D. Crane Girder and Bridge:



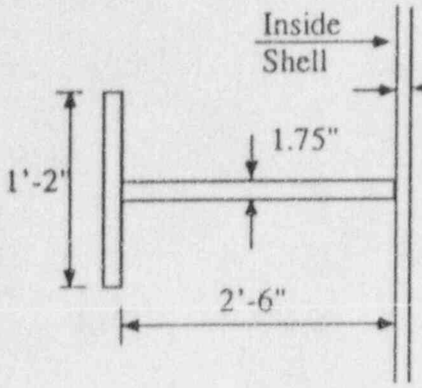
Finite Element Model of Crane Girder and Bridge



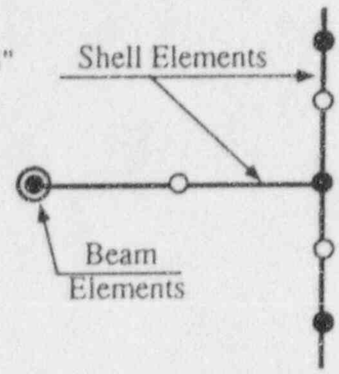
Schematic Crane Bridge Model

E. Stiffeners:

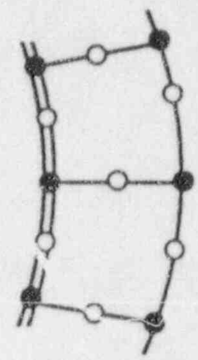
1. Upper Stiffener (Elevation 170'-0")



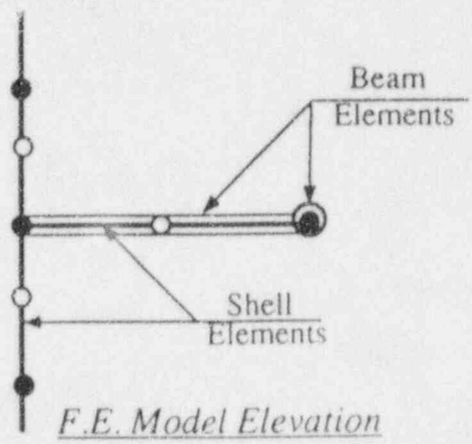
Sectional Elevation



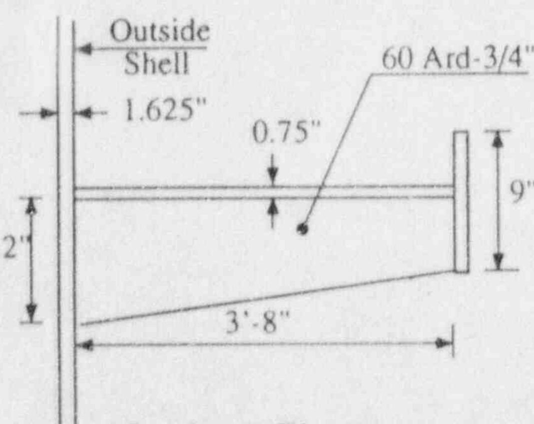
F.E. Model Elevation


Top View

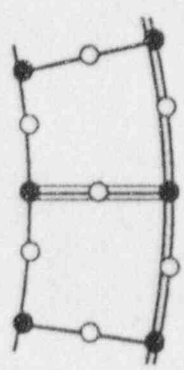
2. Lower Stiffener (Elevation 132'-3")



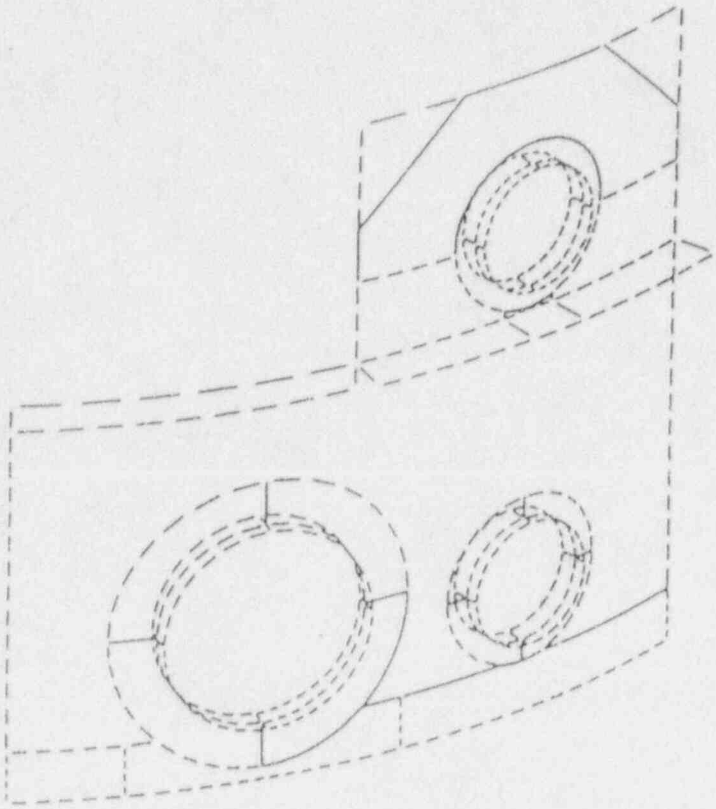
F.E. Model Elevation



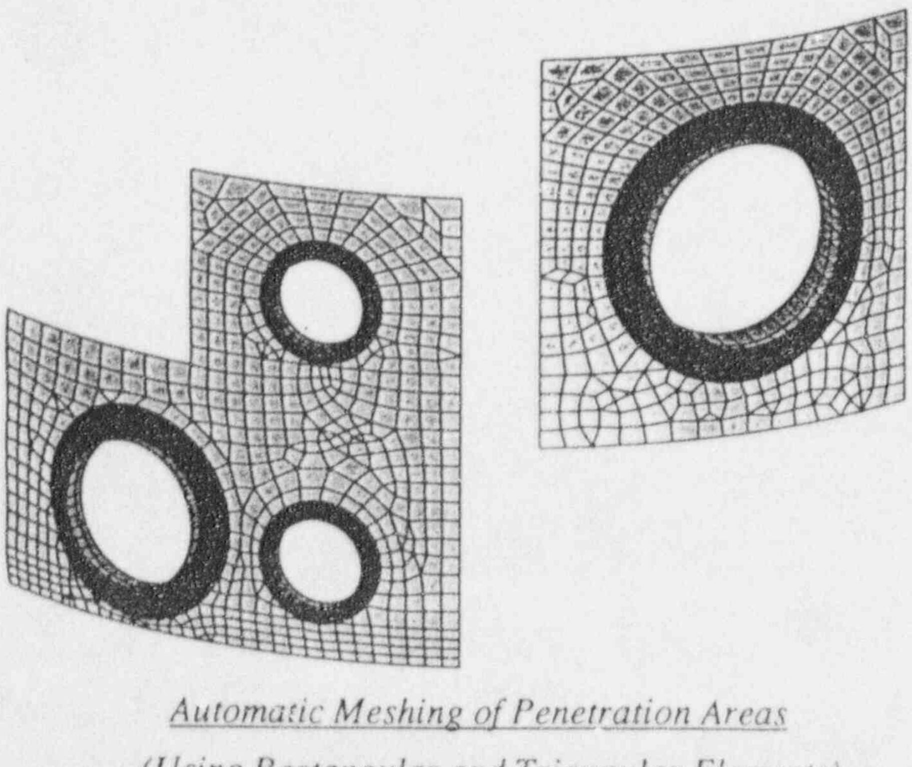
Sectional Elevation


Top View

F. Solid Modeling of Penetration Areas:



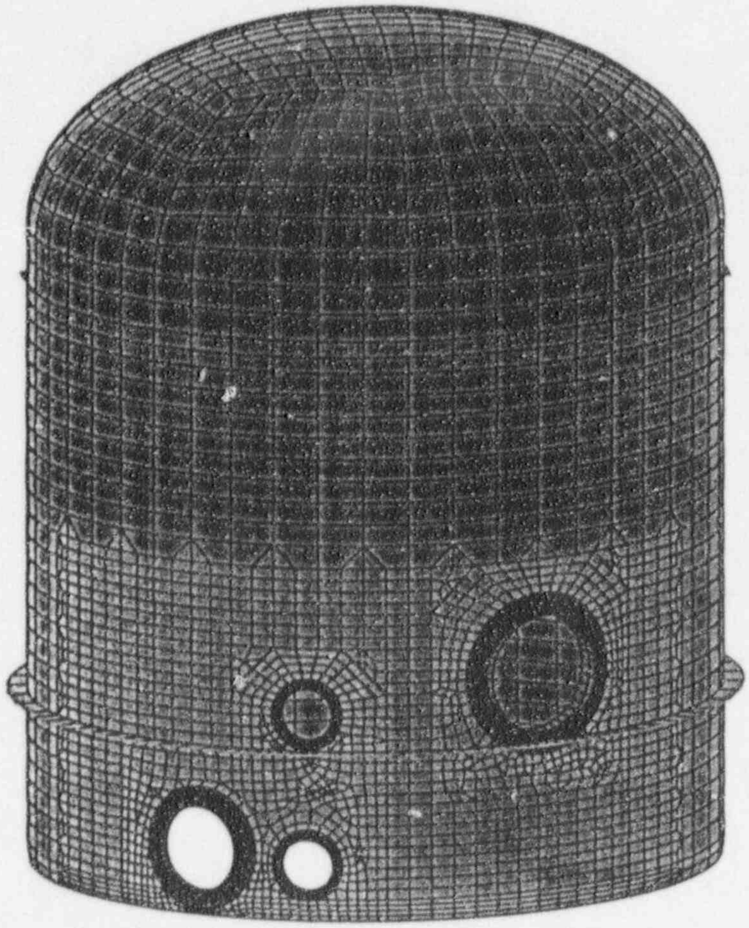
Division of the Model to Different areas for Meshing



Automatic Meshing of Penetration Areas

(Using Rectangular and Triangular Elements)

Three Dimensional Finite Element Model of AP600



Classification According to Thickness

- Number of Nodes = 12063
- Number of Elements = 4282
- Wave Front = 1431

G. Check Runs: Static Analysis with Internal Pressure

Geometric Configuration:

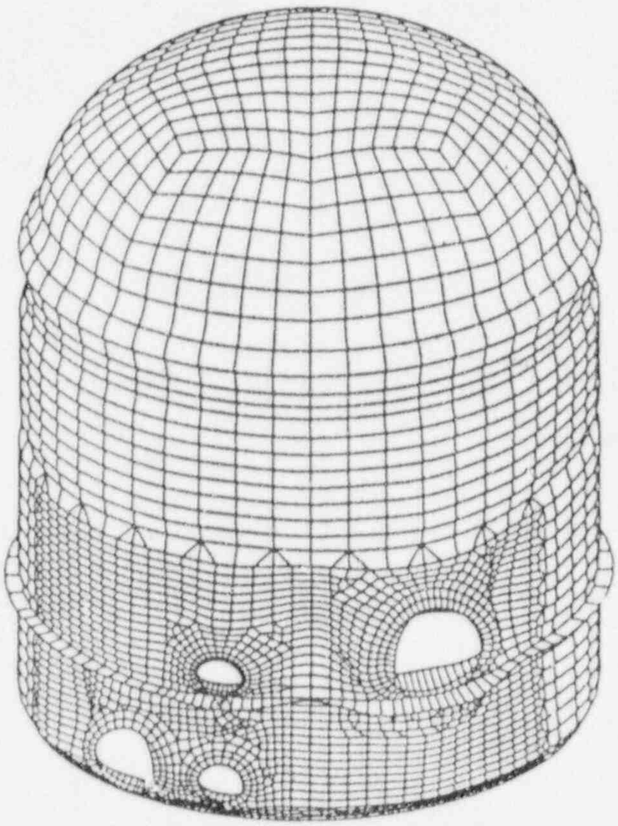
Perfect containment

Material Properties:

$E = 29x10^6$ psi, $\nu = 0.3$

Loading:

Internal pressure, P = 1 psig



Deformed Shape

Comparison of Stress Resultants with Theory

Stress Resultants	Theory	F.E. Results	%Error
In Hoop Direction (lb/in)	780	793	2.0
In Axial Direction (lb/in)	390	404	3.0

G. Check Runs: Inelastic Buckling of AP600 Sector Around Penetrations

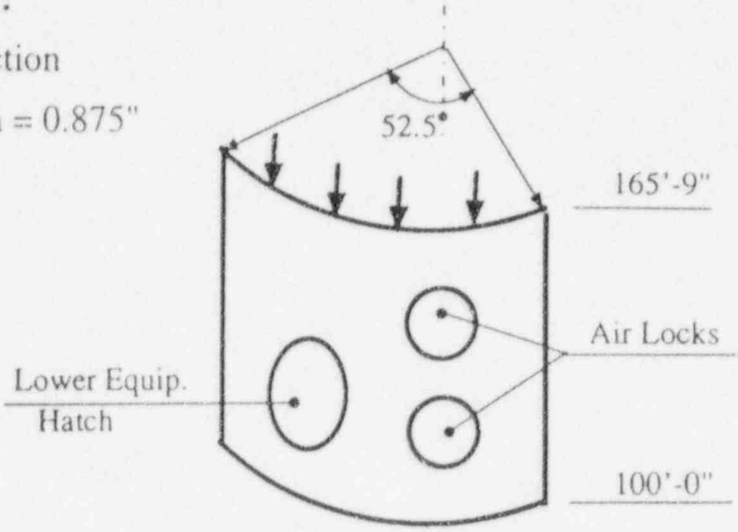
Purpose:

1. Investigate buckling behavior of penetrations area
2. Verify the adequacy of the model in penetrations area

Geometric Configuration:

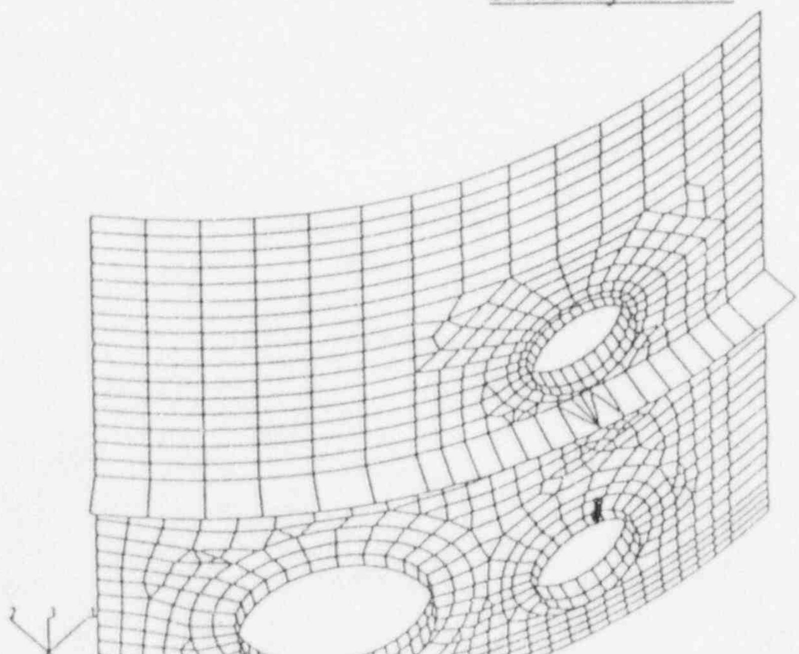
Axisymmetric imperfection

$L_W = 3.5\sqrt{rt}$ $a = 0.875''$



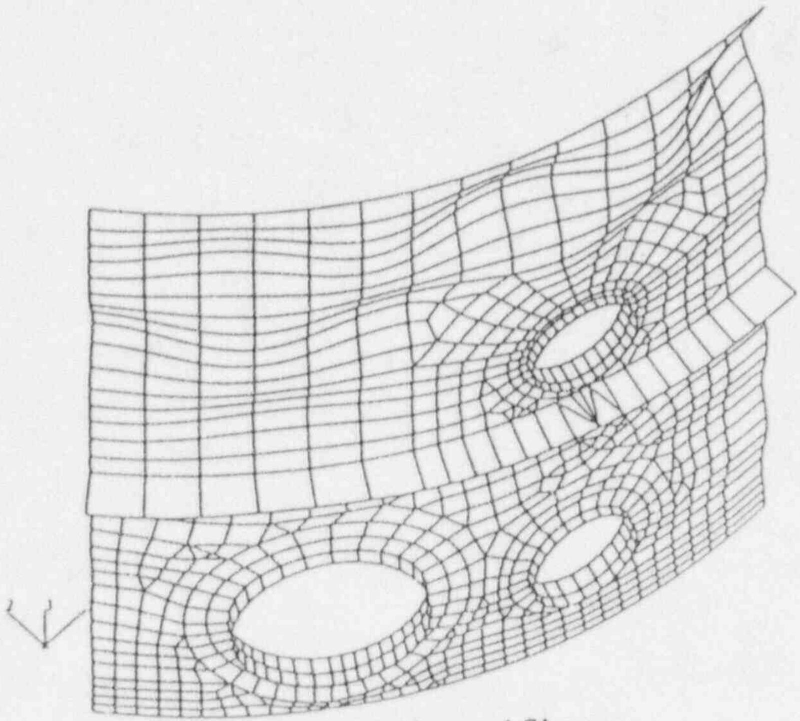
Finite Element Model:

Sector of AP600

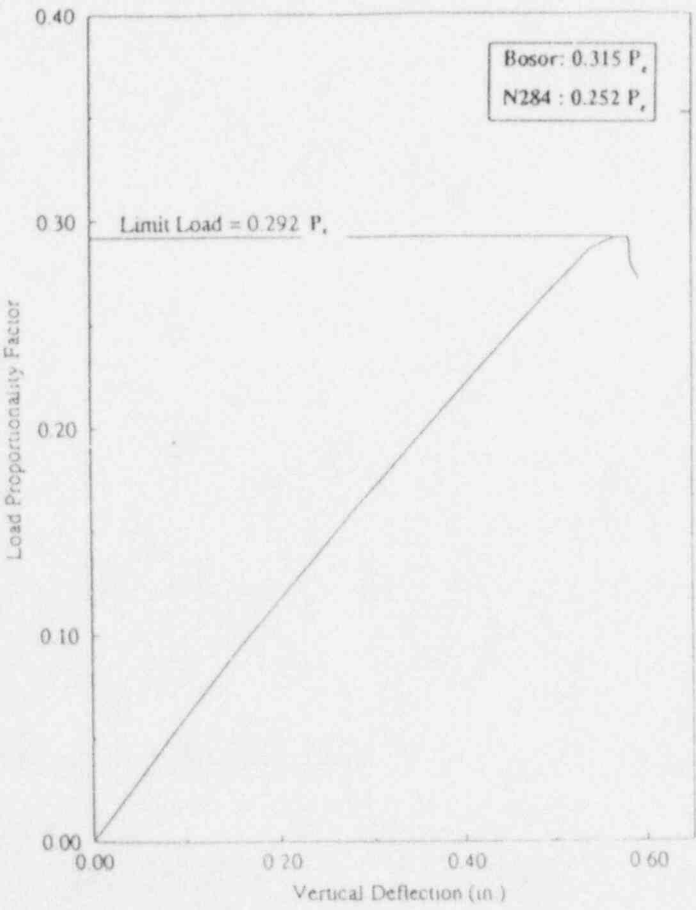


Finite Element Model

Finite Element Results



Deformed Shape



PART II: MODE FREQUENCY ANALYSIS

Probiem Configuration:

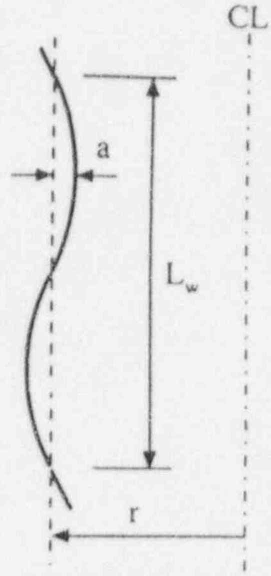
Elastic Material

Axisymmetric imperfection

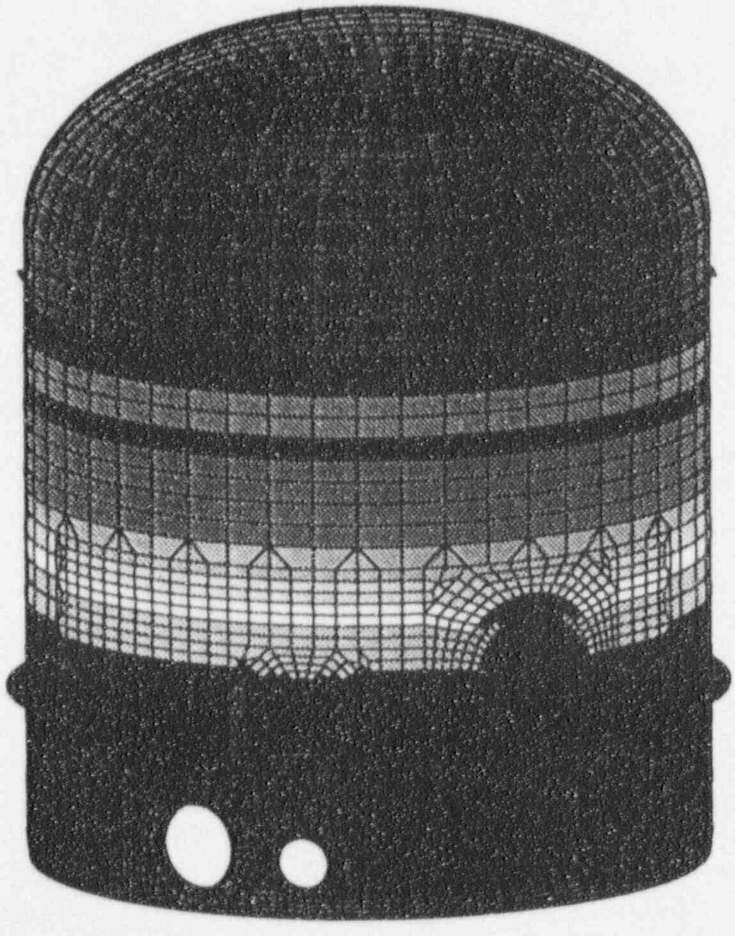
Mass of attachments smeared around circumference

Methodology:

Subspace iteration to extract the first 273 modes



Imperfection Along a Meridian



Classification According to Density

NATURAL FREQUENCIES OF AP600

Mode	Freq (Hz)	Mode	Freq (Hz)	Mode	Freq (Hz)
1	3.6859	33	8.6322	65	9.7921
2	5.9103	34	8.7485	66	9.8587
3	6.0739	35	8.8262	67	9.8829
4	6.3589	36	8.8694	68	9.9542
5	6.6476	37	8.9837	69	10.001
6	6.8504	38	8.9872	70	10.086
7	6.9049	39	9.0408	71	10.125
8	6.9649	40	9.0673	72	10.212
9	7.0101	41	9.0962	73	10.253
10	7.0573	42	9.1759	74	10.3
11	7.168	43	9.2241	75	10.346
12	7.1819	44	9.2695	76	10.358
13	7.2806	45	9.3155	77	10.411
14	7.3356	46	9.3866	78	10.506
15	7.3482	47	9.4372	79	10.593
16	7.4406	48	9.4459	80	10.624
17	7.6303	49	9.4581	81	10.625
18	7.7072	50	9.5169	82	10.649
19	7.7664	51	9.535	83	10.657
20	7.8433	52	9.5458	84	10.668
21	7.9636	53	9.5585	85	10.744
22	8.117	54	9.5707	86	10.772
23	8.1963	55	9.5781	87	10.833
24	8.2489	56	9.6158	88	10.936
25	8.2741	57	9.6474	89	10.945
26	8.3297	58	9.7083	90	10.981
27	8.3395	59	9.7322	91	11.049
28	8.3866	60	9.7408	92	11.07
29	8.4196	61	9.7544	93	11.114
30	8.4937	62	9.7585	94	11.197
31	8.5722	63	9.7687	95	11.3
32	8.5735	64	9.7822	96	11.33

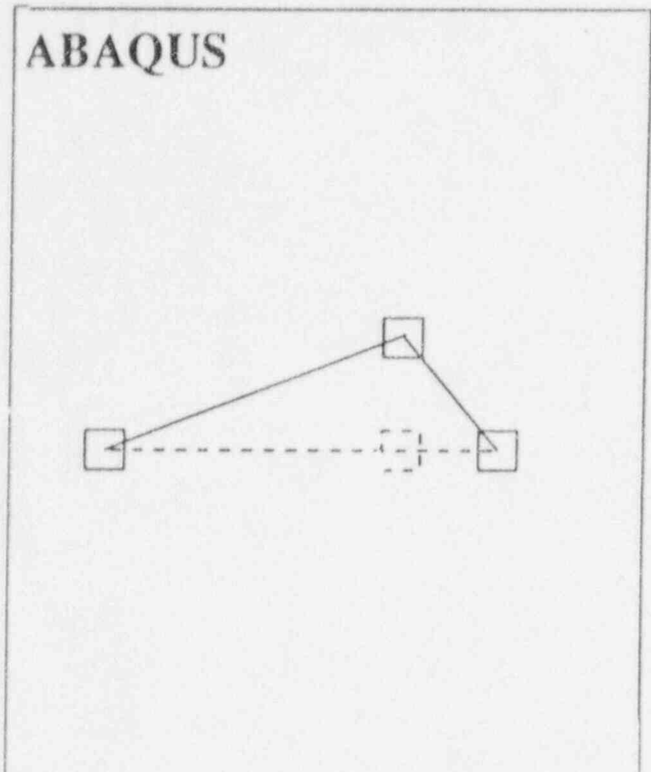
NATURAL FREQUENCIES OF AP600

Mode	Freq (Hz)	Mode	Freq (Hz)	Mode	Freq (Hz)
97	11.544	129	13.503	161	14.594
98	11.597	130	13.531	162	14.623
99	11.613	131	13.536	163	14.674
100	11.643	132	13.544	164	14.678
101	11.659	133	13.589	165	14.709
102	11.674	134	13.634	166	14.727
103	11.758	135	13.688	167	14.83
104	12.099	136	13.707	168	14.833
105	12.165	137	13.714	169	14.849
106	12.24	138	13.809	170	14.892
107	12.254	139	13.84	171	15.019
108	12.344	140	13.883	172	15.072
109	12.398	141	13.94	173	15.127
110	12.541	142	13.955	174	15.178
111	12.574	143	13.975	175	15.201
112	12.583	144	13.993	176	15.229
113	12.586	145	14.021	177	15.309
114	12.893	146	14.096	178	15.377
115	12.922	147	14.102	179	15.384
116	12.95	148	14.152	180	15.396
117	13.059	149	14.169	181	15.554
118	13.065	150	14.234	182	15.574
119	13.151	151	14.242	183	15.596
120	13.166	152	14.262	184	15.611
121	13.198	153	14.288	185	15.65
122	13.225	154	14.307	186	15.727
123	13.247	155	14.329	187	15.739
124	13.281	156	14.335	188	15.787
125	13.31	157	14.38	189	15.921
126	13.365	158	14.403	190	15.998
127	13.412	159	14.552	191	16.04
128	13.439	160	14.585	192	16.137

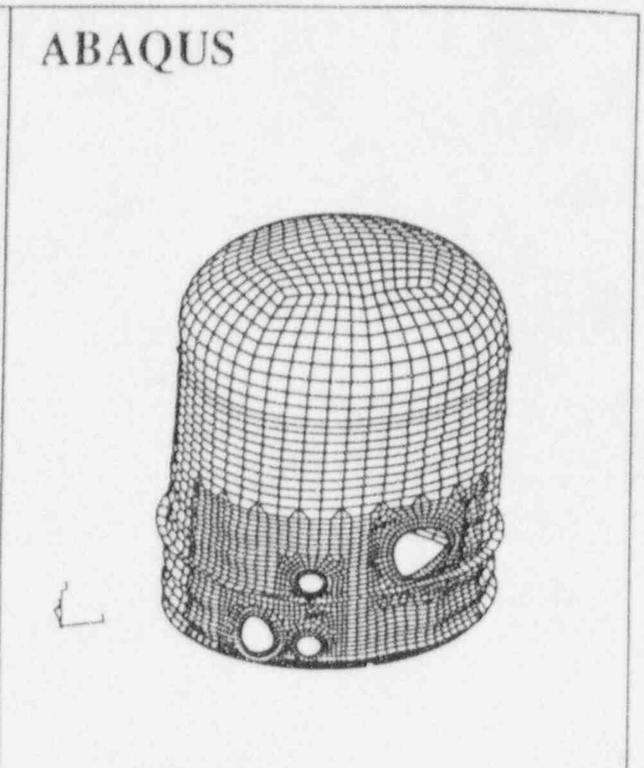
NATURAL FREQUENCIES OF AP600

Mode	Freq (Hz)	Mode	Freq (Hz)	Mode	Freq (Hz)
193	16.165	220	17.234	247	18.685
194	16.22	221	17.266	248	18.773
195	16.271	222	17.305	249	18.816
196	16.357	223	17.36	250	18.95
197	16.376	224	17.454	251	19.005
198	16.396	225	17.462	252	19.025
199	16.415	226	17.517	253	19.099
200	16.457	227	17.565	254	19.141
201	16.489	228	17.603	255	19.147
202	16.517	229	17.615	256	19.159
203	16.547	230	17.649	257	19.297
204	16.586	231	17.649	258	19.345
205	16.612	232	17.665	259	19.362
206	16.686	233	17.721	260	19.482
207	16.732	234	17.776	261	19.491
208	16.759	235	17.908	262	19.513
209	16.789	236	17.971	263	19.526
210	16.834	237	18.027	264	19.555
211	16.872	238	18.127	265	19.682
212	16.913	239	18.138	266	19.849
213	16.925	240	18.163	267	19.919
214	16.963	241	18.192	268	19.974
215	17.01	242	18.388	269	20.066
216	17.08	243	18.42	270	20149
217	17.082	244	18.508	271	20.183
218	17.181	245	18.547	272	20.217
219	17.2	246	18.653	273	20.268

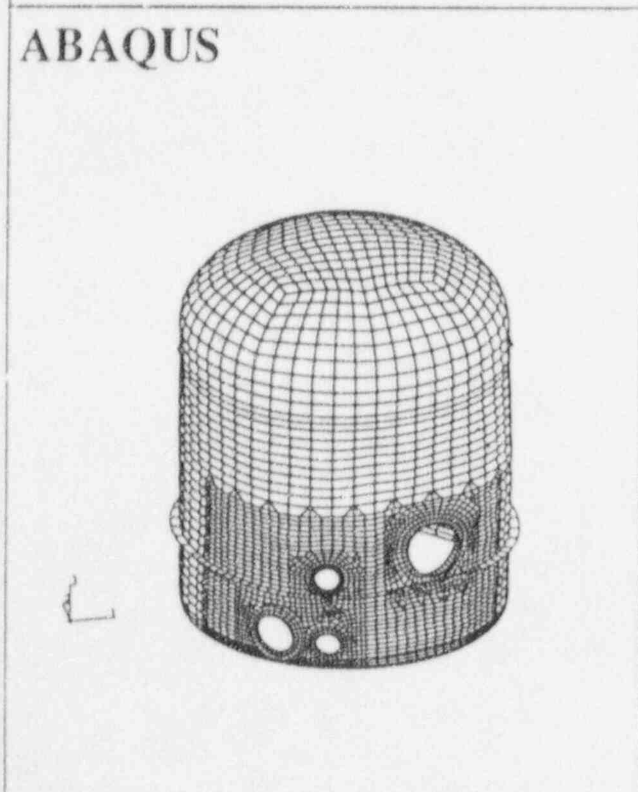
MODE SHAPES



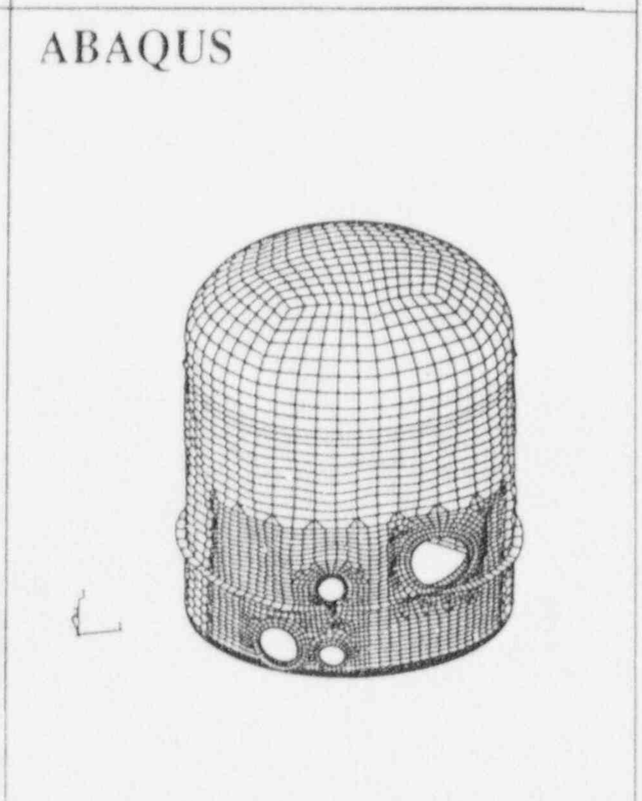
Mode (1) f=3.686 Hz



Mode (2) f=5.910 Hz



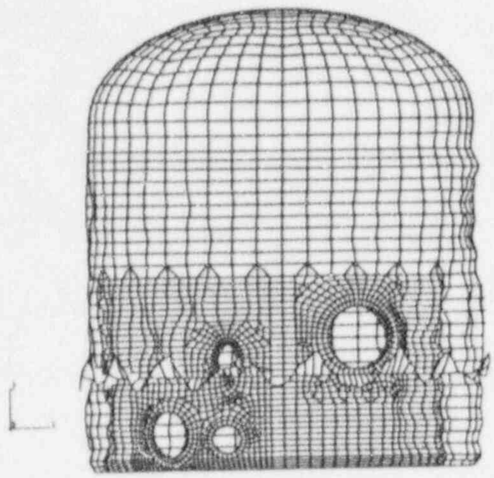
Mode (4) f=6.359 Hz



Mode (5) f=6.648 Hz

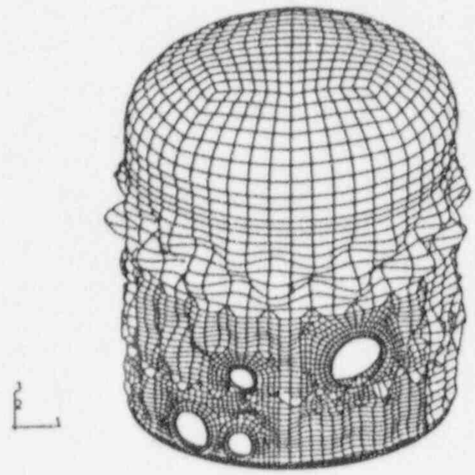
<u>MODE SHAPES</u>

ABAQUS



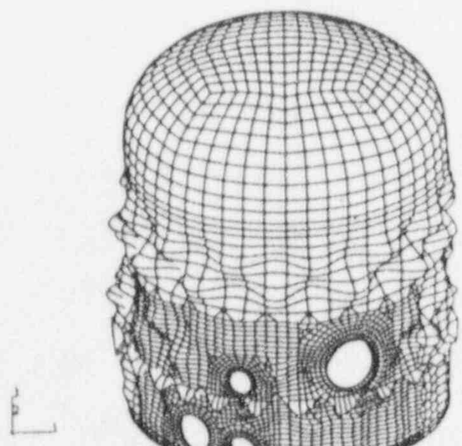
Mode (109) f=12.398 Hz

ABAQUS



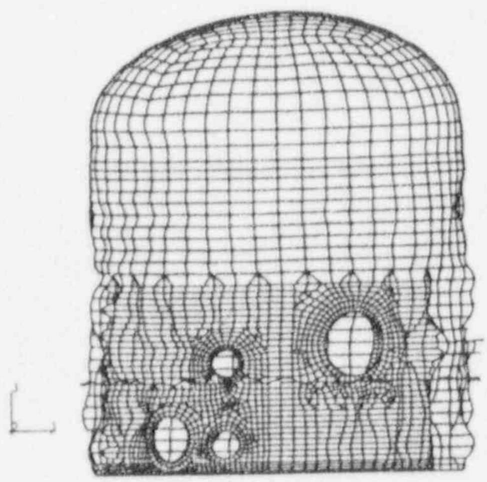
Mode (179) f=15.384 Hz

ABAQUS



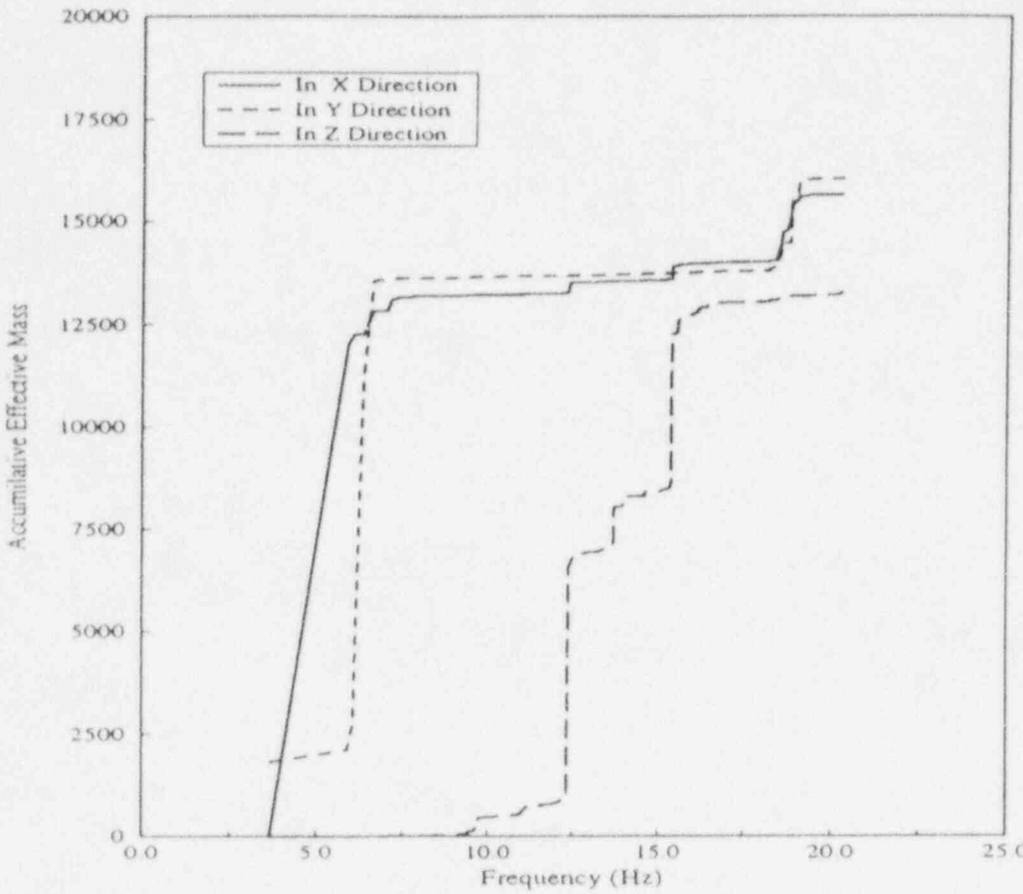
Mode (180) f=15.396 Hz

ABAQUS



Mode (249) f=18.816 Hz

TOTAL EFFECTIVE MASS



Total effective mass in X direction = 86.74 %

Total effective mass in Y direction = 88.91 %

Total effective mass in Z direction = 73.77 %

Comparison of ABAQUS and BOSOR:

- **Effective Mass:**

Percentage of Effective Mass from Total Mass

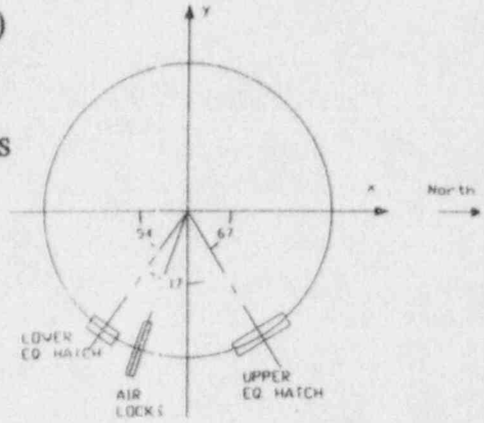
Modes	BOSOR	ABAQUS	Difference
Horizontal X	91.12 %	86.74 %	4.38 %
Horizontal Y	91.12 %	88.91 %	2.21 %
Vertical Z	83.58 %	73.77 %	9.81 %

- **Natural Frequencies:**

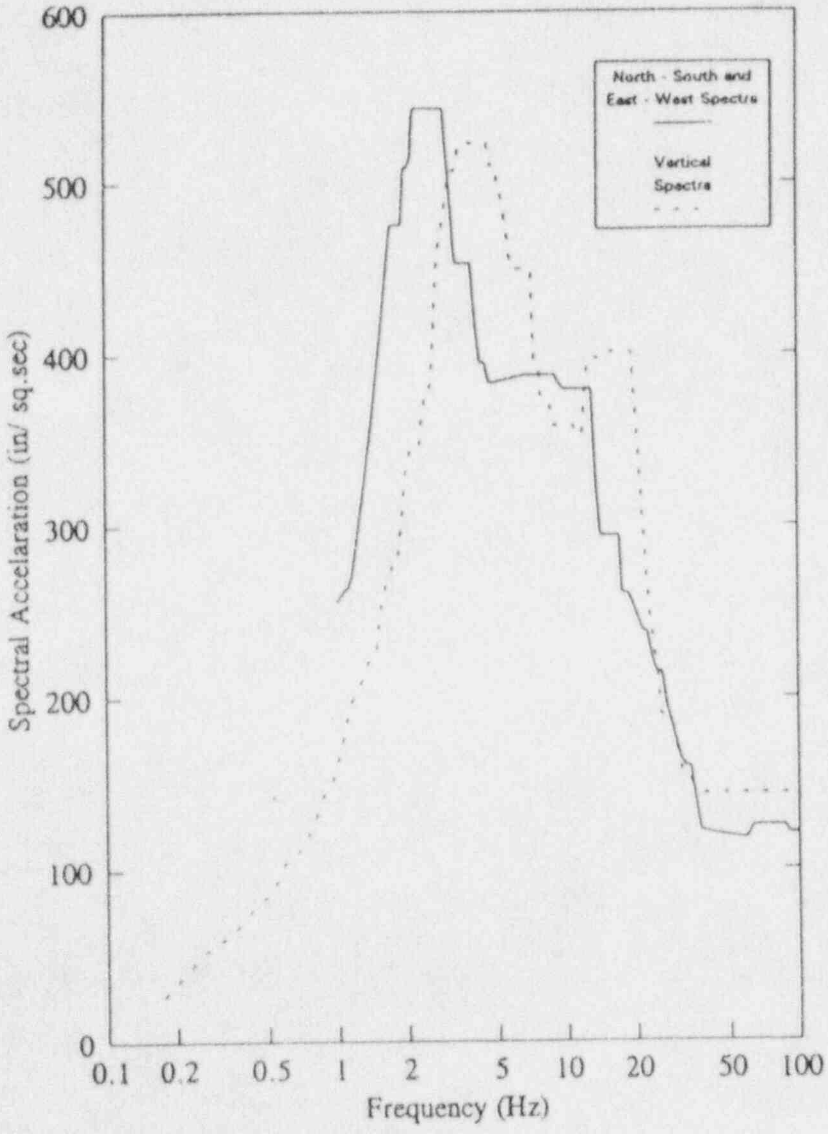
	ABAQUS	BOSOR
1st Cantilever Mode	5.90	6.14
1st Vertical Mode	12.40	13.70
2ed Vertical Mode	15.40	17.40

PART III: RESPONSE SPECTRUM ANALYSIS

- **High Frequency Modes: (Appendix A of SRP Sec. 3.7.2)**
  1. Remaining Effective Mass per D.O.F.
  2. Zero Period Accelerations in X, Y and Z directions
  3. Interia forces as static loads

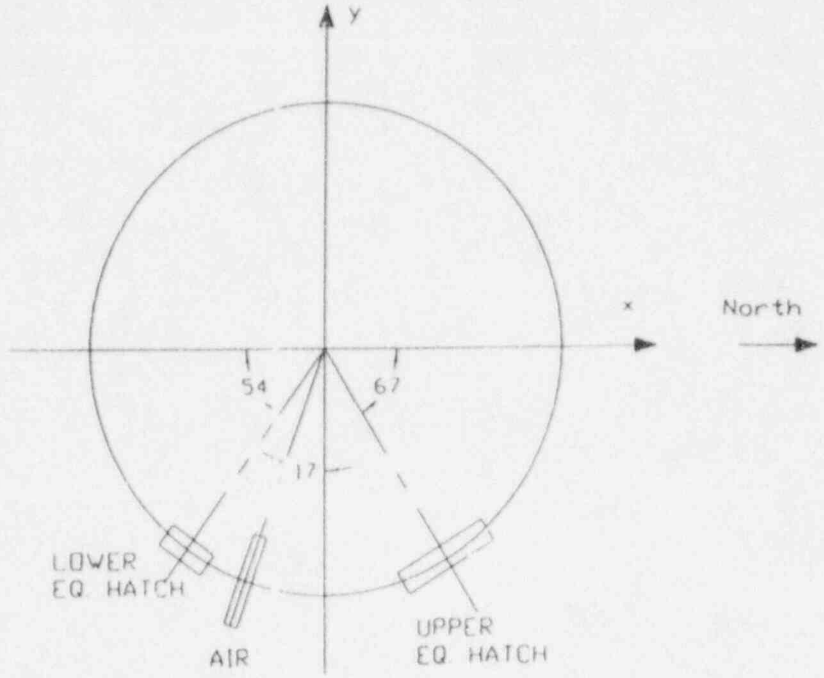


Top View

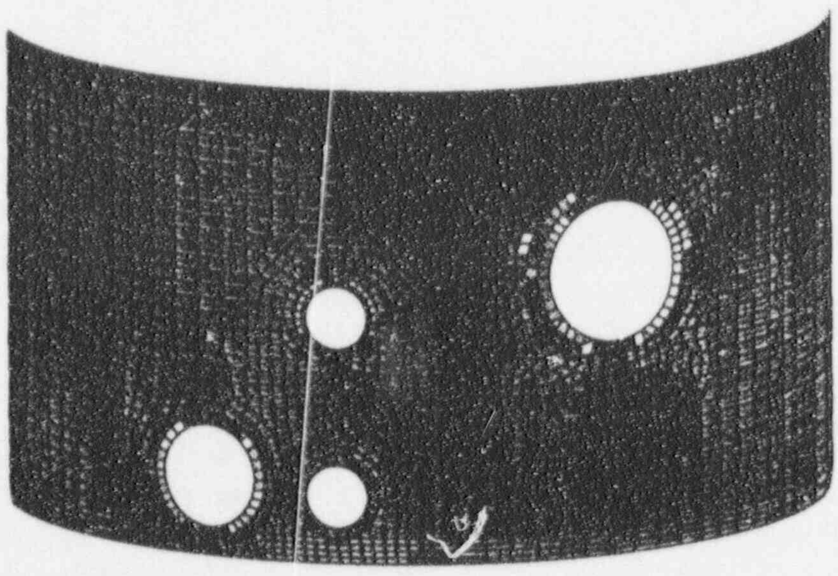


Response Spectra

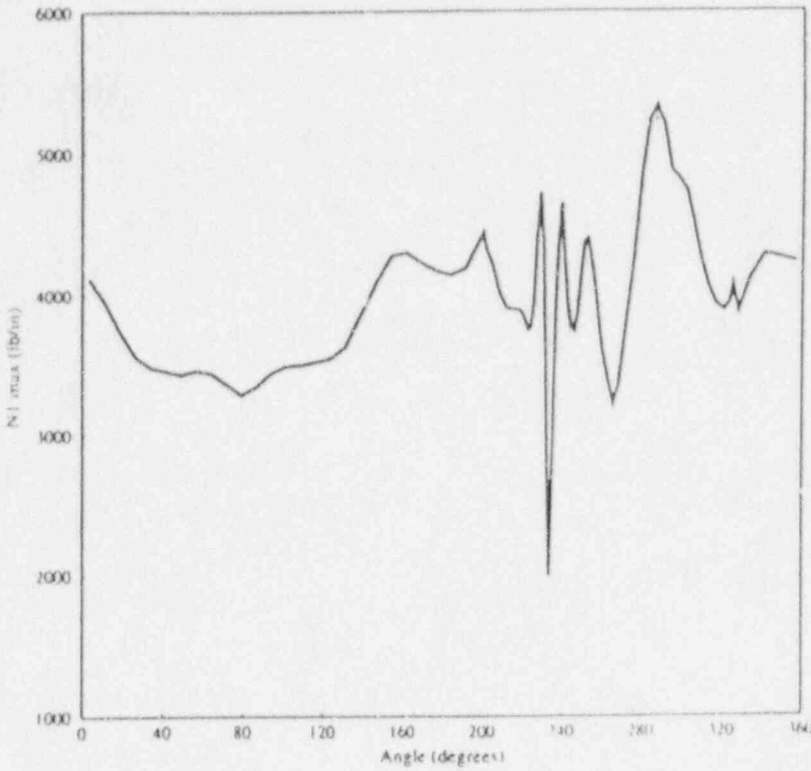
- **Peak Response:**
  1. Combination of modal responses in X, Y and Z direction by the 10% rule.
  2. Directional combination of responses by the SRSS method.



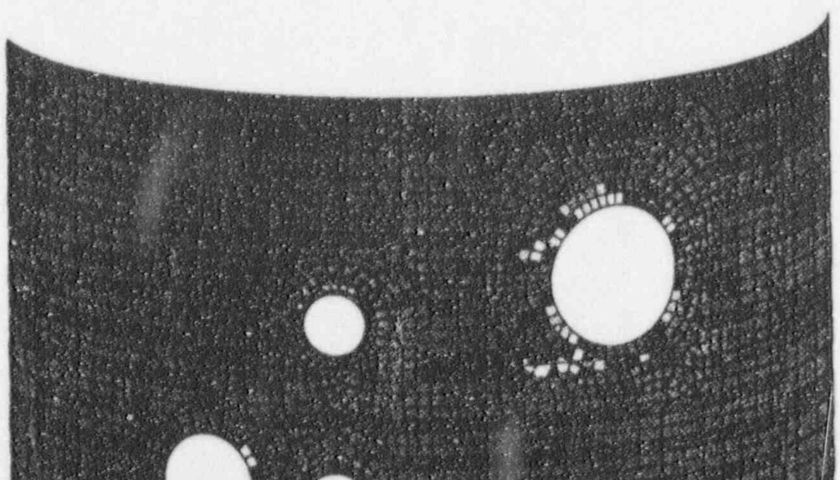
Top View



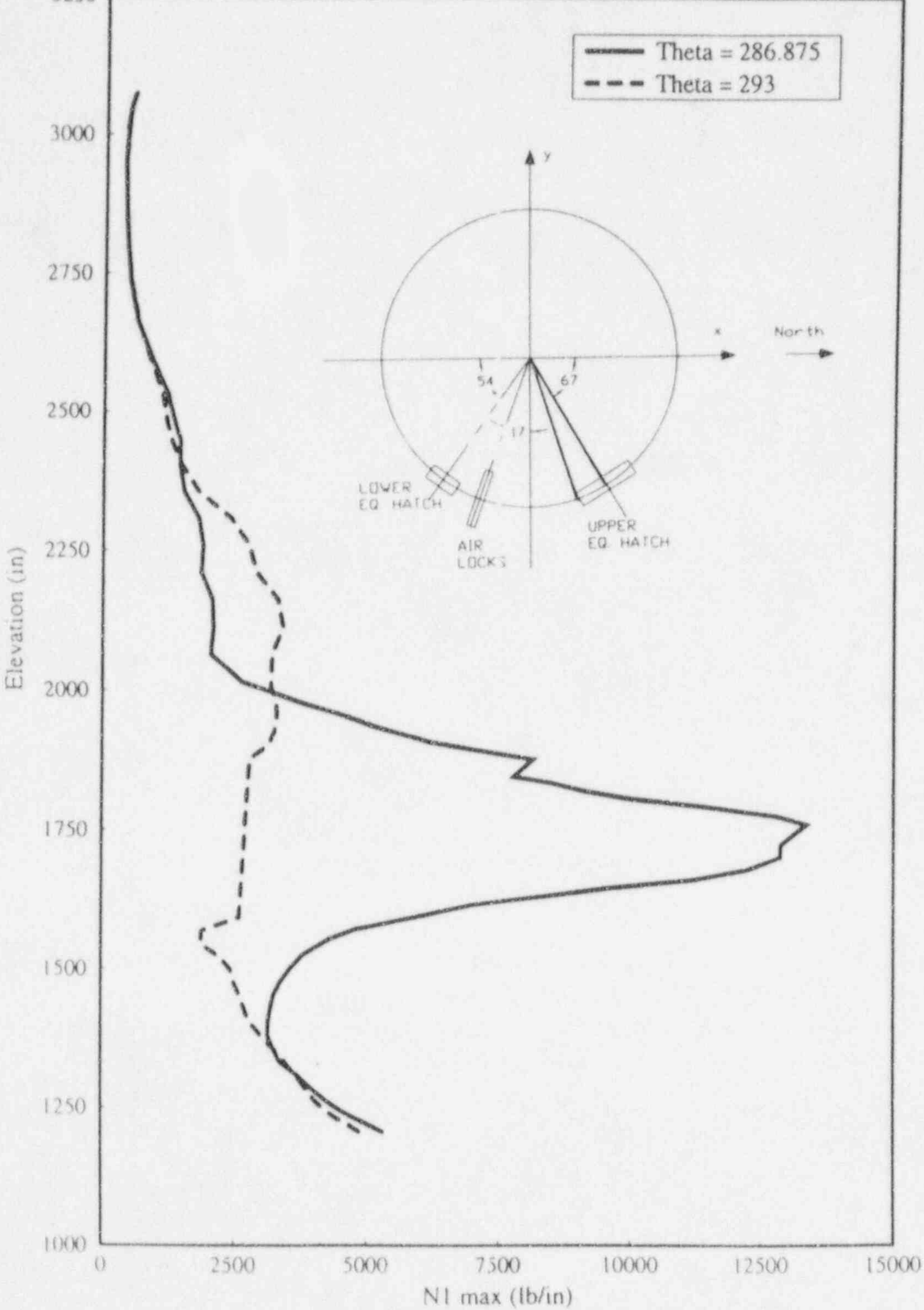
Contour Lines of N_{1max} Stress Resultants



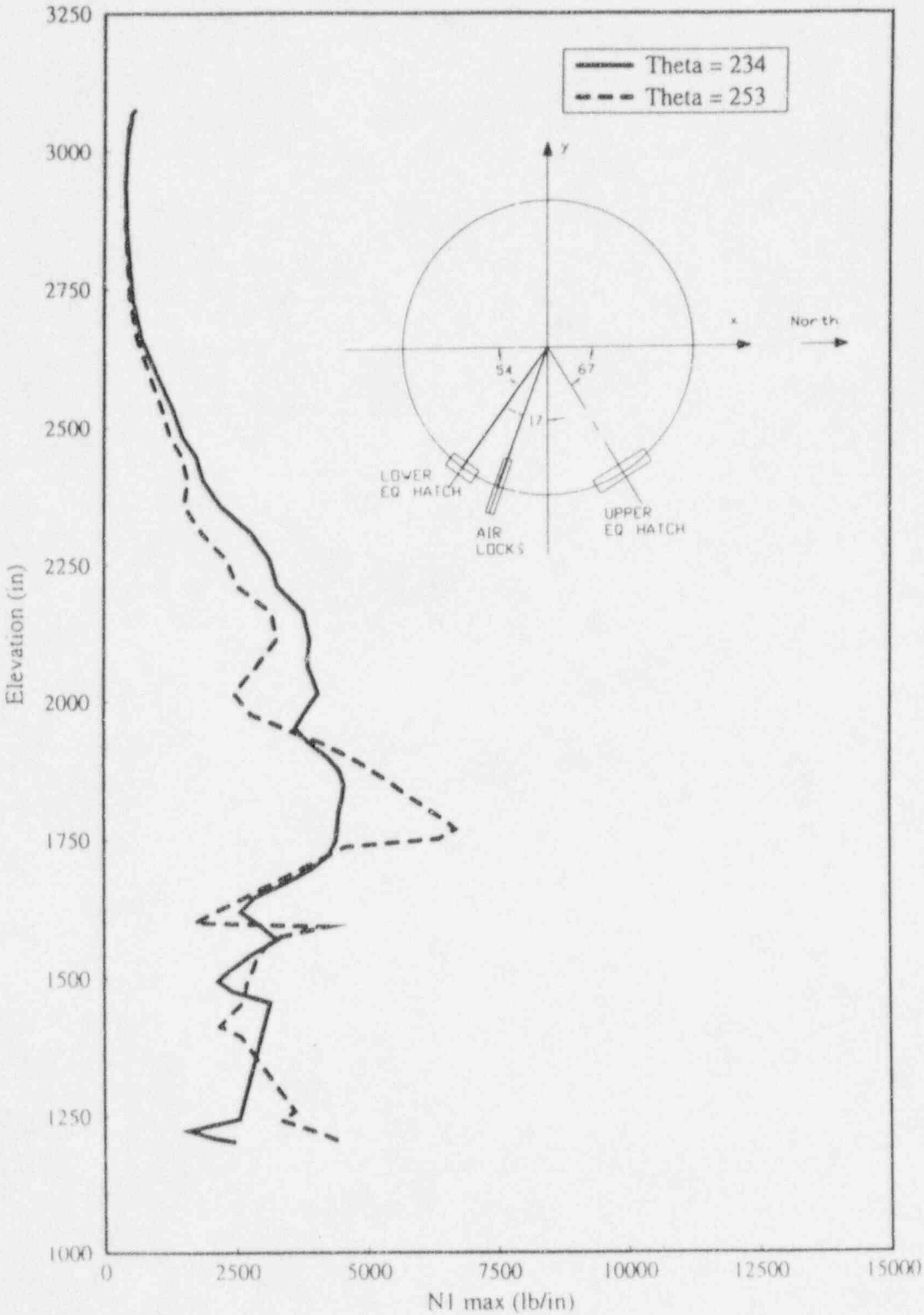
N_{1max} Stress Resultants at the Base



Contour Lines of N_{2max} Stress Resultants



Comparison of N_{1max} Stress Resultants along two Meridians

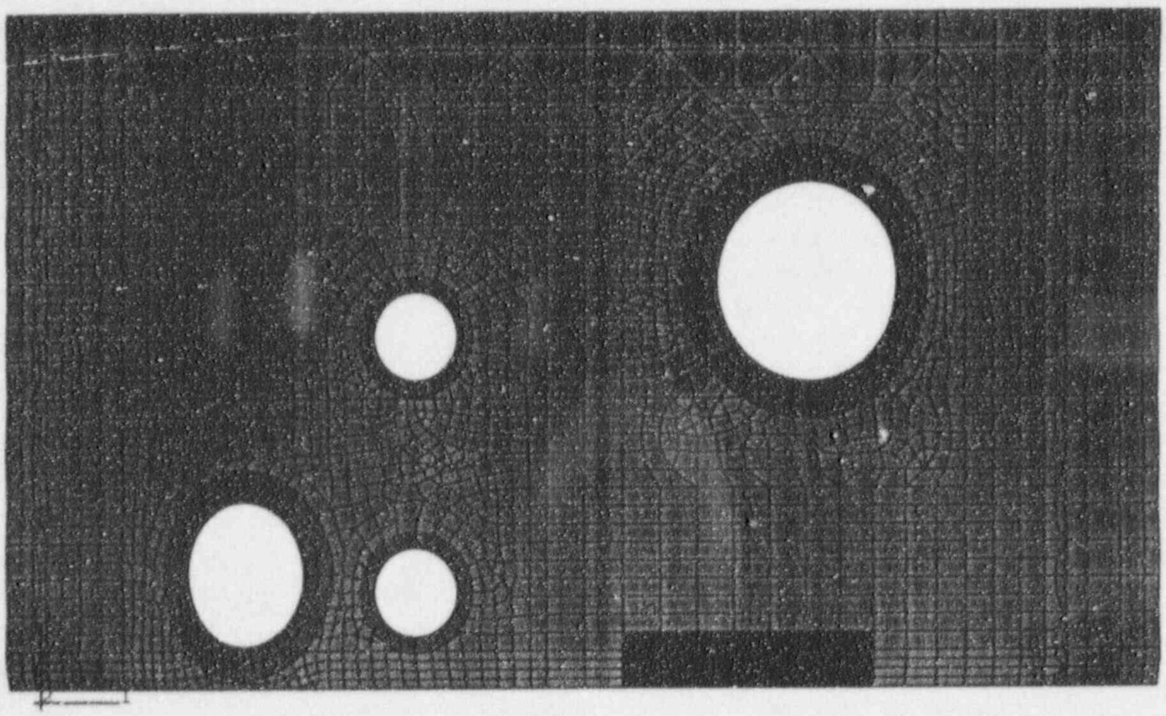


Comparison of N_{1max} Stress Resultants along two Meridians

PART IV: BUCKLING ANALYSIS

- **Equivalent Static Loads:**

Purpose: Regenerate N_{1max} Stress Resultants at Critical Regions



Critical Regions due to Seismic Loads

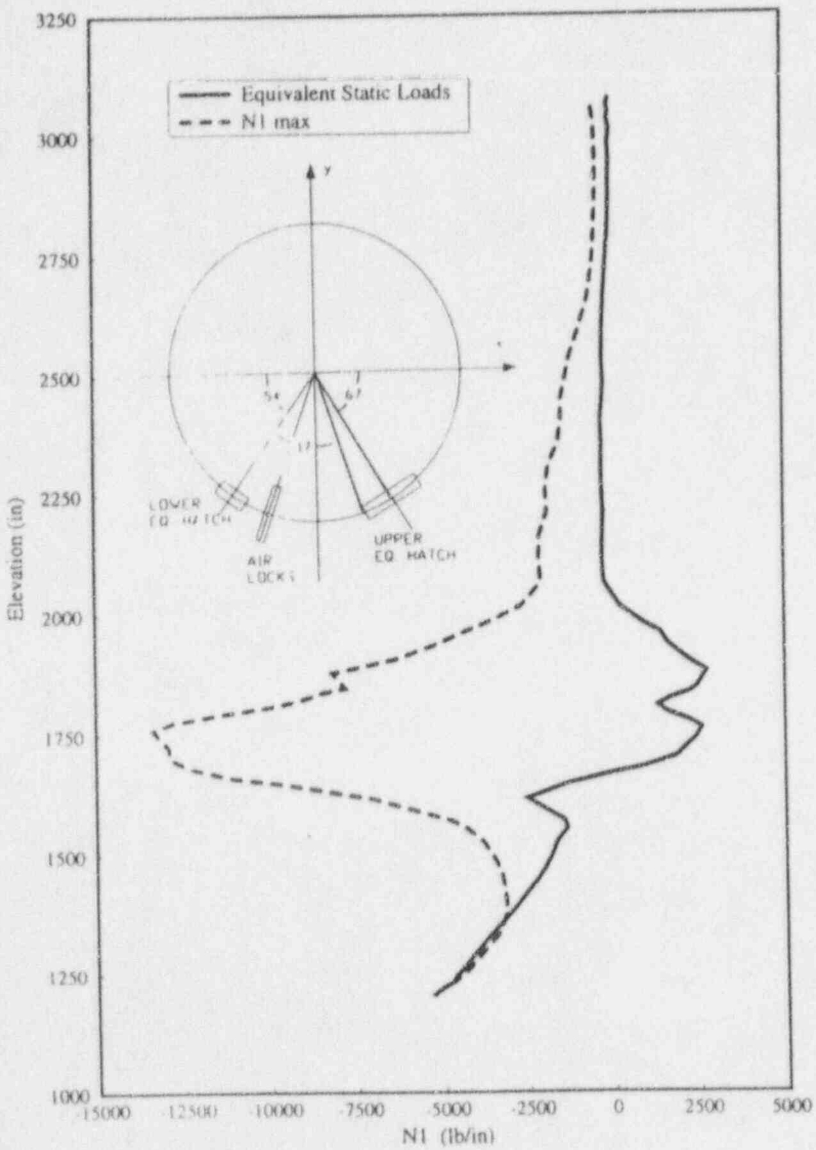
- **Load Case I : (Region A)**

<u>Modal Decomposition:</u>

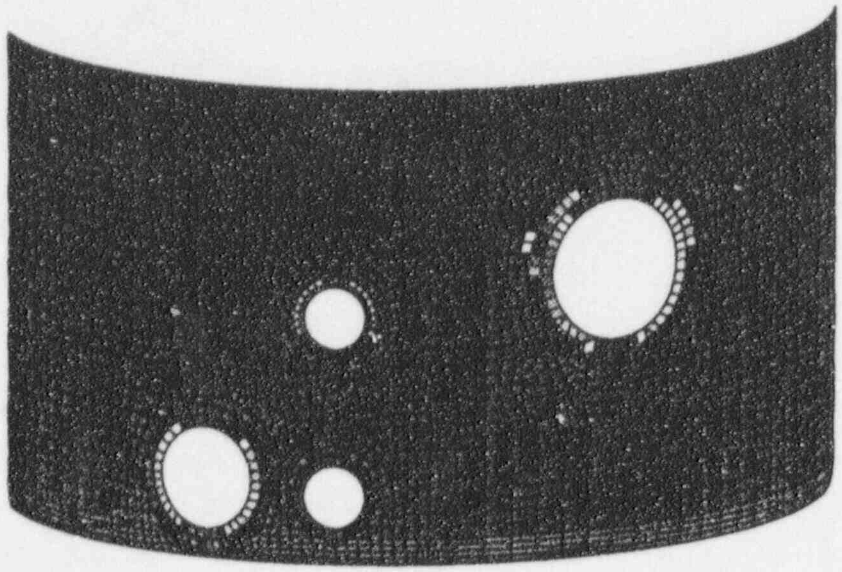
$$\{N_{1max}\} = [N_1^{\phi}]\{\psi\}$$

$$\{F_i^{\phi}\} = [M]\{\phi_i\}\omega_i^2$$

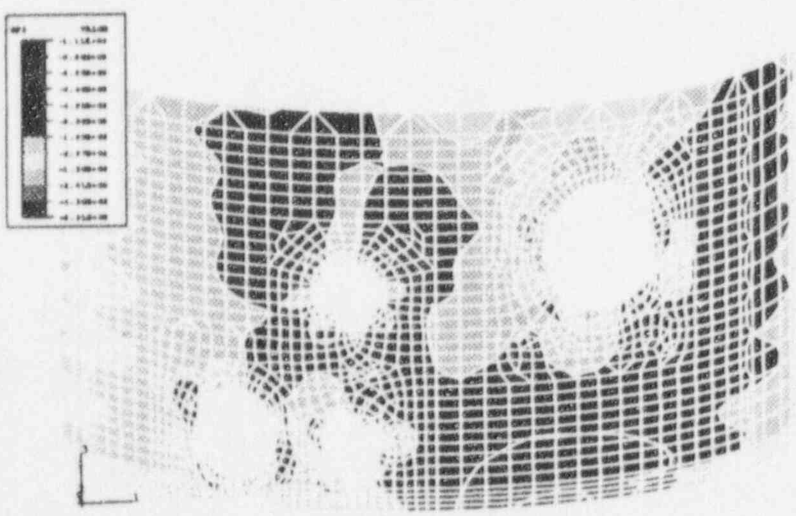
$$\{F\} = [F^{\phi}]\{\psi\}$$



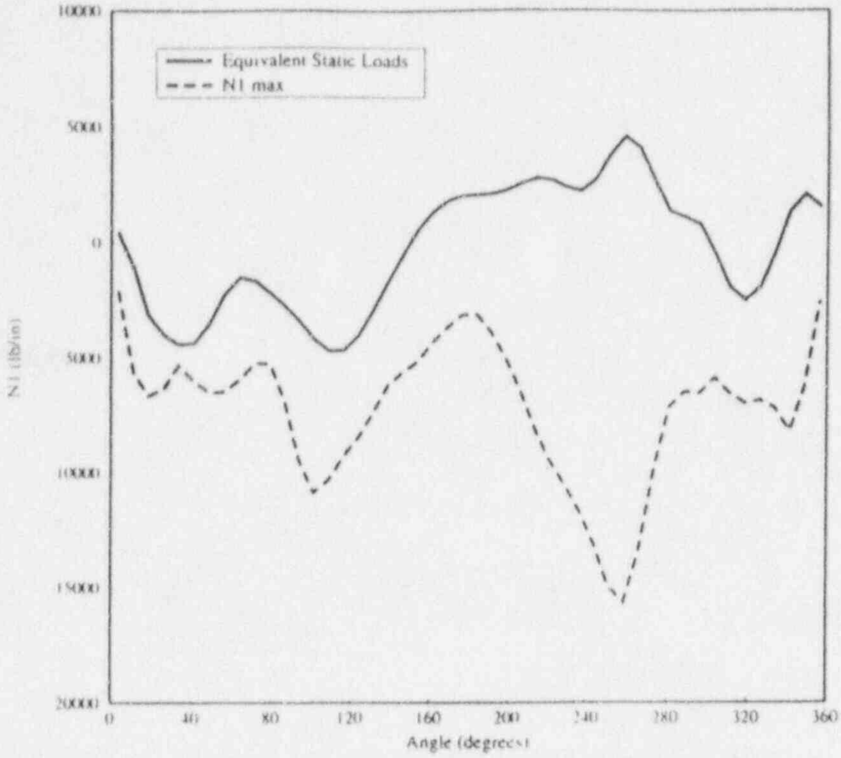
Comparison of N_1 Stress Resultants at $\theta = 268.75^{\circ}$



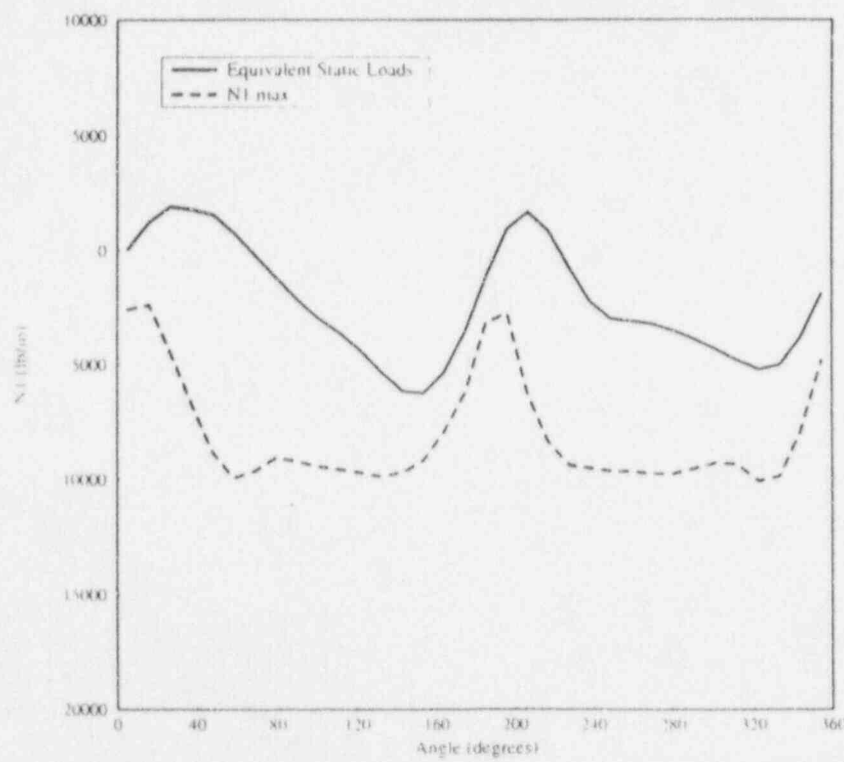
Contour Lines of N_{1max} Stress Resultants



Contour Lines of N_1 due Equivalent Static Loads



Comparison of N_1 Stress Resultants at Upper Equipment Hatch Reinforcing Collar



Comparison of N_1 Stress Resultants at Lower Equipment Hatch Reinforcing Collar

Inelastic Buckling Analysis:

- Material Properties:

  $E = 29x10^6$ psi

  $\nu = 0.3$

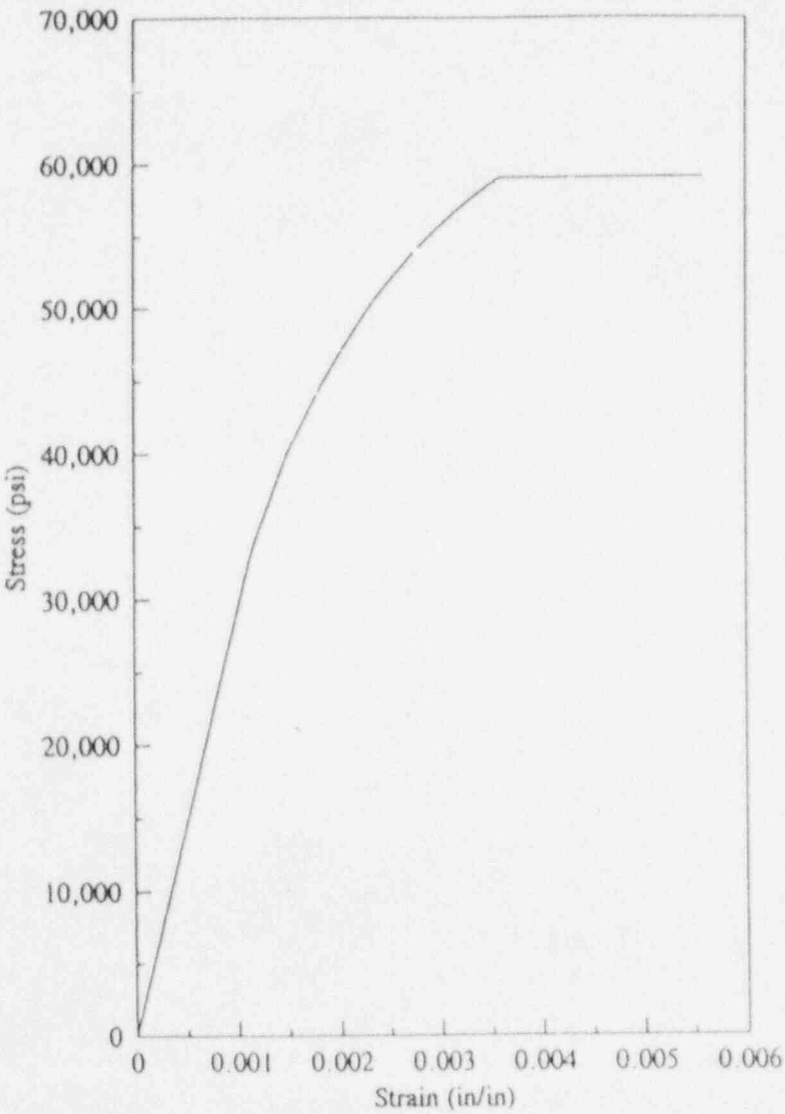
- Loading Configuration:

  a. Dead Load

  b. $\Delta T = 50^oF$

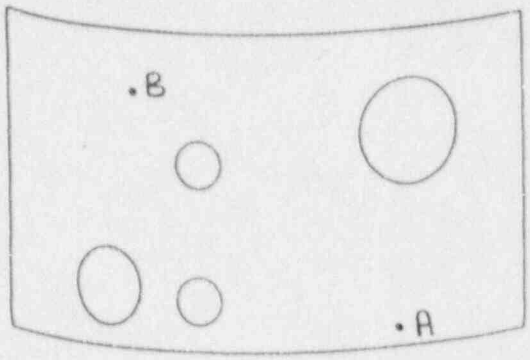
  c. External pressure, P = 3.0 psid

  d. Equivalent Static Loads

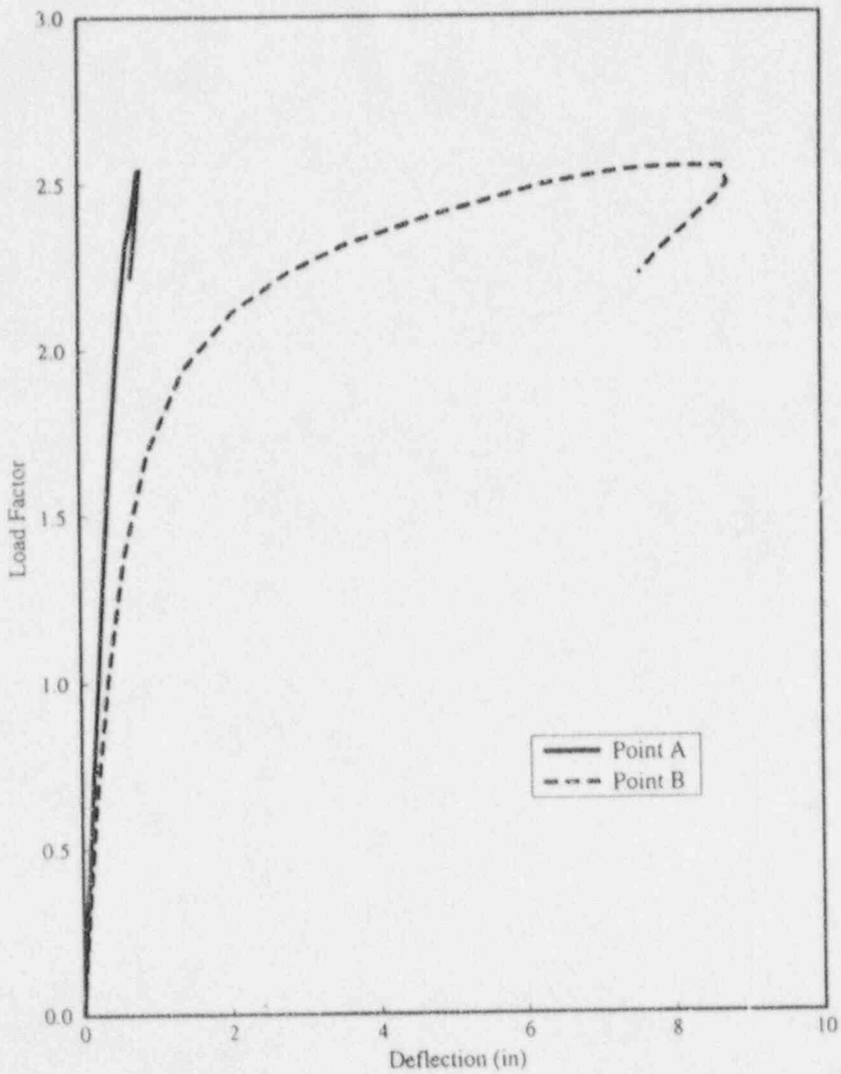


Stress-Strain Relation at $T = 120^oF$

Results:

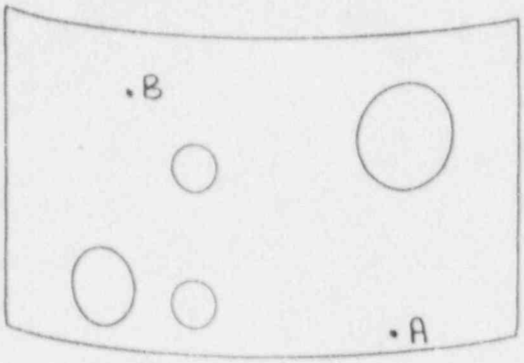


Buckling Load Factor, $\lambda = 2.54$

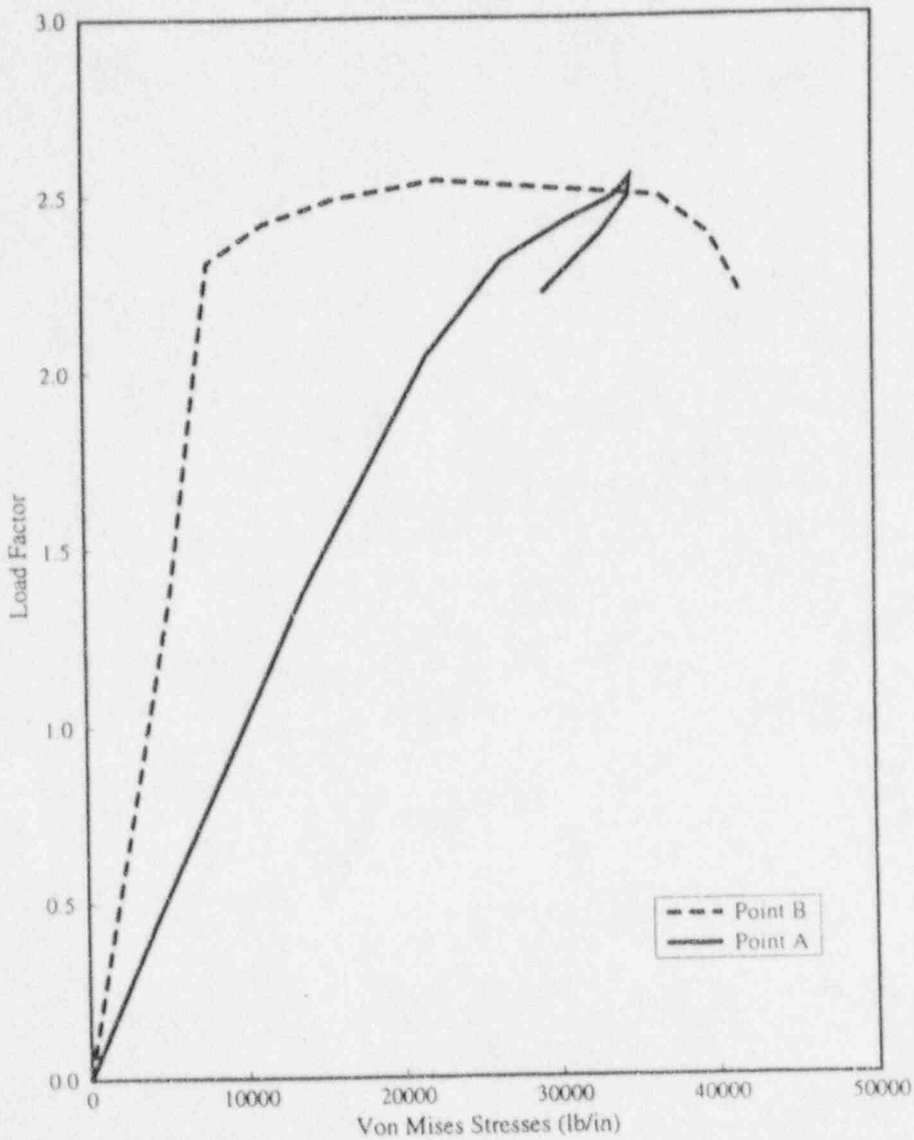


Load Deflection Curves at Points A & B

Results:



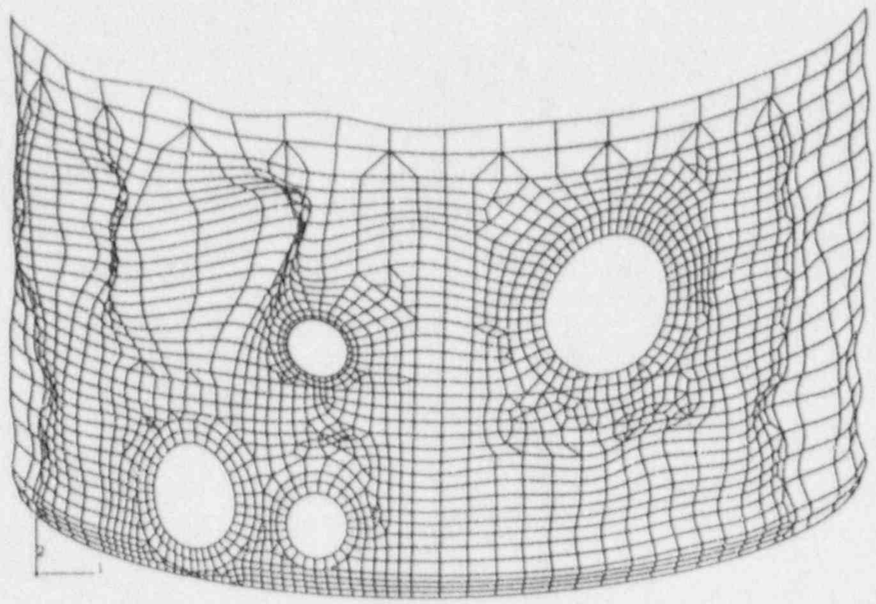
Buckling Load Factor, $\lambda = 2.54$



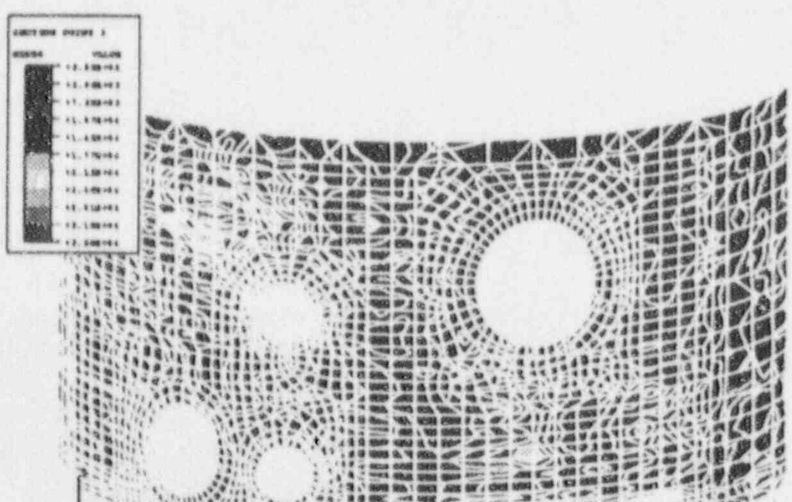
Von Mises Stresses at Points A & B

Results:

Buckling Load Factor, $\lambda = 2.54$

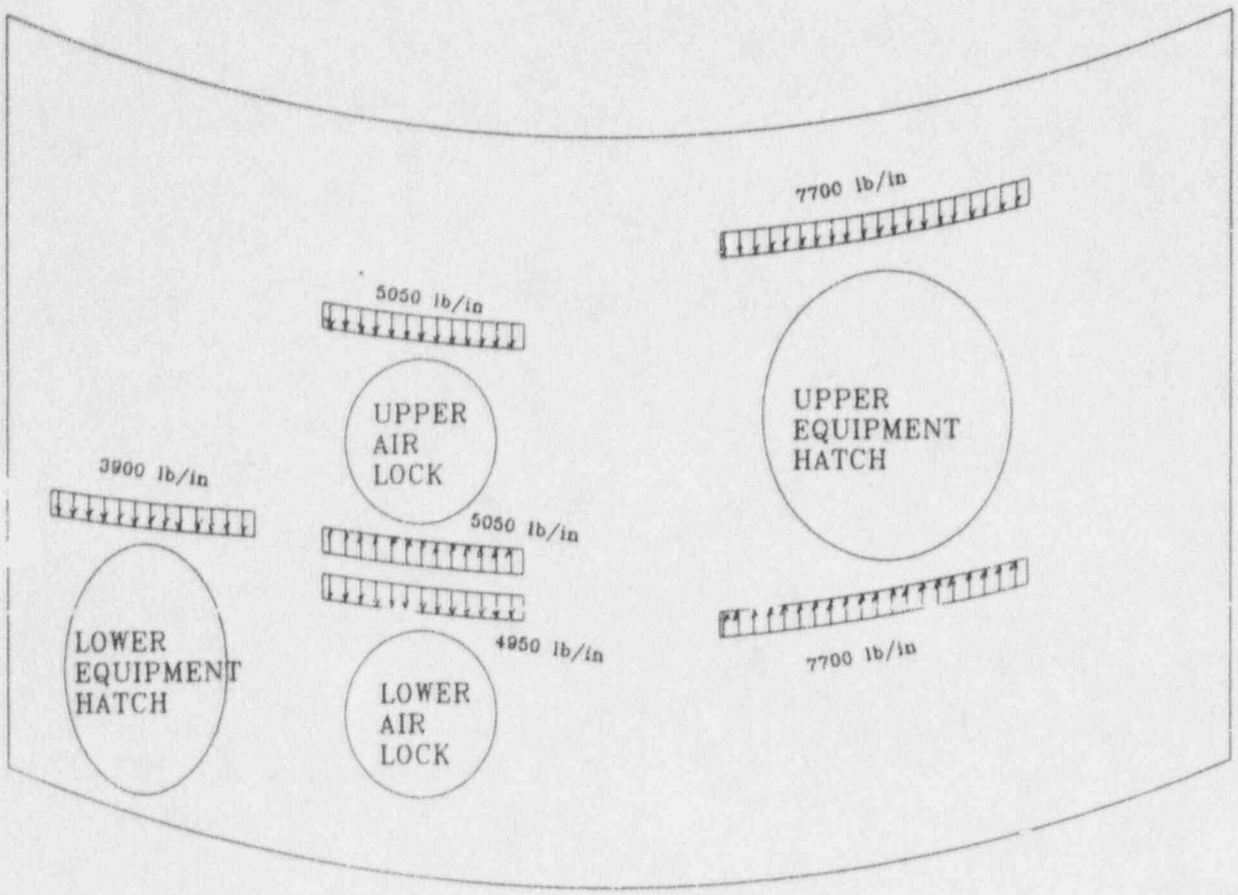


Deformed Shape at $\lambda = 2.54$

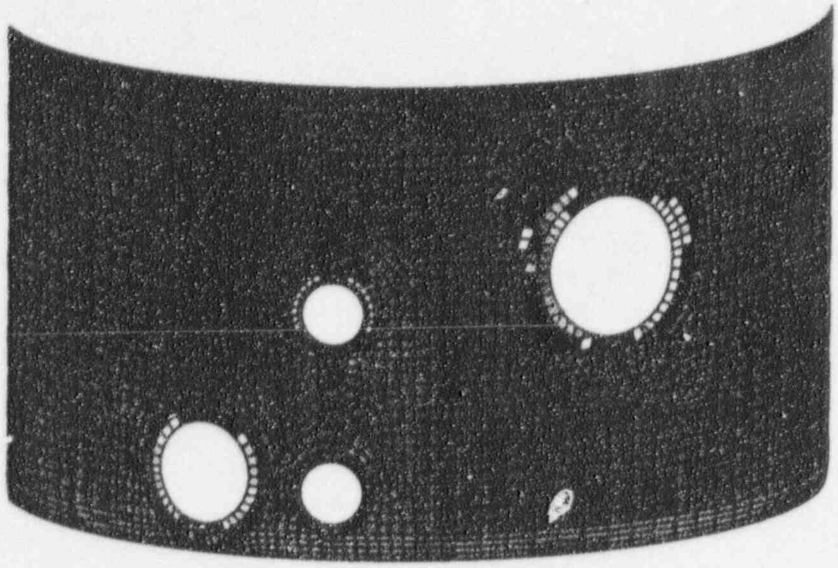


Contour Lines of Von Mises Stresses at $\lambda = 2.54$

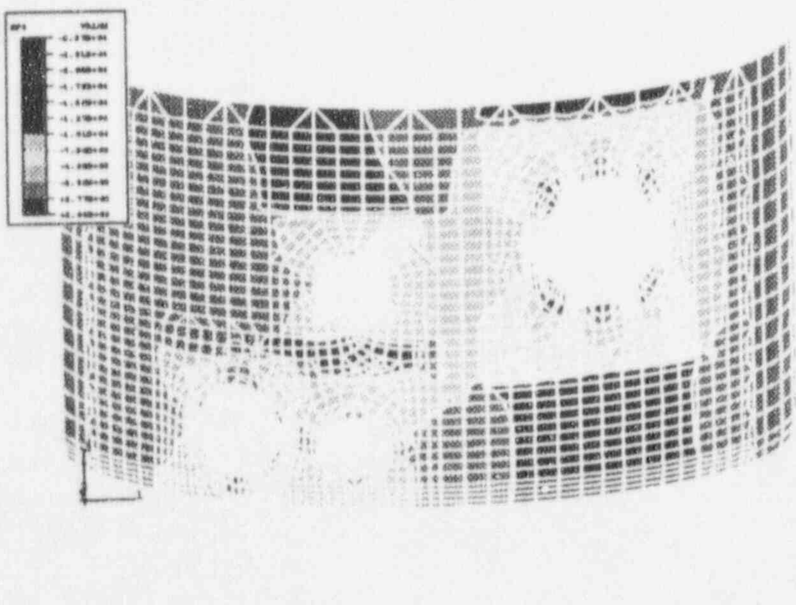
• **Load Case II : (Region B)**



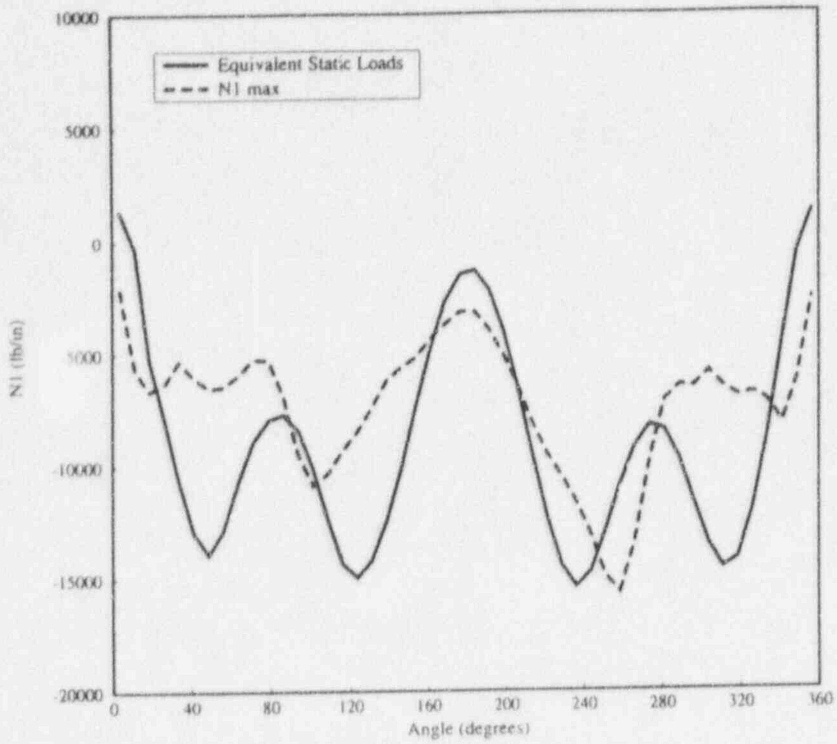
Equivalent Static Loads



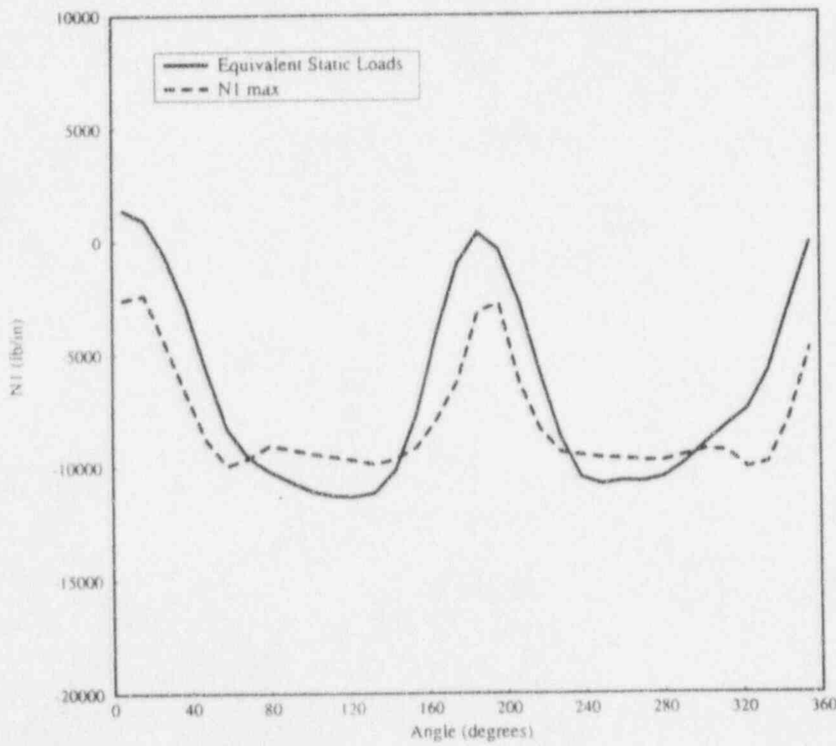
Contour Lines of N_{1max} Stress Resultants



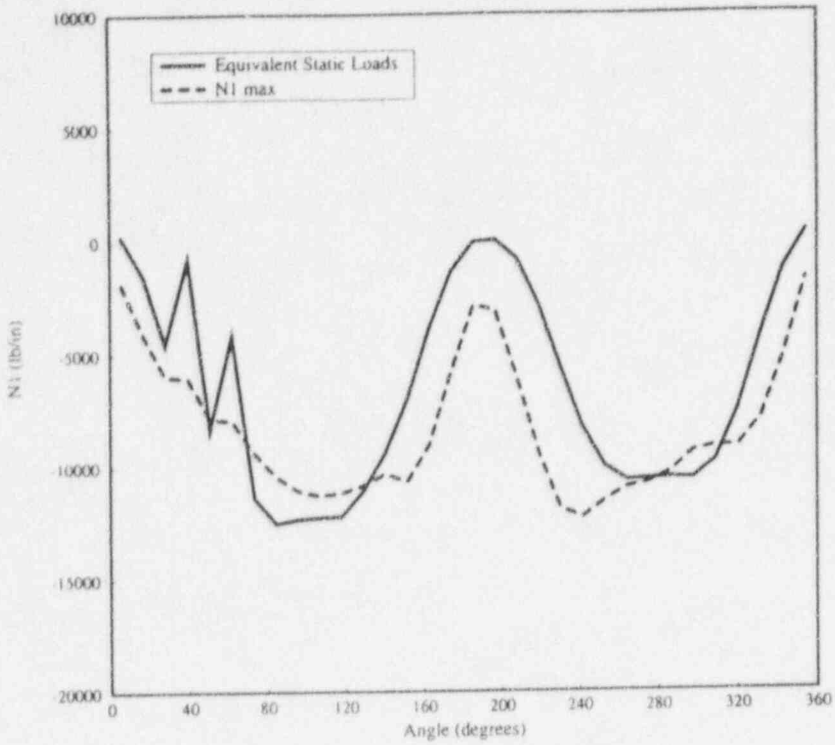
Contour Lines of N_1 due Equivalent Static Loads



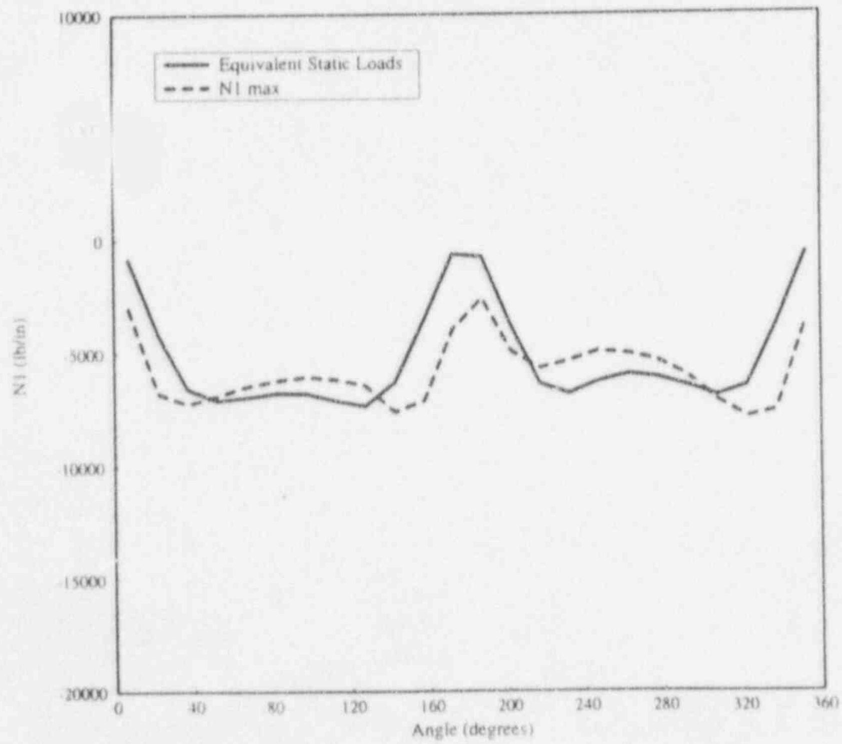
Comparison of N_1 Stress Resultants at Upper Equipment Hatch Reinforcing Collar



Comparison of N_1 Stress Resultants at Lower Equipment Hatch Reinforcing Collar



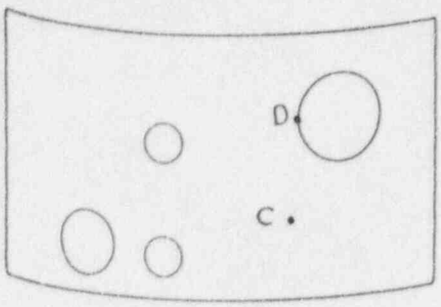
Comparison of N_1 Stress Resultants at Upper Air Lock Reinforcing Collar

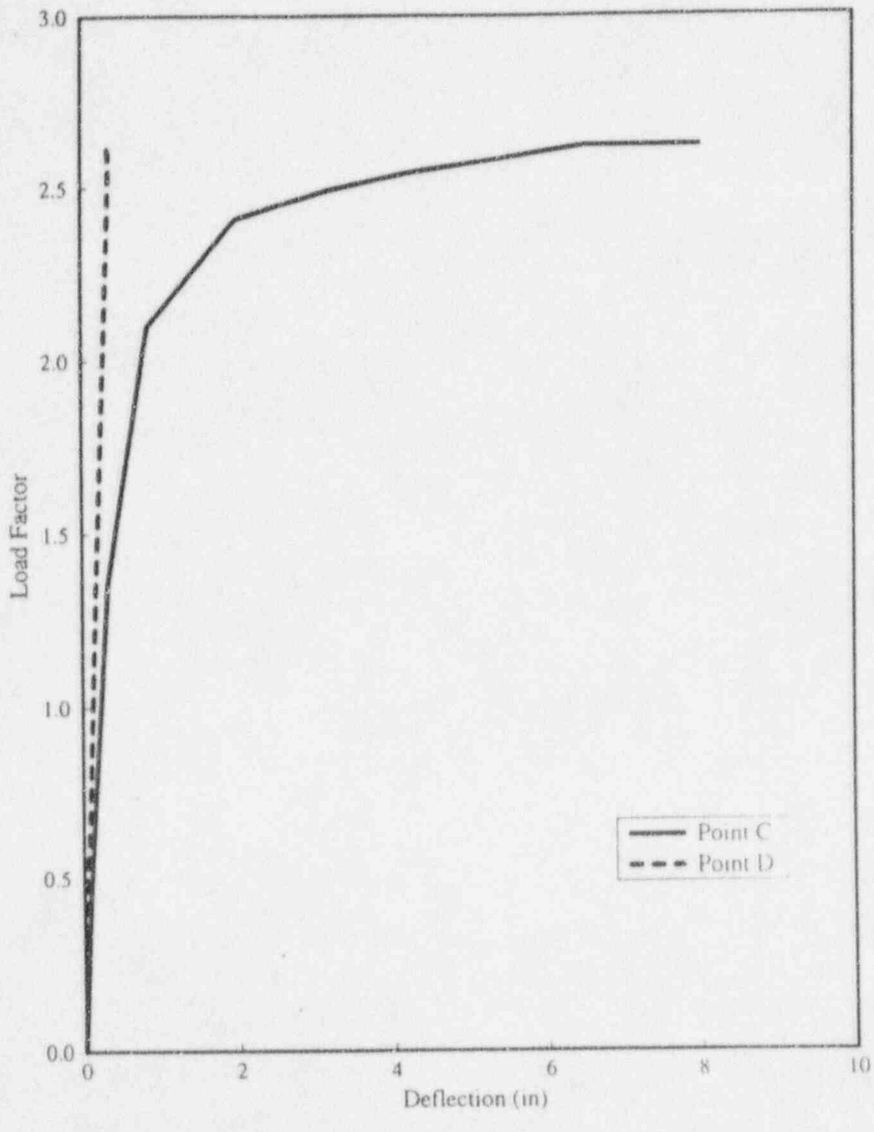


Comparison of N_1 Stress Resultants at Lower Air Lock Reinforcing Collar

Results:

Buckling Factor of Safety, $\lambda = 2.62$

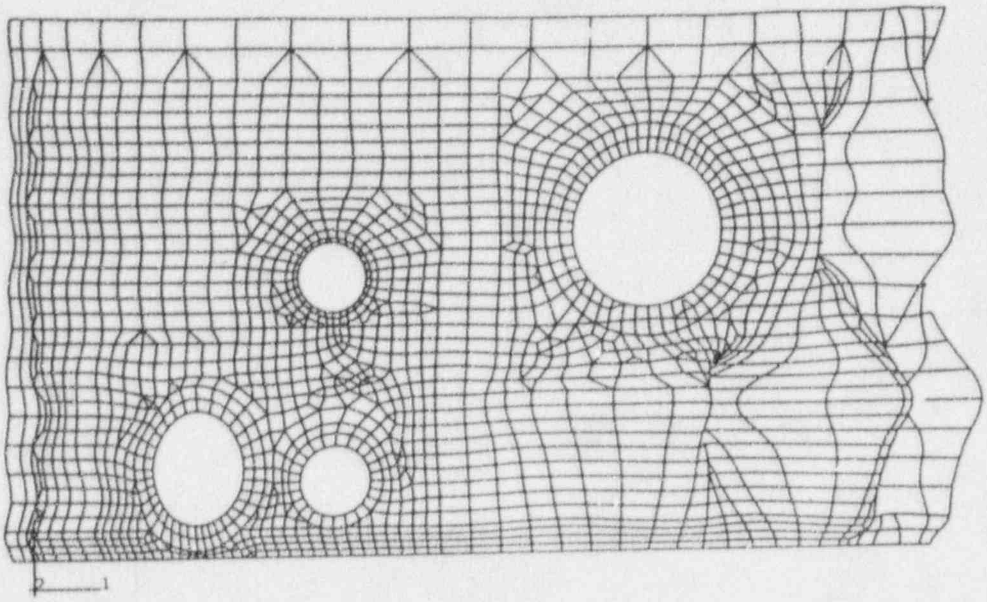




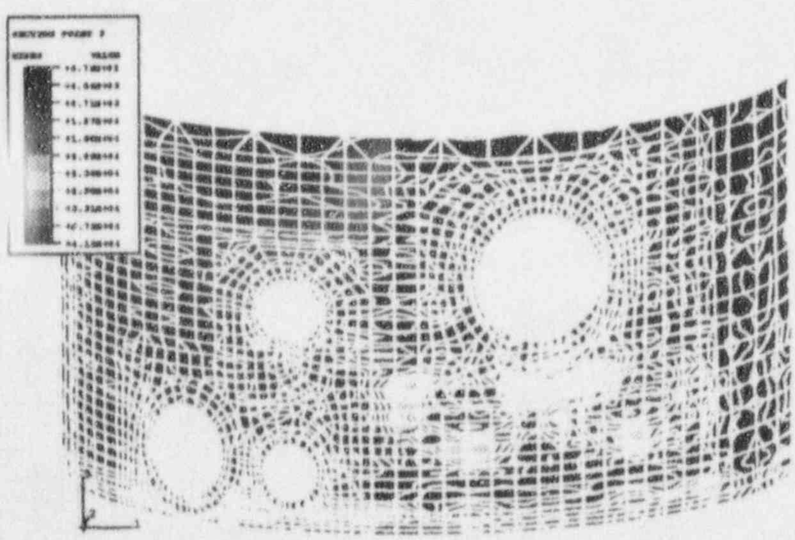
Load Deflection Curves at Points C & D

Results:

Buckling Factor of Safety, λ =2.62



Deflected Shape at λ =2.62



Contour Lines of Von Mises Stresses at λ =2.62

SUMMARY OF BUCKLING ANALYSIS

Loading Configuration: **(Level C Service Limit - DBA4)**

a. Dead and Crane Loads

b. External Pressure, P = 3.0 psig

c. Uniform Temperature, T = 120°F

d. Safe Shutdown Earthquake

Results:

Load Case	Location of Buckling	Factor of Safety
I	Near the base below the upper equipment hatch	**2.54**
II	Below the upper equipment hatch reinforcing collar	**2.62**

Conclusions:

- The containment design satisfies Reg. Guide 1.57 (F.S.=2.0), ASME Code Case N-284 (F.S.=1.67) and ASME Section NE 3222.2 (F.S.=2.5).

- The area of penetrations are adequately reinforced.

PART V: BUCKLING OF AP600 DUE TO ASYMMETRIC TEMPERATURE

A. Mesh Parameters

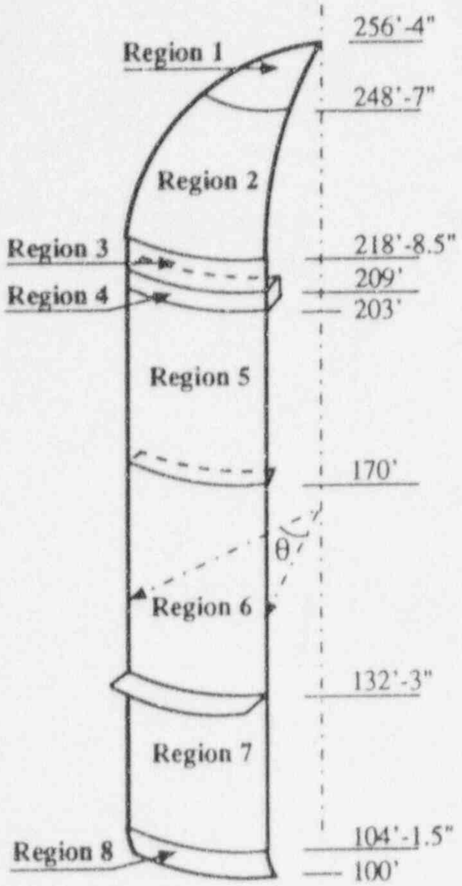
B. Thermal Stress Analysis

C. Thermal Buckling Analysis

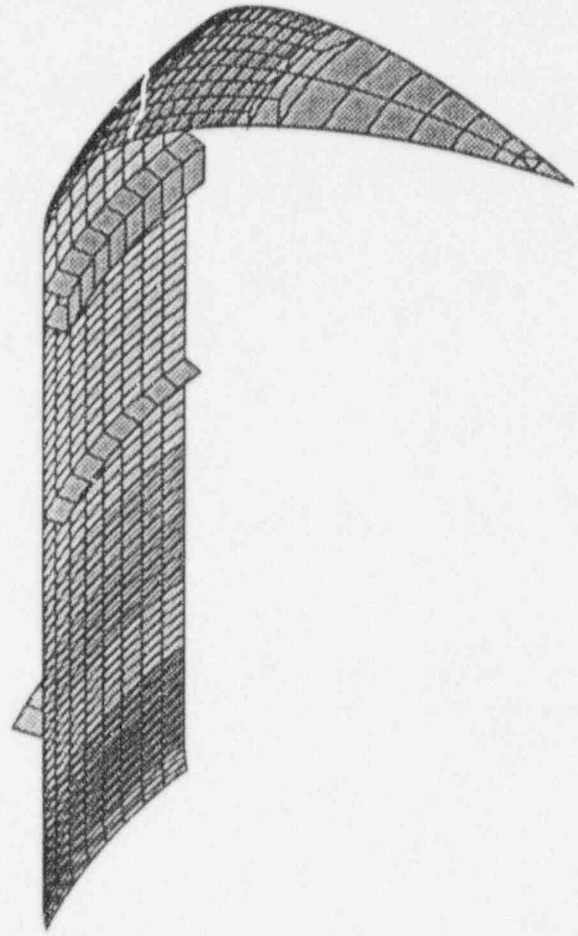
D. Buckling Analysis of AP600 at DBA1 (Case 1)

E. Buckling Analysis of AP600 at DBA1 (Case 2)

A. MESH PARAMETERS:



Discritization of the Wedge Model



Finite Element Mesh

- **Model Preprocessor Parameters:**
  1. Size of elements
  2. Imperfection shape and amplitude
  3. Number of dry strips, n
  4. Ratio of dry strip width per strip

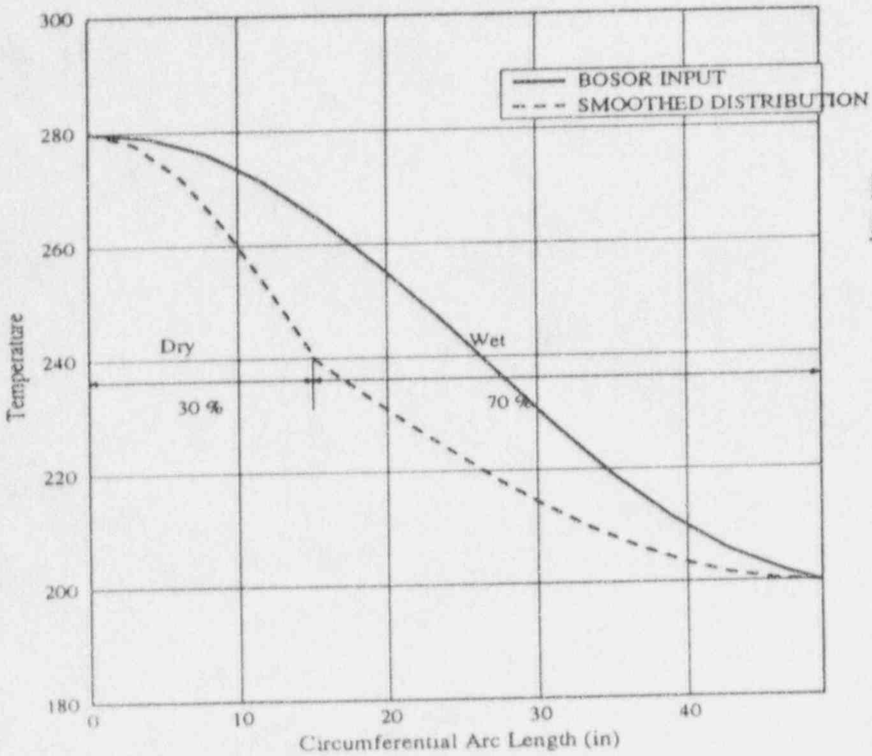
B. THERMAL STRESS ANALYSIS

Geometric Configuration:

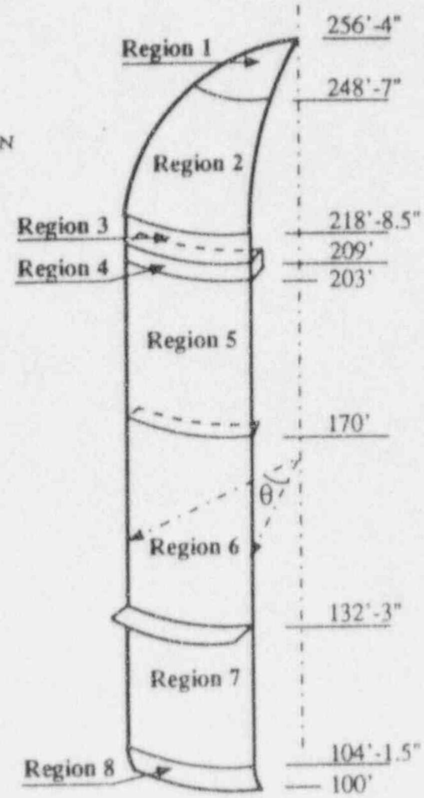
1. No geometric imperfections
2. Number of dry strips, n = 50

$$\therefore \theta = \frac{360}{2n}$$

Temperature Loading:



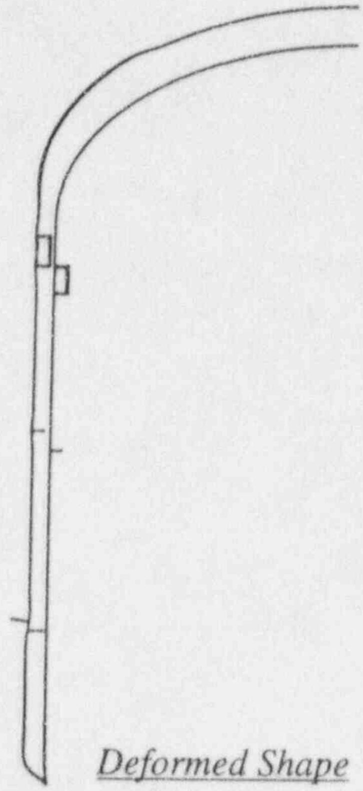
Temperature Distribution Between Elev. 248'-7" and Elev. 132'-3"



Wedge Model

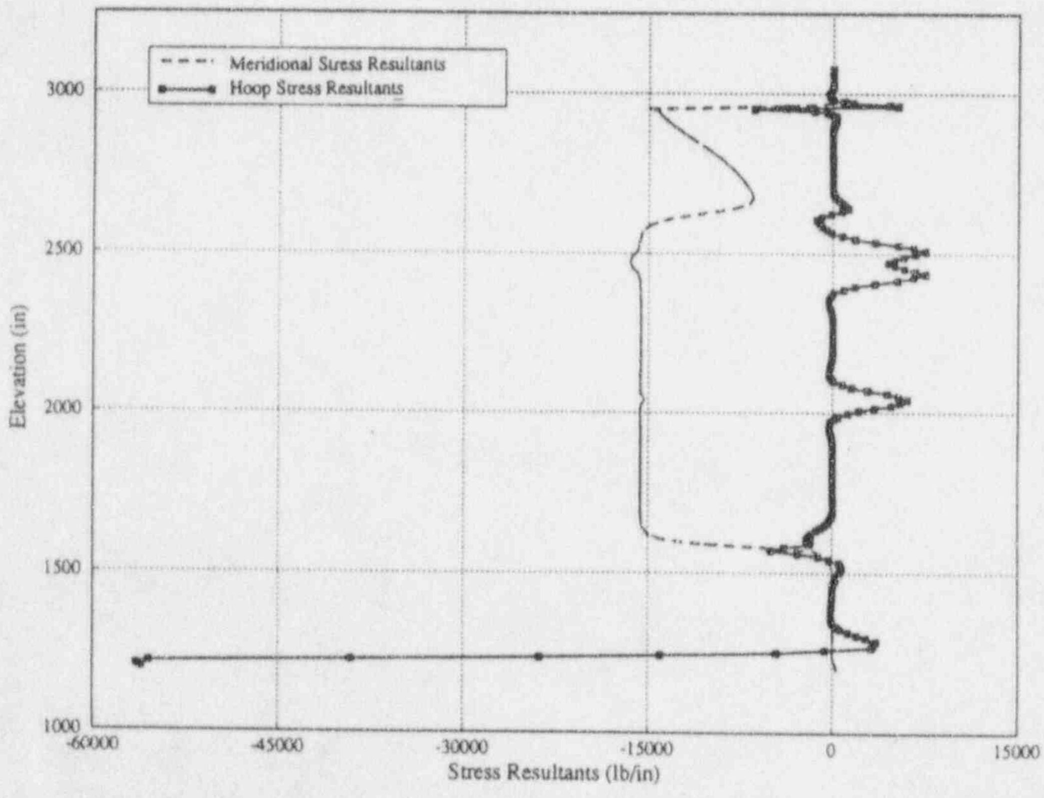
Finite Element Results:

a. Deformed Shape:



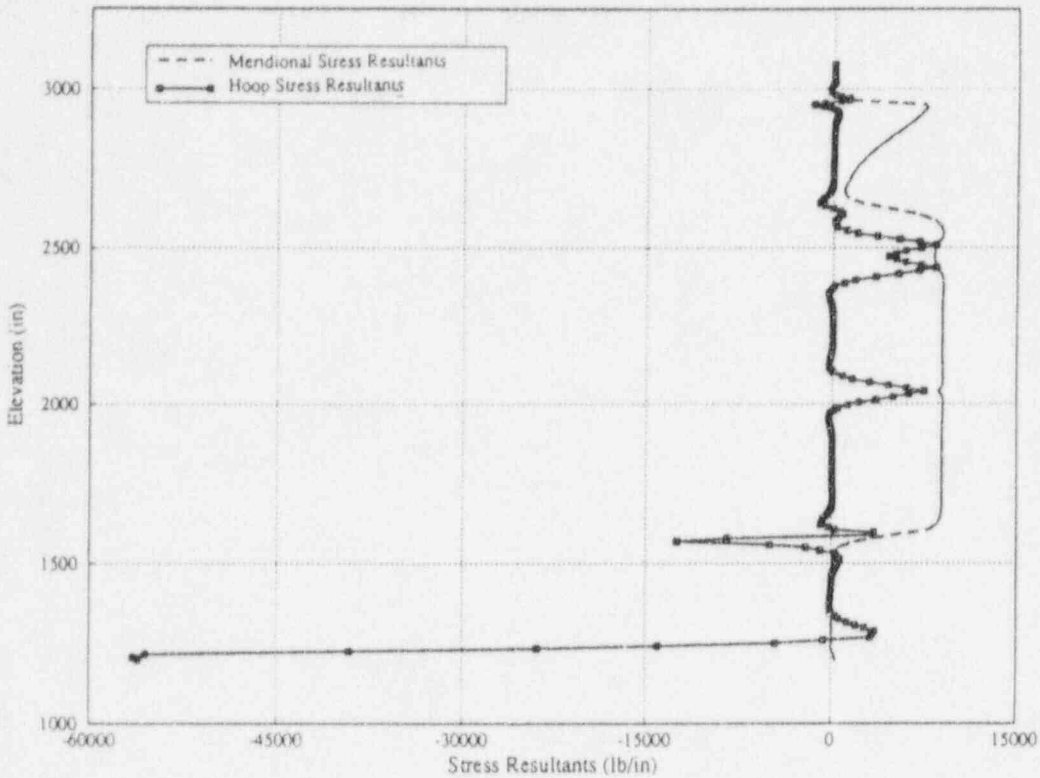
Deformed Shape

b. Stress Resultants:



N1 and N2 at the Middle of the Dry Strip

c. Stress Resultants:



N1 and N2 at the Middle of the Wet Strip

d. Comparison with CB&I Results:

Meridional stress Resultants, (kips/in)	CB&I (4/2/93 Letter)	Ames Lab
Middle of dry strip	-17.55	-15.48
Middle of wet strip	9.75	8.93

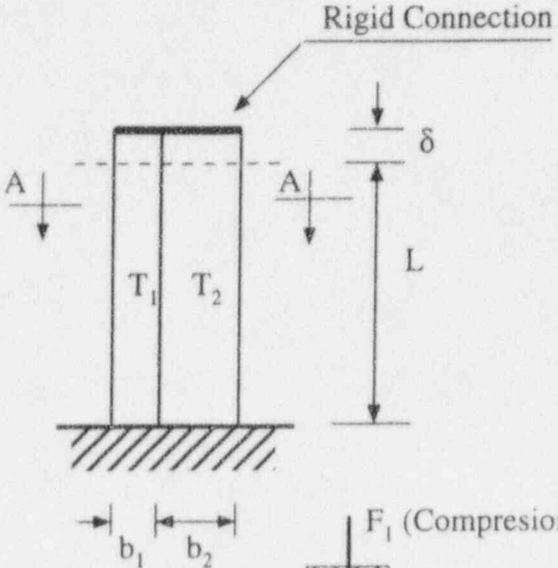
Comparison with an Approximate Strength of Material Model:

$T_1 = 280°F \quad \alpha_1 = 6.192x10^{-6}$

$T_2 = 200°F \quad \alpha_2 = 5.890x10^{-6}$

$b_1 = 30.0" \quad b_2 = 68.0"$

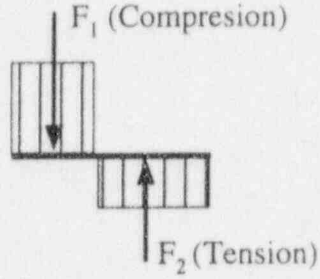
$t = 1.625"$



- From Compatability:

$$\delta_1 = \delta_2$$

$$T_1\alpha_1 L - \frac{F_1}{k_1} = T_2\alpha_2 L + \frac{F_2}{k_2}$$



Stress Distribution on Sec. A-A

- From Equilibrium of Sec. A-A

$$F_1 = F_2$$

- Solving for F and simplifying

$$F = \frac{(T_1\alpha_1 - T_2\alpha_2)k_1k_2}{(k_1+k_2)}$$

- Stress Resultants in the dry and wet strips

$$N_i = \frac{F}{b_i}$$

Verification of F.E. Results

Meridional Stress resultants (lb/in)	F.E. Solution	Theoretical Solution
Middle of Dry Strip	- 15,480	- 17,170
Middle of Wet Strip	+ 8,930	+ 7,575

C. THERMAL BUCKLING ANALYSIS:

- **Elastic Buckling Analysis:**

Configurations:

1. No Geometric Imperfections
2. Boundary Conditions
3. Temperature Loading

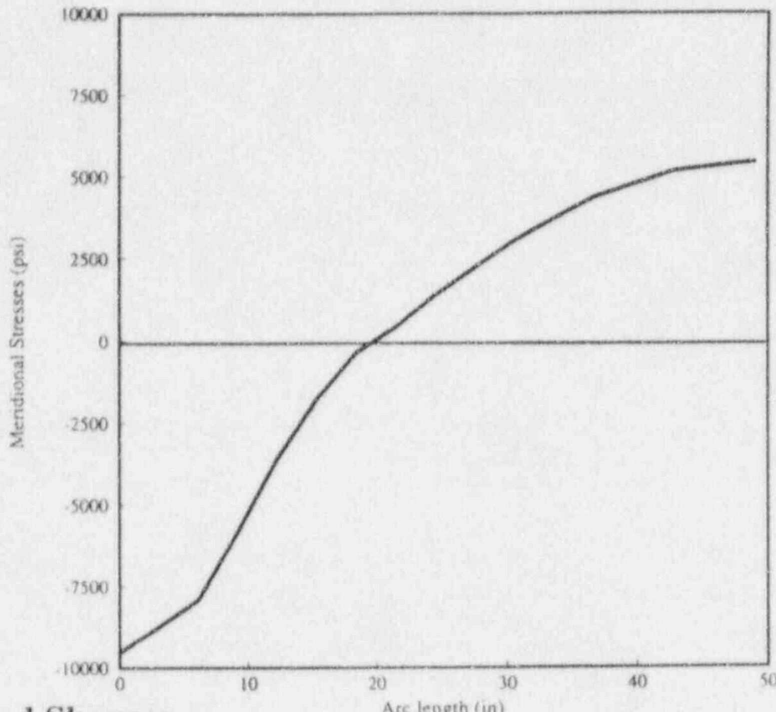
   Number of dry strips, n = 50

   Width of dry strip = 30"

   Width of wet strip = 68"

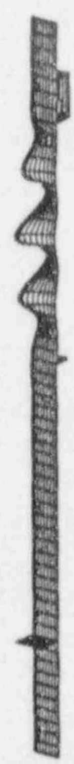
Finite Element Results:

a. Prebuckling Meridional Stresses:



b. Buckled Shapes:

Mode (1) $\lambda = 11.213$

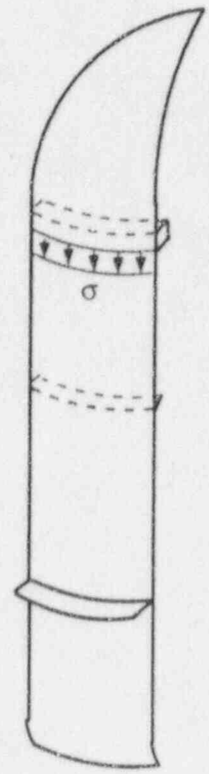


Mode (2) $\lambda = 14.235$

Assessment of the Worst Meridian Approach:

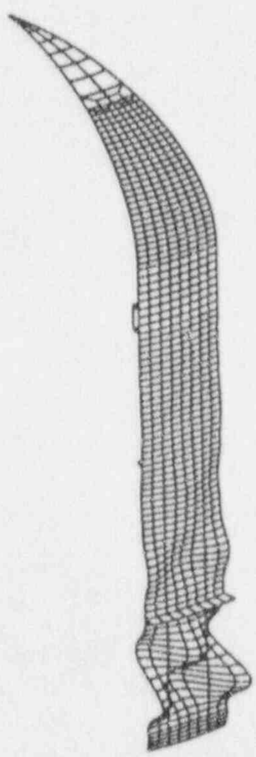
Loading:

Axial stress, $\sigma = 9.53$ ksi

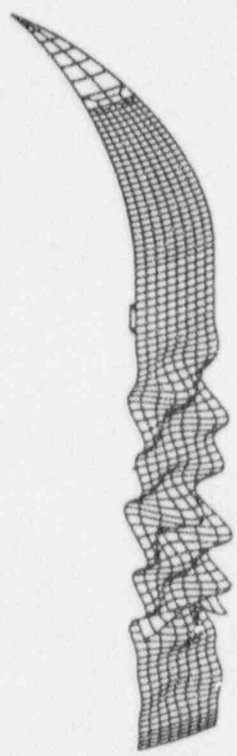


Axially Loaded Wedge Model

Finite Element Results:



Mode (1) $\lambda = 6.790$



Mode (2) $\lambda = 6.832$

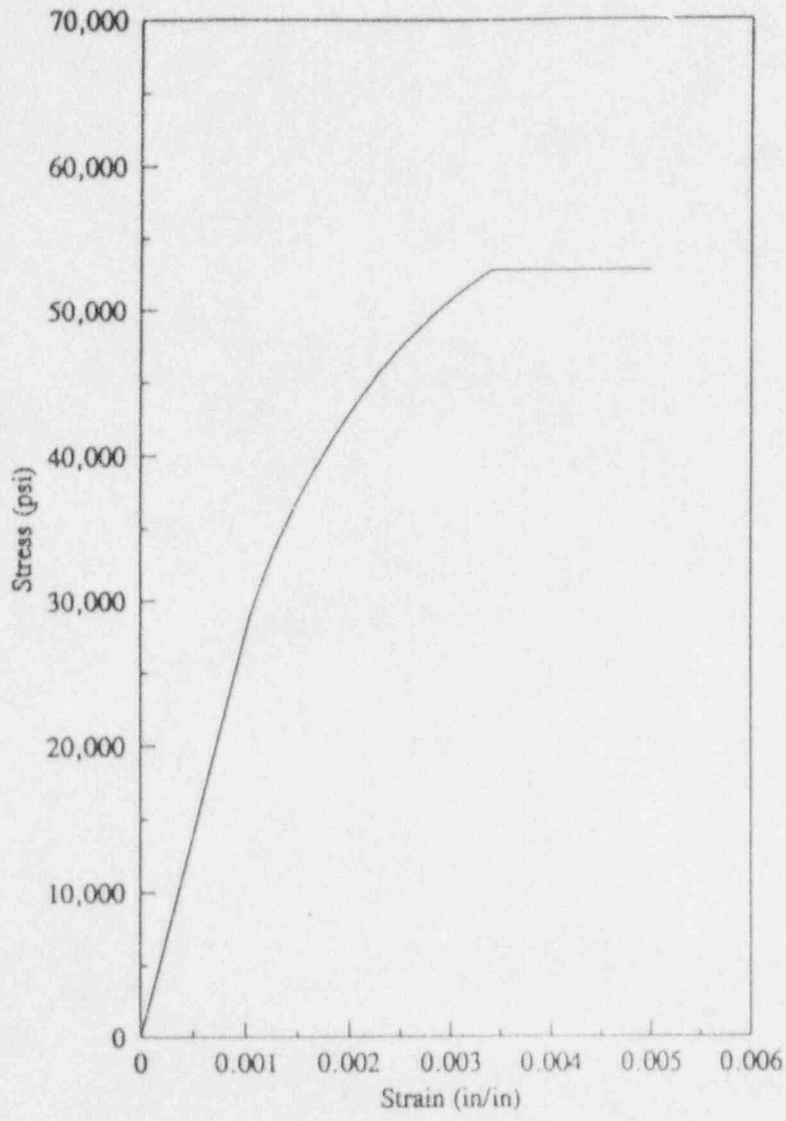
- **Inelastic Buckling Analysis:**

Configurations:

$E = 27.4 \times 10^6$ psi

$\nu = 0.3$

Stress-Strain Curve at T = 280°F



Stress-Strain Curve at T = 280°F

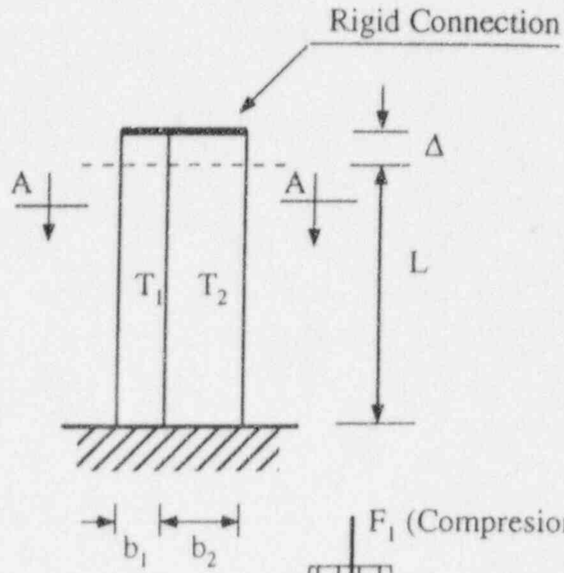
Sensitivity Study:

a. Geometric Imperfections

b. Number of Dry Strips, n

c. Percentage of the Dry Strip Width, d

A. Geometric Imperfections:



- **Axisymmetric Imperfections:**

Theoretical Background:

From compatability

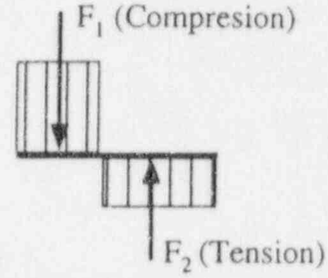
$$T_1\alpha_1 L - \frac{F}{\Delta_1 K_1} = T_2\alpha_2 L + \frac{F}{\Delta_2 K_2}$$

where

$$\Delta_1 = 1 - \frac{F}{F_{E1}}$$

$$\Delta_2 = 1 + \frac{F}{F_{E2}}$$

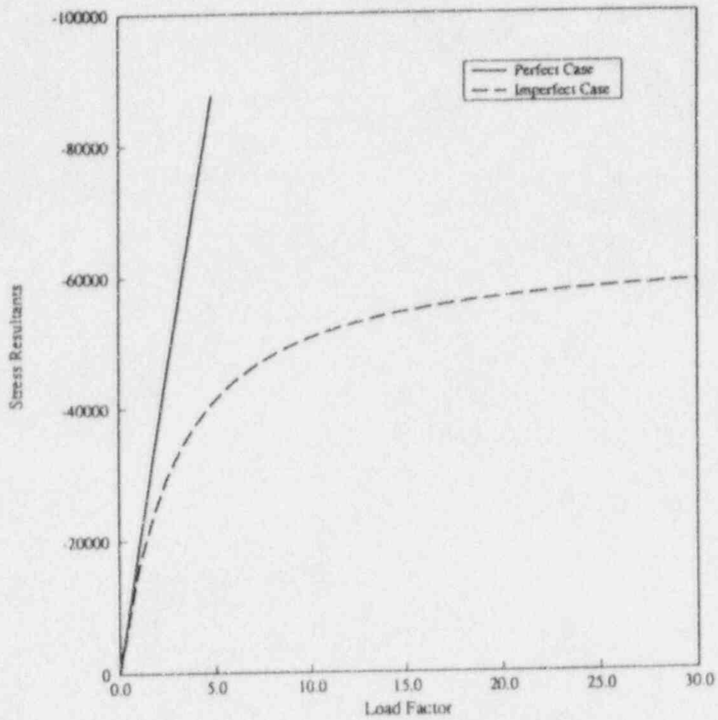
$$\therefore\ F = \frac{\Delta_1\,\Delta_2\,K_1\,K_2\,(T_1\alpha_1 - T_2\alpha_2)L}{(\Delta_1\,K_1 + \Delta_2\,K_2)}$$



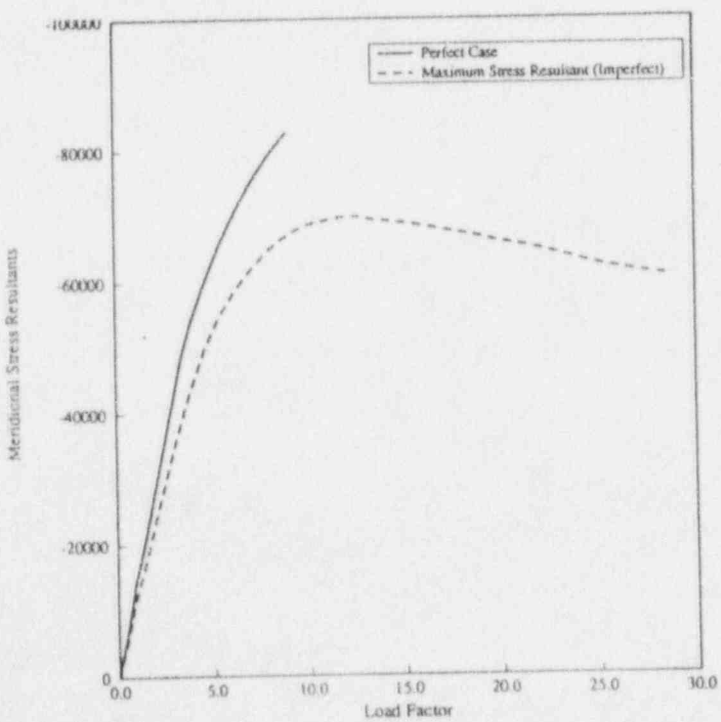
Stress Distribution on Sec. A-A

Results:

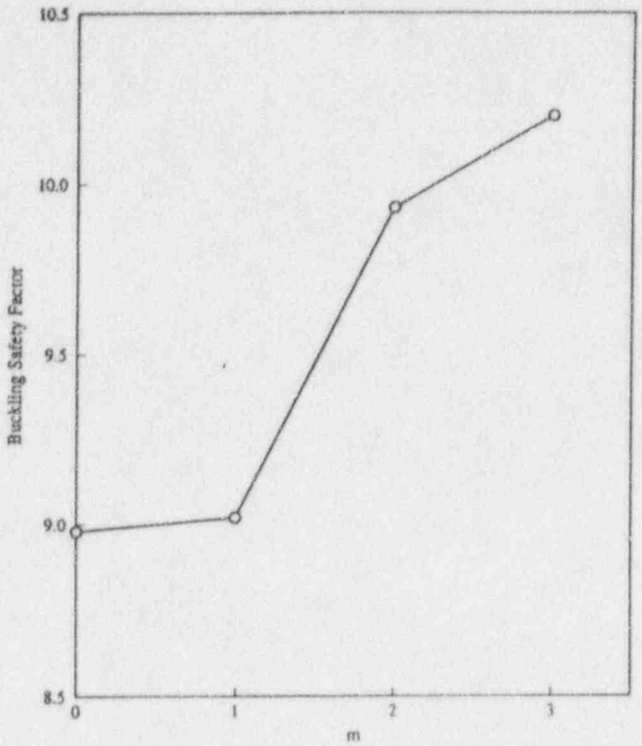
a. Theoretical Solution:



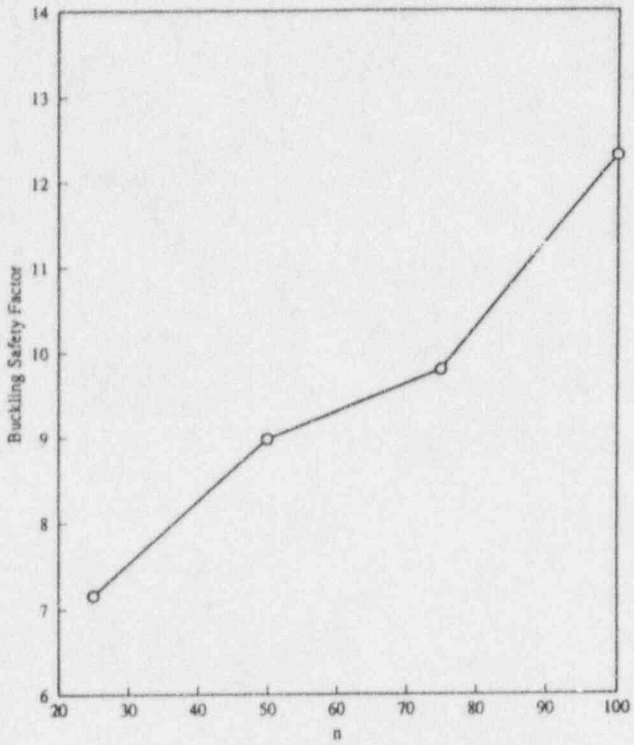
b. Finite Element Solution:



- **Hoop Imperfections:**

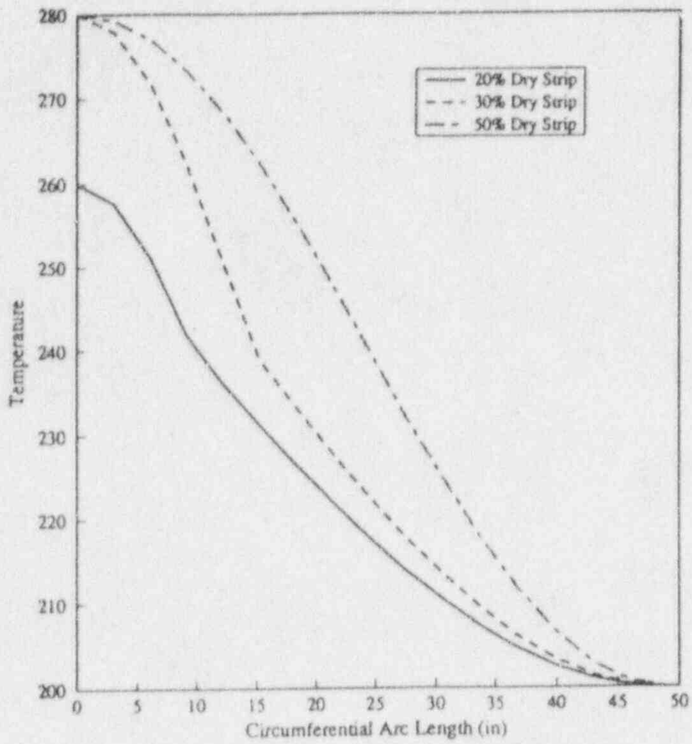


B. Number of Dry Strips, n:



C. Percentage of Dry Strip Width, d:

Temperature Distribution:



Conclusions:

1. Worst Configurations:

   Perfect shell

   $n = 25$

   $d = 30\%$

2. Minimum Buckling Factor of Safety, $\lambda = 7.16$

CB&I (4/2/93 Letter):

- The applied maximum meridional stress is about half of the allowable meridional stress.

D. BUCKLING ANALYSIS OF AP600 AT DBA1, CASE(1):

Geometric Configuration:

Sinusoidal Imperfection $L_w = 4.0\sqrt{rt}, \quad a = \frac{t}{2}$

Loading Configuration:

1. Own Weight

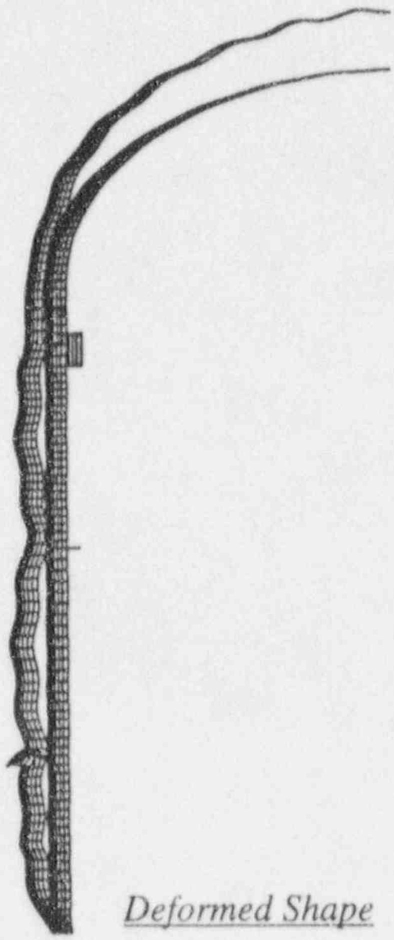
2. Crane Load

3. Internal pressure, p = 45 psi

4. Uniform temperature, T = 280°F

Finite Element Results:

a. Deformed Shape:

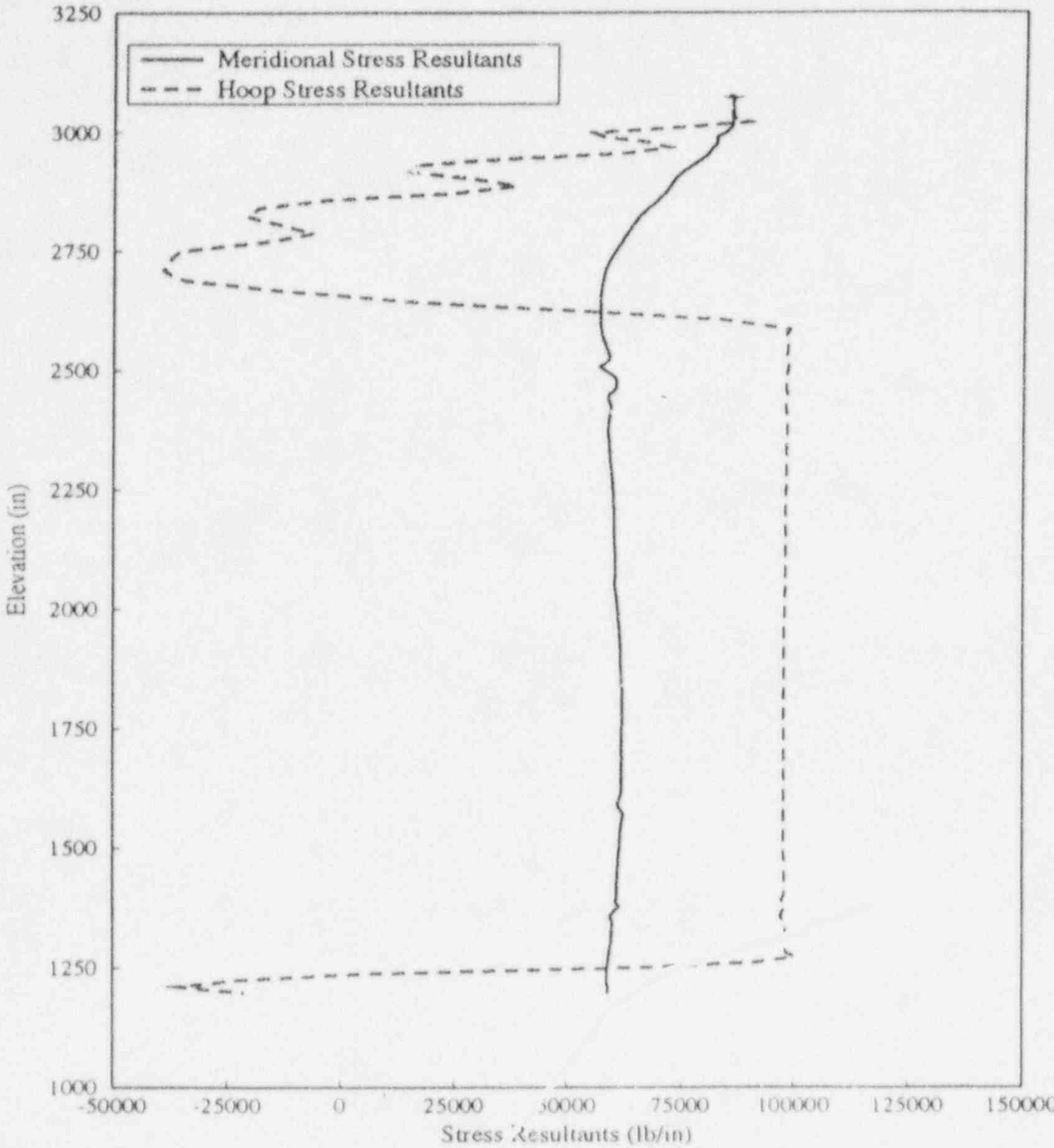


Deformed Shape

b. Failure Mode

Tensile yield of the cylindrical portion
at Load Proportionality Factor, $\lambda = 3.02$

c. Stress Resultants:



E. BUCKLING ANALYSIS OF AP600 AT DBA1, CASE 2:

Geometric Configuration:

No geometric imperfections

Loading:

Number of dry strips, n = 25

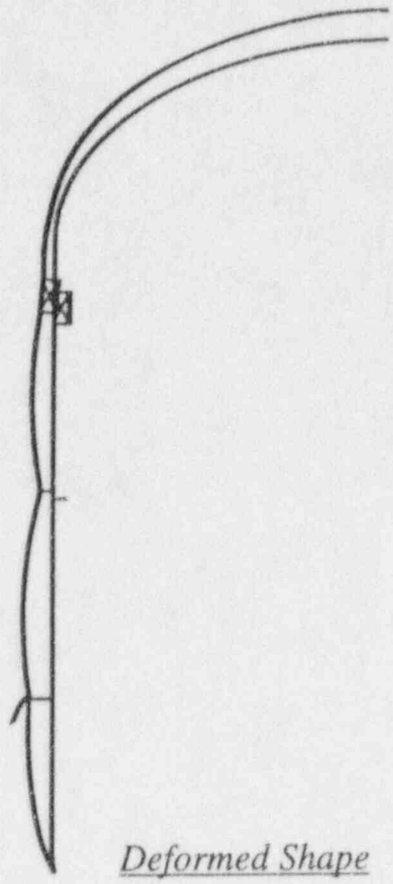
Percentage of dry strip width, d = 30 %

Width of dry strip = 58.8"

Width of wet strip = 137.2"

Finite Element Results:

a. Deformed Shape:



Deformed Shape

b. Failure Mode:

Tensile yield of the cylindrical portion
at Load Proportionality Factor, $\lambda = 3.03$

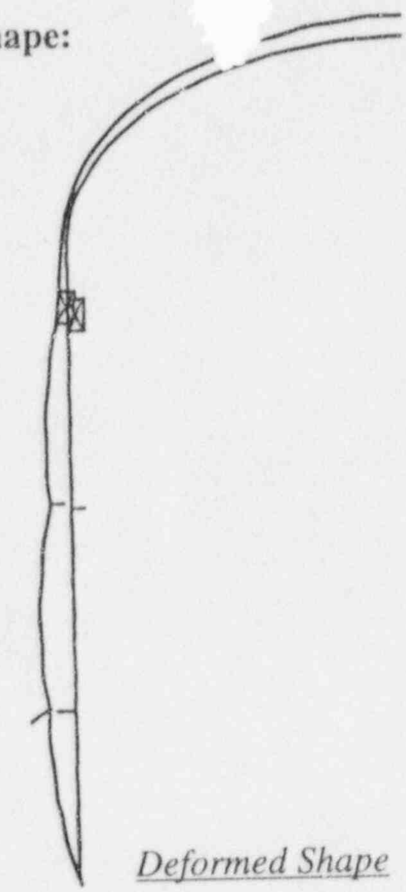
E. BUCKLING ANALYSIS OF AP600 AT DBA1, CASE 2:

Geometric Configuration:

Sinusoidal Imperfection $L_w =$ [illegible] $\sqrt{rt}$, $a = \frac{t}{2}$

Finite Element Results:

a. Deformed Shape:



Deformed Shape

b. Failure Mode:

Tensile yield of the cylindrical portion
at Load Proportionality Factor, $\lambda = 3.05$

SUMMARY OF ASYMMETRIC TEMPERATURE ANALYSIS

- **Loading Configuration:** **(Level A Service Limit-DBA1)**

  a. Dead and Crane Loads

  b. Internal pressure, P = 45 psi

  c. Uniform temperature, T = 280°F (Case 1)

Failure Mode: Tensile yielding of the cylindrical portion at Load factor, λ = 3.02

Conclusion: Satisfies ASME Code Case N-284 (F.S.=2.0) and ASME Section NE 3222.2 (F.S.=3.0)

- **Loading Configuration:** **(Level A Service Limit-DBA1)**

  a. Dead and Crane Loads

  b. Internal pressure, P = 45 psi

  c. Asymmetric temperature (Case 2)

Failure Mode: Tensile yielding of the cylindrical portion at Load factor, λ = 3.03 before asymmetric buckling due to striping (λ = 7.16)

Conclusion: Satisfies ASME Code Case N-284 (F.S.=2.0) and ASME Section NE 3222.2 (F.S.=3.0)