ENCLOSURE

WATTS BAR NUCLEAR PLANT UNITS 1 AND 2

STATIC AND LINEAR LOCAL

DYNAMIC INTERNAL PRESSURE

CAPABILITY OF THE STEEL CONTAINMENT VESSEL

TVA REPORT CEB 81-22

JUNE 12, 1981

A11141.10

TABLE OF CONTENTS

Section	Description	Page
1.0	Introduction	1
2.0	Conclusion and Summary of Results	2
3.0	Steel Containment Vessel	4
	3.1 Description and Design Parameters	4
	3.2 Applicable Codes	6
	3.3 Design Criteria	6
	3.4 Material Characteristics	7
	3.5 Static Pressure Capability Analysis	8
	3.5.1 Containment Vessel Shell	8
	3.5.2 Containment Anchorage	11
	3.5.3 Containment Penetrations	12
	3.5.3.1 Welded Spare Penetrations	12
	3.5.3.2 Bolted Head Penetrations	12
	3.5.3.3 Bellowed Penetrations	13
	3.5.3.4 Electrical Penetrations	13

TABLE OF CONTENTS (Continued)

Section	Description	Page
3.5.4	Personnel Locks	14
3.5.5	Equipment Hatch	15
3.5.6	Valve	15
3.6	Linear Local Dynamic Analysis	16
3.6.1	Finite Element Model	16
3.6.2	Boundary Conditions	16
3.6.3	Loading Conditions	18
3.6.4	Analytical Methods	18
3.6.5	Analytical Results	19
References		21

LIST OF TABLES

Table	Description	Page
1	Containment Pressure Capabilities	23
2	Circumferential Stiffeners	25
3	Equivalent Forces Representing Initial Velocities	26
4	Maximum Von Mises Stress	30

LIST OF FIGURES

Figure	Description	Page
1	Steel Containment Vessel	31
2	Containment Anchorage	32
3	Containment Penetrations	33
4	Personnel Lock	34
5	Equipment Hatch	35
6	Graphical Representation of Model	36
7	Finite Element Model of Shell Segment	37
8	Pressure-time Function of Local Detonation	38
9	Graphical Representation of Pressure Function	39
10	Deflection Versus Time for Node at Load Center for the Fixed Radial Boundary Condition	40
11	Isometric Plot of Deflection in Load Region for Time = 0.007 Sec for the Fixed Radial Boundary Condition	41
12	Von Mises Stress Contour Plot for Time = 0.007 Sec for the Fixed Radial Boundary Condition	42

1.0 INTRODUCTION

As part of the Watts Bar Nuclear Plant safety evaluation, TVA wanted to demonstrate that the interim hydrogen control system will provide, with reasonable assurance, protection against breach of containment in the event that a substantial quantity of hydrogen is generated. As part of this evaluation, studies were done to provide assurance that the containment shell is capable of withstanding pressures which exceed original design capability and also the effects of a postulated local hydrogen detonation. The Nuclear Engineering Branch has developed a representative pressure profile from such a hypothetical detonation (see figure 8). This report documents the results of structural evaluations to determine the static-pressure-retaining capabilities of the containment and the effects of the postulated hydrogen detonation.

2.0 CONCLUSIONS AND SUMMARY OF RESULTS

The Watts Bar containment and its appurtances were evaluated to determine their limiting pressure capacities. In this report the term "pressure capability" is coined to mean the capability of a steel containment shell including its appurtances of resisting internal pressure without gross deformation or uncontrained yielding. For this analysis the minimum ASME Boiler and Pressure Vessel Code materials yield strengths were used along with the maximum shear strength stress criterion. Various considerations such as actual material yield strength, Von Mises criterion, and material nonlinearities suggest that the containment shell can sustain significantly higher pressure than reported here.

The element limiting the pressure capacity of the containment shell is the 1-3/8 inch shell midway between the stiffeners at elevations 744 feet 6 inches and 733 feet 6 inches. Looking at the total containment system the element governing pressure capacity is the personnel locks bulkhead with a capacity of 53.5 lb/in^2g. If additional capacity is required, these bulkheads can be stiffened so that they are no longer the controlling link in the containment system. Table 1 provides a summary of the various element static pressure capacities.

Linear dynamic structural analyses were performed on a panel segment of the containment vessel between elevations 721 feet 3 inches and 757 feet 6 inches and between azimuths 150° and 210°. The detonation pressure pulse was centered at elevation 739 feet 0 inch and azimuth 180° in the 1-3/8 inch cylindrical shell plate which is the limiting area of the containment vessel. Using symmetry about the 180° azimuth the panel between azimuths 150° and 180° was modeled and analyzed. Two sets of boundary conditions were considered as described in subsection 3.6.2.

The results of the analyses showed that the boundary conditions did not have a significant effect on maximum displacements and stresses. Figure 12 shows the Von Mises stress contour plot for the fixed radial boundary condition. Note that the stresses in the panel die out well before they reach the boundaries. This verifies that the response is local in nature and the panel size selected is sufficient.

The maximum shell displacements for the two boundary conditions are 0.22 inch and 0.22 inch. The maximum stresses, which occurred in the 1-3/8 inch shell plate, for the two boundary conditions are 5.4 k/in^2 and 6.7 k/in^2.

The results of the analyses show that the containment has the capability to withstand the local hydrogen detonation considered. Since the maximum stress in the 1-3/8 inch cylindrical shell plate is 6.7 k/in^2 and the minimum ASME Code yield strength of the plate is 38.0 k/in^2, there is a factor of safety of 5.6 against yield.

3.0 STEEL CONTAINMENT VESSEL

3.1 Description and Design Parameters. The containment vessel at Watts Bar is a low-leakage, free-standing steel structure consisting of a cylindrical wall, a hemispherical dome, and a bottom liner plate encased in concrete. Figure 1 shows the outline and configuration of the containment vessel.

The structure consists of side walls measuring 111 feet 8-5/8 inches in height from the top of the concrete base to the spring line of the dome and has an inside diameter of 115 feet 0 inch. The bottom liner plate is 1/4 inch thick; the cylinder varies from 1-3/8 inch thickness at the bottom to 1-1/2 inches thick at the spring line, and the dome varies from 1-3/8 inch thickness at the spring line to 13/16 inch thickness (minimum) to 15/16 inch thickness at the apex.

The containment vessel is provided with circumferential ring stiffeners with vertical stiffening between elevations 703 feet 9-3/8 inches and 716 feet 7-3/8 inches on the exterior of the shell. These stiffeners are required to satisfy design requirements for pressure transient loads combined with seismic, thermal, and operating loads. The circumferential stiffeners were installed on approximately 11 foot centers to ensure stability and alignment of the shell. Vertical stiffeners are spaced at 5^{o} intervals, and other locally stiffened areas are provided around major openings and penetrations as required. Figure 1 shows the arrangement of circumferential stiffeners. Table 2 gives the size and elevation of circumferential stiffeners.

An equipment hatch with an inside diameter of 20 feet 0 inch has been provided to enable passage of large equipment and components into the containment during plant shutdown.

Two personnel access locks were provided for each containment vessel. Each personnel lock is a welded steel assembly with a door at each end equipped with a double compressible seal to ensure leak tightness.

The containment anchorage system consist of 360 anchor bolts 3-1/2 inch diameter equally spaced on two radii, 57 feet 0 inch and 58 feet 1-3/8 inches, from the containment centerline. Each pair of anchor bolts has a 2 feet 0 inch by 2 feet 0 inch by 4-3/8 inch anchor plate which extends 6 feet 3 inches into the rough pour concrete (figure 2).

3.2 Applicable Codes. The design of the containment vessel meets the requirements of the 1971 American Society of Mechanical Engineers (ASME) Code, Section III, Subsection NE, winter 1971 Addenda.

3.3 Design Criteria. The following pressures and temperatures were used in the design of the vessel:

Overpressure test (1)	16.9 lb/in^2g
Maximum internal pressure (2)	15.0 lb/in^2g at 250° F
Design internal pressure (2)	13.5 lb/in^2g at 250° F
Leakage rate test pressure	15.0 lb/in^2g
Design external pressure	2.0 lb/in^2g
Lowest service metal temperature	30° F
Operating ambient temperature	120° F
Operating internal temperature	120° F
Design temperature	250° F

(1) Overpressure test pressure is 1.25 times design internal pressure as required by ASME Code, NE-6322.

(2) See Paragraph NE-3312 of Section III of the ASME Code which states that the "design internal pressure" of the vessel may differ from the "maximum containment pressure," but in no case shall the design internal pressure be less than 90 percent of the maximum containment internal pressure.

3.4 Material Characteristics. The pressure-retaining material used in the containment vessels including equipment access hatches, personnel access locks, penetrations, and attachments meet the requirements of the ASME Code, including Charpy impact requirements for a maximum test metal temperature of 0° F. The shell plates meet the requirements of ASME Specification SA-516 Grade 70. This specification requires a minimum yield strength of 38 k/in^2.

Yield Criteria. The 1971 ASME Code in Section III, NB-3215 presents a method of calculating stress intensities from the principal stress differences. These are then compared to the allowable stress. The allowable stress criteria used in these pressure capability analyses is the maximum shear stress criteria. If the Von Mises yield (maximum distortion energy) criteria is applied; the critical stress, σ_{CR}, is calculated from the principal stresses by the following formula:

$$\sigma_{CR} = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 \sigma_2}$$

Where σ_1 and σ_2 are the principal stresses in the meridional and hoop directions. For an unstiffened cylindrial vessel under uniform pressure, the maximum Von Mises stress would be approximately 15 percent greater than the corresponding ASME stress intensities. Therefore, using the Von Mises criteria in conjunction with this analysis will result in predicted shell capability up to 15 percent higher than the ASME criteria.

3.5 Static Pressure Capability Analysis. This section describes the analyses performed to evaluate the containment system to determine the static pressure capacity. The containment system was analyzed using standard empirical formulas.

3.5.1 Containment Vessel Shell. The stresses in the cylindrical shell and dome due to internal pressure are essentially membrane except in the vicinity of the embedment at the base and the horizontal ring stiffeners. At these locations secondary bending occurs due to restraint of the embedment and the self-constraint resulting from the local stiffening.

The stiffener spacing on the Watts Bar Containment is approximately 11 feet. Thus, there affect on the internal pressure retaining capability of the shell is negligible. Therefore, the hoop stress and meridional stress in the cylinder can be calculated respectively by

$$\sigma_t = \frac{Pr}{t} \quad \text{and} \quad \sigma_l = \frac{Pr}{2t}$$

where r is the vessel radius and t is the shell thickness. Hence, if σ_t is equal to the ASME Code yield mimimum strength for SA 516 Grade 70, the shell membrane hoop stress in 1-3/8 inch plate midway between the stiffeners at elevations 744 feet 6 inches and 733 feet 6 inches governs maximum static pressure. Using the maximum shear stress criterion the minimum pressure capability is 74.3 lb/in^2g. If the Von Mises criterion is applied as described in subsection 3.4 the resulting pressure capacity is 85.8 lb/in^2g.

3.5.1.1 <u>Containment Dome</u>. The dome on the Watts Bar Containment vessel is hemispherical, unstiffened geometry which transitions from 1-3/8 inch plate at springline to 13/16 inch to 15/16 inch plate at the apex. The stress in both the meridional and hoop directions can be determined by the following expression:

$$\sigma_l = \sigma_c = \frac{Pr}{2t}$$

where r is the radius of the hemisphere and t is the thickness. Note, that the minimum thickness is 13/16 inch and this region will govern pressure capability of the dome. If the stress intensity is equal to the minimum ASME yield strength the pressure capacity would be 89.5 lb/in^2g. The Von Mises and Maximum Shear Stress pressure capacities are equal for a hemispherical dome.

3.5.1.2 <u>Discontinuity Stress at the Dome to Cylinder Intersection</u>. The joint at the cylinder to dome intersection has a self-induced meridional bending moment under the application of internal pressure. This moment was evaluated for the Watts Bar containment using the equation in reference 8, table XIII, case 31. In this analysis, the stiffeners were conservatively neglected.

The results of this evaluation indicate that this moment is insignificant. The expression for the meridional moment is as follows:

$$M_o = p(-2.131 \text{ in}^3/\text{in})$$

where internal pressure, p, is in lb/in^2g.

3.5.2 <u>Containment Anchorage</u>. The allowable containment pressure loading on the containment anchorage, figure 2, was calculated considering bolt preload, applied tensile load due to internal pressure, and compressive load due to the deadweight of the containment vessel. The permissible concrete tearout load was also calculated using the criteria in reference 9.

Based on these analyses, the governing consideration for the anchorage system is concrete tearout. The limiting internal containment pressure corresponding to this condition is 133.7 lb/in^2g.

3.5.3 Containment Penetrations. The controlling cases for each different type penetration were considered in the containment penetration analyses. All of the Watts Bar containment penetrations were grouped under four classifications: welded spare, bolted head, bellowed, and electrical penetrations.

3.5.3.1 Welded Spare Penetrations. The welded spare penetrations, figure 3a, have welded flat heads which are located on the outboard end of the penetration nozzles. The penetration controlling critical pressure under this classification is penetration X-8. The maximum pressure for this penetration using minimum yield strength of SA 516, Grade 70 is 913.0 lb/in^2g.

3.5.3.2 Bolted Head Penetrations. Penetrations falling under this classification have bolted flat covers with double O-ring seals on the outboard end of the nozzle (figure 3b). The governing bolted head penetration is penetration X-79B. The maximum pressure again based on minimum yield strength is 956 lb/in^2g.

3.5.3.3 Bellowed Penetrations. Obviously, the weak link in the bellowed penetrations is the bellows itself. The bellows' construction consists of a wire mesh sandwiched between two stainless steel plies (figure 3c).

Pressures substantially above the design pressure would tend to balloon the convolutions, but this would not affect its pressure retaining capability. Tube Turns Corporation, the bellows supplier for Watts Bar has reviewed all of the bellows' assemblies; and their analysis indicates that the minimum rupture pressure of all the bellows is 212 lb/in^2g (penetration X-13A, B, C, and D).

3.5.3.4 Electrical Penetrations. The most likely leak path in the electrical inserts is between the electrodes and weldment assembly which is filled with a filler material. Similar penetrations have been tested to 100 lb/in^2g by the manufacturer without leakage. All of the Watts Bar electrical containment penetration inserts have been certified to 60 lb/in^2g by their supplier, Westinghouse, Incorporated.

3.5.4 Personnel Locks. The personnel locks, figure 4, consist of the penetration sleeve with two 8 foot 7 inch diameter cylinders approximately 4 feet 6 inches long by 3/8 inch thick full penetration welded to each side. The ends are capped with 1/2 inch thick flat reinforced bulkheads having doors with double compression seals for leak tightness. Internal pressure in the containment would cause the inner door gaskets to seat; therefore, the latches would not be loaded under internal pressure. The shell insert satisfies full area replacement.

The lock barrel, bulkhead with stiffeners and lock doors were analyzed using empirical formulae. The results compared favorably with the finite element analysis performed on the Sequoyah Nuclear Plant lock bulkhead which is very similar except for the door frame stiffeners. The lock pressure capability with the addition of a 1 by 4 flat bar on center horizontal stiffener of the lock bulkhead making it a tee section (Action is being taken to implement this modification) is 53.5 lb/in^2g. Note, these bulkheads could be further stiffened to the point where the lock is no longer the controlling link in the containment system.

3.5.5 Equipment Hatch. The containment equipment hatch, figure 5, consists of the shell insert, a 20 foot 0 inch diameter door and twenty 1-1/4 inch diameter swing bolts equally spaced. The door is a 20 foot 0 inch radius spherically dished head 3/4 inch thick and convex to internal pressure with a tension ring skirt. The seals have double compression gaskets between the door tension ring and penetration sleeve. The shell insert satisfies full area replacement of the shell.

Of primary concern is the hatch door. An internal pressure on the hatch door would act to seat the door seals; therefore, the swing bolts would not be loaded. The critical element in the door is buckling of the dished head under internal pressure. Using reference 6 the critical buckling pressure for the hatch door is 73 lb/in^2g. Since the critical buckling stress in reference 6 is based on tests, the effects of initial imperfections are considered. Although hatch door buckles it would still retain internal pressure until the door tension ring yields at 98 lb/in^2g.

3.5.6 Valve. The minimum isolation valve rating on the Watts Bar containment is 150 lb/in^2g.

3.6 Linear Local Dynamic Analysis. This section of the report describes the analysis performed to evaluate the response of the shell to a local hydrogen detonation. A panel analysis was performed for the portion of the shell between elevations 721 feet 3 inches and 757 feet 6 inches, and between azimuths 150^{o} and 210^{o}.

3.6.1 Finite Element Model. Figure 6 shows a graphical representation of the area considered. Included within this area were shell plates of 1-3/8 inch thickness. The circumferential stiffeners were modeled as off-set beams with the dimensions shown in table 2. To allow greater refinement within the region considered, symmetry is invoked along the 180^{o} azimuth. The finite element model of the 30^{o} segment is shown in figure 7.

3.6.2 Boundary Conditions. To effectively evaluate the shell, two sets of boundary conditions along the outer boundaries of the model were assumed. The first set represented the segment as part of the larger shell, while the second represented the segment as a curved panel. The following boundary conditions were assumed.

3.6.2.1 To represent the panel as part of the larger shell:

a. Rotation (ROTZ) assumed equal to 0.0 along the 150° and 180° azimuths.

b Rotation (ROTX) assumed equal to 0.0 along the radal axis at all points on the boundary.

c. Rotation (ROTY) assumed equal to 0.0 along the tangential axis at elevations 721 feet 3 inches and 757 feet 6 inches.

d. Radial displacements (UX) allowed to translate freely at all points on the boundary.

e. Tangential displacements (UY) assumed equal to 0.0 along the 150° and 180° azimuths.

f. Vertical displacements (UZ) assumed equal to 0.0 at elevation 721 feet 3 inches and 757 feet 6 inches.

3.6.2.2 To represent the panel as a isolated segment of the total shell the following change to the displacement data of subsection 3.6.2.1 was made.

a. Displacement in the radial direction (UX) was assumed equal to 0.0 at all boundary nodes except along azimuth 180°.

3.6.3 Loading Conditions. The loading on the shell consisted of a time varying pressure as shown on figure 8. This conservative pressure pulse peak is based upon information contained in Naval Weapons Center technical paper NWC-TP-6089 (reference 7), and represents the largest peak overpressure outside the detonable mixture. The pressure is assumed to be constant over a diameter of 6 feet, and to decrease in the ratio of $(r_0/r)^3$ until its magnitude is 0.0 lb/in^2g at a distance of approximately 9 feet from the center of the loaded region. The pressure distribution is shown on figure 9. Note from figure 8 that this pressure pulse is of short duration with the maximum pressure of 181 lb/in^2g occurring at 0.1 milliseconds after detonation and decreasing to 0.0 lb/in^2g at 0.5 milliseconds.

3.6.4 Analytical Method. A detail computer model of the shell segment between elevations 721 feet 3 inches and 756 feet 6 inches, and between azimuths 150° and 180° was formulated using the ANSYS revision 3 computer code. The model utilized both the STIF-43 qudrilateral shell element with bending and membrane stiffness (shell plates) and STIF-44 3-D off-set beam element with bending stiffness (circumferential stiffeners). The finite element model is shown on figure 7. As previously discussed in subsection 3.6.2, two sets of boundary conditions were assumed. Table 3 lists the equivalent forces calculated to represent the initial velocities imparted to the shell by the impulse function. Using a uniform time step of 0.0001 second, the response of the shell was then evaluated through time for a duration of 0.1 second. Section 3.16.1 of reference 4 describes in more detail the analytical method used.

3.6.5 Analytical Results. The response of the vessel to the pressure pulse is cyclic in nature. Figure 10 shows the time history of the radial displacement of the vessel at the center of the applied loading for the fixed radial boundary condition (subsection 3.5.2.2). Figure 11 is a plot of the maximum vessel displacement which occurs at 0.007 seconds for the fixed radial boundary condition. Note that the large displacement responses are in the shell plate between the stiffeners, where the maximum displacement is 0.22 inch. A contour plot of the Von Mises stress at the time of maximum response for the fixed radial displacement boundary condition is shown in figure 12. The local nature of the response is vividly illustrated by this plot. The Von Mises stress at key points in the region of the load are listed in table 4. The maximum Von Mises stress is 6.7 k/in^2 and occurs in the 1-3/8 inch cylindrical shell plate.

The analytical results for the free radial boundary condition (subsection 3.5.2.1) are similar to the results for the fixed radial boundary condition. The maximum displacement response is 0.22 inch and the maximum Von Mises stress is 5.4 k/in^2.

The results from these analyses indicate that the stresses resulting from a hydrogen detonation are localized and are much less than the minimum yield stress.

REFERENCES

1. "Analysis of Three Mile Island - Unit 2 Accident," NSAC-1, Appendix HYD.

2. "Watts Bar Nuclear Plant - Steel Containment Vessels - Nuclear Record Package."

3. Timoshenko, S. P., and Woinowsky - Krieger, S., "Theory of Plates and Shells," 2nd edition, McGraw Hill Book Company, New York, 1959.

4. ANSYS Users Manual, Swanson Analysis Systems, revision 3, August 1, 1978.

5. UCLA - Eng - 7661, "On the Failure Modes of Alternate Containment Designs Following Postulated Core Meltdown."

6. Biggs, J. M., "Introduction to Structural Dynamics," McGraw-Hill Book Company, New York, 1964.

7. Naval Weapons Center, Technical Paper NWC-TP-6089, "Peak Overpressures for Internal Blast," June 1979.

8. Roark, Raymond, J., "Formulas for Stress and Strain," 4th edition, McGraw-Hill Book Company, New York, 1965.

9. Tennessee Valley Authority, "Concrete Anchorages," Civil Design Standard DS-C61.

10. Timoshenko, Stephen P., "Theory of Elastic Stability," 2nd edition, McGraw-Hill Book Company, New York, 1961.

TABLE 1

WATTS BAR NUCLEAR PLANT

CONTAINMENT PRESSURE CAPABILITIES

(lb/in^2g)

Critical Section	Critical Pressure/ Rating	Pressure Capacity Minimum ASME Yield Strength (Maximum Shear Stress)	Pressure Capacity Minimum ASME Yield Strength (Von Mises)
Cylindrical shell plate - elevation 744'-6"-733'-6"		74.3	85.8
Dome shell plate		89.5	89.5
Penetration			
Welded spare		913.0	
Bolted head		956.0	
Bellows		212.0	
Electrical	60.0*		

*Indicates vendor pressure rating.

TABLE 1 (Continued)

Critical Section	Critical Pressure/ Rating	Pressure Capacity Minimum ASME Yield Strength (Maximum Shear Stress)	Pressure Capacity Minimum ASME Yield Strength (Von Mises)
Personnel lock		53.5	
Equipment hatch	73.0+	98.0	
Containment anchorage		133.7	
Valves (containment isolation)	150.0 (min)*		

+Critical pressure based on buckling.

*Indicates vendor pressure rating.

TABLE 2

WATTS BAR CONTAINMENT VESSELS

CIRCUMFERENTIAL STIFFENERS

No.	Elevation	Size
1	703'-9-3/8"	10" x 1-3/8"
2	716'-7-3/8"	22" x 1-3/8"
3	724'-6"	22" x 1-3/8"
4	733'-6"	22" x 1-3/8"
5	744'-6"	22" x 1-3/8"
6	754'-0"	22" x 1-3/8"
7	763'-6"	22" x 1-3/8"
8	773'-0"	22" x 1-3/8"
9	782'-6"	22" x 1-3/8"
10	792'-0"	22" x 1-3/8"
11	801'-6"	22" x 1-3/8"
12	811'-0"	22" x 1-3/8"

TABLE 3

WATTS BAR CONTAINMENT VESSELS

EQUIVALENT FORCES REPRESENTING INITIAL VELOCITIES

Location		
Elevation	Azimuth	Initial Force (lb)
731.5	176.0	3817.03
731.5	177.0	3310.68
731.5	178.0	2804.35
731.5	179.0	2804.35
731.5	180.0	1402.17
733.5	174.5	3310.68
733.5	176.0	4673.91
733.5	177.0	6543.48
733.5	178.0	6325.34
733.5	179.0	6107.75
733.5	180.0	3053.6
735.0	172.5	3817.03
735.0	174.5	4673.91
735.0	176.0	6107.25
735.0	177.0	8550.1
735.0	178.0	10993.0
735.0	179.0	13130.57
735.0	180.0	6565.29
736.0	172.5	3310.68

TABLE 3--(Continued)

Location		
Elevation	Azimuth	Initial Force (lb)
736.0	174.5	6543.48
736.0	176.0	8550.1
736.0	177.0	13130.57
736.0	178.0	15268.14
736.0	179.0	20269.74
736.0	180.0	10134.87
737.0	172.5	3310.68
737.0	174.5	6325.34
737.0	176.0	10993.0
737.0	177.0	15268.14
737.0	178.0	20269.74
737.0	179.0	25271.38
737.0	180.0	12635.68
738.0	172.5	2804.35
738.0	174.5	6107.25
738.0	176.0	13130.57
738.0	177.0	20269.74
738.0	178.0	25271.38
738.0	179.0	25271.38
738.0	180.0	12635.68
739.0	172.5	2804.35
739.0	174.5	6107.25
739.0	176.0	13130.57
739.0	177.0	20269.74
739.0	178.0	25271.38

TABLE 3 (Continued)

Location		
Elevation	Azimuth	Initial Force (lb)
739.0	179.0	25271.38
739.0	180.0	12635.68
740.0	172.5	2804.35
740.0	174.5	6107.25
740.0	176.0	13130.57
740.0	177.0	20269.74
740.0	178.0	25271.38
740.0	179.0	25271.38
740.0	180.0	12635.68
741.0	172.5	3310.68
741.0	174.5	6325.34
741.0	176.0	10993.0
741.0	177.0	15268.14
741.0	178.0	20269.74
741.0	179.0	25271.38
741.0	180.0	12635.68
742.0	172.5	3310.68
742.0	174.5	6543.48
742.0	176.0	8550.1
742.0	177.0	13130.57
742.0	178.0	15268.14
742.0	179.0	20269.74
742.0	180.0	10134.87
743.0	172.5	3817.03
743.0	174.5	4673.91

TABLE 3 (Continued)

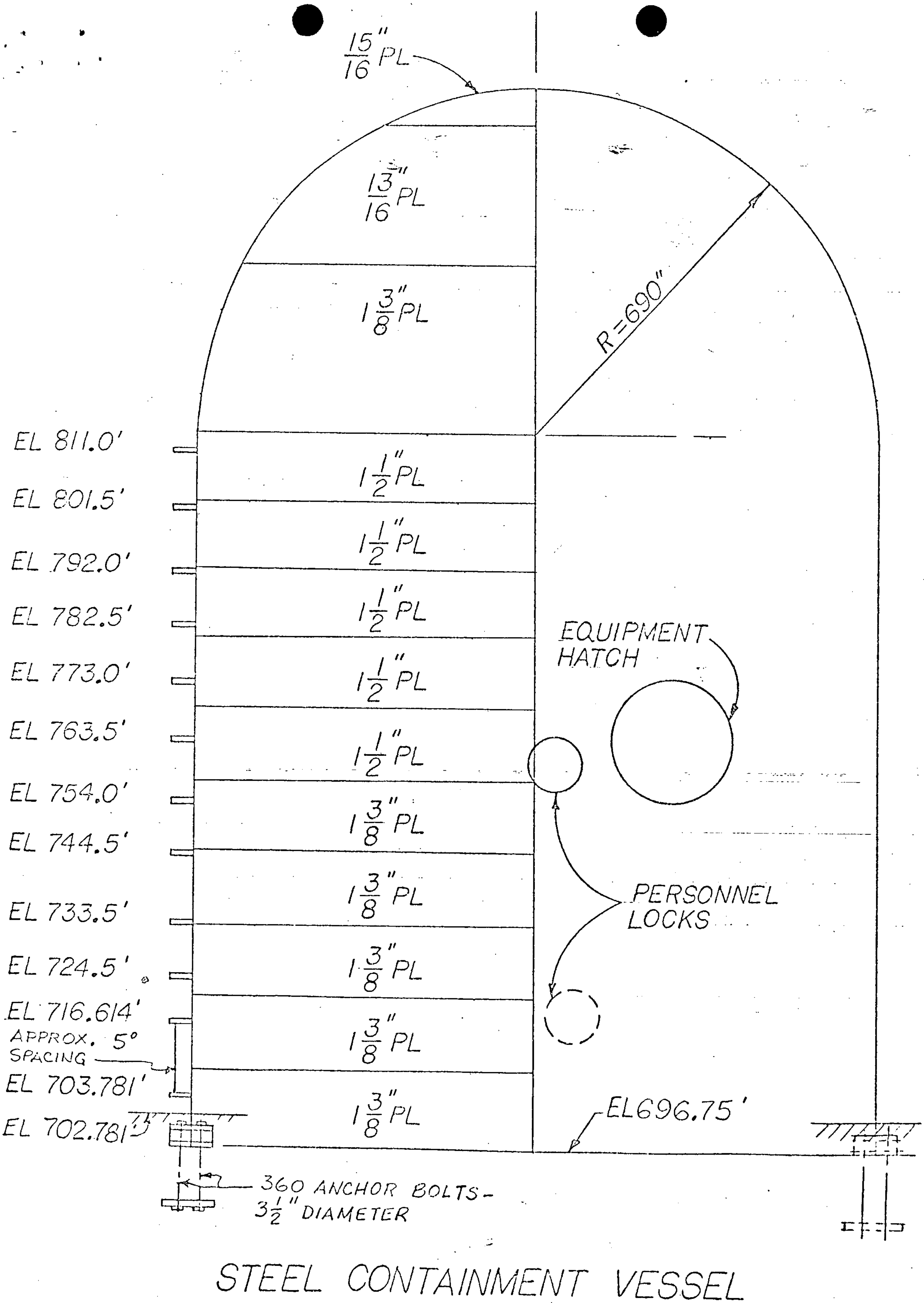
Location		
Elevation	Azimuth	Initial Force (lb)
743.0	176.0	6107.25
743.0	177.0	8550.1
743.0	178.0	10993.0
743.0	179.0	13130.57
743.0	180.0	6565.29
744.5	174.5	3310.68
744.5	176.0	4673.91
744.5	177.0	6543.48
744.5	178.0	6325.34
744.5	179.0	6107.25
744.5	180.0	3053.6
746.5	176.0	3817.03
746.5	177.0	3310.68
746.5	178.0	2804.35
746.5	179.0	2804.35
746.5	180.0	1402.17

TABLE 4

WATTS BAR CONTAINMENT VESSELS

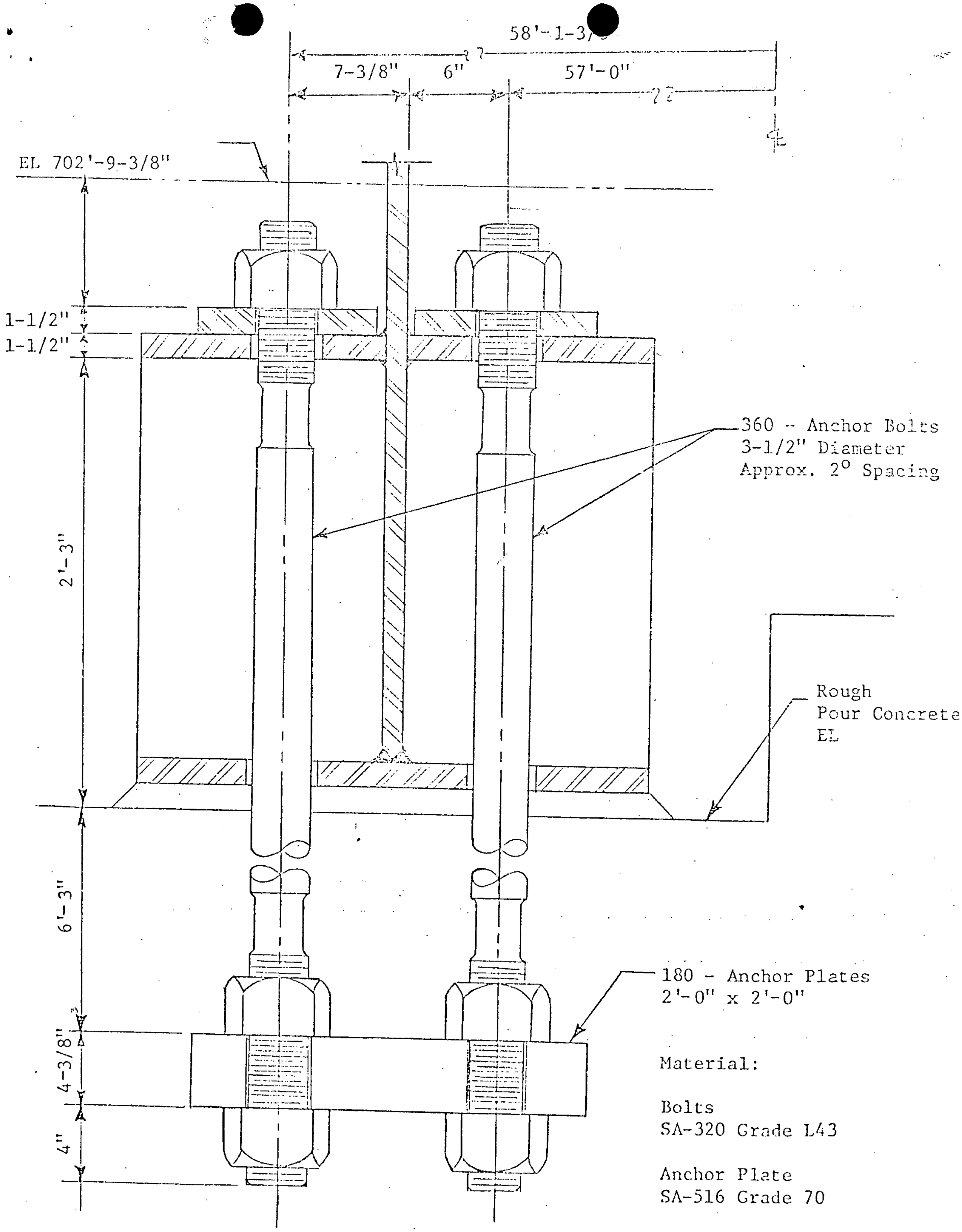
MAXIMUM STRESS

Member	Maximum Stress (k/in^2) Free Radial Boundary Condition	Fixed Radial Boundary Condition
Plate		
1-3/8" (Von Mises Stress)	5.4	6.7
Circumferential		
Stiffener (bending and axial stress)	4.9	3.8
(Elevation 733'-6")		



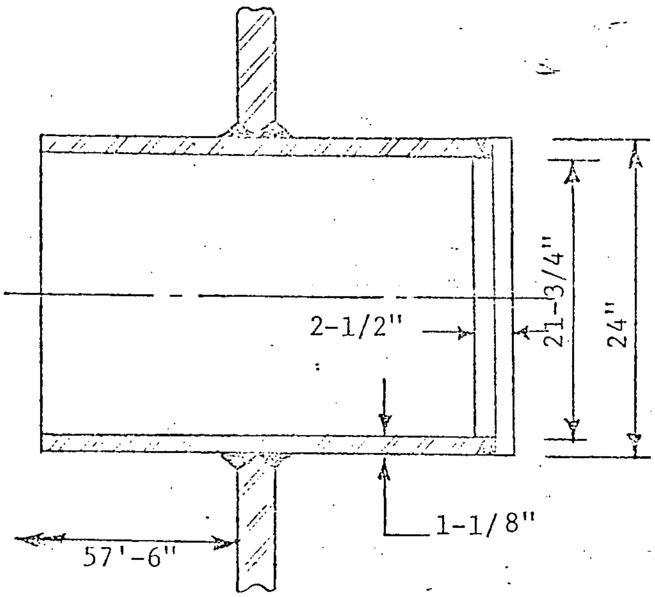
15/16" PL
13/16" PL
1 3/8" PL
R=690"
EL 811.0'
EL 801.5'
EL 792.0'
EL 782.5'
EL 773.0'
EL 763.5'
EL 754.0'
EL 744.5'
EL 733.5'
EL 724.5'
EL 716.614'
APPROX. 5° SPACING
EL 703.781'
EL 702.781'
1 1/2" PL
1 1/2" PL
1 1/2" PL
1 1/2" PL
1 1/2" PL
1 3/8" PL
1 3/8" PL
1 3/8" PL
1 3/8" PL
1 3/8" PL
EQUIPMENT HATCH
PERSONNEL LOCKS
EL696.75'
360 ANCHOR BOLTS- 3 1/2" DIAMETER
STEEL CONTAINMENT VESSEL

FIGURE 1

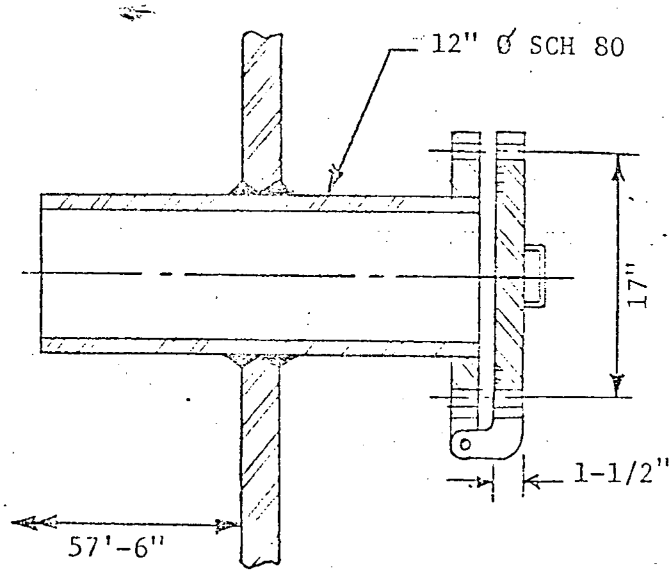


CONTAINMENT ANCHORAGE

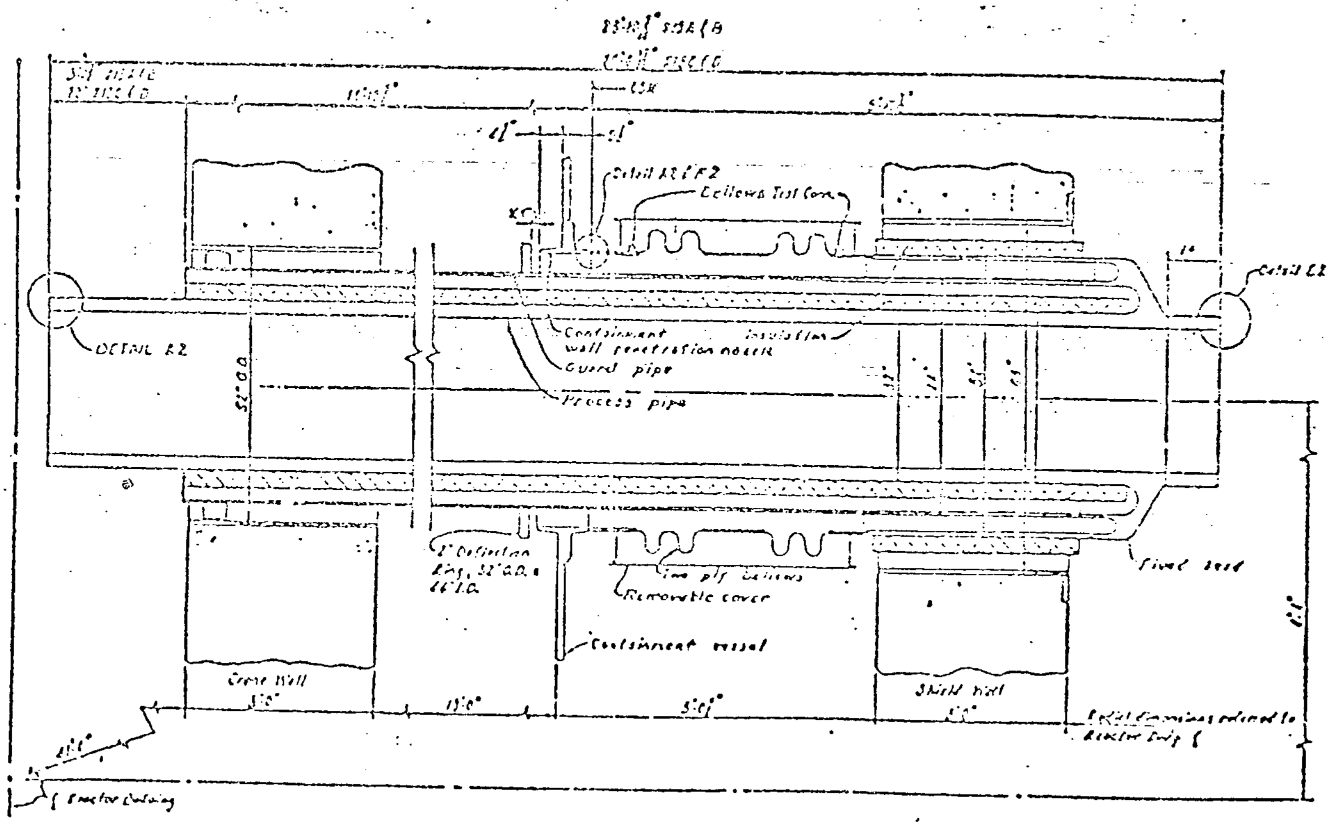
FIGURE 2



WELDED SPARE
a.



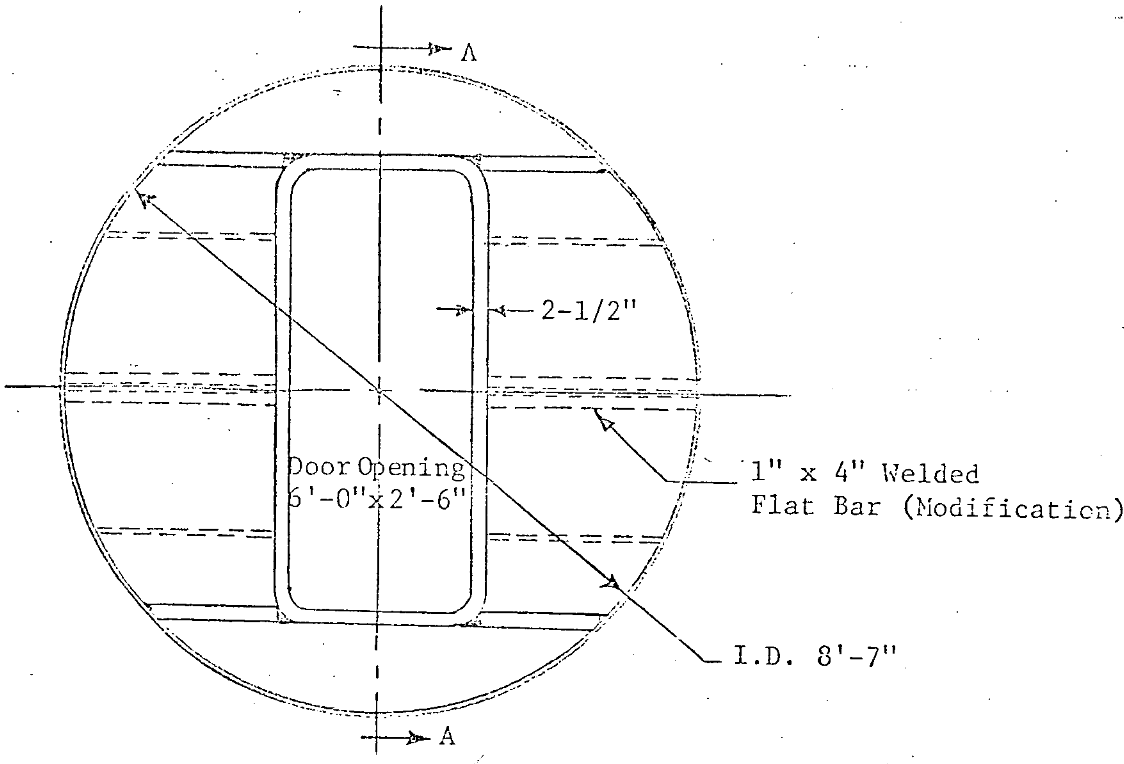
BOLTED HEAD
b.



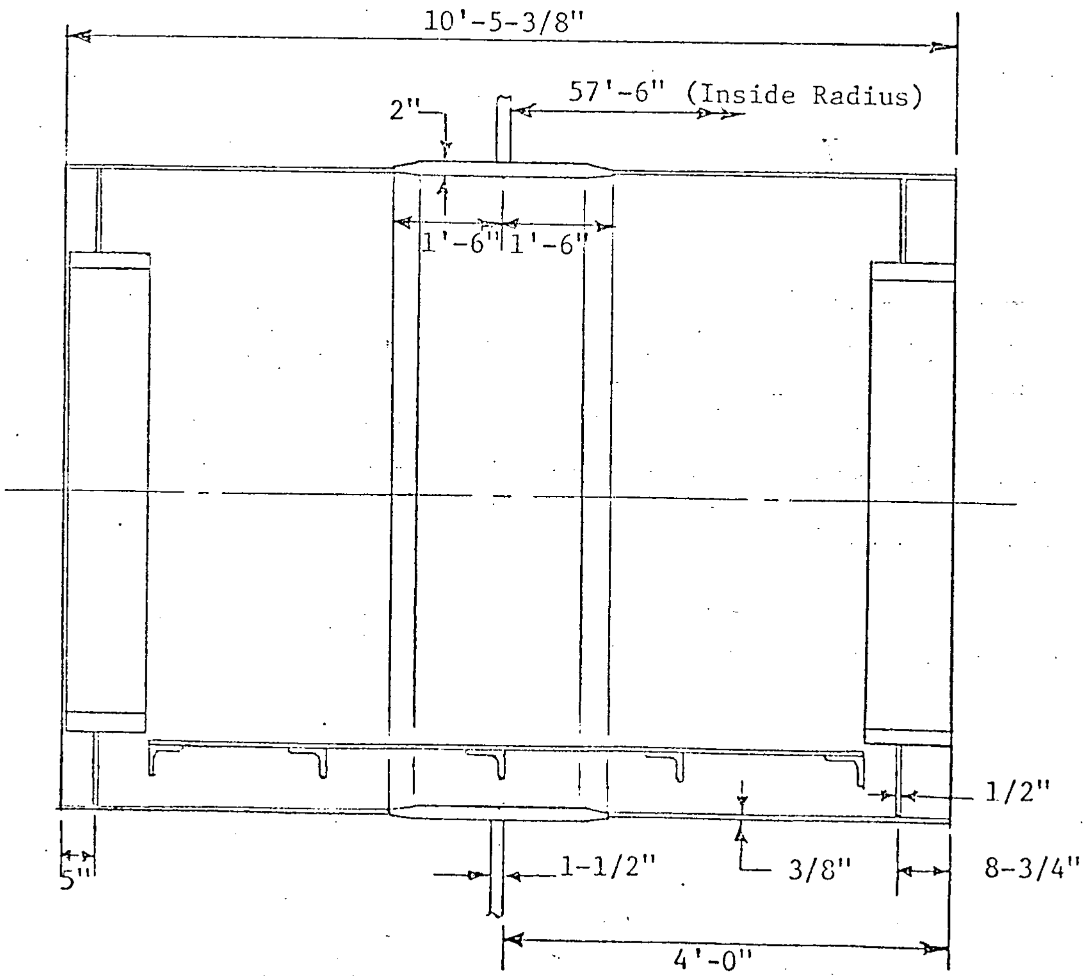
BELLOWED
c.

CONTAINMENT PENETRATIONS

FIGURE 3



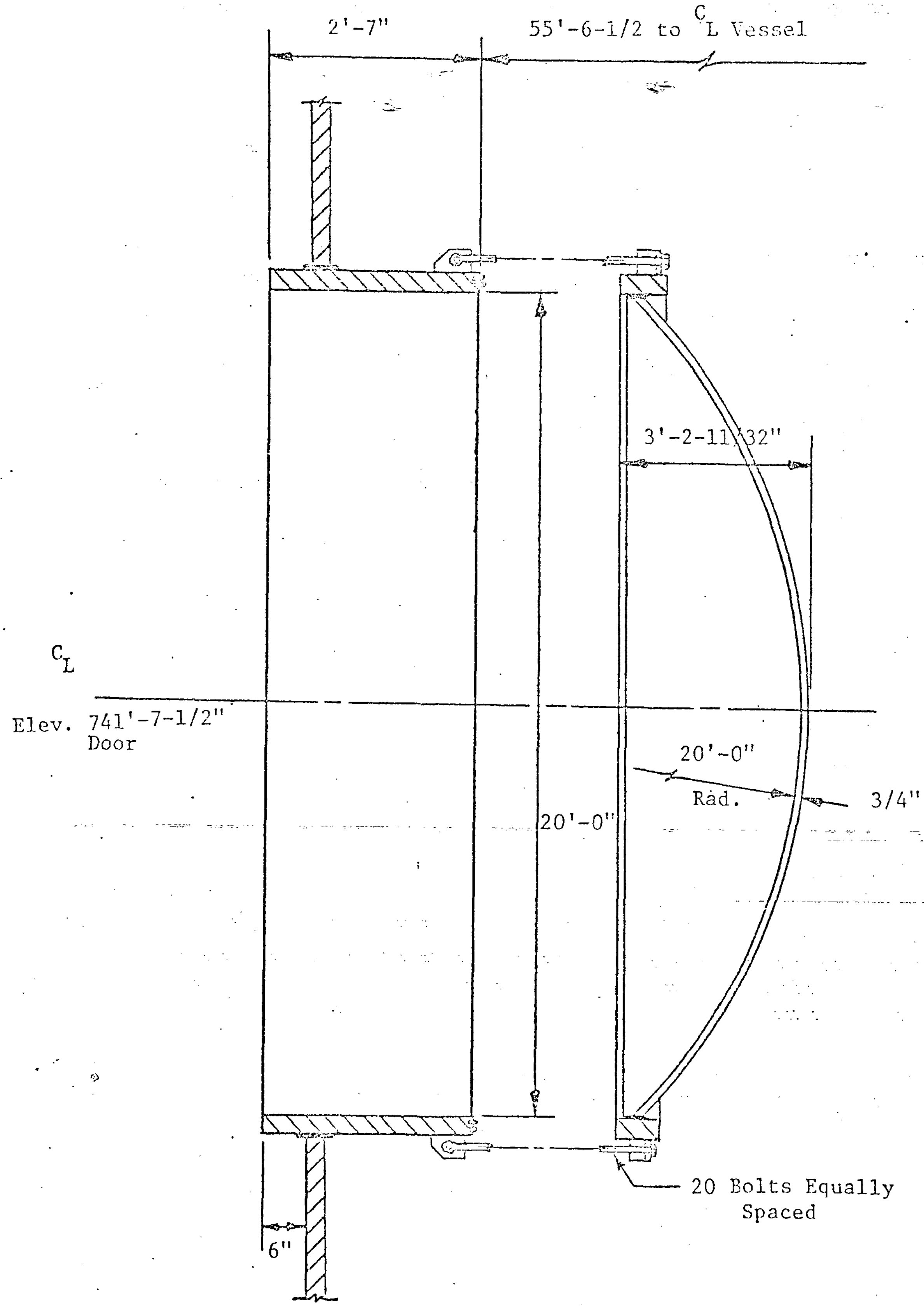
END VIEW



SECTION A-A

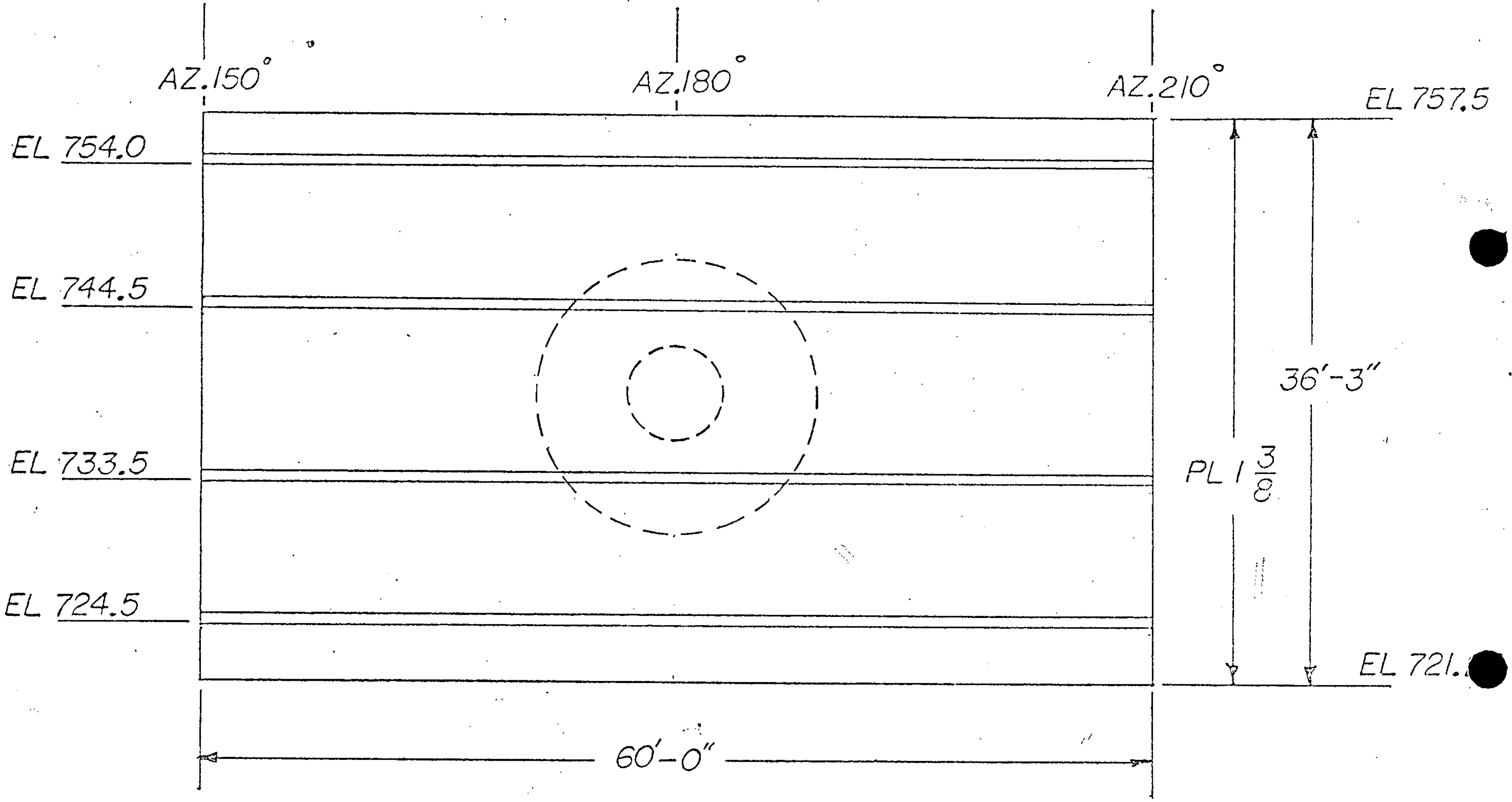
PERSONNEL LOCK

FIGURE 4



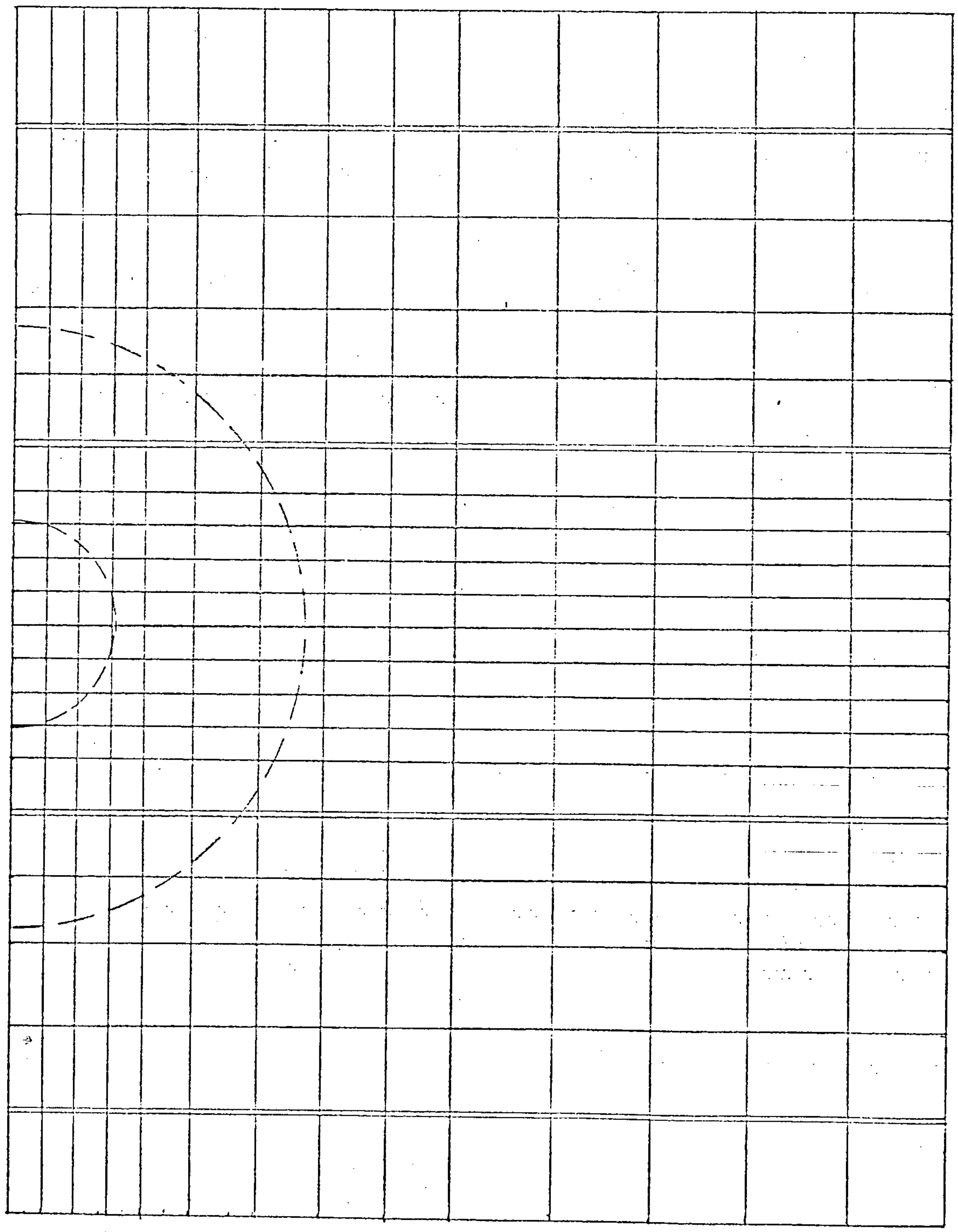
EQUIPMENT HATCH

FIGURE 5



GRAPHICAL REPRESENTATION OF MODEL

FIGURE 6



FINITE ELEMENT MODEL OF SHELL SEGMENT

FIGURE 7

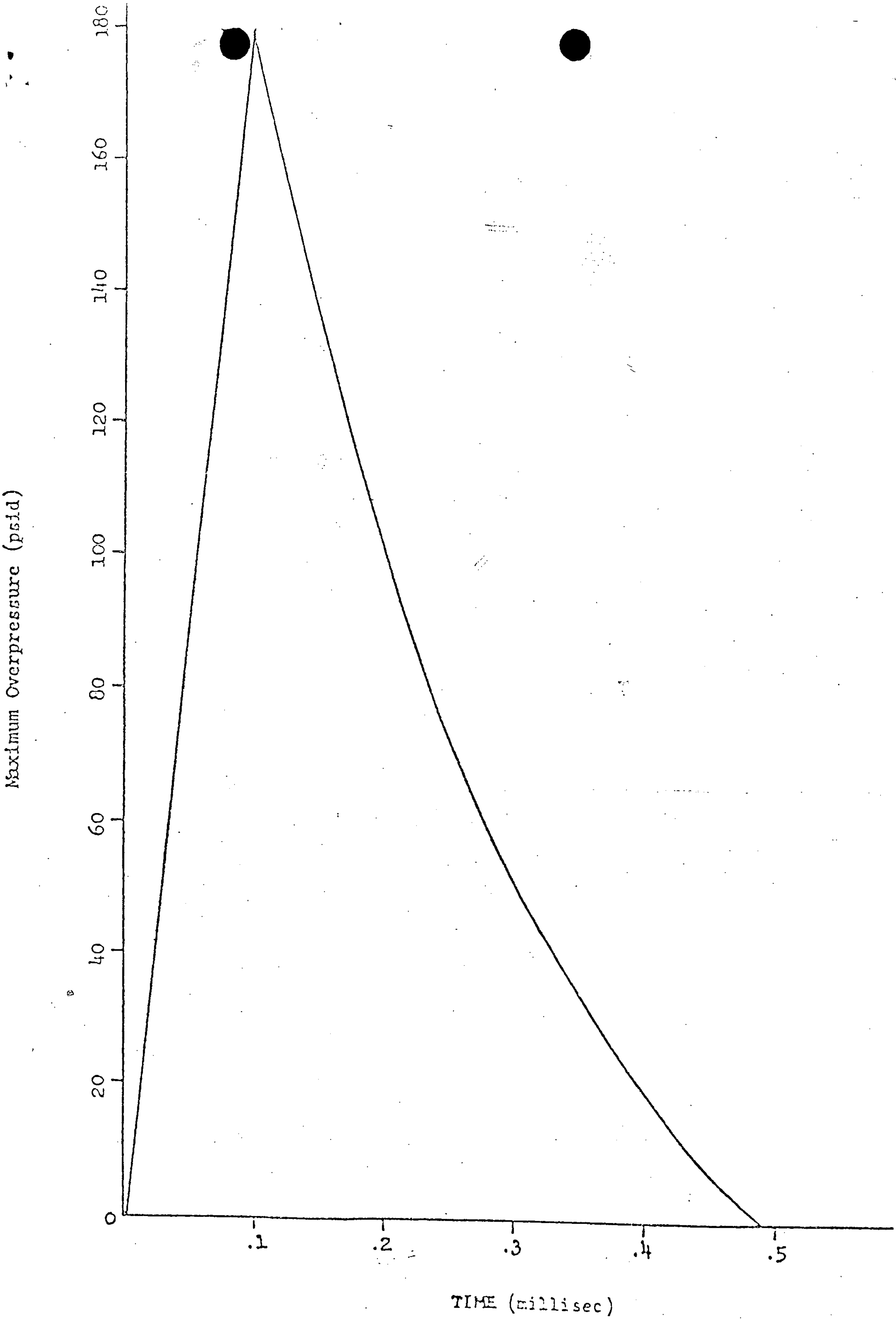


FIGURE 8

PRESSURE - TIME FUNCTION OF LOCAL DETONATION

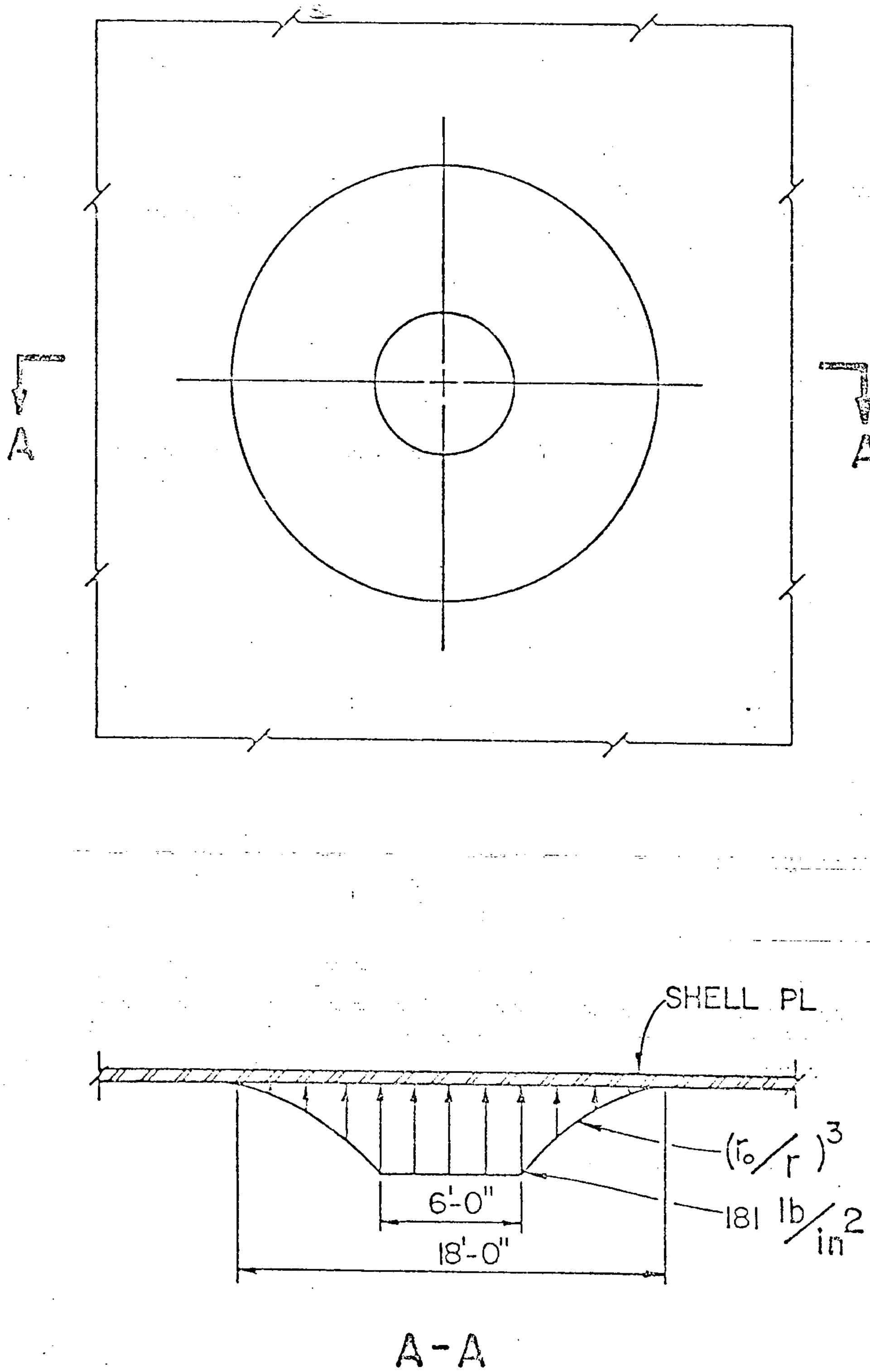
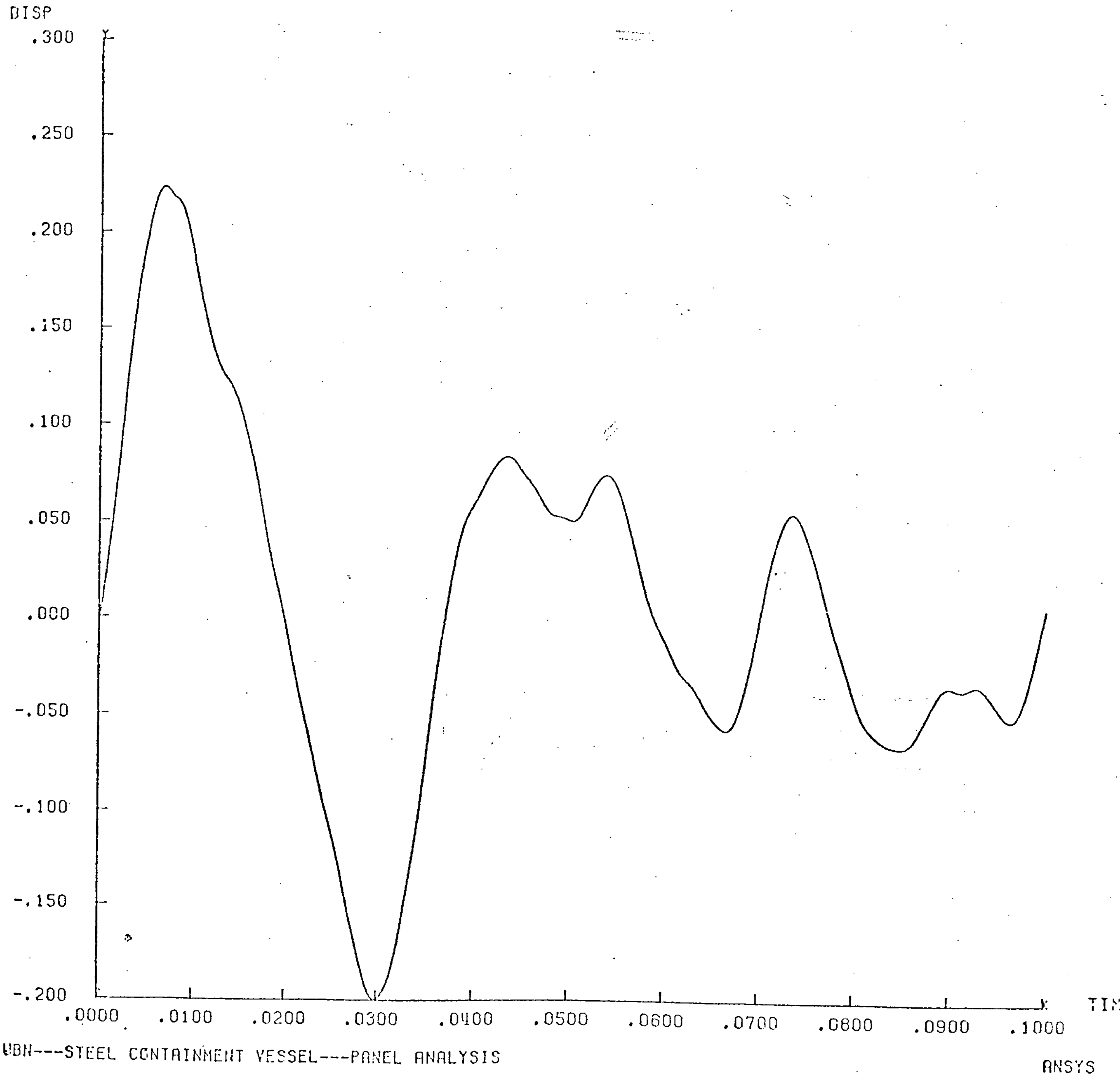
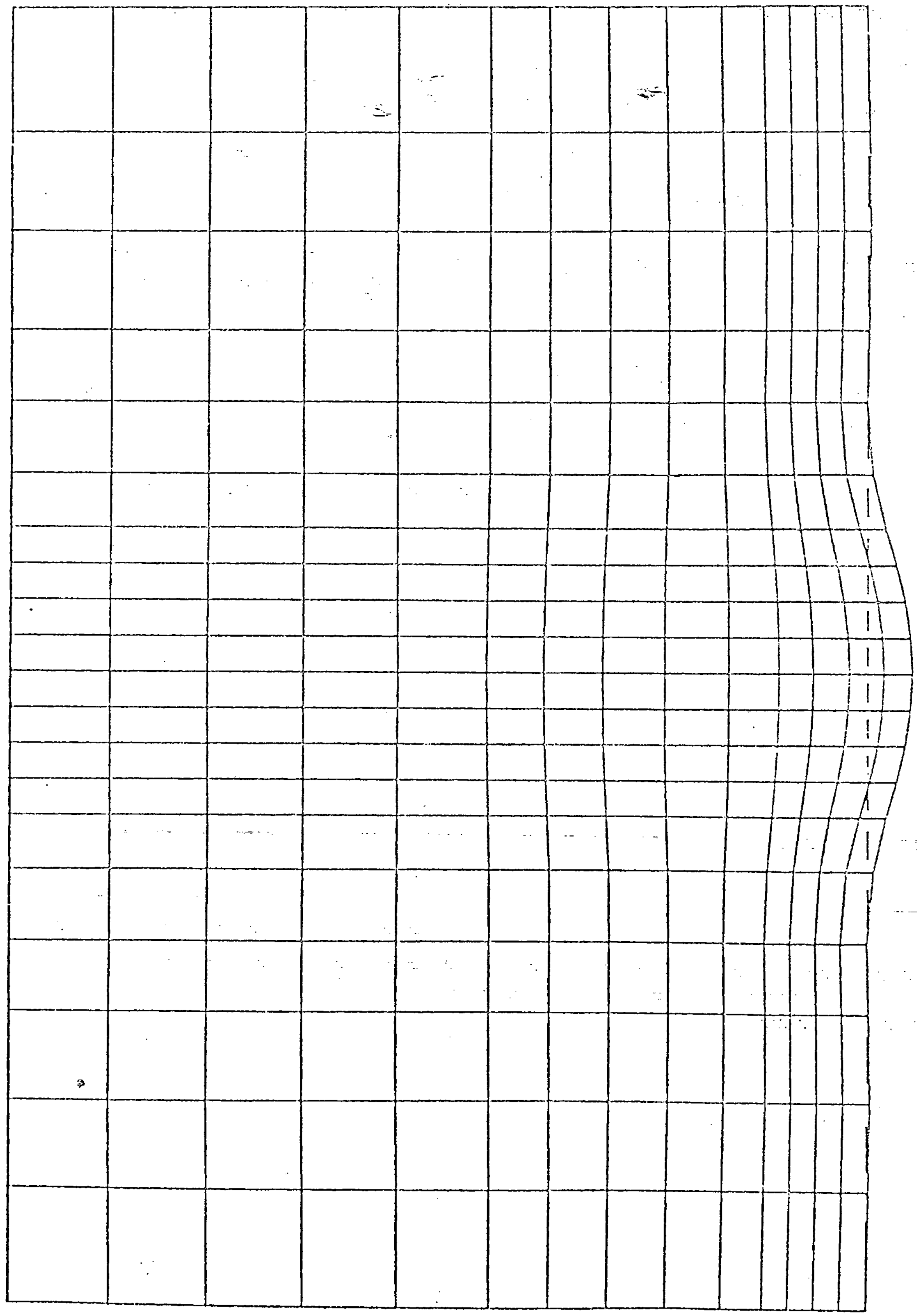


FIGURE 9
GRAPHICAL REPRESENTATION OF
PRESSURE FUNCTION

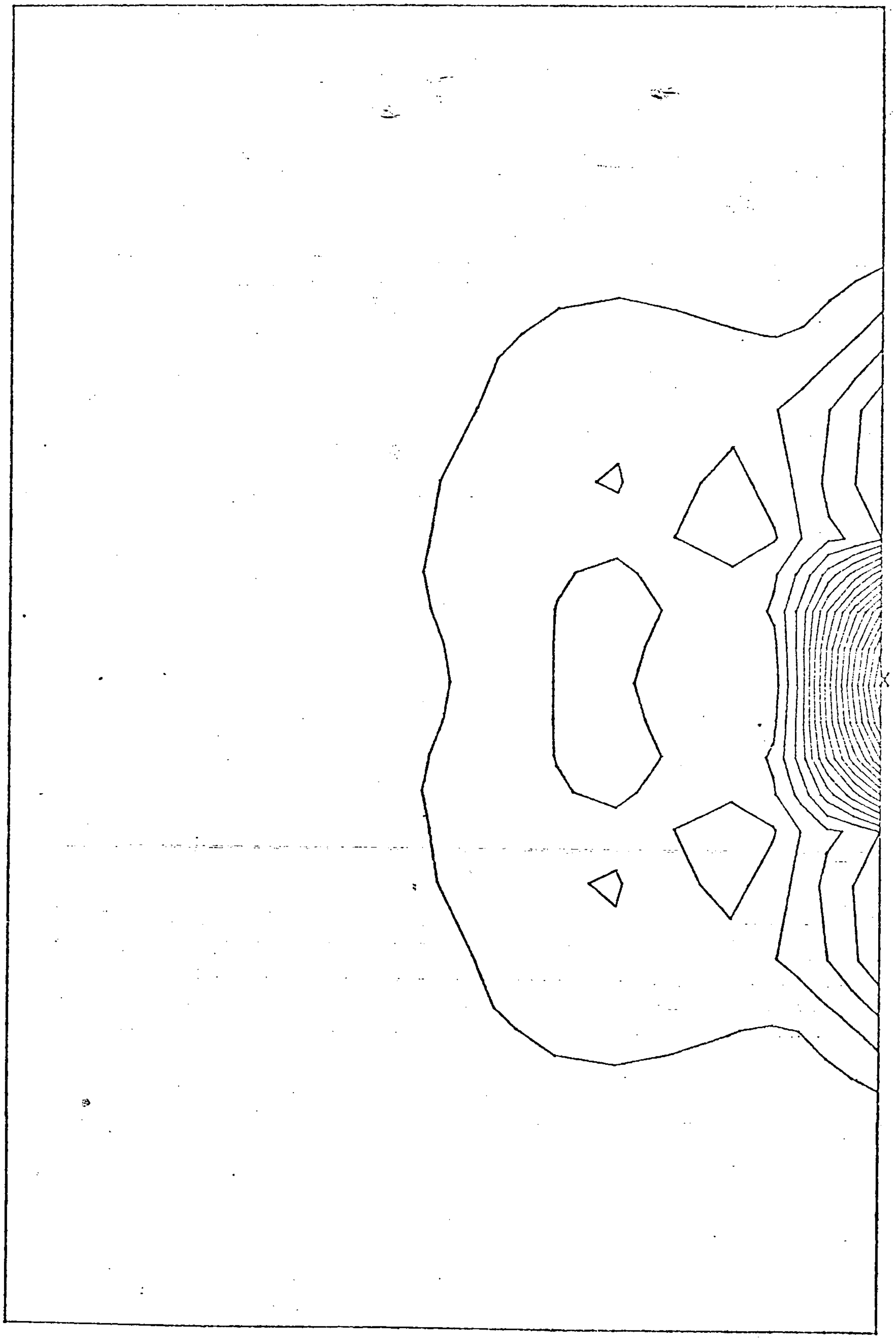


DEFLECTION VERSUS TIME FOR NODE
AT LOAD CENTER FOR FIXED RADIAL
BOUNDARY CONDITION

FIGURE 10



--WATTS BAR NUCLEAR PLANT---HYDROGEN EXPLOSION---CONTAINMENT ANALYSIS--
ISOMETRIC PLOT OF DEFLECTION IN LOAD REGION
FOR TIME = 0.007 SEC FOR THE FIXED BOUNDARY CONDITION
FIGURE 11



--WATTS BAR NUCLEAR PLANT---HYDROGEN EXPLOSION---CONTAINMENT ANALYSIS--
VON MISES STRESS CONTOUR PLOT FOR TIME = 0.007 SEC
FOR THE FIXED RADIAL BOUNDARY CONDITION
FIGURE 12