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STRUCTURAL RESEARCH SERIES NO. 346

STRENGTH AND BEHAVIOR OF PRESTRESSED CONCRETE VESSELS FOR NUCLEAR REACTORS-VOLUME II

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Subcontract No. 2906
Contract No. W-7405-eng-26

A REPORT ON AN INVESTIGATION CARRIED OUT AS
PART OF THE PRESTRESSED CONCRETE REACTOR VESSEL
PROGRAM OF THE OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION
FOR THE U. S. ATOMIC ENERGY COMMISSION

UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS
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A Report on an Investigation
carried out as part of the
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Urbana, Illinois

CONTENTS

STRENGTH AND BEHAVIOR OF PRESTRESSED CONCRETE VESSELS FOR NUCLEAR REACTORS VOLUME II

APPENDIX A

MATERIAL PROPERTIES, SPECIMEN FABRICATION, TEST SETUP

Appendix A

A1 MATERIALS

A1.1 Concrete

Test vessels PV1 and PV2 were cast from ready-mix concrete obtained from a local plant. The mix was specified to contain pea gravel aggregate and seven bags of type I cement per cubic yard of concrete.

Test vessels PV3 through PV14 were cast from concrete mixed in the laboratory. The proportions by weight of cement:sand:gravel were 1.00:3.51:3.40. Type III cement was used with a water cement ratio of 0.74. The aggregates were crushed limestone with a maximum particle size of one in. and Wabash River sand.

The concrete for vessel PV15 contained pea gravel aggregate and Wabash River sand with type III cement. The proportions by weight of cement:sand:gravel were 1.00:2.77:3.07 and the water cement ratio was 0.56. The end slab and top two inches of the skirt of vessel PV16 were cast from the same mix used for vessels PV3 through PV14. The remainder of the skirt was cast with the mix used for vessel PV15.

Table A1 gives the properties of the concrete used in the end slabs of the vessels. Two batches of concrete were required to cast vessels PV3 through PV10. Vessels PV11 through PV16 required three batches of concrete. Compression tests were conducted on five 6x12-in. cylinders from each batch. Five 6x6-in. cylinders were cast from the batch used in the end slab for use in the split cylinder test. Figure A1a shows the range of the modulus of elasticity measurements. Figure A1b is a plot of the results of the individual splitting-strength tests versus the average compressive strength in each vessel.

Two creep racks were assembled as shown in Figure A2. The results of the creep and shrinkage determinations are presented in Fig. A3. Each curve represents the average of readings from three cylinders. The 6x12-in. cylinders used for creep and shrinkage measurements were cast from concrete with the same proportions as the concrete in the vessels. The concrete in Batch I was left in the cylinder forms for two days, cured under wet burlap for seven days, and loaded to 1000 psi on 9 February 1968 at the age of eleven days. The concrete in Batch II was left in the forms for two days, cured under wet burlap for six days, and loaded to 1000 psi on 16 February 1968 at the age of ten days. Three ten-in. gage lines were established on each cylinder for measurement of deformations. Companion cylinders for each creep rack were also equipped with gage lines and stored in the laboratory for shrinkage measurements. All measurements were taken with a 0.0001-in. Whittemore gage over a ten-in. gage length. The environmental control in the laboratory is set at 50 percent relative humidity and 72°F.

A1.2 Longitudinal Reinforcement

Vessels PV1 and PV11 through PV16 were prestressed with 0.775-in. diameter Stressteel rods. Vessels PV2 through PV10 were prestressed with 1/2-in. diameter seven-wire strand.

The results of a tensile test of a 30-in. Stressteel rod are plotted in Fig. A4. The strain was measured using an eight-in. extensometer. The ultimate stress in the rod, which had a measured cross-sectional area of 0.471 sq. in. was 140 ksi.

The apparatus used to determine the "spring factor" of the 1/2-in. strand is shown in Fig. A5. The length of strand between strandvises is approximately the same as the length between the vises in the test setup. The load on the strand was cycled six times between zero and thirty kips. The load deformation characteristics of the strand under these testing conditions are presented for the first three loadings in Fig. A6. By the third loading cycle the stiffness of the strand was constant. The stiffness of the strand depended on the torsional fixity of the strandvises and on the slippage of the outer wires relative to the central wire. The nominal area of the strand was 0.151 sq. in.

A1.3 Circumferential Reinforcement

The wire that was used to prestress the vessels circumferentially was obtained from INTERPACE. Tests conducted on samples cut from the unstressed coil before prestressing and cut from the wire on the vessels after pressure testing showed no significant difference in stress-strain response. Typical stress-strain curves for each size wire used are shown in Fig. A7.

The wire used on vessels PV1 through PV10 had a diameter of 0.192 in. and a computed area of 0.0290 sq. in. Deformations to about two percent were measured with a two-in. electrical extensometer. The strain at failure was obtained from measuring the change in length of a five-in. gage length etched into the wire before the test.

The wire used on vessels PV11 through PV16 had a diameter of 0.250-in. and a computed area of 0.0491 sq. in. The wire was tested on a

Baldwin testing machine. Tests were made using a two-in. electrical extensometer to measure deformations. Another set of tests was made using a portable strain indicator to read strain from two BLH HE121 strain gages. The two strain gages were mounted on opposite sides of the wire and wired in series in order to average the strain readings.

A1.4 Liner Materials

The neoprene used to seal the pressure vessels was purchased in 200-lb. rolls. The sheets were 72 in. wide and 1/16 in. thick. It was specified as "60 Durometer Shore A Black neoprene Sheeting, Type #260".

The O-ring material was obtained in 200-ft lengths. The diameters of the 3/16-in. and 3/4-in. O-ring stock were 0.210 ± 0.010-in. and 0.750 ± 0.010-in. respectively. The material was specified as "70 Durometer Shore A Extruded Buna N O-ring cord stock".

The caulking used to complete the seal at the end slab was General Electric Silicone Caulking.

Sheets of aluminum with a thickness of 0.017-in. were used on the sides and end slabs of some of the vessels. Sheets of 16-oz. soft copper were used on vessels PV12 through PV16 in addition to the aluminum sheets.

A2 FABRICATION

A2.1 Casting and Curing

The pressure vessels were cast in the steel form shown in Fig. A8. The same outer form was used for all sixteen vessels. This form was rolled from 5/16-in. steel plate and reinforced with rolled 2x2x1/4 in. angles. The inner form, which was a closed cylinder, and the outer form are bolted to a 1/2-in. thick base plate. The inner form for vessels PV1 through PV10, thirty-in. inside diameter, was rolled from 3/16-in. plate. Both forms used the same five-piece construction. Holes were drilled into the base plate to receive 7/8-in. diameter rods which formed ducts for the longitudinal prestressing. For vessels PV15 and PV16 which had two rows of longitudinal prestressing., 1-in. round electrical conduit was used to form the ducts for the second row of prestressing. The tops of the rods and sections of conduit were secured by a template of 1/2-in. steel plate which was supported by sections of 4-in. wide channel attached to the sides of the form. The center of the template plate was cut out to permit access to the form for the concrete and to facilitate finishing the surface of the concrete.

Vessels PV1 and PV2 were cast continuously from ready-mix concrete. All other specimens were cast in either two or three batches as noted previously. The batches were proportioned so that the end slab and at least 2-in. of the skirt were cast from a single batch. The concrete was vibrated internally with an electric vibrator during casting. Five 6x12-in. cylinders were cast from each batch. Five 6x6-in. cylinders were also cast from the end slab batch for use in the splitting test. The side walls of vessels PV11 through PV16 were reinforced with No. 4 bars to have a reinforcement ratio of one percent. The bars were placed longitudinally about 1/2-in. from the outside surface of the concrete.

When the concrete had begun to set, usually about three hours after casting, the greased rods and conduit sections were manually extracted and the top of the vessel was trowelled to a smooth finish. The vessels were then covered with polyethylene film until the form was struck on the second day after casting. The vessels were cured under wet burlap for one week in the laboratory which had environmental control set at 70°F and 50 percent relative humidity.

A2.2 Circumferential Prestressing

The INTERPACE plant at South Beloit, Illinois, made their facilities available for applying the circumferential prestressing wire. A mandrel and end fittings as shown in Fig. A9 were designed to adapt the vessels to the equipment at INTERPACE, which is normally used to wrap concrete pipe. The vessels were transported to and from South Beloit by truck.

Anchors for the prestressing wire were cast into the vessels. An anchor is shown bolted to the form in Fig. A10a. Figure A10b shows a closeup of the anchor. A steel block about 3/4 x 3/4 x 1-1/4 in. is grooved and stamped, forming a toothed channel to grasp the wire. The block is then welded to a 3/8-in. diameter rod that has been bent into a U-shape to provide anchorage. The block and rod are hardened as a unit. The anchors were provided by INTERPACE and performed very well throughout the test series.

The prestressing operation was started by securing the wire in the anchor at the closed end. This was done by driving the wire into the toothed channel with a hammer. The first wrap of prestress was applied at a slightly reduced load. Subsequent wraps of the 0.192-in. diameter wire were applied at a tension of 4800 lb. Tension in subsequent wraps of the 0.250-in. diameter wire were applied at a tension of 7,800 lb.

A schematic diagram of the machine at INTERPACE is shown in Fig. A11. When the mandrel and vessels were in place, an axial load of about 20,000 lb was applied to create a friction force between the end fittings and the rubber bearing surfaces on the turning heads. The turning heads were rotated by a motor mounted at one end of the frame. The prestressing wire passed through a straight duct about 50 ft long from an uncoiling area to a friction wheel. The wire then passed through a load cell above the friction wheel and travelled overhead to the spacing apparatus which ran on a track above the mandrel and vessels. The spacing apparatus could advance automatically at a rate proportional to rotation of the turning heads or be adjusted by an operator. Tension was developed in the wire at the friction wheel by a D. C. motor which supplied a resisting torque. The load cell, which is located above the friction wheel, gave an account of the tension in the wire. Deviation from the desired load could be compensated by adjusting the torque transmitted by the D. C. motor. The load cell was calibrated to indicate the tension in the wire at the turning heads.

Approximately five minutes were required to prestress a vessel. Figure A12 contains two plots showing the variation of the load in the wire as wrapping proceeded from the end slab of the vessel toward the open end. The data for Fig. A12 were obtained from recording equipment at INTERPACE which showed a plot of load versus time.

The force in the wire as it was being wrapped around the specimen was known. To obtain the effective prestress at the time of the test, the following procedure was used. All calculations referred to the prestress around the end slab. The initial prestress was assumed to be the force in the wire less the calculated effect of the reduction in diameter of the vessel due to elastic deformation of the concrete. The time-dependent losses were estimated using the creep and shrinkage data given in Fig. A3. Relaxation of the prestress wire, estimated to be less than four percent in most cases, was ignored because of lack of directly relevant data and because the scatter in the time-dependent properties of the concrete was expected to be much larger. The increase in circumferential prestress caused by longitudinal prestressing was calculated by assuming that the Poisson's ratio for concrete was 0.15.

A2.3 Longitudinal Prestressing

Vessel PV1 was prestressed longitudinally with ten 0.775-in. diameter Stressteel bolts. Vessels PV2 through PV10 were prestressed with seven-wire, 0.5-in. diameter strand. The use of strand was more economical and permitted the longitudinal restraining force of the prestressing tendons to be more evenly distributed about the periphery of the vessel. With the higher pressure required for vessels PV11 through PV16, it was necessary to use Stressteel bolts for prestressing in order to develop the necessary clamping force at the base.

Strain gages were placed on some of the Stressteel bolts, and these bolts were calibrated in the laboratory. Loading of the bolts was accomplished with a 30 ton Simplex jack with the scheme shown in Fig. A13. The jack chair permitted a nut to be tightened against a 3x3x1-in. steel bearing plate so that the load in the jack could be transferred with a minimum loss. For vessels PV13 through PV16 where sixty bolts were used for the prestressing, a continuous steel plate 1 1/4-in. thick was used for the bearing plate rather than the individual plates. The load in the bolts after the jack was released varied from 40 to 45 kips. The average load in the bolts after prestressing was completed, was less than 40 kips since the loading of a bolt adjacent to an already loaded bolt tended to reduce the load carried by the loaded bolt. The effect was increased as the number of bolts used for the prestressing was increased.

Figure A14 shows the method of prestressing the strand. The applied load was monitored either by a load cell between the jack and the top strandvise or by measuring the oil pressure in the line to the Simplex jack. Those strands that were to be monitored during the test were equipped with a load cell between the four-in. plate at the open end of the vessel and the bottom strandvise. After a load of 24 kips was applied, the jaws of the strandvises were set either by driving slotted wedges between the bearing plate and the strandvise or by driving the jaws down the strand with an implement designed to fit around the strand and inside the body of the vise. Those strands equipped with load cells under the four-in. plate carried an average load of about 20 kips after the jack was released.

The force in the strand for vessels PV2 through PV10 and in the Stressteel bolts for PV1 was monitored immediately after prestressing. To obtain the effective prestress at the time of the test, the time-dependent losses were estimated using the creep and shrinkage data given in Fig. A3 and subtracted from the initial prestress. The force in the Stressteel bolts for vessels PV11 through PV16 was monitored immediately after prestressing and immediately before the test so that the vertical prestressing force was known at the time of the test.

A2.4 Liner

A detail of the liner in each vessel is provided in Appendix B. The scheme for sealing vessels PV1 through PV5 was as follows. After cleaning the inside and filling the voids with Hydrocal, successive layers of 1/16-in. neoprene, 18 gage sheet metal, and 1/16-in. neoprene were placed on the inside surface of the end slab, using contact cement to hold them in place. A six-in. wide strip of 20-gage sheet metal was cemented to the side wall just below the end slab (Fig. B1.2).

The connection between the concrete and the steel sealing ring was achieved by welding an eight-in. wide strip of sheet metal to the ring. The neoprene sheet placed on the side wall butted the seal on the end slab and lapped over the sheet metal at the sealing ring. Contact cement was used to secure the neoprene to all surfaces except to the sheet metal at the sealing ring where rubber cement was used. Rubber cement was also used at the lapped joint in the neoprene. All surfaces to be cemented were carefully cleaned with benzene.

The seal at the junction of the end slab and side wall was made by embedding a 3/4-in. O-ring in General Electric Silicone Caulking. The seal between the steel base plate and the sealing ring was made by compressing a 3/16-in. O-ring into the groove in the base plate (Fig. A15).

Difficulties were encountered with this method of sealing at higher pressures. The details of the seal were changed for vessels PV6 through PV12. These changes are reported in Appendix B. The seal for vessel PV12 proved to be satisfactory for high pressures and was used without change for the remaining vessels.

The seal used for vessel PV12 through PV16 consisted of lining the wall and end slab with a sheet of 0.017-in. thick aluminum bonded to the concrete with rubber cement (Fig. B12.1). Next, a liner of 16-oz. soft copper was placed over the aluminum. The copper-aluminum interface was greased so that the copper would not develop large stress concentrations during deformation. The copper sheet used on the end slab had a one-in. lip which was soldered to the copper sheet on the wall. The lap in the copper wall sheet was also soldered as was the copper-steel joint at the one-in. steel base ring. The vessels were then lightly prestressed longitudinally and pressurized to 50 psi gas pressure to deform the metal liners to the contours of the concrete and to check for any major leaks in the liner. A layer of 1/16-in. thick neoprene was placed over the copper and secured with rubber cement. A 3/4-in. neoprene O-ring was also installed at the junction of the end slab and the side wall.

A3 TEST SETUP

The test shed was erected on the grounds of the Structural Dynamics Laboratory which is situated in farmland about three miles south of the university campus (Fig. A16a). The shed is a wooden enclosure built on a twelve-ft square slab-on-grade floor. It features a 5 by 5 ft steel test chamber in its center which extends from the floor through a hole in the roof. The test chamber was constructed of four 4 x 4 x 3/8 in. angles which extend vertically from the corners of the opening to the floor with 0.5 in. steel plate on the four sides. Figure A16b shows vessel PV8 inside the test chamber after the test. A hatch was provided to cover the hole in the roof when the shed was not in use. During tests the hole was covered with layers of wire mesh to impede concrete projectiles. For vessels PV11 through PV16, three layers of wire blast mats were used to cover the hole. The blast mats were anchored with 3/8-in. cable fastened to ground anchors at the sides of the shed.

After the liner and one-in. steel ring were in place (see Section A2.3 on the assembly of the liner) the vessel was placed on a four-in. thick circular steel plate shown in Fig. A15. A 3/16-in. O-ring was compressed between the one-in. ring and the four-in. closure plate to complete the seal. In vessels PV1 through PV8 a ten cubic-ft block-out was provided to fill part of the void inside the vessel and reduce the quantity of compressed gas that would be released when failure occurred. The block-out was a closed cylinder filled with vermiculite concrete for the first three tests. On the third test a leak in the block-out permitted it to become filled with gas, causing the block-out to burst when the vessel failed. In subsequent vessels up to PV8 the block-out was filled with water. In vessels PV9 through PV16 the entire vessel was filled with water to within approximately 1/2-in. of the end slab.

Figure A17 shows the gas supply and pressure regulating scheme used to pressurize the vessels. Nitrogen gas was admitted to the vessels in the test shed through a 1/4-in. copper line from a series of gas supply bottles. The pressure within the vessel was monitored by a Bourdon test gage with 1/4 percent accuracy which was connected by a second 1/4-in. copper line to the vessel. This second line for pressure measurement eliminated error in the pressure reading due to gas flow in the line. The gas supply line and pressure monitoring line were connected through the steel base plate on the vessel.

Vessels PV9 and PV10 were exceptions to the general test setup in that they were tested using oil pressure and were tested inside the Structural Dynamics Laboratory. The remote monitoring of the tests was not necessary since compressed gas was not used in the test and the failure did not result in a violent release of energy.

A4 INSTRUMENTATION AND TEST PROCEDURE

In general the instrumentation consisted of deflection measurements across one diameter of the head and down the side on a line at one end of this diameter, strain measurements on the concrete on the inside face of the end slab on four diameters 45 degrees apart and on the outside face on two diameters, strain measurements on the circumferential prestressing steel, and change in force in the load cells on some of the longitudinal prestressing tendons. The diameter on the outside of the end slab on which deflections were measured was offset 3 degrees from one of the diameters on which strains were measured. The strain gages on the circumferential steel reinforcement were placed after the steel was wrapped so that only the change in strain during the test was measured. The load cells on the longitudinal prestressing were monitored during the prestressing operation and during the test so that the total load could be calculated. The Stressteel bolts were gaged with BLH A-19 strain gages and calibrated in a testing machine, thus eliminating the need for external load cells for the bolts. The actual number of measurements of each type and their locations are shown in Appendix B for each test.

The strain gages used on the concrete were BLH type A12 which have a one-in. gage length and are flat wound wire gages with paper backing. These gages were applied with Eastman 910 cement. There was some concern that the strain gages located on the inside of the head would be affected by the normal pressure on the gage grid. This problem has been the subject of several investigations one of which is reported in Ref. A1. These studies show that gages which are properly applied have a response resulting from normal pressure sufficiently small that it could not be distinguished from the scatter in the strain measurements for these tests. On the inside of the head the gages were applied by first sanding the concrete to a smooth finish and then placing a layer of cement on the concrete and allowing it to set. The gages were then cemented to this prepared surface with Eastman 910 cement and a soft rubbery protective coating placed over the gage. After the protective coating had set, a 1/16 in. sheet of neoprene was glued over the gages to provide further protection and assure that the applied pressure was uniformly distributed over the gage. In vessels PV7 through PV16, the end slab was covered with a 1/4-in. thick layer of Hydrocal. Conductors from the inside strain gages were glued to the inside wall of the test vessel from the gages to the corner where the head and wall meet. At this point a hole was drilled through the wall and the leads run through this hole which was then resealed with epoxy. The entire inside surface of the end slab was then covered with a 1/4-in. thick layer of hydrocal. The neoprene gas seal was then placed over the hydrocal which covered the wires and the hole in the wall. On vessels PV11 through PV16, the gage wires were run down the inside of the vessel and out between the concrete and the one-in. steel ring. Channels 1 in. wide by 1/4-in. deep were cast in the concrete to accommodate the gage wires. On the outer surface of the concrete the strain gages were applied in the same manner, but no protective coating was used on them. The strain gages used to measure change in strain of the circumferential reinforcement were BLH type A19 which is a flat grid wire gage with a gage length of 1/16 in. and temperature compensation for steel. These gages were applied with Eastman 910 cement following standard procedures.

The load cells used to measure load in the longitudinal strand consisted of 6-in.-long aluminum cylinders 1 3/8 in. in diameter with a 5/8 in. longitudinal hole drilled through it. The aluminum in these cylinders was a soft bar stock of 2014 alloy and was heat treated in our laboratory to meet specifications for 2014-T6 temper. Four strain gages were cemented to the outside of these cylinders andwired into a full bridge. The strand was threaded into these cylinders at the lower end of the test specimen, and the change in strain monitored as the load changed in the strand. Before they were used, the load cells were calibrated in a testing machine by applying a direct compression to them. Different numbers of load cells were used in the various tests as indicated in Appendix B.

All the tests except PV9 and PV10, were performed in the test shed which was about 100 ft from the Structural Dynamics Laboratory. Approximately 135 ft of cable was required to reach the area where readings were taken in the main laboratory. A 4-conductor cable with heavy rubber coating passing through an overhead metal cable tray was used between the two buildings. This cable is Belden 8424 and contains 20 gage conductors. Several of the tests were performed during the winter so a heater was placed in the test shed to keep it warm enough for men to work. It was not possible to maintain room temperature at all times with this heater but temperature compensating strain gages were placed in the test chamber with the test specimen. The specimen was then left in the test shed for sufficient time to allow the temperature to stabilize.

Strains on the first 5 specimens were read with two BLH portable strain indicators model number 120 C in the main laboratory at the end of the 135 ft lead wires. This strain indicator is designed to excite the bridge with an alternating square wave in order to reduce the effects of capacitance in the leads to the strain gages. However, since the leads were rather long in this case special precautions were taken. For each type of bridge used on the test vessel the effect of a given shunt was read with the indicator at the bridge. Then, with the strain indicator connected to the bridge through the long leads, the gage factor was adjusted so that the same shunt had the same effect on the bridge. This slightly adjusted gage factor was then used when the strains were read during the test. During tests PV6, PV7, and PV8 strains were read with an automatic device assembled from components in our own laboratory. An automatic stepping switch was used to switch gages, the voltage difference across two corners of the bridge was read with a digital volt meter, and the resulting voltage was printed on a paper tape with a line printer. The device was calibrated by applying shunts of known value to the bridges and the compensation for long leads was made in a manner similar to that used for the portable strain indicator. Strains read with the portable strain indicator have an accuracy of the order of $\pm$ 5 μ in./in. while those read with the automatic reading device were somewhat more erratic and have and accuracy of approximately $\pm$ 20 μ in./in. The portable strain indicators used for tests PV1 through PV5 were used for tests PV9 through PV16.

Deflections across the head of the specimen and down the outside wall were measured with 0.001 in. Ames dial gages located within the test shed but outside the test specimen enclosure. The dial gages were connected to piano wires which were strung over ball bearing pulleys and attached to metal tabs glued to the specimen. Tension springs connected to the back end of the dial gage plunger kept the piano wire taut. The pulleys over the top of the specimen were attached to an arm which was broken off by the flying debris each time a specimen failed. The dial gages were read with a closed circuit television hookup with the receiver in the main laboratory. The television camera was located inside the test shed but outside the test specimen enclosure, had a telephoto lens so that the dial gage face almost filled the television receiver screen, and was mounted on a system of two television antenna rotors so that it could be adjusted in direction for each gage. This arrangement proved quite satisfactory for this purpose, though some of the gages were damaged by the sudden tension on the piano wire at failure of the specimen. A second television camera was set up outside the test specimen enclosure and aimed through a hole in the enclosure at a mirror to observe crack development on the end slab of the vessels.

Pressure was applied to the inside of the specimen with bottled nitrogen through a regulator. With this regulator in the line, a pressure could be set and maintained in the specimen though there was a small leak, because more gas would be supplied through the regulator as soon as the pressure dropped below the set value. Pressure within the specimen was monitored with a Bourdon pressure gage. During a test the gas pressure was increased in increments and once the pressure was set and became stable all measurements were taken. Approximately 10 to 15 minutes were usually required to take all the readings. The size of pressure increments varied between tests depending on the anticipated maximum pressure. In general the size of the increments was reduced as failure approached.

TABLE A1

CONCRETE PROPERTIES

Mark	Age at Test days	Slump in.	Modulus of Elasticity psi x10 ^{6}	Splitting Strength 6x6-in. cylinder psi	Compressive Strength 6x12-in. cylinder psi
PV1	71	3 1/2	4.2	432	5680
PV2	105	5	3.5	398	4955
PV3	36	1	4.2	450	6250
PV4	38	1 3/4	4.2	380	5680
PV5	32	3/4	4.1	439	6250
PV6	42	1	4.1	398	5805
PV7	54	1	4.6	506	6720
PV8	78	1 1/4	4.8	443	7230
PV9	71	1 1/2	4.3	446	7140
PV10	54	1 1/2	4.0	394	7005
PV11	64	1	4.5	514	6830
PV12	89	3	4.4	456	5860
PV13	84	1 1/4	4.2	490	6750
PV14	107	2 1/4	4.3	465	6880
PV15	39	1 1/2	4.2	531	7340
PV16	79	2	4.0	518	7450

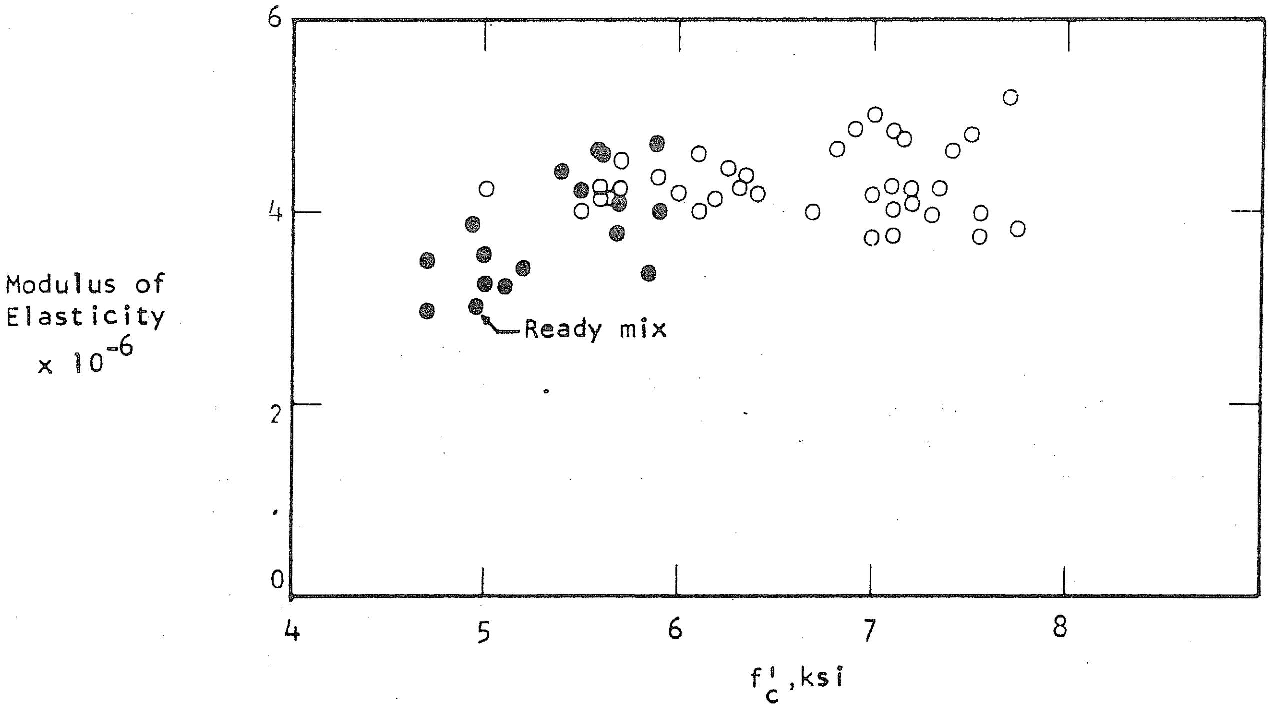


FIG. A1a MODULUS OF ELASTICITY vs COMPRESSIVE STRENGTH

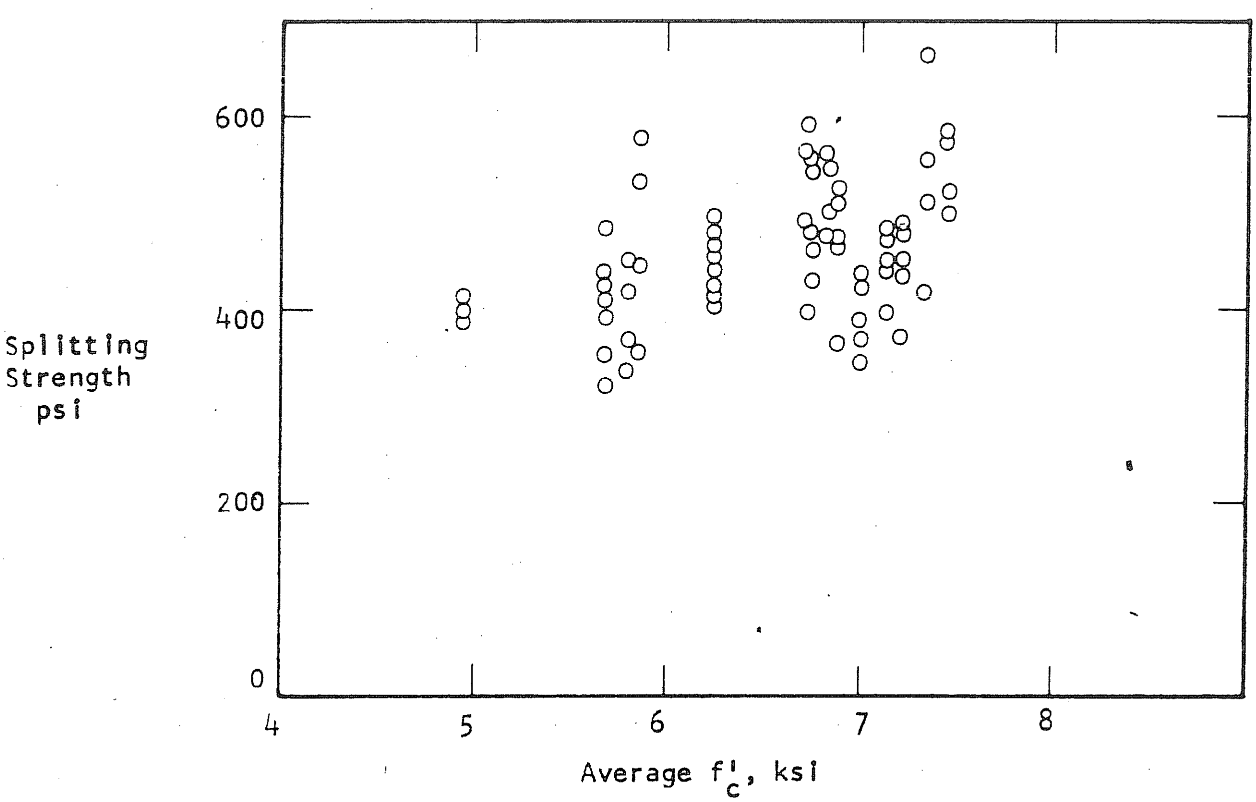


FIG. A1b SLITTING STRENGTH vs AVERAGE COMPRESSIVE STRENGTH

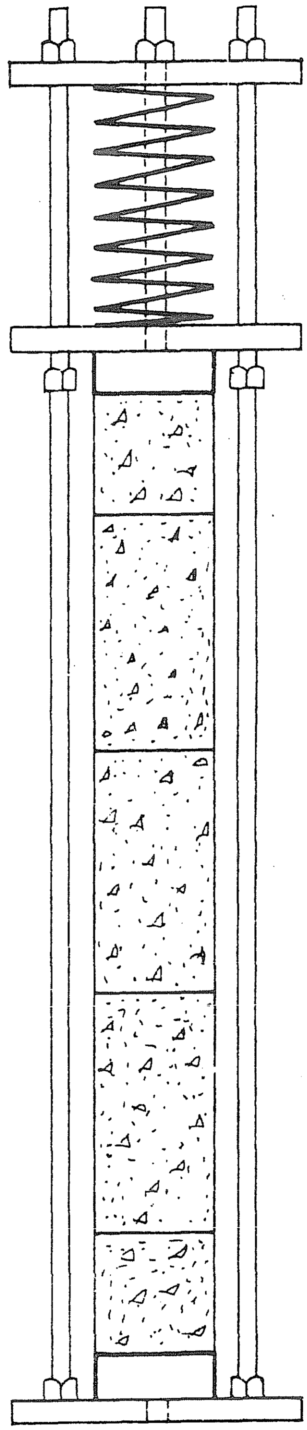


FIG. A2 CREEP RACK

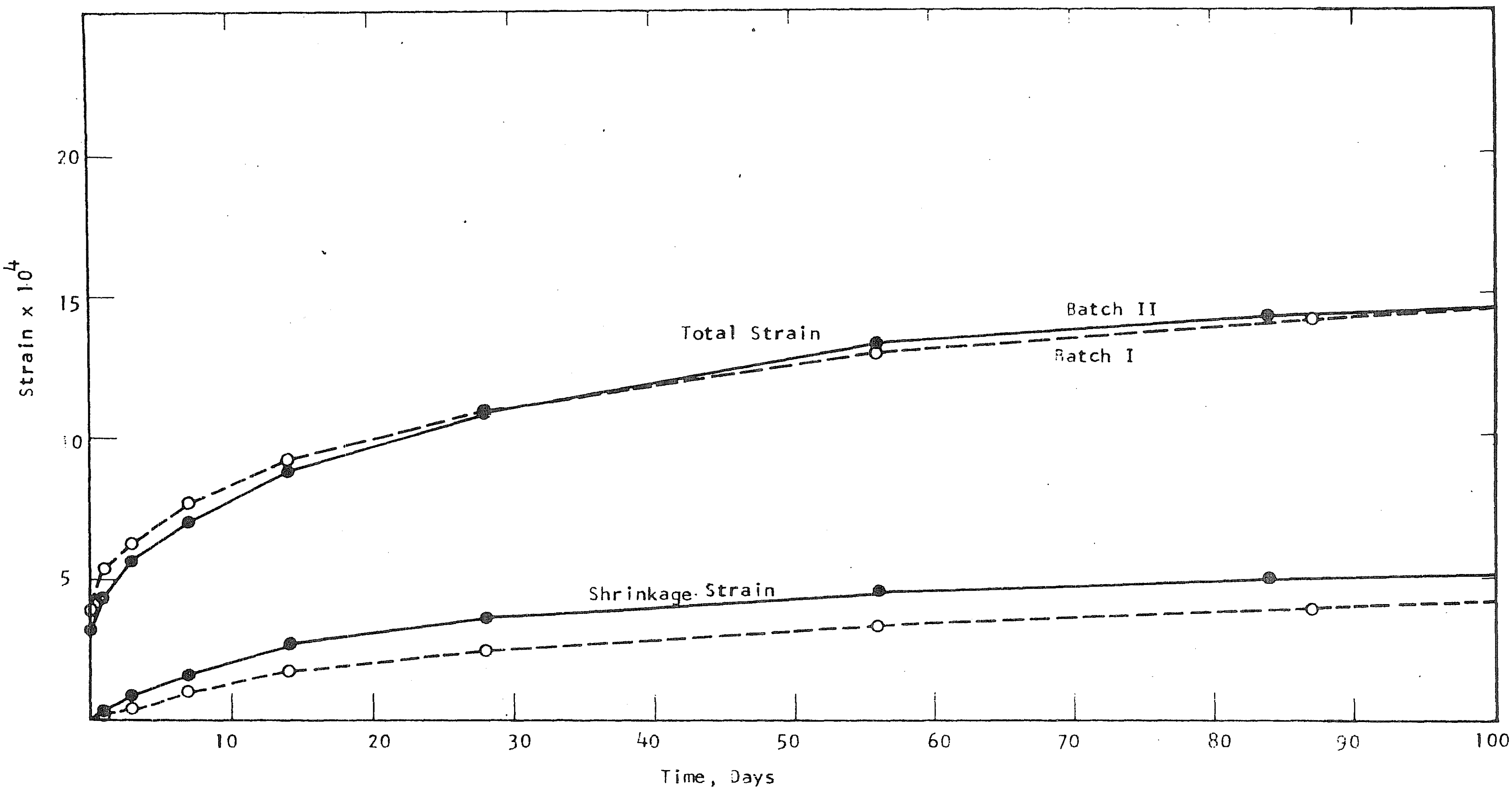


FIG. A3 SHRINKAGE STRAIN AND TOTAL STRAIN FOR 6x12-in. CYLINDER UNDER 1000 psi COMPRESSION

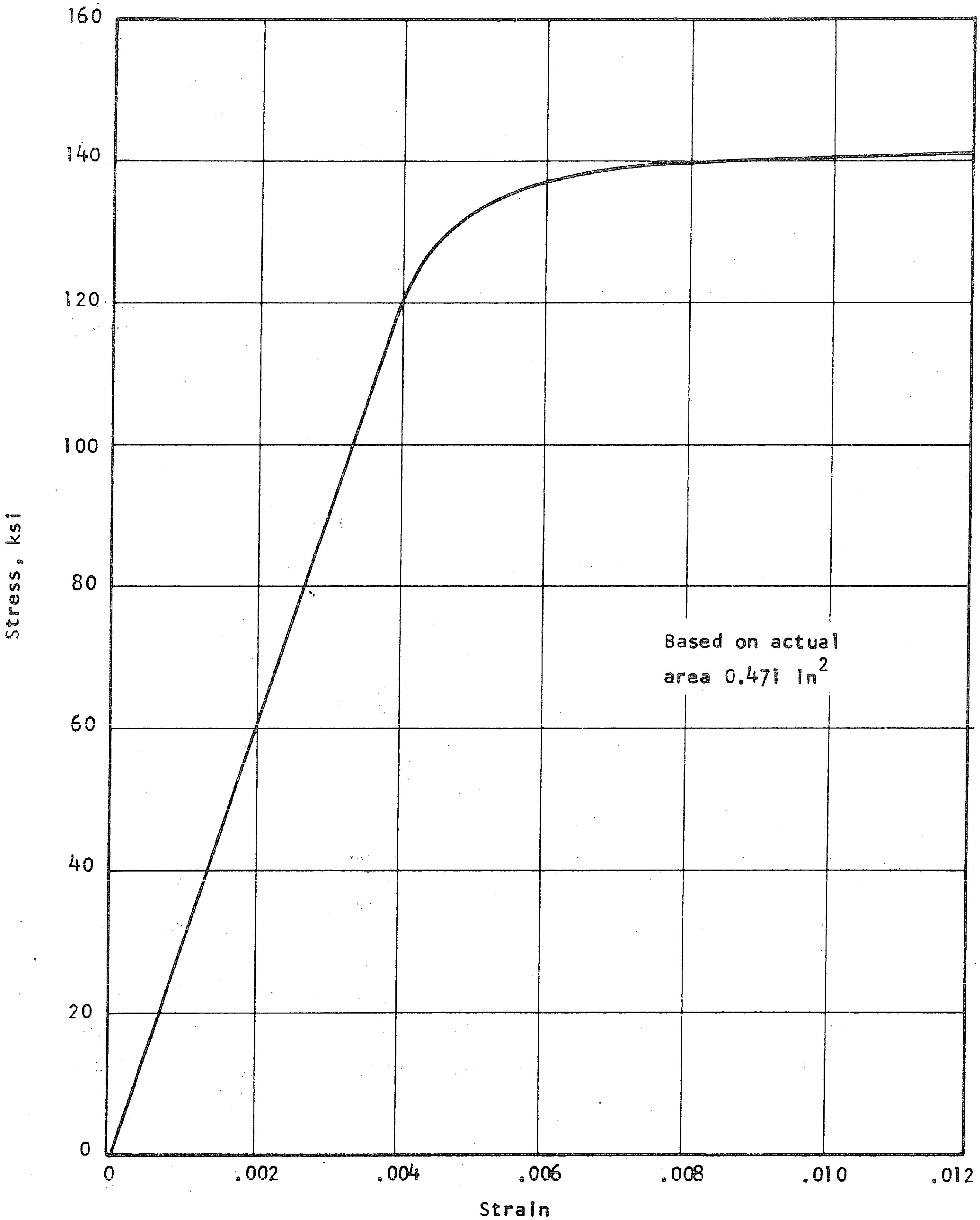


FIG. A4 STRESS-STRAIN CURVE FOR STRESSTEEL RODS

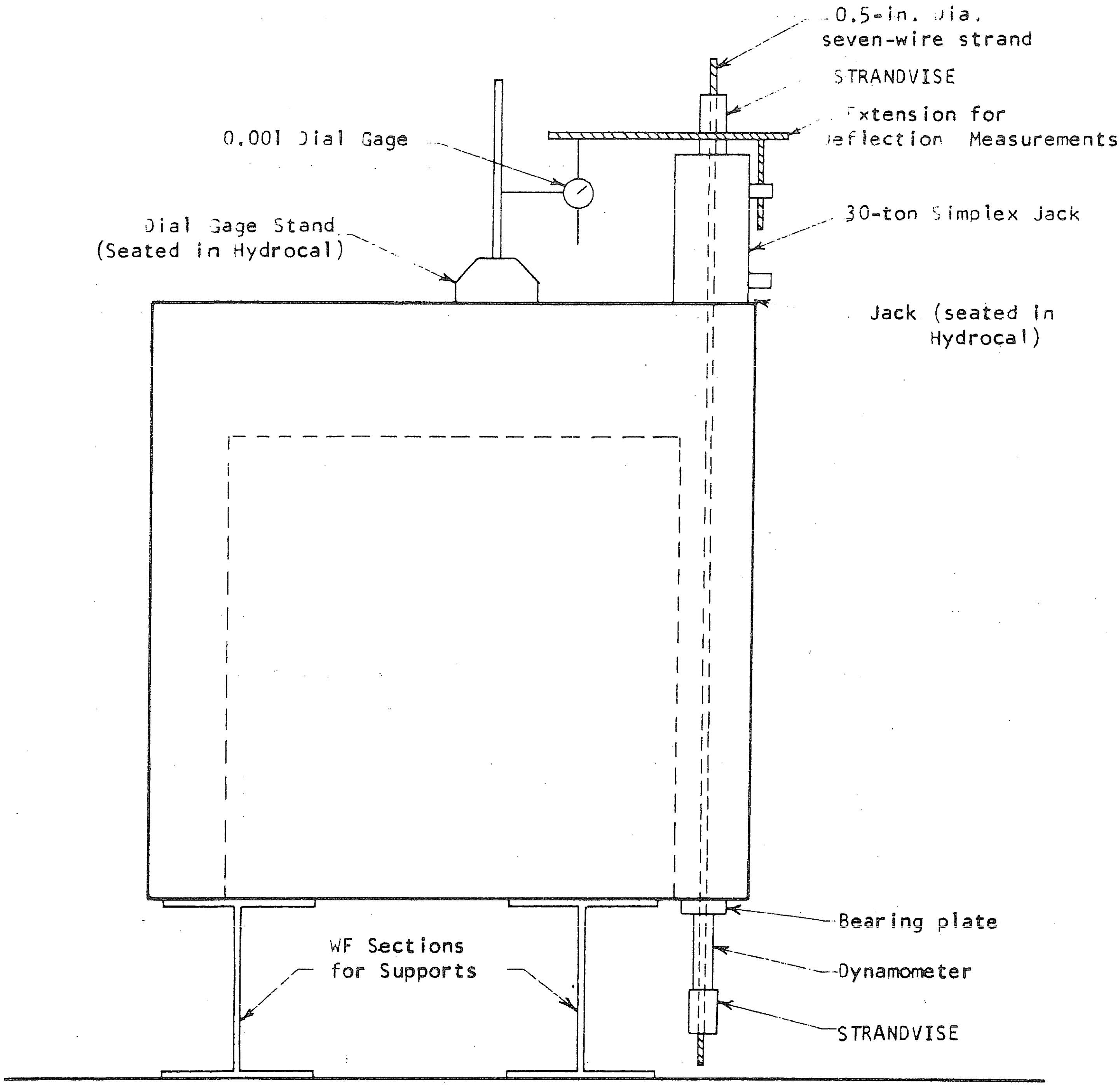


FIG. A5 APPARATUS FOR LOAD-DEFLECTION TEST ON SEVEN-WIRE STRAND

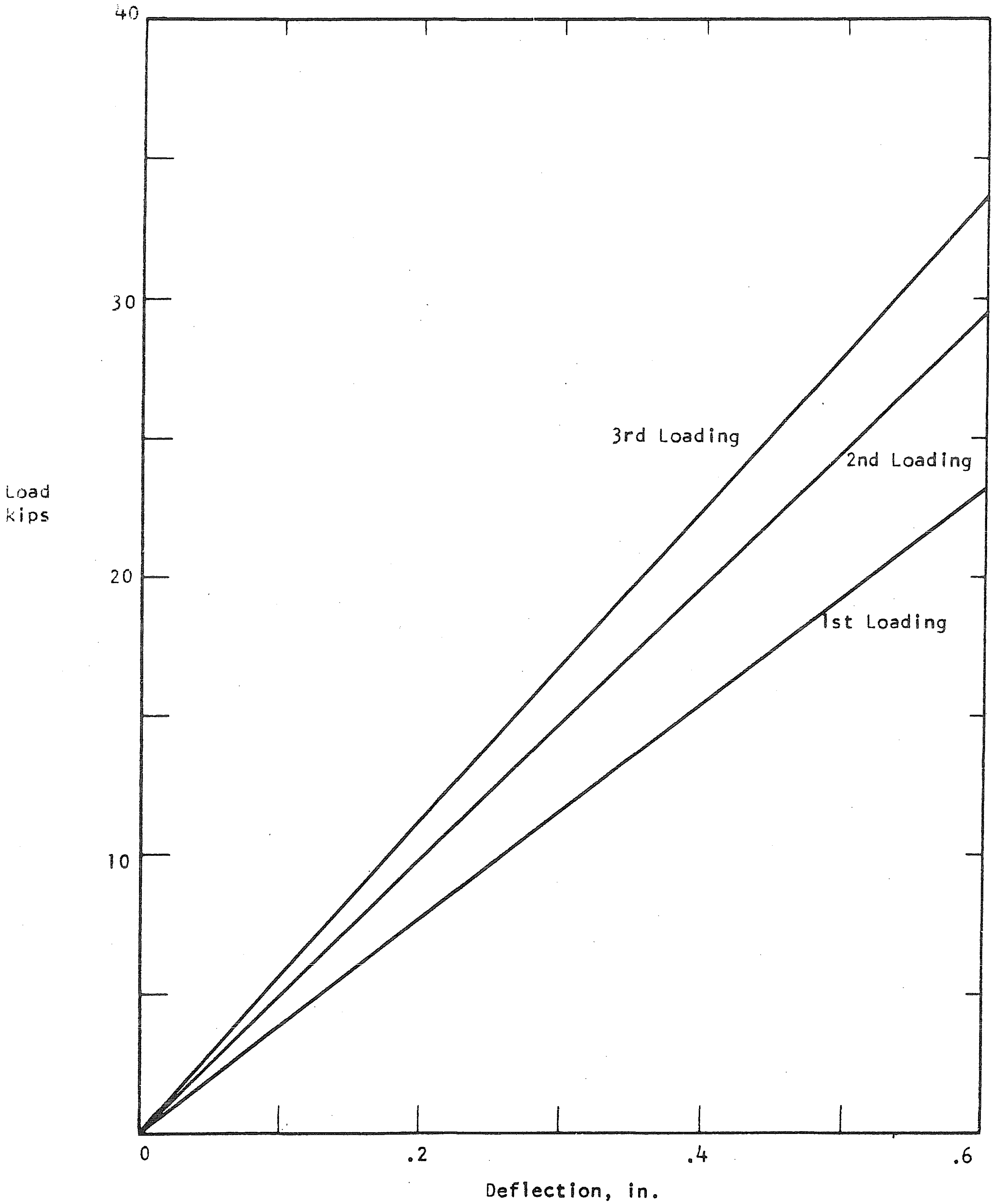


FIG. A6 LOAD vs DEFLECTION CURVES FOR SEVEN-WIRE STRAND

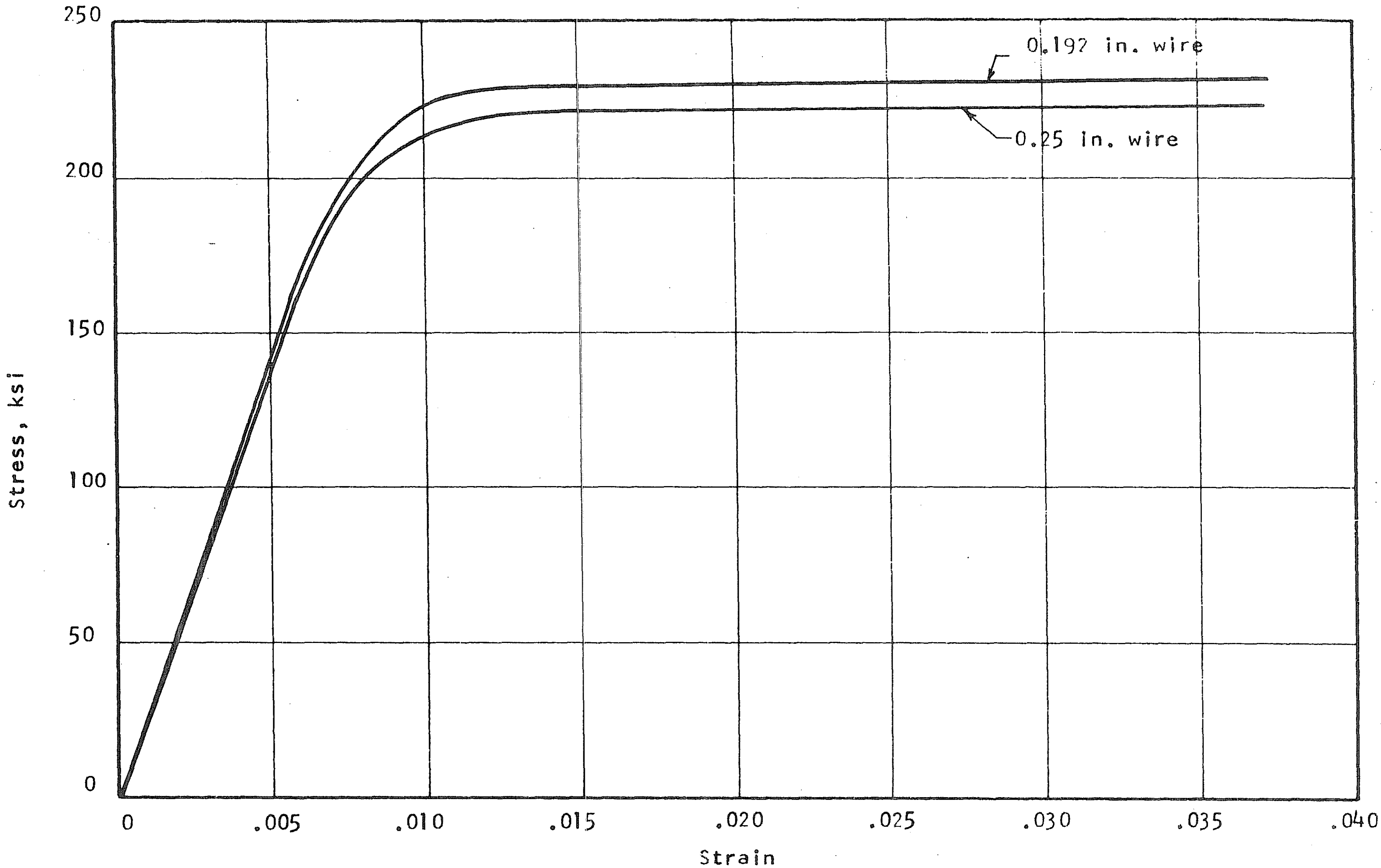


FIG A7 STRESS-STRAIN CURVE FOR PRESTRESSING WIRE

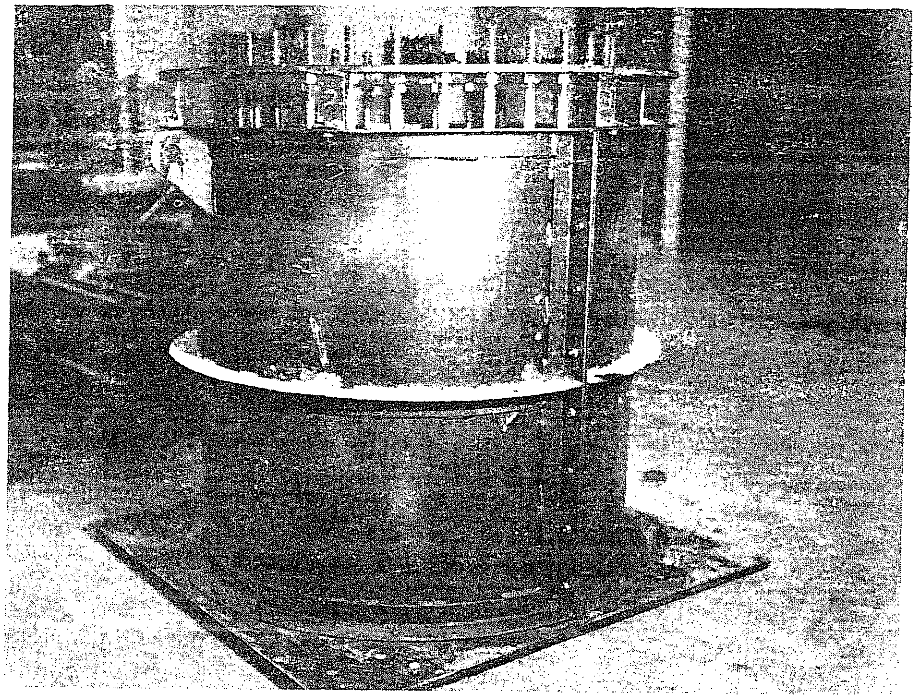


FIG. A8a PICTURE OF STEEL FORMS SHOWING TEMPLATE

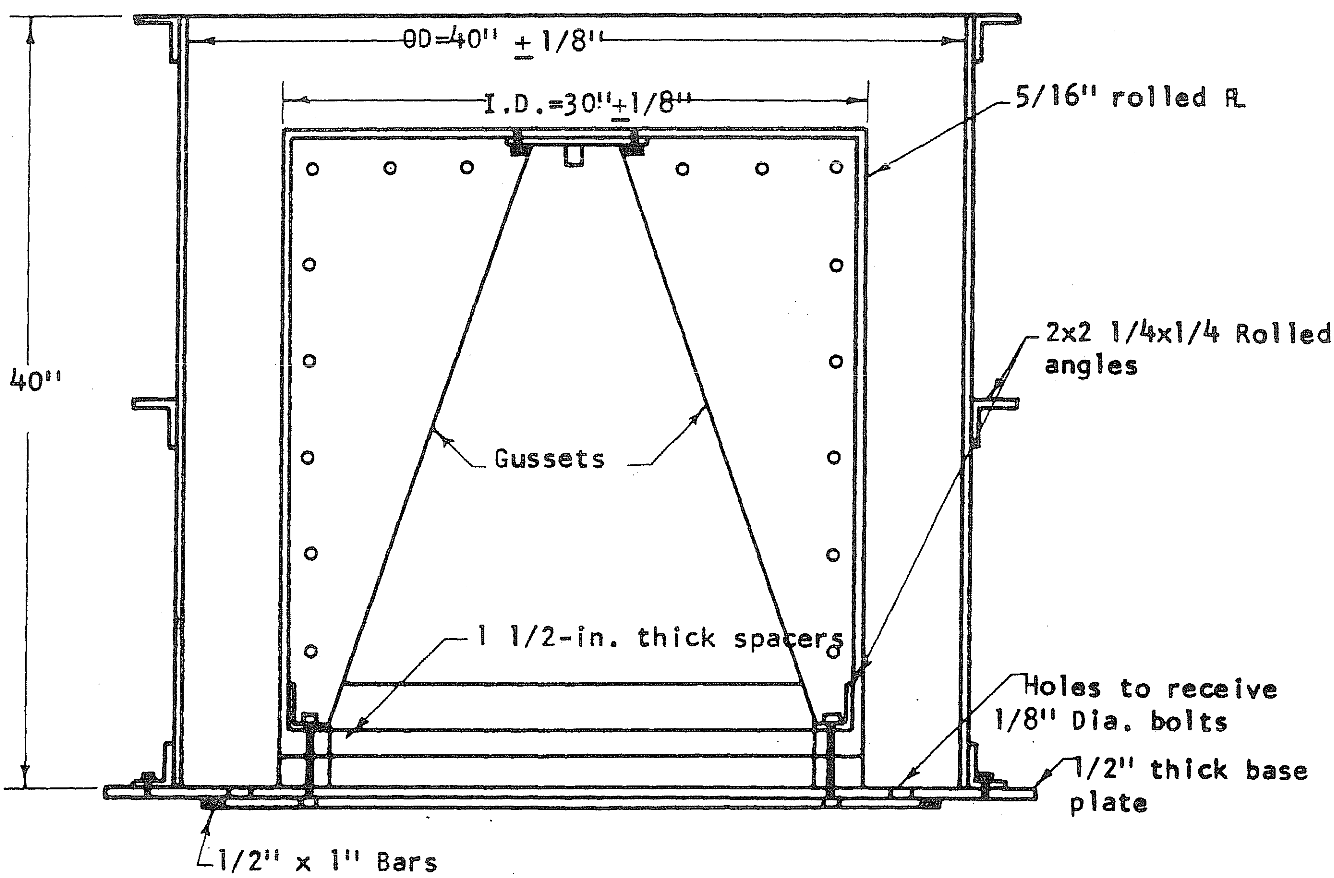


FIG. A8b DETAIL OF THE STEEL FORMS USED TO CAST PRESSURE VESSELS

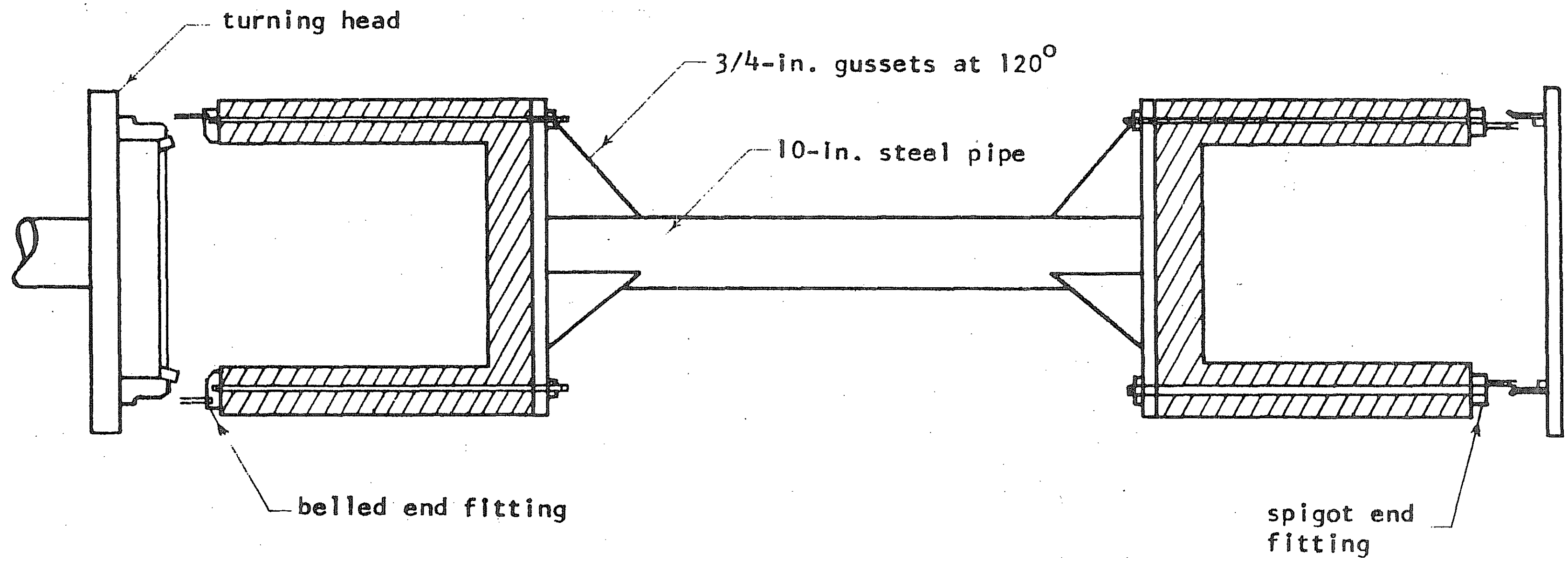


FIG. A9 SETUP FOR CIRCUMFERENTIAL PRESTRESSING

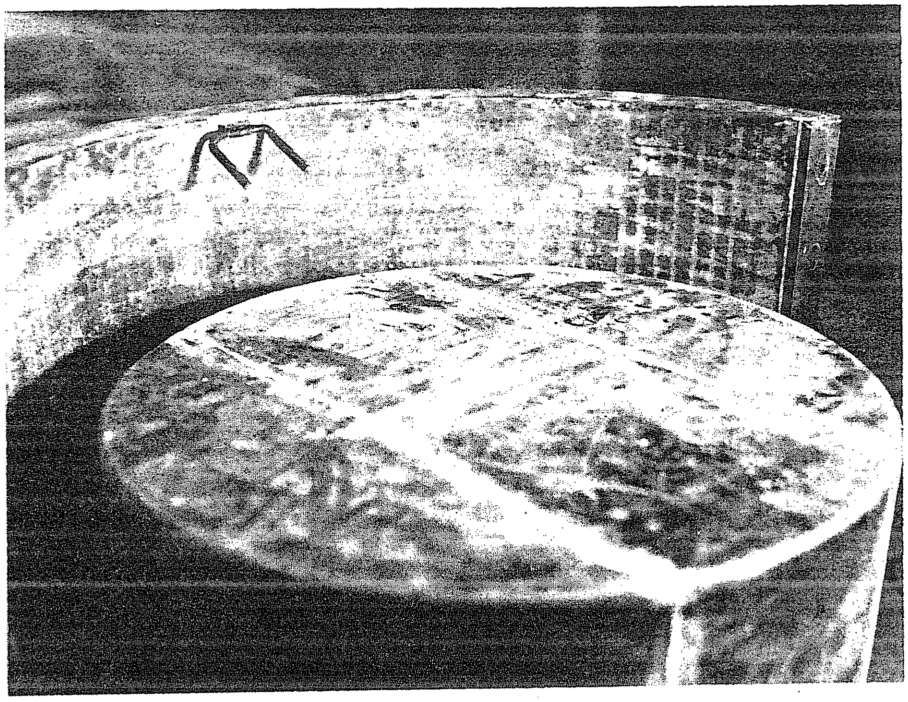


FIG. A10a ANCHOR BOLTED TO FORM

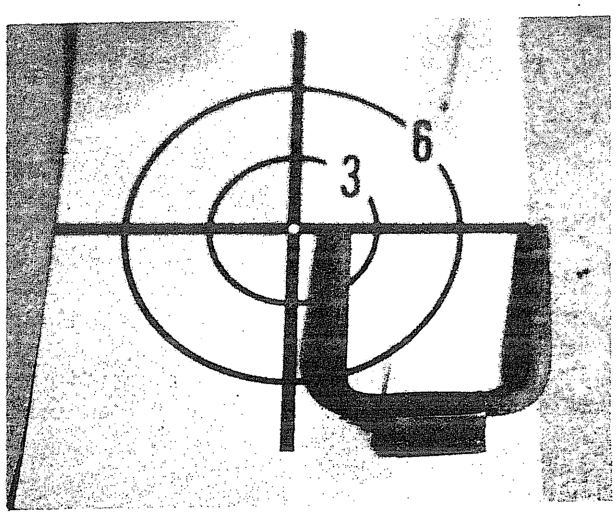


FIG. A10b CLOSEUP OF A TYPICAL ANCHOR

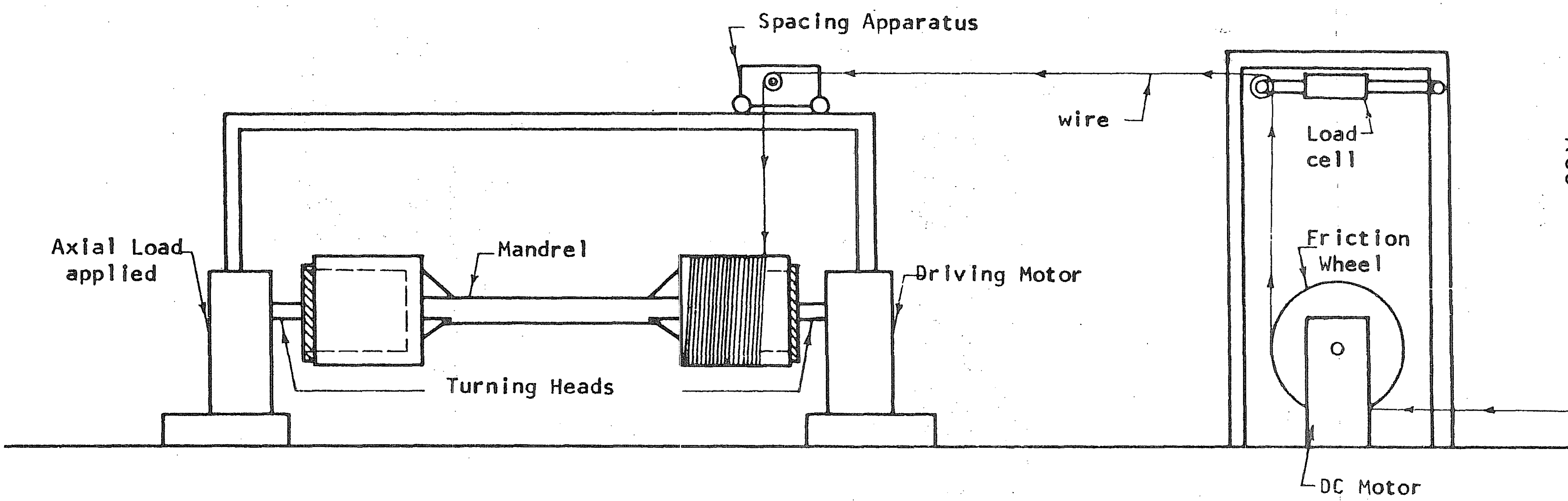


FIG. A11 SCHEMATIC DIAGRAM OF THE EQUIPMENT AT INTERPACE USED TO PRESTRESS THE PRESSURE VESSELS

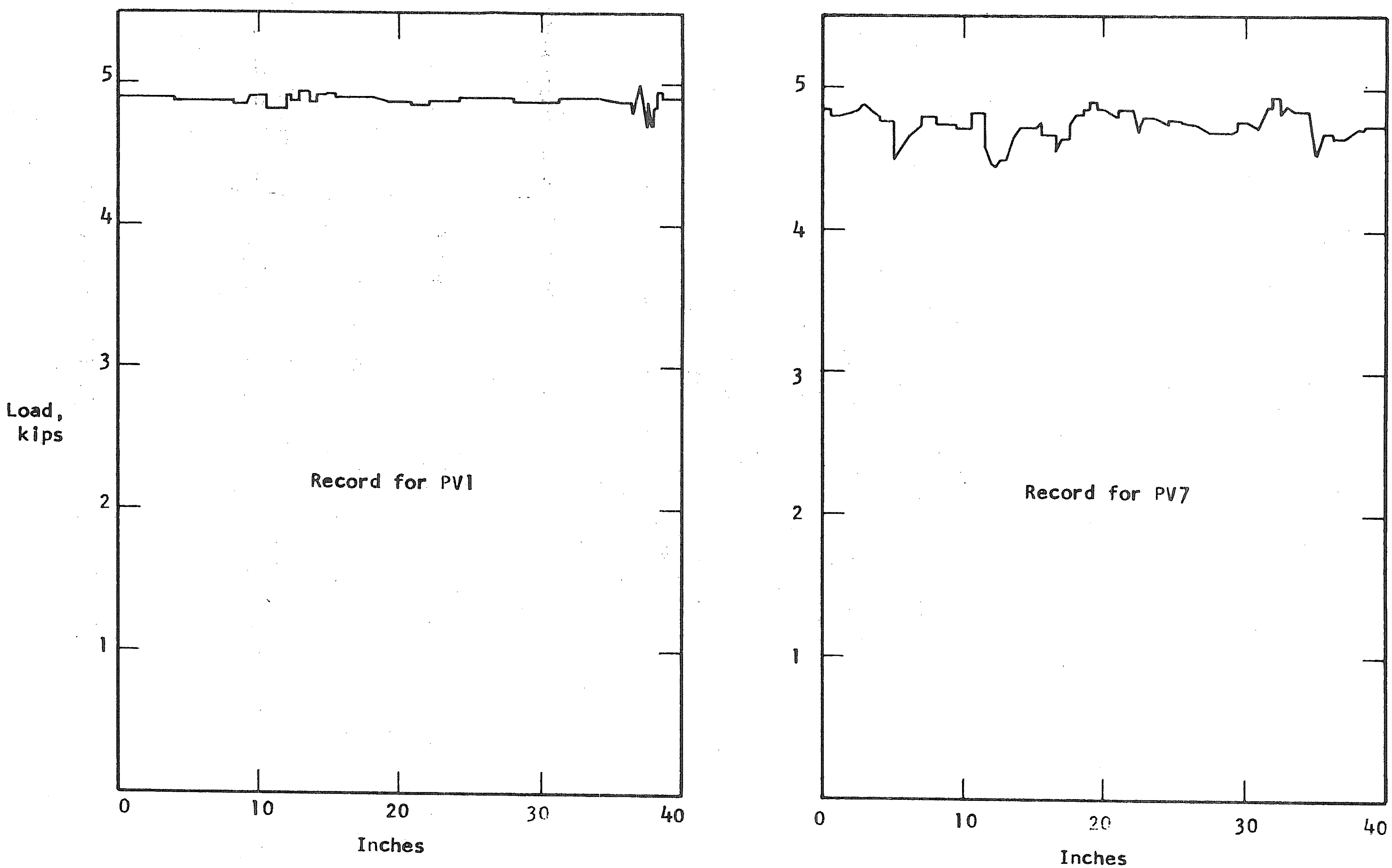


FIG. A12 LOAD IN WIRE vs DISTANCE FROM THE OUTSIDE OF THE END SLAB FOR PV1 AND PV7

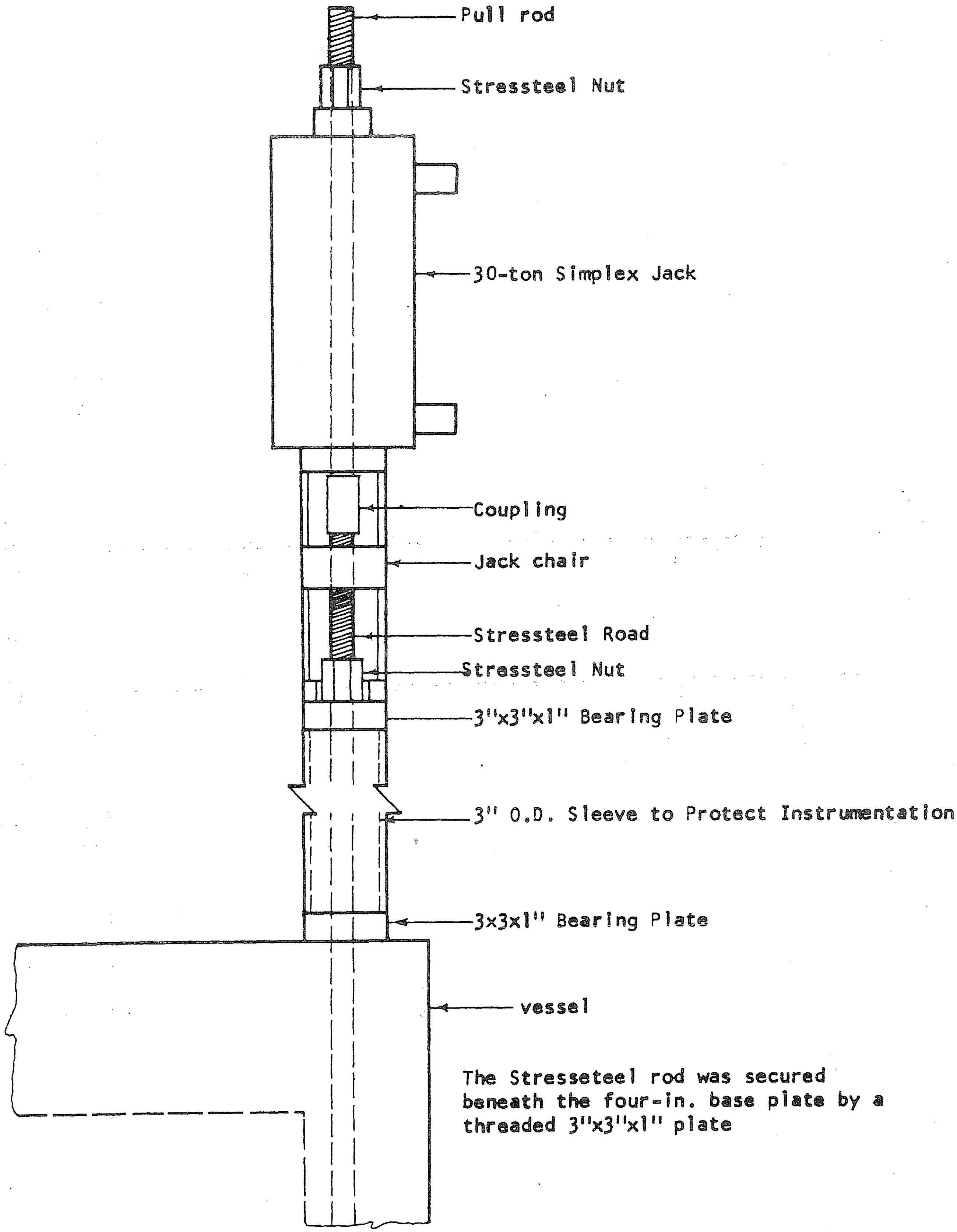


FIG. A13 APPARATUS USED TO PRESTRESS STRESSTEEL RODS

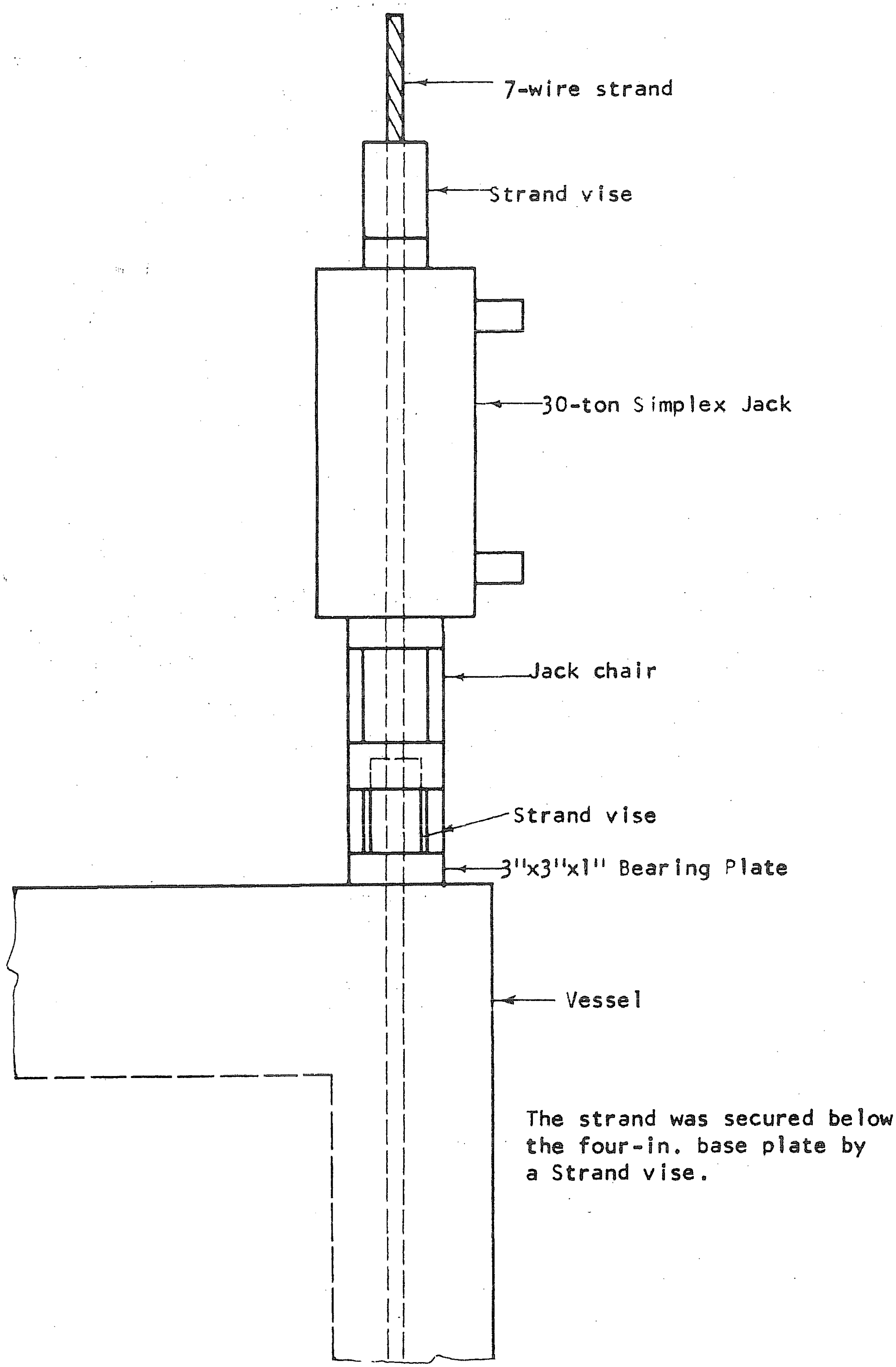
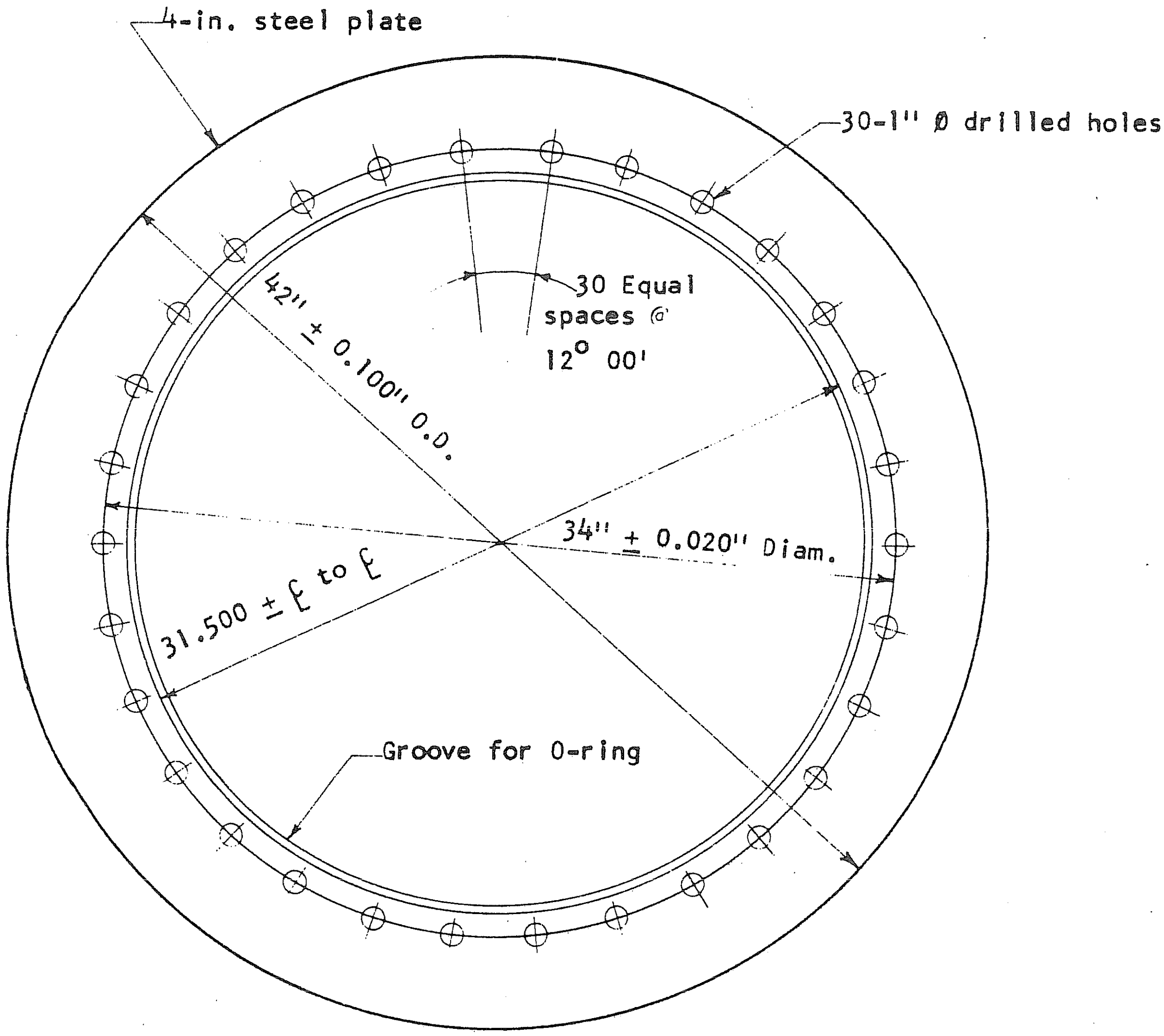
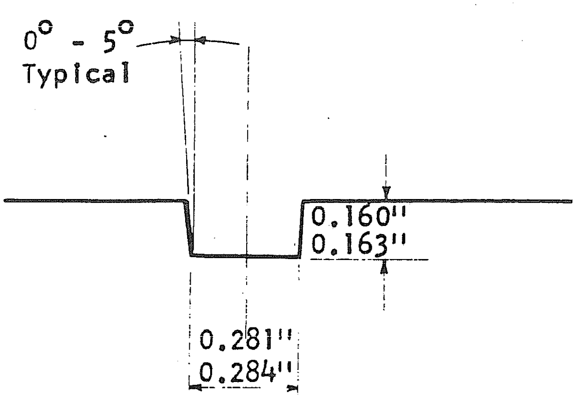


FIG. A14 APPARATUS USED TO PRESTRESS THE STRAND

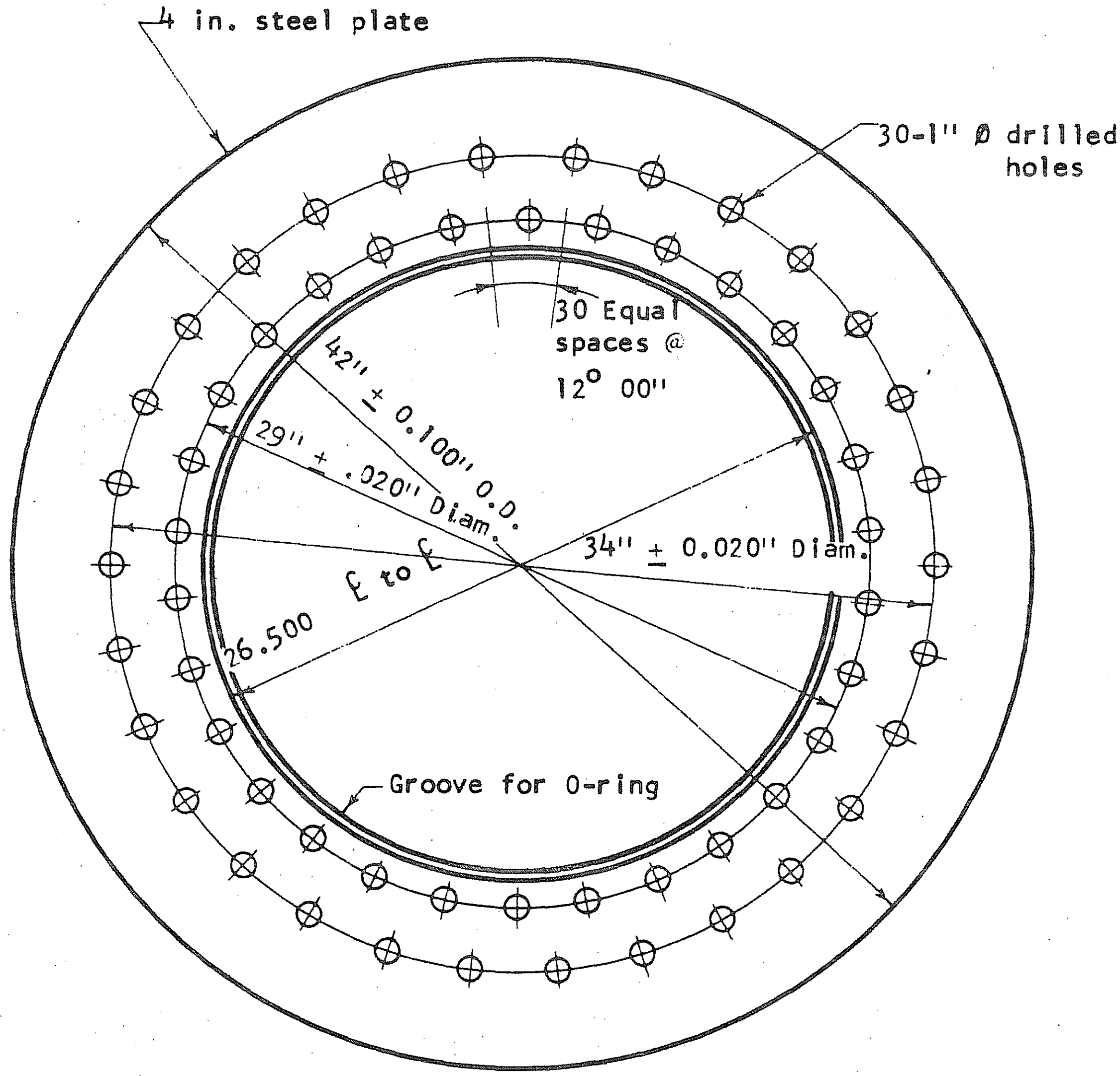


Base Plate

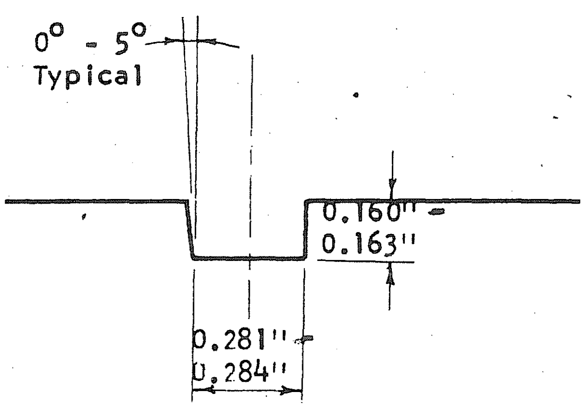


Detail of Groove

FIG. A15a BASE PLATE



Base Plate



Detail of Groove

FIG. A15b Base Plate

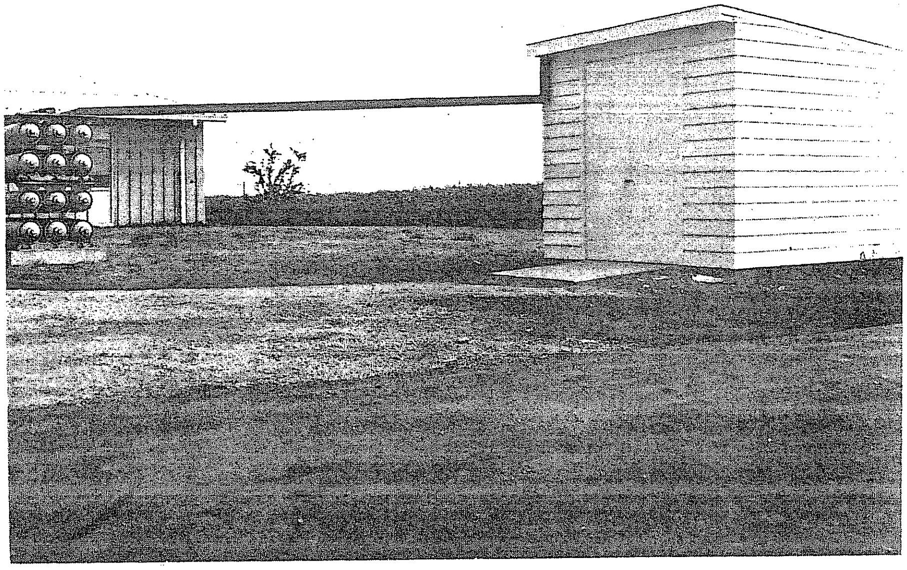


FIG. A16a THE TESTING SHED

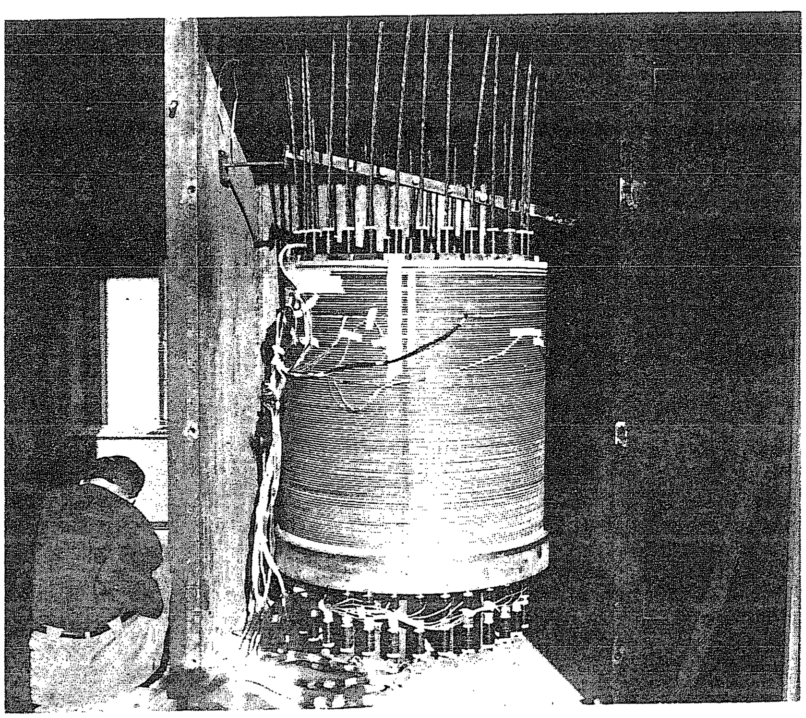


FIG. A16b PV8 IN THE TEST CHAMBER

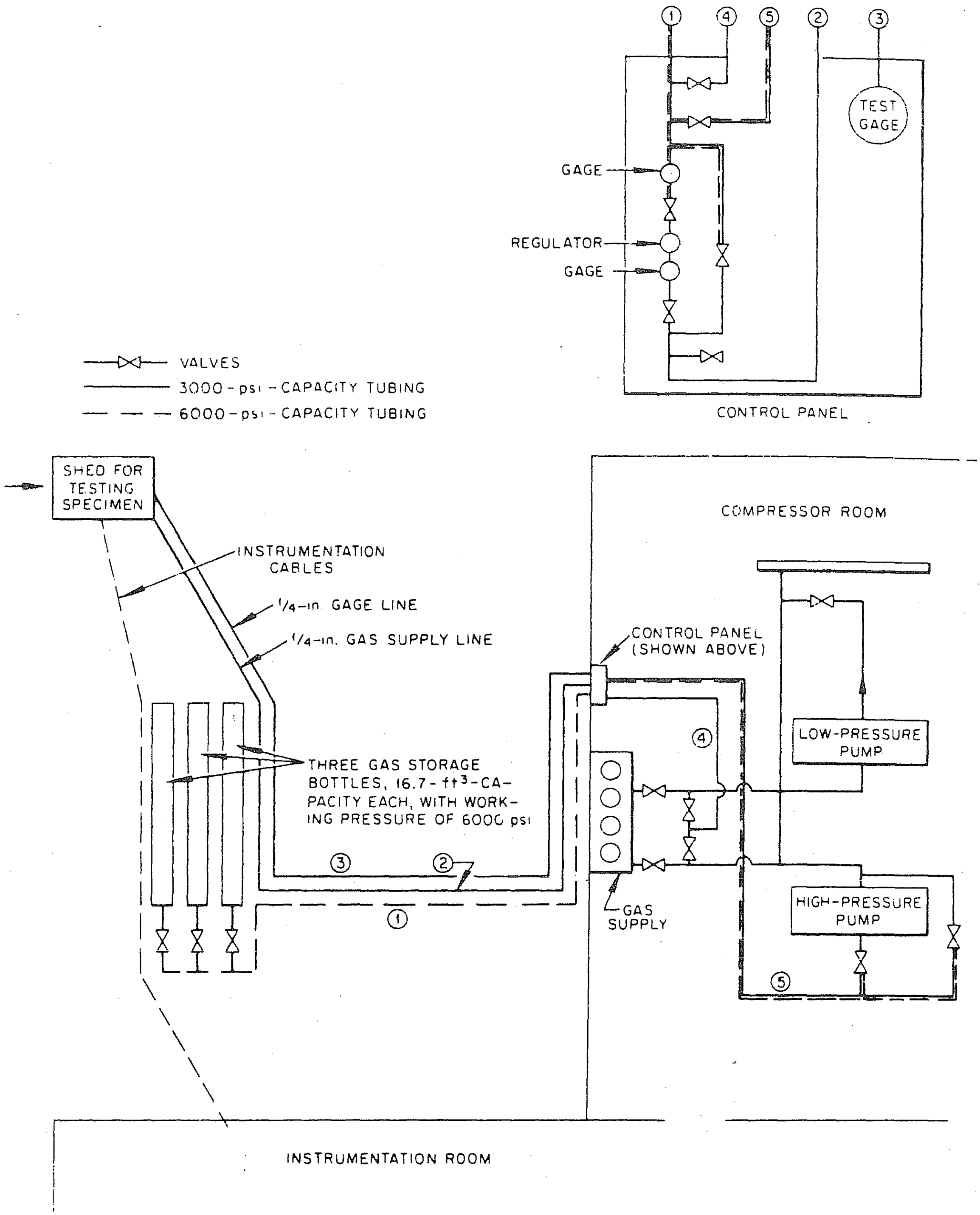


FIG. A17 SCHEMATIC DRAWING OF GAS SUPPLY AND CONTROL SYSTEMS FOR TESTS OF PRESTRESSED-CONCRETE VESSELS

APPENDIX B

TEST DATA

APPENDIX B

TEST DATA

INTRODUCTION

This appendix contains test descriptions and data for each of the 16 vessel tests. The dates of casting, prestressing, and testing of each specimen is recorded in Table B1. Vessel dimensions, prestress data, concrete strength, type of failure, and failure pressure are summarized in Tables 2.1 and 2.2 of the first volume of this report. For convenient reference these tables are repeated as Tables B2 and B3 in this appendix.

The numerical designation of each section corresponds to the designation of the vessel which it describes. Each section consists of a description of the test and descriptive information concerning the vessel and instrumentation, followed by the data resulting from the test in graphic form. The nominal thickness and wire spacing, designated t and s respectively, are given in the captions for each section. Those data which were obviously in error were discarded in order to reduce the volume of material. Some editing of data was performed where it was apparent that the zero for strain shifted, or that an error was made in a reading. The data consists first of deflection information and then concrete strains, circumferential reinforcement strains, and changes in longitudinal reinforcement force. The strain and force measurements presented were started after prestress was completed, and therefore are the result of application of internal pressure.

Development of leaks prevented completion of tests PV6, PV8, and PV11 on the first try. These vessels were resealed and retested; a third attempt was required for PV6 and a fourth for PV11 before failure was attained. For these three vessels complete data for only the first tests are presented. The sealing details, center deflection of the end slab, and change in load in the longitudinal reinforcement are presented for the final test as well.

The same general arrangement of instrumentation was used for tests PV1 through PV5. A different but consistent arrangement of strain gage locations was used for tests PV6 through PV16 except for PV14 which was different from the other two arrangements. The locations of the gages for each test vessel are shown in the appendix and minor changes in instrumentation may be detected in the descriptive material.

TABLE B1

CHRONOLOGY

Mark	Casting	Circumferential Prestressing	Longitudinal Prestressing	Testing
PV1	8-17-67	9-23-67	10-16-67	10-27-67
PV2	8-23-67	9-23-67	12-1-67	12-6-67
PV3	11-16-67	12-15-67	12-19-67	12-22-67
PV4	11-29-67	12-15-67	1-2-68	1-5-68
PV5	12-18-67	1-9-68	1-16-68	1-19-68
PV6	12-22-67	1-9-68	1-29-68	2-2-68
PV6.1	--	--	2-6-68	2-8-68
PV6.2	--	--	2-8-68	2-8-68
PV7	1-4-68	1-22-68	2-22-68	2-27-68
PV8	1-10-68	1-22-68	3-20-68	3-26-68
PV8.1	--	--	3-27-68	3-28-68
PV9	4-17-68	5-2-68	6-26-68	6-27-68
PV10	4-24-68	5-2-68	6-17-68	6-18-68
PV11	7-15-68	7-31-68	9-11-68	9-17-68
PV11.1	--	--	9-23-68	9-25-68
PV11.2	--	--		
PV11.3	--	--		
PV12	7-19-68	7-31-68	10-10-68	10-16-68
PV13	8-14-68	9-4-68	11-1-68	11-6-68
PV14	8-19-68	9-4-68	11-21-68 12-2-68	12-4-68
PV15	11-7-68	11-26-68	12-13-68	12-16-68
PV16	11-12-68	11-26-68	1-3-69 1-24-69	1-28-69

TABLE B2

PROPERTIES OF THE TEST VESSELS

Mark	Slab Thickness	Wall Thickness	Circum. Prestress			Long. Prestress			Concrete		
			Wire Dia.	Wire Spacing	Force per Wire	Tendon Type[a]	Number	Total Force	Comp. Strength	Tens. Strength	Young's Mod.
	in.	in.	in.	in.	kips			kips	psi	psi	10^6 psi
PV1	6	5	0.192	1.0	4.55	Rod	10	388	5680	432	4.2
PV2	6	5	0.192	1.0	4.45	Strand	24	388	4955	398	3.5
PV3	7.5	5	0.192	1.0	4.68	Strand	24	392	6250	450	4.2
PV4	6	5	0.102	0.67	4.49	Strand	24	583	5680	380	4.2
PV5	7.5	5	0.192	0.67	4.59	Strand	24	524	6250	439	4.1
PV6	9	5	0.192	0.67	4.51	Strand	30	606	5805	398	4.1
6.1					4.48			639			
6.2					4.47		22	469			
PV7	9	5	0.192	0.33	4.23	Strand	30	693	6720	506	4.6
PV8	7.5	5	0.192	0.33	4.09	Strand	30	626	7230	443	4.8
8.1								700			
PV9	9	5	0.192	0.33	4.10	Strand	30	750	7140	446	4.3
PV10	7.5	5	0.192	0.33	4.12	Strand	30	750	7005	394	4.0
PV11	7.5	7.5	0.250	0.25	6.06	Rod	30[b]	694	6830	504	4.5
11.1					5.72			1030			
PV12	10	7.5	0.250	0.25	5.73	Rod	30	727	5860	456	4.4
PV13	12.5	7.5	0.250	0.25	5.82	Rod	60	1356	6750	490	4.2
PV14	15	7.5	0.250	0.25	5.56	Rod	60	1370	6880	465	4.3
PV15	7.5	7.5	0.250	0.25	6.47	Rod	60	1200	7340	531	4.2
PV16	10	7.5	0.250	0.25	5.94	Rod	60	1995	7450	518	4.0

[a] 0.75-in. round Stressteel rods or 0.5-in. round seven-wire strand

[b] This vessel was prestressed longitudinally with 28 rods and two lengths of strand.

TABLE B3
MEASURED INTERNAL PRESSURES AT FAILURE

Mark	Span / Slab Thickness ratio[a]	Wall Thickness in.	Concrete Strength f'_c psi	Circum. Prestress Index[b] ksi	Long. Prestress Index[c] ksi	Pressure at Failure psi	Mode of Failure[d]
PV1	5	5	5680	0.30	0.55	295	F
PV2	5	5	4955	0.30	0.55	240	FL
PV3	4	5	6250	0.31	0.55	370	F
PV4	5	5	5650	0.45	0.82	390	F
PV5	4	5	6250	0.46	0.74	465	F
PV6	3.3	5	5805	0.45	0.86	570	L
PV6.1					0.90	585	L
PV6.2					0.66	555	F
PV7	3.3	5	6720	0.84	0.98	870	F
PV8	4	5	7230	0.82	0.84	625	L
8.1					0.99	640	F
PV9	3.3	5	7140	0.82	1.06	887	F
PV10	4	5	7005	0.87	1.06	740	F
PV11	3.3	7.5	6830	1.94	1.41	1600	L
PV11.1				1.83	2.10	2040	S
PV12	2.5	7.5	5860	1.83	1.48	2650	CL
PV13	2	7.5	6750	1.86	2.76	3450	VL
PV14	1.67	7.5	6880	1.78	2.79	3690	VL
PV15	3.3	7.5	7340	2.07	2.44	2300	S
PV16	2.5	7.5	7450	1.90	4.06	3200	S

[a] Ratio of internal diameter to slab thickness

[b] Ratio of circumferential prestressing force per unit length to the internal diameter

[c] Ratio of total longitudinal prestressing force to area of cavity at a transverse section

F: Flexural failure of end slab

S: Shear failure of end slab

L: Liner leakage

FL: Test stopped by liner leakage at incipient failure in flexure

CL: Leakage caused by circumferential cracking in the side wall

VL: Leakage caused by longitudinal cracking in the side wall

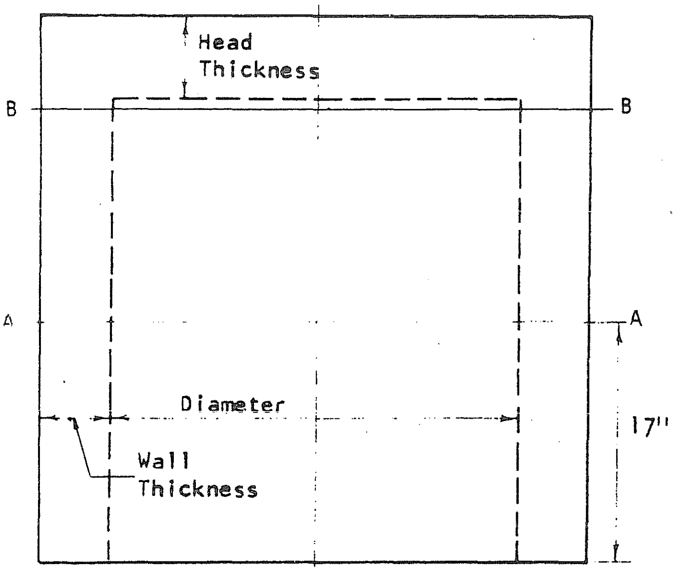
B1. Test Vessel PV1 (t = 6.0 in., s = 1.0 in.)PV1

Test vessel PV1 was cast from ready-mix concrete and was nearly two months old at the time of the test. When the form was struck, a circumferential crack in the side wall immediately below the end slab was observed inside the specimen. The cause of this crack was evidently the settlement of the concrete after casting while it was still plastic.

The testing of PV1 was completed without any problems. The test chamber had been lined with 3/4-in. plywood, and the hatch was covered with a single layer of steel netting. Both of these measures proved to be insufficient to restrain the force of the explosion when the vessel failed at 295 psi. A photograph showing the damage is given in Fig. B1.21a.

The entire test lasted about three hours. The pressure was increased in increments of 25 psi up to 100 psi, when the increment of loading was decreased to 20 psi. The final cracking mode is illustrated by a photograph of the pieces of the end slab which were reassembled after the test (Fig. B1.21b).

Vessel PV1 was prestressed longitudinally with 3/4-in. Stressteel rods. Nine of the ten rods in the vessel had been instrumented with strain gages and calibrated. These were monitored during the test.



Wall Thickness, in.		
Axis \ Plane	AA	BB
N	5.05	
NE	4.94	
E	4.70	
SE	4.84	
S	4.90	
SW	5.10	
W	5.10	
NW	5.21	

Inside Diameter, in.		
Axis \ Plane	AA	BB
N-S	$30\frac{4}{32}$	$29\frac{31}{32}$
NE-SW	$30\frac{0}{32}$	$29\frac{31}{32}$
E-W	$30\frac{0}{32}$	$30\frac{1}{32}$
SE-NW	$30\frac{1}{32}$	$29\frac{31}{32}$

FIG. B1.1 DIMENSIONS OF PV1

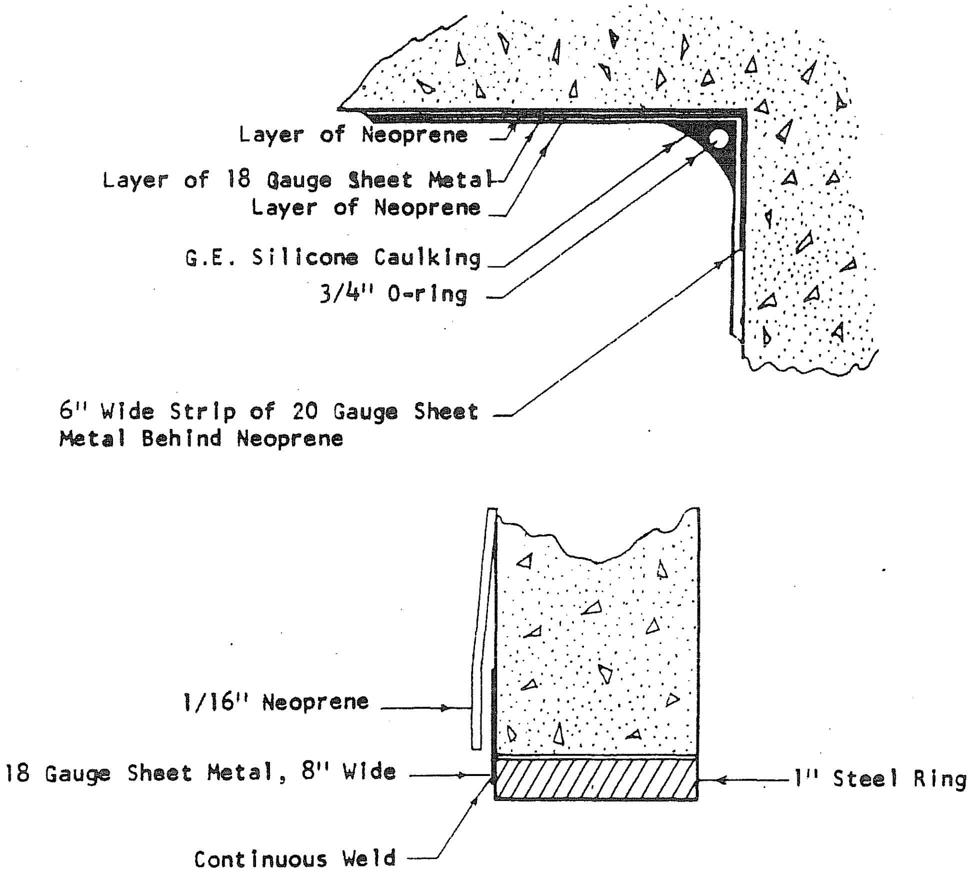
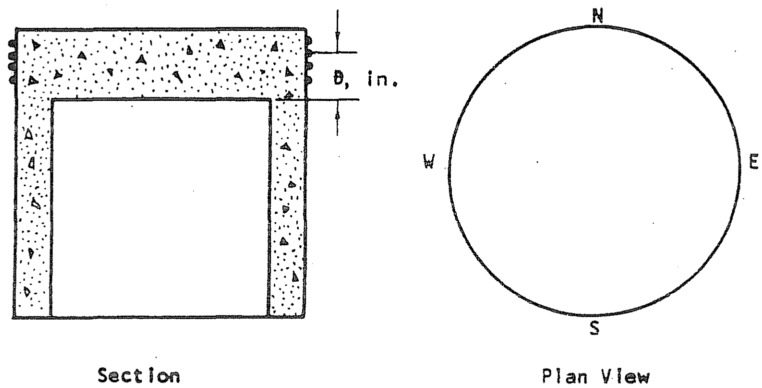


FIG. B1.2 SEALING DETAIL FOR PV1



Wrap No.	D_N	D_E	D_S	D_W
1	5 3/8	5	5	5 2/8
2	4 7/8	3 7/8	4 6/8	4 4/8
3	3 5/8	2 7/8	3 1/8	3 3/8
4	2 4/8	1 7/8	2 1/8	2 3/8
5	1 4/8	7/8	1	1 1/4
6	4/8	-1/8	0	1/4

FIG. B1.3 MEASURED LOCATION OF THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE ENDS OF THE N-S AND E-W DIAMETERS ON PV1

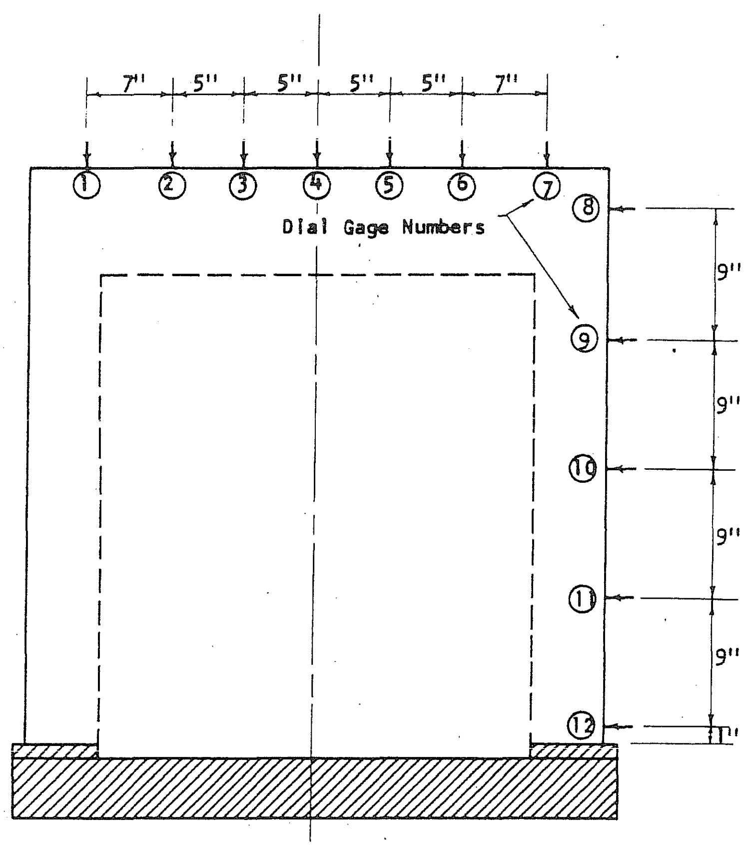


FIG. B1.4 LOCATION OF DEFLECTION GAGES ON PV1

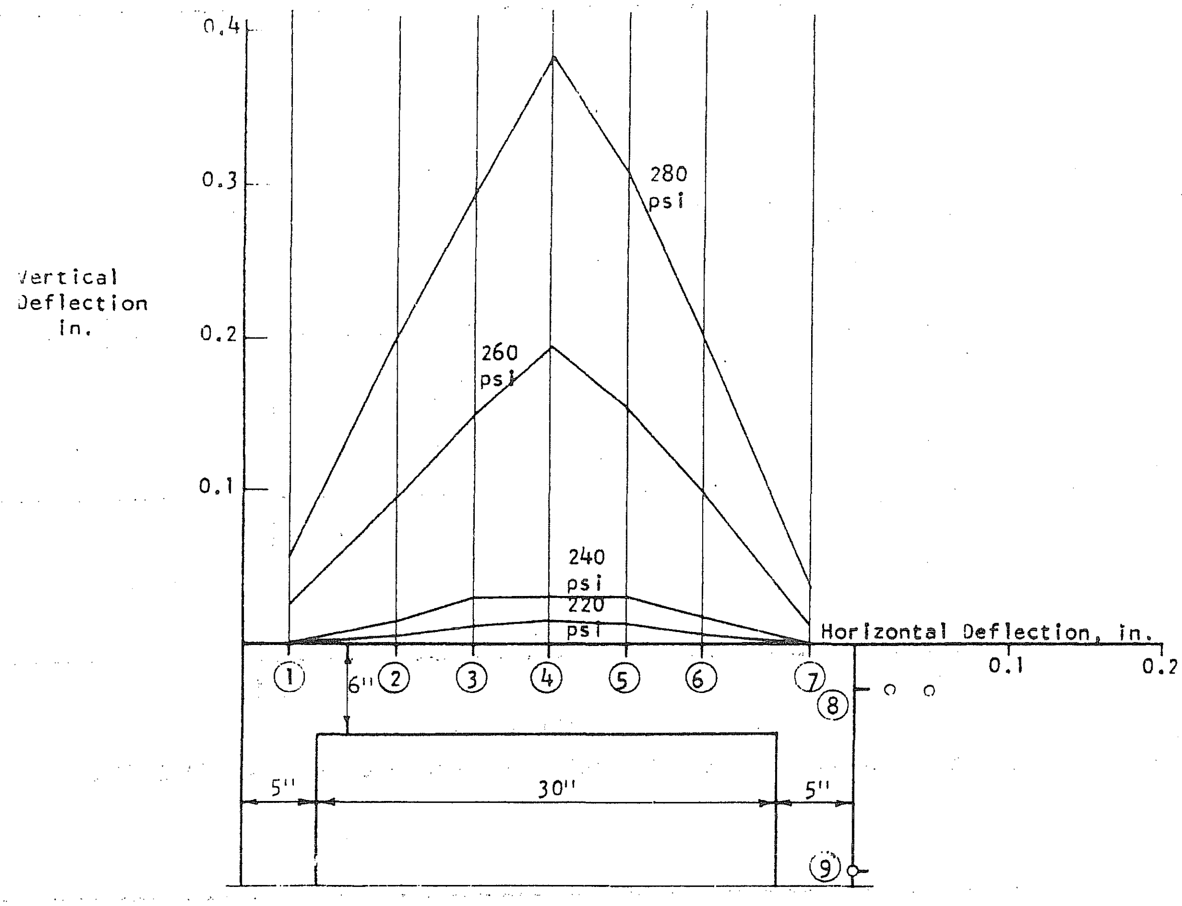


FIG. B1.5 DEFLECTION PROFILES OF THE END SLAB ALONG THE N-S DIAMETER OF PV1

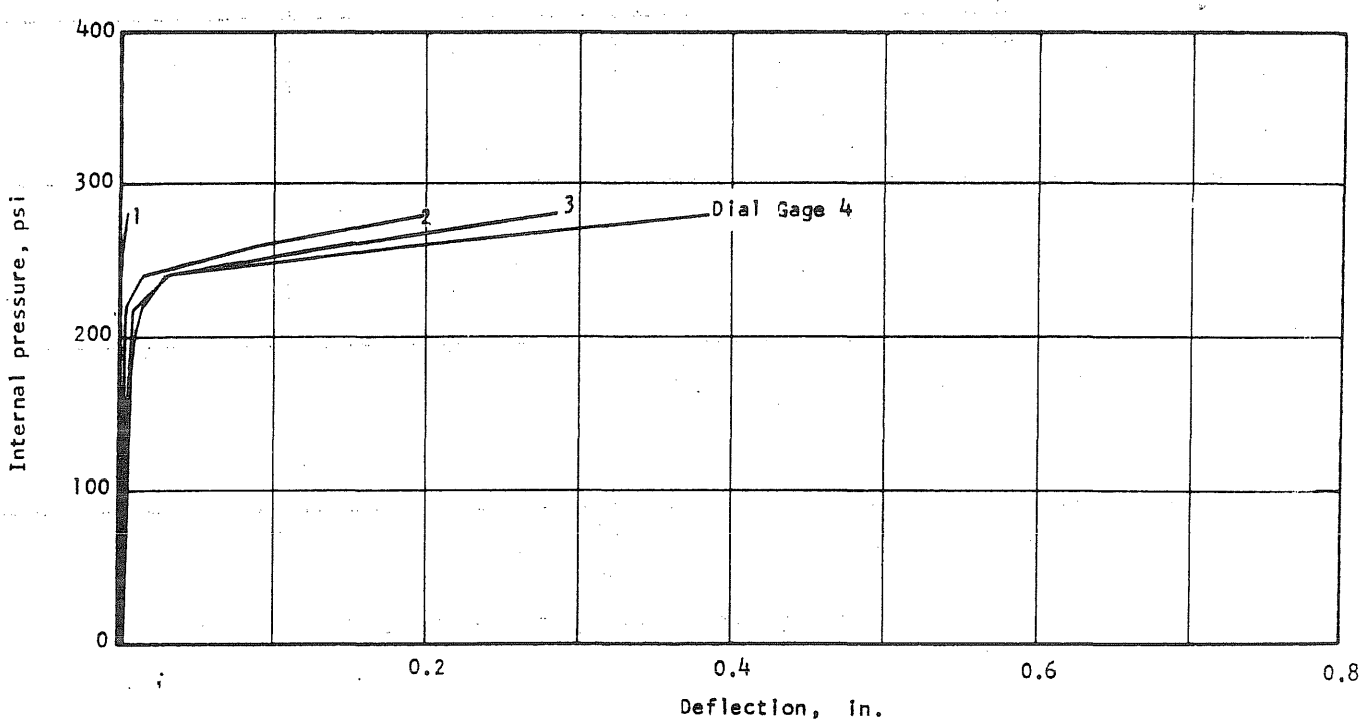


FIG. B1.6 APPLIED PRESSURE vs DEFLECTION ALONG THE N-HALF OF THE N-S DIAMETER OF PV1

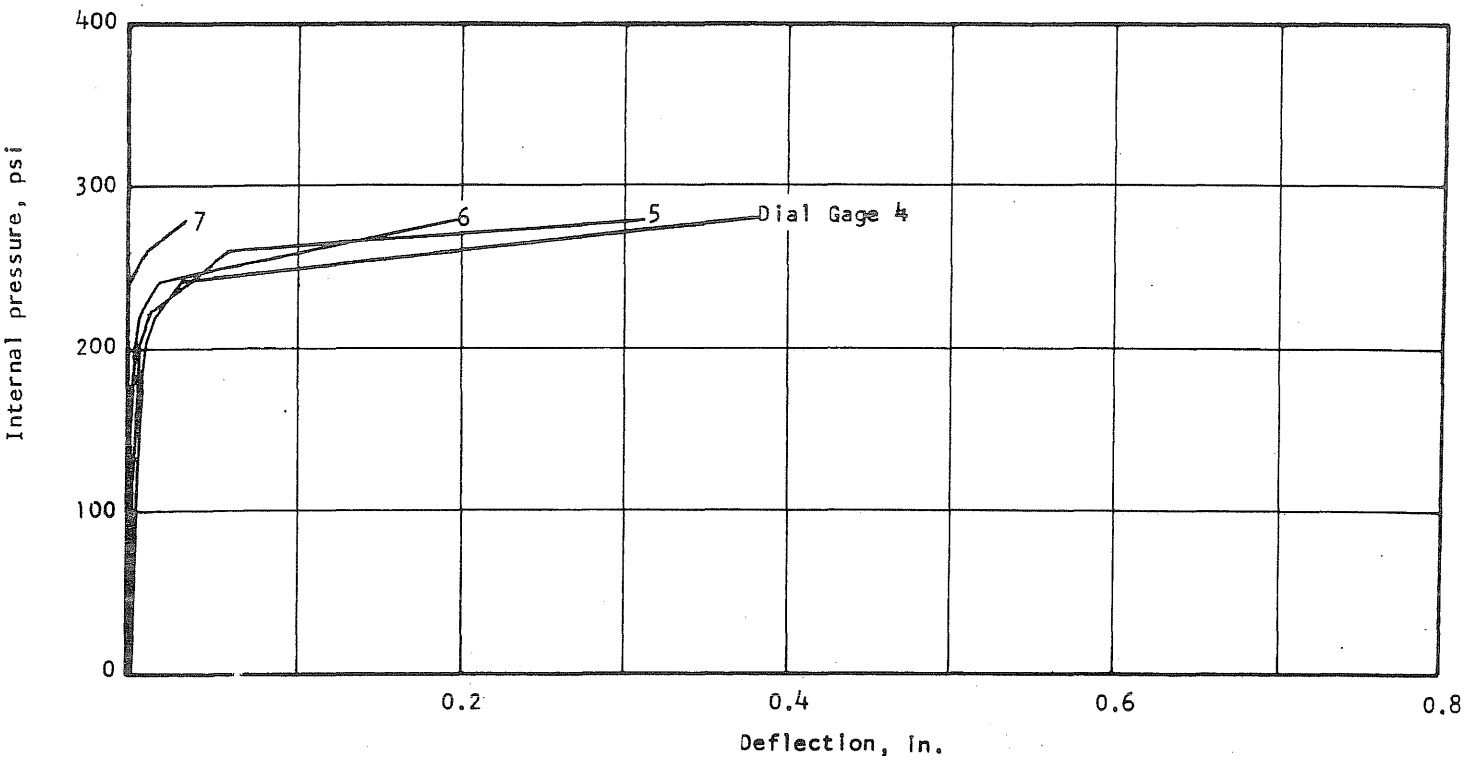


FIG. B1.7 APPLIED PRESSURE vs DEFLECTION ALONG THE S-HALF OF THE N-S DIAMETER OF PV1

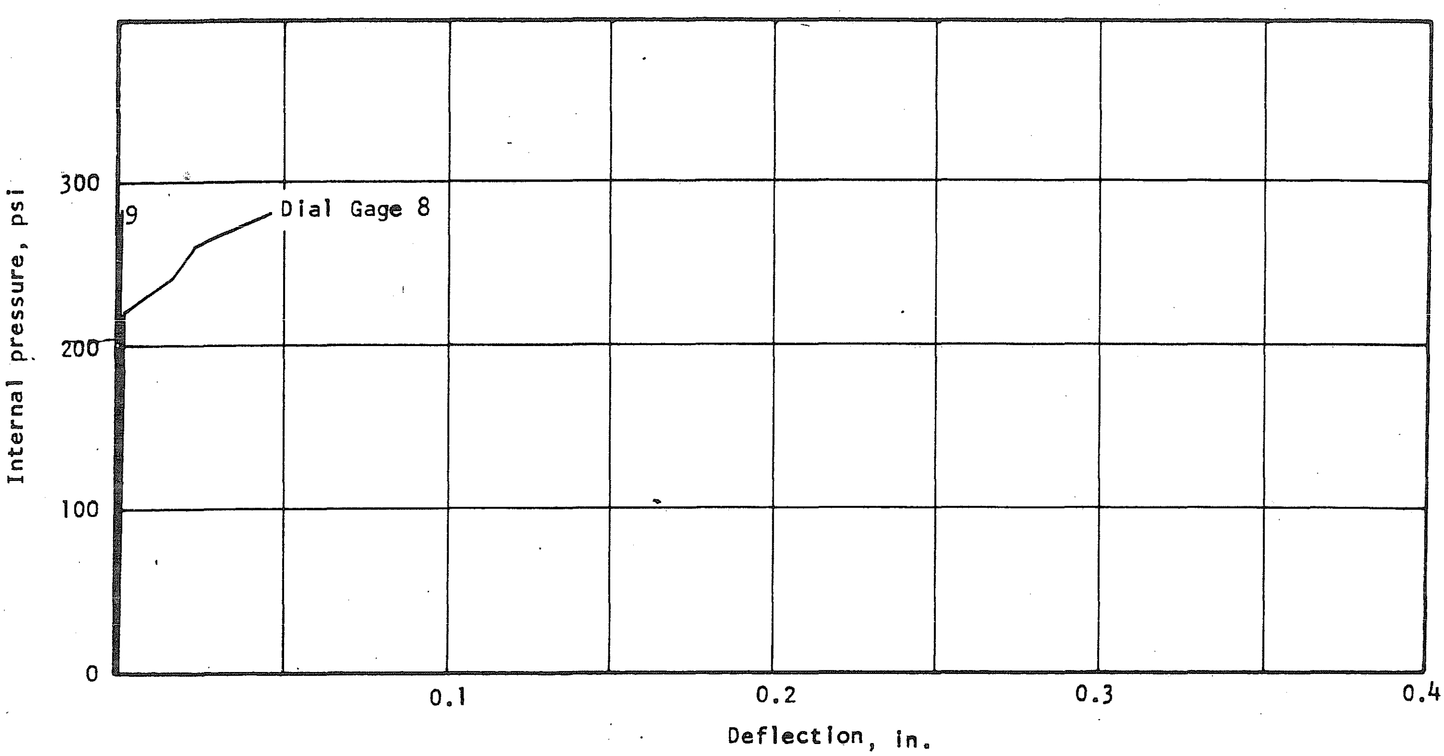
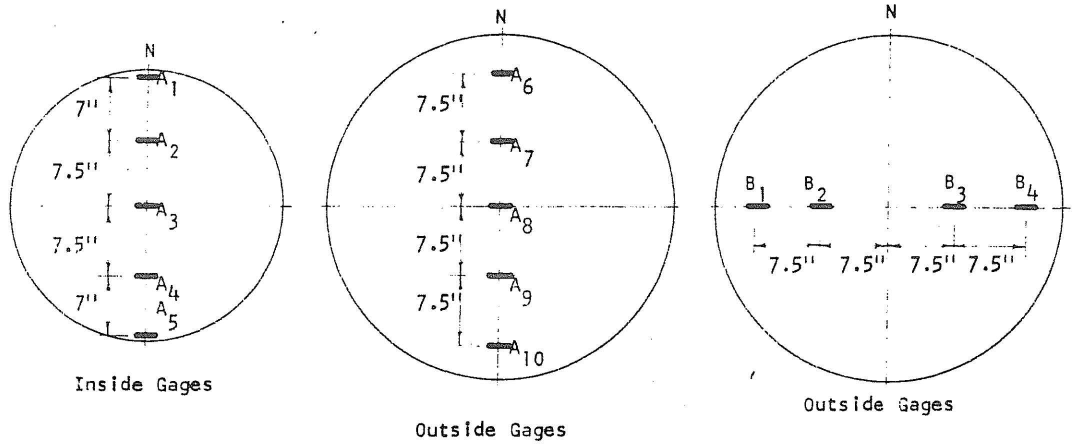
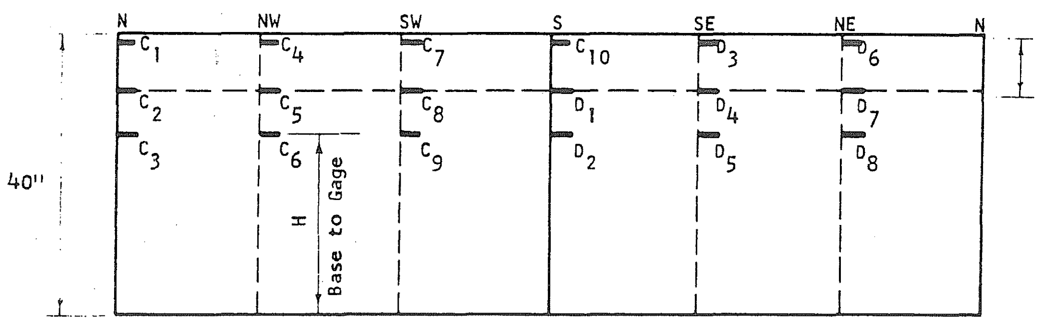


FIG. B1.8 APPLIED PRESSURE vs DEFLECTION OF THE SIDE WALL ON PV1

Concrete Gages on The Slab

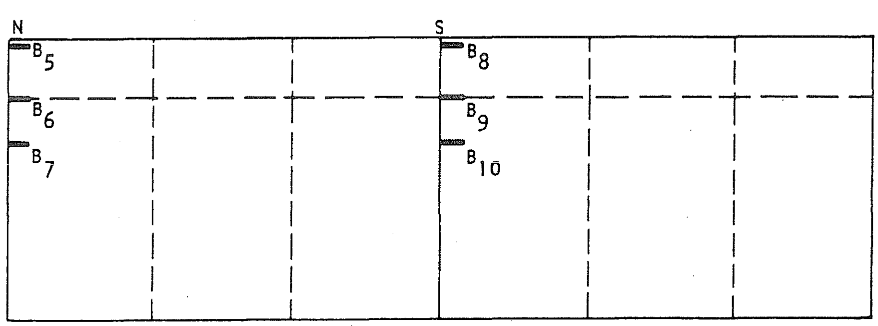


Steel Gages on Prestressing Wire



Gage	Axis	H	Gage	Axis	H	Gage	Axis	H
C_1	N	37 5/8	C7	SW	38 3/8	D3	SE	38 0/8
C_2	N	32 5/8	C8	SW	33 3/8	D4	SE	33 0/8
C_3	N	27 5/8	C9	SW	28 2/8	D5	SE	28 0/8
C_4	NW	38 5/8	C10	S	38 2/8	D6	NE	37 6/8
C_5	NW	33 4/8	D1	S	33 1/8	D7	NE	32 6/8
C_6	NW	28 4/8	D2	S	28 1/8	D8	NE	27 6/8

Concrete Gages on The Outside of the Vessel



Gage	Axis	H	Gage	Axis	H
B5	N	37 0/8	B8	S	37 6/8
B6	N	32 1/8	B9	S	32 6/8
B7	N	27 0/8	B10	S	27 6/8

FIG. B1.9 STRAIN GAGE LOCATIONS ON PV1

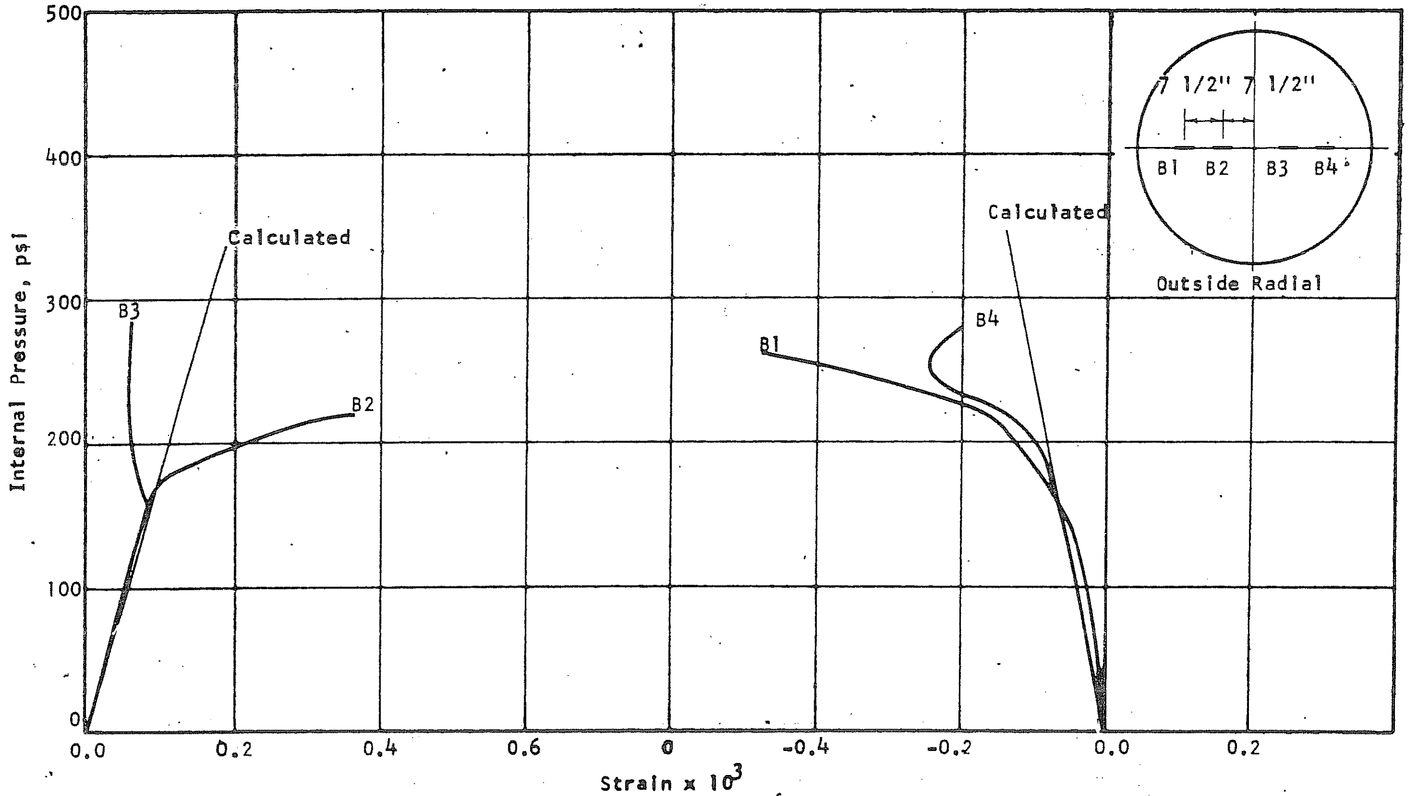


FIG. B1.10 CONCRETE STRAINS, VESSEL PV1

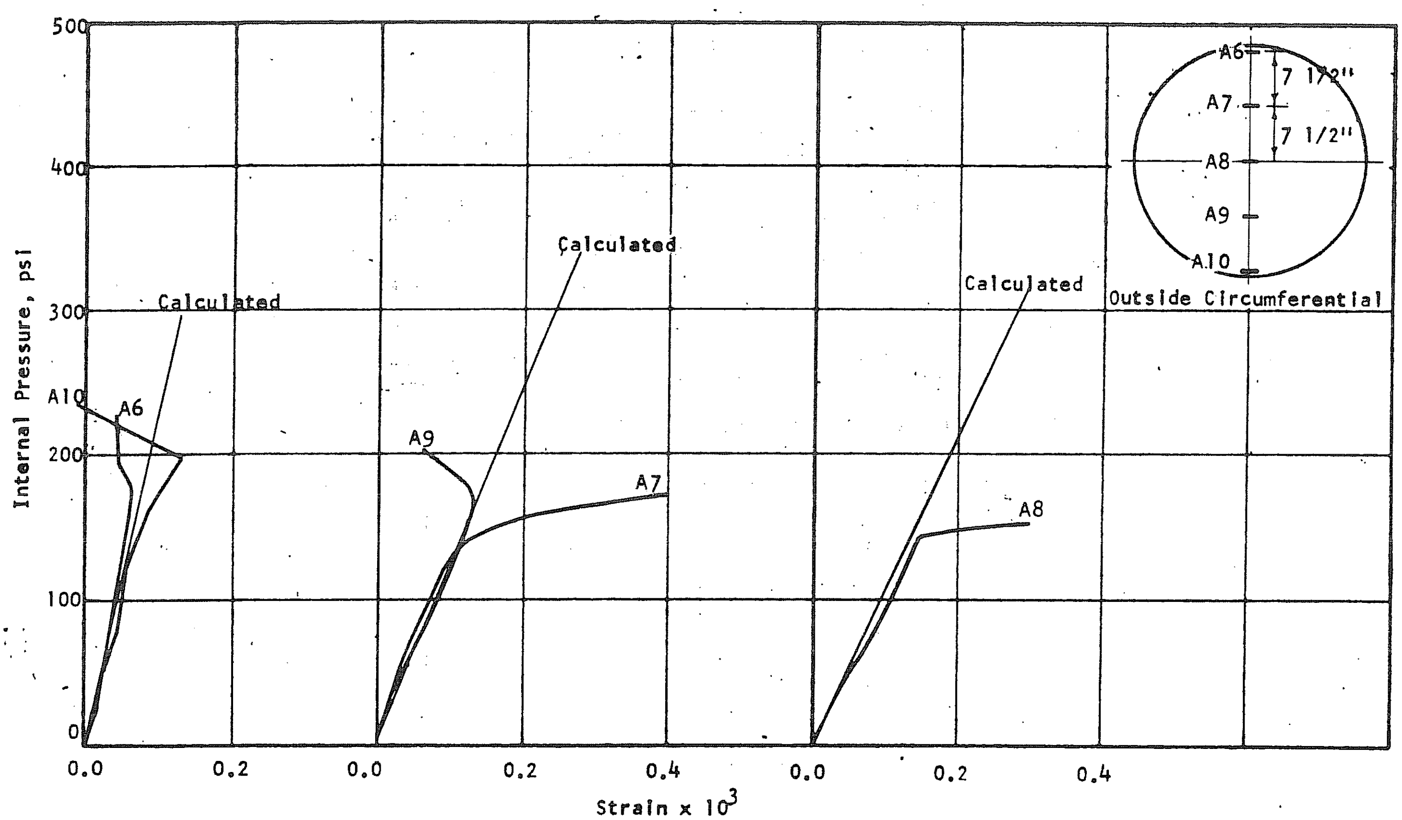


FIG. B1.11 CONCRETE STRAINS, VESSEL PV1

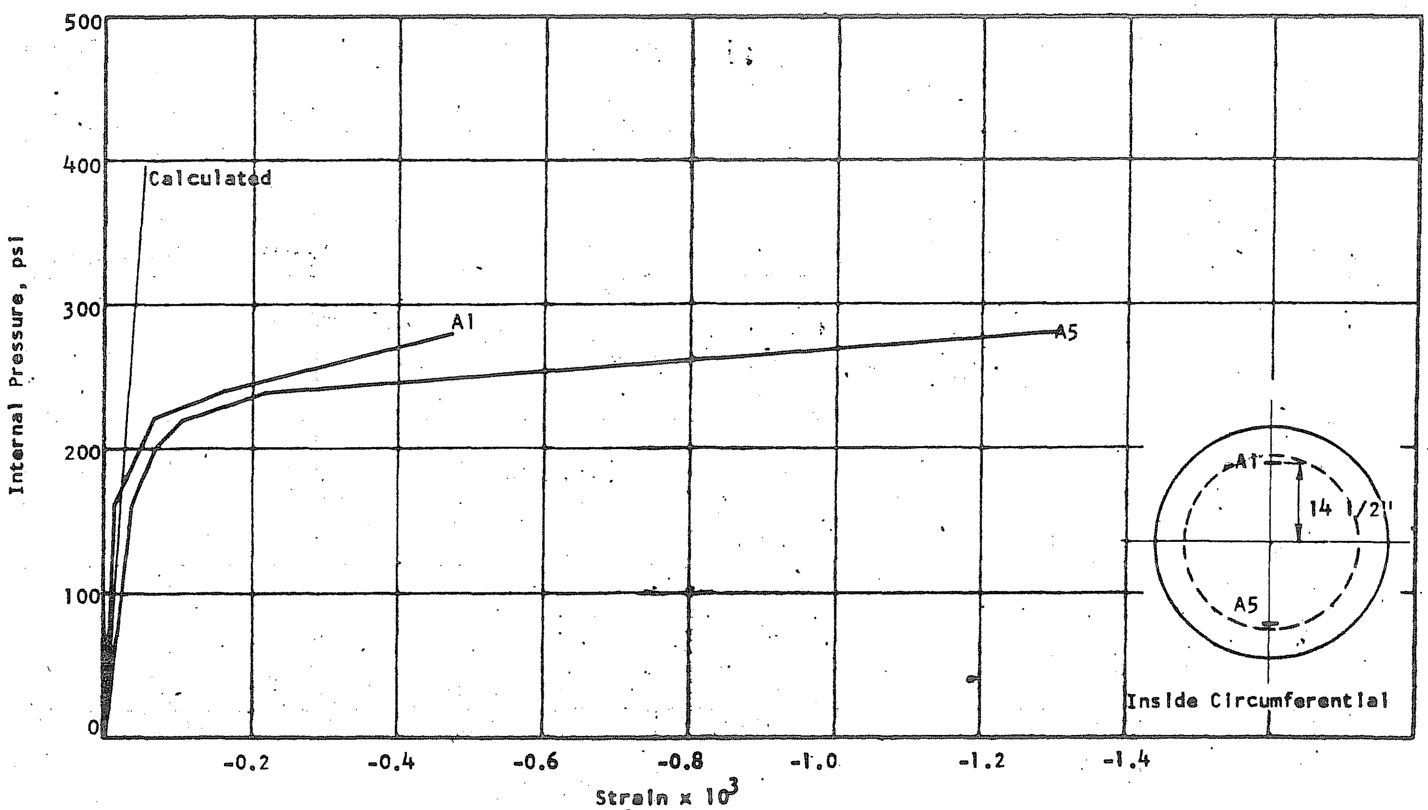


FIG. B1.12 CONCRETE STRAINS, VESSEL PV1

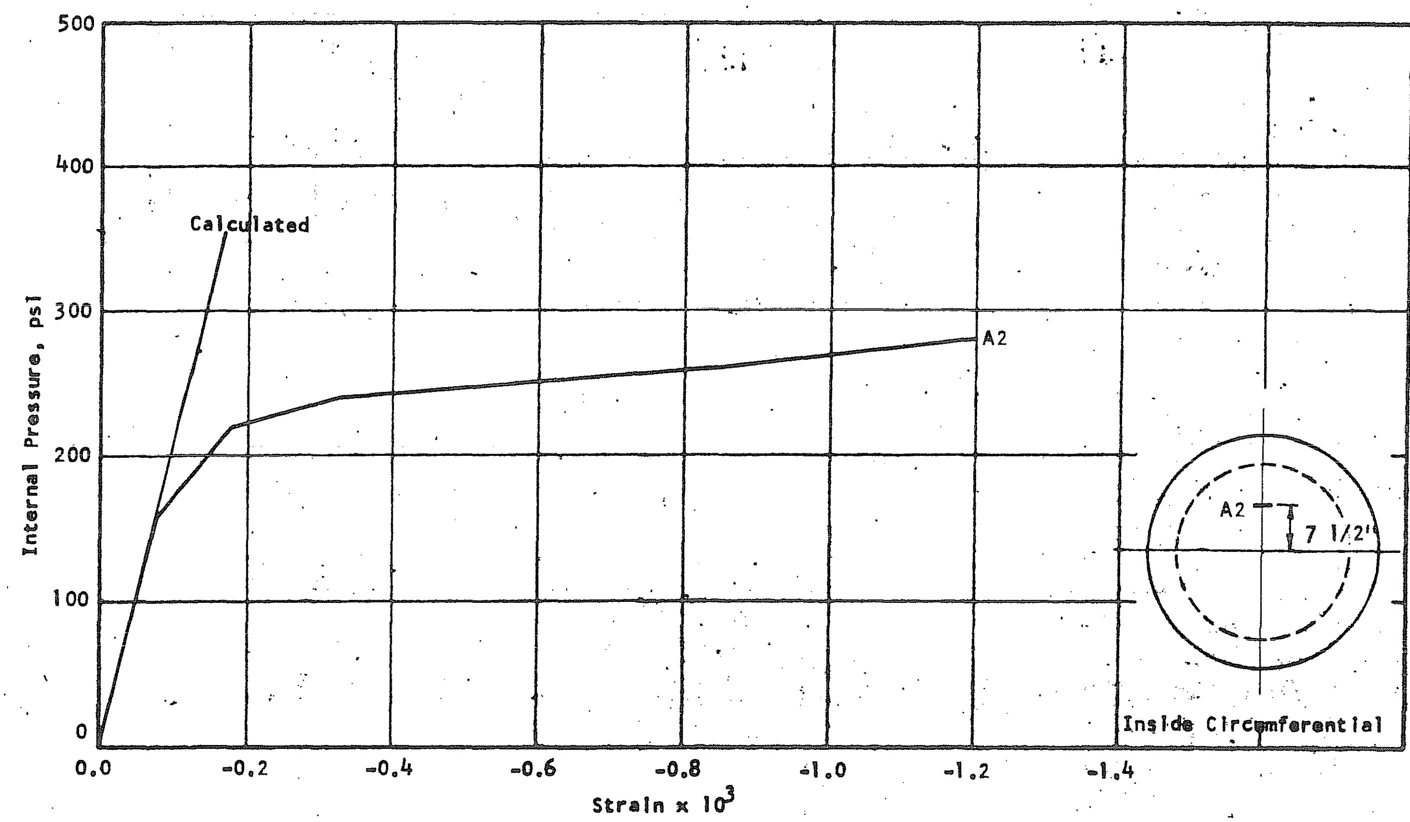


FIG. B1.13 CONCRETE STRAINS, VESSEL PV1

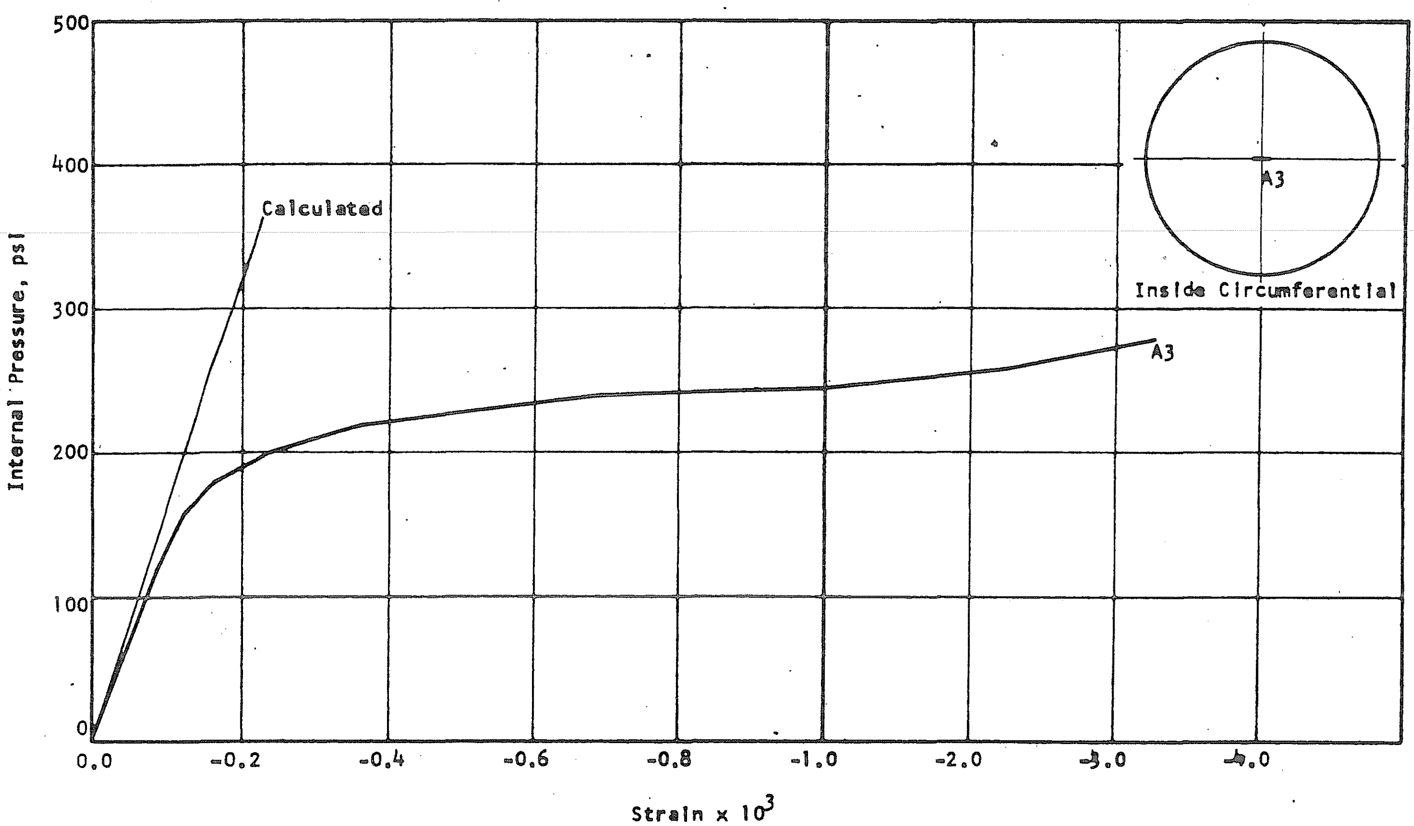


FIG. B1.14 CONCRETE STRAINS, VESSEL PV1

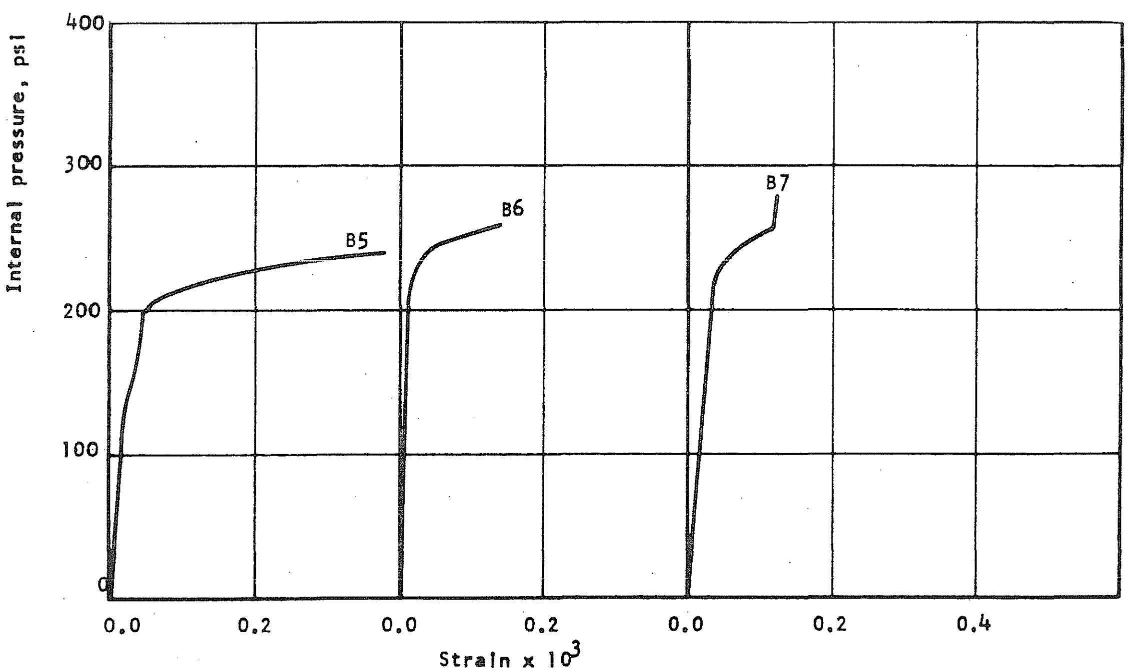


FIG. B1.15 APPLIED PRESSURE vs CIRCUMFERENTIAL STRAIN IN THE WALL OF THE VESSEL AT THE N-END OF THE N-S DIAMETER OF PV1

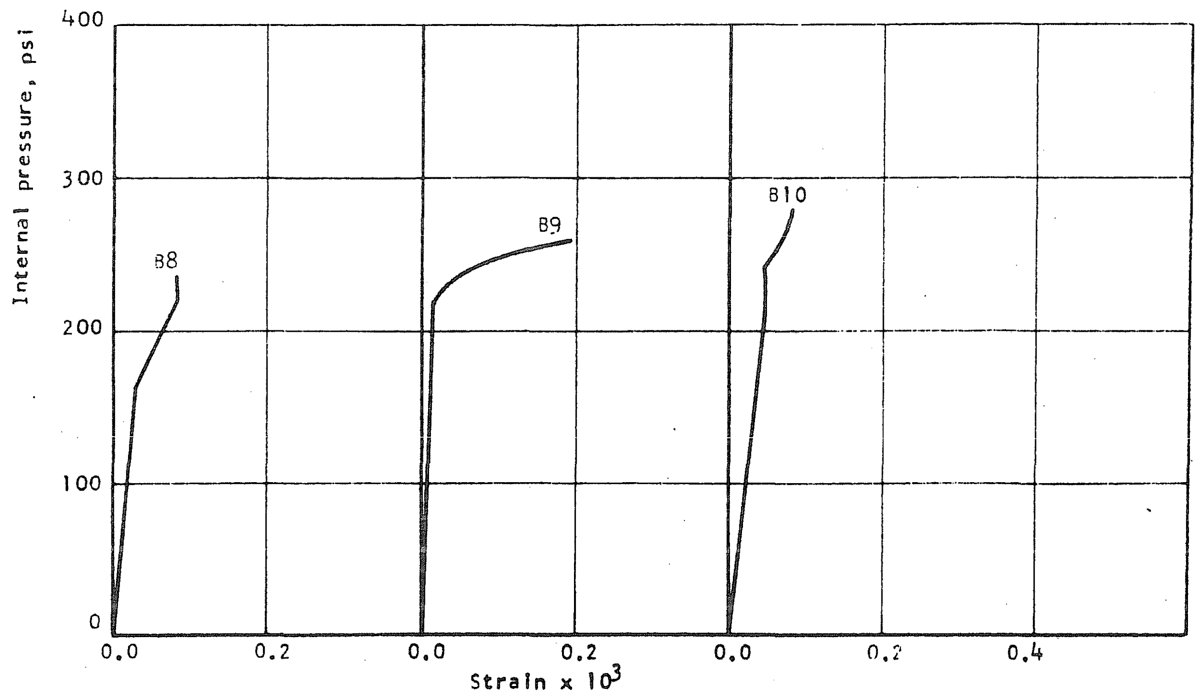


FIG. B1.16 APPLIED PRESSURE vs CIRCUMFERENTIAL STRAIN IN THE WALL OF VESSEL AT THE S-END OF THE N-S DIAMETER OF PV1

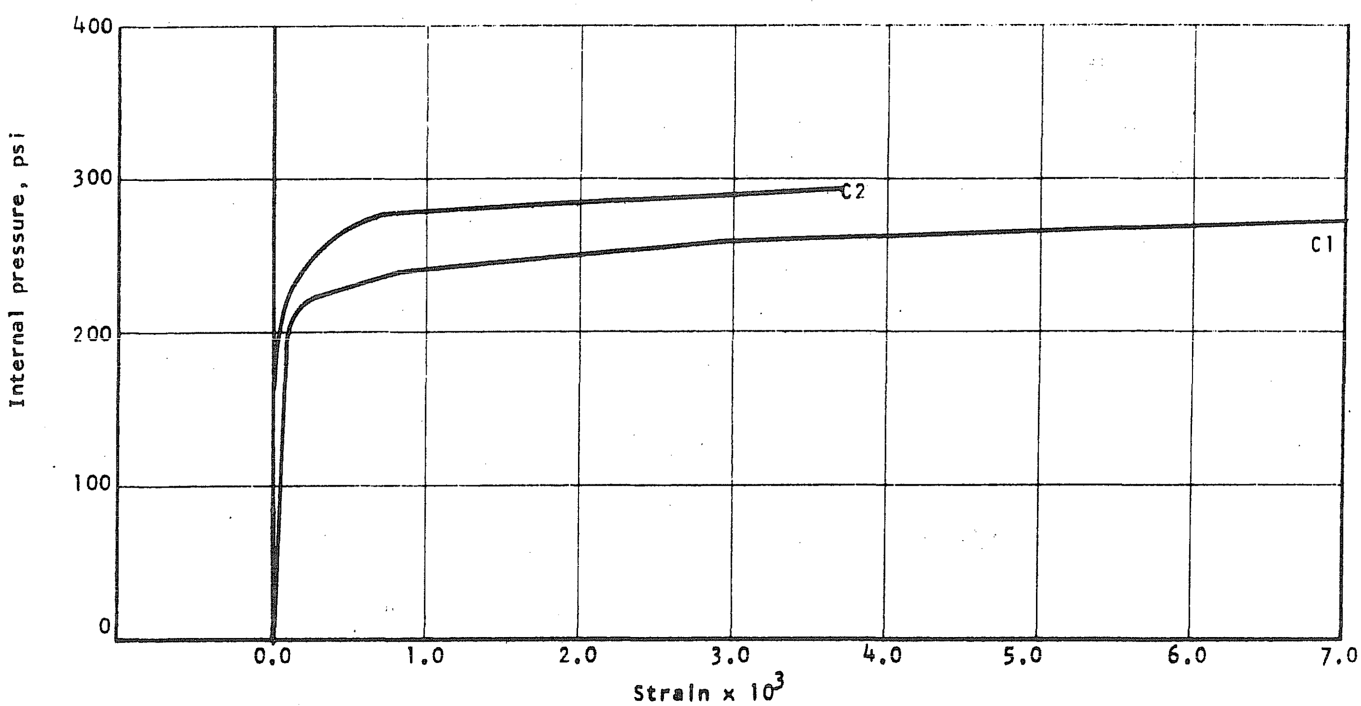


FIG. B1.17 APPLIED PRESSURE vs STRAIN IN THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE N-END OF THE N-S DIAMETER OF PV1

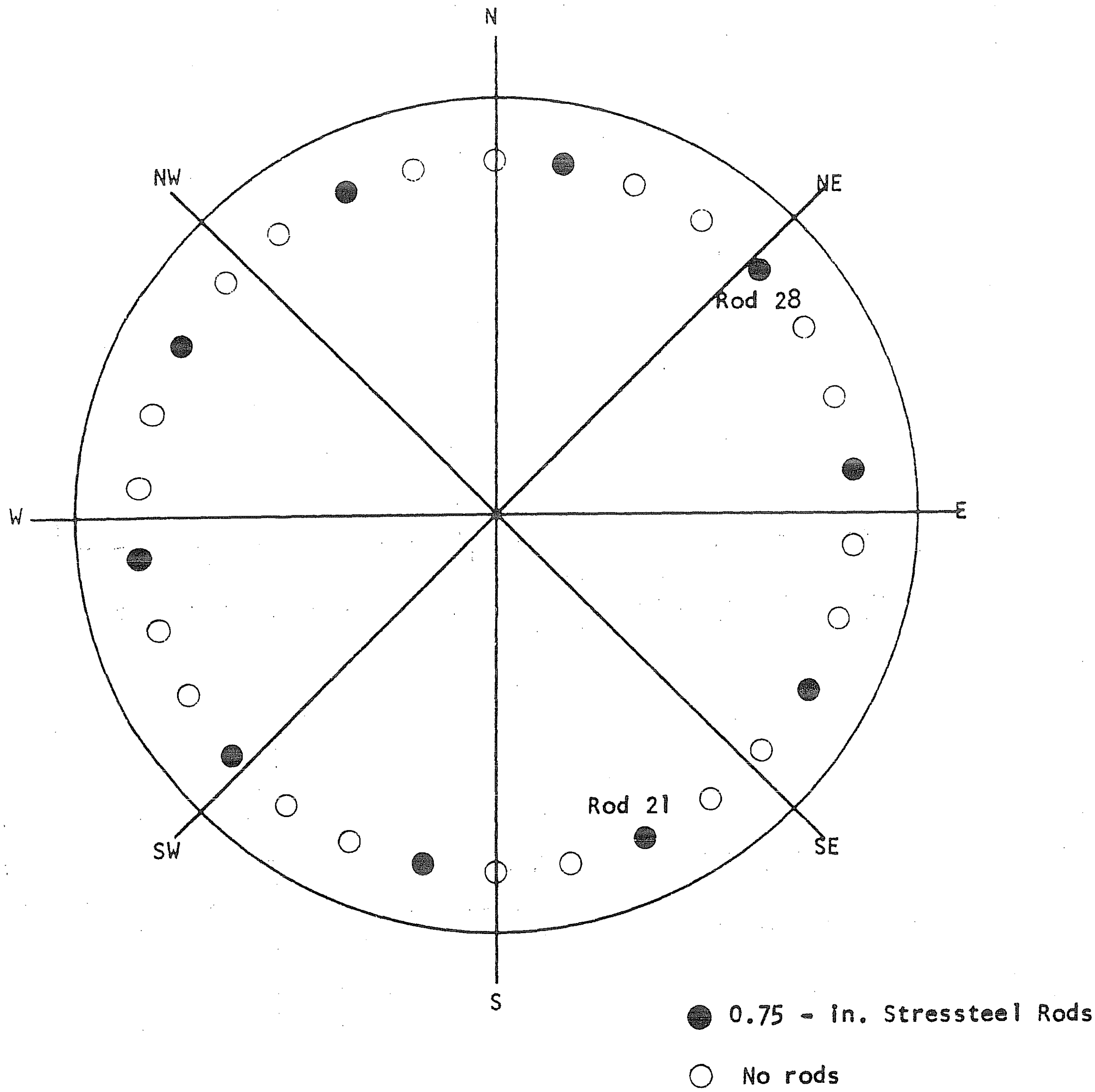


FIG. B1.18 LOCATION OF LONGITUDINAL REINFORCEMENT

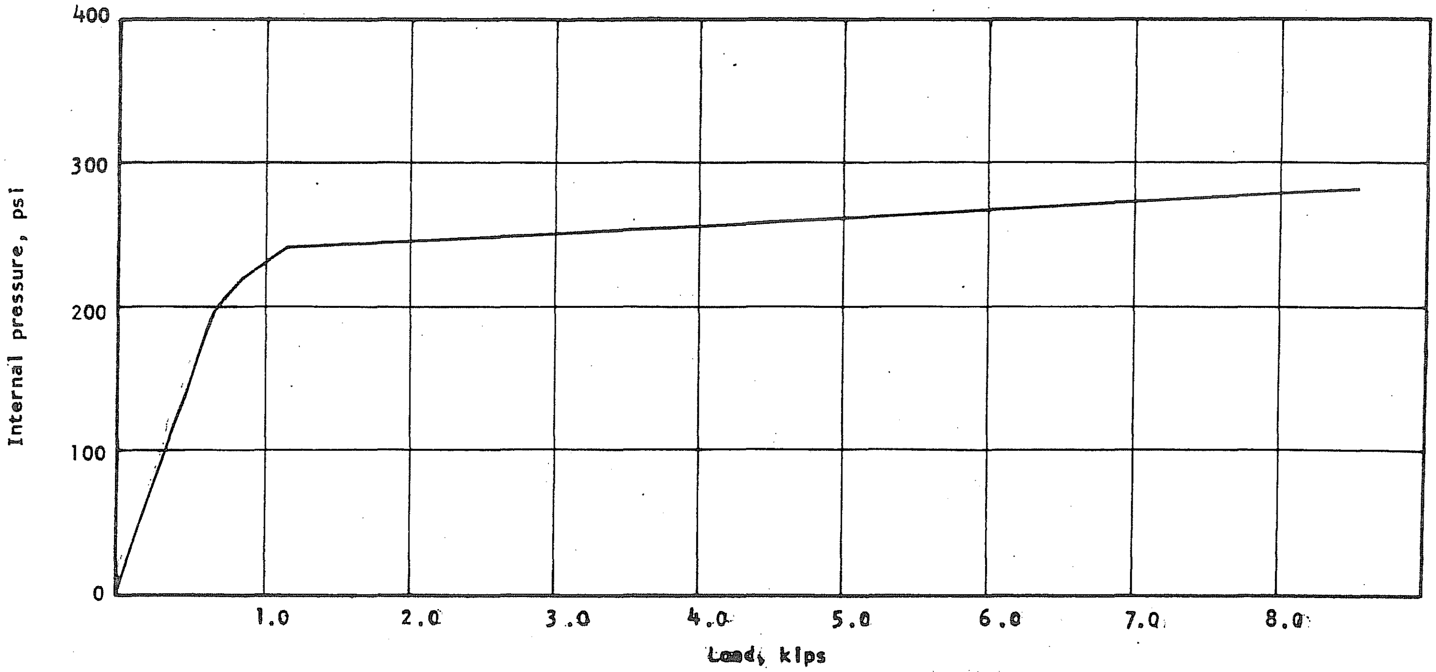


FIG. B1.19 APPLIED PRESSURE vs THE INCREASE IN LOAD IN STRESSTEEL ROD 28 IN PV1

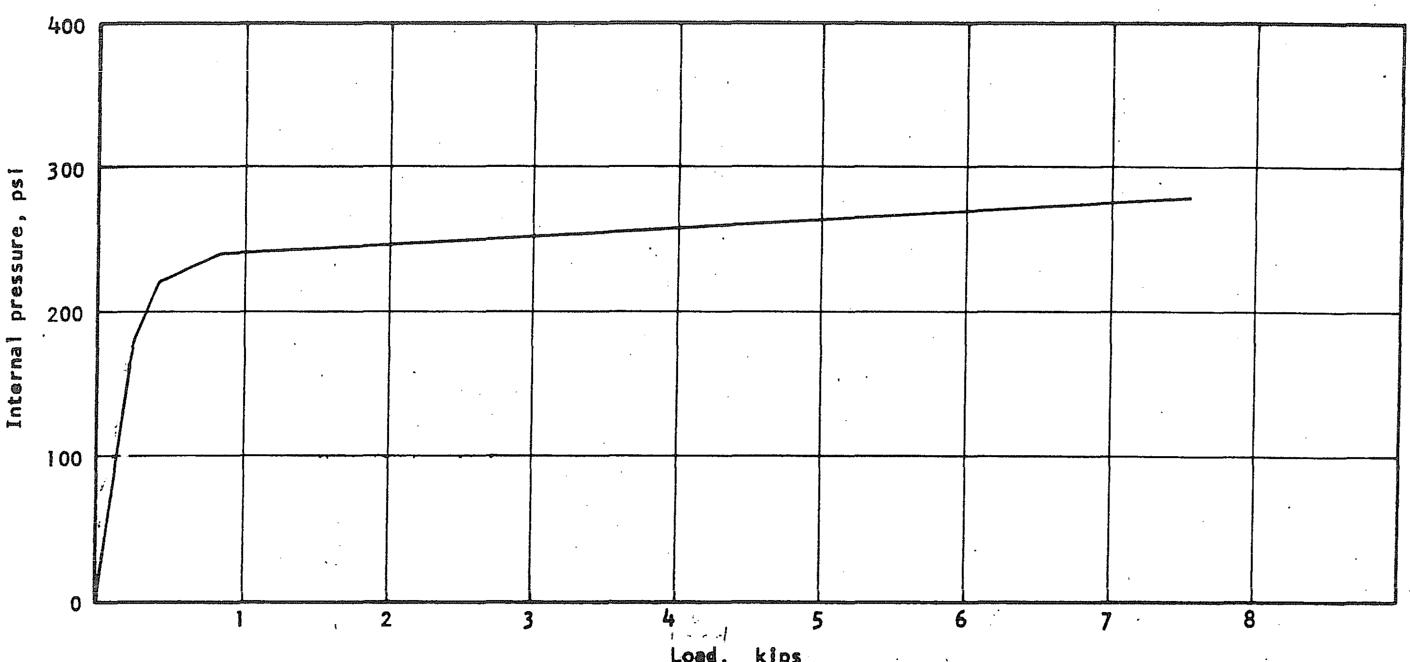


FIG. B1.20 APPLIED PRESSURE vs THE INCREASE IN LOAD IN STRESSTEEL ROD 21 IN PV1

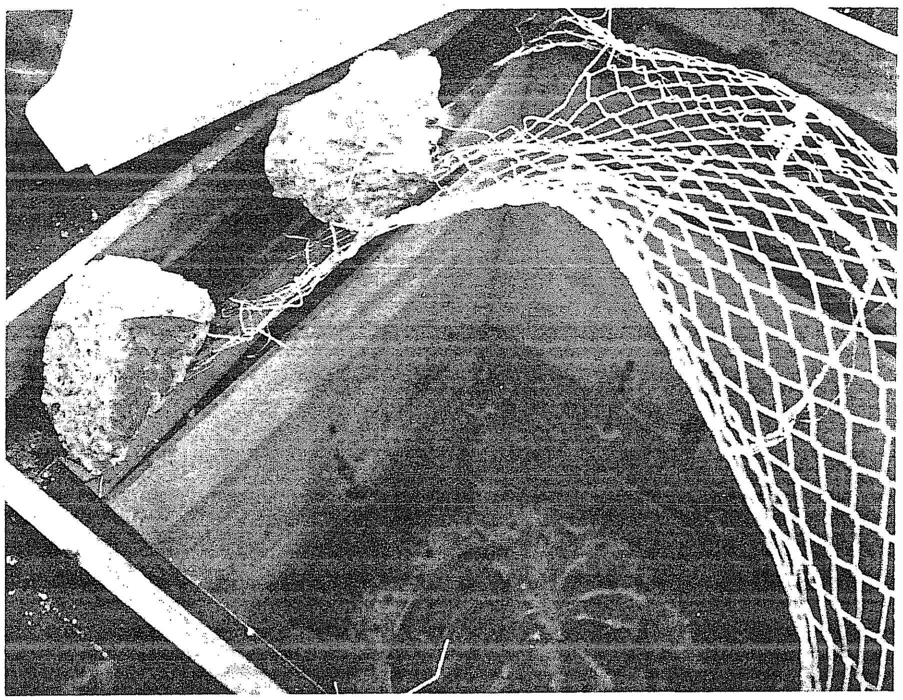


FIG. B1.21a DAMAGE TO NETTING AND PLYWOOD LINER

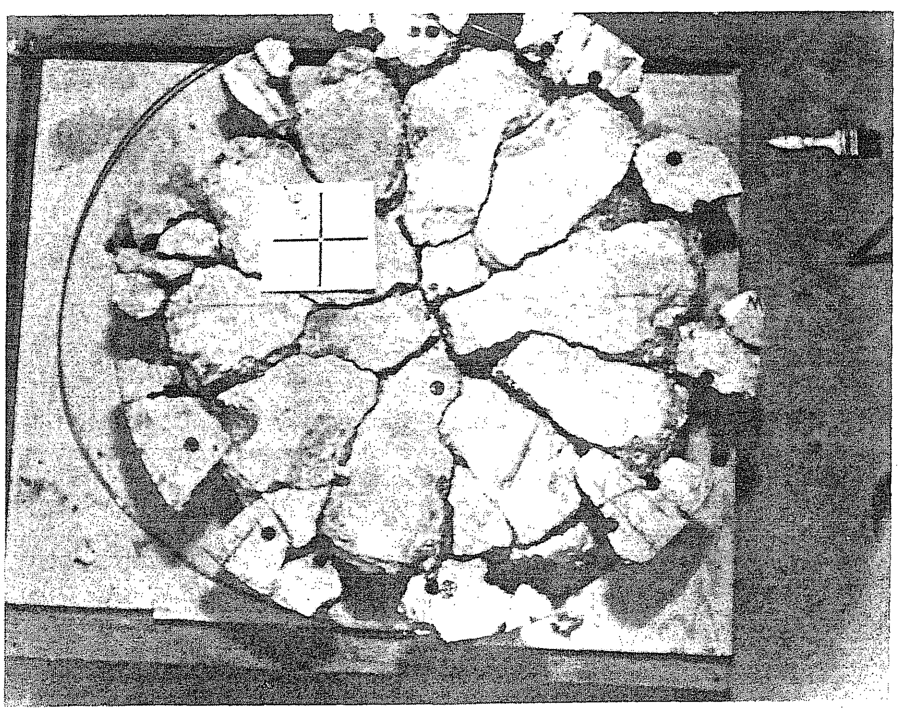


FIG. B1.21b REASSEMBLED PIECES OF THE END SLAB OF PV1

B2 Test Vessel PV2 (t = 6 in., s = 1.0 in.)

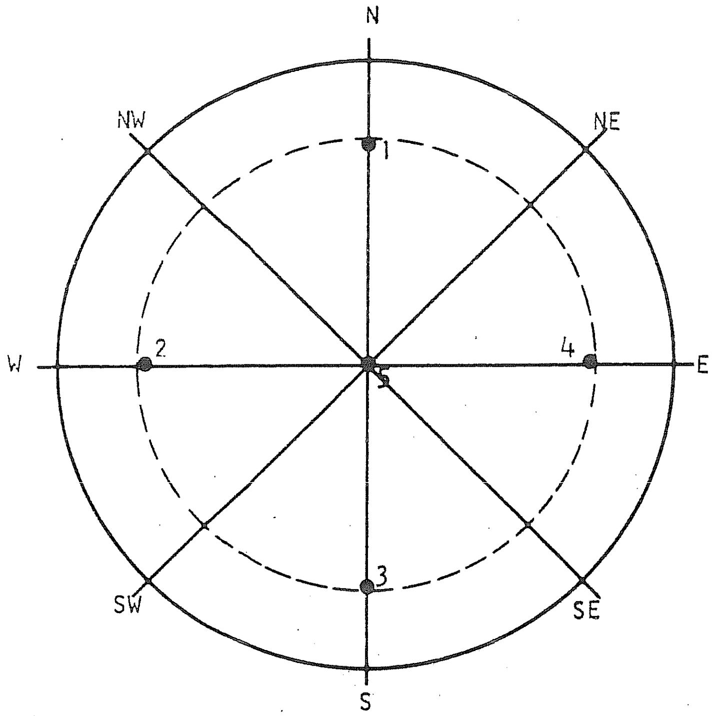
Test vessel PV2 was cast from ready-mix concrete. As in PV1 a circumferential crack at the junction of the slab and skirt was observed inside the specimen when the form was struck.

After the testing of PV1, the test chamber was lined with 0.5-in. thick steel plate rather than plywood. A television camera was installed so that the head of PV2 could be observed during the test. The first crack on the outside of the slab was visible at 170 psi. A second crack became visible at about 220 psi.

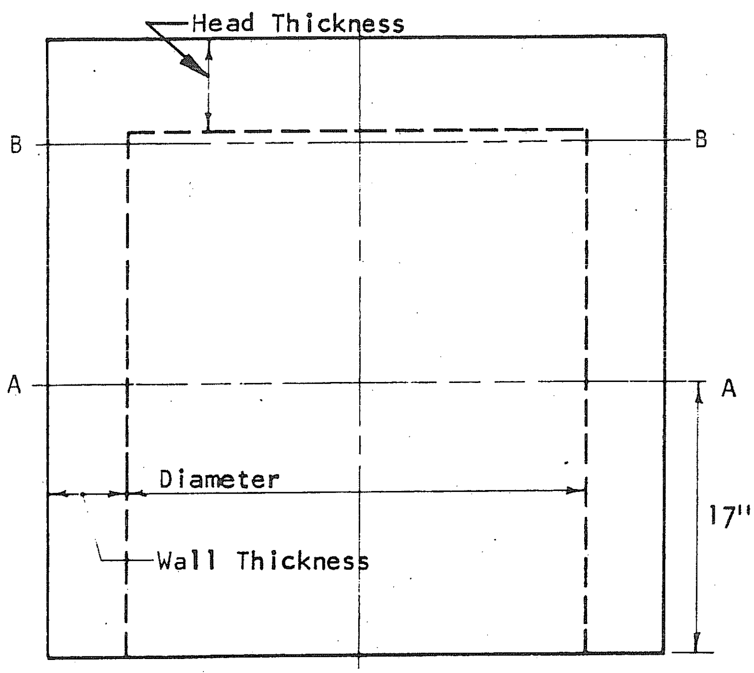
This test also required about 3 hours for completion. The first load increment was 20 psi followed by increments of 10 psi up to the maximum pressure reached which was 240 psi. The vessel had a small leak throughout the test and loading could not be continued to failure. The maximum deflection at the center of the head was 0.8-in. when the test had to be stopped.

Vessel PV2 was longitudinally reinforced with twenty-four 0.5-in. diameter seven-wire strands. None of the strands were equipped with load cells. The vessel was sealed the same way as PV1 except for an extra layer of neoprene on the inside of the end slab which was cut to fit between the gage wires on the end slab in order to make the inside neoprene layer more smooth.

The crack pattern in the end slab is illustrated in Fig. B2.19.



Head Thickness	
Point No.	Inches
1	$6 \frac{0}{32}$
2	$5 \frac{31}{32}$
3	$5 \frac{30}{32}$
4	$6 \frac{1}{32}$
5	$6 \frac{0}{32}$



Wall Thickness, in.		
Plane / Axis	AA	BB
N	4.99	5.17
NE	5.13	5.17
E	4.90	4.87
SE	5.00	5.00
S	4.89	5.01
SW	4.93	5.01
W	4.88	4.86
NW	4.99	5.02

Inside Diameter, in.		
Plane / Axis	AA	BB
N-S	$30\frac{3}{32}$	$29\frac{29}{32}$
NE-SW	$30\frac{1}{32}$	$29\frac{31}{32}$
E-W	$29\frac{31}{32}$	$30\frac{0}{32}$
SE-NW	$30\frac{0}{32}$	$29\frac{30}{32}$

FIG. B2.1 DIMENSIONS OF PV2

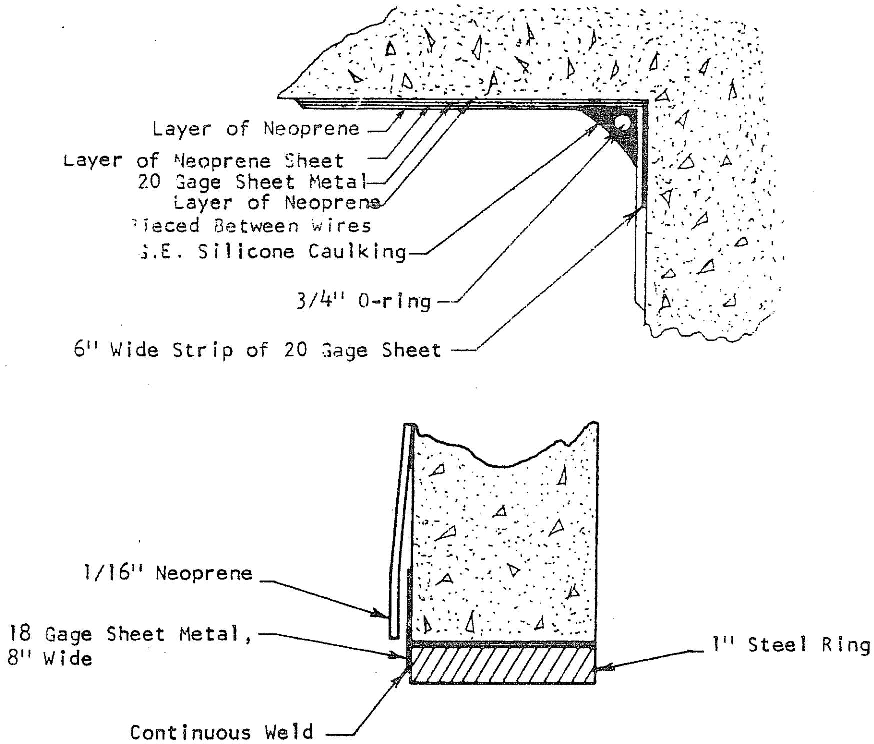
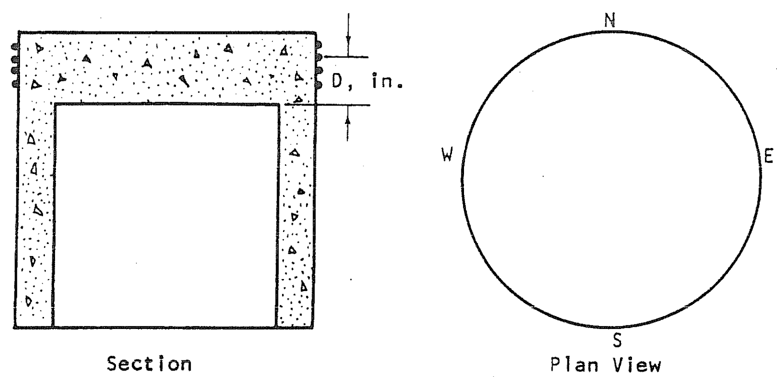


FIG. B2.2 SEALING DETAIL FOR PV2



Wrap No.	N	W	S	E
1	5 3/8	5 1/4	5	5
2	4 7/8	4 1/2	4 3/4	3 15/16
3	3 5/8	3 3/8	3 1/8	2 7/8
4	2 1/2	2 5/16	2 1/16	1 13/16
5	1 1/2	1 1/4	1	3/4
6	1/2	1/4	0	-1/8

FIG. B2.3 MEASURED LOCATION OF THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE ENDS OF THE N-S AND E-W DIAMETERS ON PV2

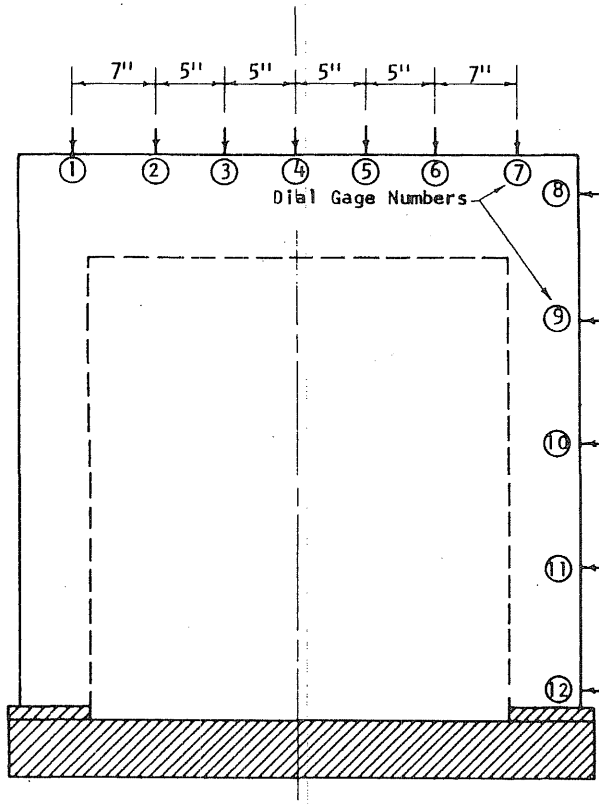


FIG. B2.4 LOCATION OF DEFLECTION GAGES ON PV2

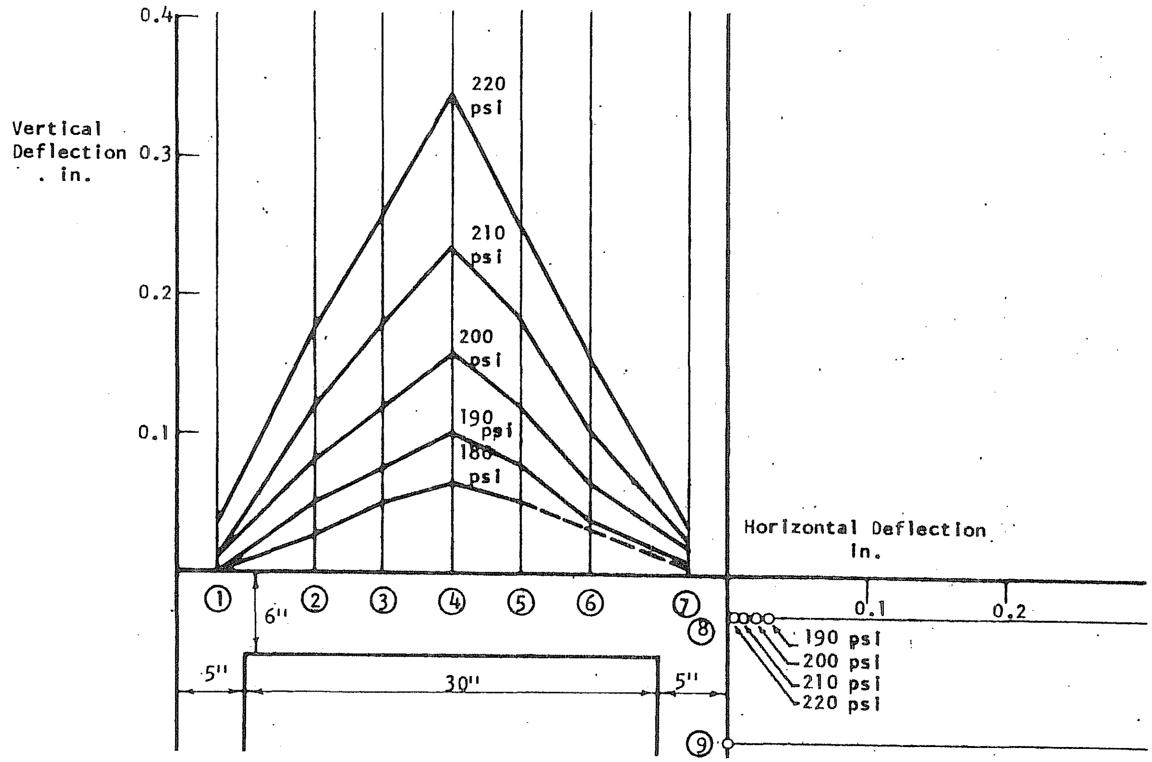


FIG. B2.5 DEFLECTION PROFILES OF THE END SLAB ALONG THE N-S DIAMETER OF PV2

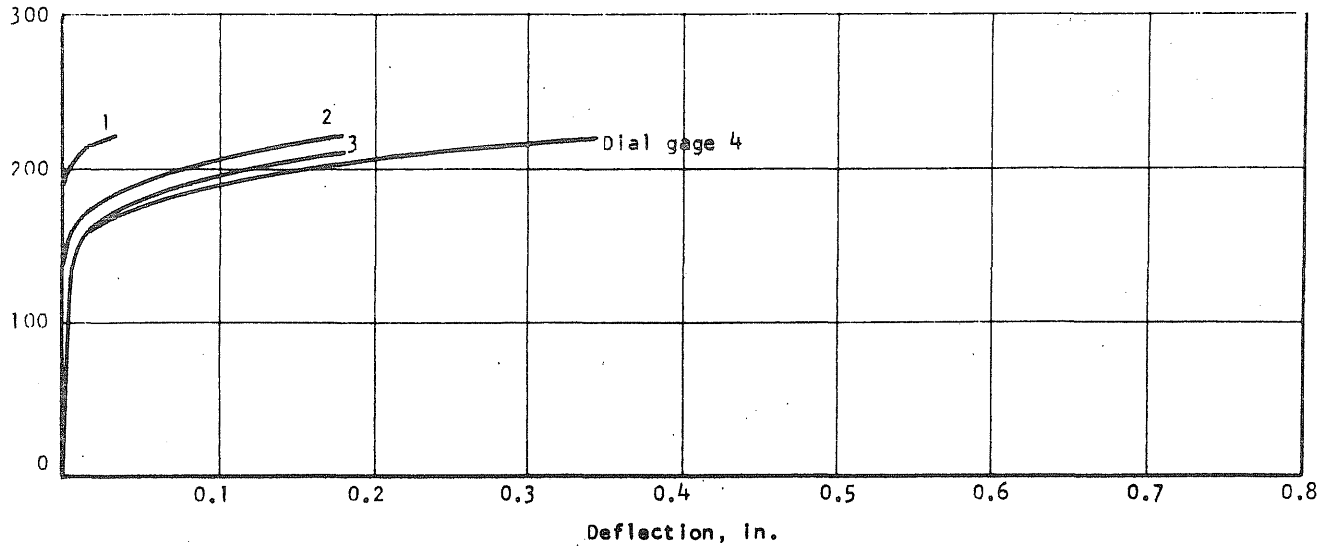


FIG. B2.6 APPLIED PRESSURE vs DEFLECTION ALONG THE N-HALF OF THE N-S DIAMETER OF PV2

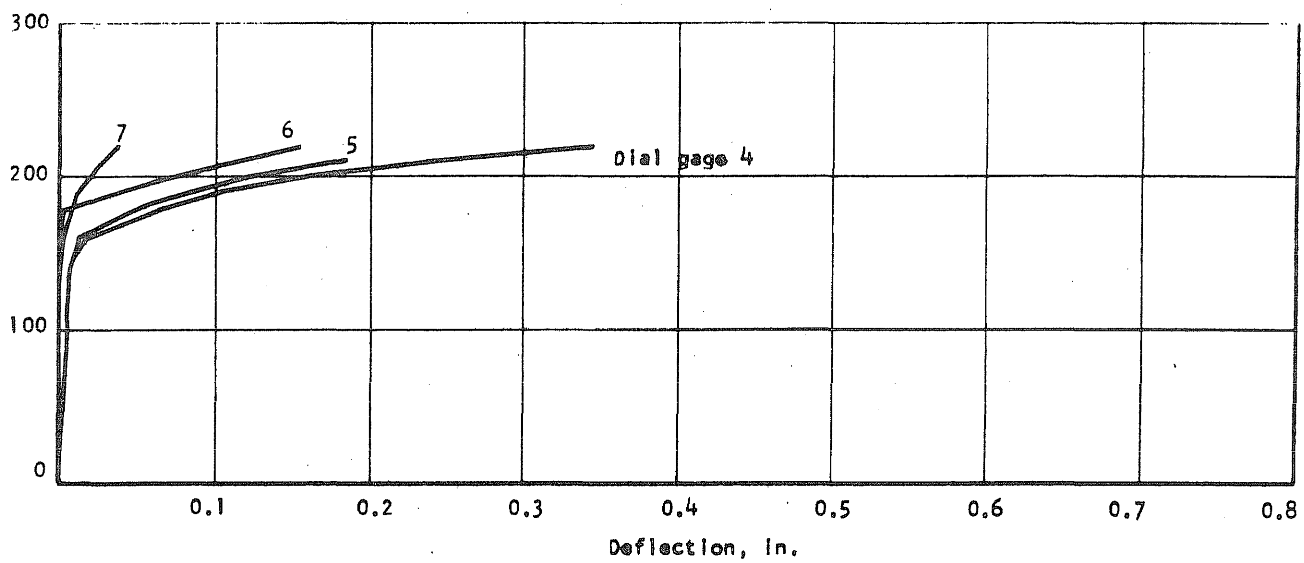


FIG. B2.7 APPLIED PRESSURE vs DEFLECTION ALONG THE S-HALF OF THE N-S DIAMETER OF PV2

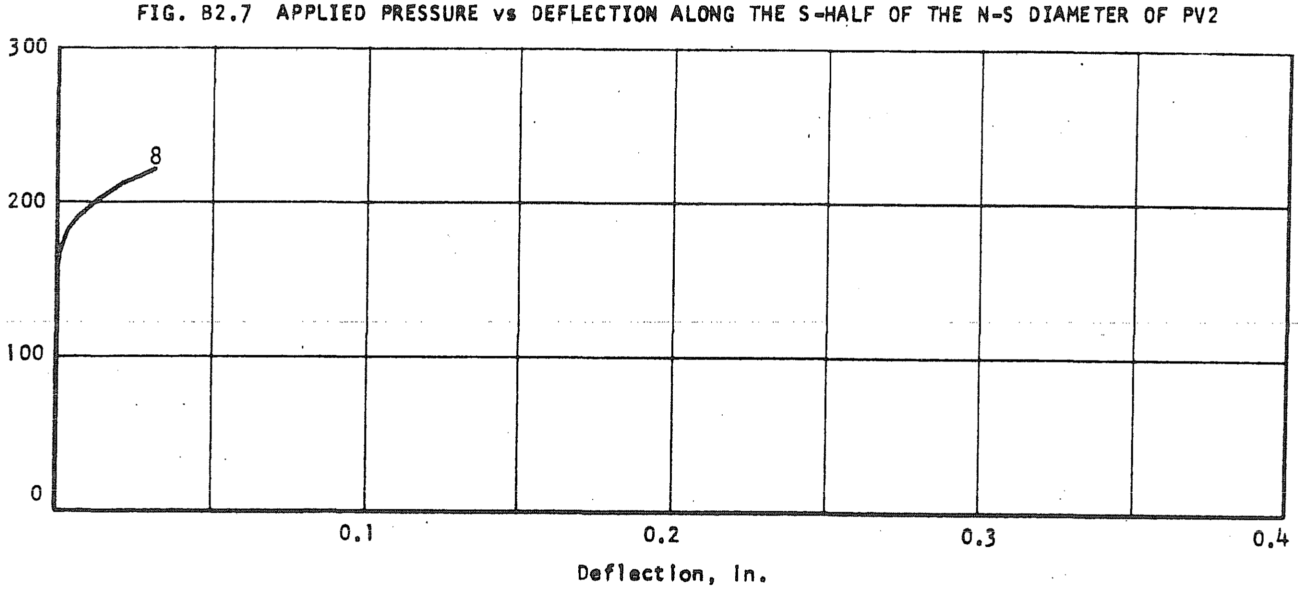
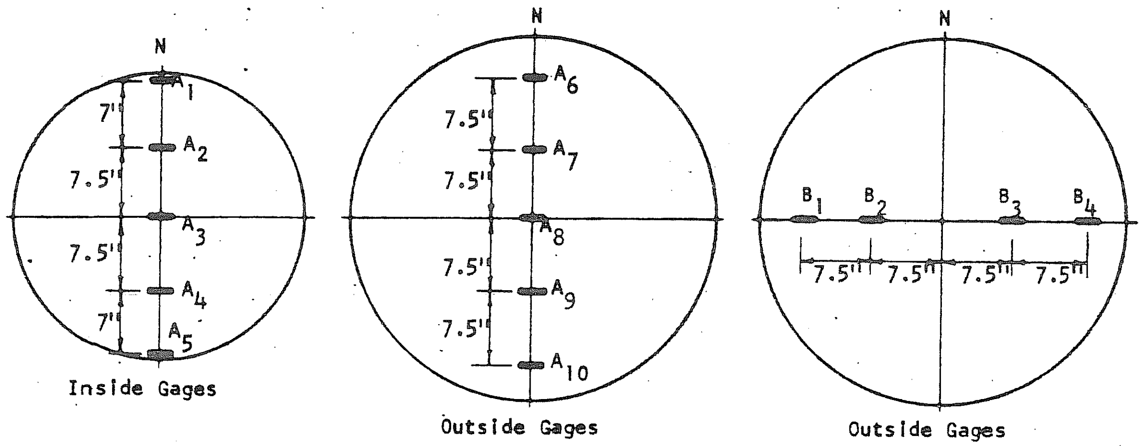
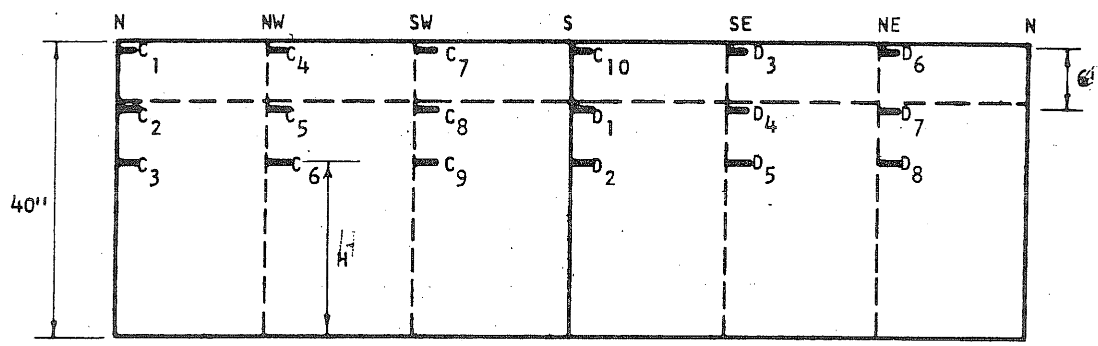


FIG. B2.8 APPLIED PRESSURE vs DEFLECTION OF THE SIDE WALL OF PV2

Concrete Gages On The End Slab

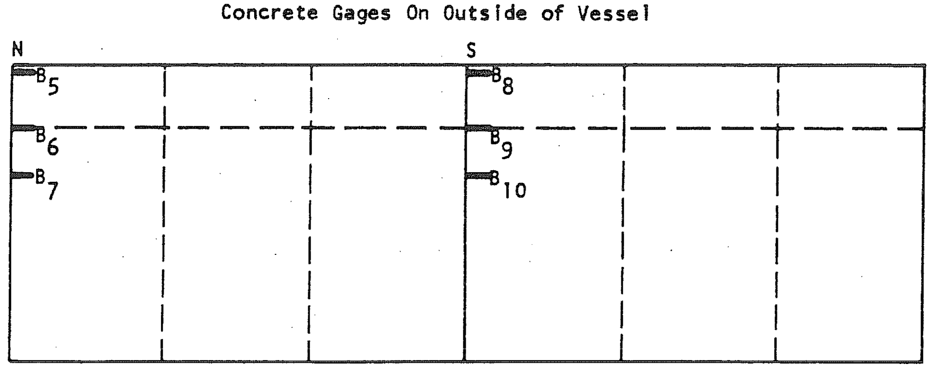


Steel Gages On Prestress Wire



Gage	Line	H	Gage	Line	H	Gage	Line	H
C_1	N	37 10/16	C_7	SW	38 6/16	D_3	SE	38 0/16
C_2	N	32 10/16	C_8	SW	33 5/16	D_4	SE	33 0/16
C_3	N	27 10/16	C_9	SW	28 5/16	D_5	SE	28 0/16
C_4	NW	38 10/16	C_{10}	S	38 4/16	D_6	NE	37 13/16
C_5	NW	33 7/16	D_1	S	33 2/16	D_7	NE	32 12/16
C_6	NW	28 7/16	D_2	S	28 2/16	D_8	NE	27 12/16

Concrete Gages On Outside of Vessel



Gage	Axis	H	Gage	Axis	H
B_5	N	37 0/16	B_8	S	37 12/16
B_6	N	32 2/16	B_9	S	32 12/16
B_7	N	27 0/16	B_{10}	S	27 13/16

FIG. B2.9 STRAIN GAGE LOCATIONS ON PV2

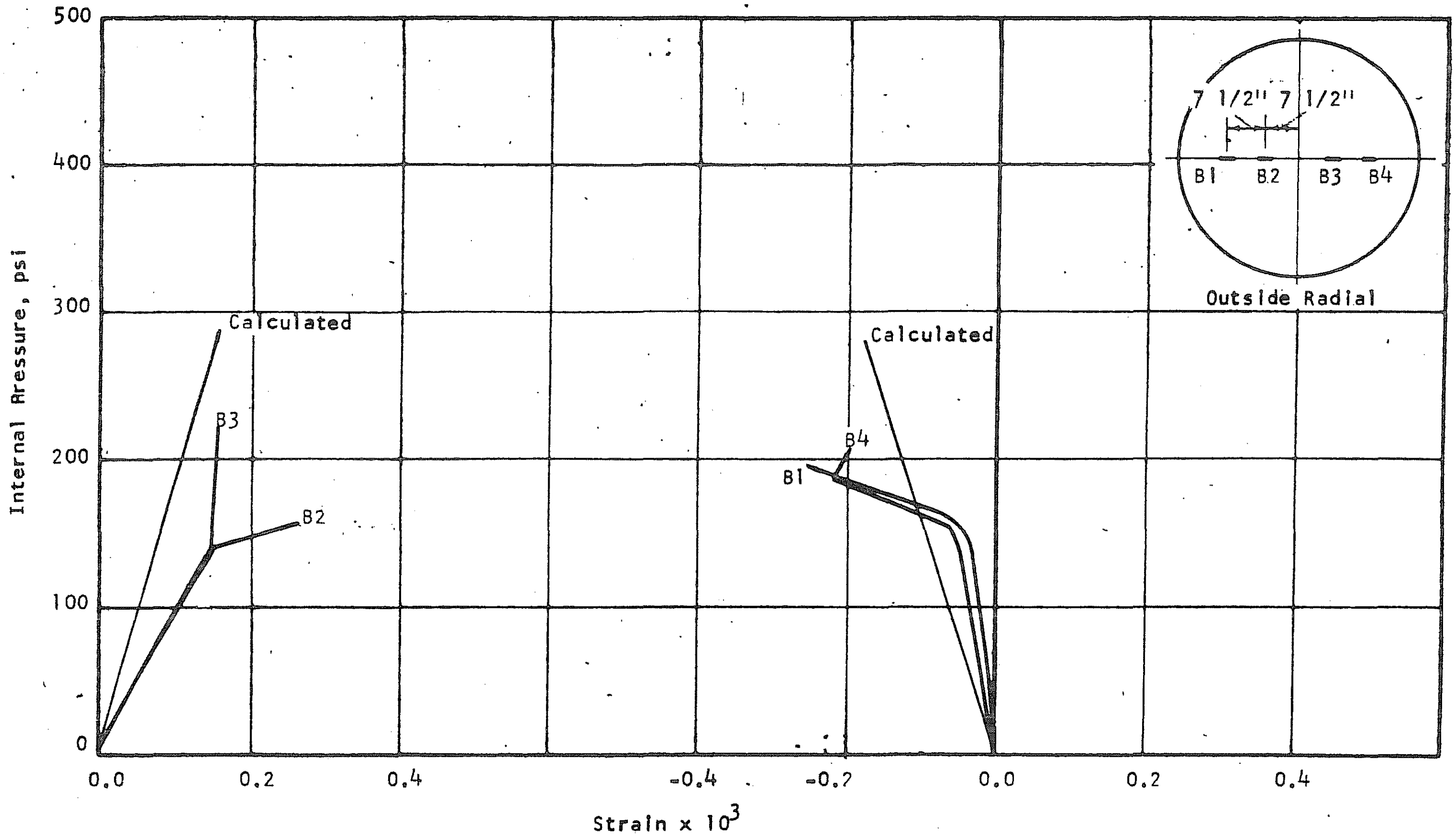


FIG. B2.10 CONCRETE STRAINS, VESSEL PV2

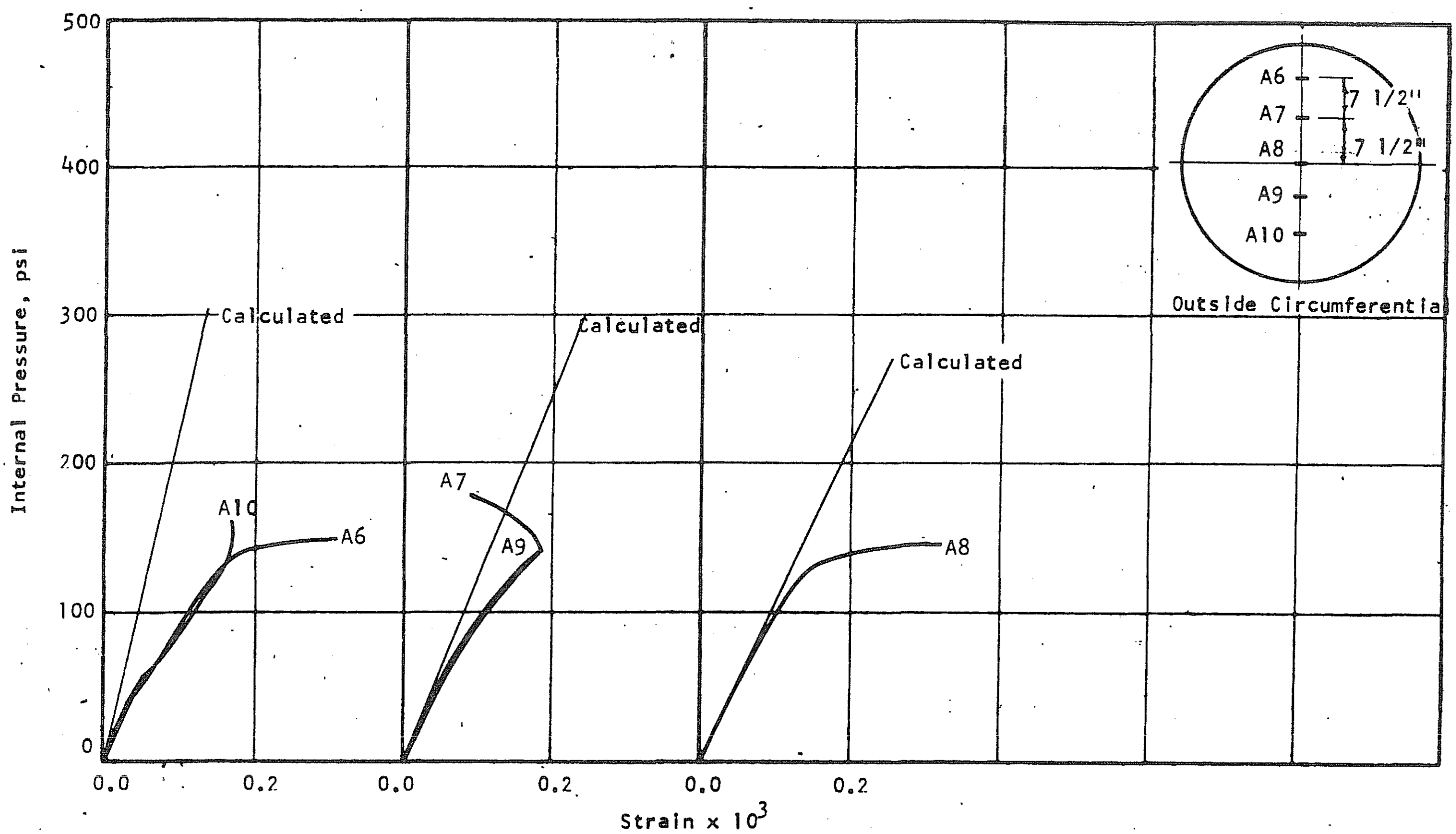


FIG. B2.11 CONCRETE STRAINS, VESSEL PV2

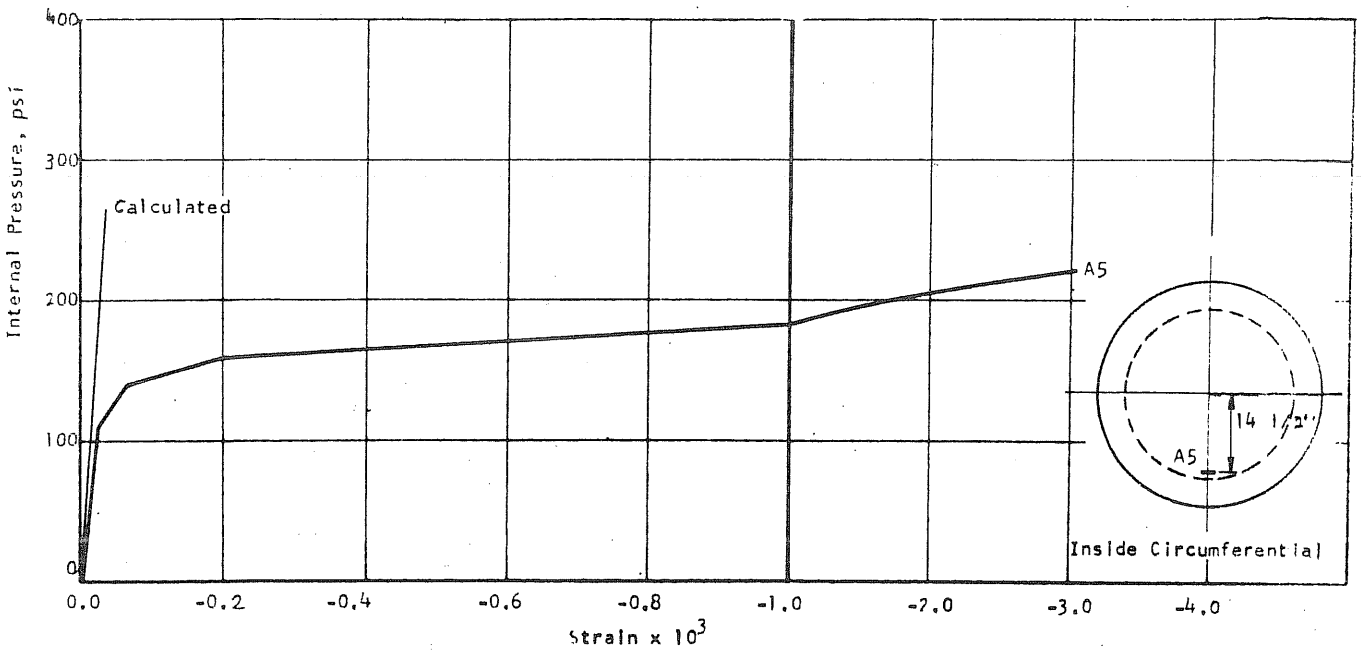


FIG. B2.12 CONCRETE STRAINS, VESSEL PV2

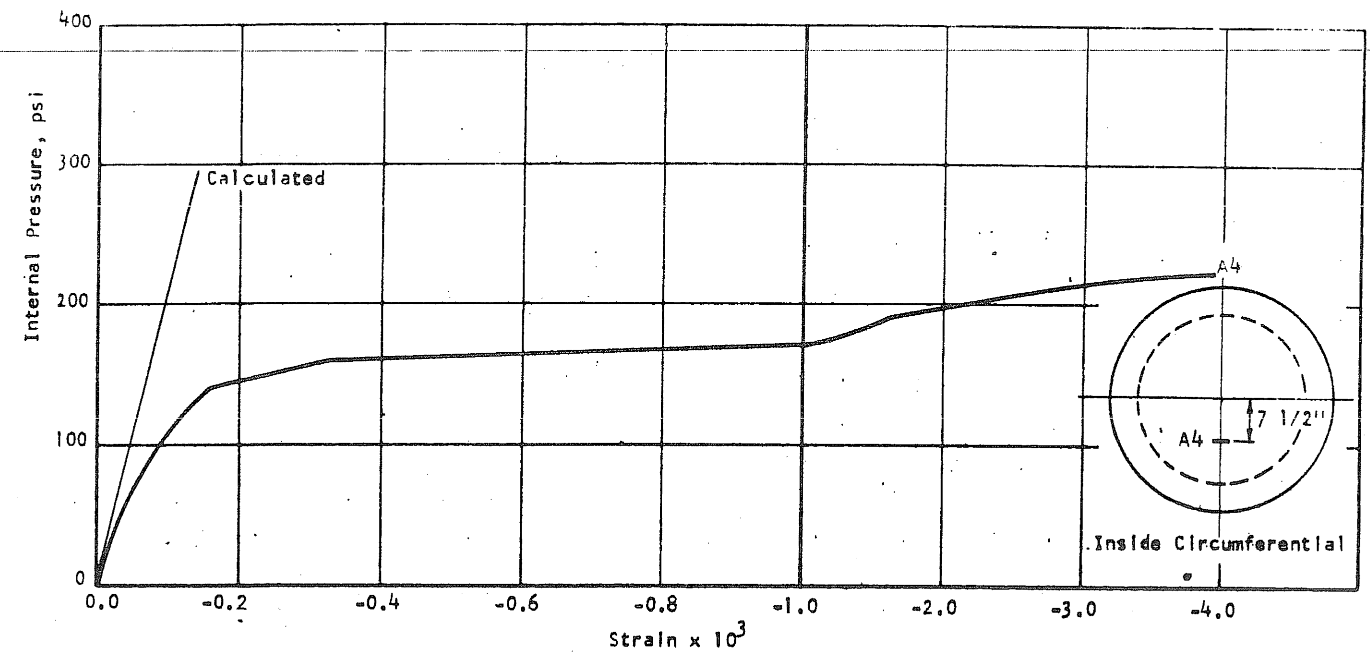


FIG. B2.13 CONCRETE STRAINS, VESSEL PV2

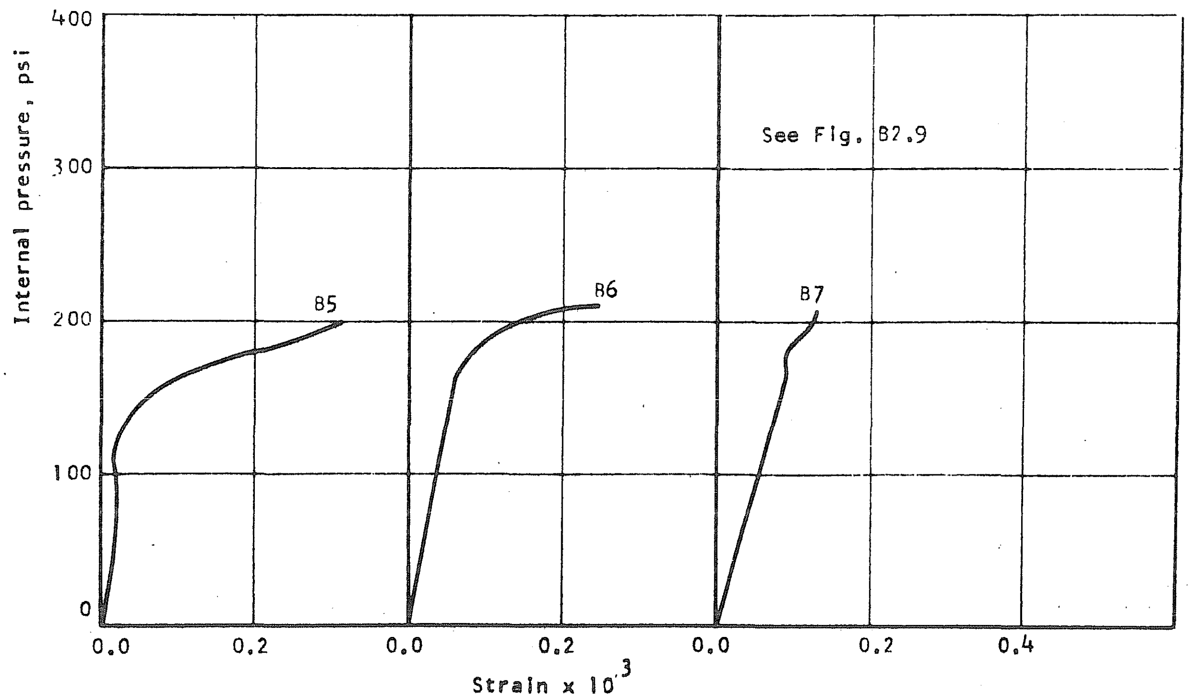


FIG. B2.14 APPLIED PRESSURE vs CIRCUMFERENTIAL STRAIN IN THE WALL OF THE VESSEL AT THE N-END OF THE N-S DIAMETER OF PV2

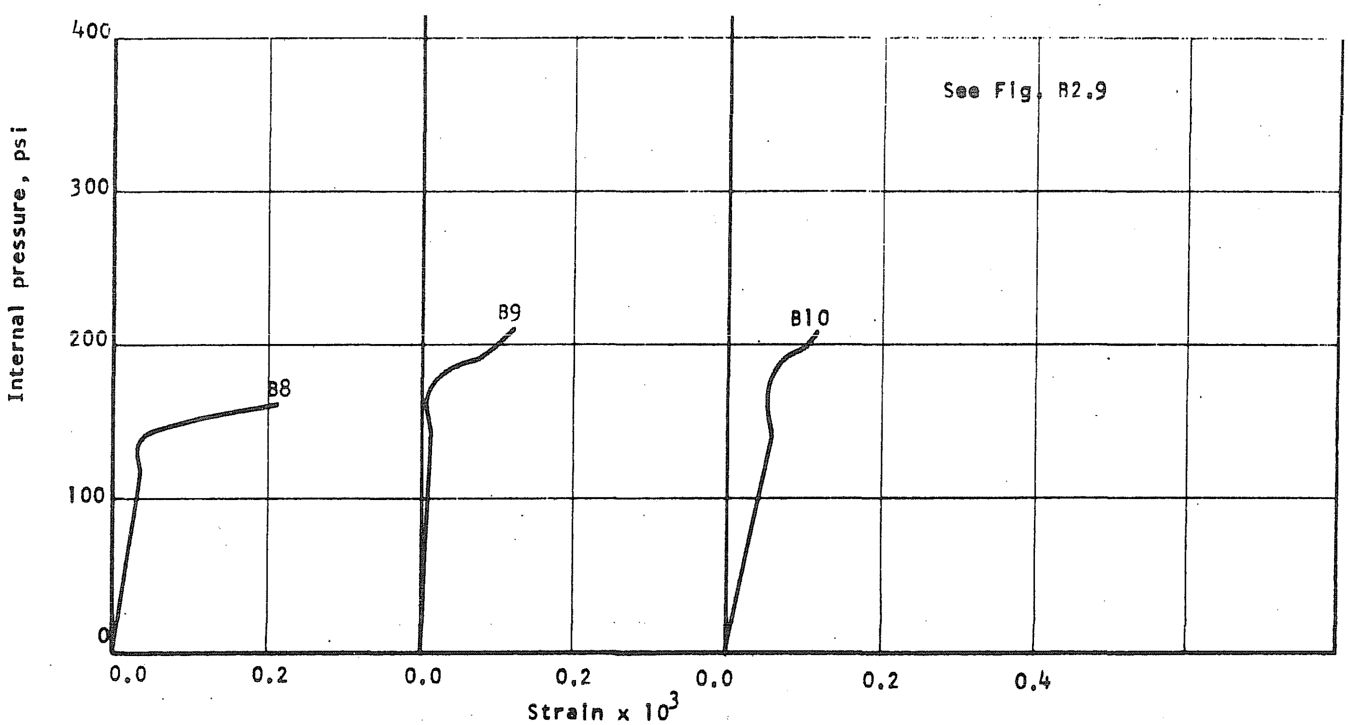


FIG. B2.15 APPLIED PRESSURE vs CIRCUMFERENTIAL STRAIN IN THE WALL OF THE VESSEL AT THE S-END OF THE N-S DIAMETER OF PV2

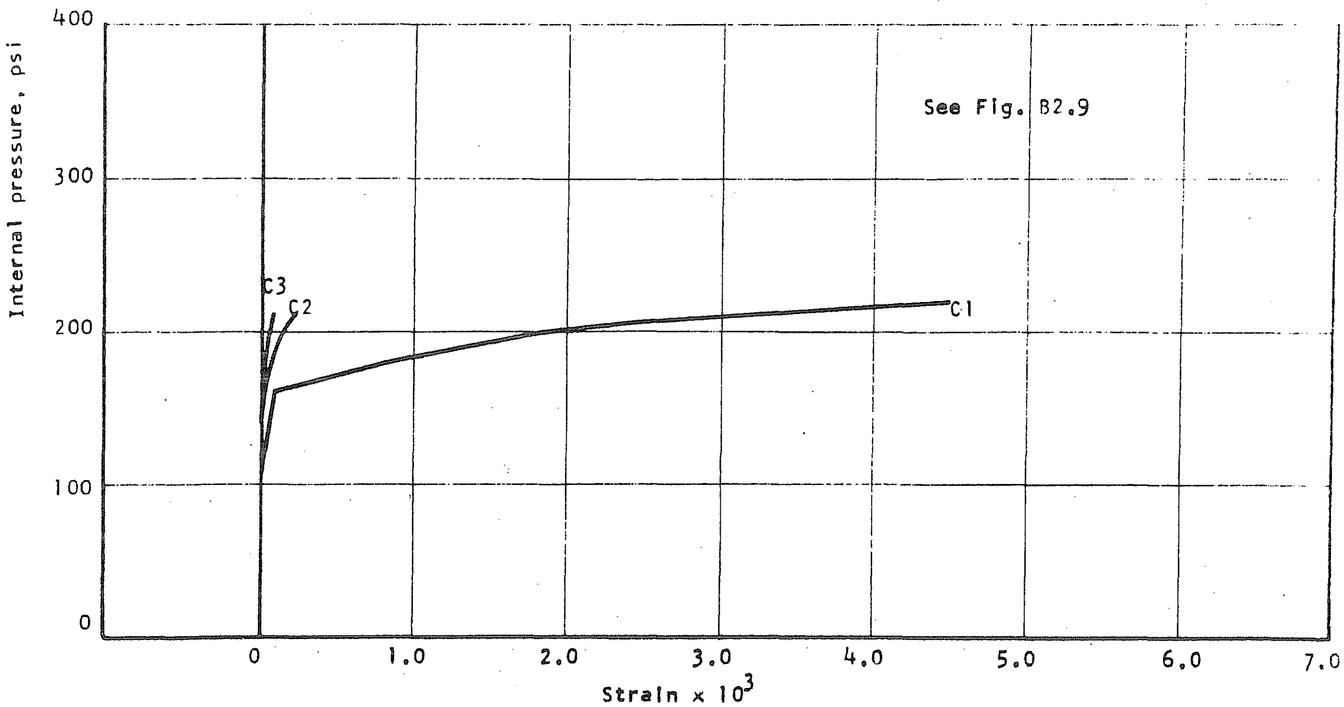


FIG. B2.16 APPLIED PRESSURE vs STRAIN IN THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE N-END OF THE N-S DIAMETER OF PV2

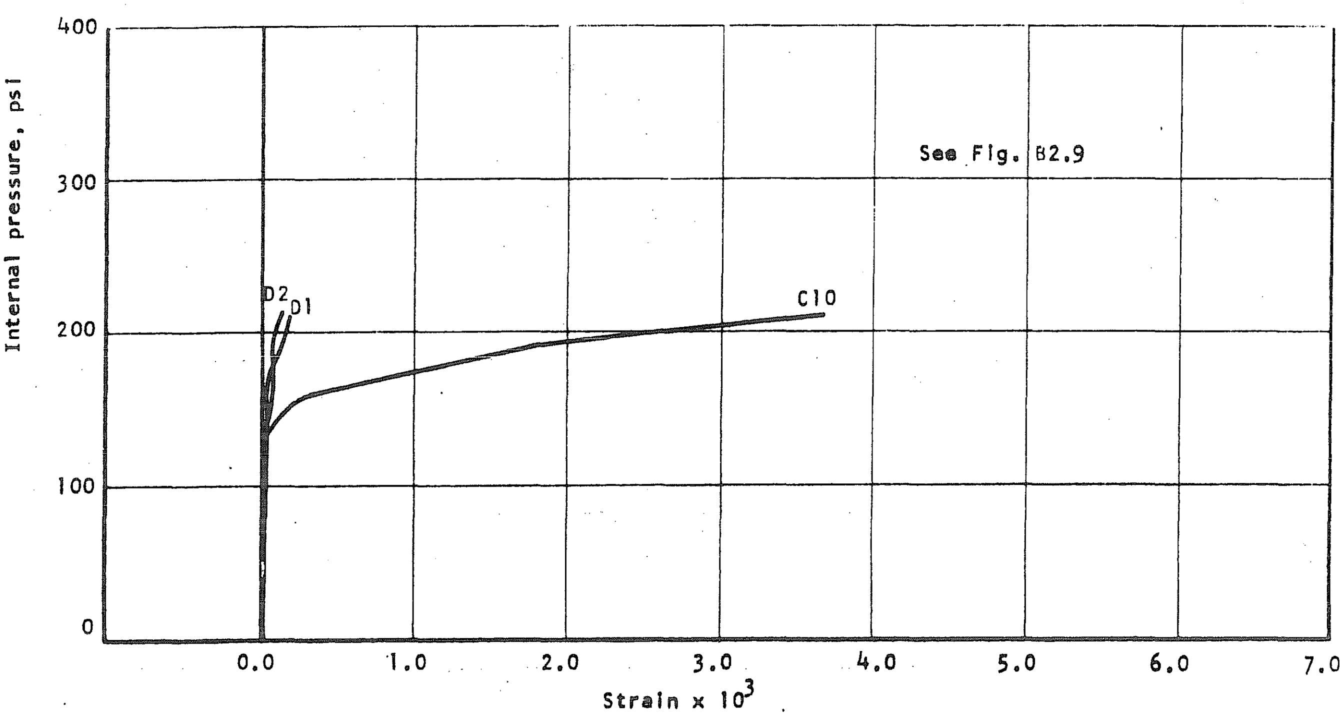


FIG. B2.17 APPLIED PRESSURE vs STRAIN IN THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE S-END OF THE N-S DIAMETER OF PV2

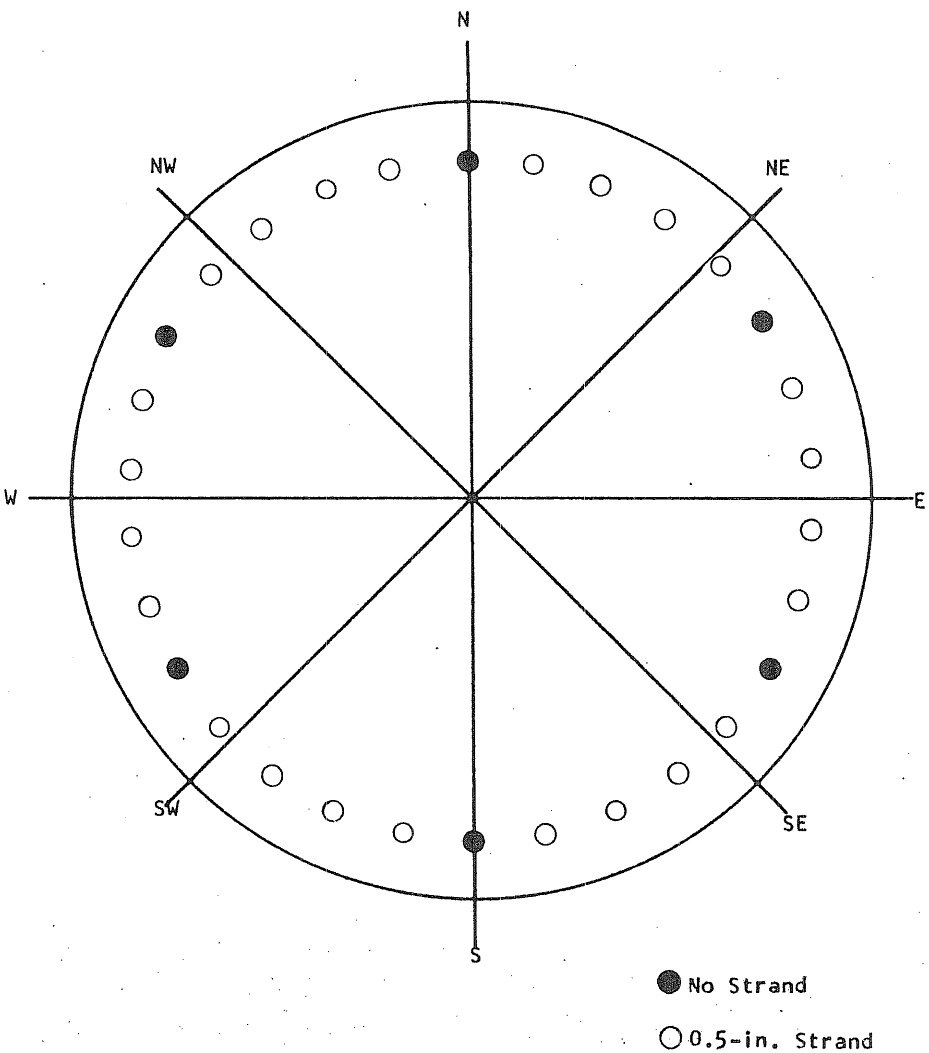


FIG. B2.18 LOCATION OF LONGITUDINAL REINFORCEMENT

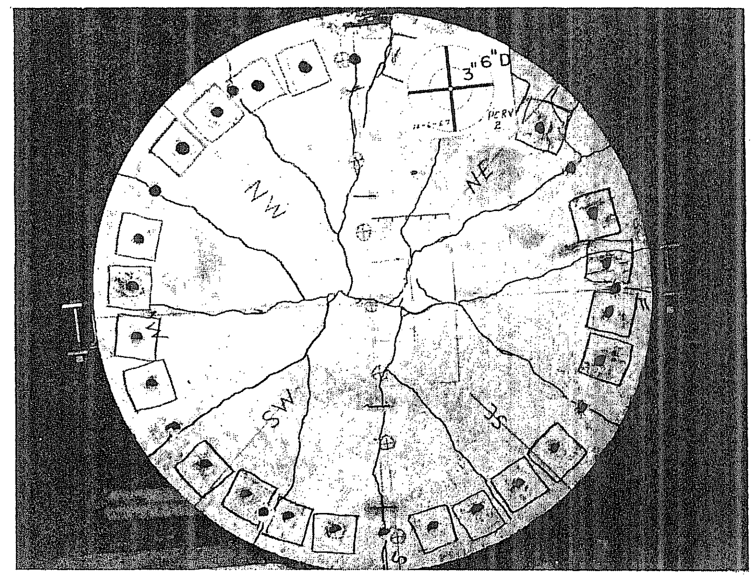


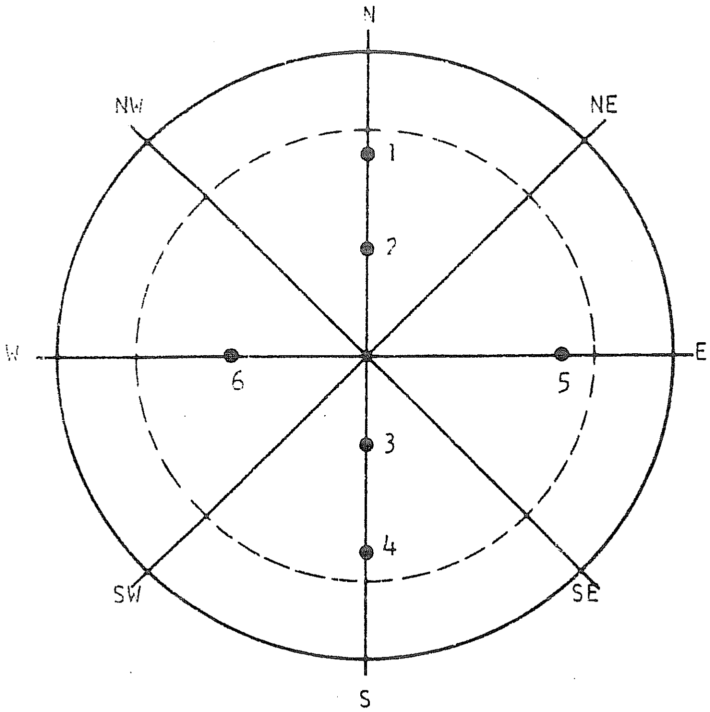
FIG. B2.19 END SLAB OF PV2 AFTER TESTING

B3 Test Vessel PV3 (t = 7 1/2 in., s = 1.0 in.)

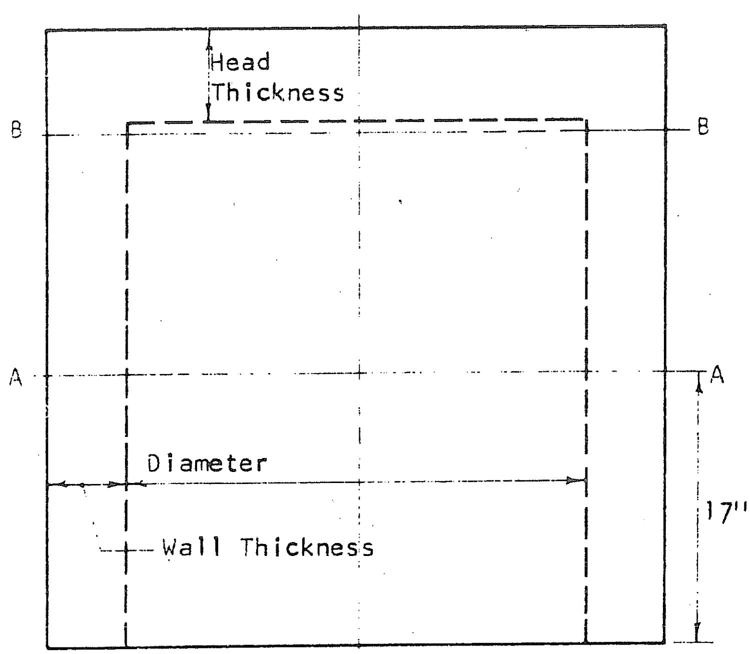
Test vessel PV3 was the first vessel cast from concrete mixed in the laboratory. It was free of cracks at the time of the test.

About three hours were required for the test. Loading was increased in increments of 20 psi until the vessel failed at 370 psi. No problems were encountered with the liner, which was sealed in the same manner as PV2. The block-out inside the vessel also failed when the vessel failed. The blockout, which was a closed steel cylinder filled with vermiculite concrete, developed a leak during the course of the test. When the pressure surrounding the vessel was reduced by failure of the vessel, the gas trapped inside the block-out caused it to burst.

The longitudinal tendons were 0.5-in. strand in PV3. Load cells were placed on nine of the twenty-four strands and were monitored during the test. The crack pattern in the end slab is illustrated by a photograph of the reassembled end slab in Fig. B3.22.



Head Thickness	
Point No.	Inches
1	7.8
2	7.8
3	7.75
4	7.8
5	7.7
6	7.75



Wall Thickness, in.		
Axis \ Plane	AA	BB
N		5.00
NE		4.76
E		4.855
SE		5.03
S		5.11
SW		5.12
W		4.95
NW		5.05

Inside Diameter, in.		
Axis \ Plane	AA	BB
N-S	$30\frac{5}{32}$	$29\frac{31}{32}$
NE-SW	$30\frac{1}{32}$	2 $\frac{31}{?2}$
E-W	30	$30\frac{1}{32}$
SE-NW	$30\frac{1}{32}$	$29\frac{31}{32}$

FIG. B3.1 DIMENSIONS OF PV3

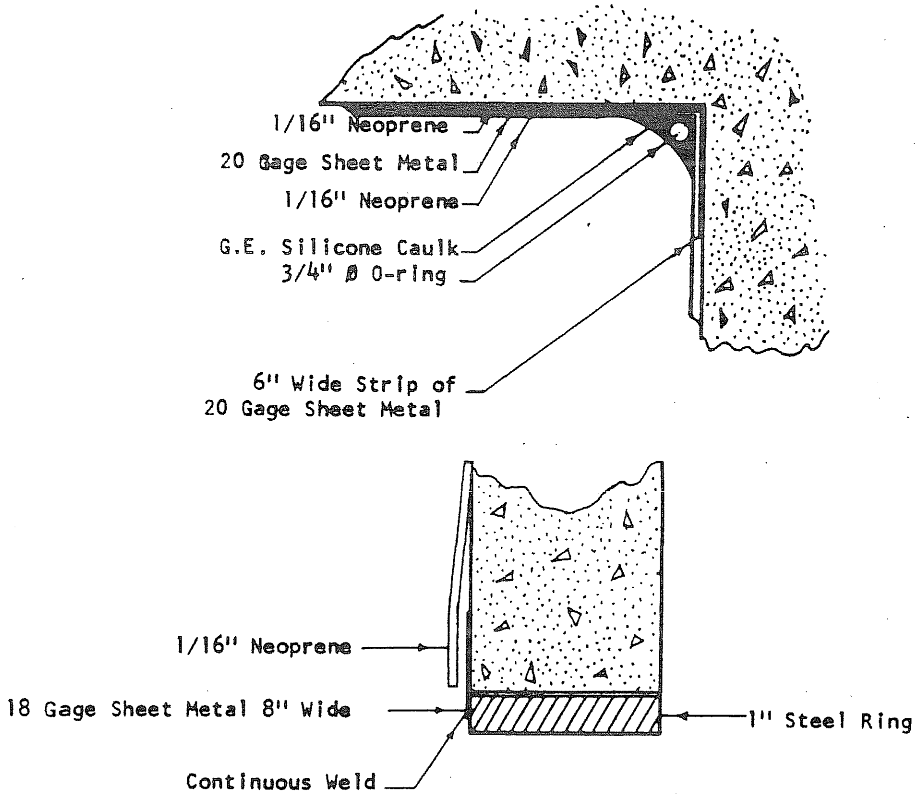
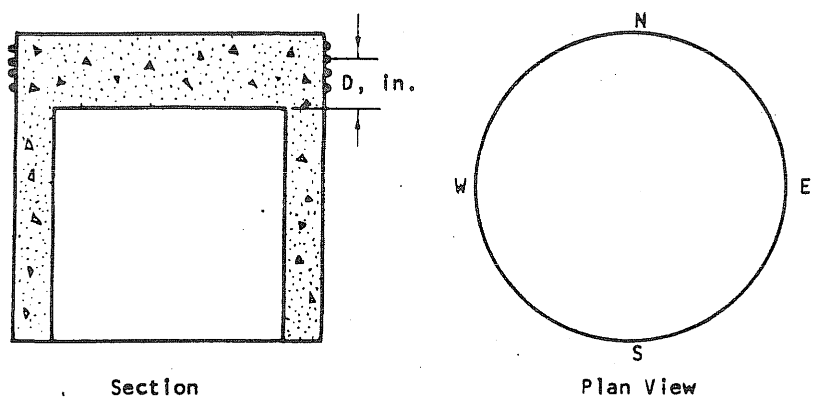


FIG. B3.2 SEALING DETAIL FOR PV3



Wrap No.	D_N	D_E	D_S	D_W
1	6 14/16	6 15/16	6 13/16	6 14/16
2	6 5/16	6 4/16	6 5/16	6 7/16
3	5 14/16	5 11/16	6 2/16	6 1/16
4	5 1/16	4 13/16	5 9/16	5 5/16
5	4 1/16	3 14/16	4 10/16	4 7/16
6	3	2 12/16	3 10/16	3 6/16
7	1 15/16	1 12/16	2 9/16	2 6/16
8	15/16	11/16	1 9/16	1 5/16
9	-1/16	-5/16	9/16	5/16

FIG. B3.3 MEASURED LOCATION OF THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE ENDS OF THE N-S AND E-W DIAMETERS ON PV3

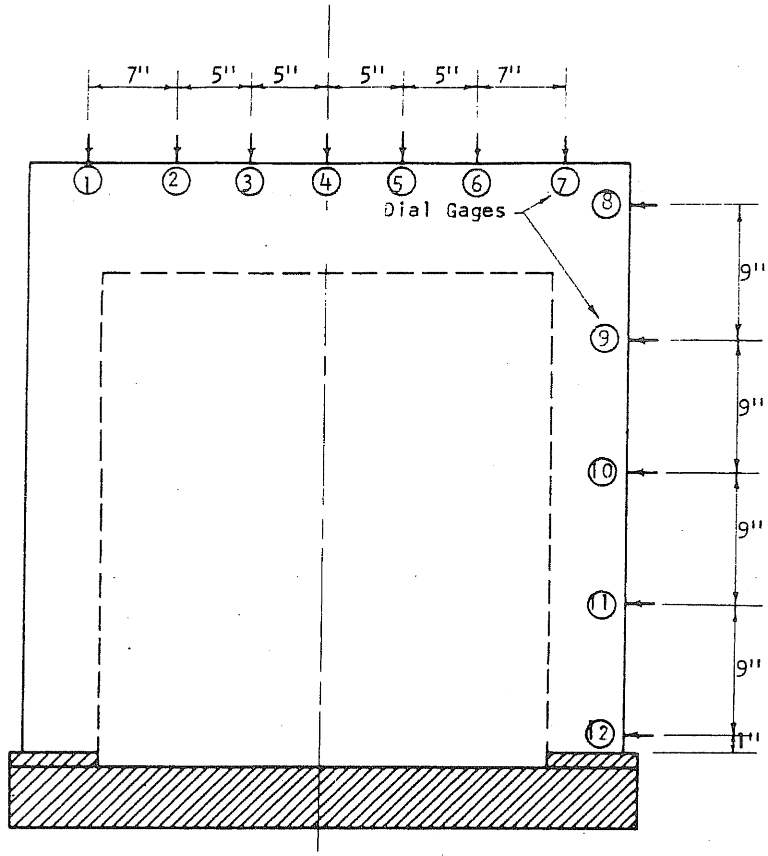


FIG. B3.4 LOCATION OF DEFLECTION GAGES ON PV3

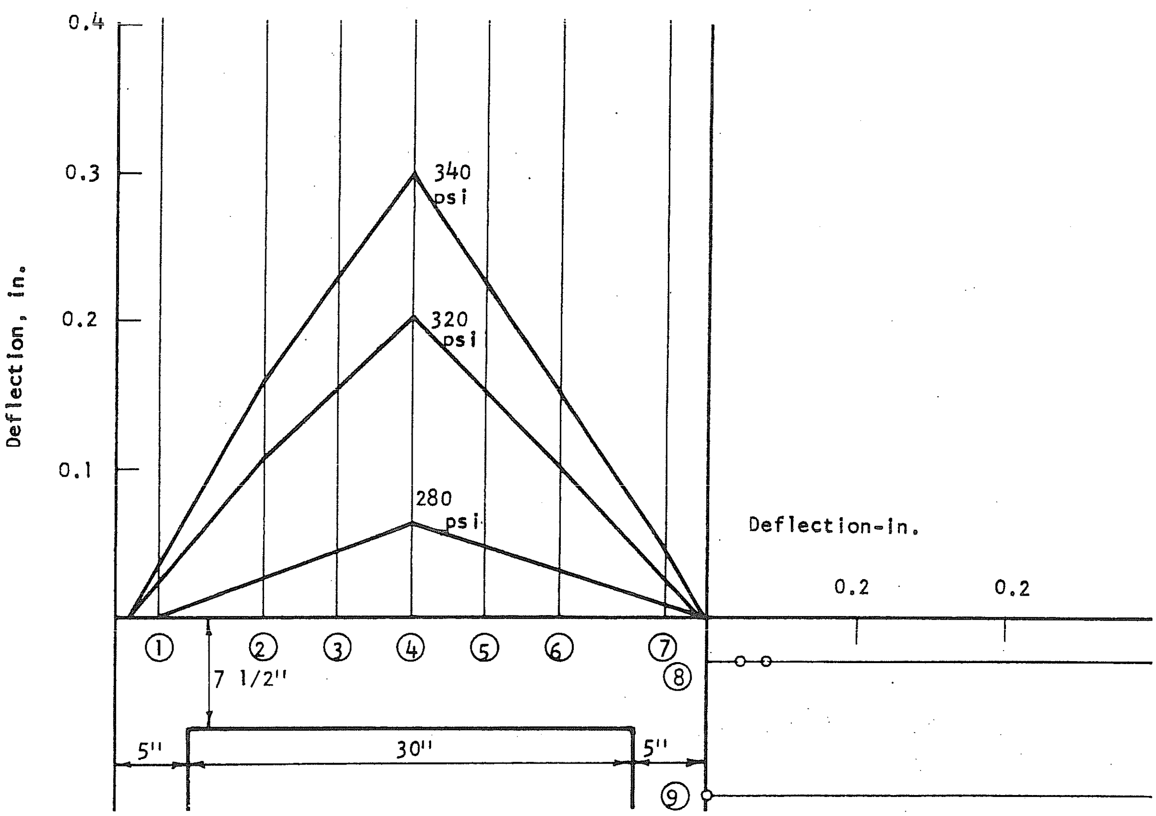


FIG. B3.5 DEFLECTION PROFILES OF THE END SLAB ALONG THE N-S DIAMETER OF PV3

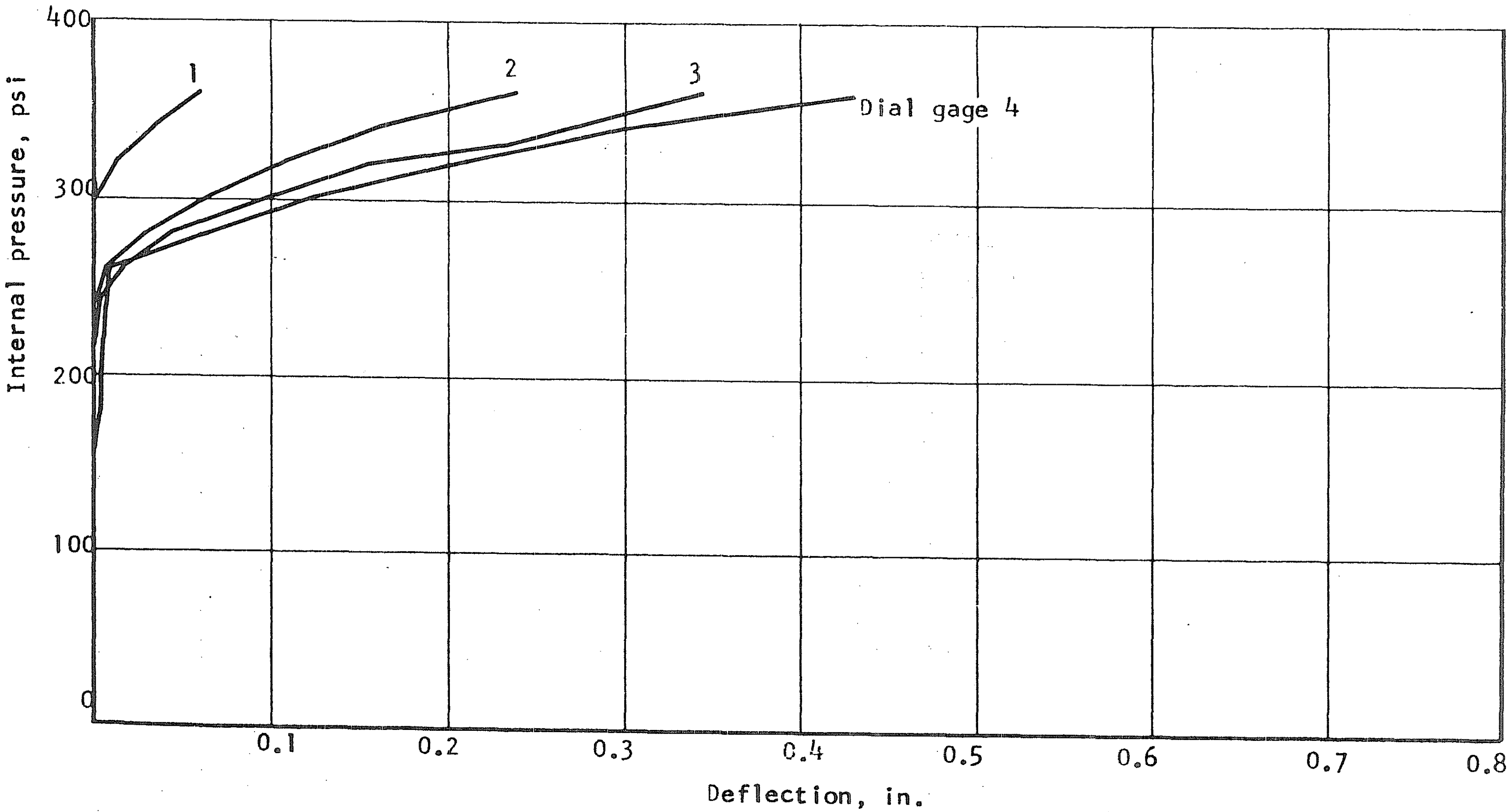


FIG. B3.6 APPLIED PRESSURE vs DEFLECTION ALONG THE N-HALF OF THE N-S DIAMETER OF PV3

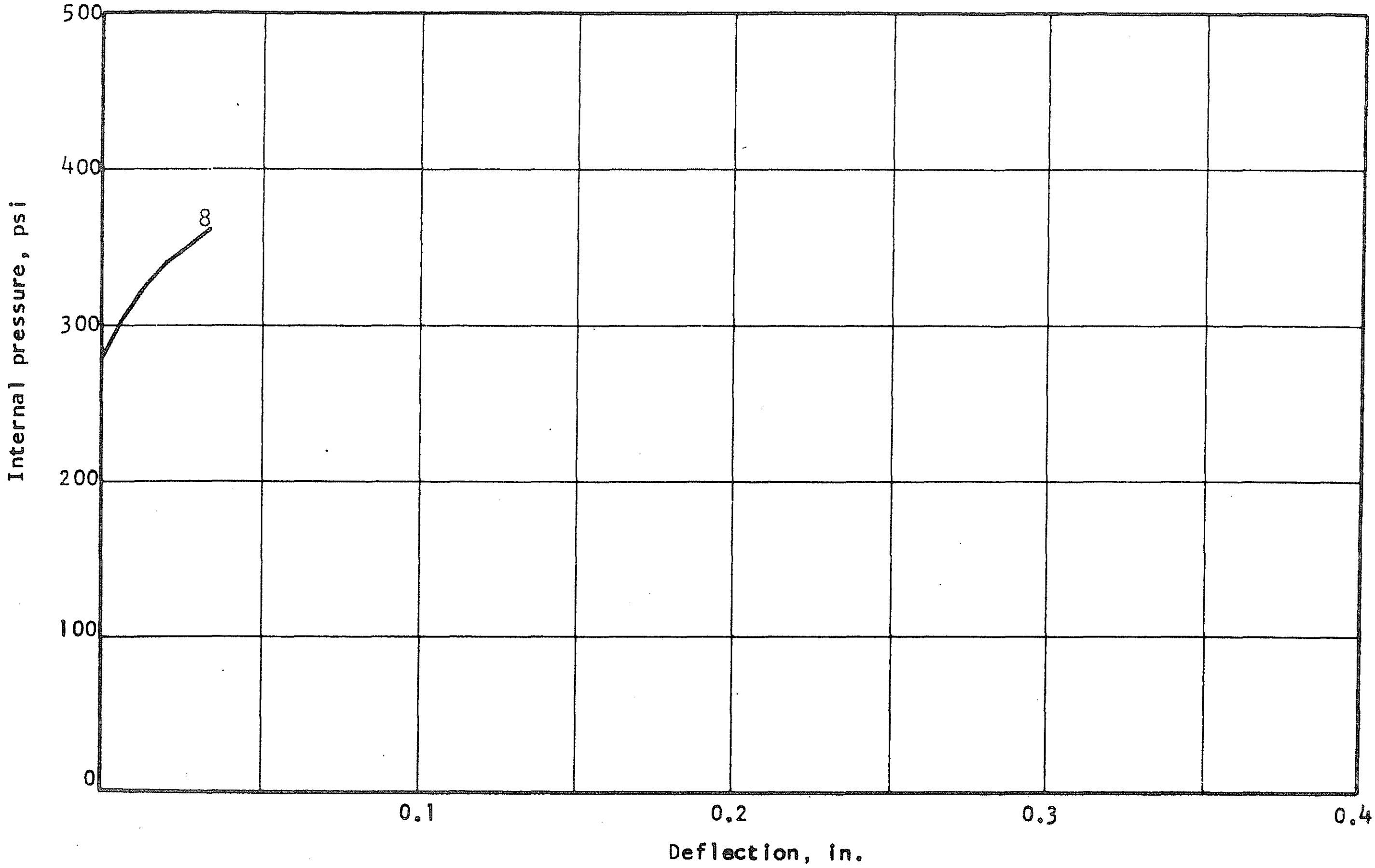


FIG. B3.8 APPLIED PRESSURE vs DEFLECTION OF THE SIDE WALL OF PV3

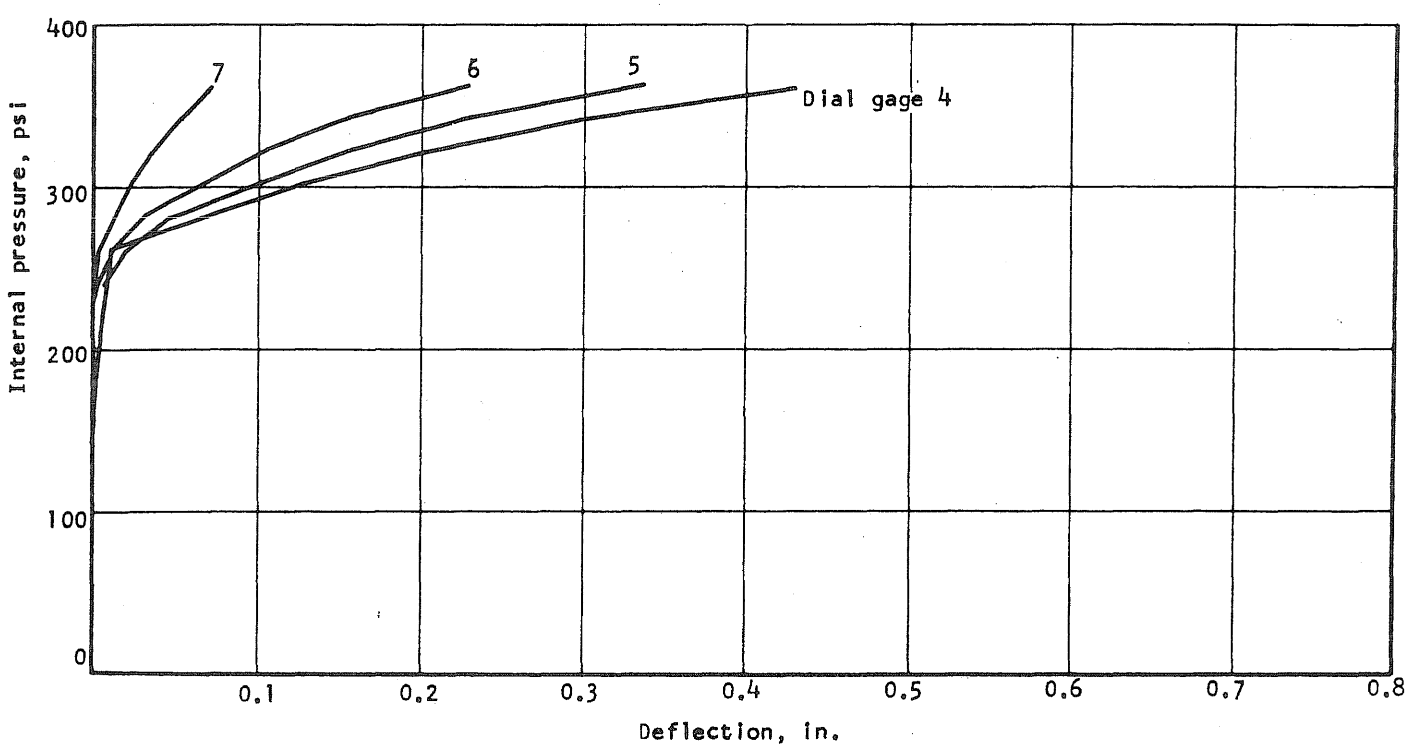
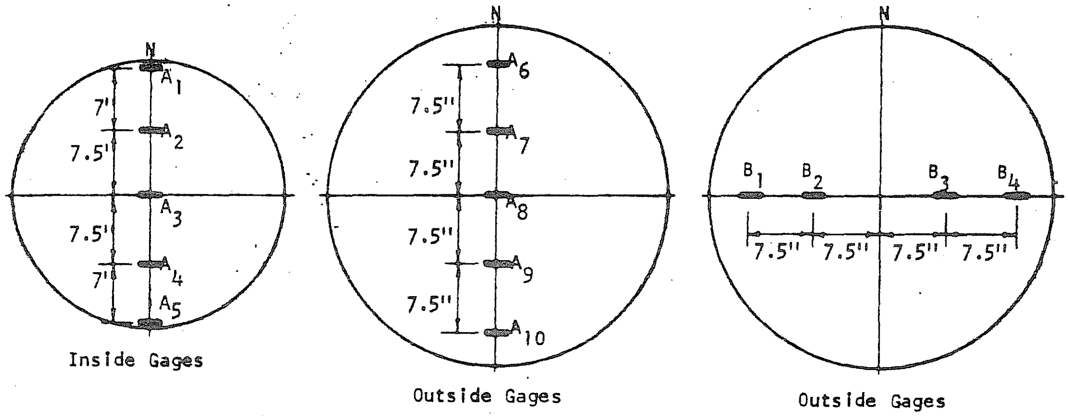
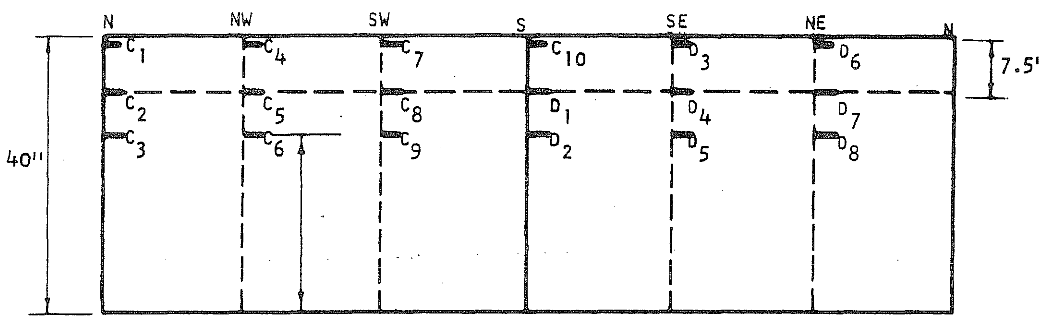


FIG. B3.7 APPLIED PRESSURE vs DEFLECTION ALONG THE S-HALF OF THE N-S DIAMETER OF PV3

Concrete Gages On The Slab

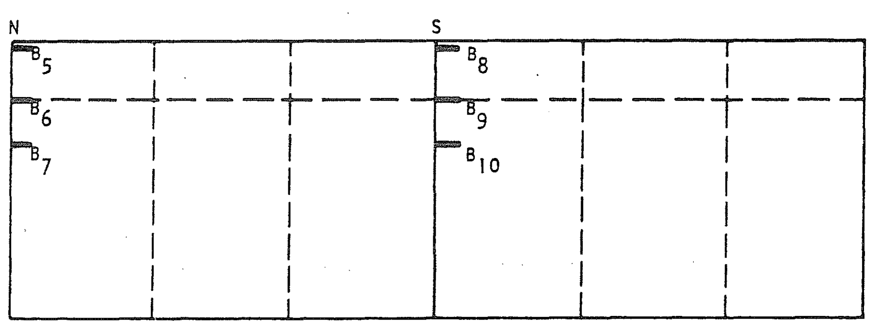


Steel Gages On Prestressing Wire



Gage	Axis	H	Gage	Axis	H	Gage	Axis	H
C_1	N	38 13/16	C_7	SW	38 14/16	D_3	SE	38 12/16
C_2	N	32 7/16	C_8	SW	32 7/16	D_4	SE	32 10/16
C_3	N	27 8/16	C_9	SW	27 8/16	D_5	SE	27 4/16
C_4	NW	38 14/16	C_{10}	S	38 13/16	D_6	NE	38 13/16
C_5	NW	32 10/16	D_1	S	32 1/16	D_7	NE	32 5/16
C_6	NW	27 10/16	D_2	S	27 3/16	D_8	NE	27 6/16

Concrete Gages on Outside of Vessel



Concrete gages were placed as close to corresponding steel gages as possible

Gage	Axis	H	Gage	Axis	H
B_5	N	38 10/16	B_8	S	38 5/16
B_6	N	31 15/16	B_9	S	32 9/16
B_7	N	27 0/16	B_{10}	S	26 12/16

FIG. B3.9 STRAIN GAGE LOCATIONS ON PV3

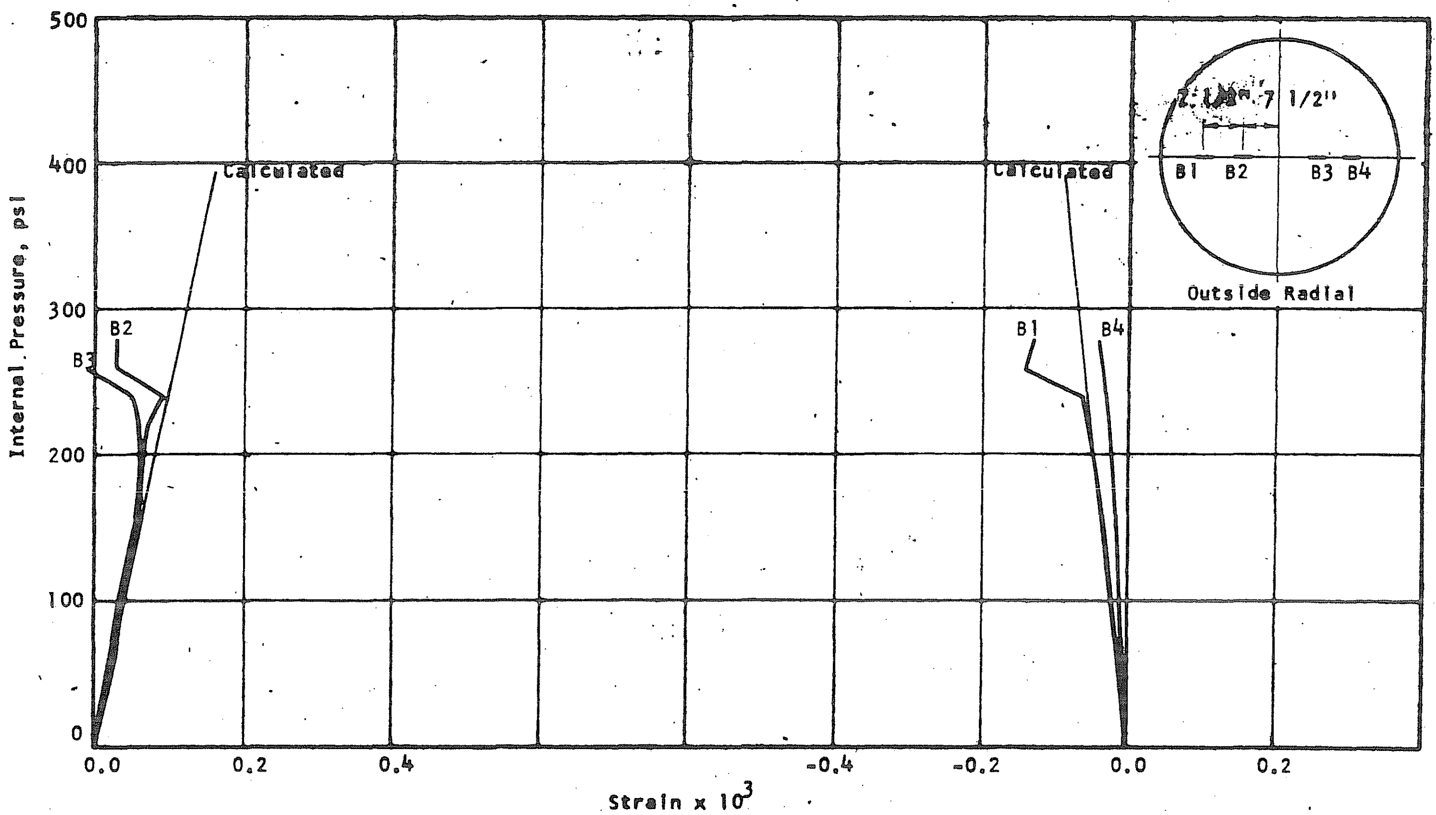


FIG. B3.10 CONCRETE STRAINS, VESSEL PV3

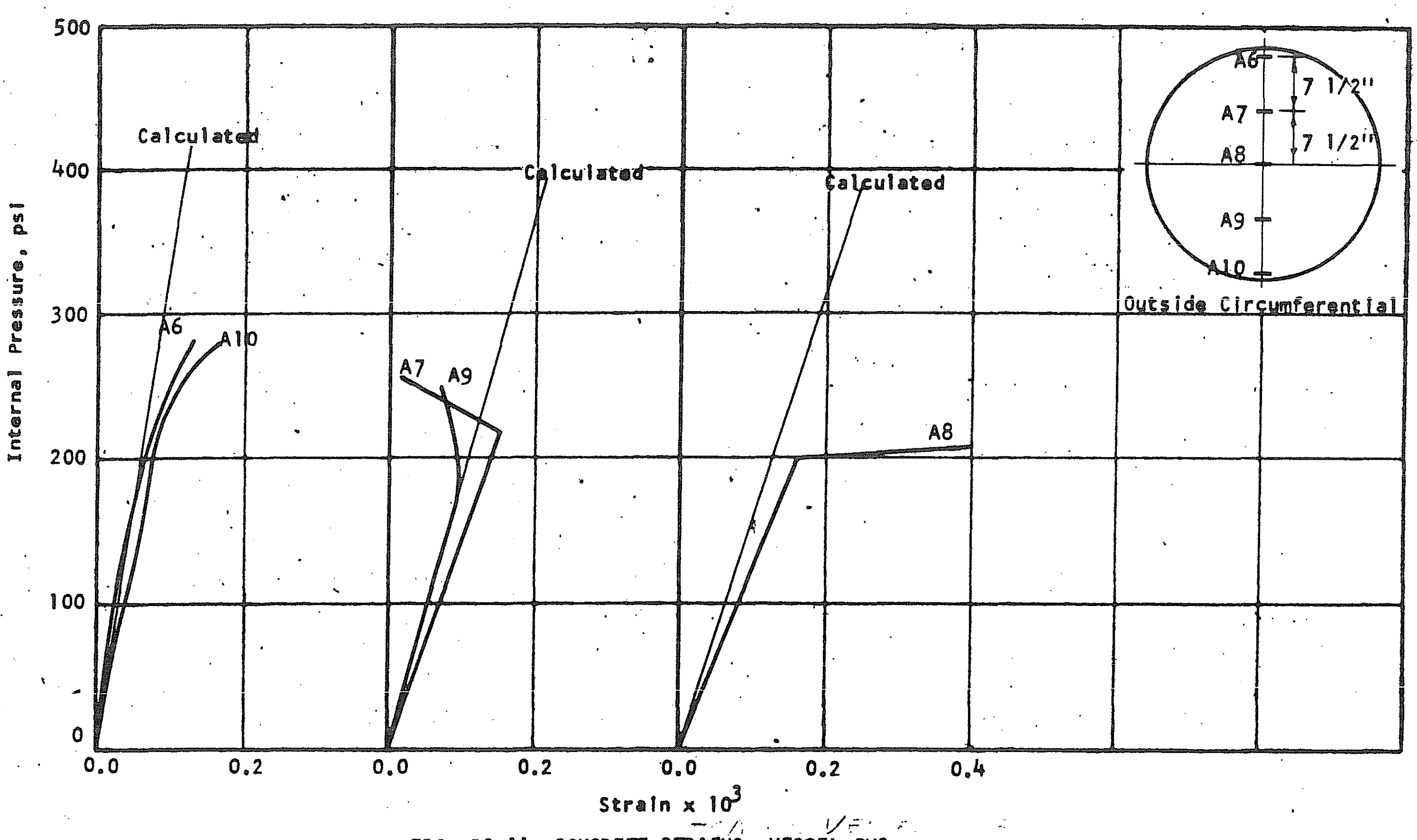


FIG. B3.11 CONCRETE STRAINS, VESSEL PV3

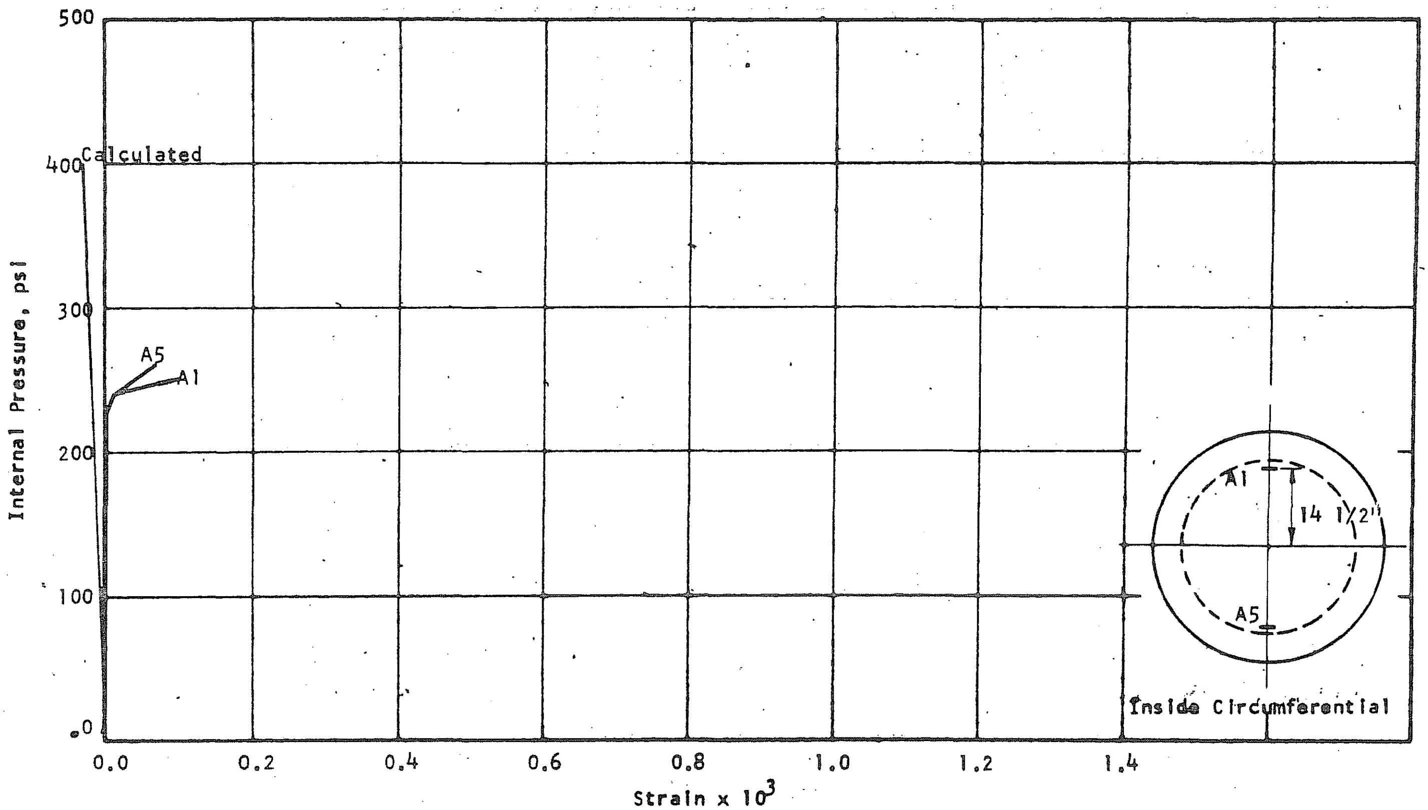


FIG. B3.12 CONCRETE STRAINS, VESSEL PV3

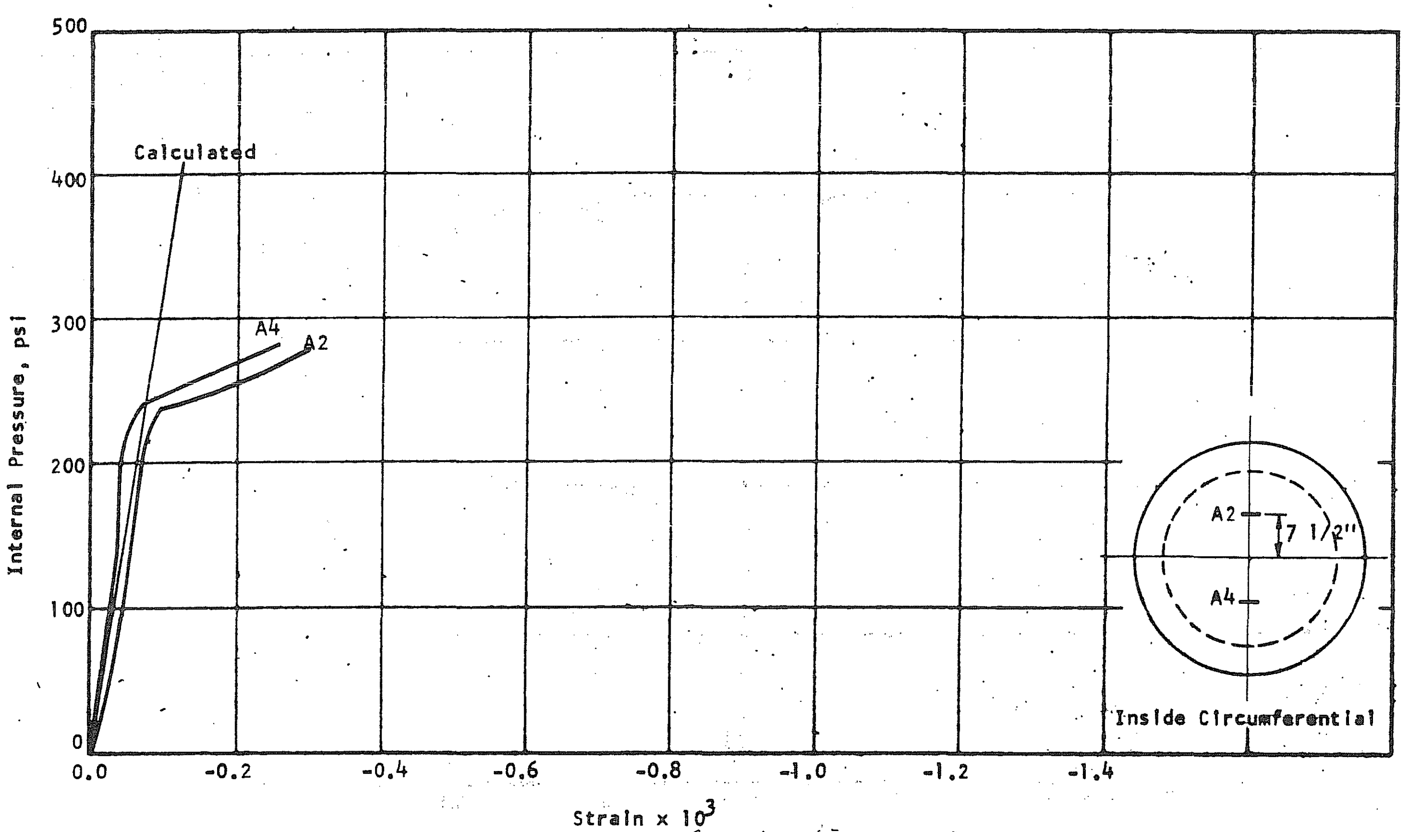


FIG. B3.13 CONCRETE STRAINS, VESSEL PV3

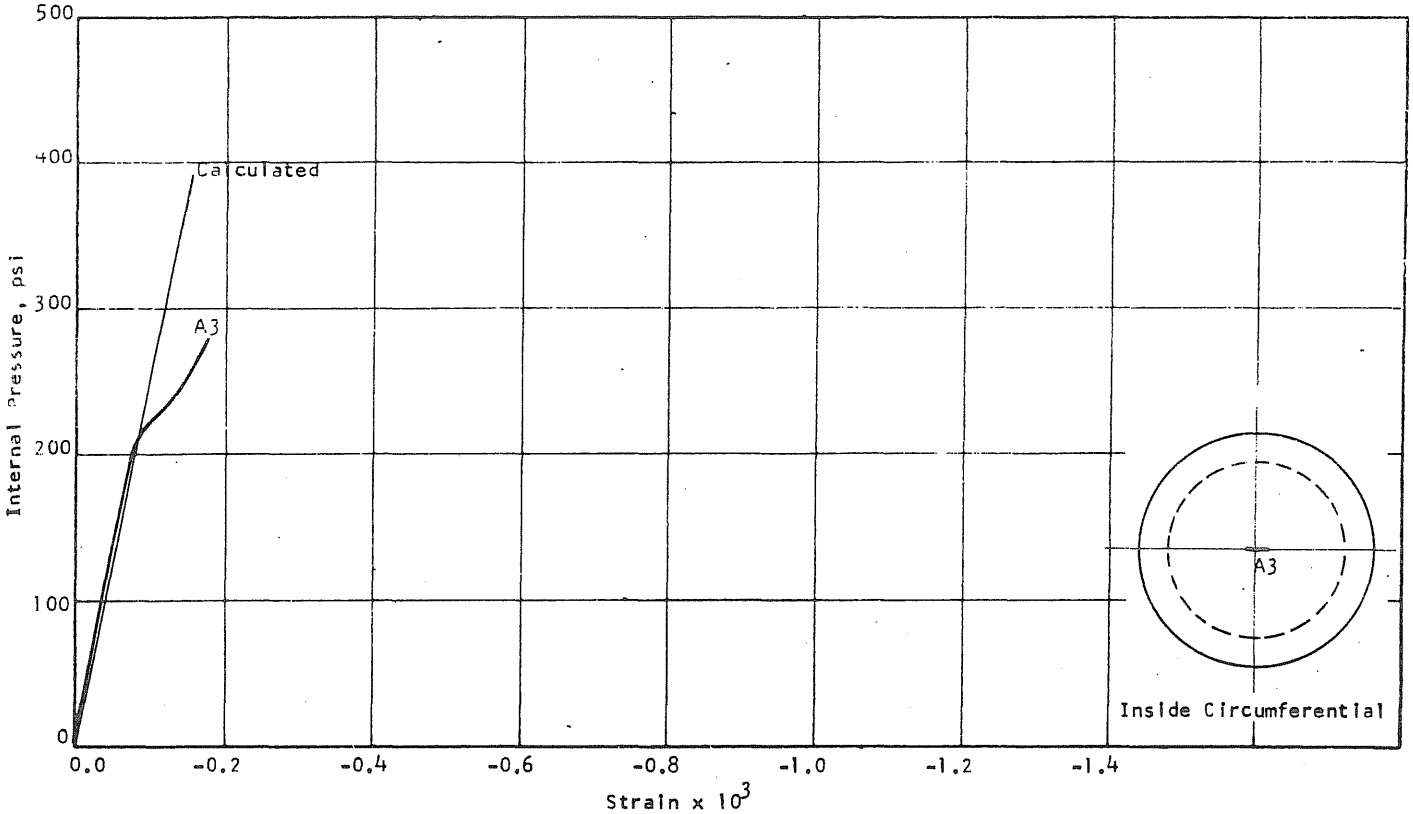


FIG. B3.14 CONCRETF STRAINS, VESSEL PV3

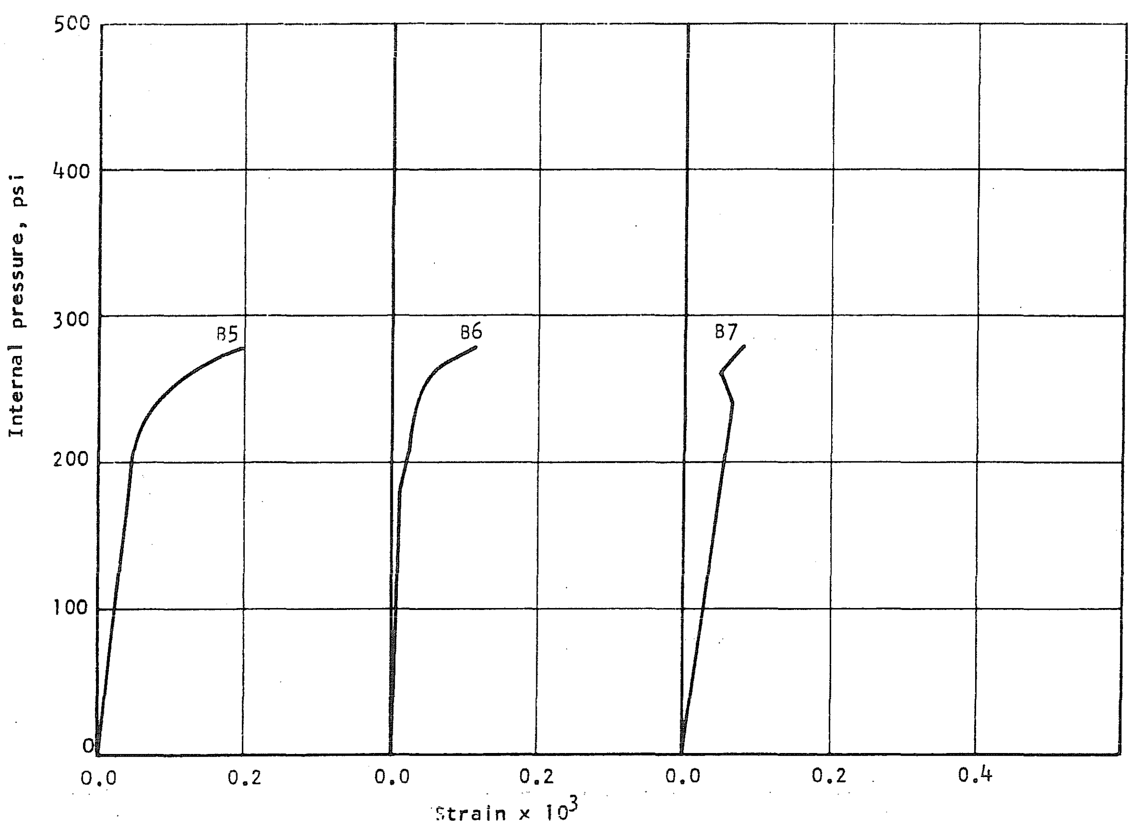


FIG. B3.15 APPLIED PRESSURE vs CIRCUMFERENTIAL STRAIN IN THE WALL OF THE VESSEL AT THE N-END OF THE N-S DIAMETER OF PV3

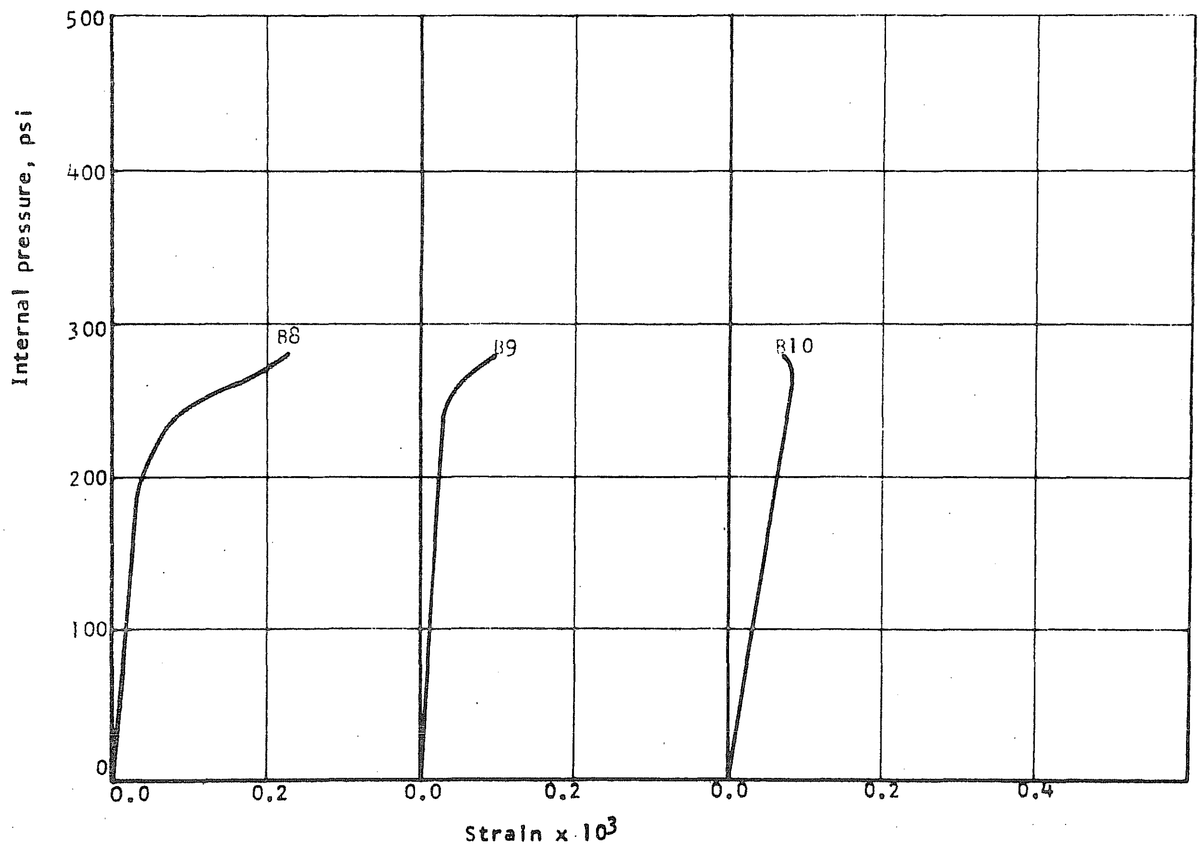


FIG. B3.16 APPLIED PRESSURE vs CIRCUMFERENTIAL STRAIN IN THE WALL OF THE VESSEL AT THE S-END OF THE N-S DIAMETER OF PV3

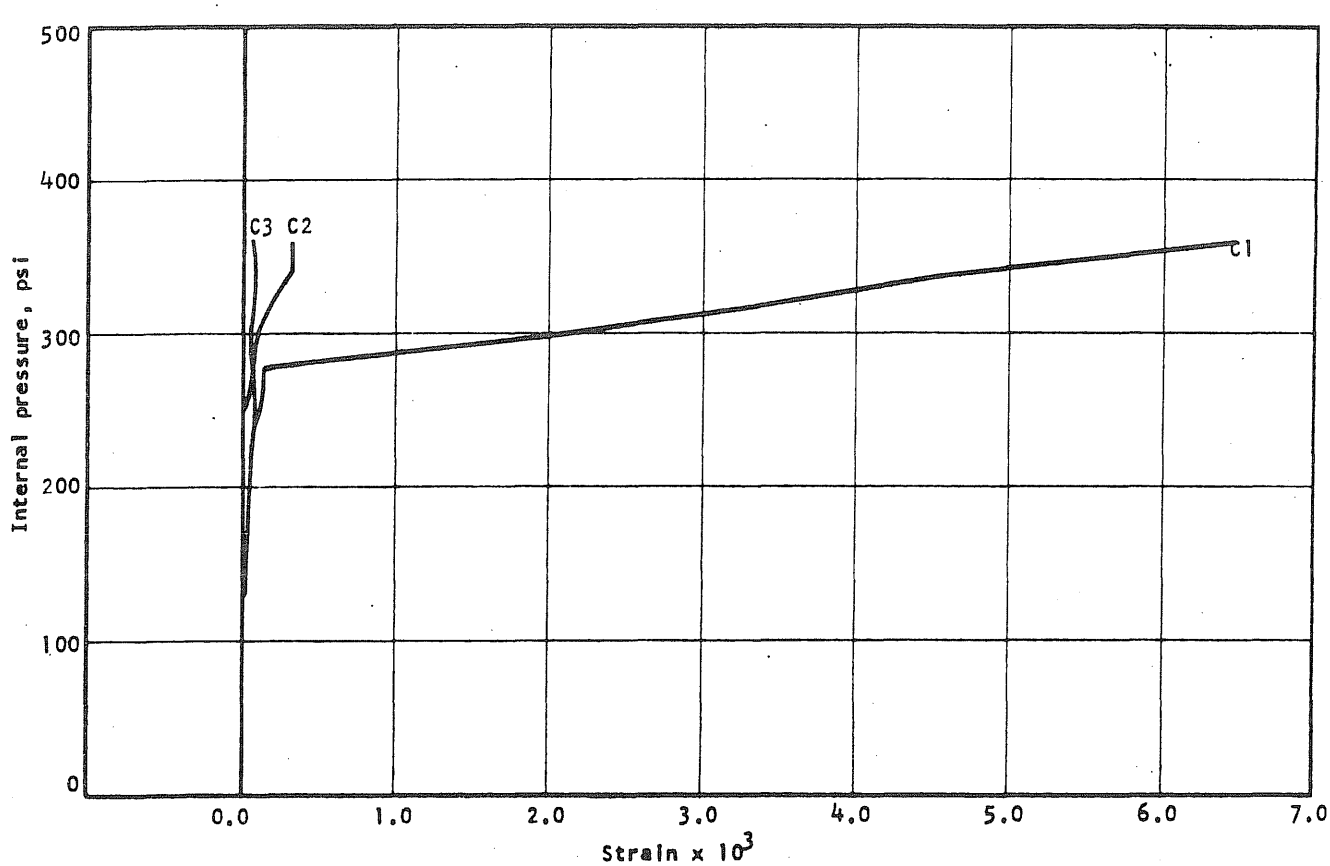


FIG. B3.17 APPLIED PRESSURE vs STRAIN IN THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE N-END OF THE N-S DIAMETER OF PV3

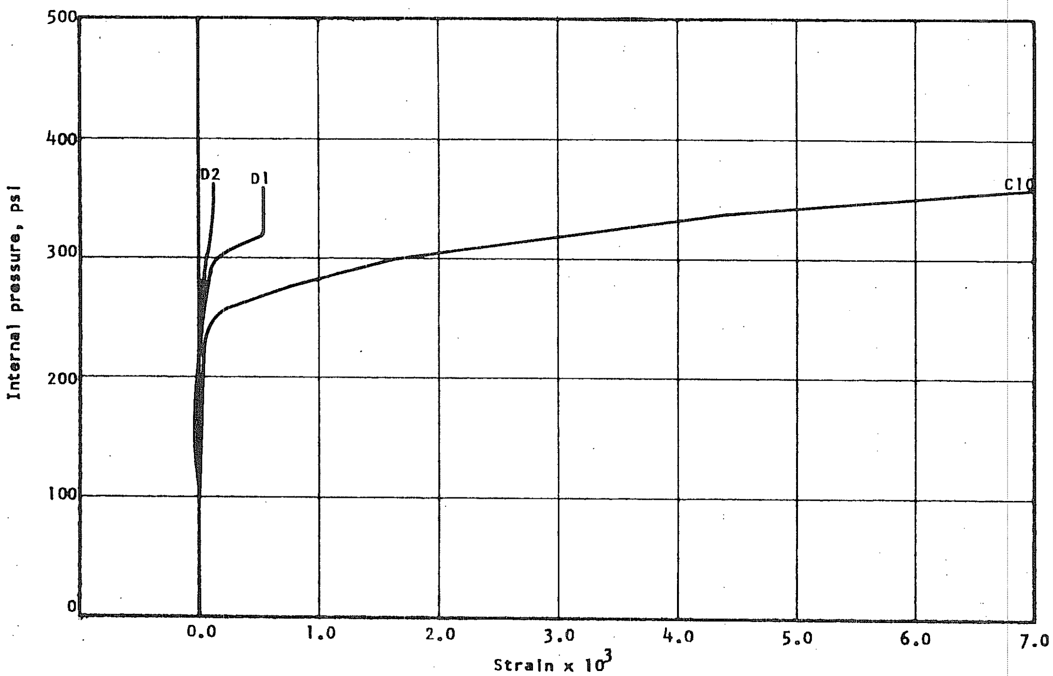


FIG. B3.18 APPLIED PRESSURE vs STRAIN IN THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE S-END OF THE N-S DIAMETER OF PV3

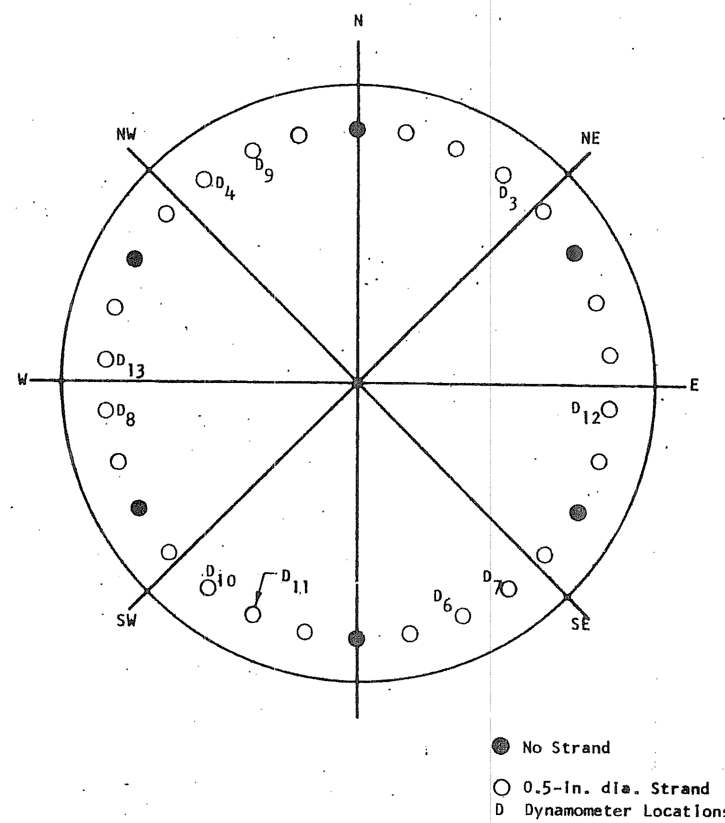


FIG. B3.19 LOCATION OF LONGITUDINAL REINFORCEMENT

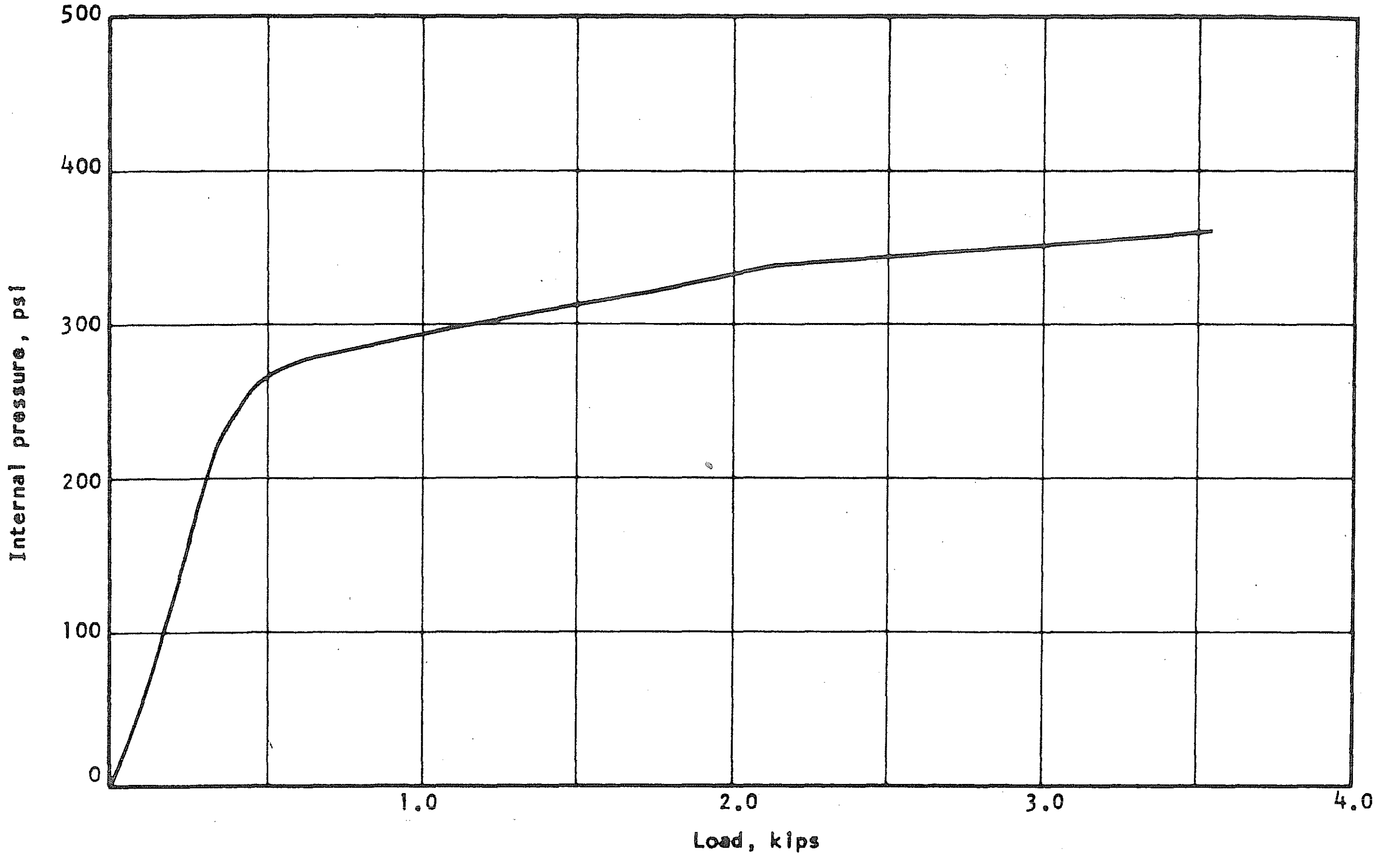


FIG. B3.20 APPLIED PRESSURE vs INCREASE IN LOAD IN DYNAMOMETER NO. 11 IN PV3

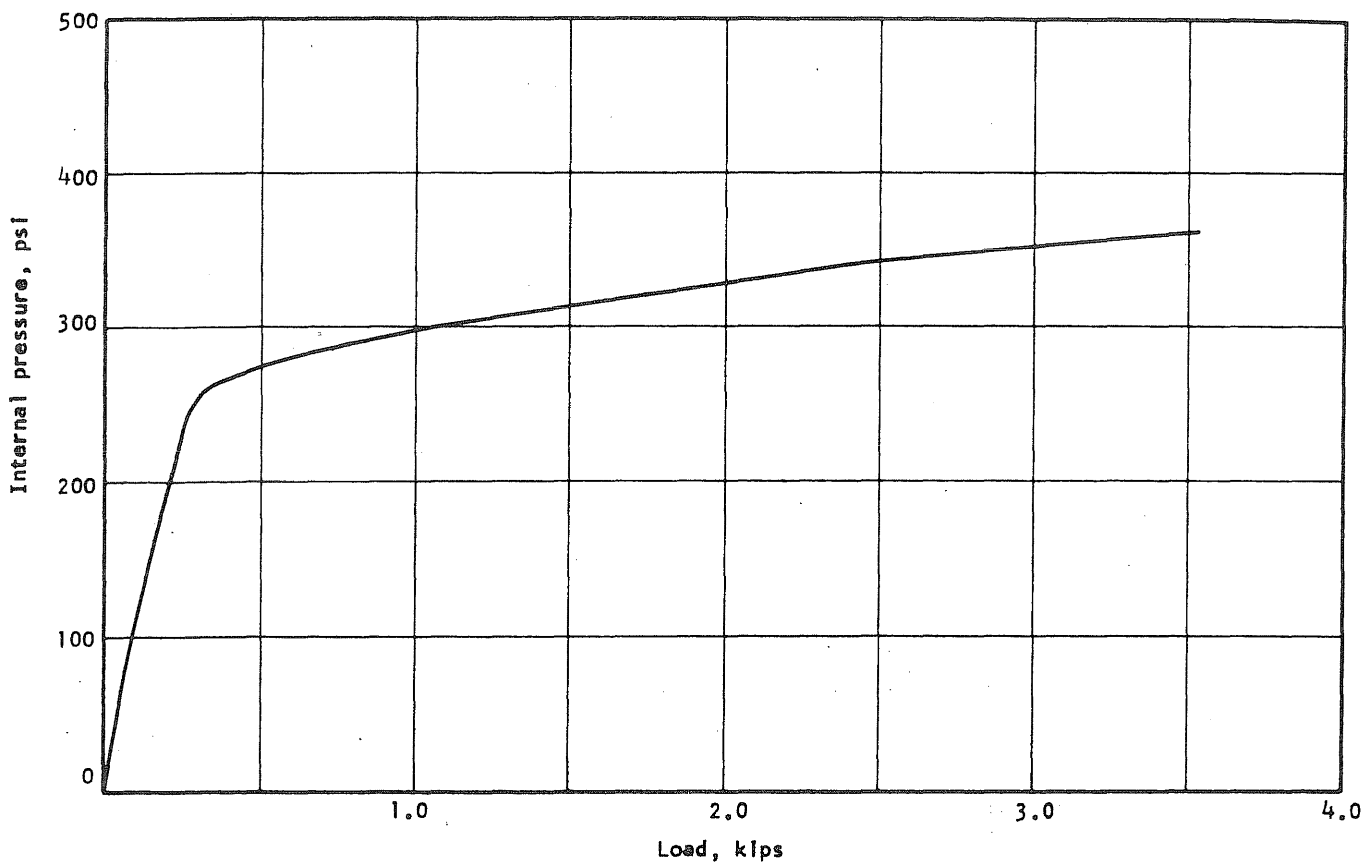


FIG. B3.21 APPLIED PRESSURE vs INCREASE IN LOAD IN DYNAMOMETER NO. 3 IN PV3

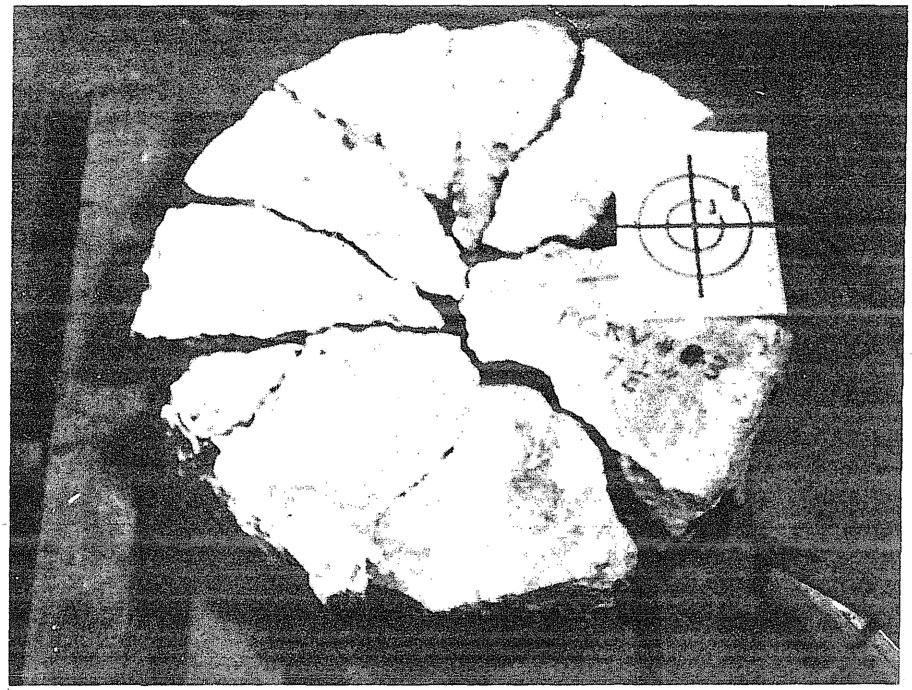


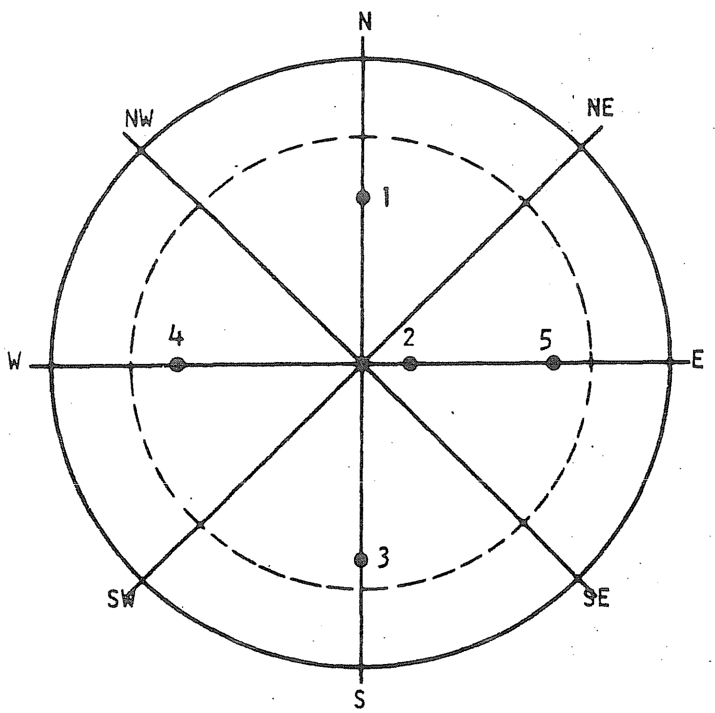
FIG. B3.22 REASSEMBLED END SLAB OF PV3

B4 Test Vessel PV4 (t = 4 in., s = 2/3 in.)

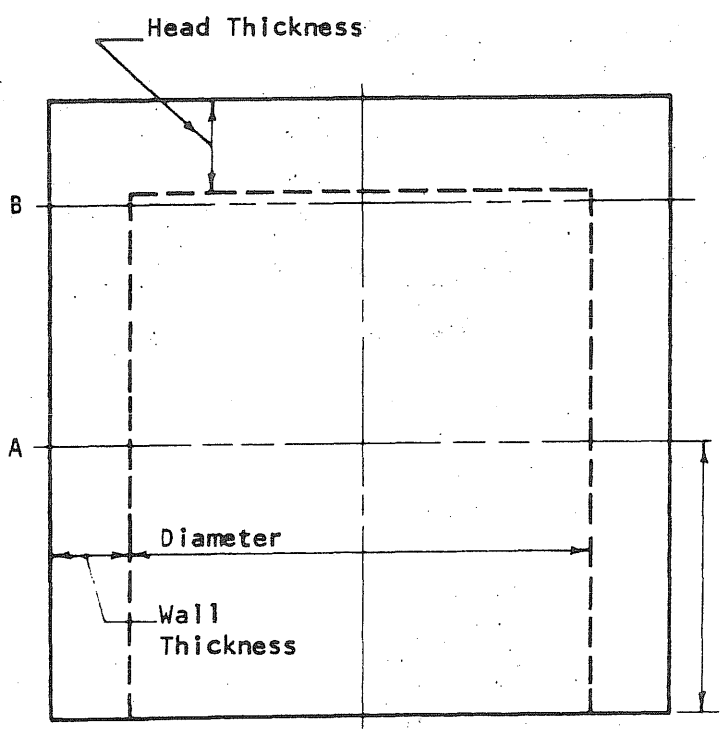
Test vessel PV4 was tested in the manner described for PV1 through PV3 with no unusual occurrences. It was cast of concrete mixed in the laboratory and had no visible cracks at the time of the test.

Nearly four and one-half hours were required to test PV4 as loading proceeded in 20 psi increments to a pressure of 310 psi, when the increment of loading was decreased to 10 psi until the vessel failed at 390 psi. No problems were encountered with the gas seal. The block-out used in PV4 was a steel cylinder filled with water.

Twelve of the twenty-four strands were equipped with load cells and were monitored during the test. The crack pattern in the end slab is illustrated in Fig. B4.21.



Head Thickness	
Point No.	Inches
1	6.0
2	6.1
3	6.2
4	6.0
5	6.2



Wall Thickness, in.		
Plane / Axis	AA	BB
N		5.07
NE		5.10
E		4.98
SE		5.01
S		5.02
SW		5.04
W		4.97
NW		5.02

Inside Diameter, in.		
Plane / Axis	AA	BB
N-S		$29\frac{30}{32}$
NE-SW		$29\frac{30}{32}$
E-W		$30\frac{1}{32}$
SE-NW		$29\frac{30}{32}$

FIG. B4.1 DIMENSIONS OF PV4

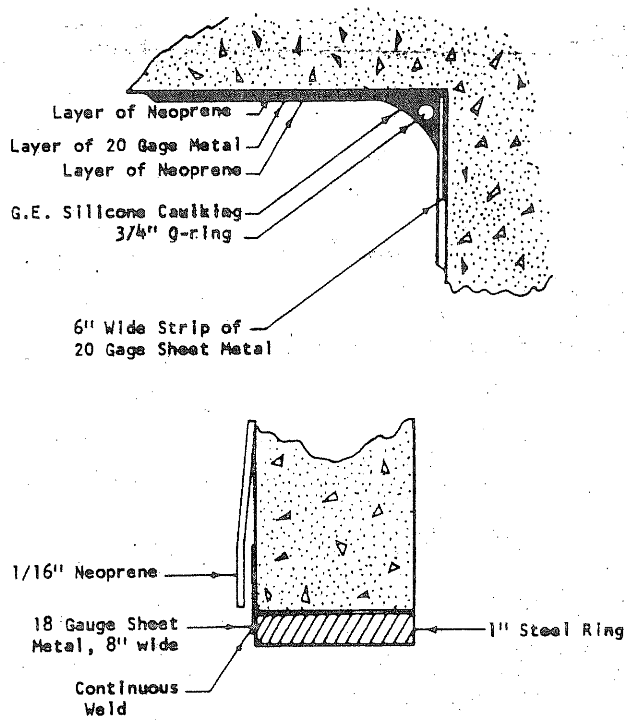
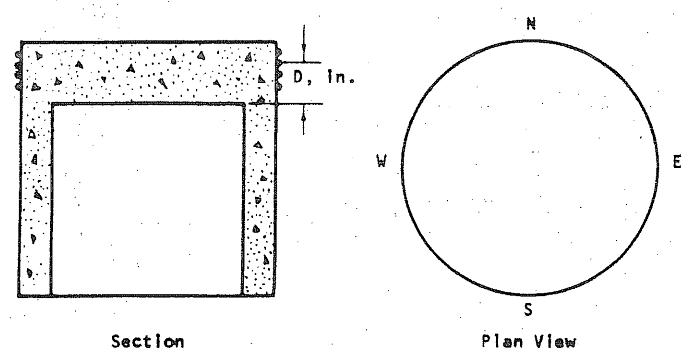


FIG. B4.2 SEALING DETAIL FOR PV4



Wrap No.	D_N	D_E	D_S	D_W
1	5 5/16	5 9/16	5 10/16	5 8/16
2	4 14/16	5 1/16	5 2/16	5
3	4 10/16	4 8/16	4 10/16	4 9/16
4	4 3/16	3 15/16	4 2/16	4 1/16
5	3 9/16	3 4/16	3 7/16	3 7/16
6	2 15/16	2 10/16	2 13/16	2 12/16
7	2 4/16	1 15/16	2 2/16	2 2/16
8	1 10/16	1 4/16	1 7/16	1 7/16
9	14/16	10/16	12/16	12/16
10	4/16	-1/16	2/16	1/16

FIG. B4.3 MEASURED LOCATION OF THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE ENDS OF THE N-S AND E-W DIAMETERS ON PV4

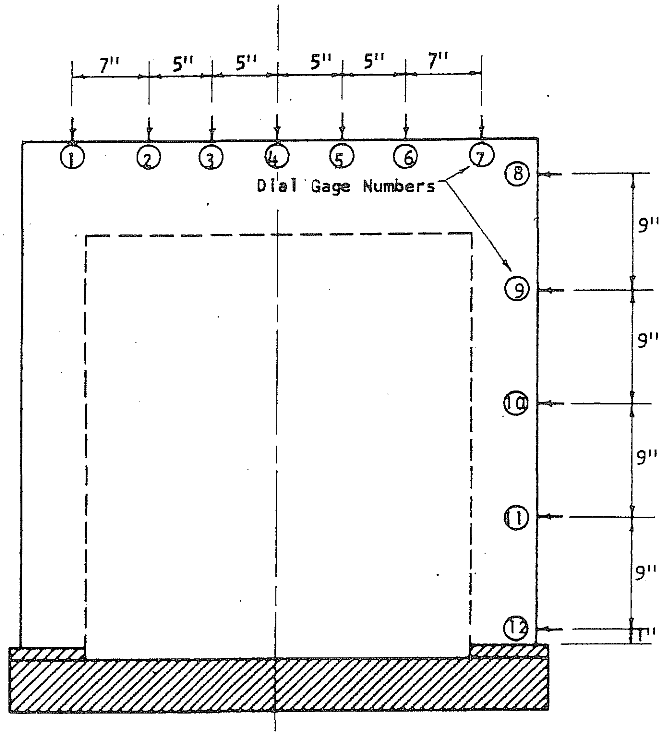


FIG. B4.4 LOCATION OF DELFECTION GAGES ON PV4

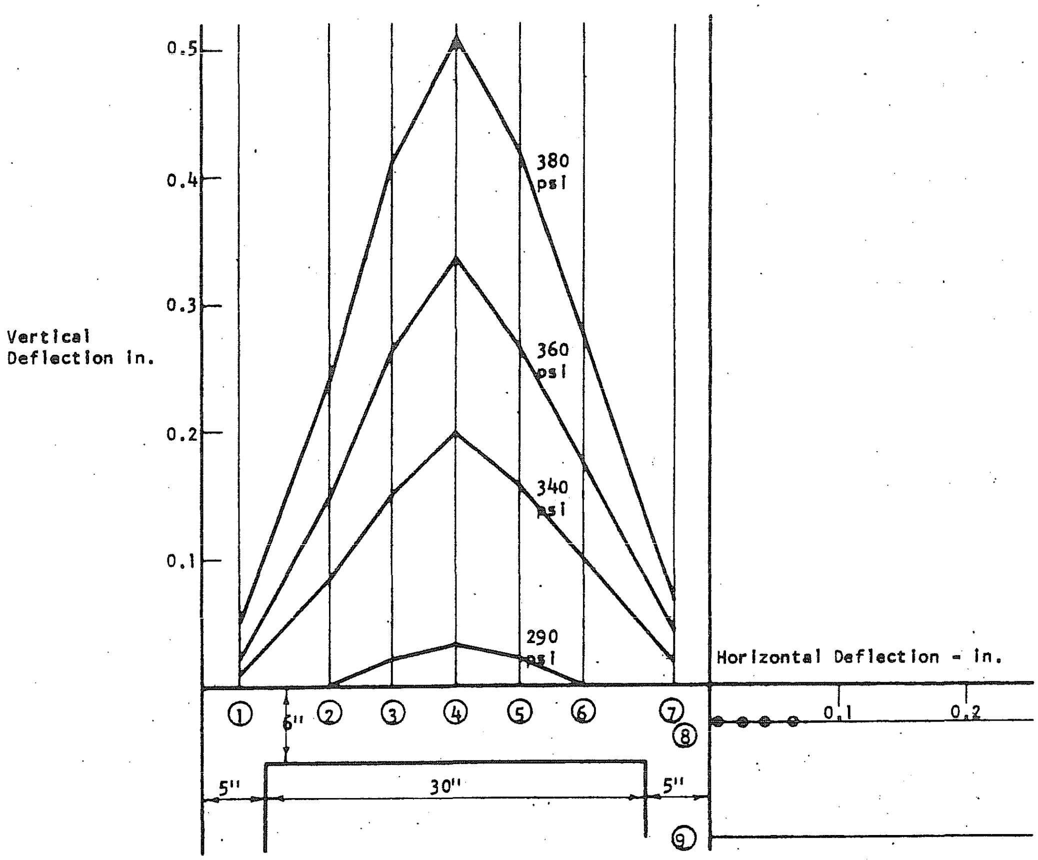


FIG. B4.5 DEFLECTION PROFILES OF THE SLAB ALONG THE N-S DIAMETER

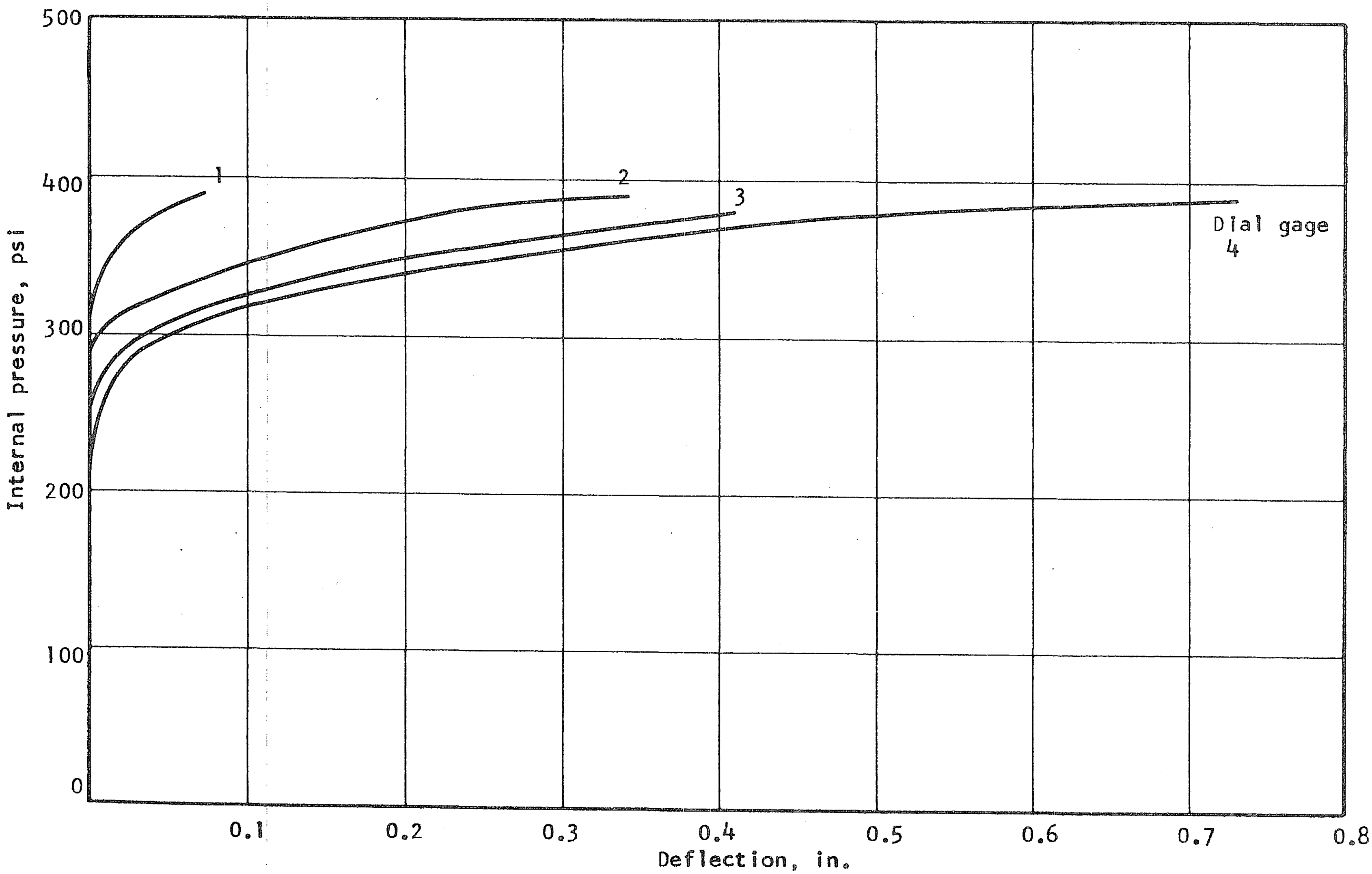


FIG. B4.6 APPLIED PRESSURE vs DEFLECTION ALONG THE N-HALF OF THE N-S DIAMETER OF PV4

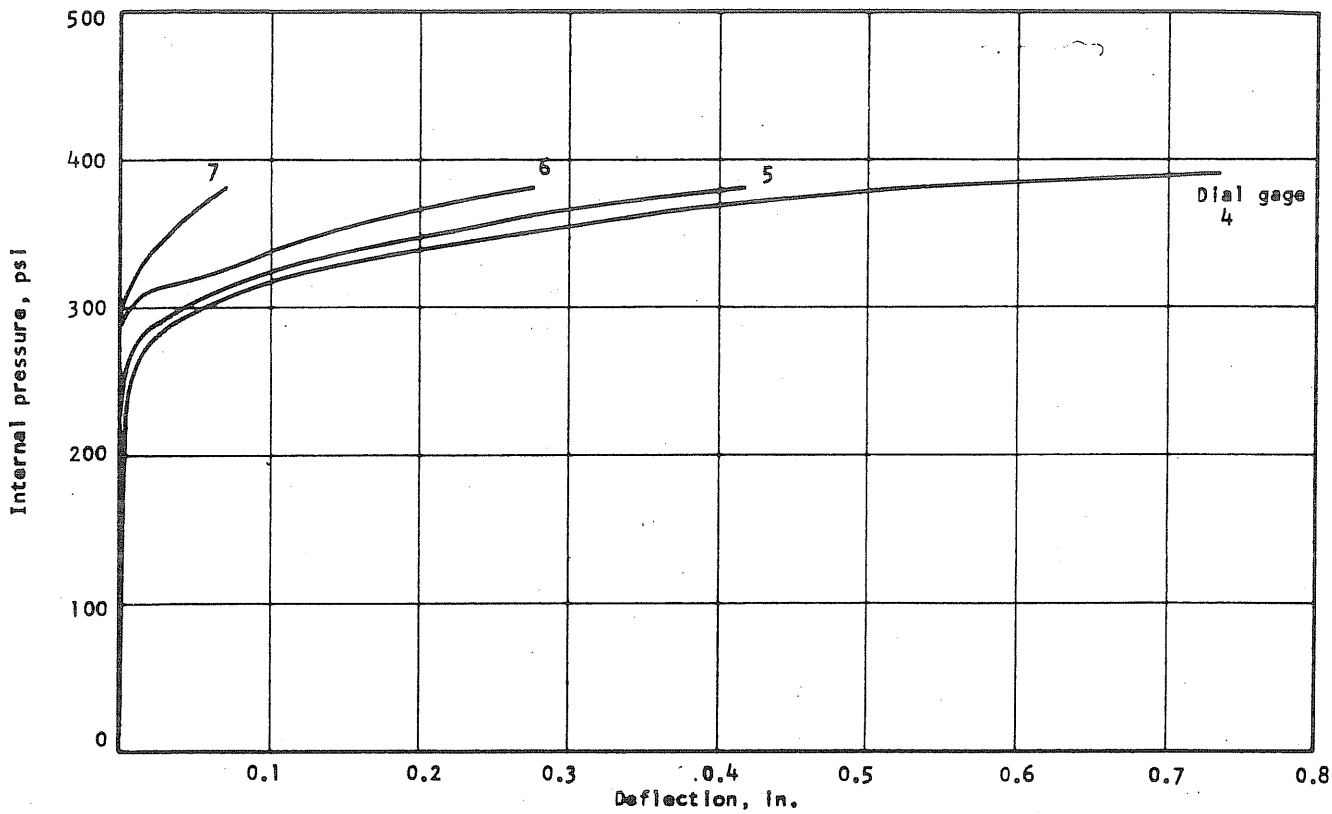


FIG. B4.7 APPLIED PRESSURE vs DEFLECTION ALONG THE S-HALF OF THE N-S DIAMETER OF PV4

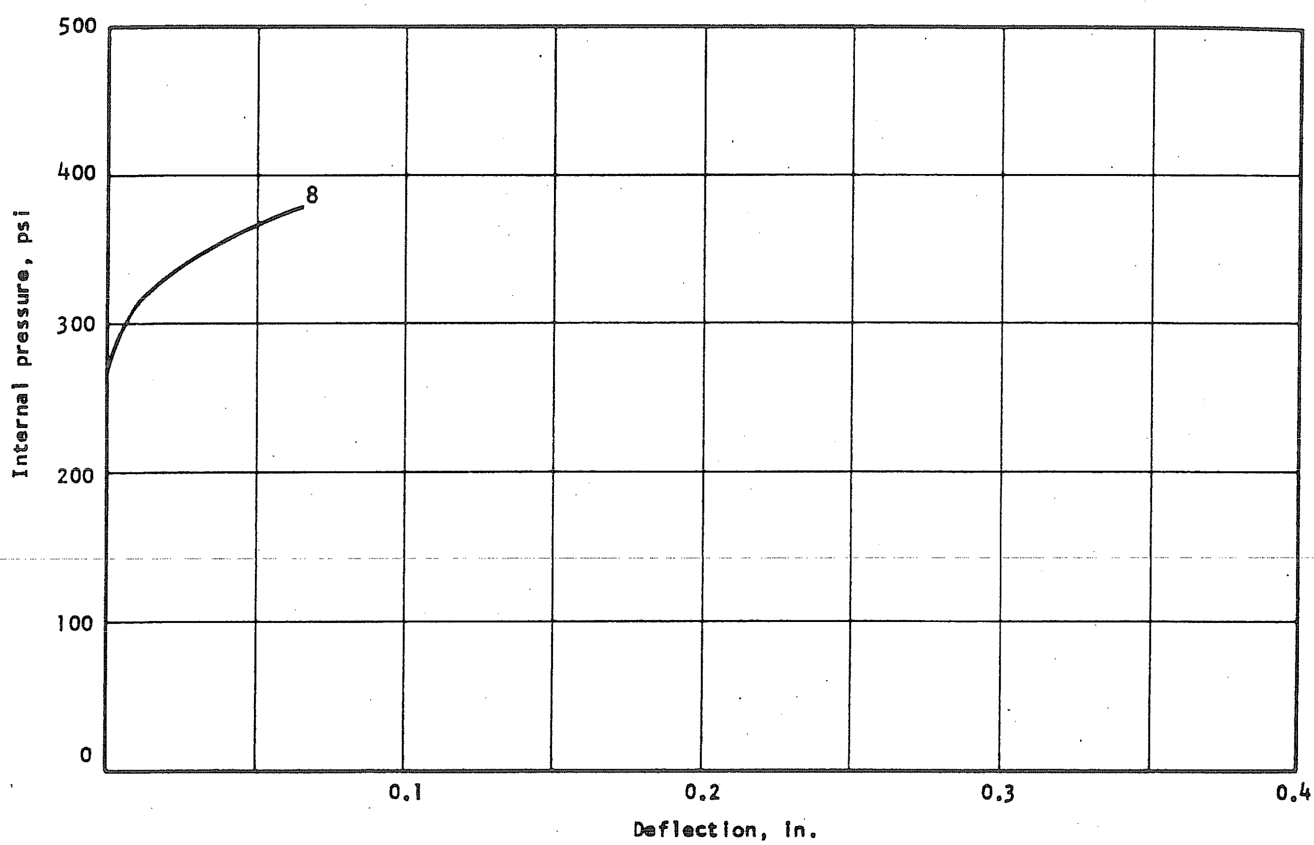
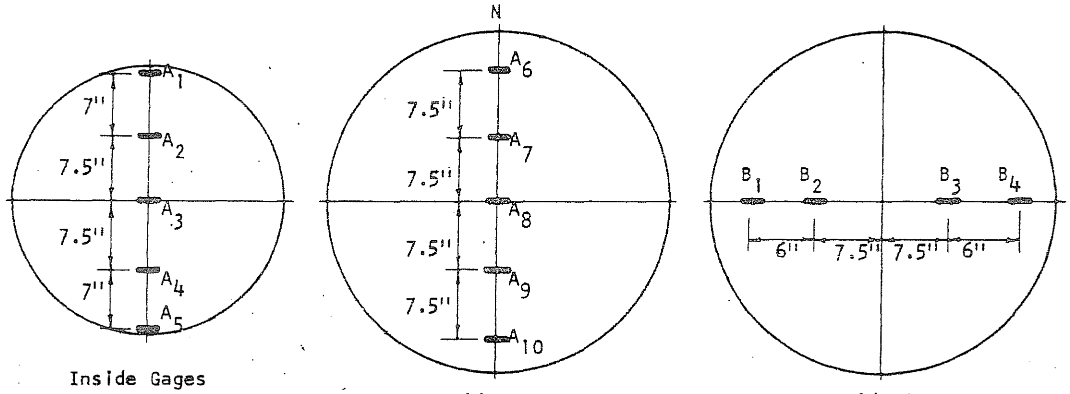


FIG. B4.8 APPLIED PRESSURE vs DEFLECTION OF THE SIDE WALL OF PV4

Concrete Gages on The Slab

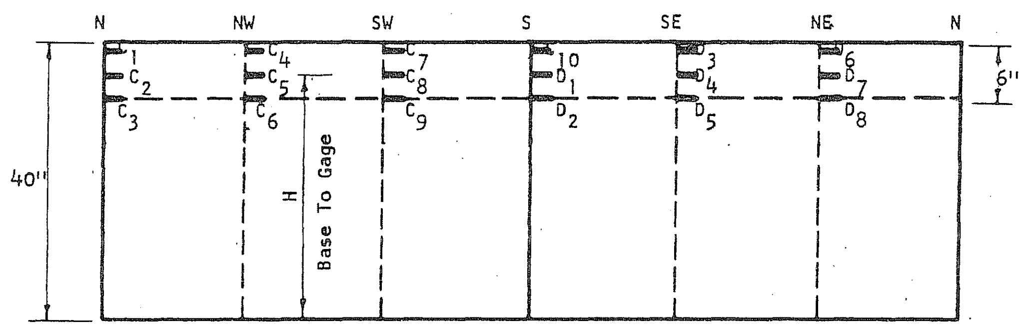


Inside Gages

Outside Gages
N-S Axis

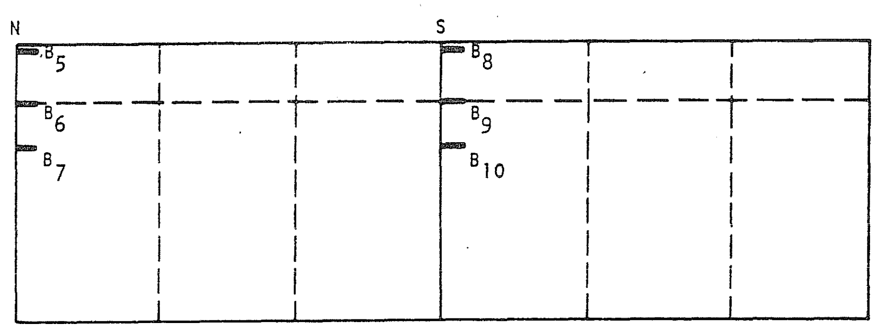
Outside Gages
E-W Axis

Steel Gages on Prestressing Wire



Gage	Line	H	Gage	Line	H	Gage	Line	H
C_1	N	38 13/16	C_7	SW	39 1/16	D_3	SE	39 2/16
C_2	N	36 13/16	C_8	SW	36 13/16	D_4	SE	36 11/16
C_3	N	34 4/16	C_9	SW	34 2/16	D_5	SE	34 1/16
C_4	NW	38 15/16	C_{10}	S	39 3/16	D_6	NE	39 0/16
C_5	NW	36 12/16	D_1	S	36 13/16	D_7	NE	36 8/16
C_6	NW	34 2/16	D_2	S	34 2/16	D_8	NE	33 14/16

Concrete Gages on The Outside of The Vessel



Gage	Line	H	Gage	Line	H
B_5	N	38 6/16	B8	S	38 14/16
B6	N	36 8/16	B9	S	36 7/16
B7	N	33 15/16	B10	S	33 12/16

FIG. B4.9 STRAIN GAGE LOCATIONS ON PV4

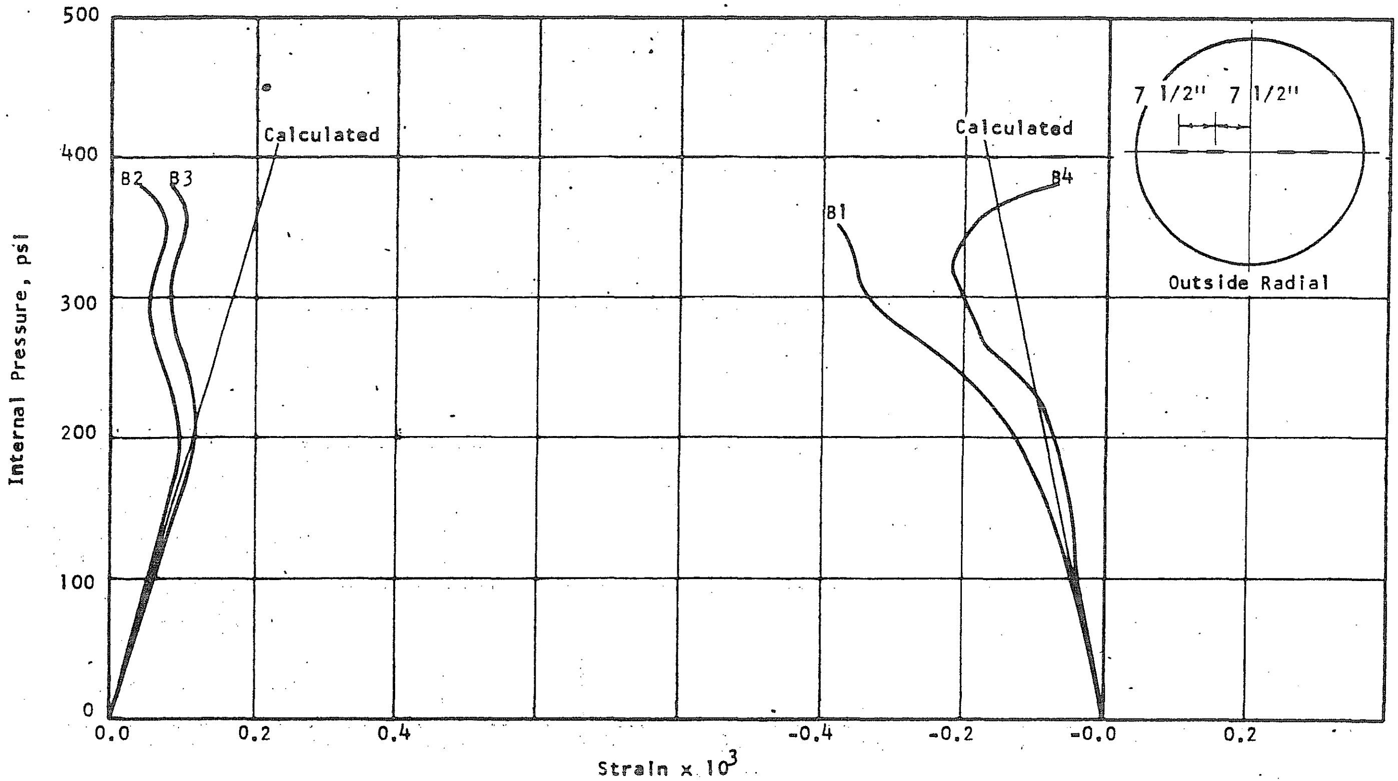


FIG. B4.10 CONCRETE STRAINS, VESSEL PV4

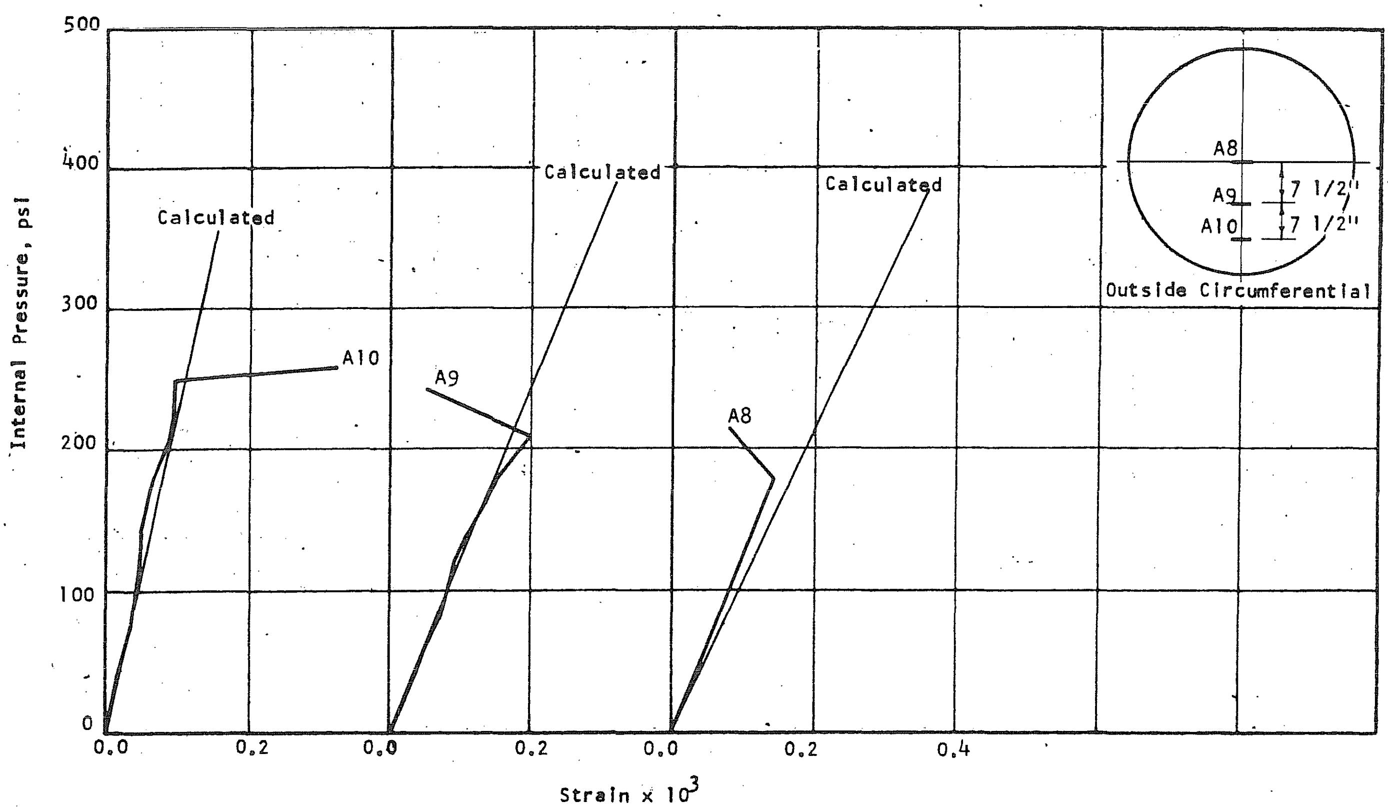


FIG. B4.11 CONCRETE STRAINS, VESSEL PV4

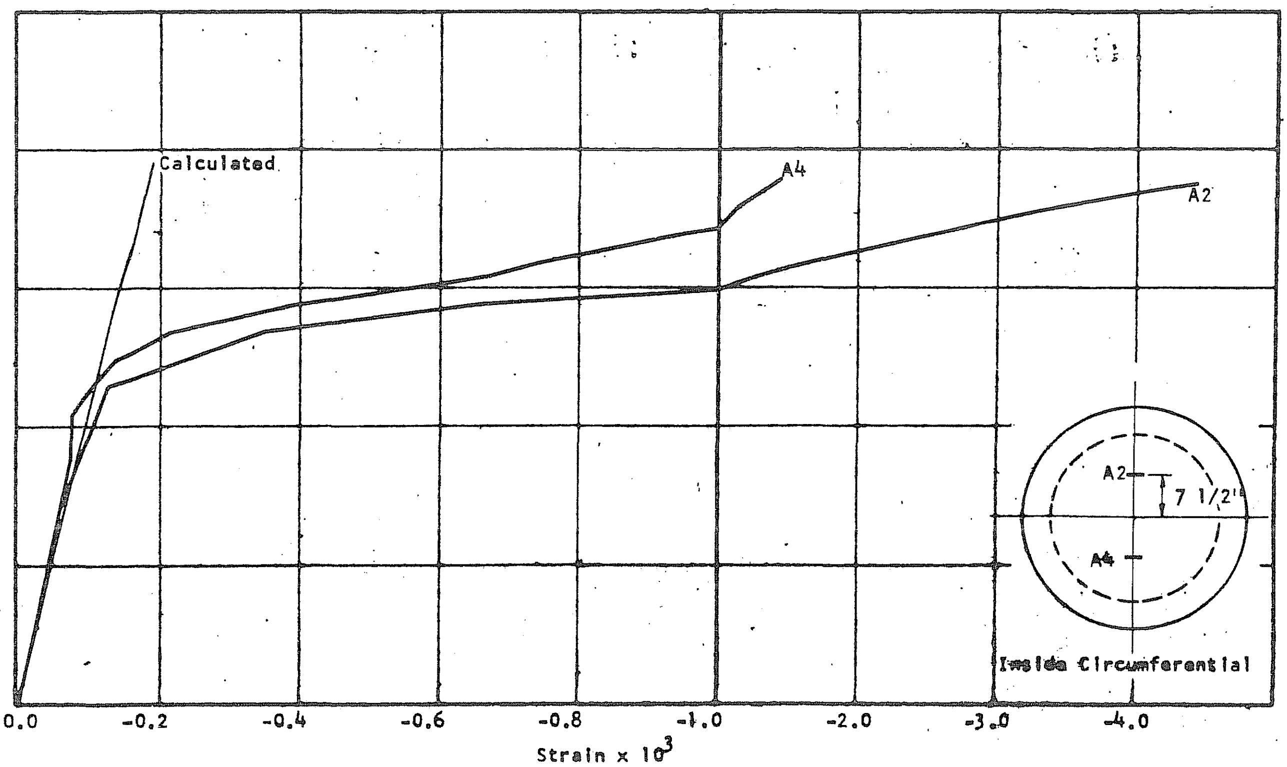


FIG. B4.12 CONCRETE STRAINS, VESSEL PV4

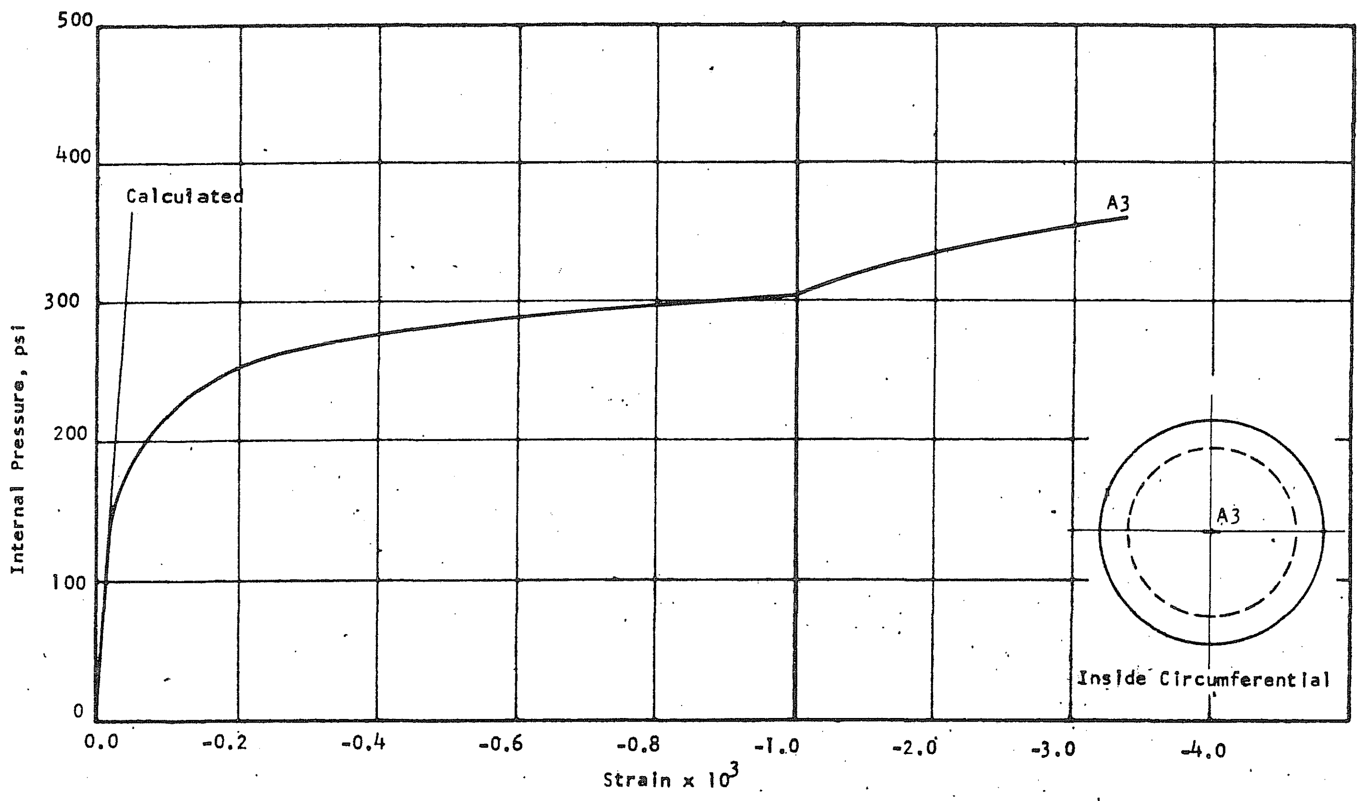


FIG. B4.13 CONCRETE STRAINS, VESSEL PV4

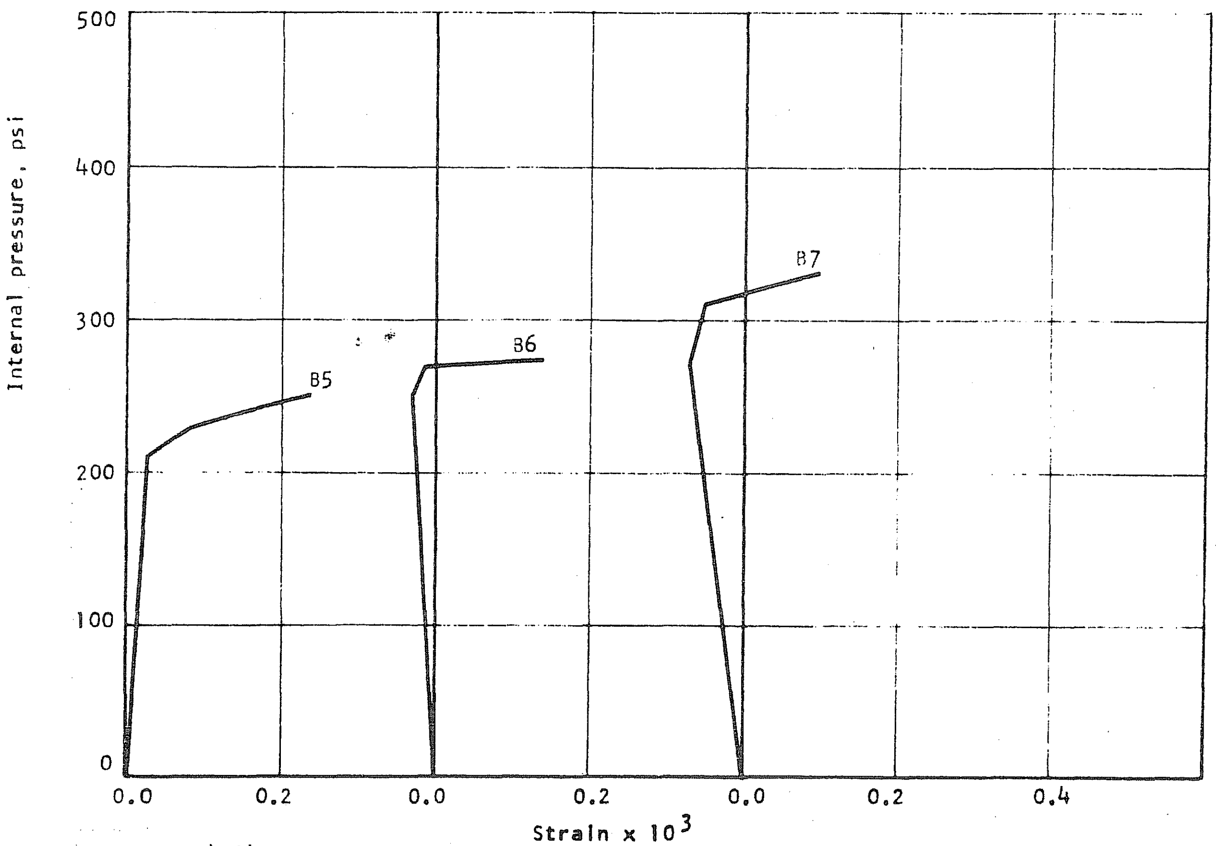


FIG. B4.14 APPLIED PRESSURE vs CIRCUMFERENTIAL STRAIN ON THE WALL OF THE VESSEL AT THE N-END OF THE N-S DIAMETER OF PV4

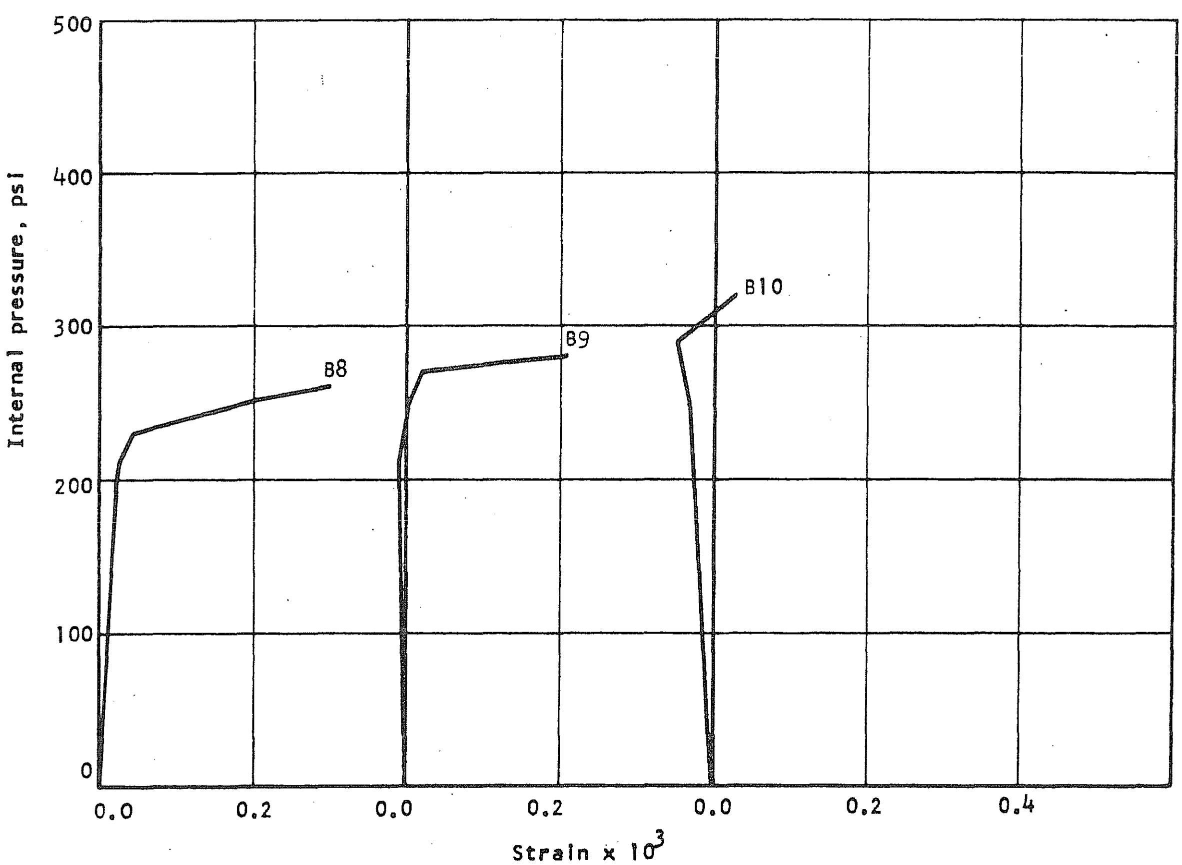


FIG. B4.15 APPLIED PRESSURE vs CIRCUMFERENTIAL STRAIN IN THE WALL OF THE VESSEL AT THE S-END OF THE N-S DIAMETER OF PV4

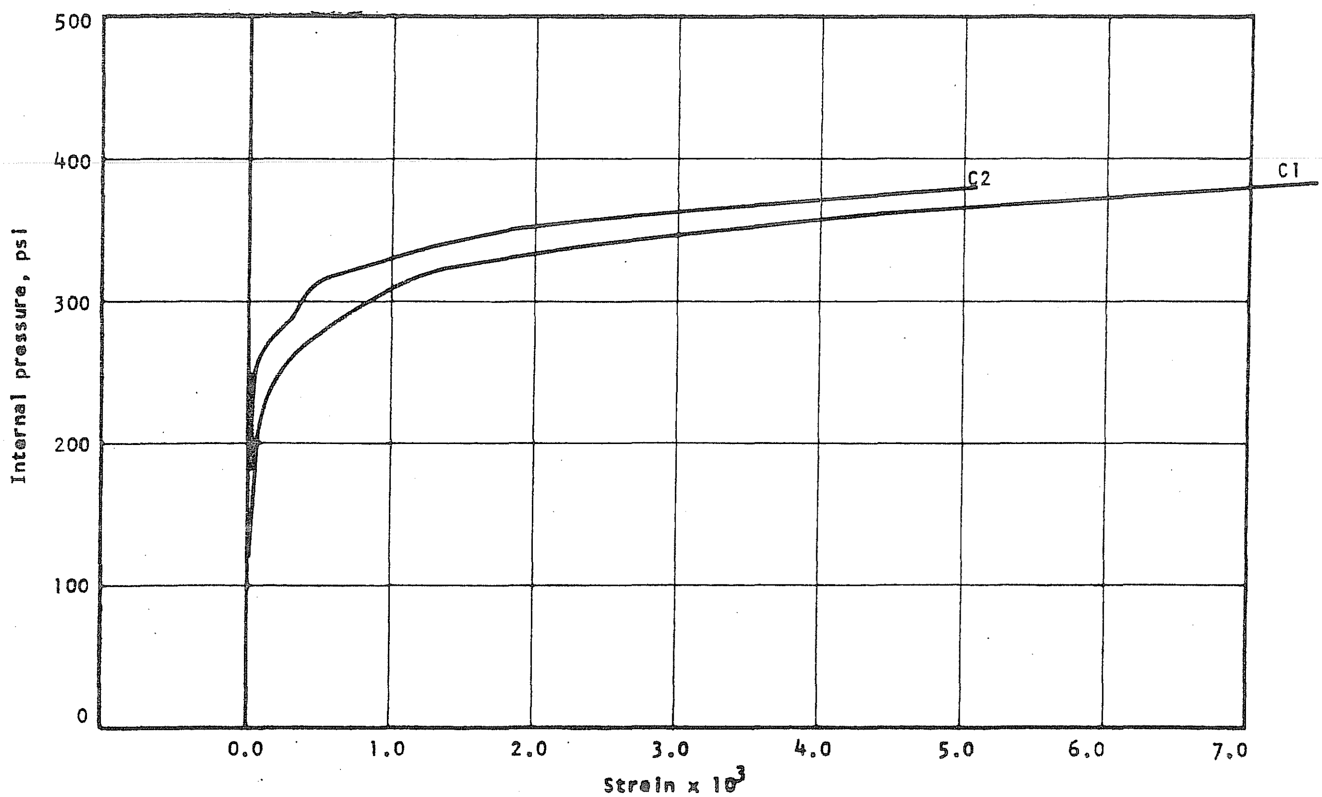


FIG. B4.16 APPLIED PRESSURE vs STRAIN IN THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE N-END OF THE N-S DIAMETER OF PV4

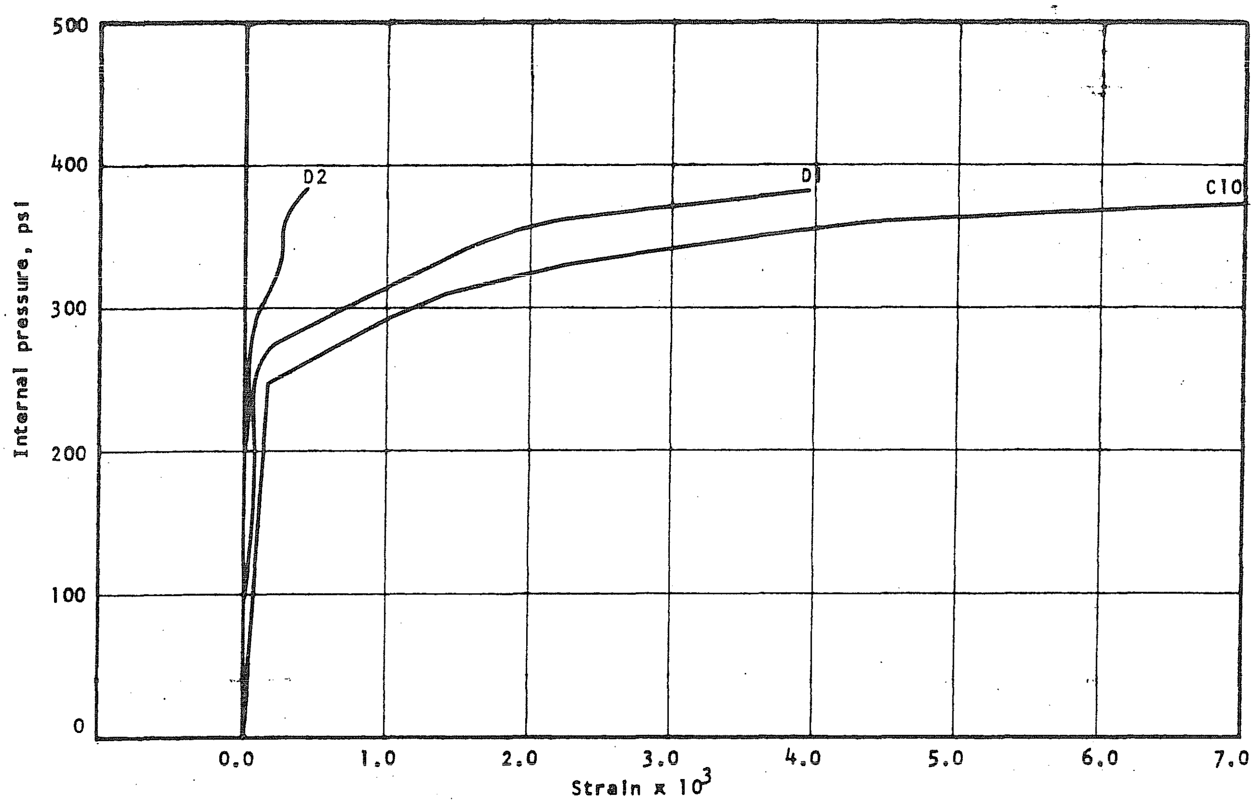


FIG. B4.17 APPLIED PRESSURE vs STRAIN IN THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE S-END OF THE N-S DIAMETER OF PV4

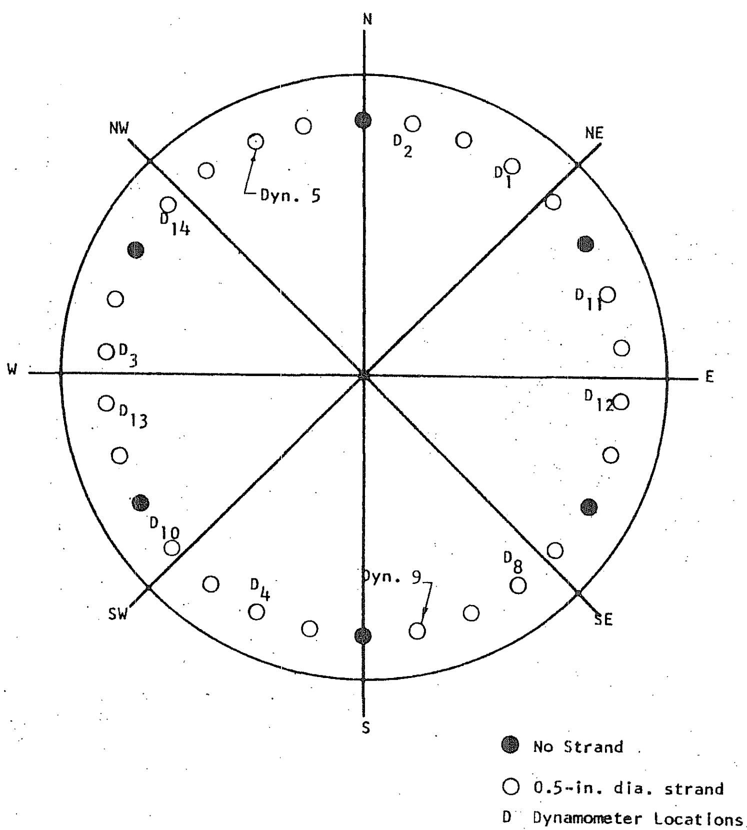


FIG B4.18 LOCATION OF LONGITUDINAL REINFORCEMENT

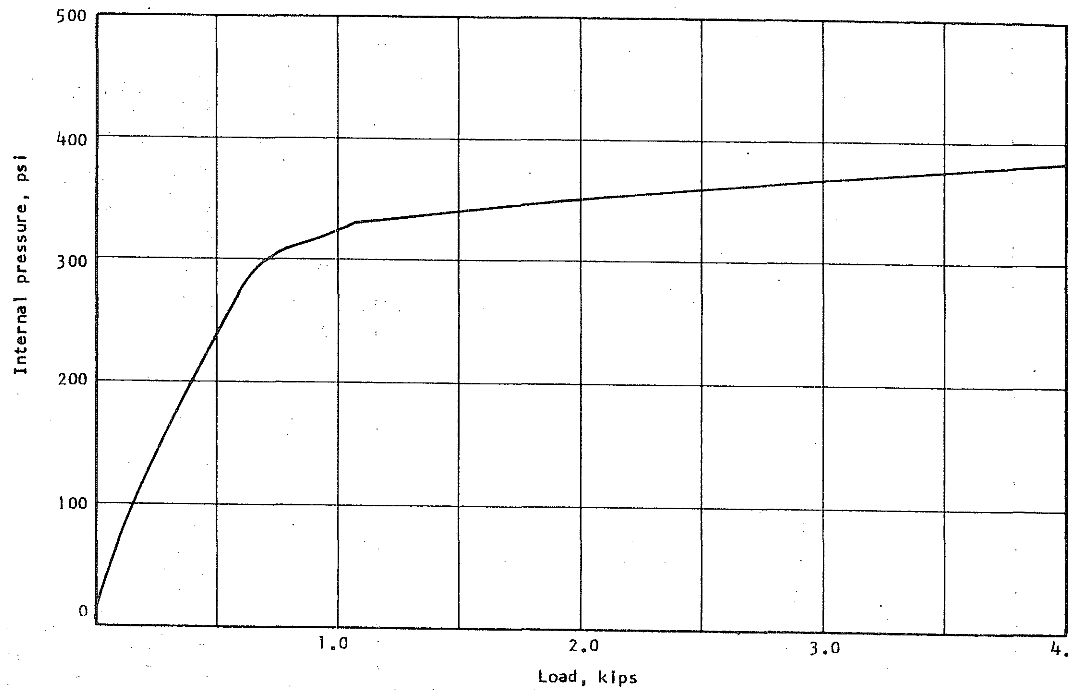


FIG. B4.19 APPLIED PRESSURE vs INCREASE IN LOAD IN DYNAMOMETER NO. 5 IN PV4

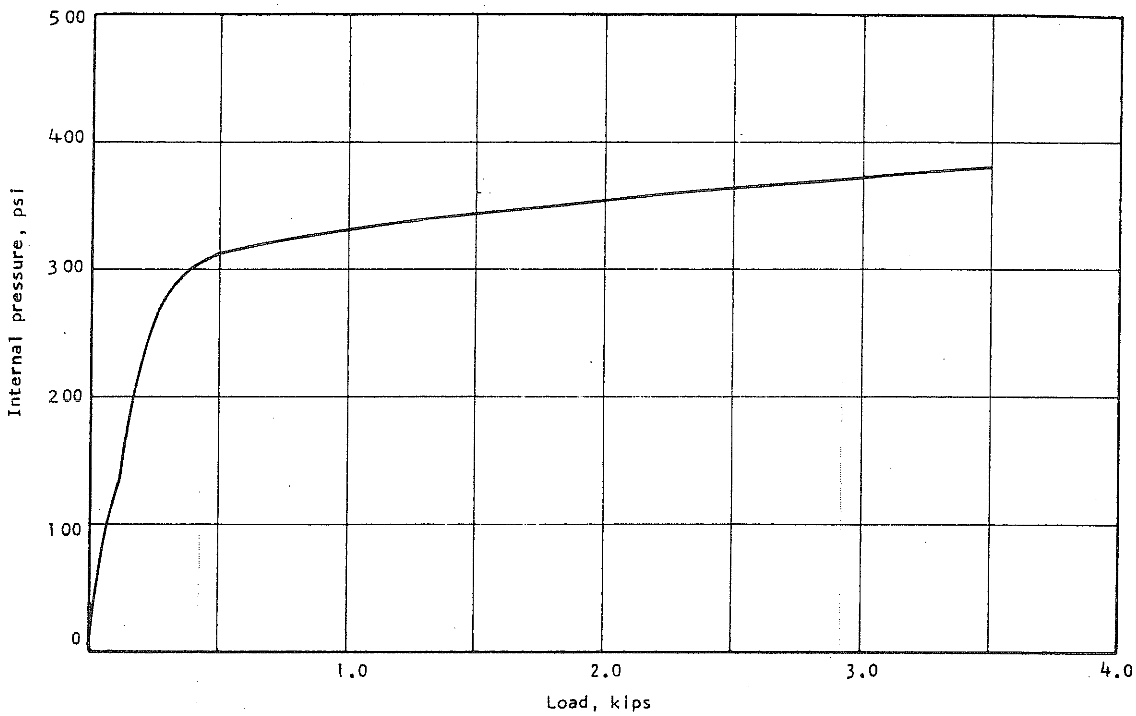


FIG. B4.20 APPLIED PRESSURE vs INCREASE IN LOAD IN DYNAMOMETER NO. 9 IN PV4

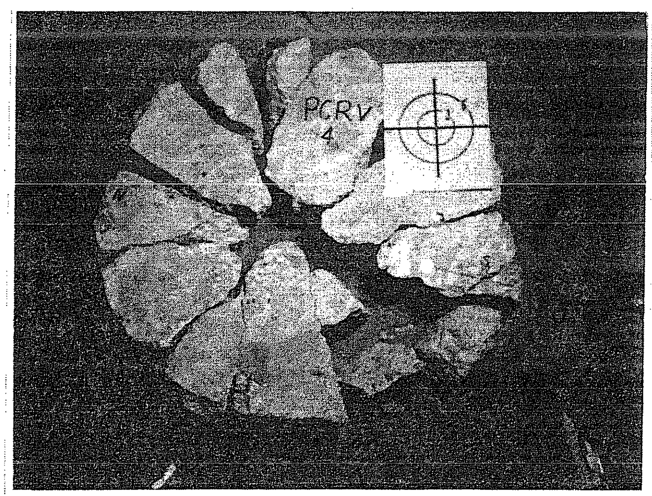


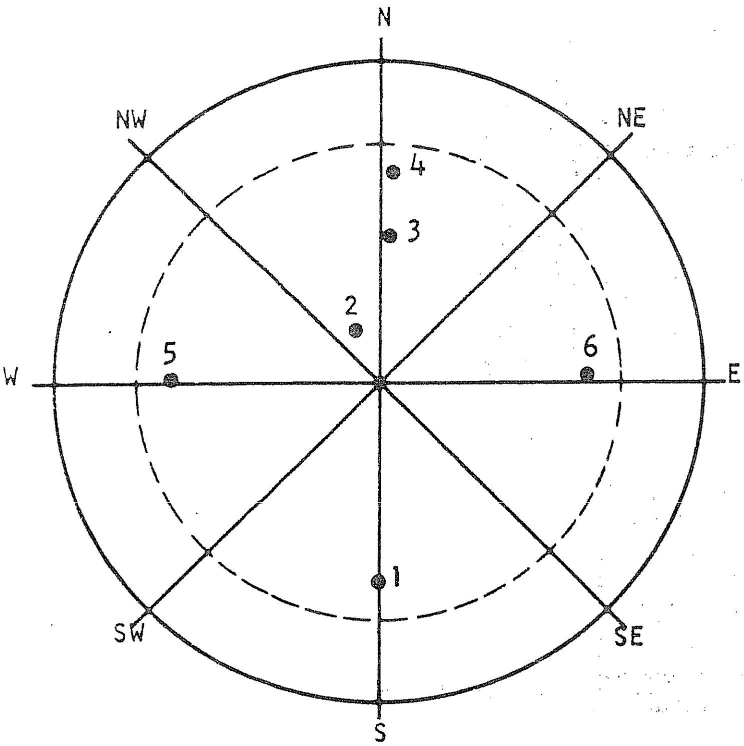
FIG. B4.21 REASSEMBLED END SLAB OF PV4

B5 Test Vessel PV5 (t = 7 1/2 in., s = 2/3 in.)

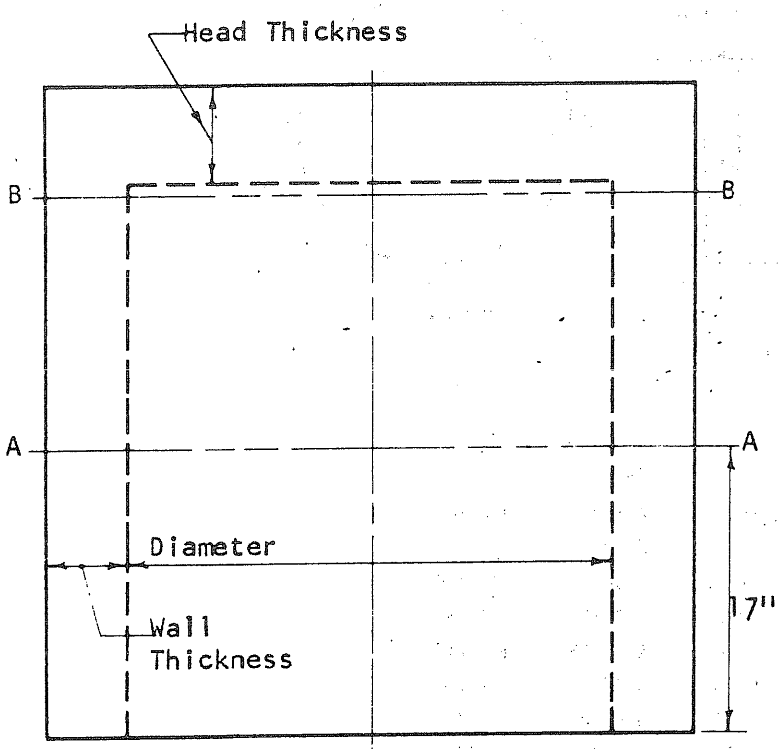
Test vessel PV5 was also tested with no unusual difficulties. It had no visible cracks before the test.

About three hours were required to test PV5. Internal pressure was increased in increments of 50 psi up to a pressure of 200 psi. Loading then proceeded in 25 psi increments until the vessel failed at 465 psi. The crack pattern in the end slab is illustrated in Fig. B5.22.

The longitudinal tendons and the method of sealing were the same as for PV5.



Head Thickness	
Point No.	Inches
1	7.7
2	7.75
3	7.75
4	7.65
5	7.75
6	7.60



Wall Thickness, in.		
Axis \ Plane	AA	BB
N		5.25
NE		5.07
E		4.86
SE		4.90
S		5.02
SW		5.04
W		5.00
NW		5.20

Inside Diameter, in.		
Axis \ Plane	AA	BB
N-S		$29\frac{12}{16}$
NE-SW		$29\frac{14}{16}$
E-W		$29\frac{15}{16}$
SE-NW		$29\frac{14}{16}$

FIG. B5.1 DIMENSIONS OF PV5

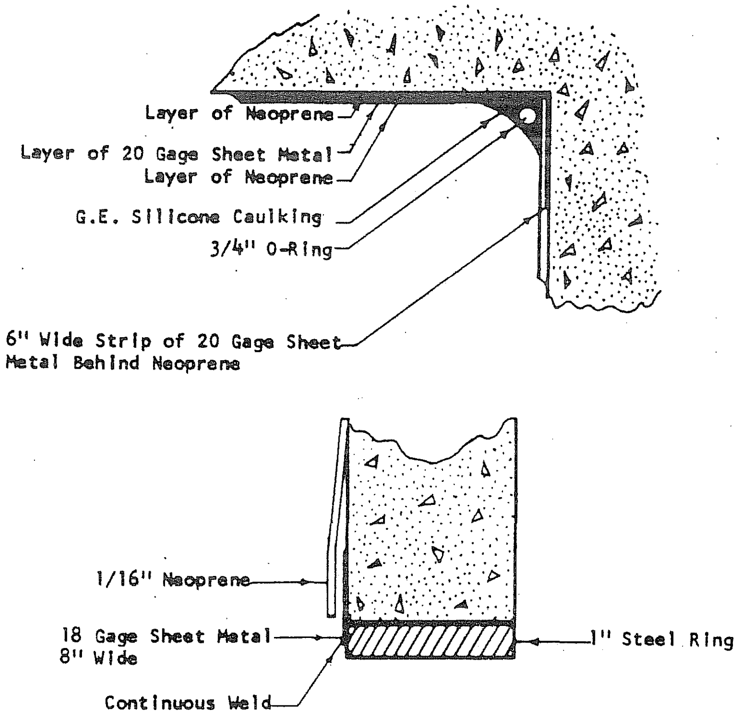
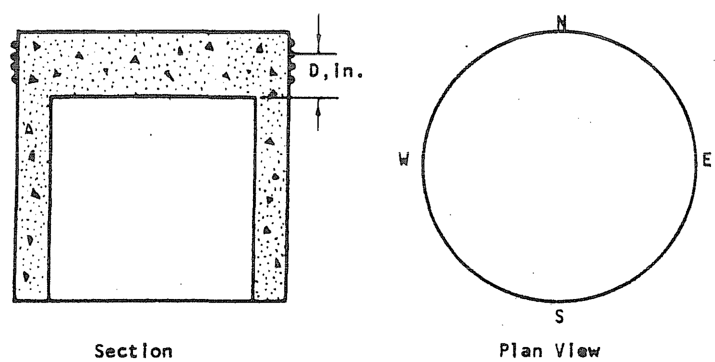


FIG. B5.2 SEALING DETAIL FOR PV5



Wrap No.	D_N	D_E	D_S	D_W
1	6 13/16	6 14/16	6 14/16	7 0/16
2	6 6/16	6 3/16	6 1/16	6 1/16
3	6 2/16	5 15/16	5 12/16	5 12/16
4	5 10/16	5 7/16	5 5/16	5 5/16
5	5 4/16	5 0/16	4 13/16	4 12/16
6	4 11/16	4 6/16	4 2/16	4 1/16
7	4 0/16	3 12/16	3 8/16	3 7/16
8	3 6/16	3 1/16	2 14/16	2 13/16
9	2 11/16	2 7/16	2 3/16	2 2/16
10	2 0/16	1 12/16	1 8/16	1 7/16
11	1 6/16	1 1/16	14/16	12/16
12	11/16	7/16	-8/16	2/16

FIG. B5.3 MEASURED LOCATION OF THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE ENDS OF THE N-S AND E-W DIAMETERS ON PV5

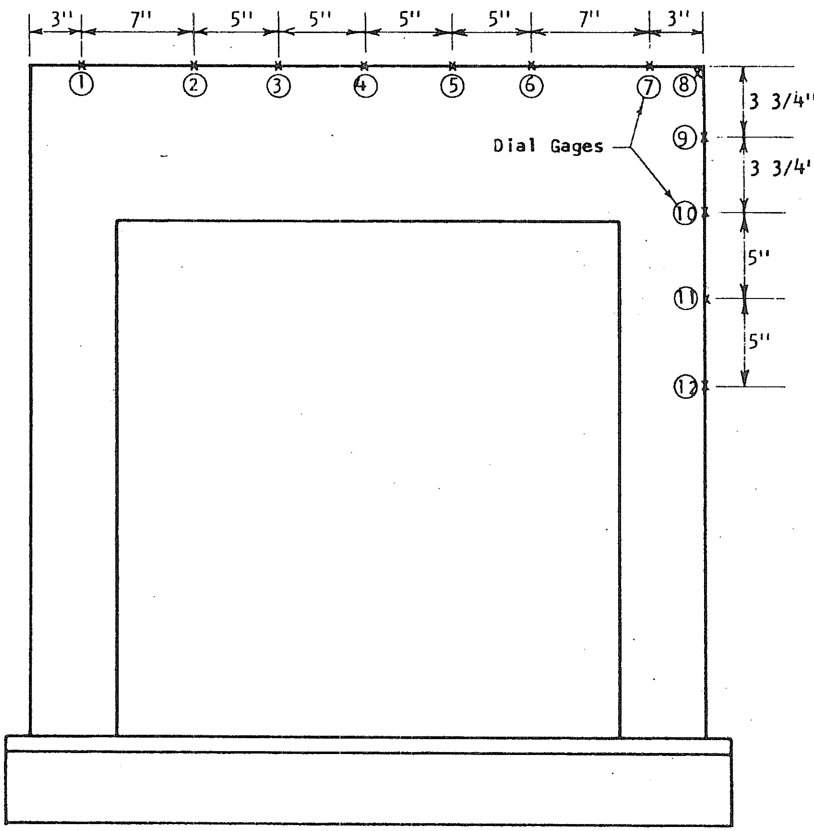


FIG. B5.4 LOCATION OF DEFLECTION GAGES ON PV5

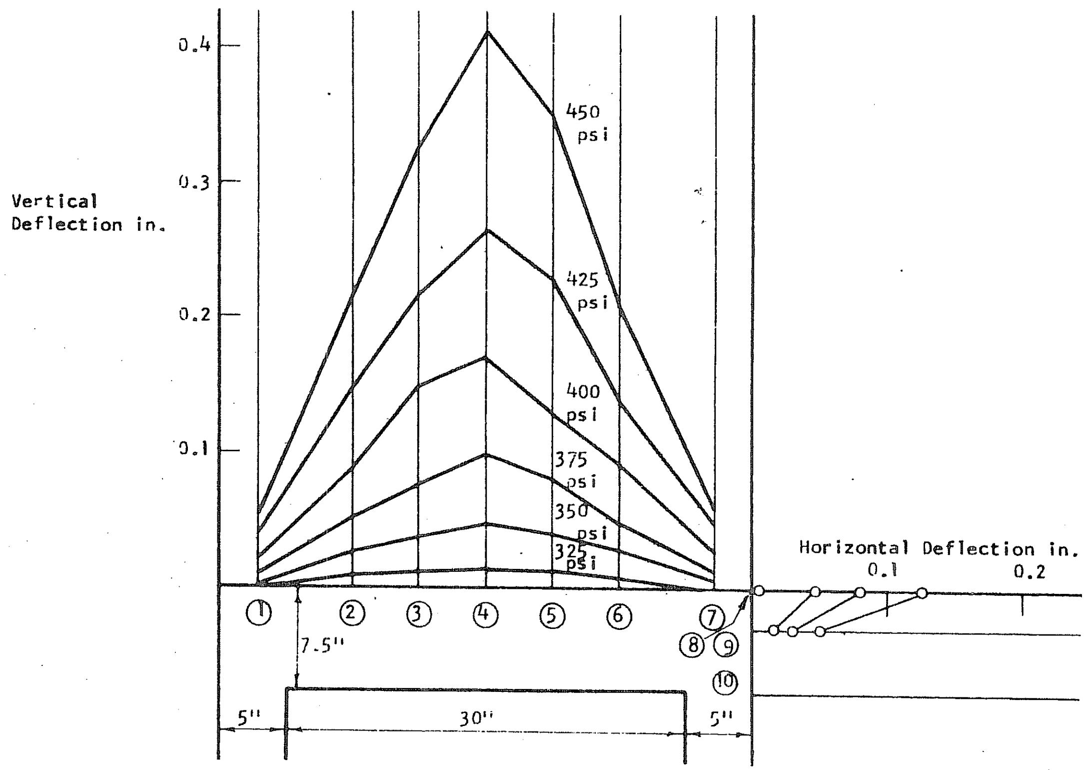


FIG. B5.5 DEFLECTION PROFILES OF THE END SLAB ALONG THE N-S DIAMETER OF PV5

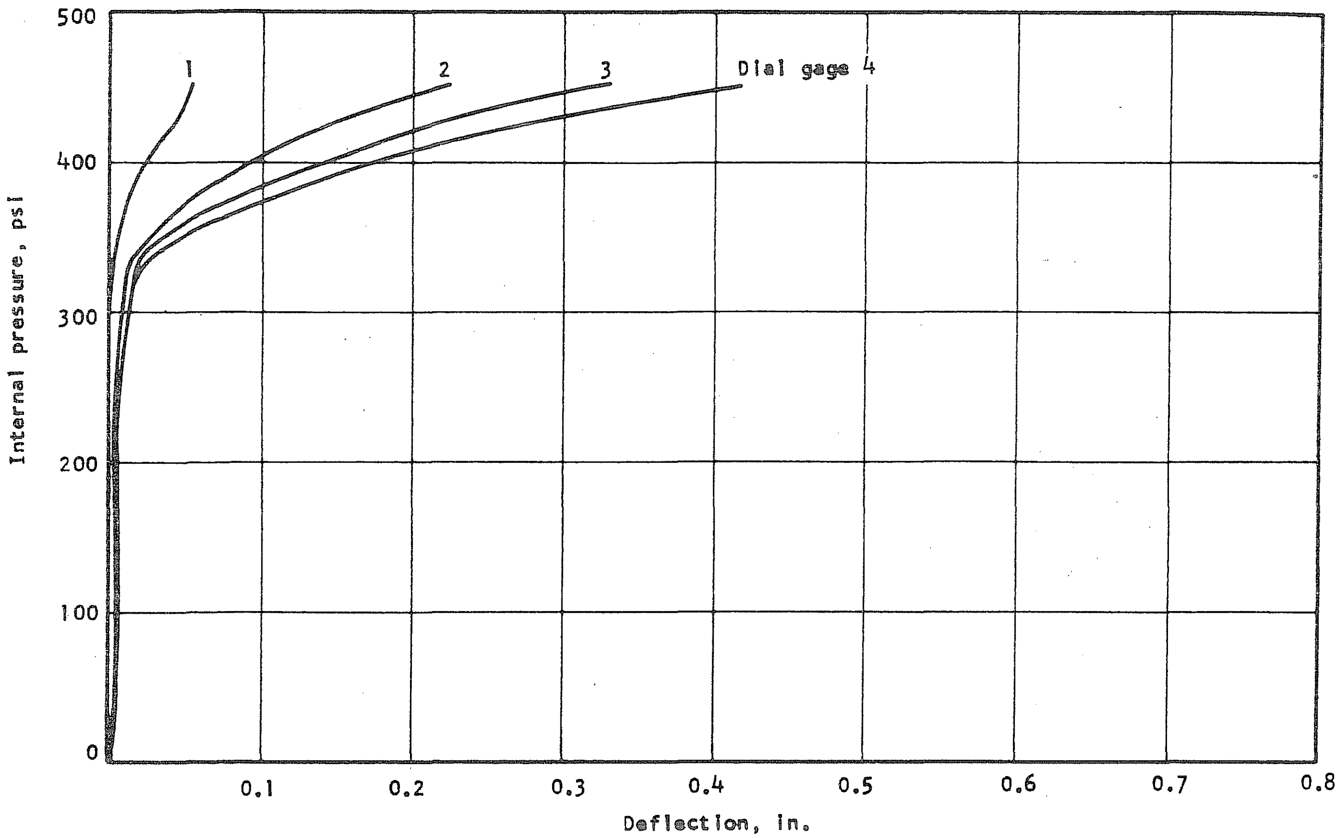


FIG. B5.6 APPLIED PRESSURE vs DEFLECTION ALONG THE N-HALF OF THE N-S DIAMETER OF PV5

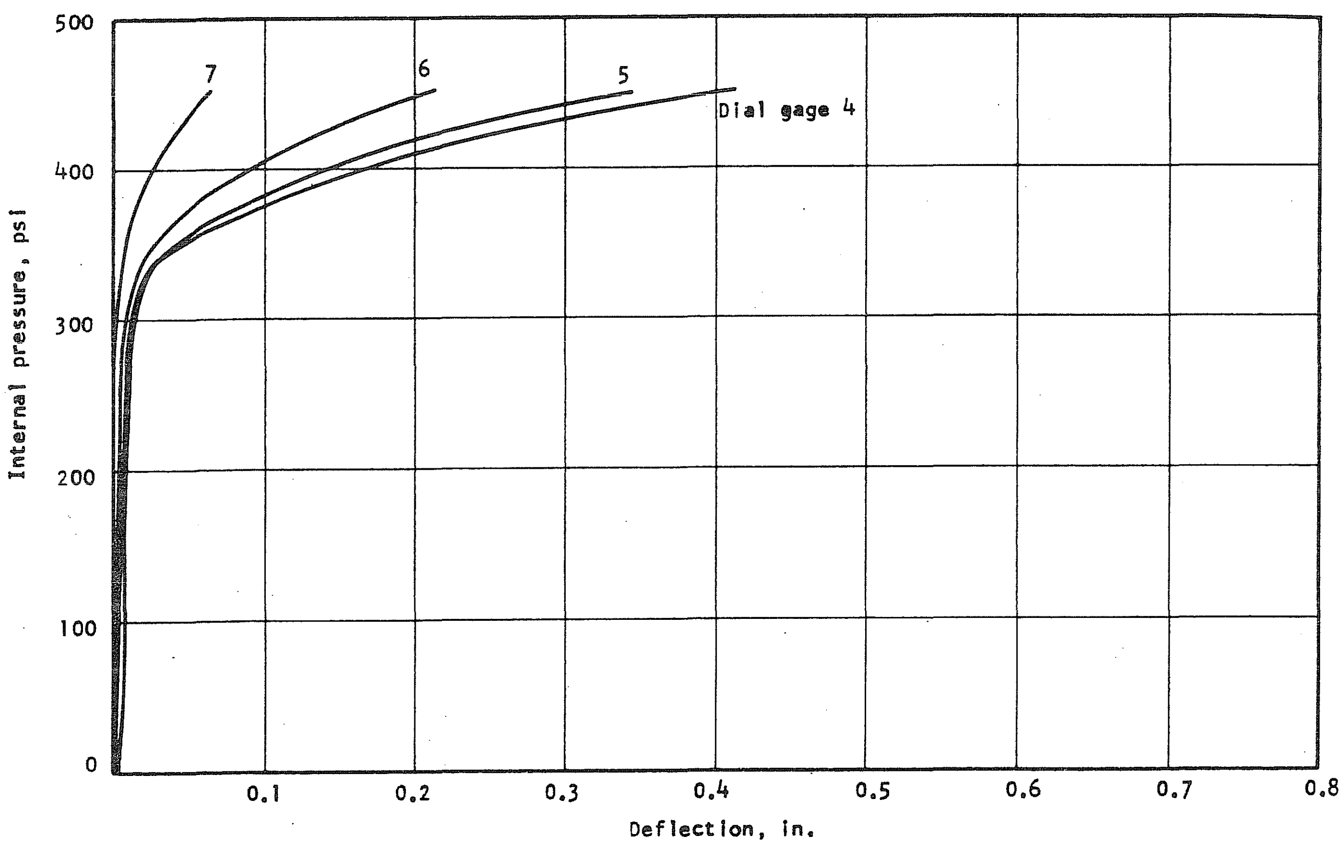


FIG. B5.7 APPLIED PRESSURE vs DEFLECTION ALONG THE S-HALF OF THE N-S DIAMETER OF PV5

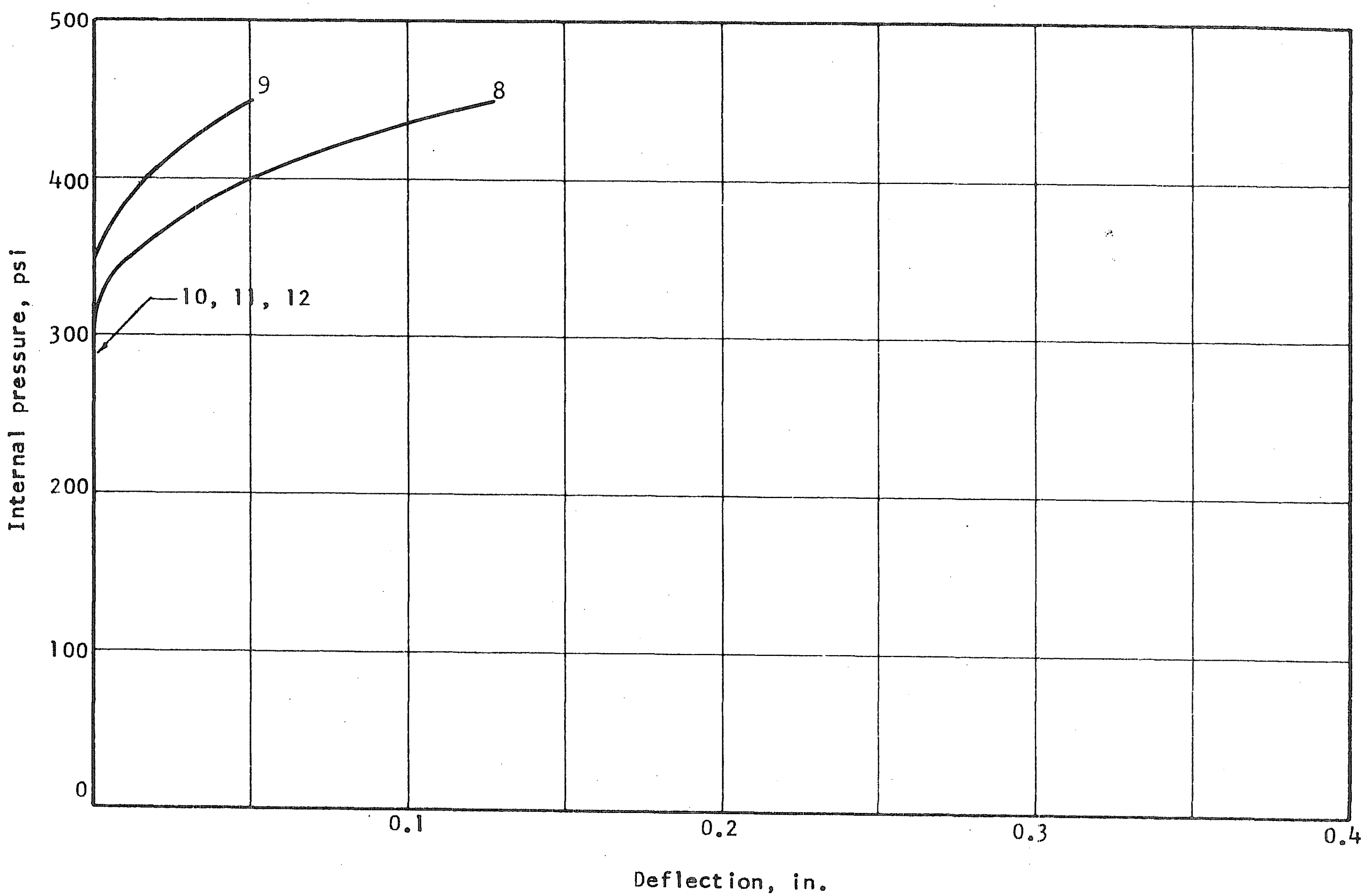
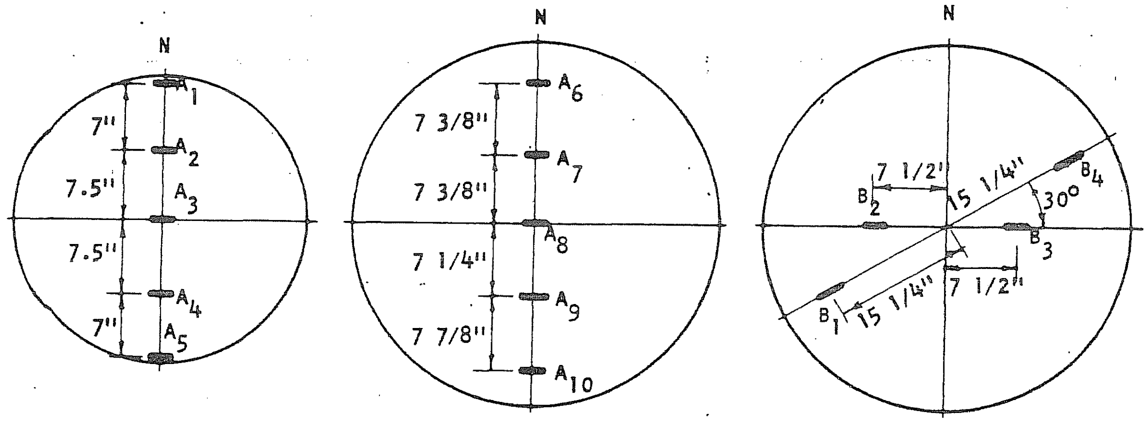
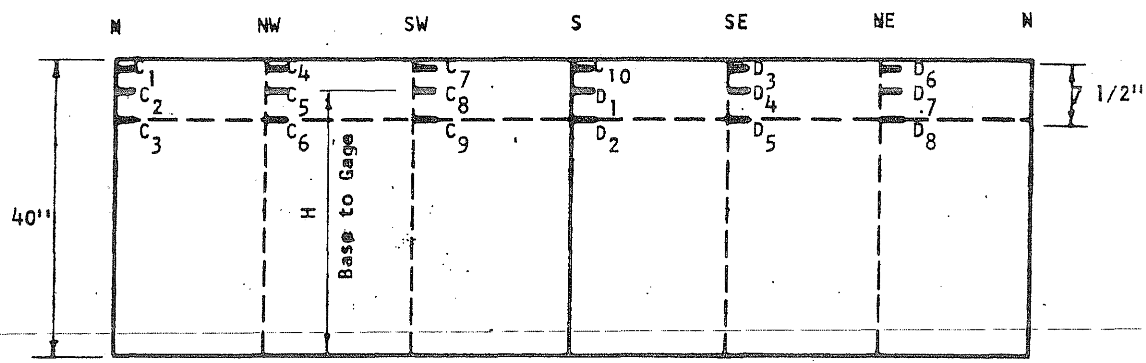


FIG. B5.8 APPLIED PRESSURE vs DEFLECTION OF THE SIDE WALL OF PV5

Concrete Gages On The Slab

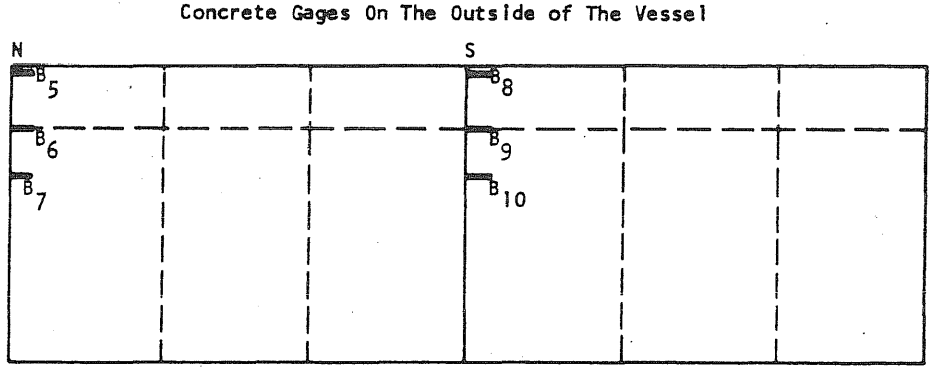


Steel Gages On Prestressing Wire



Gage	Axis	H	Gage	Axis	H	Gage	Axis	H
C_1	N	38 9/16	C_7	SE	38 10/16	D_3	SW	38 10/16
C_2	N	35 13/16	C_8	SE	35 8/16	D_4	SW	36 0/16
C_3	N	32 8/16	C_9	SE	32 3/16	D_5	SW	32 10/16
C_4	N	38 12/16	C_{10}	S	38 9/16	D_6	NW	38 10/16
C_5	NE	35 11/16	D_1	S	35 6/16	D_7	NW	35 4/16
C_6	NE	32 6/16	D_2	S	32 1/16	D_8	NW	32 9/16

Concrete Gages On The Outside of The Vessel



Gage	Axis	H	Gage	Axis	H
B_5	N	38 5/16	B_8	S	39 11/16
B_6	N	36 2/16	B_9	S	35 10/16
B_7	N	32 14/16	B_{10}	S	31 12/16

FIG. B5.9 STRAIN GAGE LOCATIONS ON PV5

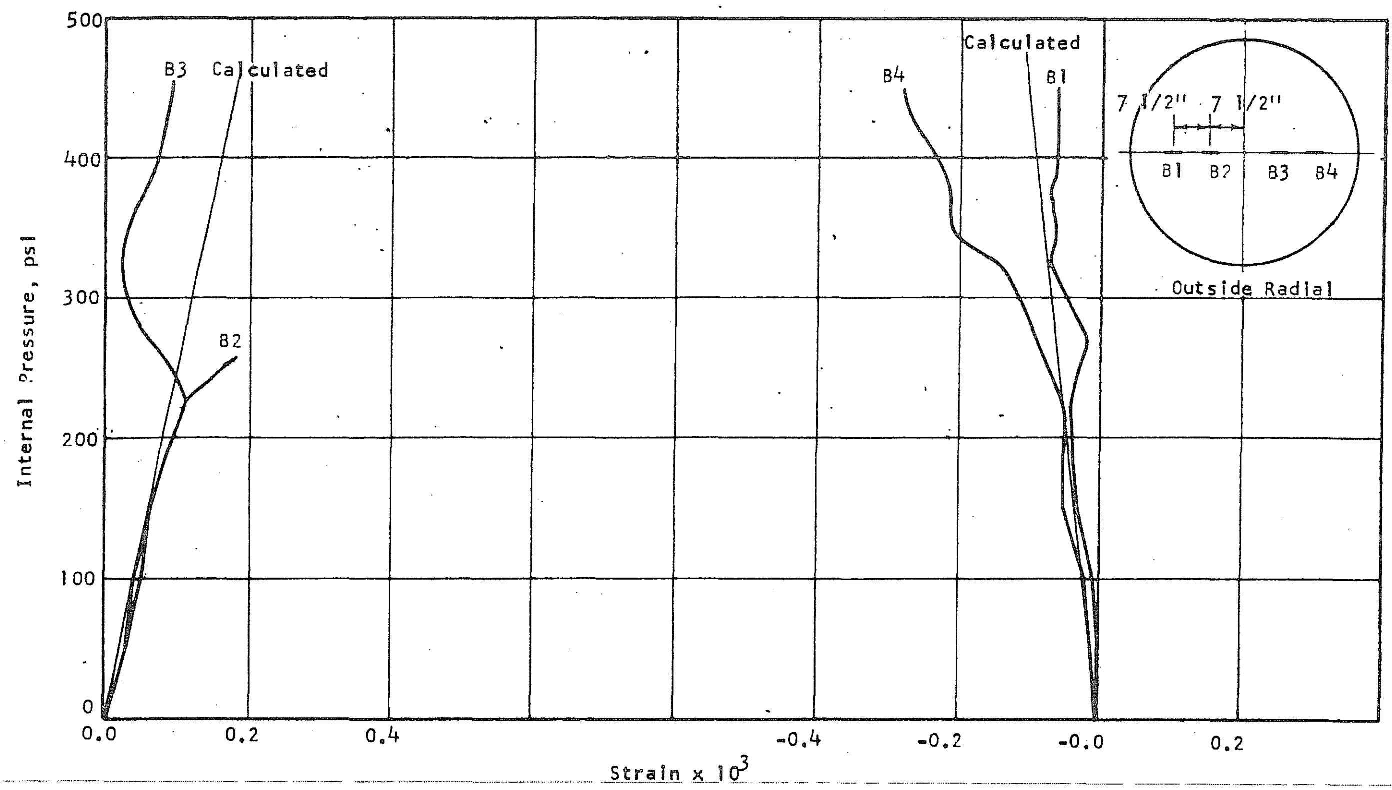


FIG. B5.10 CONCRETE STRAINS, VESSEL PV5

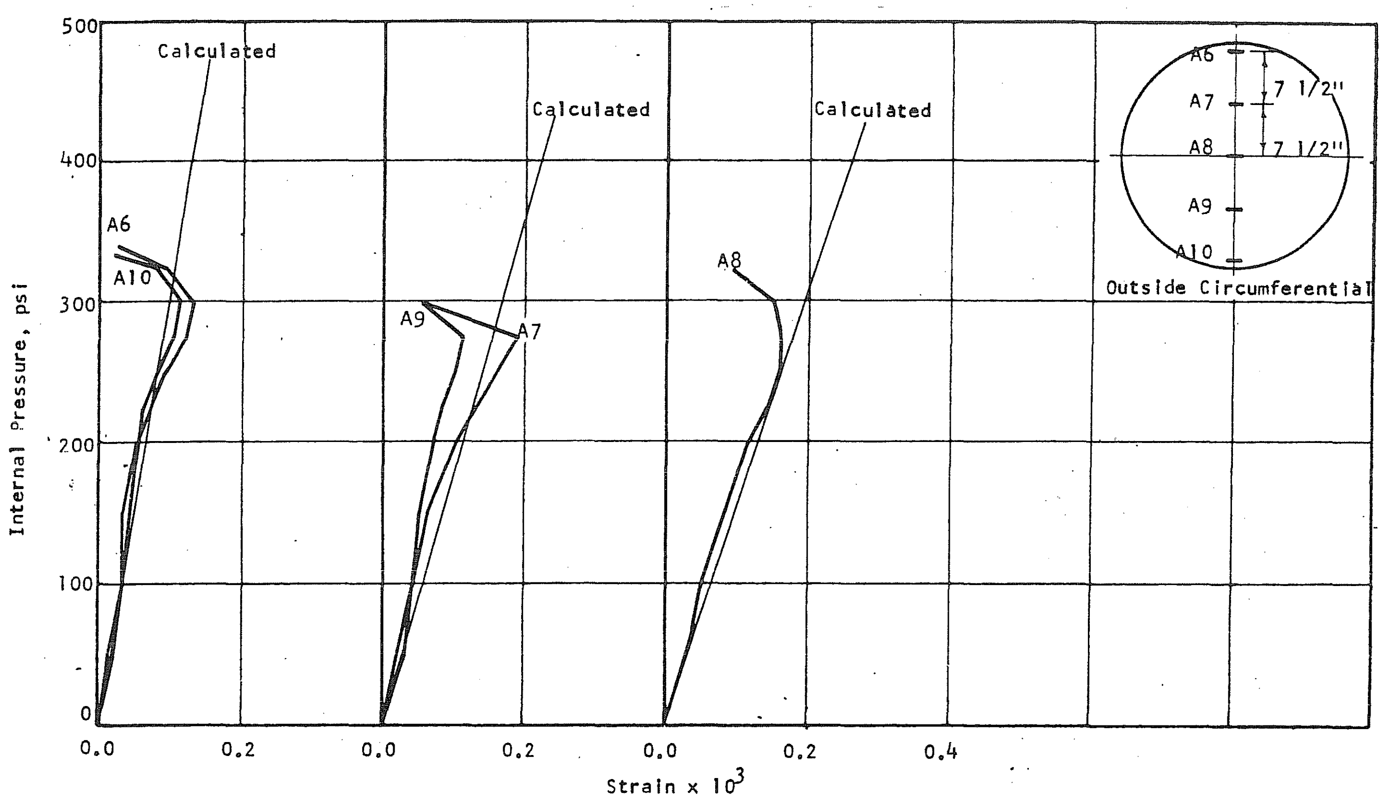


FIG. B5.11 CONCRETE STRAINS, VESSEL PV5

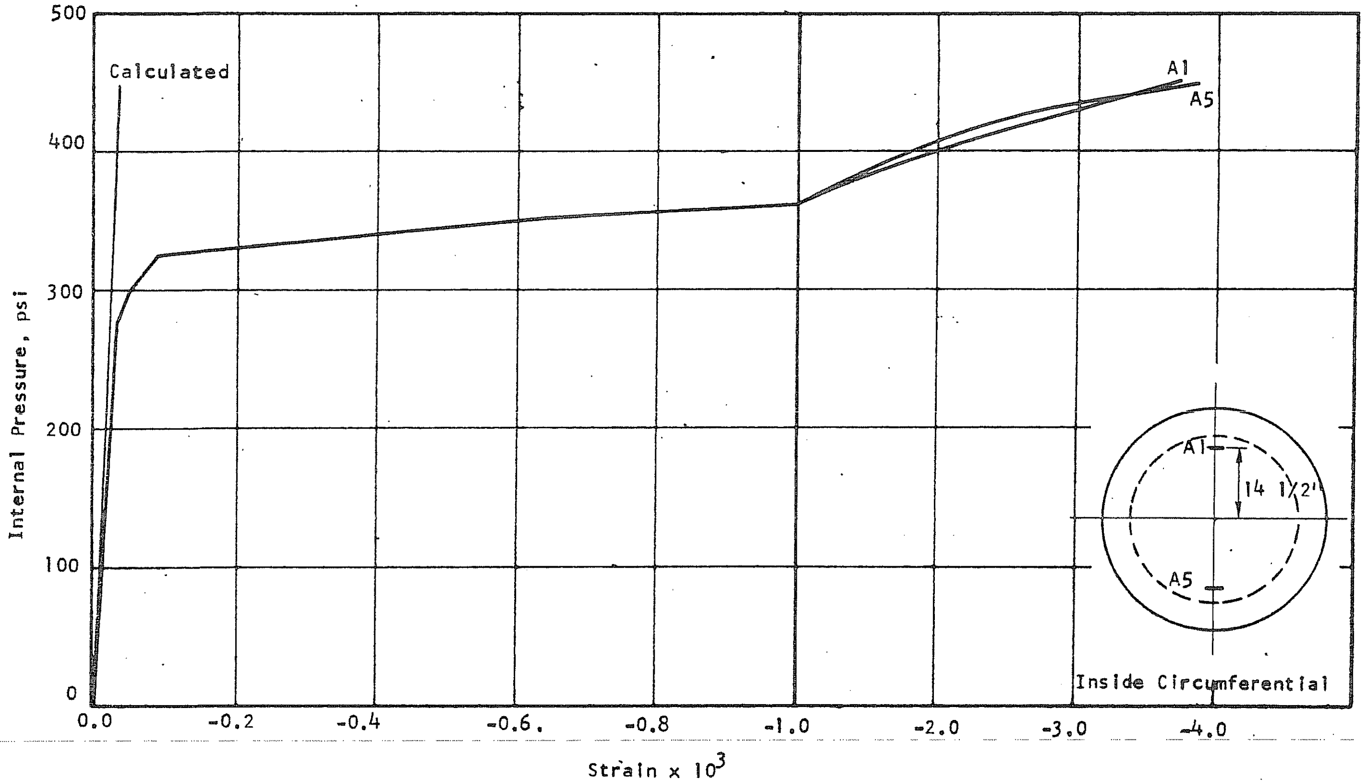


FIG. B5.12 CONCRETE STRAINS, VESSEL PV5

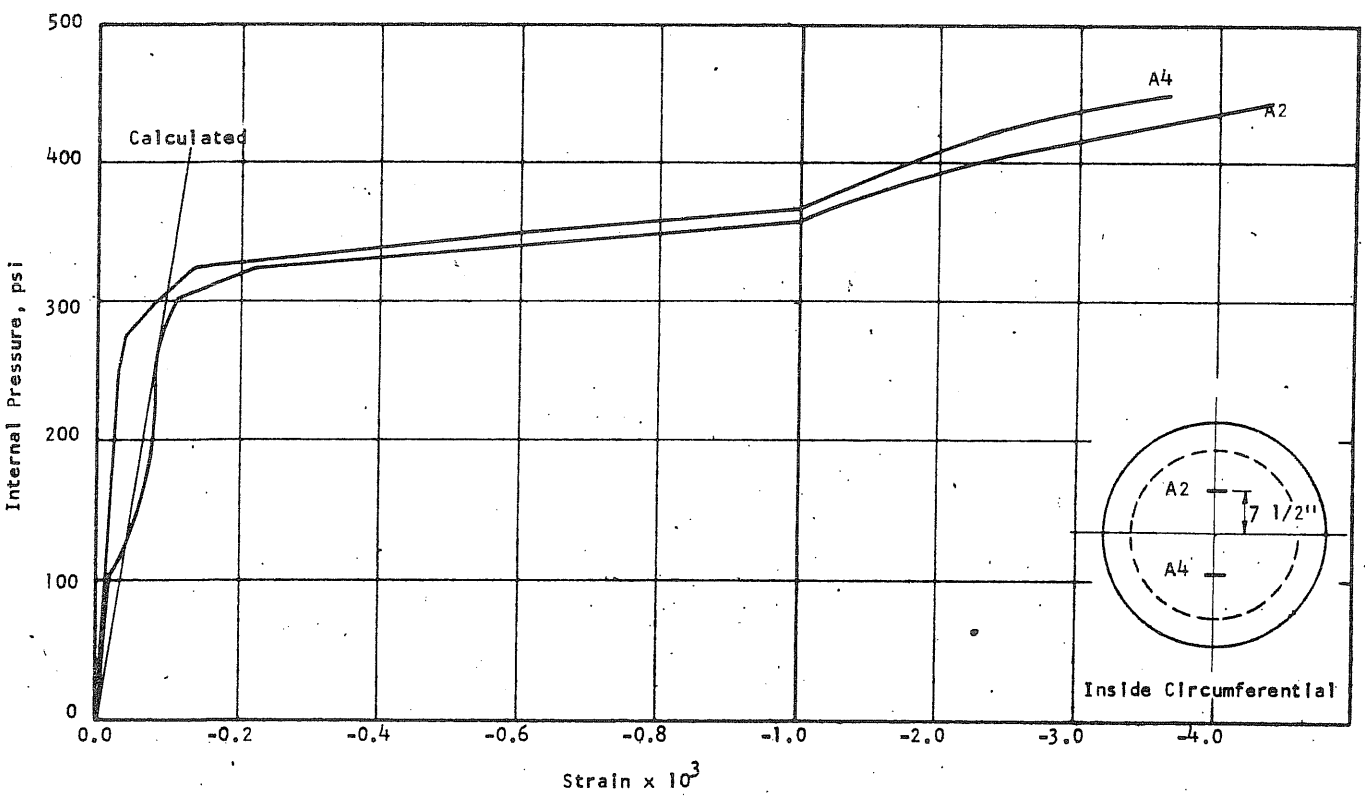


FIG. B5.13 CONCRETE STRAINS, VESSEL PV5

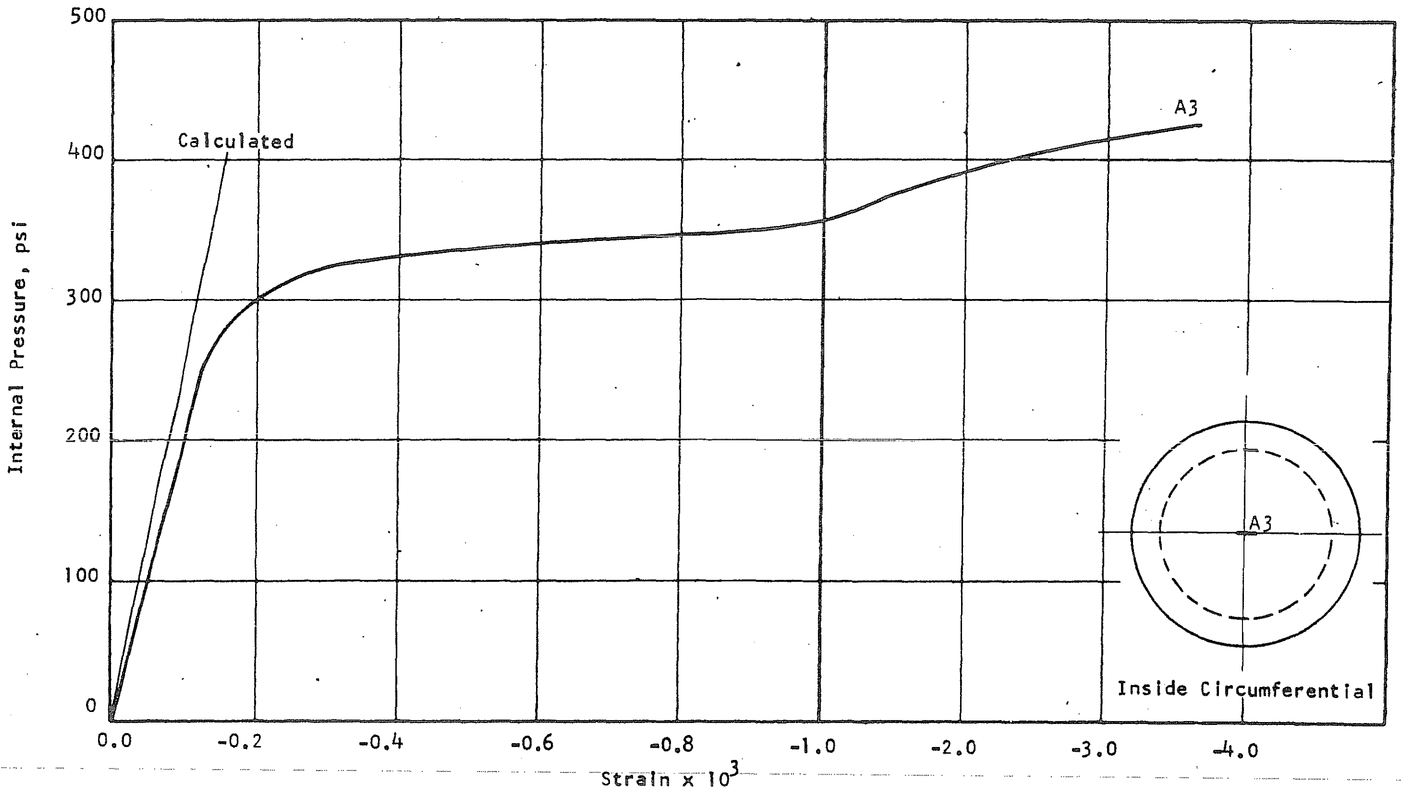


FIG. B5.14 CONCRETE STRAINS, VESSEL PV5

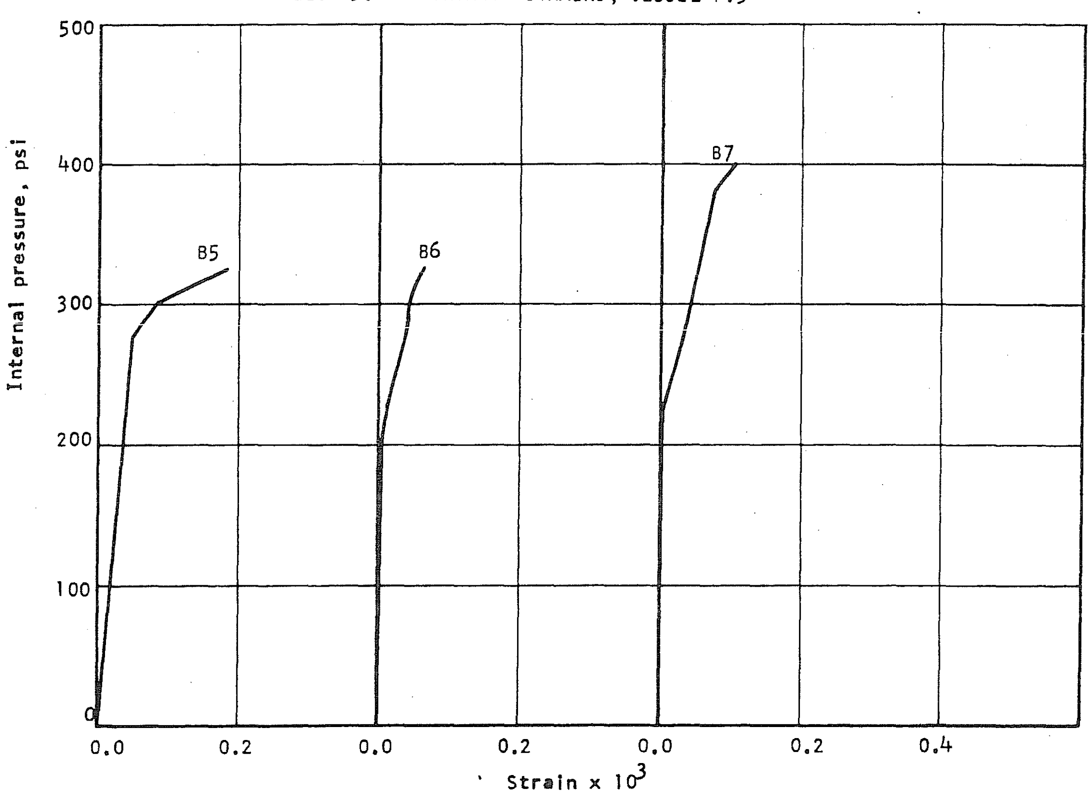


FIG. B5.15 APPLIED PRESSURE vs CIRCUMFERENTIAL STRAIN IN THE WALL OF THE VESSEL AT THE N-END OF THE N-S DIAMETER OF PV5

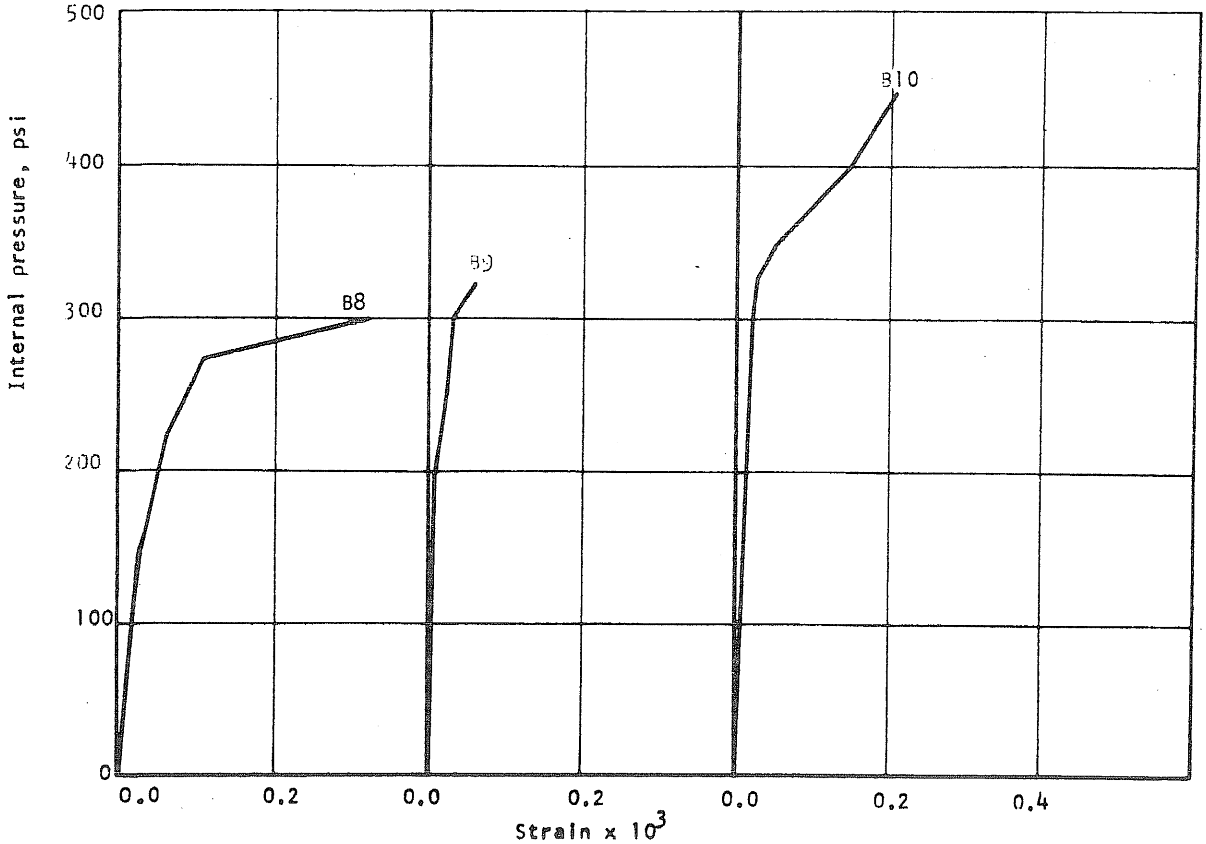


FIG. B5.16 APPLIED PRESSURE vs CIRCUMFERENTIAL STRAIN IN THE WALL OF THE VESSEL AT THE S-END OF THE N-S DIAMETER OF PV5

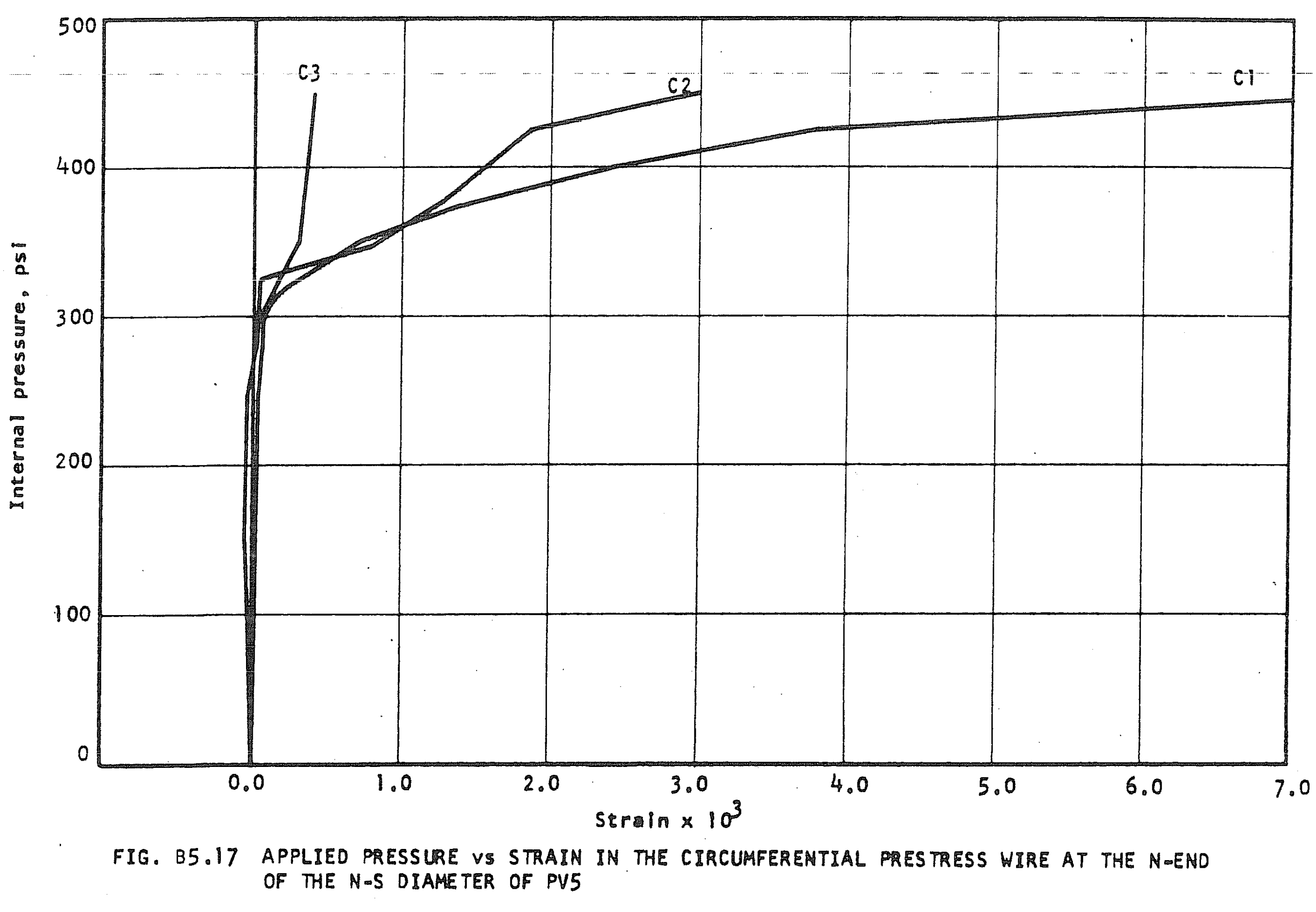


FIG. B5.17 APPLIED PRESSURE vs STRAIN IN THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE N-END OF THE N-S DIAMETER OF PV5

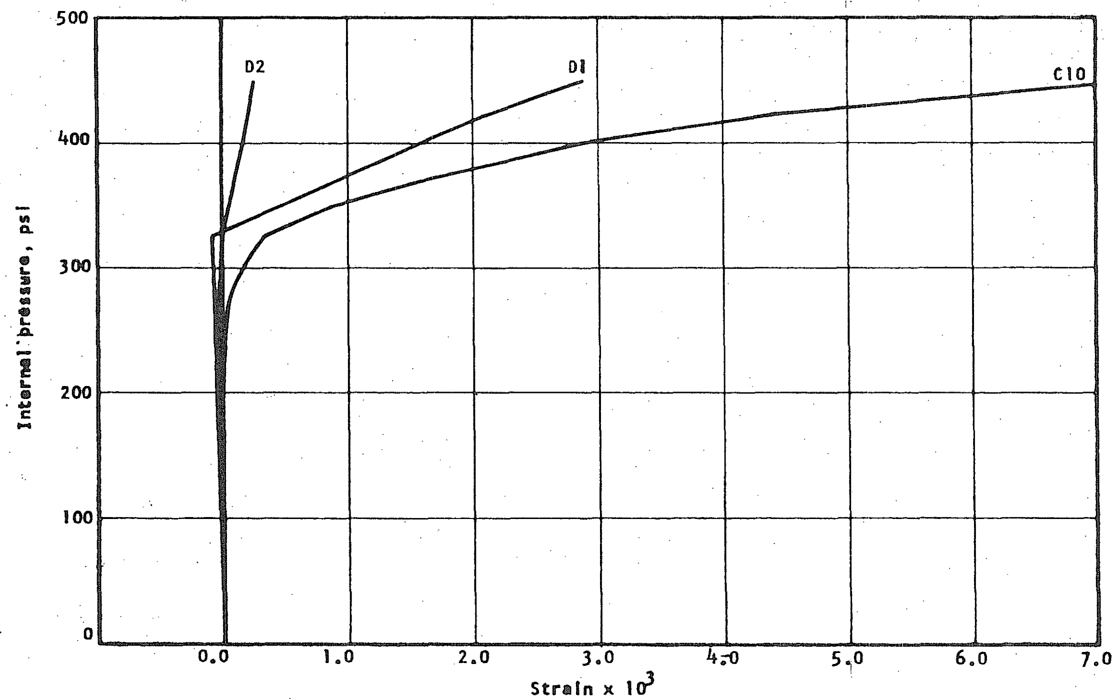


FIG. B5.18 APPLIED PRESSURE vs STRAIN IN THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE S-END OF THE N-S DIAMETER OF PV5

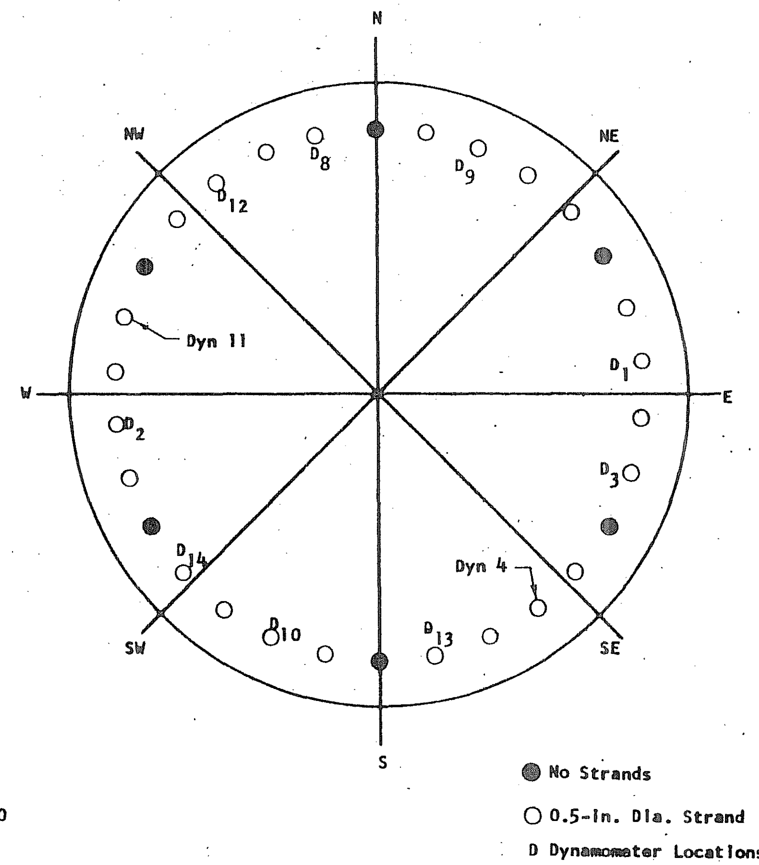


FIG. B5.19 LOCATION OF LONGITUDINAL REINFORCEMENT

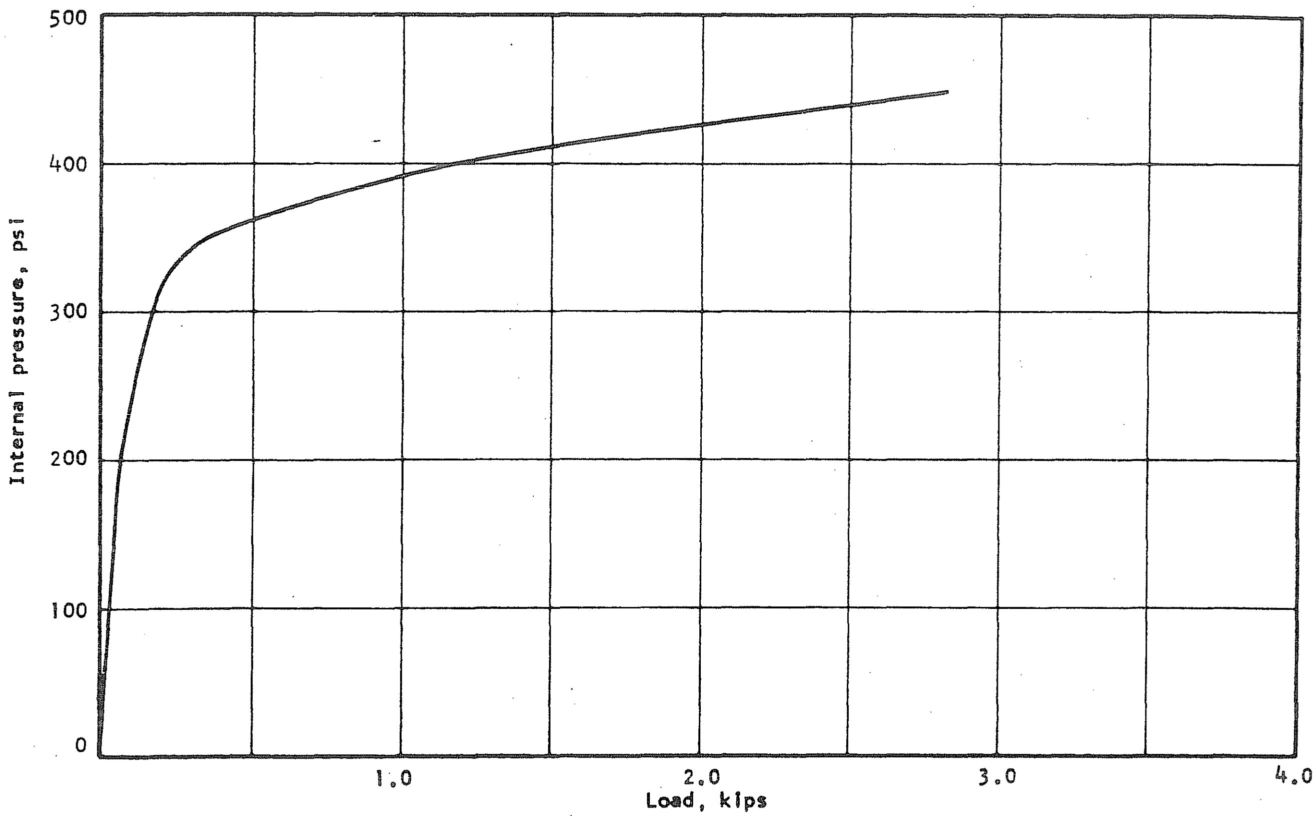


FIG. B5.20 APPLIED PRESSURE vs INCREASE IN LOAD IN DYNAMOMETER NO. 4 in PV5

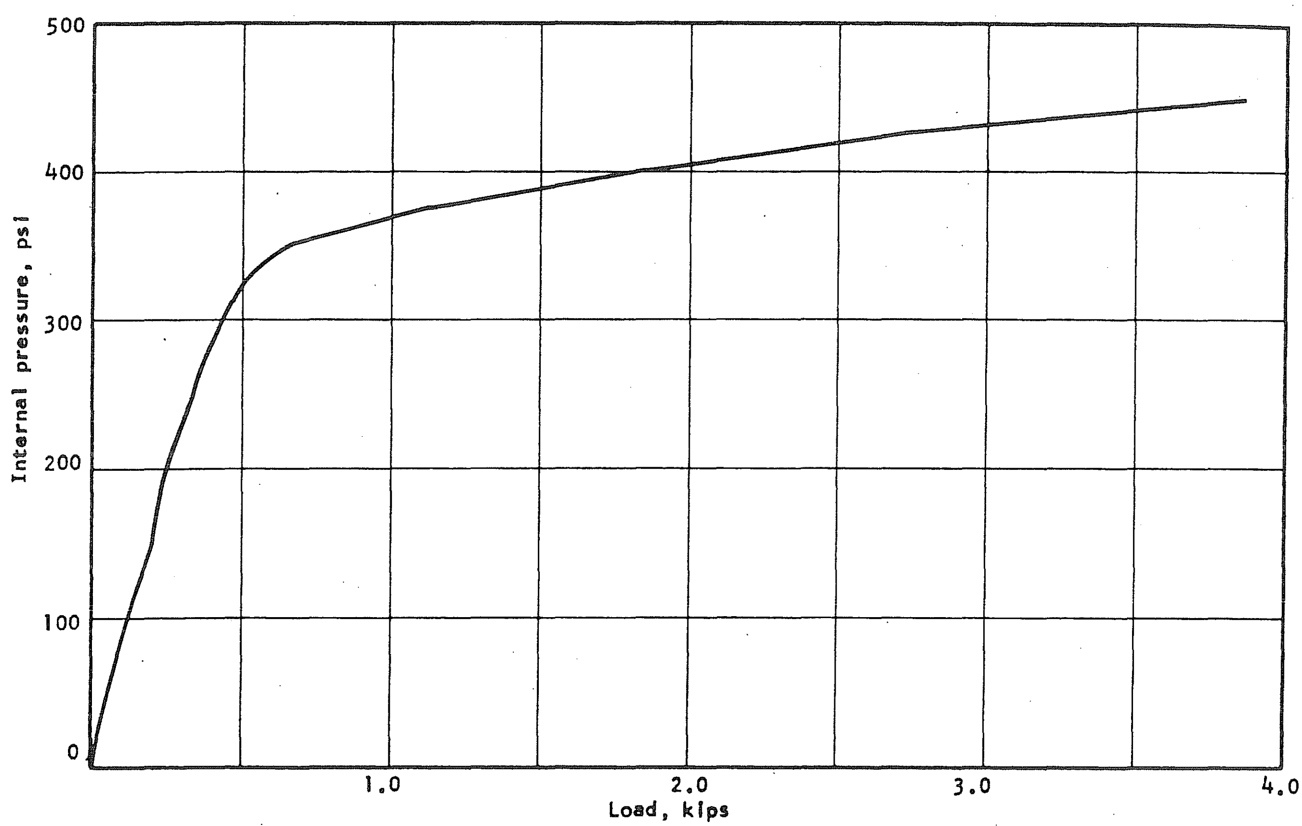


FIG. B5.21 APPLIED PRESSURE vs THE INCREASE IN LOAD IN DYNAMOMETER NO. 11 IN PV5

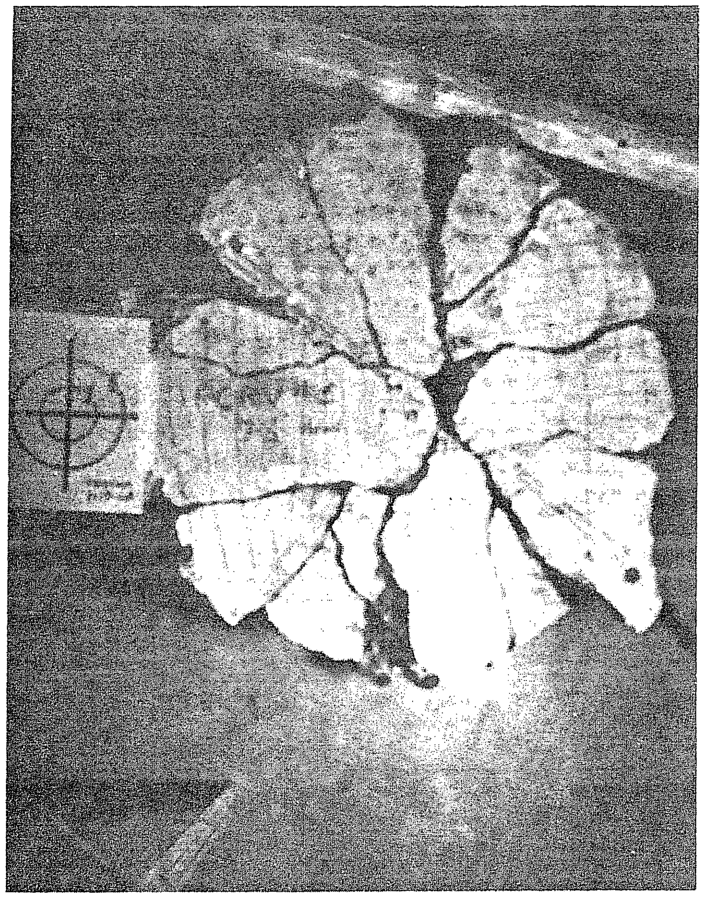


FIG. B5.22 REASSEMBLED END SLAB OF PV5

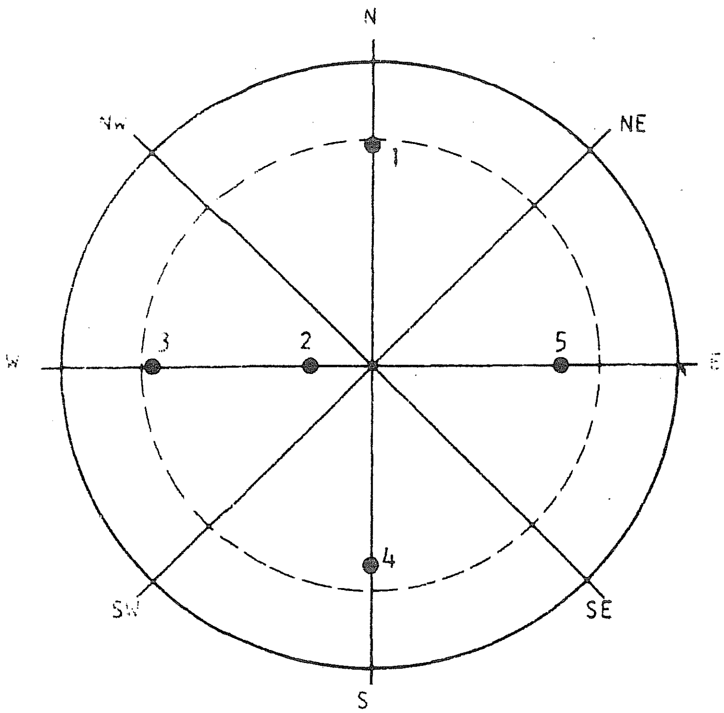
B6 Test Vessel PV6 (t = 9 in. s = 2/3 in.)

Test vessel PV6 was cast using concrete mixed in the laboratory. It was free of visible cracks at the time of the test. The longitudinal prestress was provided by thirty strands. On the first attempt to test PV6, the pressure was increased in 50 psi increments to a pressure of 250 psi. Twenty-five psi increments were added until the pressure reached 450 psi. Pressure was increased in 10 psi increments until a leak in the seal prevented a further increase in pressure at 570 psi. Data for only the first attempt at testing PV6 is presented with the exception of the pressure-deflection curve for the center of the end slab and the change in load in one longitudinal strand on the final test of the vessel. Figure B6.2 shows the sealing detail used for the first attempt. The adhesive used on this vessel was a linoleum cement. Figure B6.19a shows the crack pattern that had developed in the end slab when the test was halted.

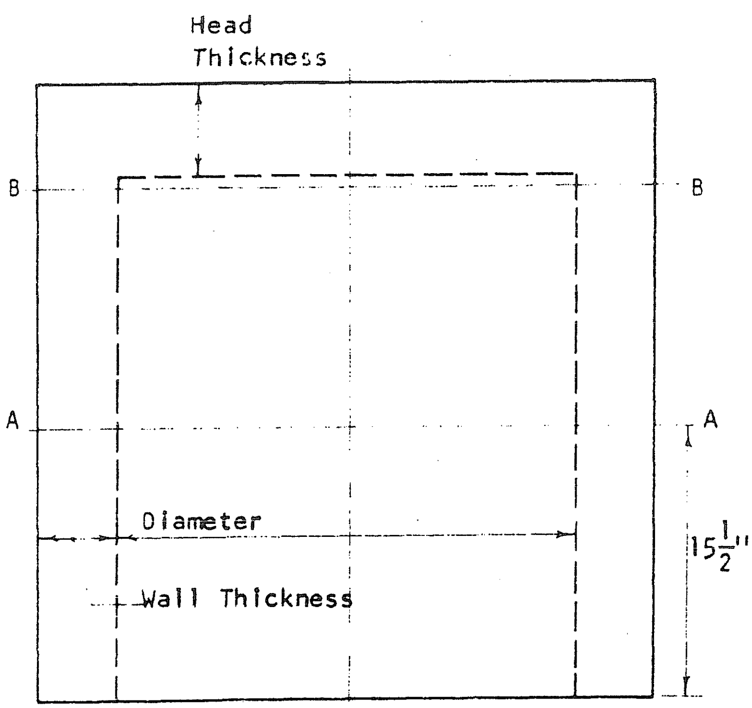
Vessel PV6 was removed from the test chamber and taken off the four-in. steel plate so that the liner could be modified as shown in Fig. B6.3. The modifications included an additional layer of neoprene on the end slab and the replacement of the neoprene on the side wall. Rubber cement was used as the adhesive in this case. The vessel was again secured to the four-in. plate with thirty strands.

The second attempt to reach the ultimate capacity of the vessel was frustrated when severe leaking prevented an increase in pressure beyond 585 psi. Visual examination of the vessel under 300 psi internal pressure disclosed a longitudinal crack about mid-height of the vessel near the SW meridian. The crack was less than 0.005 in. wide.

In order to proceed with the test, eight of the thirty longitudinal strands were removed before it was pressurized for the third time. The layout of longitudinal reinforcement is shown in Fig. B6.18. Pressure was increased in 100 psi increments to failure at a pressure of 400 psi. Fifty psi increments were added from 400 psi until the vessel failed at 555 psi. The reassembled end slab is shown in Fig. B6.19b.



Head Thickness	
Point	Inches
1	$9\frac{1}{8}$"
2	$9\frac{1}{16}$"
3	$9\frac{1}{8}$"
4	$9\frac{1}{8}$"
5	$9\frac{1}{16}$"



Wall Thickness, in.		
Axis \ Plane	AA	BB
N	4.97	
NE	4.94	
E	4.93	4.98
SE	4.97	
S	4.96	5.12
SW	5.09	
W	5.03	5.01
NW	5.06	

Inside Diameter, in.		
Axis \ Plane	AA	BB
N-S	$30\frac{4}{32}$	
NE-SW	$30\frac{0}{32}$	$30\frac{2}{32}$
E-W	$29\frac{31}{32}$	
SE-NW	$30\frac{1}{32}$	$30\frac{1}{32}$

FIG. B6.1 DIMENSIONS OF PV6

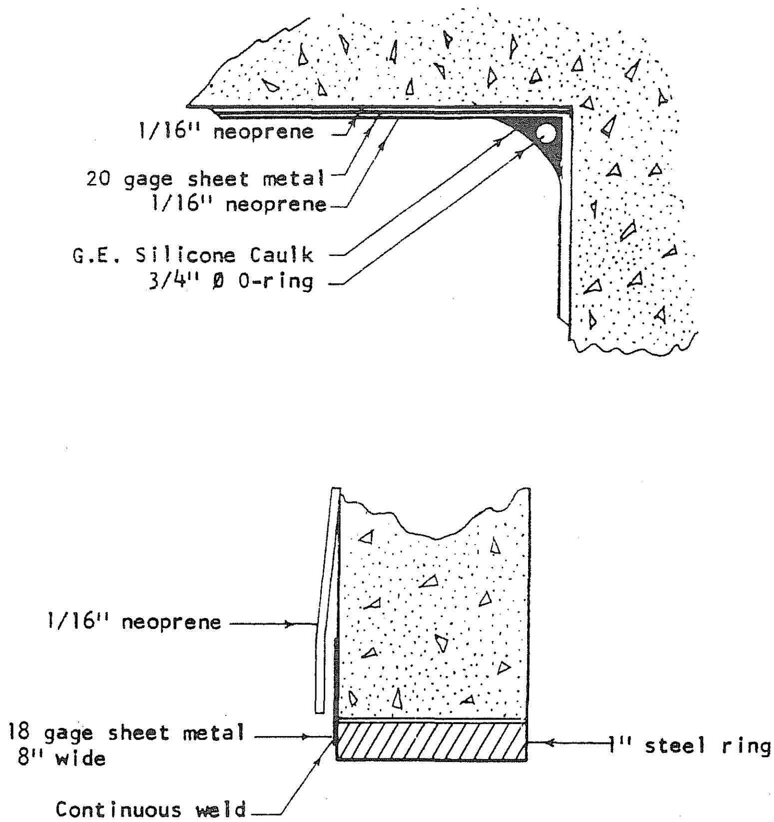
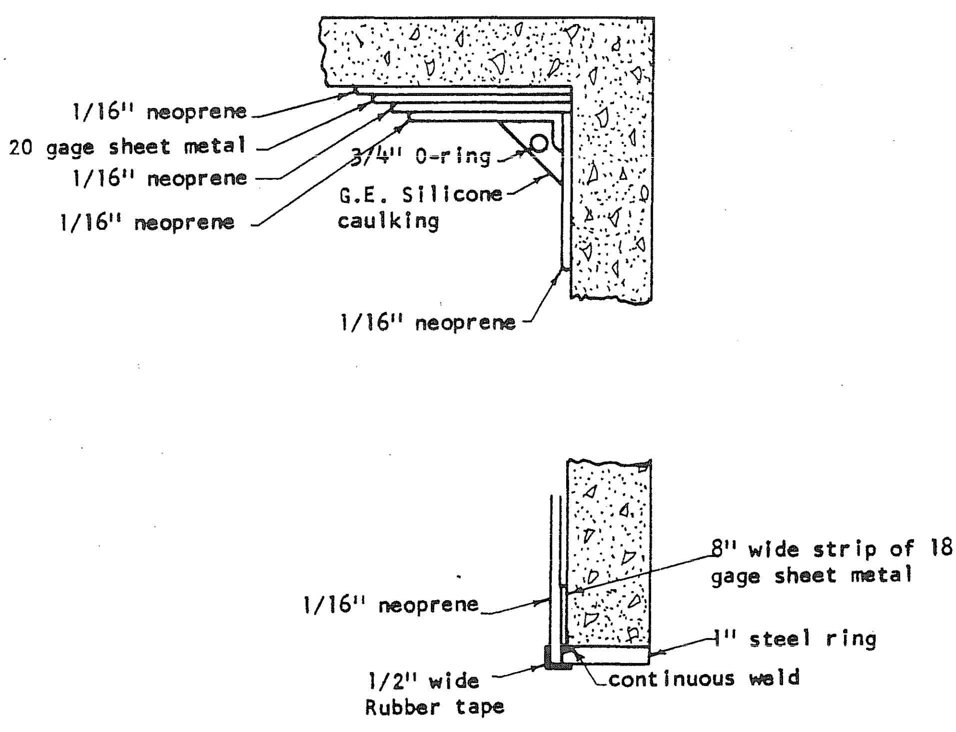
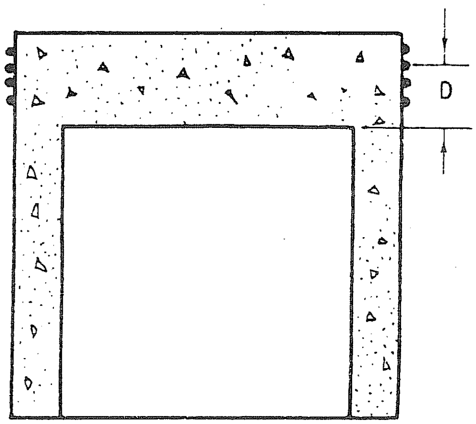
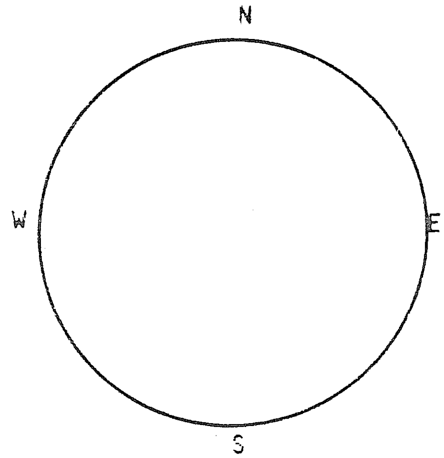


FIG. B6.2 SEALING DETAIL FOR PV6





Section



Plan View

Wrap No.	D_N	D_E	D_S	D_W
1	7 14/16	8 2/16	8 6/16	7 14/16
2	7 11/16	7 14/16	7 15/16	7 11/16
3	7 8/16	7 10/16	7 12/16	7 6/16
4	6 14/16	7 1/16	7 4/16	6 12/16
5	6 4/16	6 7/16	6 10/16	6 1/16
6	5 9/16	5 12/16	5 15/16	5 6/16
7	4 14/16	5 1/16	5 4/16	4 12/16
8	4 4/16	4 7/16	4 10/16	4 1/16
9	3 10/16	3 13/16	4 0/16	3 7/16
10	3 0/16	3 2/16	3 5/16	2 13/16
11	2 2/16	2 8/16	2 11/16	2 2/16
12	1 11/16	1 13/16	2 0/16	1 7/16
13	1 0/16	1 3/16	1 5/16	13/16
14	5/16	8/16	10/16	2/16
15	-6/16	-3/16	0	-9/16

FIG. B6.4 MEASURED LOCATION OF THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE ENDS OF THE N-S AND E-W DIAMETERS ON PV6

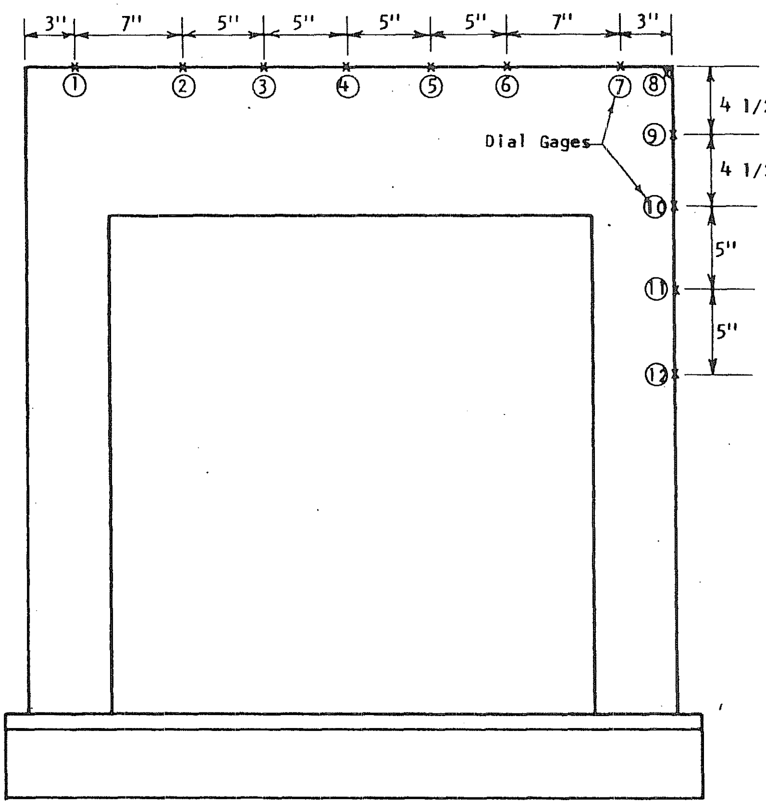


FIG. B6.5 LOCATION OF DEFLECTION GAGES ON PV6

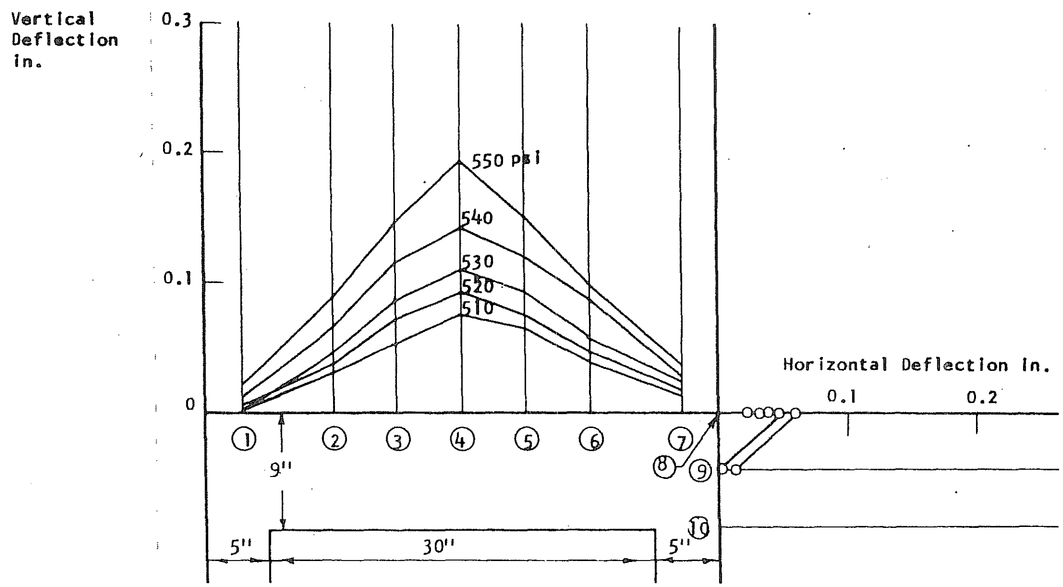


FIG. B6.6 DEFLECTION PROFILES OF THE END SLAB ALONG THE N-S DIAMETER OF PV6

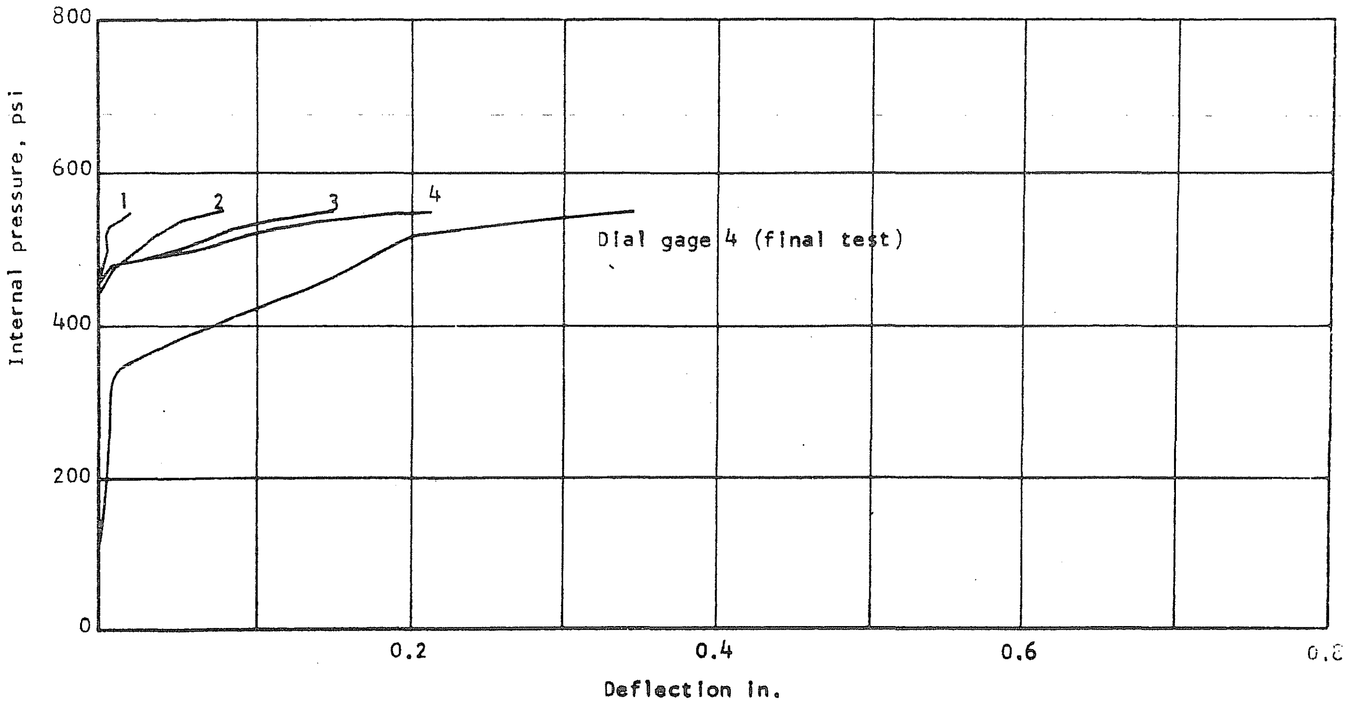


FIG. B6.7 APPLIED PRESSURE vs DEFLECTION ALONG THE N-HALF OF THE N-S DIAMETER OF PV6

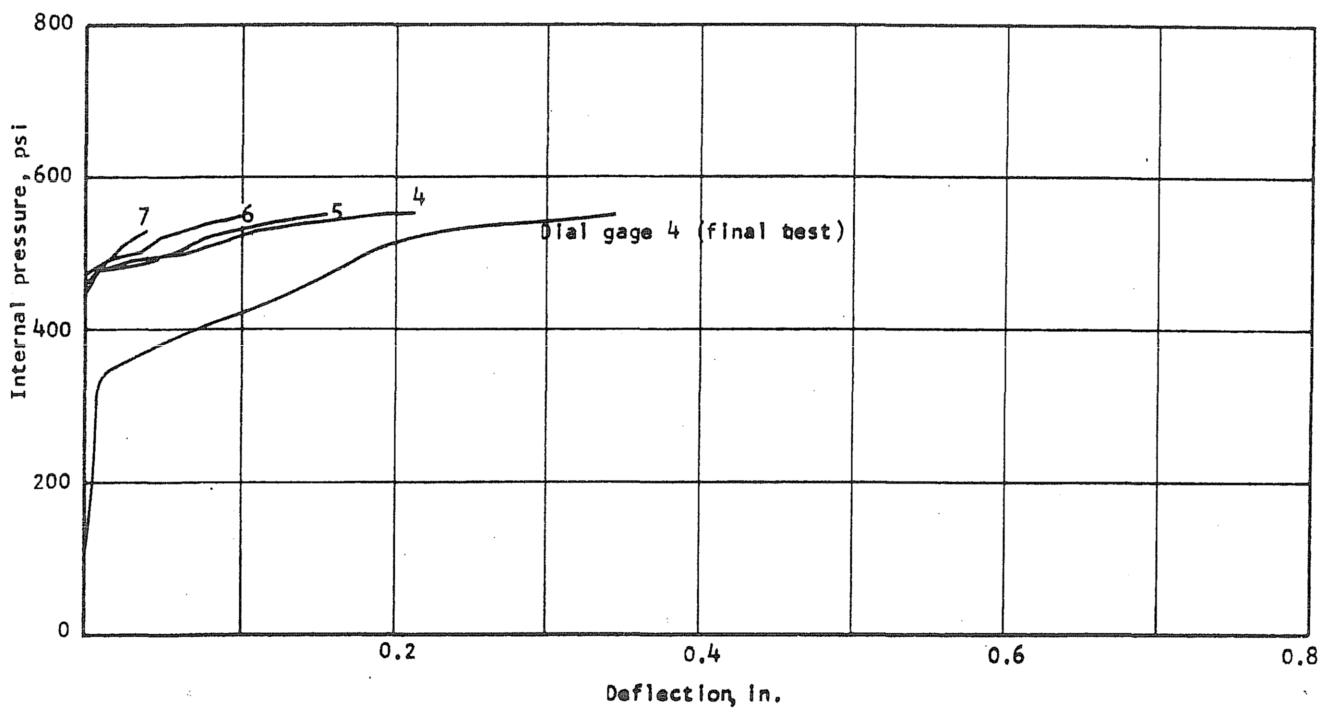


FIG. B6.8 APPLIED PRESSURE vs DEFLECTION ALONG THE S-HALF OF THE N-S DIAMETER OF PV6

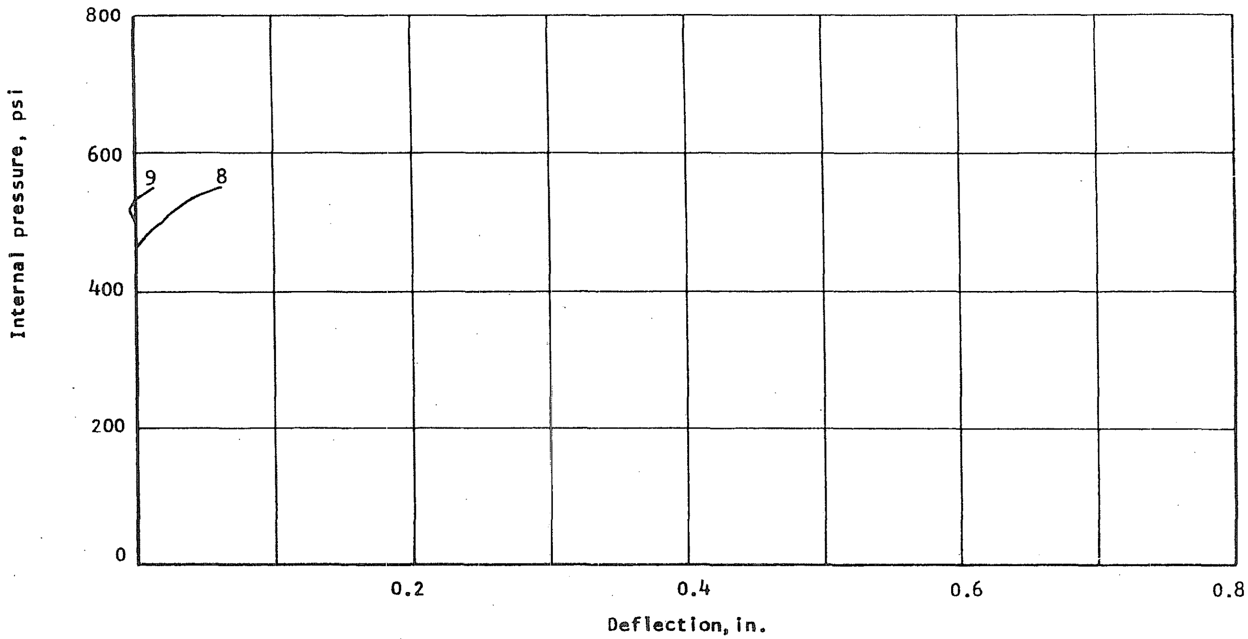


FIG. B6.9 APPLIED PRESSURE vs DEFLECTION OF THE SIDE WALL OF PV6

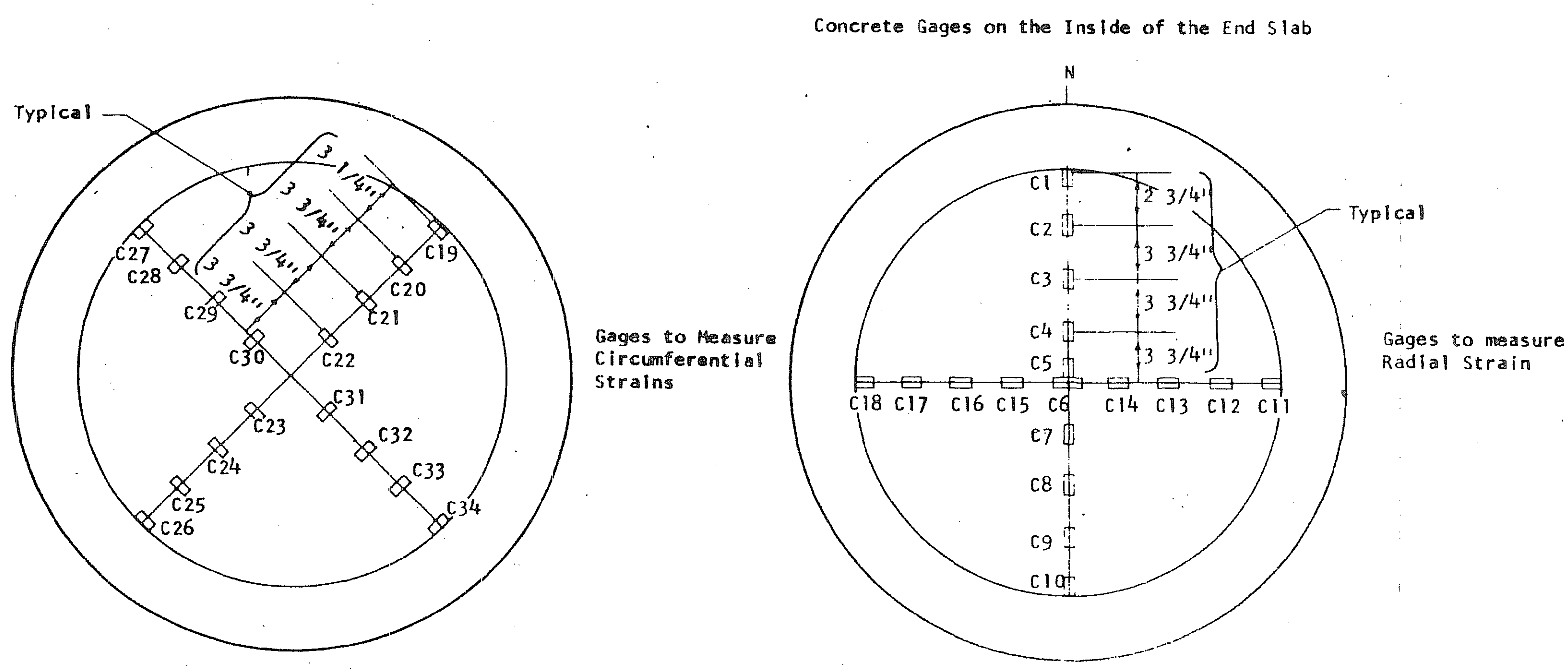
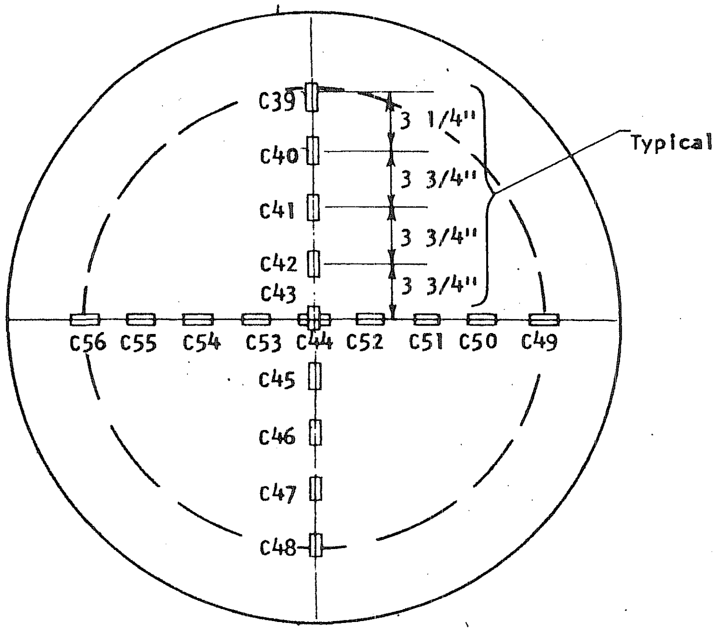
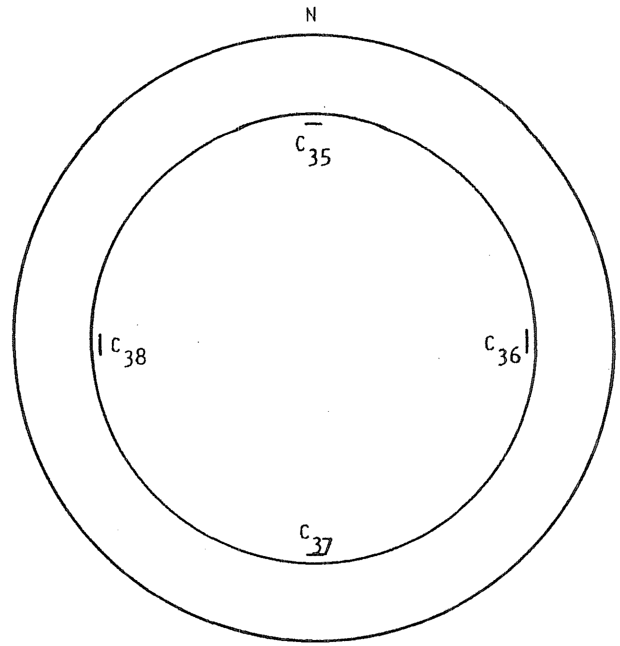


FIG. B6.10 STRAIN GAGE LOCATIONS ON PV6

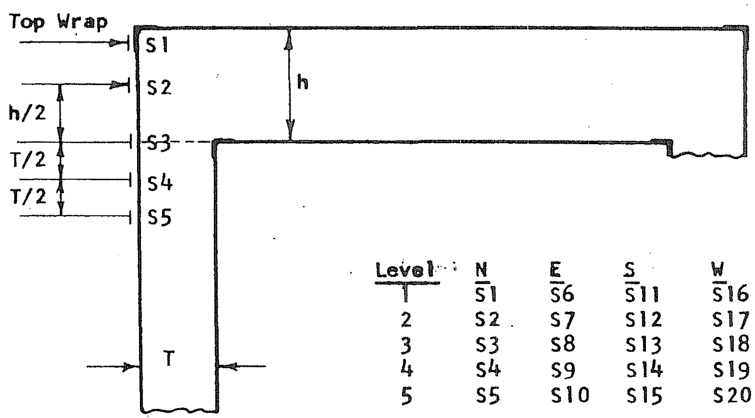
Concrete Gages on the Outside of the End Slab



Concrete Gages on The Inside Walls



Steel Gages on Circumferential Prestress Wire



Level	N	E	S	W
1	S1	S6	S11	S16
2	S2	S7	S12	S17
3	S3	S8	S13	S18
4	S4	S9	S14	S19
5	S5	S10	S15	S20

FIG. B6.10 (cont'd) STRAIN GAGE LOCATIONS ON PV6

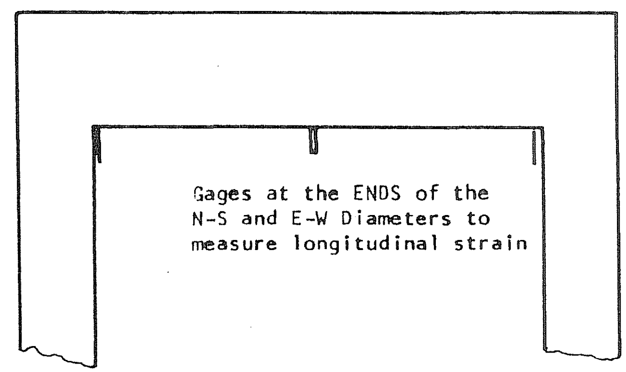


FIG. B6.10 (cont.) STRAIN GAGE LOCATIONS ON PV6

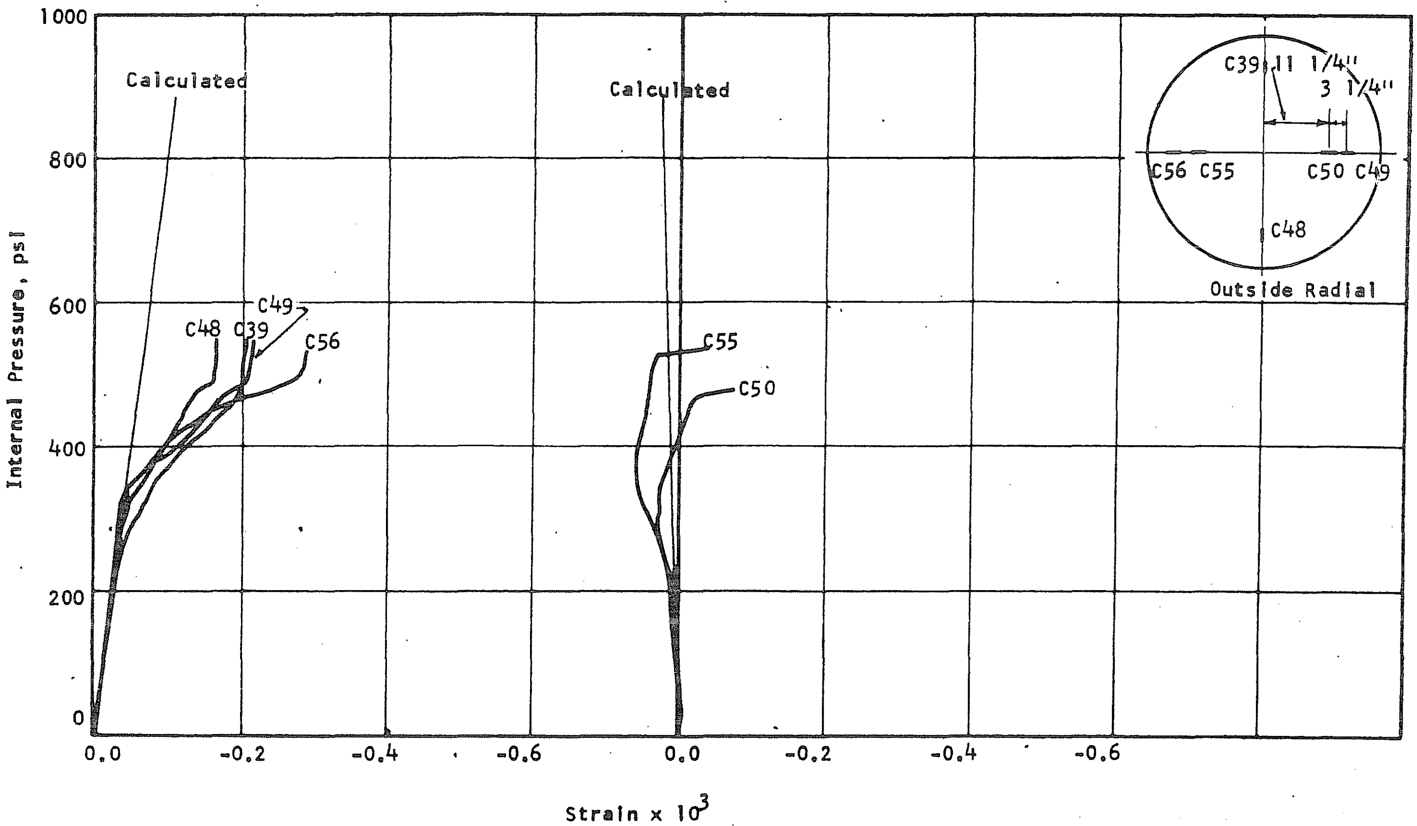


FIG. B6.11 CONCRETE STRAINS, VESSEL PV6

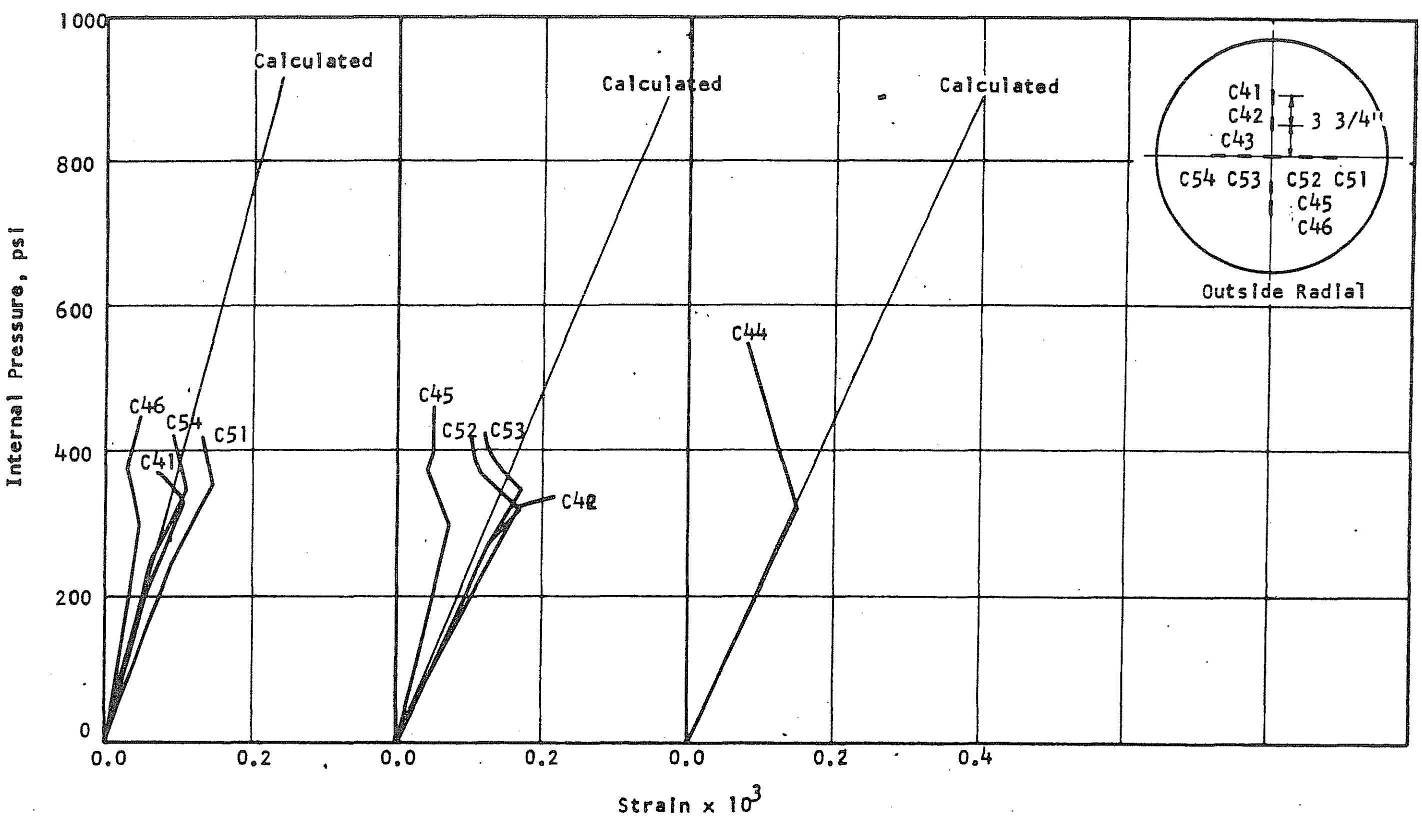


FIG. B6.1 2 CONCRETE STRAINS, VESSEL PV6

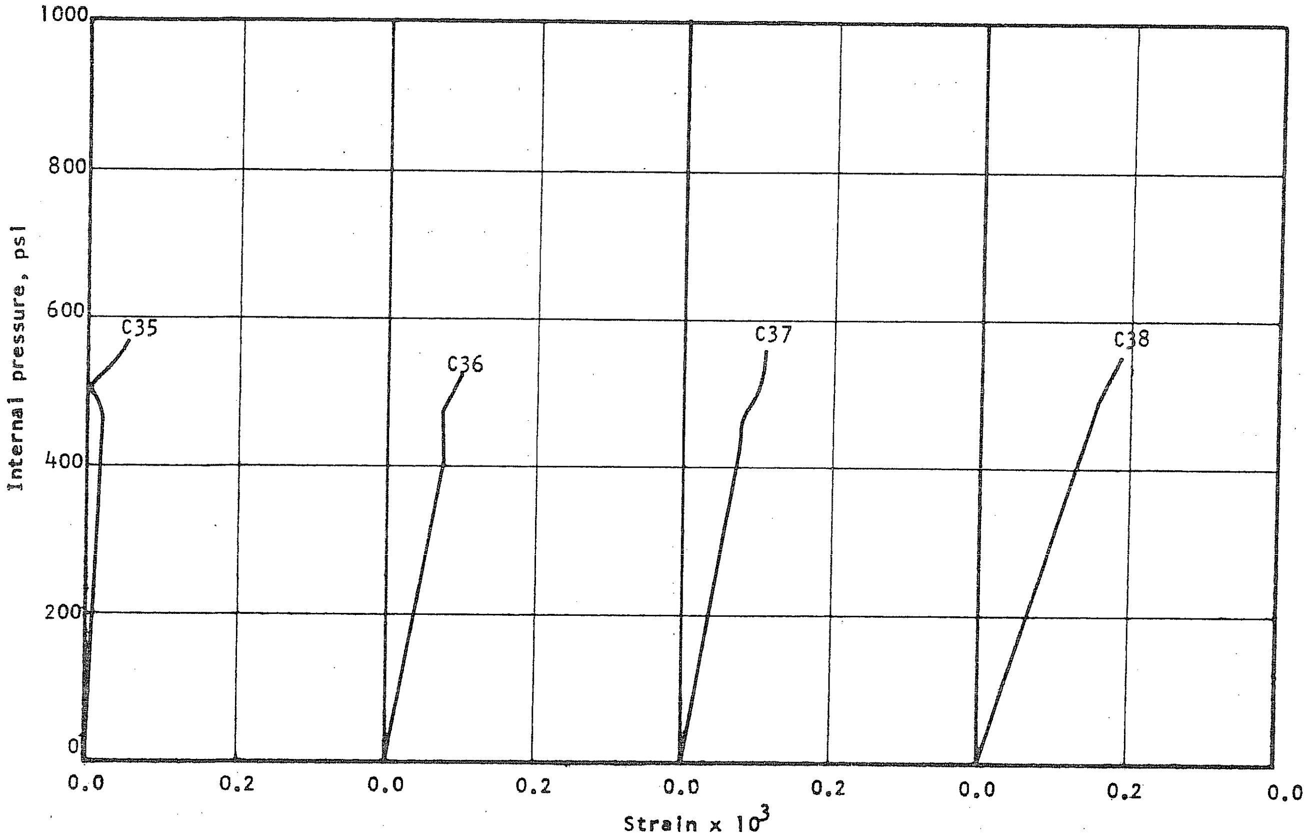


FIG. B6.13 APPLIED PRESSURE vs LONGITUDINAL STRAIN ON THE INSIDE OF THE WALL OF PV6

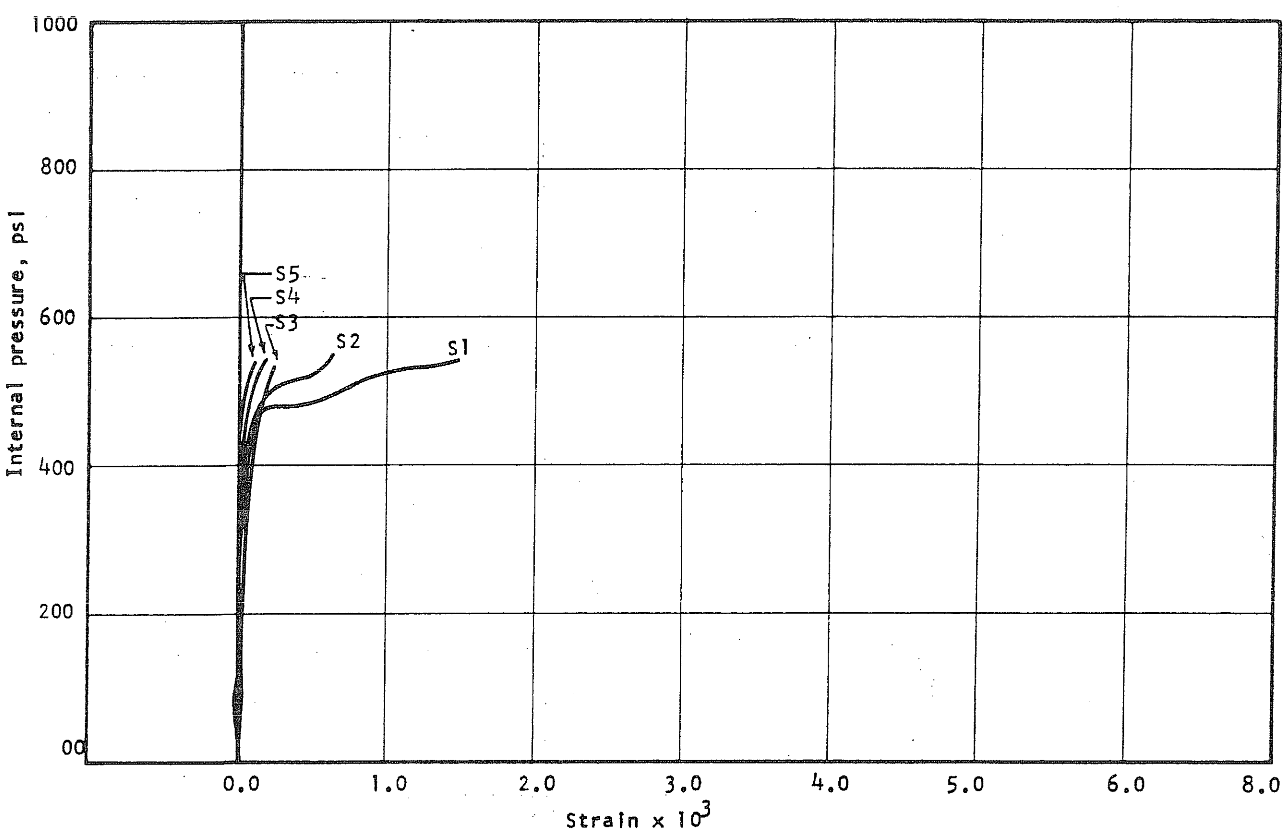


FIG. B6.14 APPLIED PRESSURE vs STRAIN IN THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE N-END OF THE N-S DIAMETER OF PV6

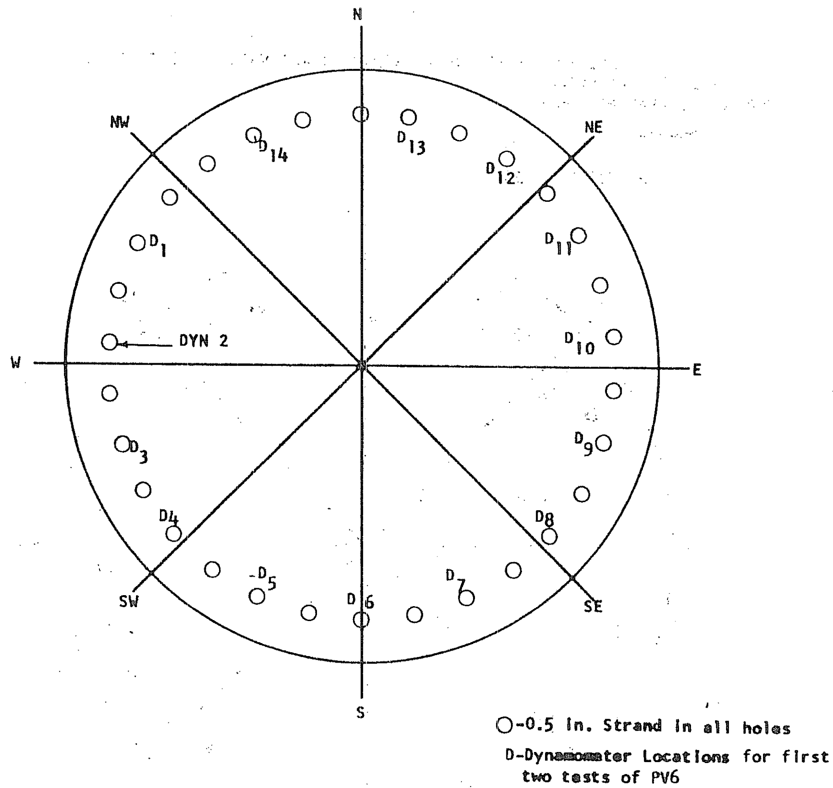


FIG. B6.15 LOCATION OF LONGITUDINAL REINFORCEMENT

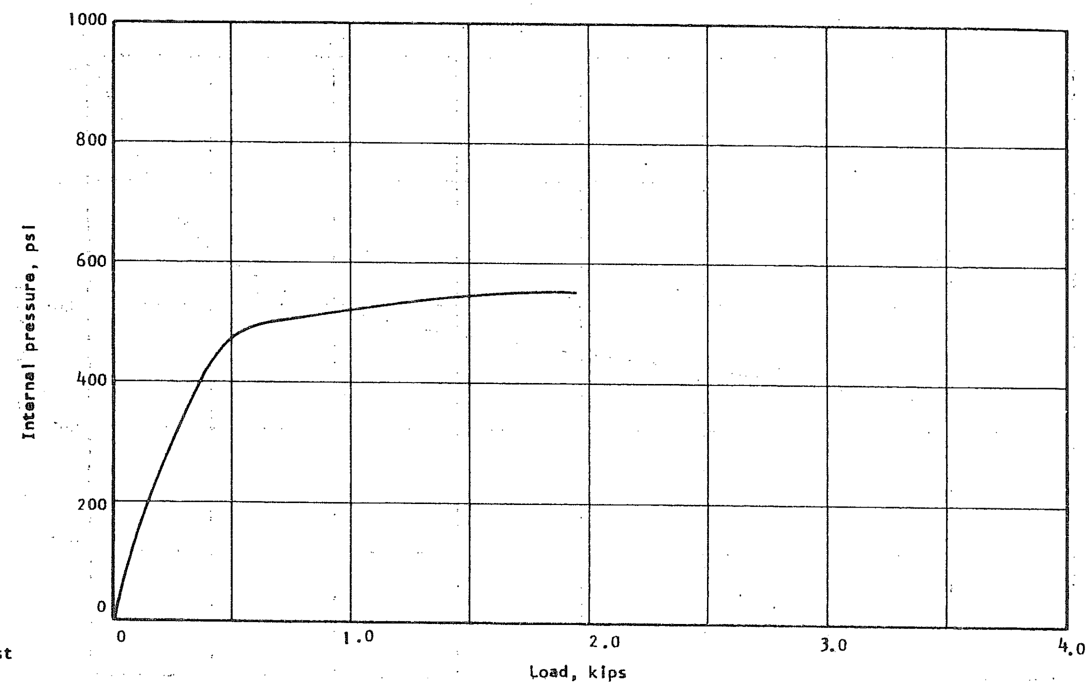


FIG. B6.16 APPLIED PRESSURE vs INCREASE IN LOAD IN DYNAMOMETER NO. 9 ON FIRST TEST OF PV6

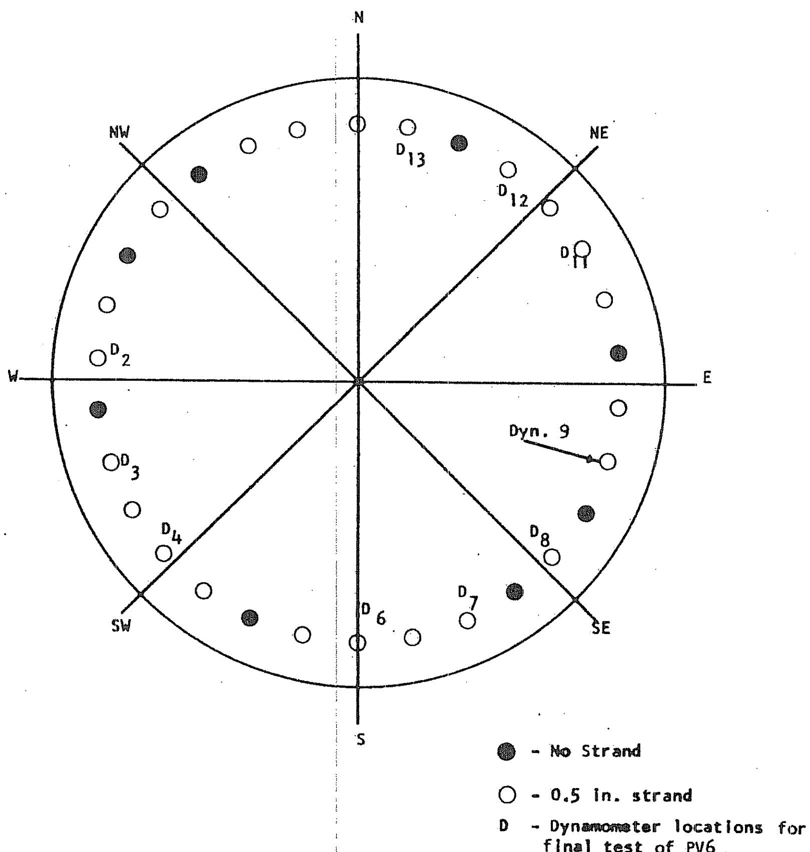


FIG. B6.3.17 LOCATION OF LONGITUDINAL REINFORCEMENT

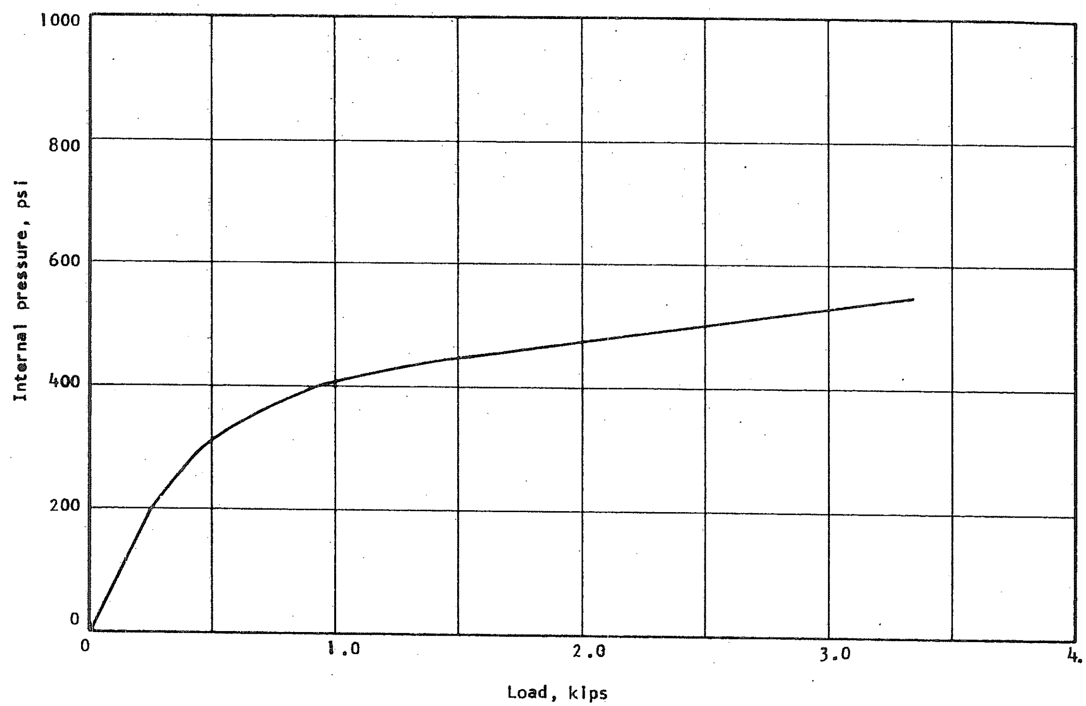


FIG. B6.18 APPLIED PRESSURE vs INCREASE IN LOAD IN DYNAMOMETER NO. 9 ON FINAL TEST OF PV6

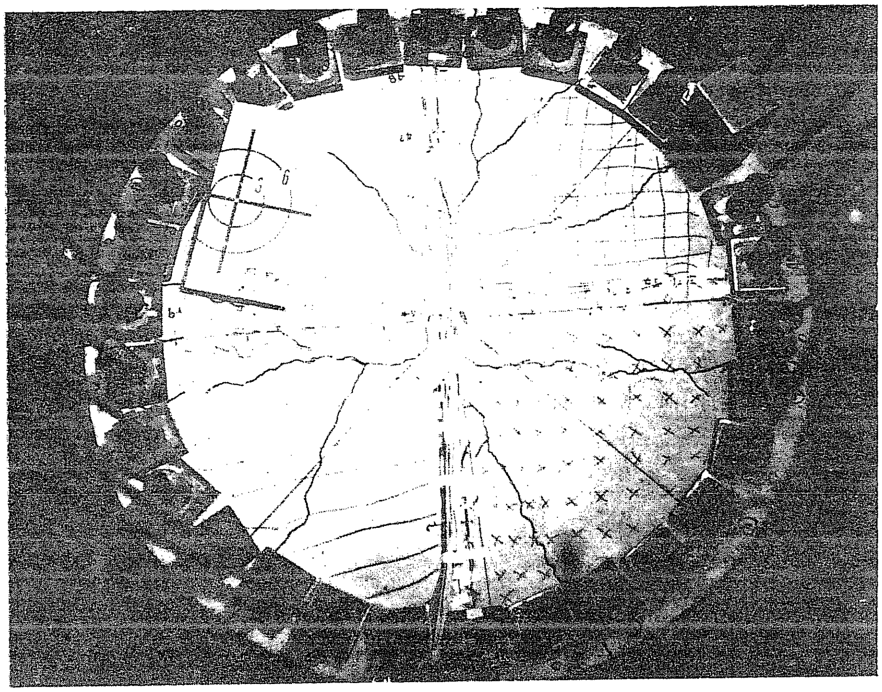


FIG. B6.19a CRACK PATTERN AFTER FIRST TEST ON PV6

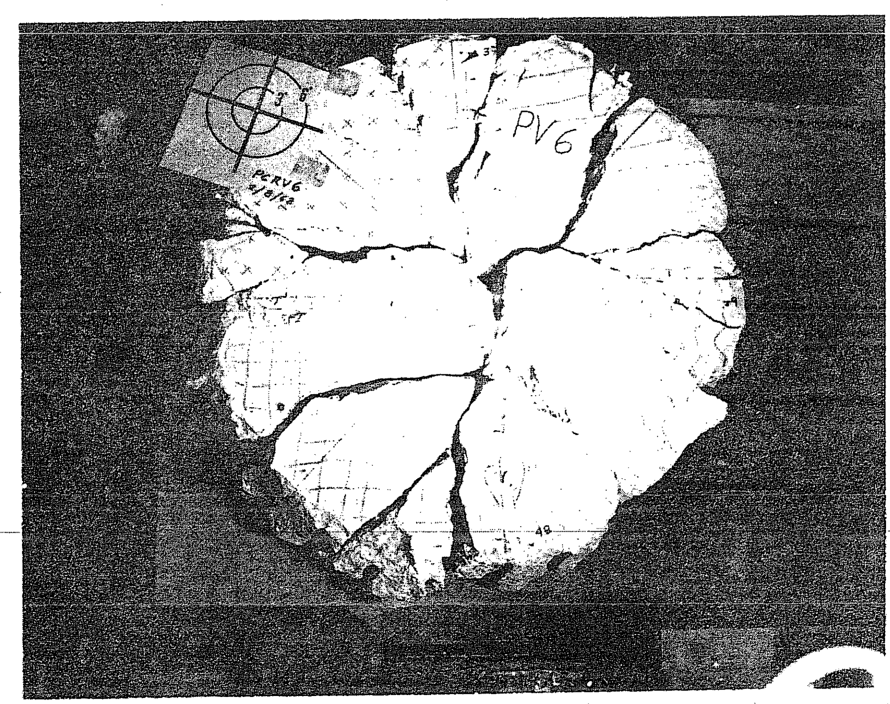


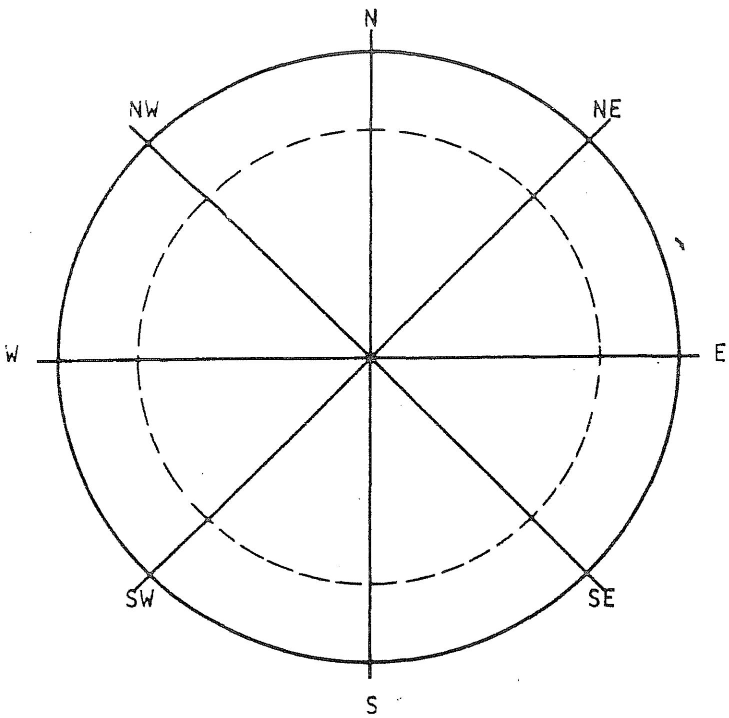
FIG. B6.19b REASSEMBLED END SLAB OF PV6

B7 Test Vessel PV7 (t = 9.0 in., s = 1/3 in.)

Test vessel PV7 was cast in the laboratory and was uncracked prior to prestressing. The circumferential prestressing applied to the vessel caused a band of circumferential cracks to develop on the outside of the vessel between seven and nine in. from the top. A corresponding band of cracks developed from twelve to nineteen in. below the top on the inside of the vessel. Four longitudinal cables stressed nominally to 24 kips were placed on the vessel to arrest further crack development during the interim between the prestressing operation and assembly of the test setup.

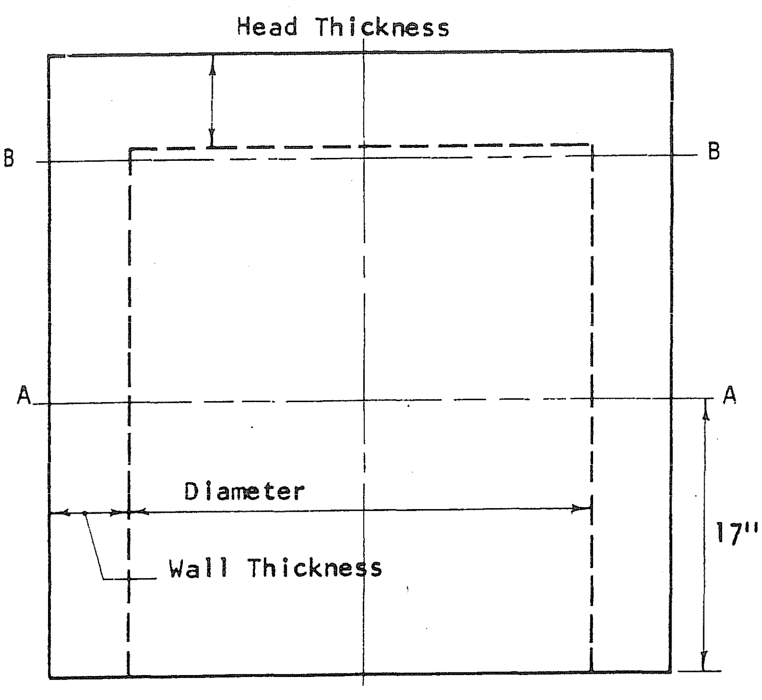
The liner for PV7 was modified considerably from the one that had been used previously. Figure B7.2 is a detail of the liner that was used for PV7. A one-half-in. thick layer of hydrocal was placed on the inside of the end slab to provide a smooth surface over strain gages. A 0.017-in. sheet of aluminum was attached to the side wall in the hope of bridging small pores or cracks more effectively. The round O-ring was replaced by one with a triangular cross section, and the neoprene sheets were lapped about one in. at the junction of the end slab and side wall in an effort to improve the performance of the seal in that vicinity. Rubber cement was used as the adhesive to hold both the aluminum and neoprene in place. Thirty 0.5-in. strands were used for longitudinal reinforcement in the test.

The testing of PV7 was carried out with no difficulty. About two hours were required for the entire test as loading proceeded in 50 psi increments to an internal pressure of 750 psi. Twenty-five psi increments were added up to a pressure of 800 psi. At 800 psi the deflection at midspan was creeping steadily. Therefore, the pressure was increased continuously until the vessel failed at 870 psi. The reassembled end slab is shown in Fig. B7.17.



Head Thickness	
Point No.	Inches
	*7 1/2

*Nominal Thickness



Wall Thickness, in.		
Axis \ Plane	AA	BB
N	5.04	5.10
NE		
E	4.89	4.85
SE		
S	4.90	5.00
SW		
W	4.90	4.90
NW		

Inside Diameter, in.		
Axis \ Plane	AA	BB
N-S	30 $\frac{2}{32}$	29 $\frac{30}{32}$
NE-SW	29 $\frac{31}{32}$	29 $\frac{30}{32}$
E-W	29 $\frac{30}{32}$	30
SE-NW	30	29 $\frac{31}{32}$

FIG. B7.1 DIMENSIONS OF PV7

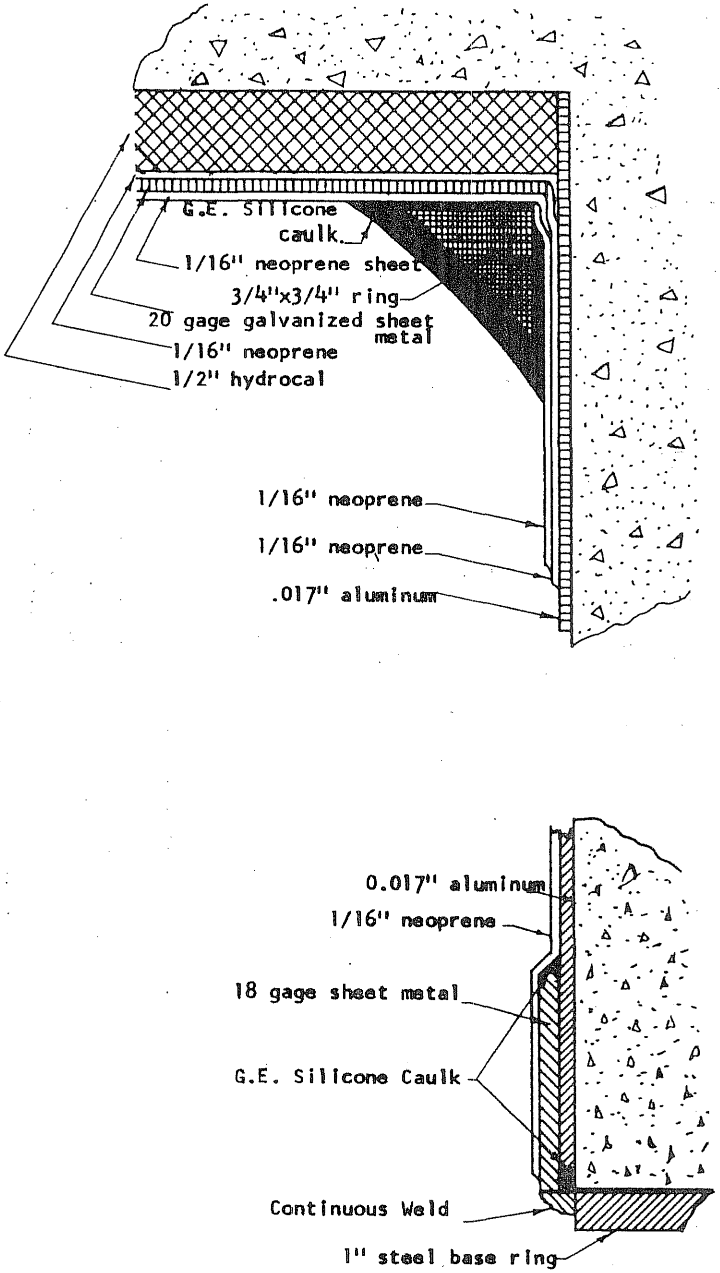
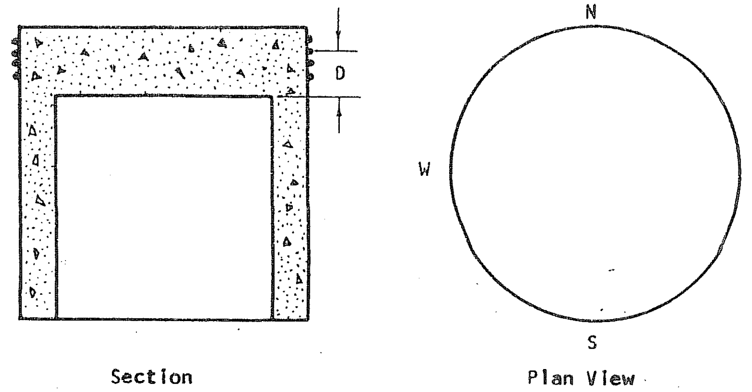


FIG. B7.2 SEALING DETAIL FOR PV7



Wrap No.	D_N	D_E	D_S	D_W
1	8 5/16	8 5/16	8 3/16	8 2/16
2	7 13/16	7 14/16	7 14/16	7 14/16
3	7 10/16	7 8/16	7 8/16	7 8/16
4	7 6/16	7 4/16	7 4/16	7 4/16
5	7 1/16	6 15/16	6 14/16	6 14/16
6	6 11/16	6 9/16	6 9/16	6 8/16
7	6 5/16	6 3/16	6 3/16	6 2/16
8	6 0/16	5 14/16	5 15/16	5 14/16
9	5 12/16	5 11/16	5 10/16	5 10/16
10	5 8/16	5 6/16	5 6/16	5 6/16
11	5 4/16	5 2/16	5 2/16	5 2/16
12	4 15/16	4 13/16	4 13/16	4 12/16
13	4 10/16	4 8/16	4 7/16	4 7/16
14	4 4/16	4 1/16	4 0/16	4 0/16
15	3 14/16	3 12/16	3 11/16	3 11/16
16	3 8/16	3 6/16	3 6/16	3 5/16
17	3 3/16	3 1/16	3 1/16	3 0/16
18	2 14/16	2 12/16	2 11/16	2 11/16
19	2 8/16	2 6/16	2 6/16	2 6/16
20	2 3/16	2 0/16	2 0/16	2 0/16
21	1 14/16	1 11/16	1 11/16	1 10/16
22	1 8/16	1 6/16	1 6/16	1 5/16
23	1 2/16	1 0/16	1 1/16	1 0/16
24	13/16	11/16	11/16	10/16
25	8/16	5/16	6/16	6/16
26	3/16	0/16	0/16	-1/16

FIG. B7.3 MEASURED LOCATION OF THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE ENDS OF THE N-S AND E-W DIAMETERS ON PV7

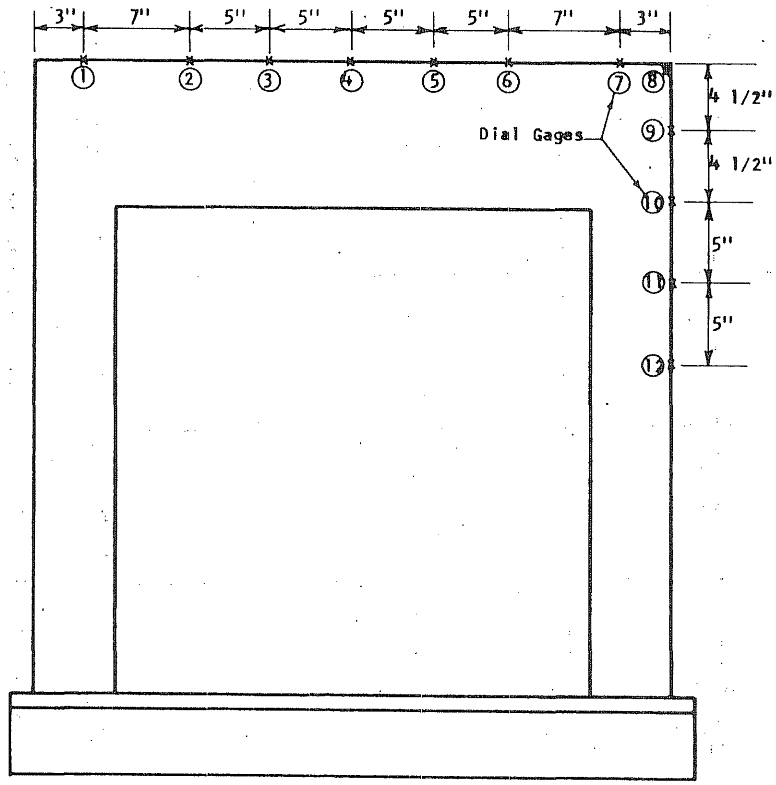


FIG. B7.4 LOCATION OF DEFLECTION GAGES ON PV7

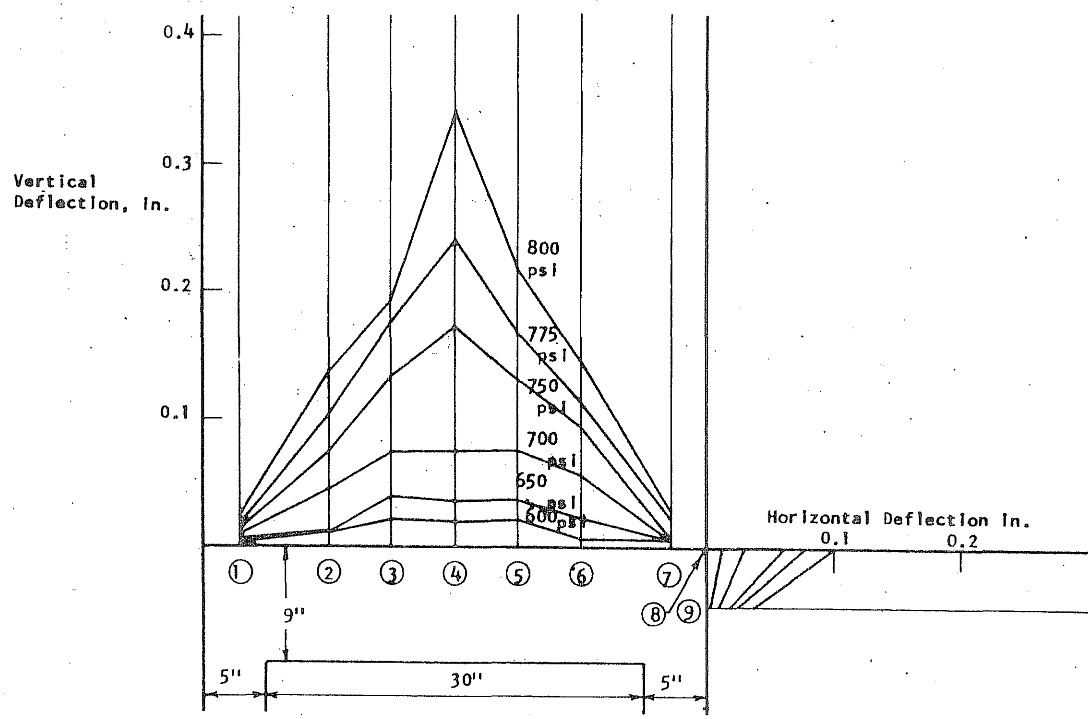


FIG. B7.5 DEFLECTION PROFILES OF THE END SLAB ALONG THE N-S DIAMETER OF PV7

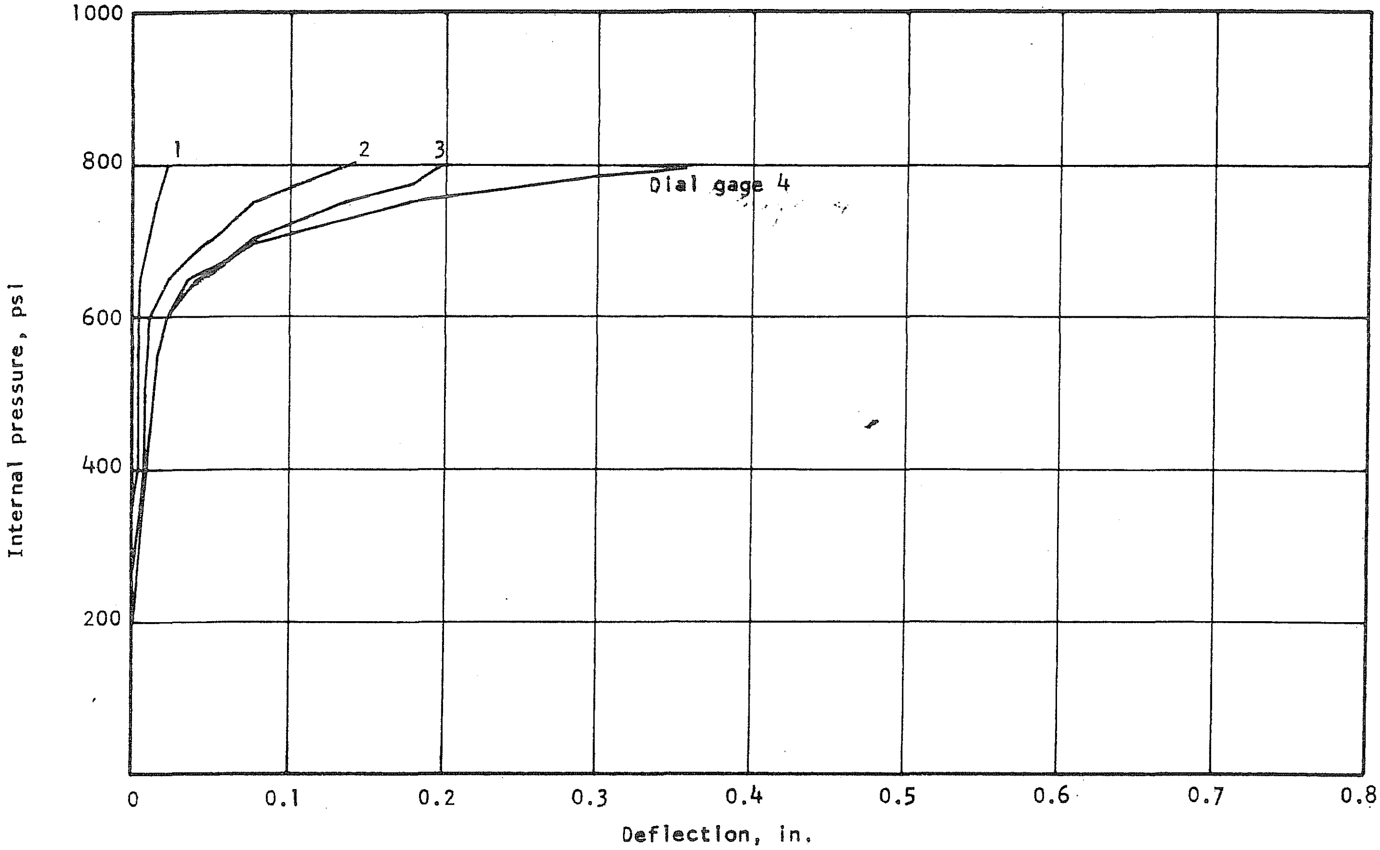


FIG. B7.6 APPLIED PRESSURE vs DEFLECTION ALONG THE N-HALF OF THE N-S DIAMETER OF PV7

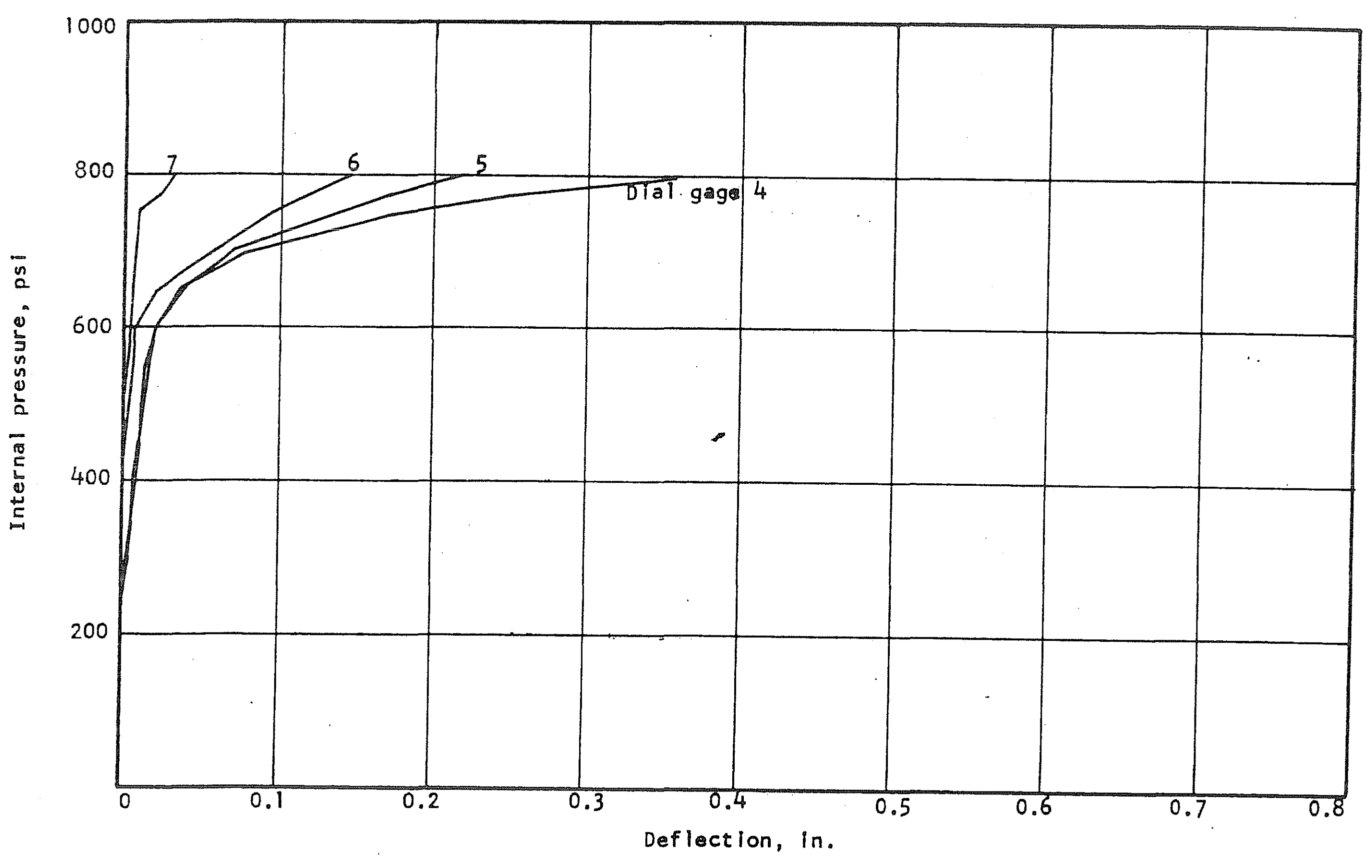


FIG. B7.7 APPLIED PRESSURE vs DEFLECTION ALONG THE S-HALF OF THE N-S DIAMETER OF PV7

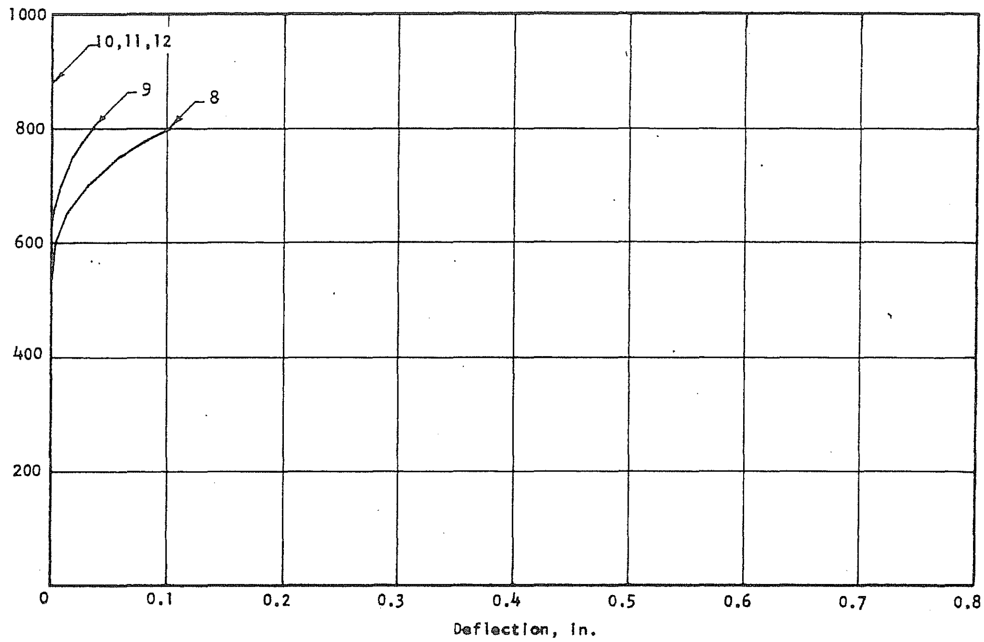


FIG. B7.8 APPLIED PRESSURE vs DEFLECTION OF THE SIDE WALL OF PV7

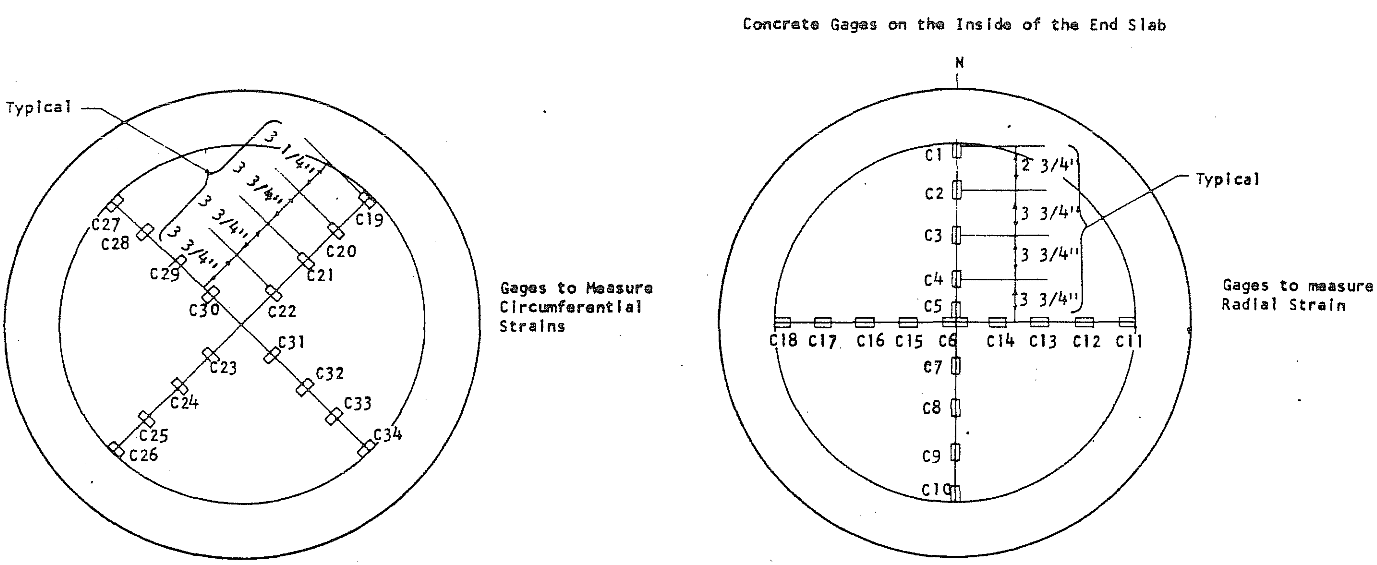
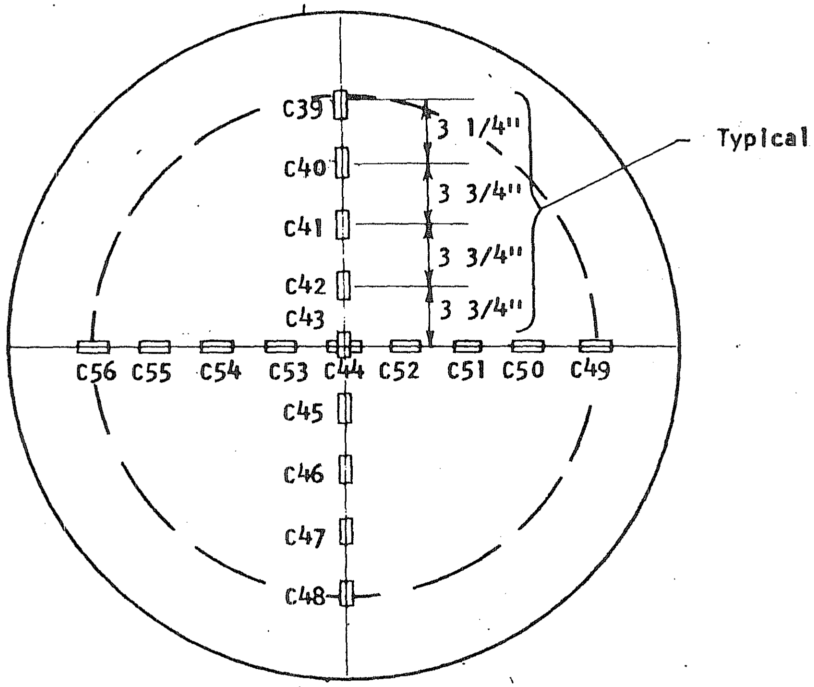
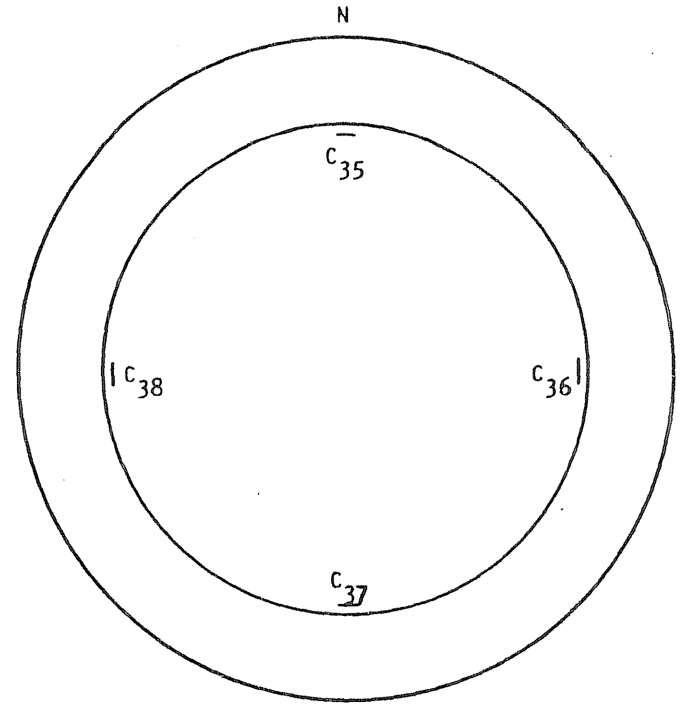


FIG. B7.9 STRAIN GAGE LOCATIONS ON PV7

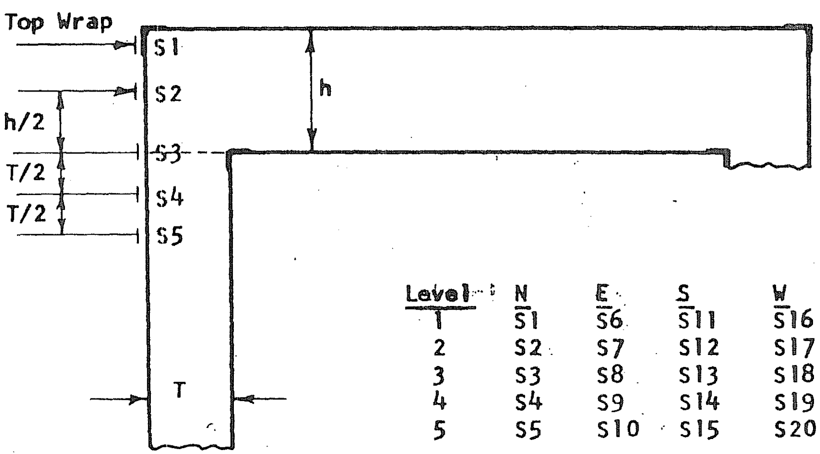
Concrete Gages on the Outside of the End Slab



Concrete Gages on The Inside Walls



Steel Gages on Circumferential Prestress Wire



Level	N	E	S	W
1	S1	S6	S11	S16
2	S2	S7	S12	S17
3	S3	S8	S13	S18
4	S4	S9	S14	S19
5	S5	S10	S15	S20

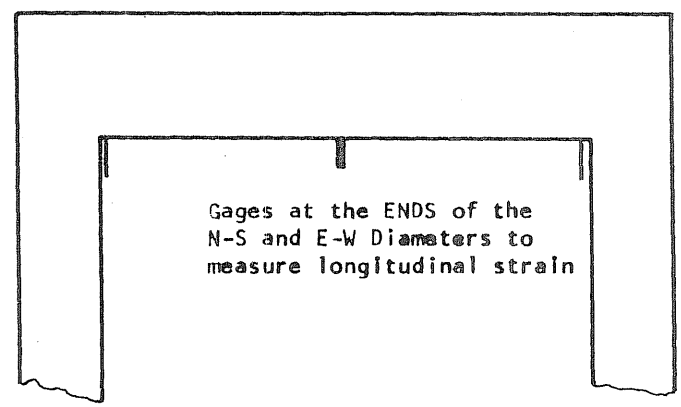


FIG. B7.9 (cont.) STRAIN GAGE LOCATIONS ON PV7

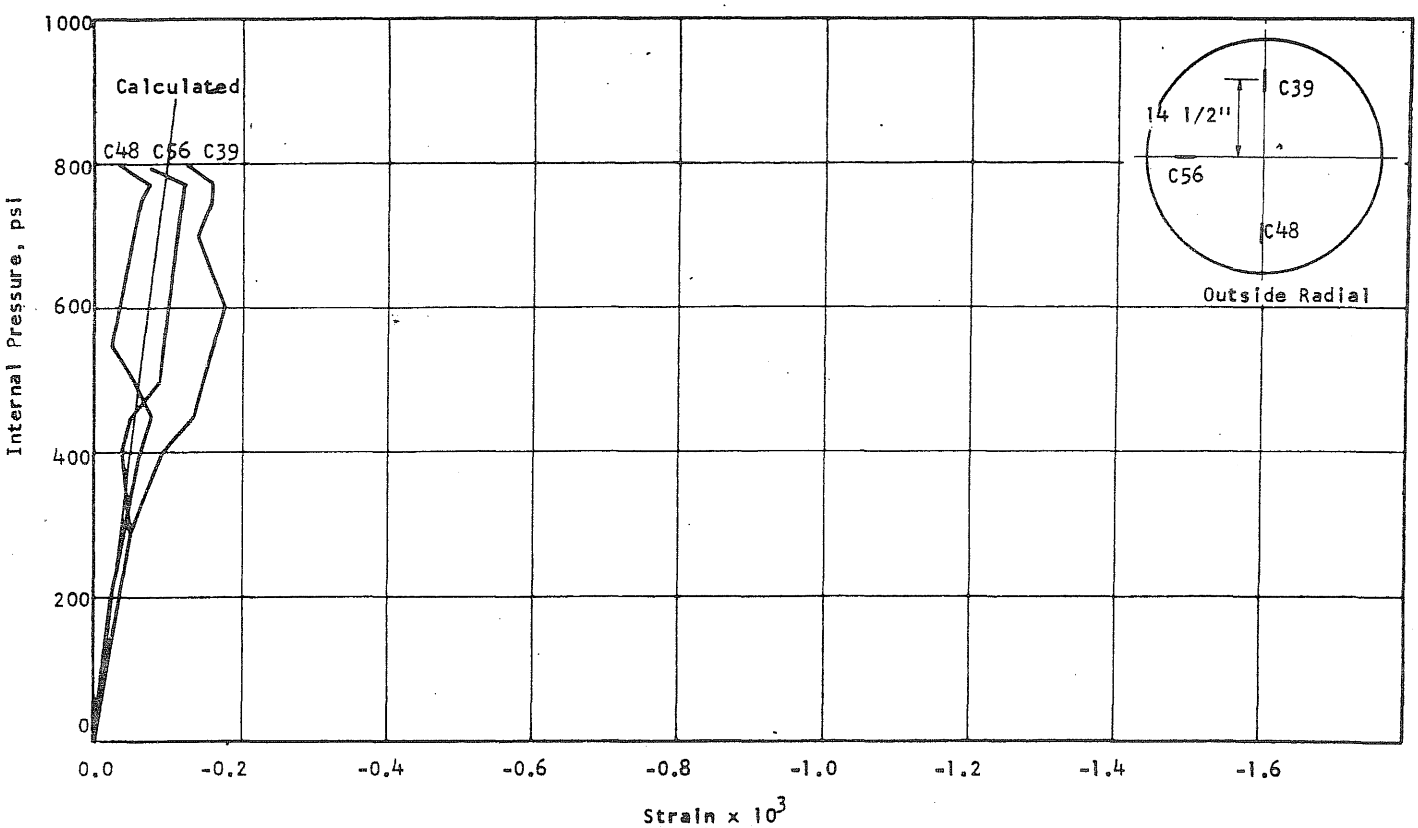


FIG. B7.10 CONCRETE STRAINS, VESSEL PV7

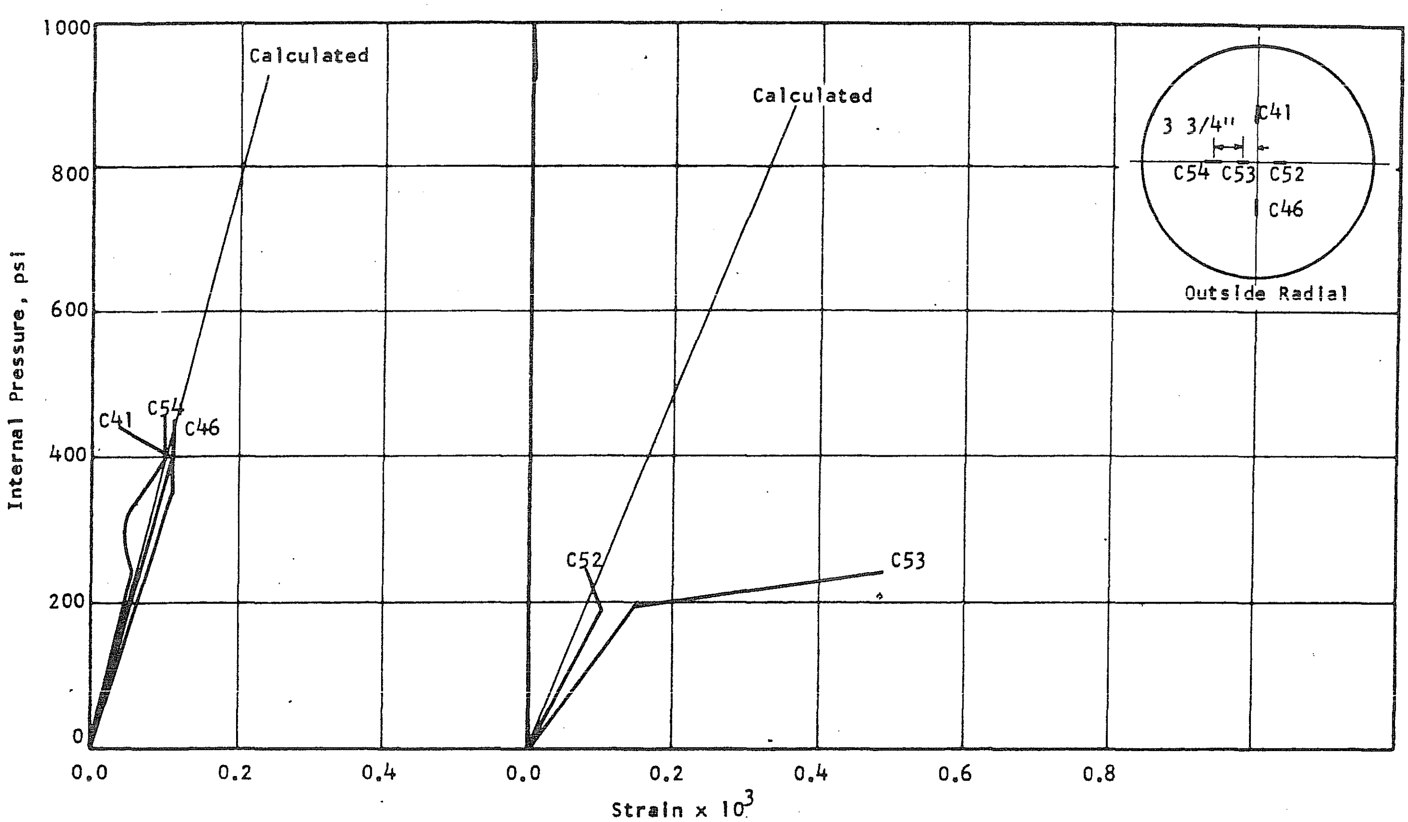


FIG. B7.10 (cont'd) CONCRETE STRAINS, VESSEL PV7

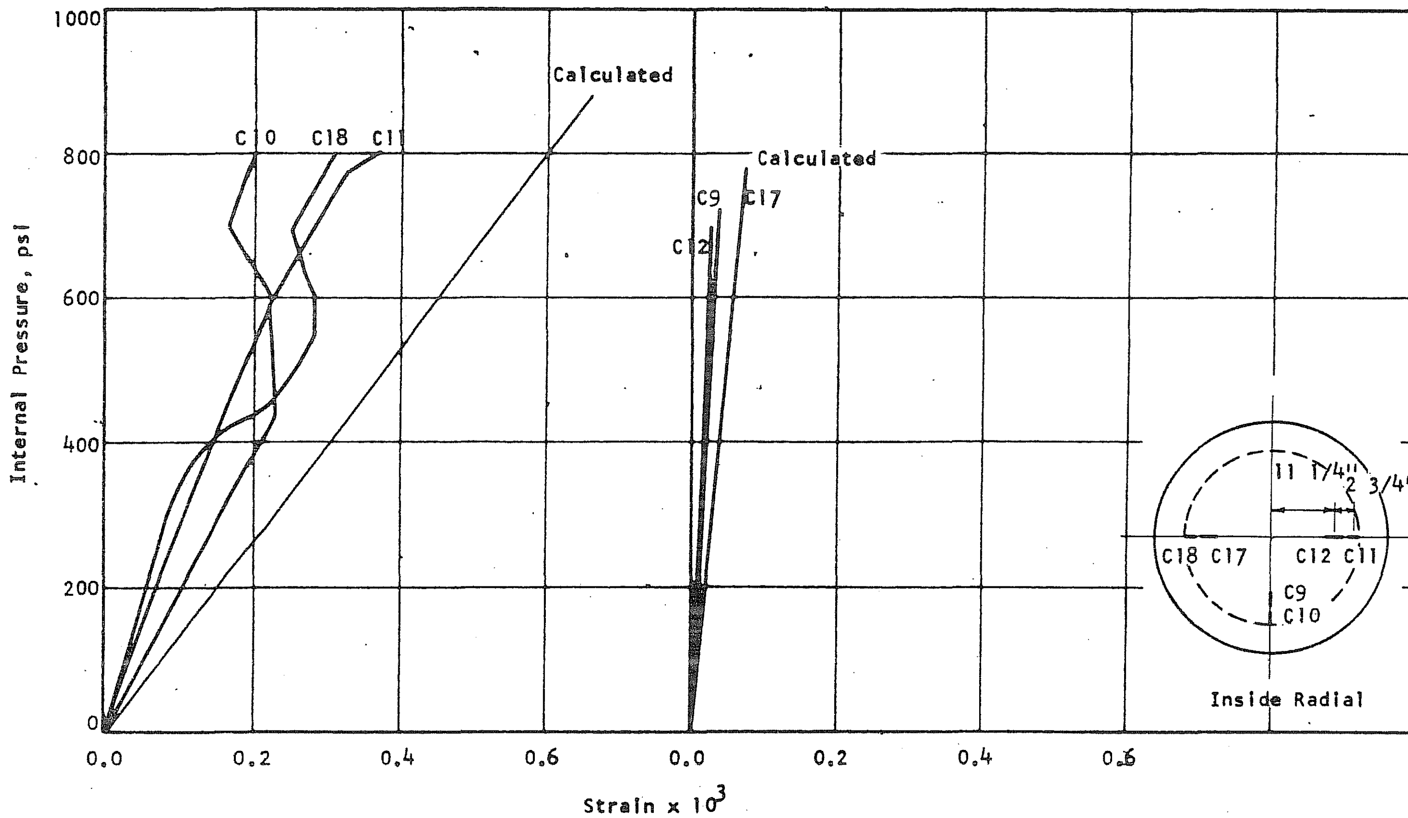


FIG. B7.11 CONCRETE STRAINS, VESSEL PV7

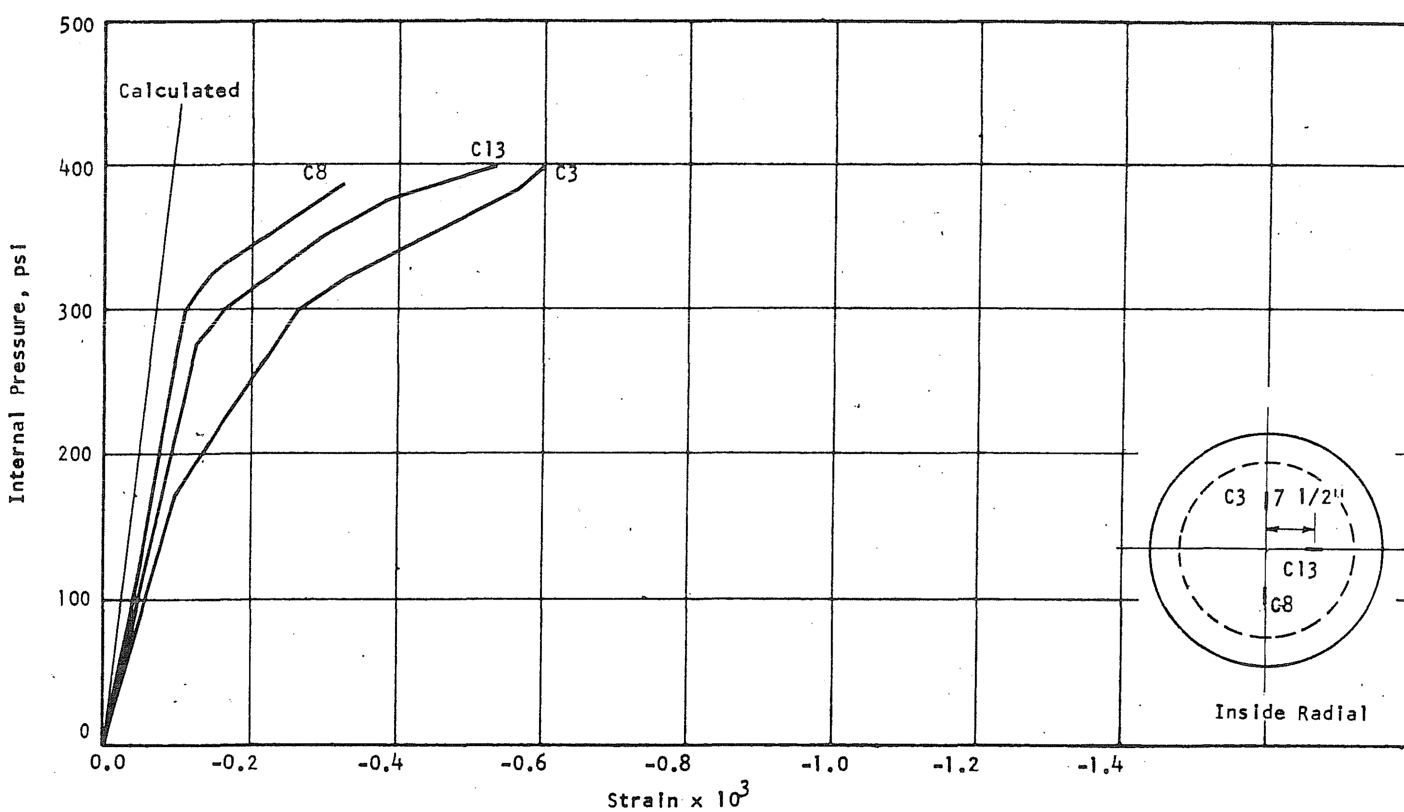


FIG. B7.11 (cont'd) CONCRETE STRAINS, VESSEL PV7

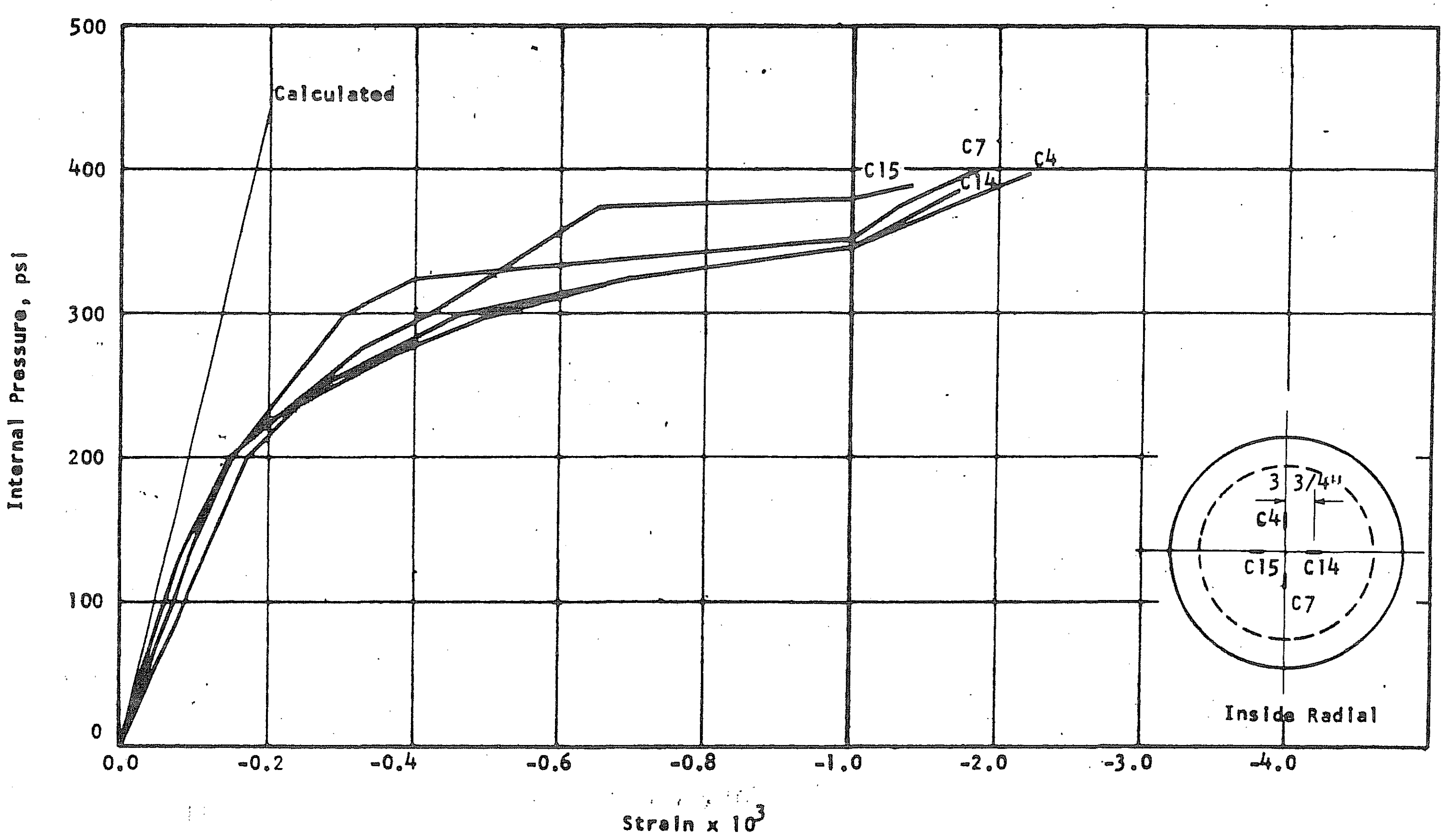


FIG. B7.11 (cont'd) CONCRETE STRAINS, VESSEL PV7

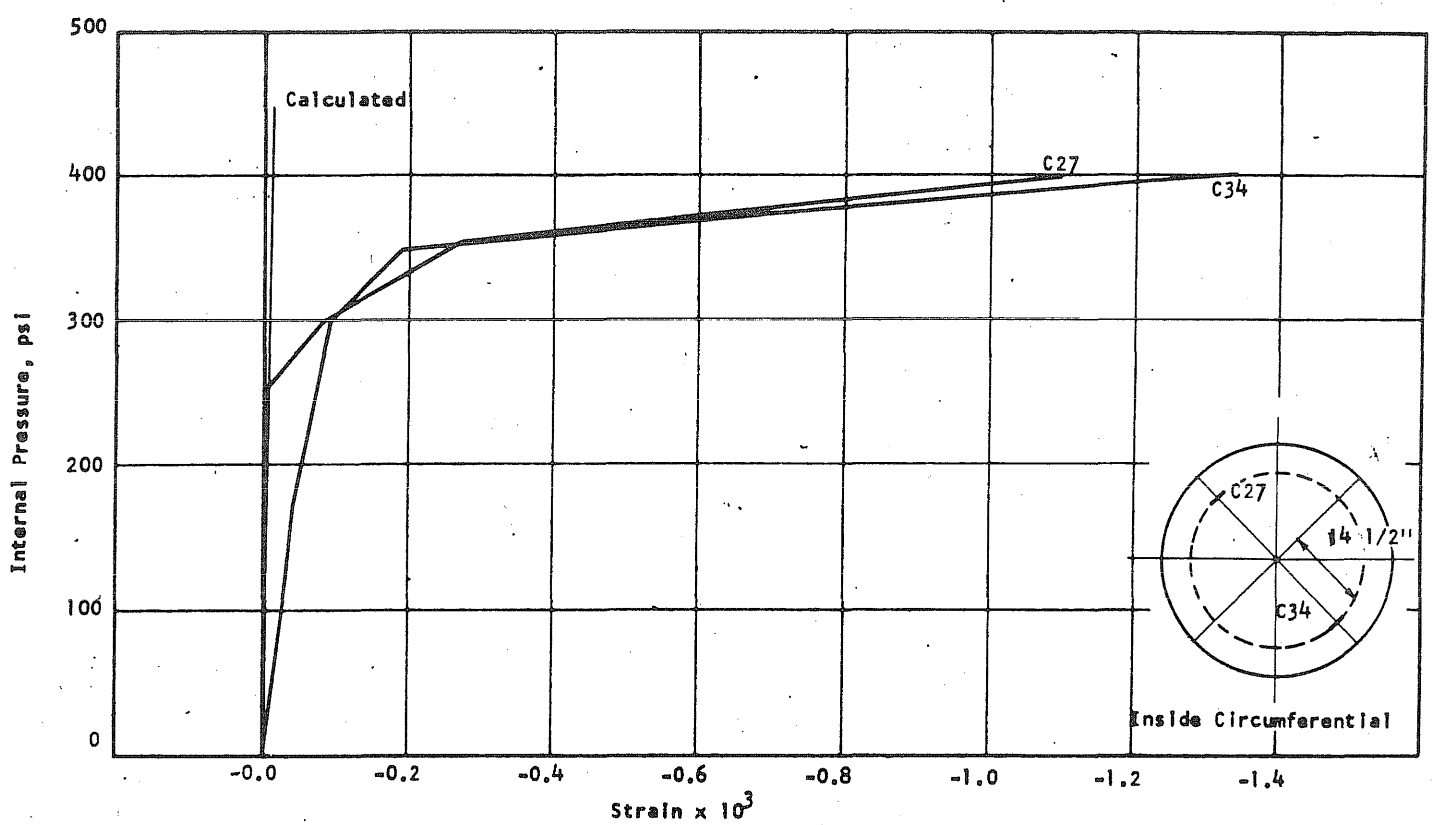


FIG. B7.12 CONCRETE STRAINS, VESSEL PV7

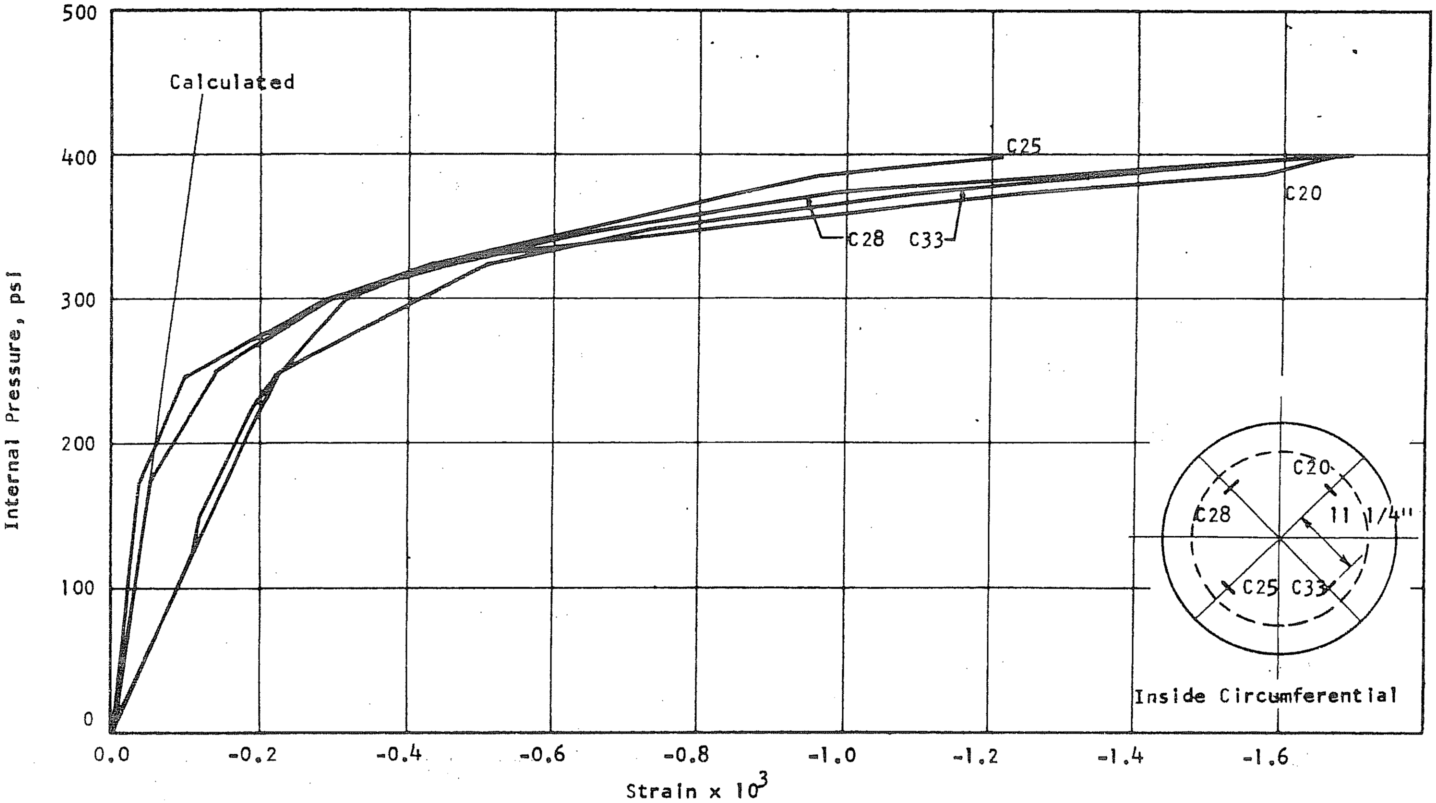


FIG. B7.12 (cont'd) CONCRETE STRAINS, VESSEL PV7

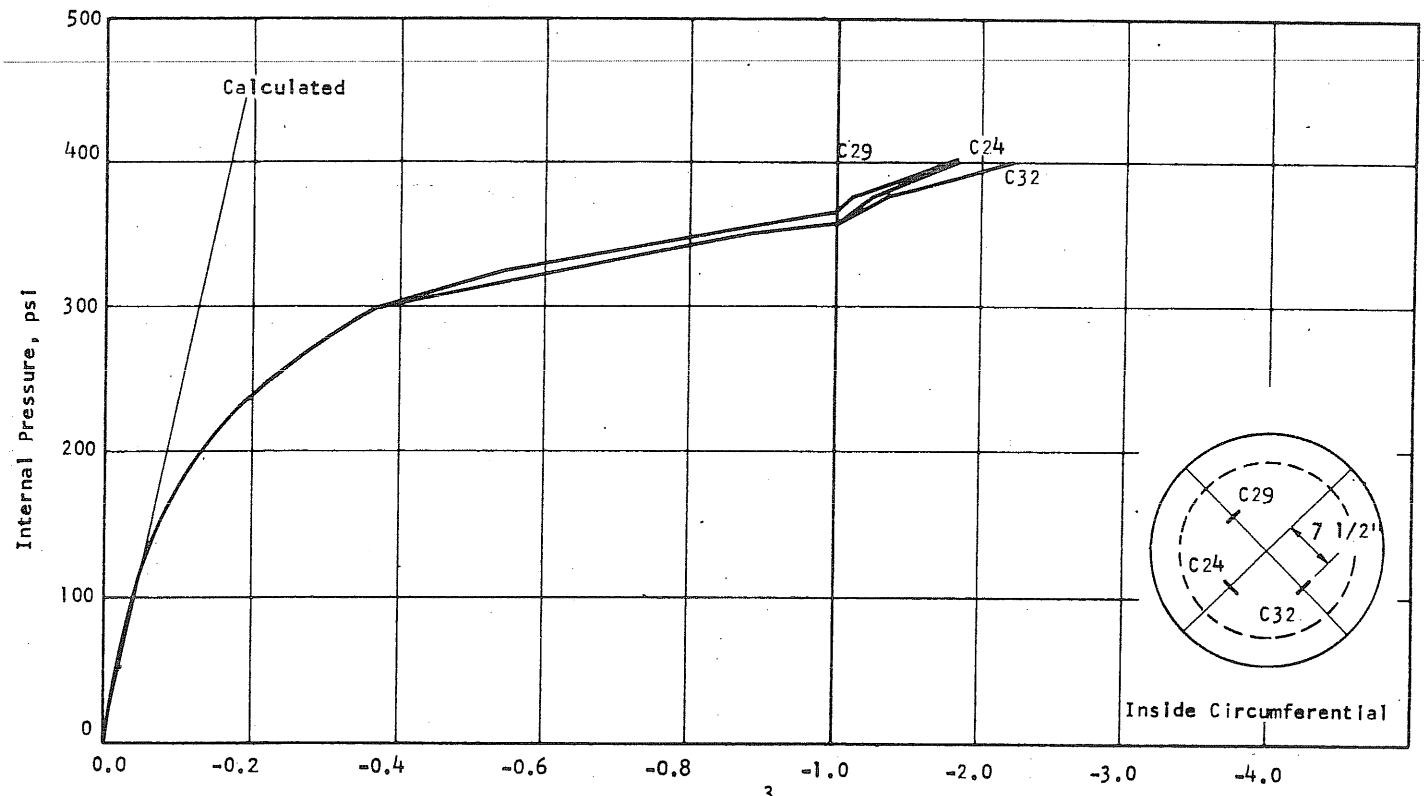


FIG. B7.12 (cont'd) CONCRETE STRAINS, VESSEL PV7

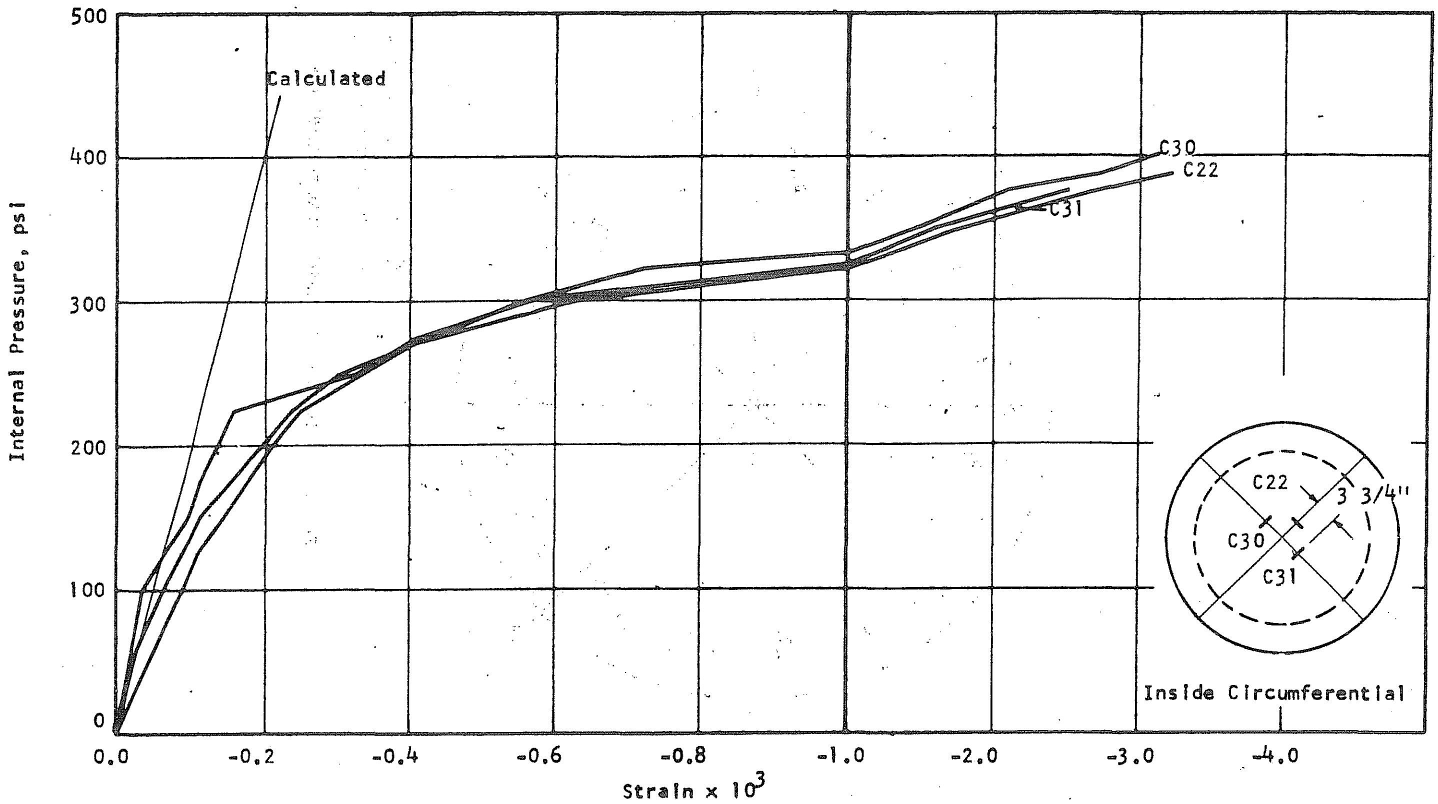


FIG. B7.12 (cont'd) CONCRETE STRAINS, VESSEL PV7

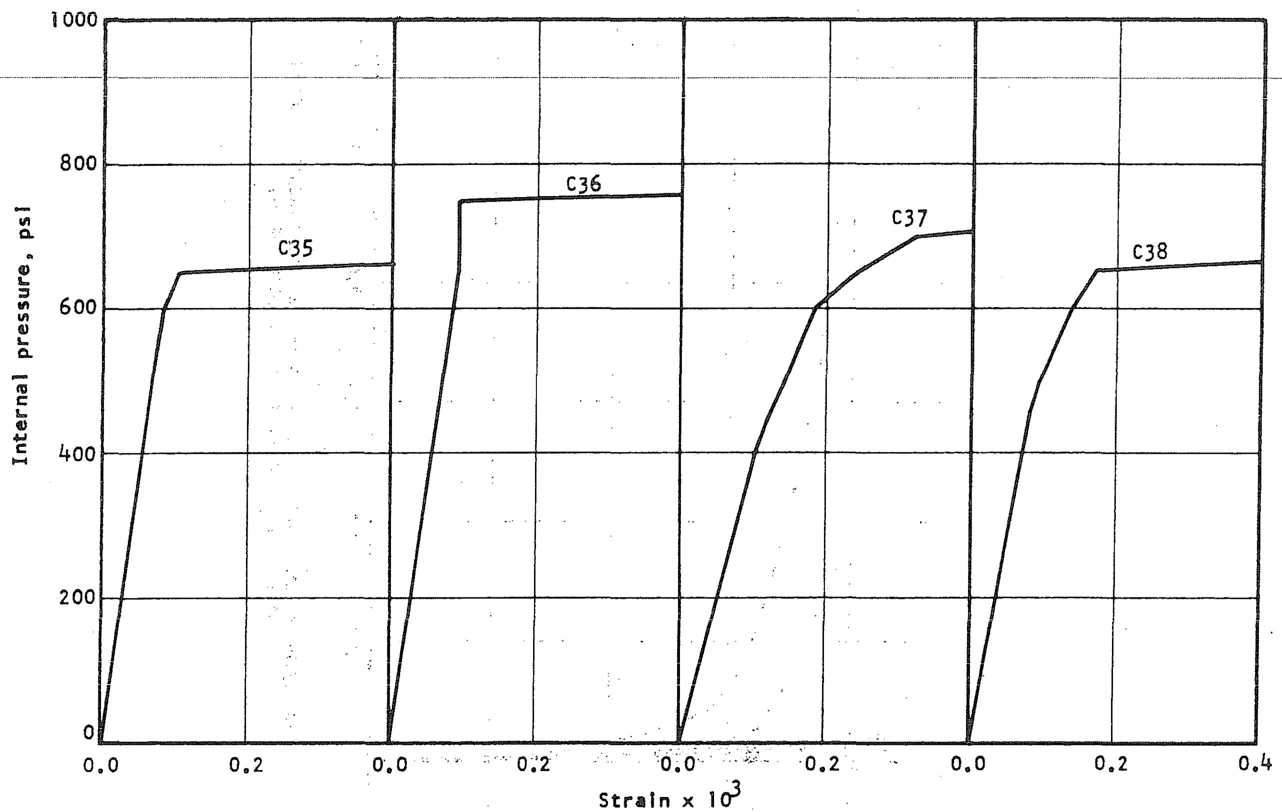


FIG. B7.13 APPLIED PRESSURE vs LONGITUDINAL STRAIN ON THE N-SIDE OF THE WALL OF PV7

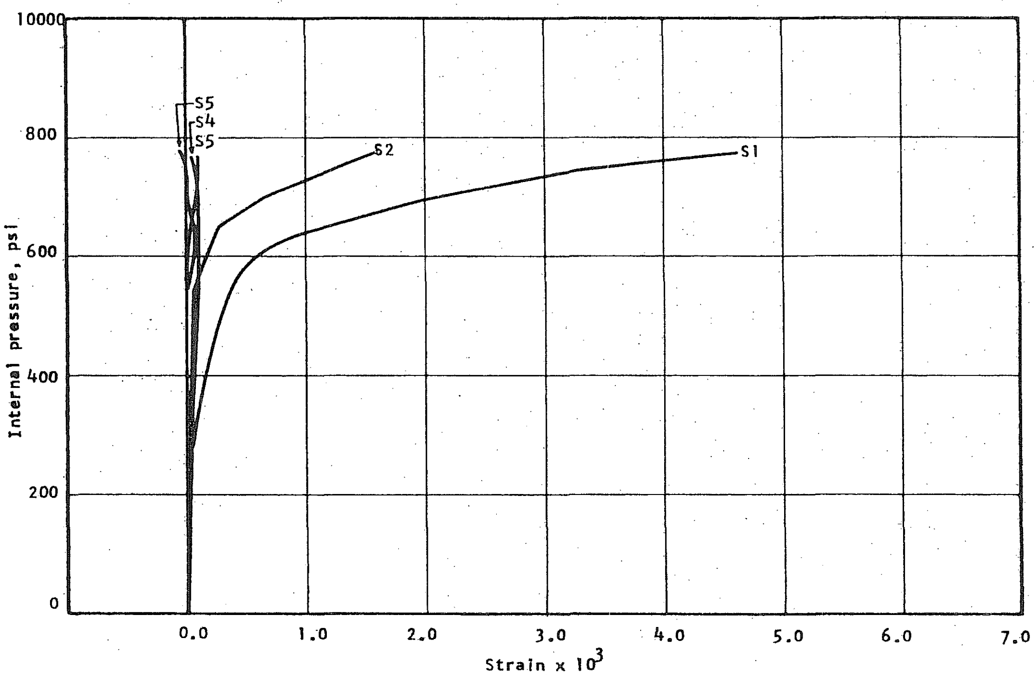


FIG. B7.14 APPLIED PRESSURE vs STRAIN IN THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE N-END OF THE N-S DIAMETER OF PV7

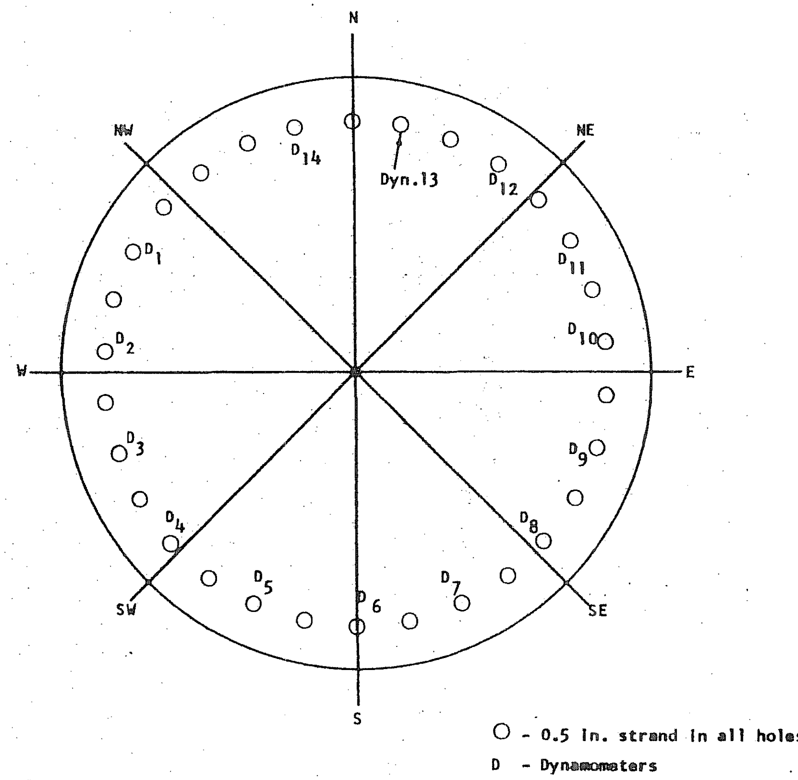


FIG. B7.15 LOCATION OF LONGITUDINAL REINFORCEMENT

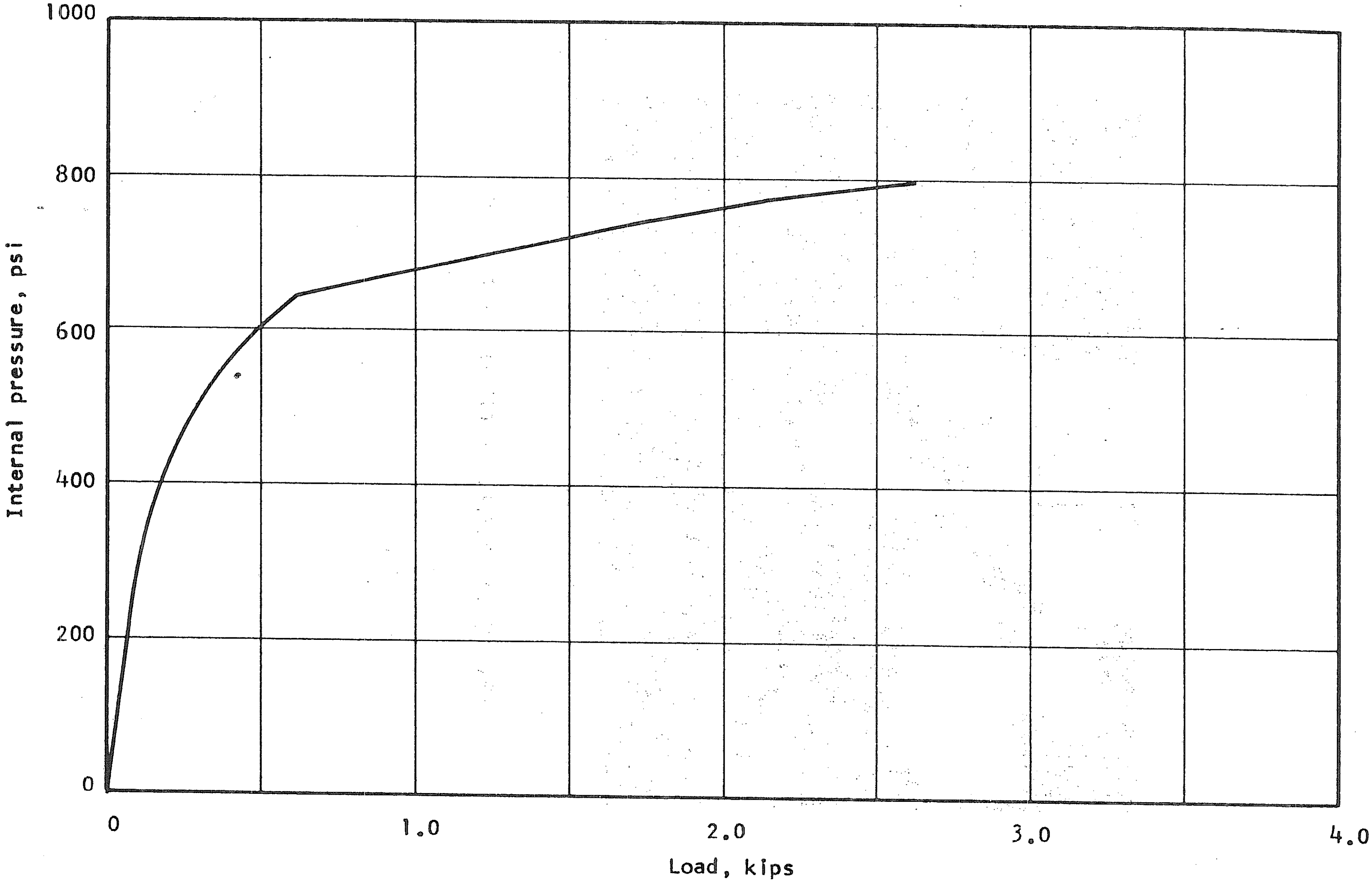


FIG. B7.16 APPLIED PRESSURE vs INCREASE IN LOAD IN DYNAMOMETER NO. 13 ON PV7

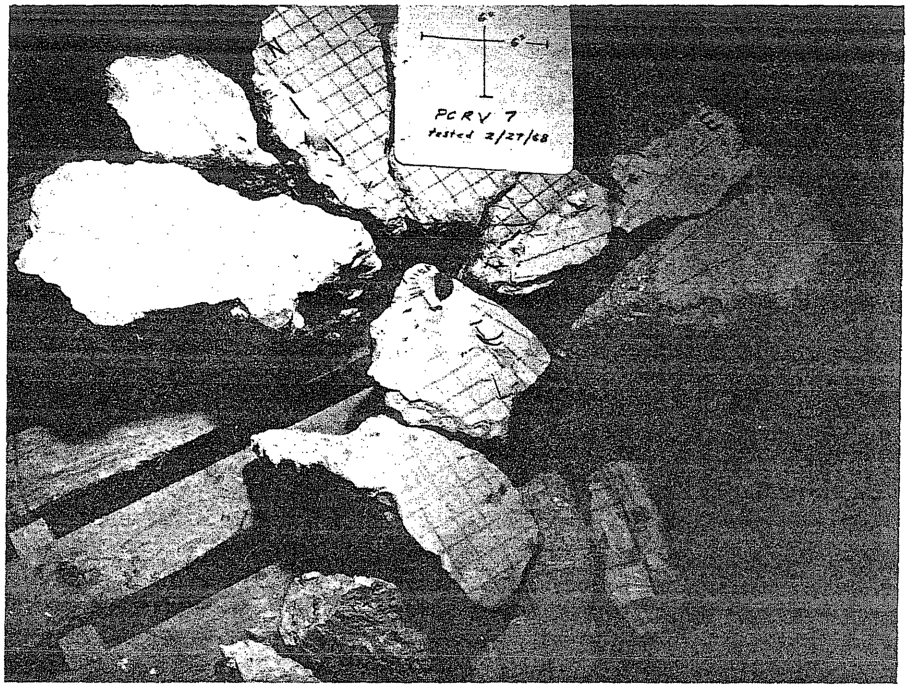


FIG. B7.17 PIECES OF THE END SLAB OF PV7

B8 Test Vessel PV8 (t = 7 1/2 in., s = 1/3 in.)

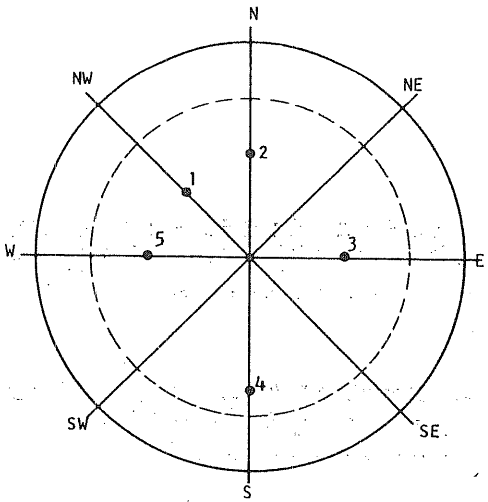
The same crack pattern observed in PV7 after circumferential prestressing was evident in PV8. In PV8 the band of circumferential hairline cracks on the outside of the vessel was from six to seven in. below the top of the vessel. The band of hairline cracks on the inside of the vessel was from ten to sixteen in. below the top of the end slab. Four longitudinal tendons with a load of 24 kips in each were placed on the vessel to arrest further cracks development.

A detail of the liner used on the first attempt to test PV8 is shown in Fig. B8.2. No sheet metal was placed on the end slab. The liner was fabricated by fitting the sheets of neoprene over a form of the same dimensions as the inside of the vessel. The joints at the end slab and the side wall was made by lapping the sheets of neoprene and applying rubber cement to contact surfaces. The neoprene liner was placed in the vessel as a unit and attached to the aluminum and hydrocal with rubber cement. A one-half-in. wide strip of rubber tape was placed around the periphery of the vessel at the joint between the one-in. ring and the neoprene liner. The longitudinal prestressing force was provided by thirty strands. A load cell was placed on each strand.

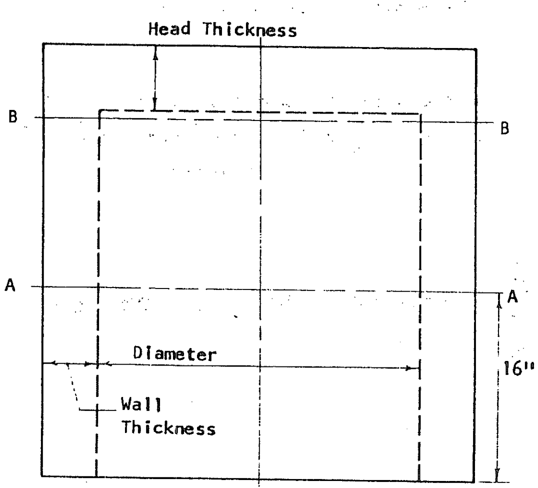
The first attempt at testing PV8 was not successful. Pressure was increased in 100 psi increments to a pressure of 200 psi and in 50 psi increments until a leak prevented further increase in pressure at 625 psi. Deflection and strain readings suggest that the vessel was close to failure when the test was stopped. The deflection at the center of the end slab reached 0.79 in., and the strains in the prestressing wire were of a magnitude that the top three layers were loose when the vessel was depressurized.

The method of sealing PV8 for the second attempt is shown in Fig. B8.3. The neoprene on the walls was omitted and the O-ring method of sealing the joint at the end slab was employed. Thirty strands were used for longitudinal prestressing.

One hundred psi load increments were applied until the internal pressure reached 400 psi. The pressure was then increased to 450 psi in 25 psi increments. Readings were taken again at 500 psi. Loading was increased continuously until the vessel failed at 640 psi. A photograph of the pieces of the end slab is shown in Fig. B8.20.



Head Thickness	
Point No.	Inches
1	$7 \frac{11}{16}$
2	$7 \frac{12}{16}$
3	$7 \frac{10}{16}$
4	$7 \frac{8}{16}$
5	$7 \frac{9}{16}$



Wall Thickness, in.		
Plane / Axis	AA	BB
N	4.95	5.14
NE		
E	4.95	4.96
SE		
S	4.95	4.99
SW		
W	4.88	4.82
NW		

Inside Diameter, in.		
Plane / Axis	AA	BB
N-S	$30 \frac{2}{32}$	$29 \frac{31}{32}$
NE-SW	$29 \frac{30}{32}$	$29 \frac{31}{32}$
E-W	$29 \frac{30}{32}$	$30 \frac{0}{32}$
SE-NW	$30 \frac{0}{32}$	$29 \frac{30}{32}$

FIG. B8.1 DIMENSIONS OF PV8

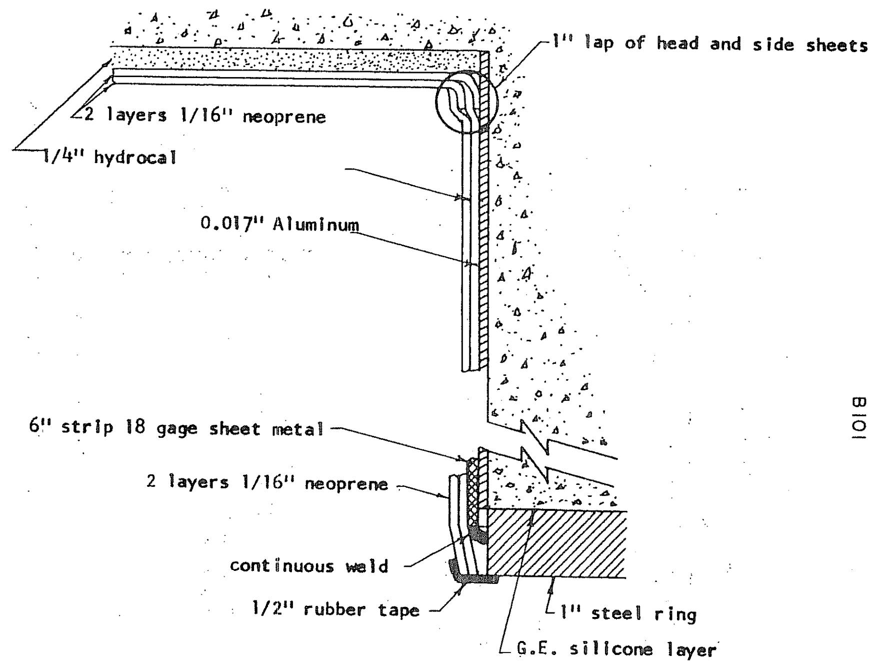


FIG. B8.2 SEALING DETAIL FOR PV8

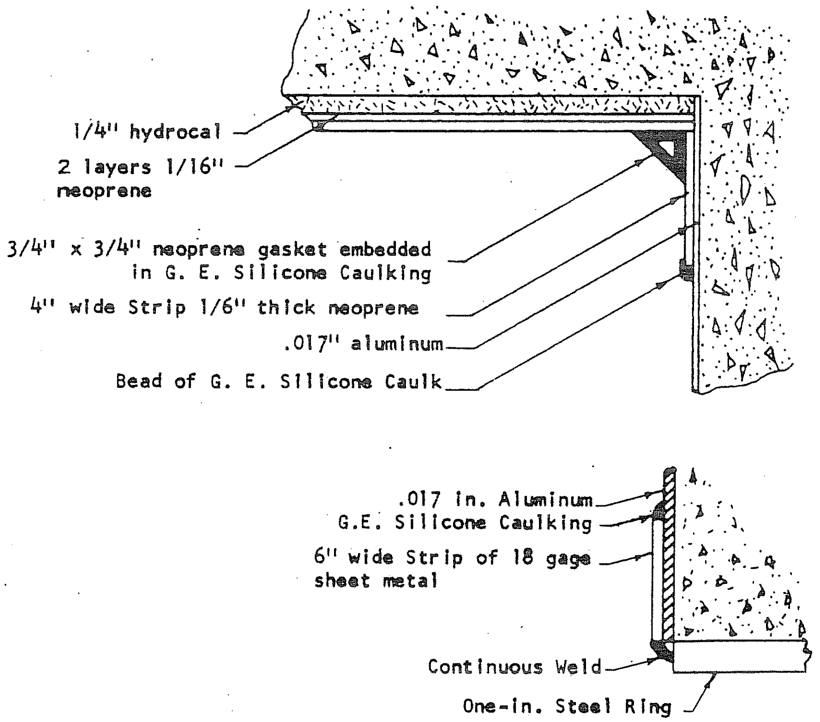
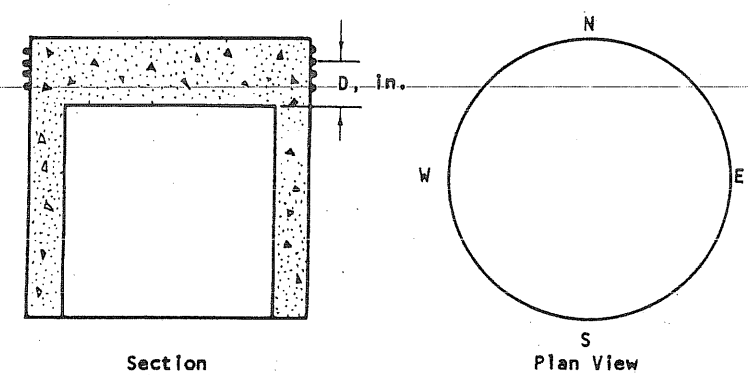


FIG. B8.3 SEALING DETAIL FOR PV8



Wrap No.	D_N	D_E	D_S	D_W
1	6 12/16	6 5/16	6 8/16	6 8/16
2	6 3/16	5 15/16	5 15/16	6 0/16
3	5 14/16	5 8/16	5 8/16	5 9/16
4	5 2/16	5 3/16	5 3/16	5 5/16
5	5 4/16	4 15/16	4 15/16	5 1/16
6	4 15/16	4 10/16	4 10/16	4 12/16
7	4 10/16	4 5/16	4 5/16	4 7/16
8	4 5/16	3 15/16	3 15/16	4 1/16
9	3 14/16	3 8/16	3 9/16	3 10/16
10	3 8/16	3 3/16	3 4/16	3 5/16
11	3 3/16	2 15/16	2 14/16	3 0/16
12	2 12/16	2 8/16	2 8/16	2 9/16
13	2 7/16	2 2/16	2 2/16	2 4/16
14	2 2/16	1 13/16	1 14/16	1 15/16
15	1 13/16	1 8/16	1 8/16	1 9/16
16	1 7/16	1 2/16	1 3/16	1 4/16
17	1 2/16	14/16	14/16	15/16
18	14/16	2/16	9/16	10/16
19	8/16	3/16	2/16	4/16
20	3/16	-3/16	-2/16	-1/16

FIG. B8.4 MEASURED LOCATION OF THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE ENDS OF THE N-S AND E-W DIAMETERS ON PV8

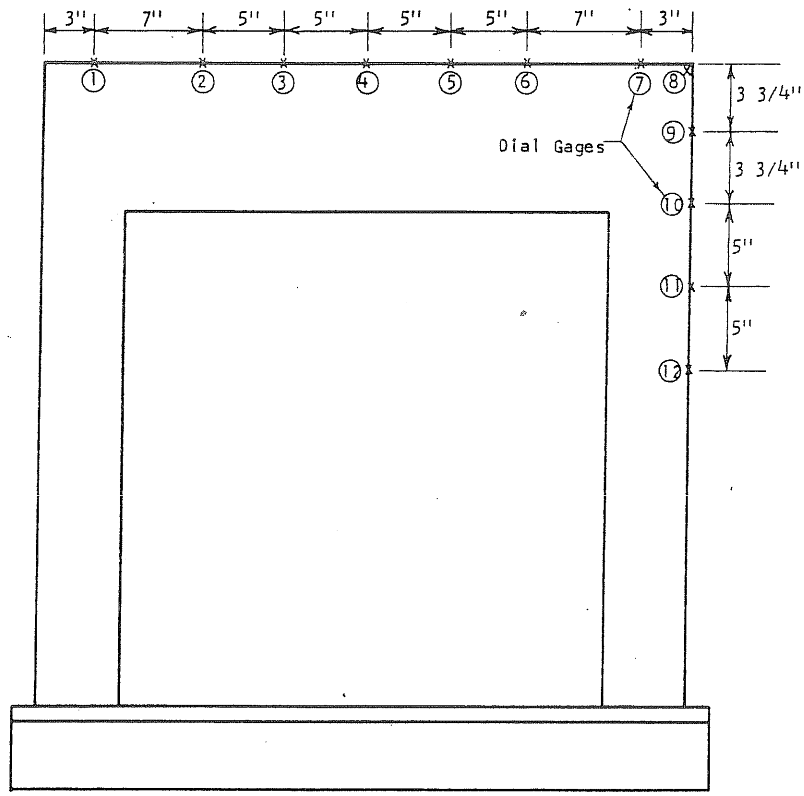


FIG. B8.5 LOCATION OF DEFLECTION GAGES ON PV8

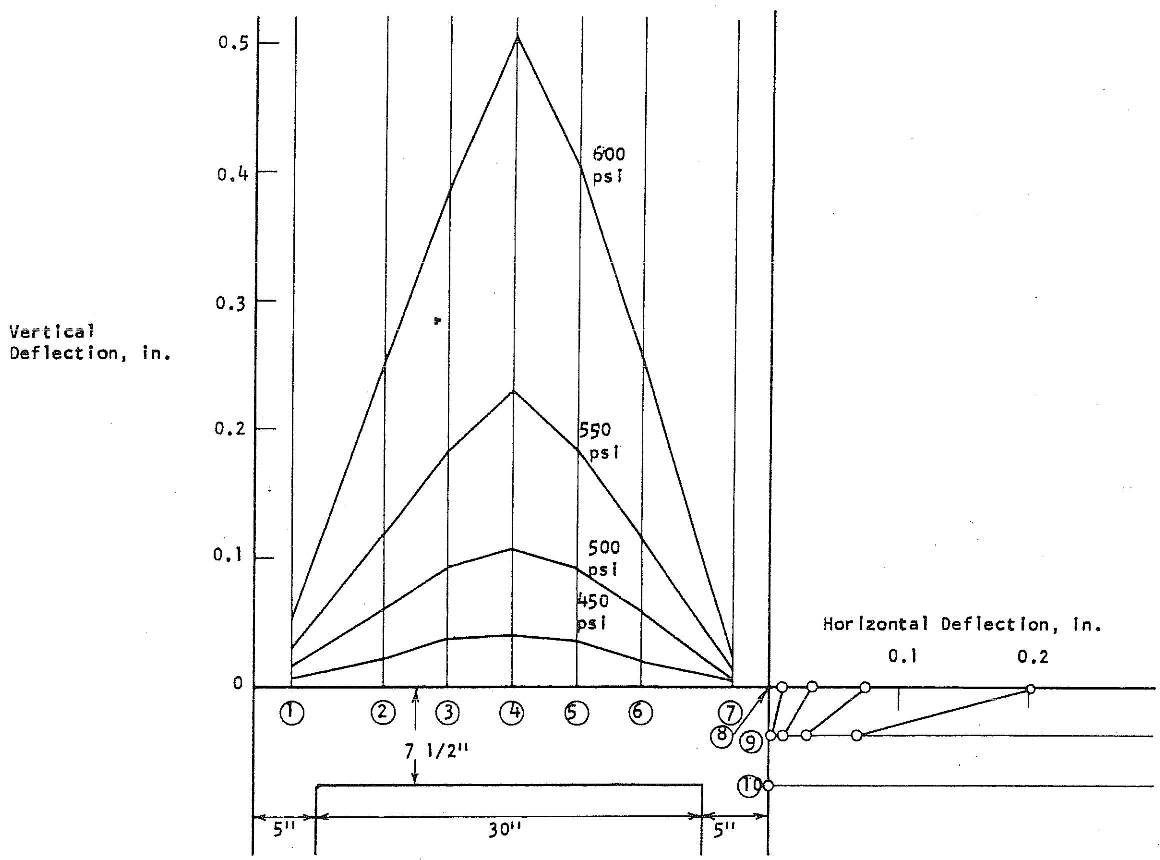


FIG. B8.6 DEFLECTION PROFILES OF THE END SLAB ALONG THE N-S DIAMETER OF PV8

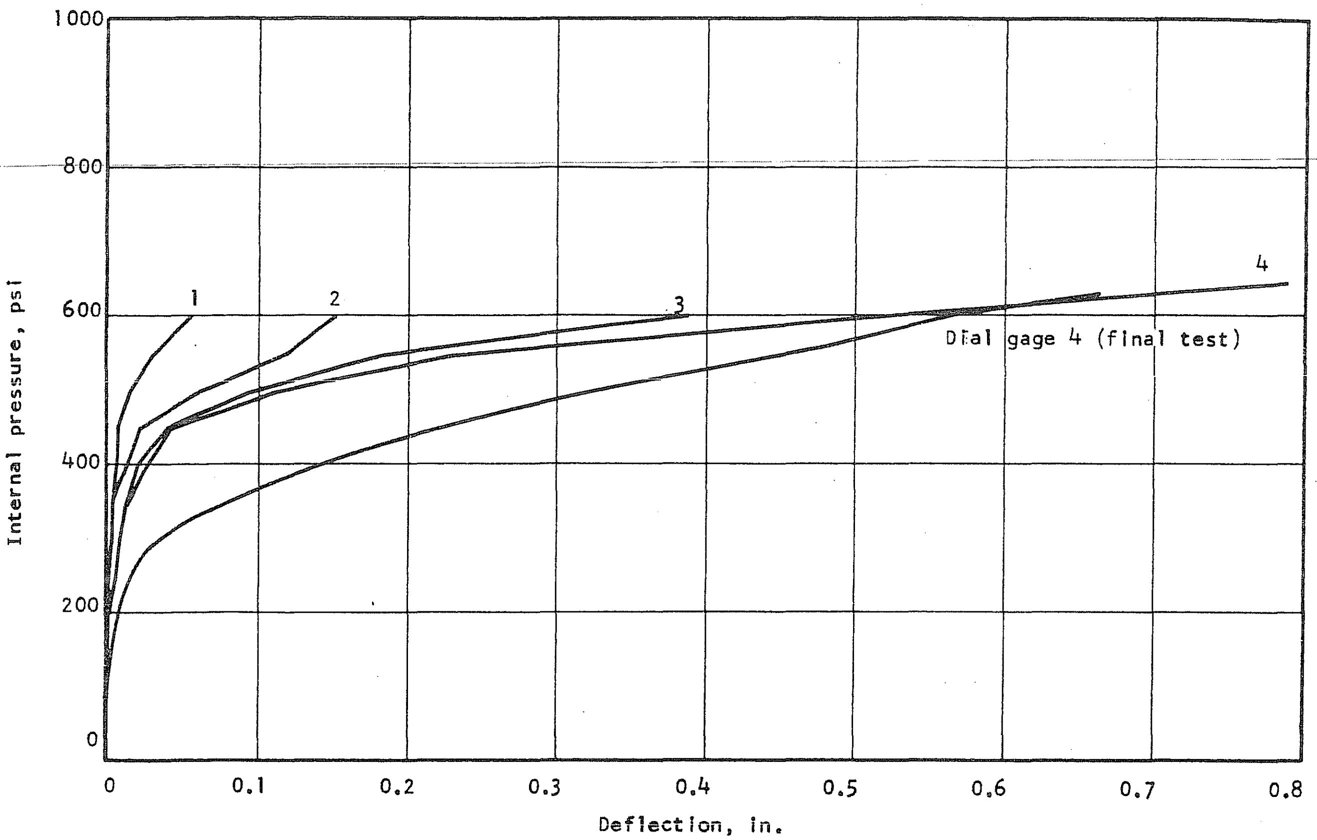


FIG. B8.7 APPLIED PRESSURE vs DEFLECTION ALONG THE N-HALF OF THE N-S DIAMETER OF PV8

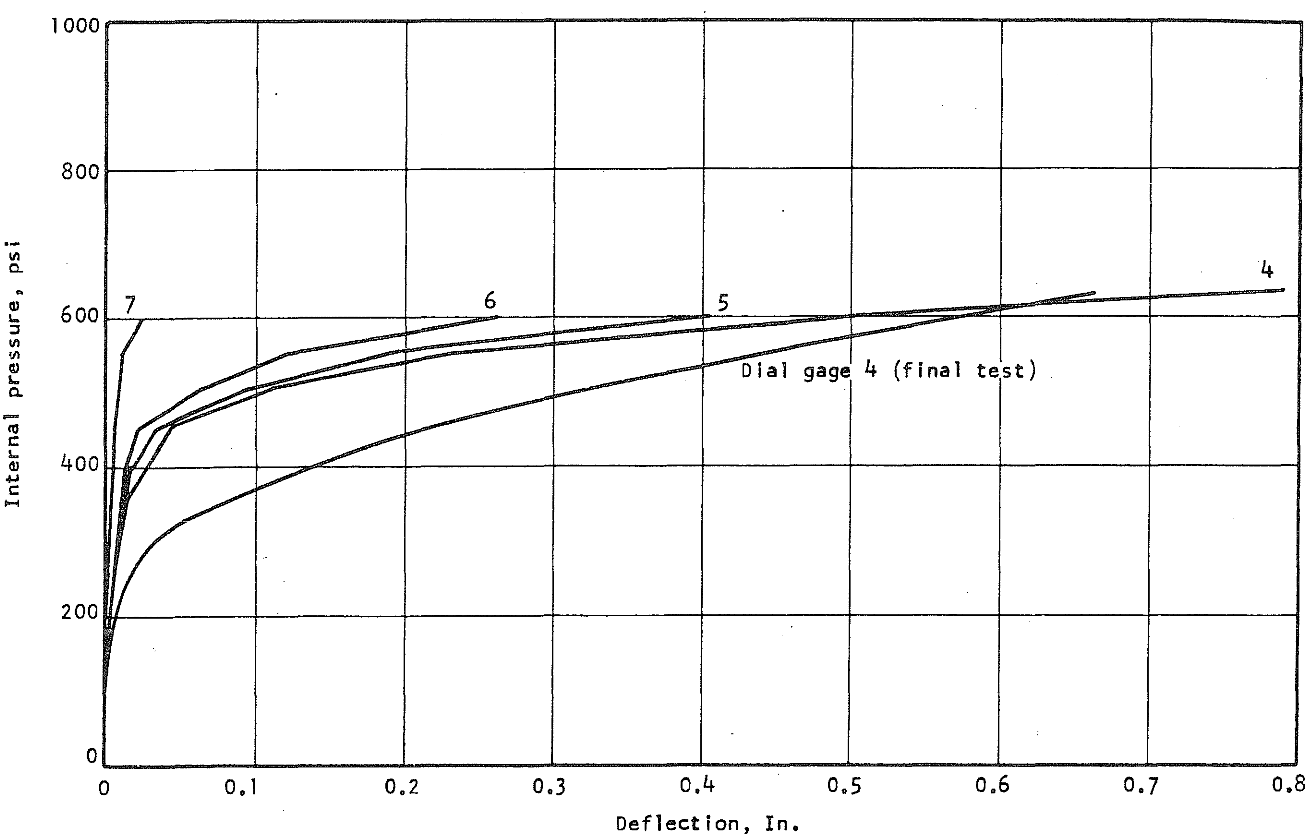


FIG. B8.8 APPLIED PRESSURE vs DEFLECTION ALONG THE S-HALF OF THE N-S DIAMETER OF PV8

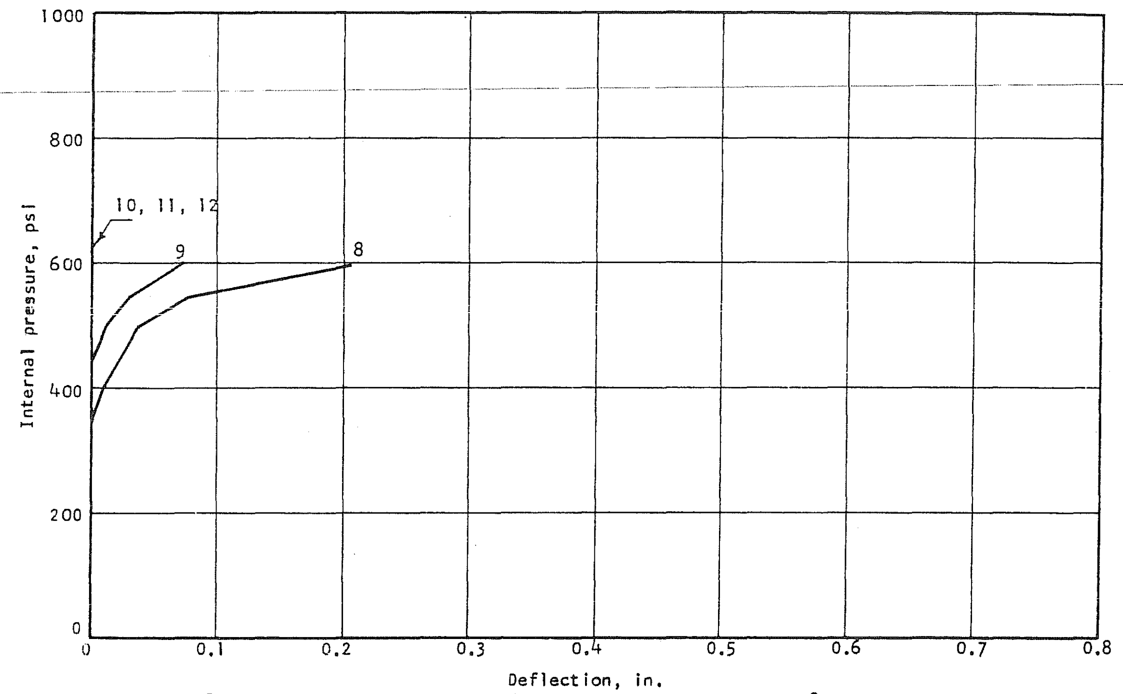
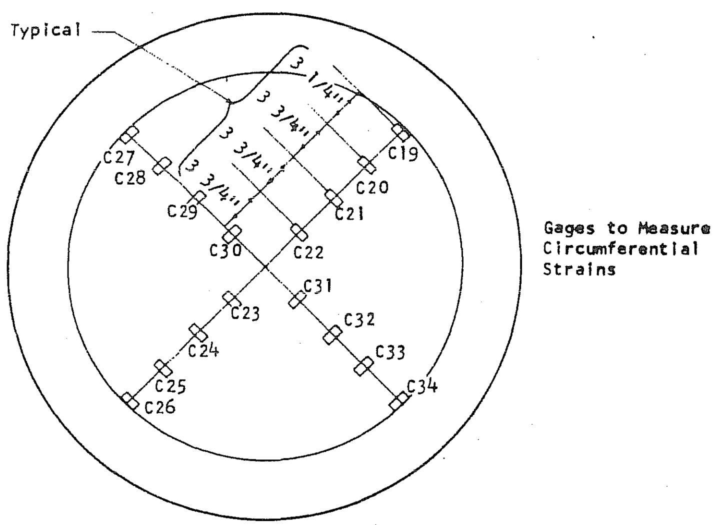


FIG. B8.9 APPLIED PRESSURE vs DEFLECTION OF THE SIDE WALL OF PV8



Concrete Gages on the Inside of the End Slab

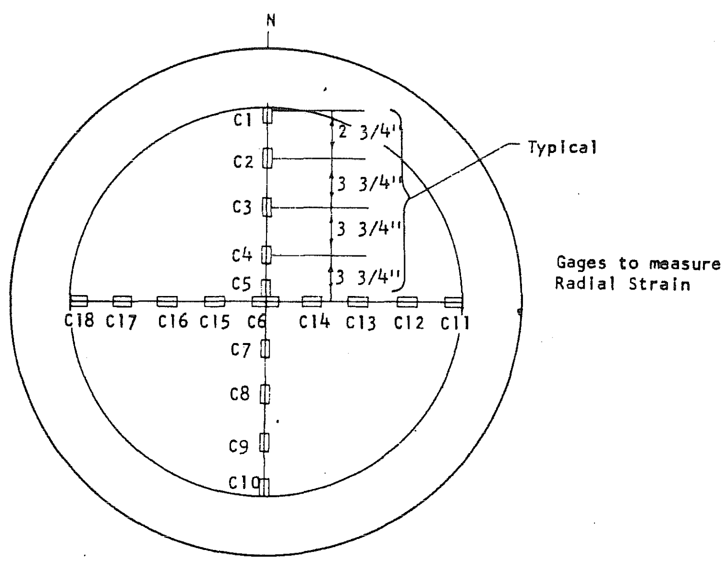
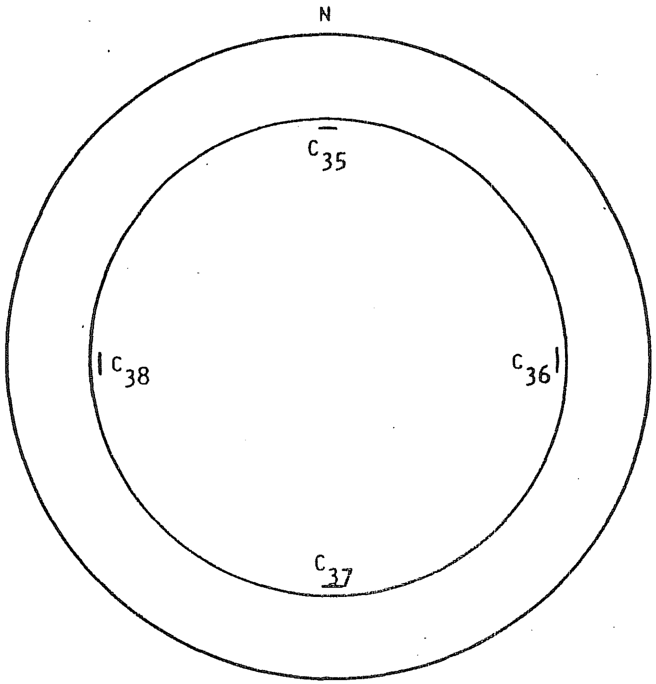


FIG. B8.10 STRAIN GAGE LOCATIONS ON PV8

Concrete Gages on The Inside Walls



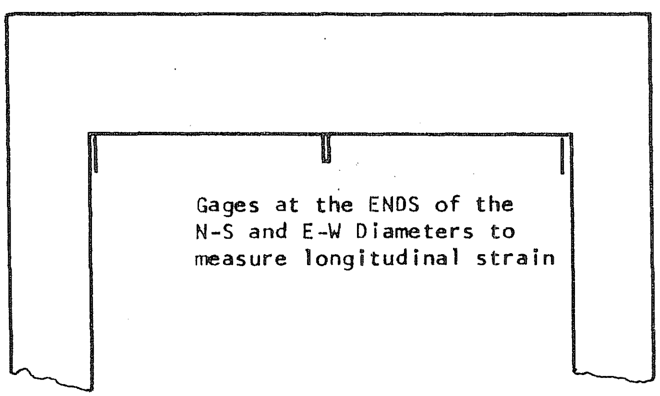
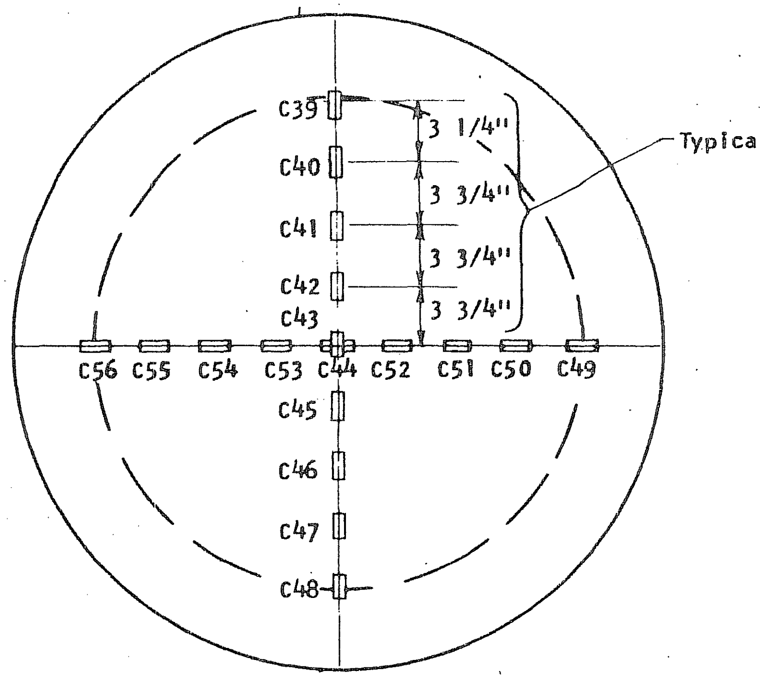
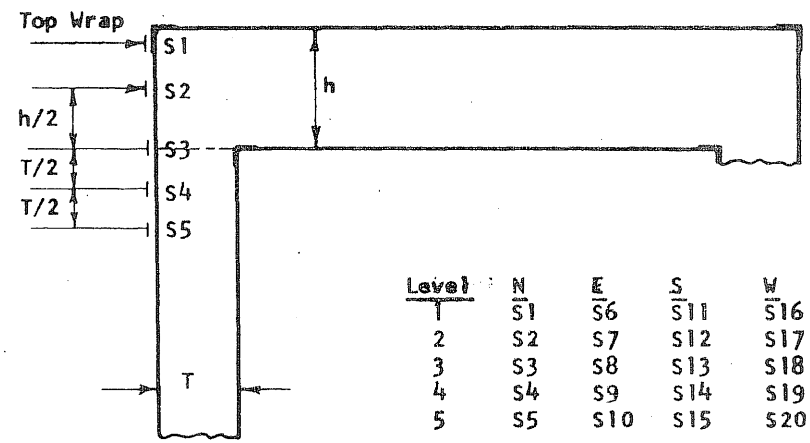


FIG. B8.10 (cont.) STRAIN GAGE LOCATIONS ON PV8

Concrete Gages on the Outside of the End Slab



Steel Gages on Circumferential Prestress Wire



Level	N	E	S	W
1	S1	S6	S11	S16
2	S2	S7	S12	S17
3	S3	S8	S13	S18
4	S4	S9	S14	S19
5	S5	S10	S15	S20

FIG. B8.10 (cont'd) STRAIN GAGE LOCATIONS ON PV8

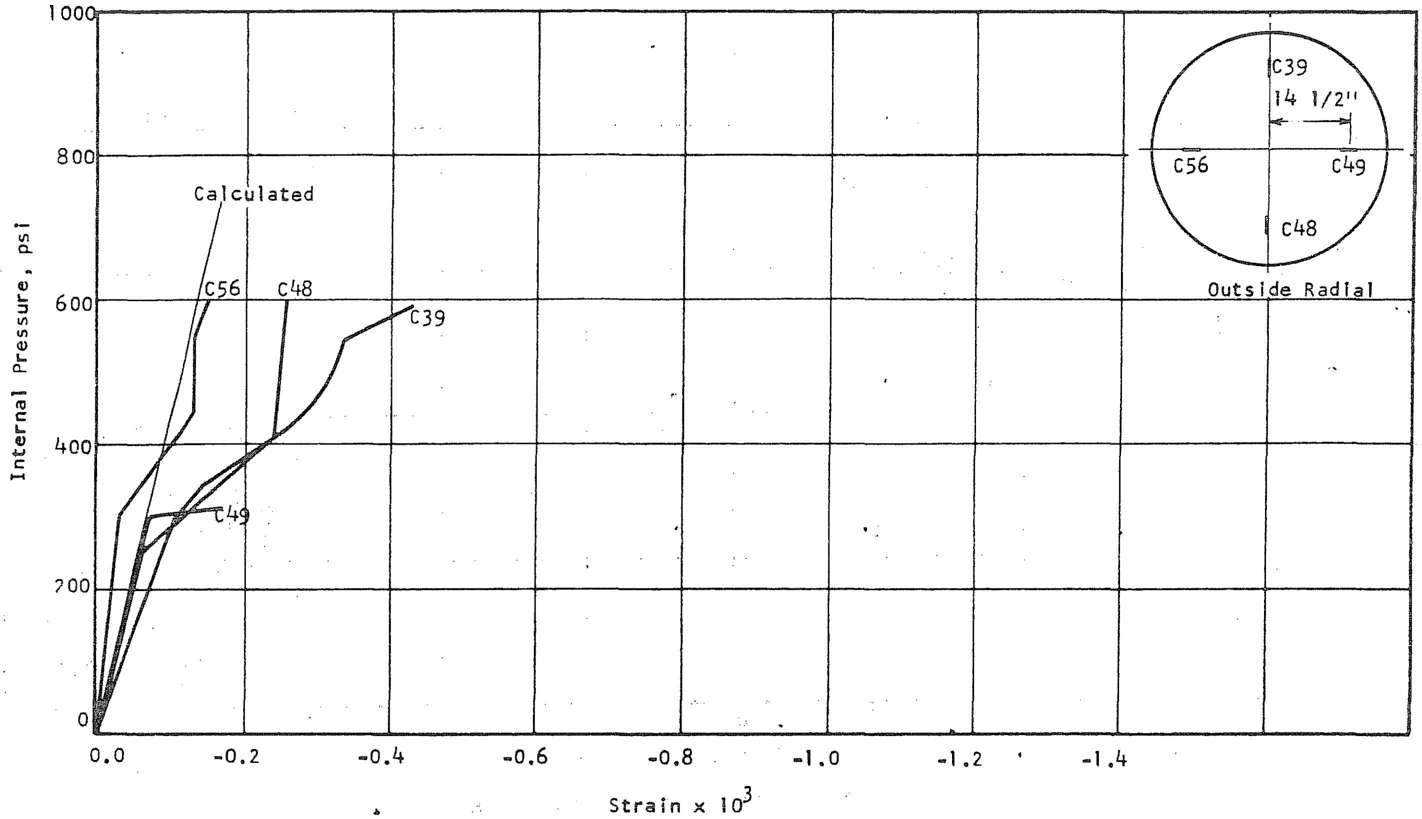


FIG. B8.11 CONCRETE STRAINS, VESSEL PV8

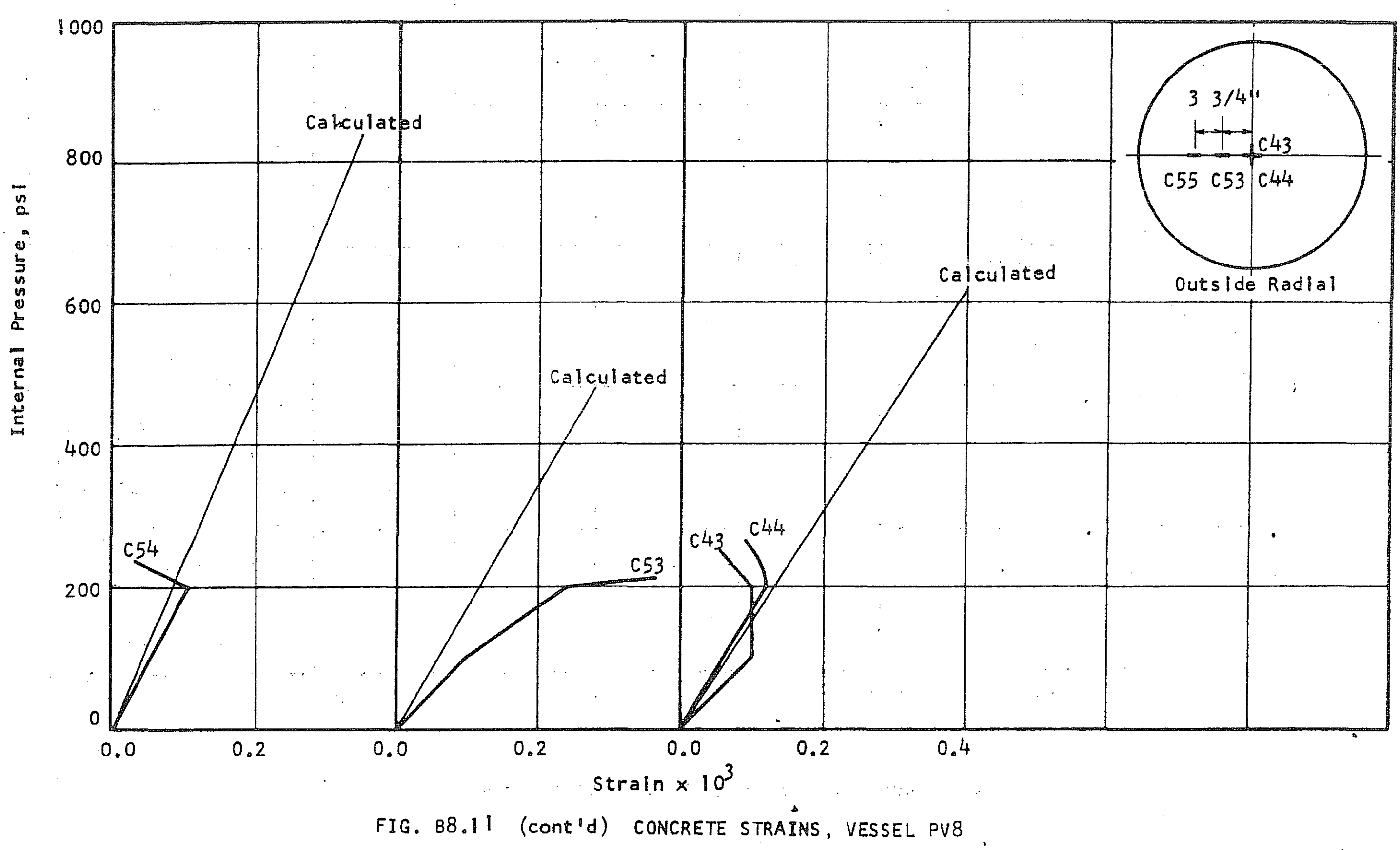


FIG. B8.11 (cont'd) CONCRETE STRAINS, VESSEL PV8

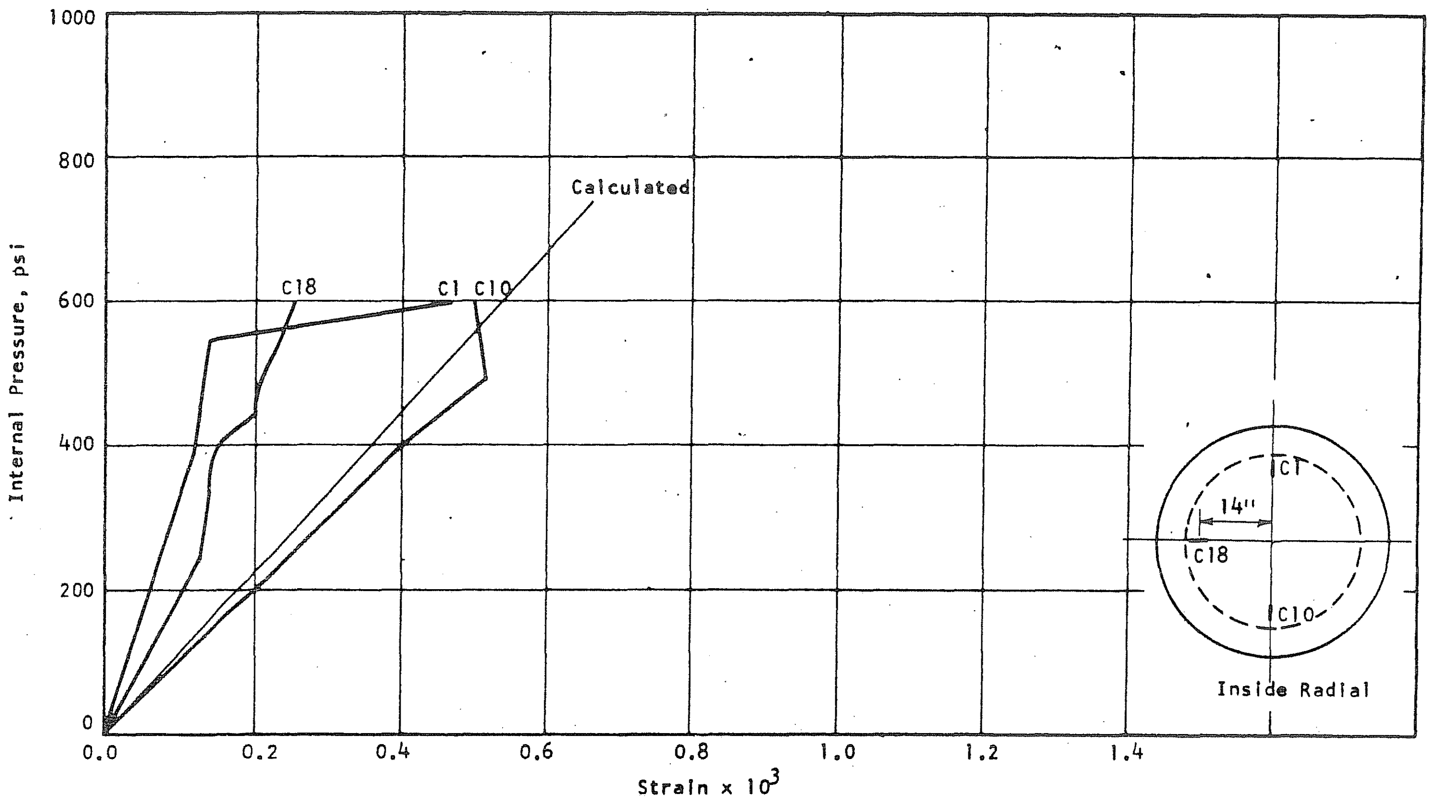


FIG. B8.12 CONCRETE STRAINS, VESSEL PV8

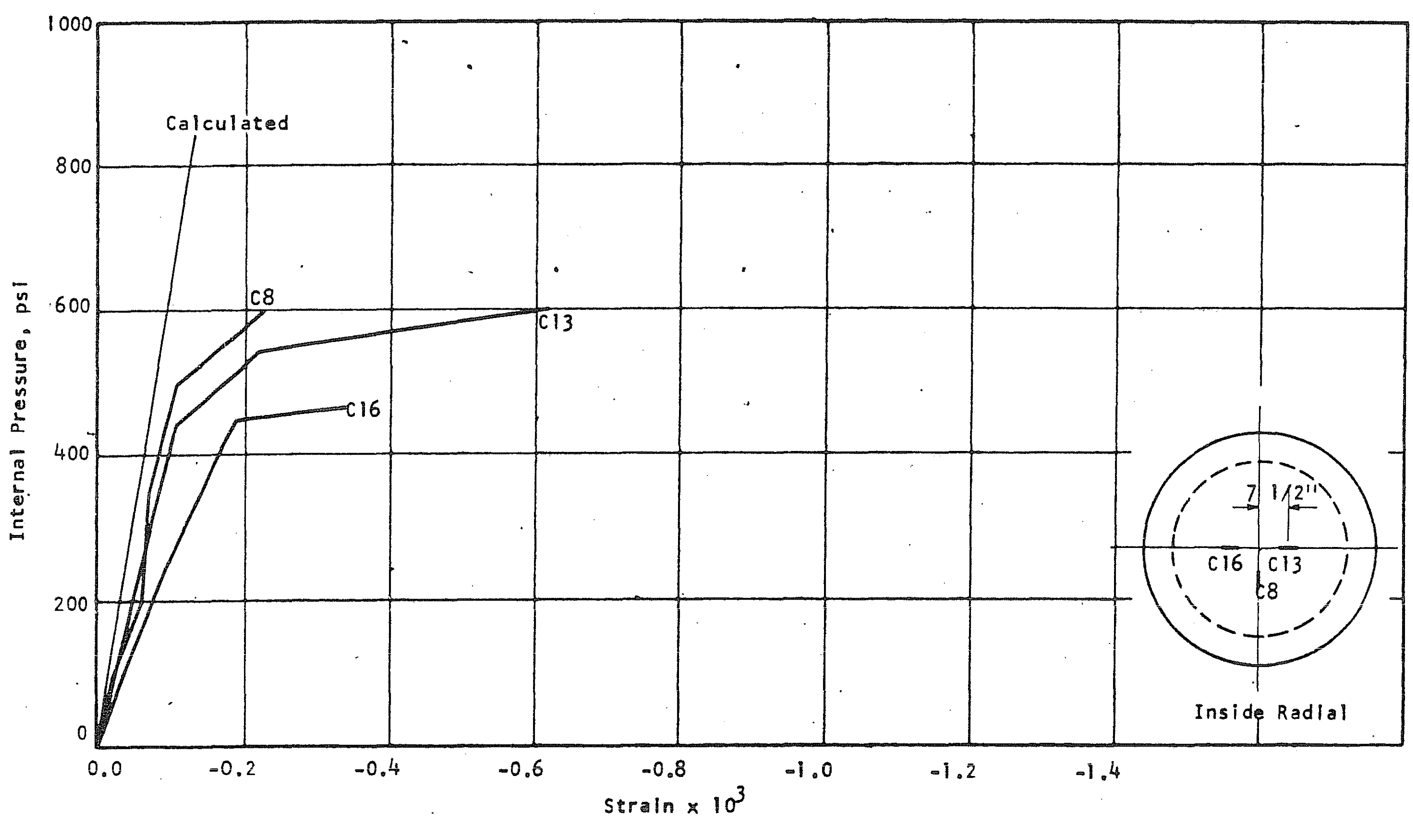


FIG. B8.12 (cont'd) CONCRETE STRAINS, VESSEL PV8

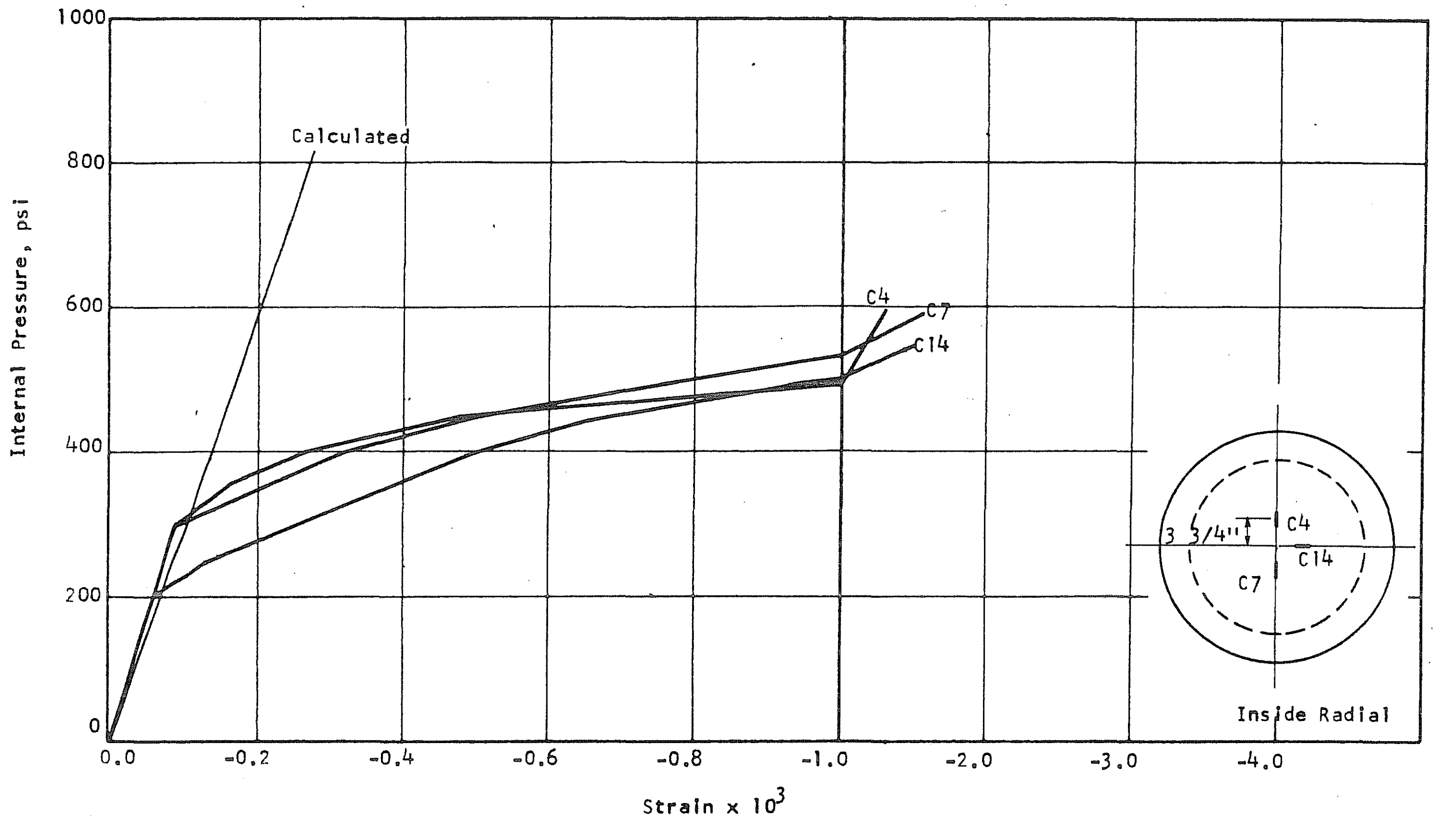


FIG. B8.12 (cont'd) CONCRETE STRAINS, VESSEL PV8

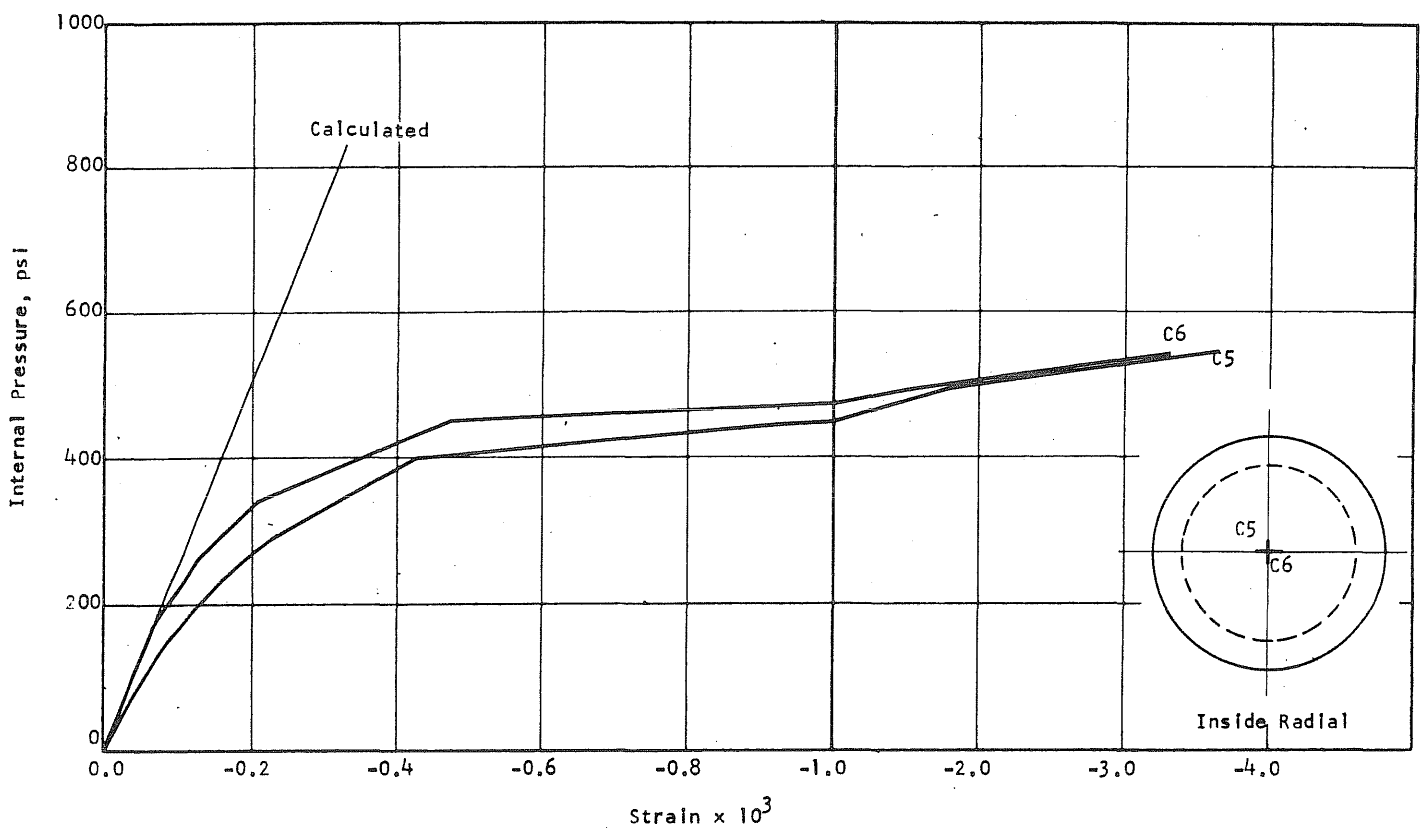


FIG. B8.12 (cont'd) CONCRETE STRAINS, VESSEL PV8

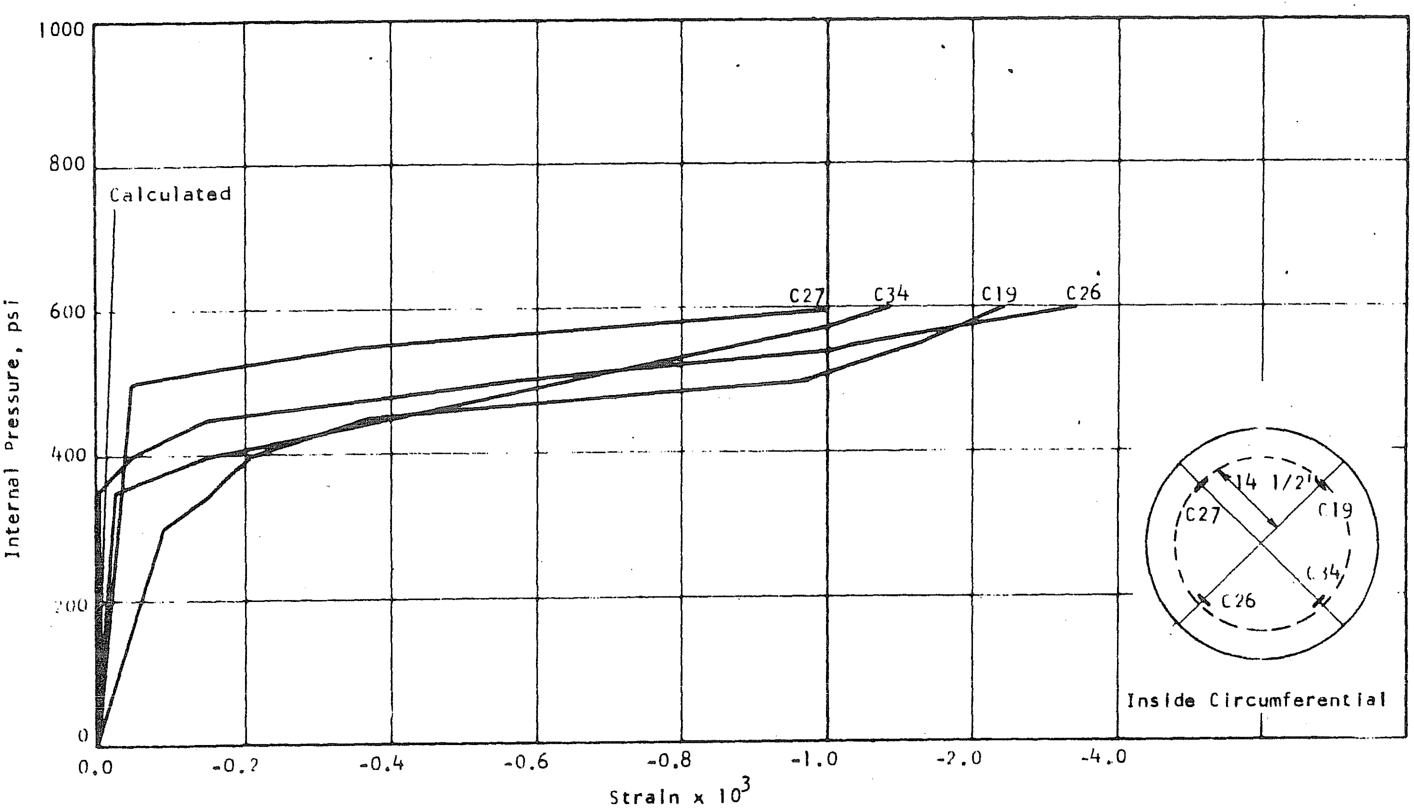


FIG. B8.13 CONCRETE STRAINS, VESSEL PV8

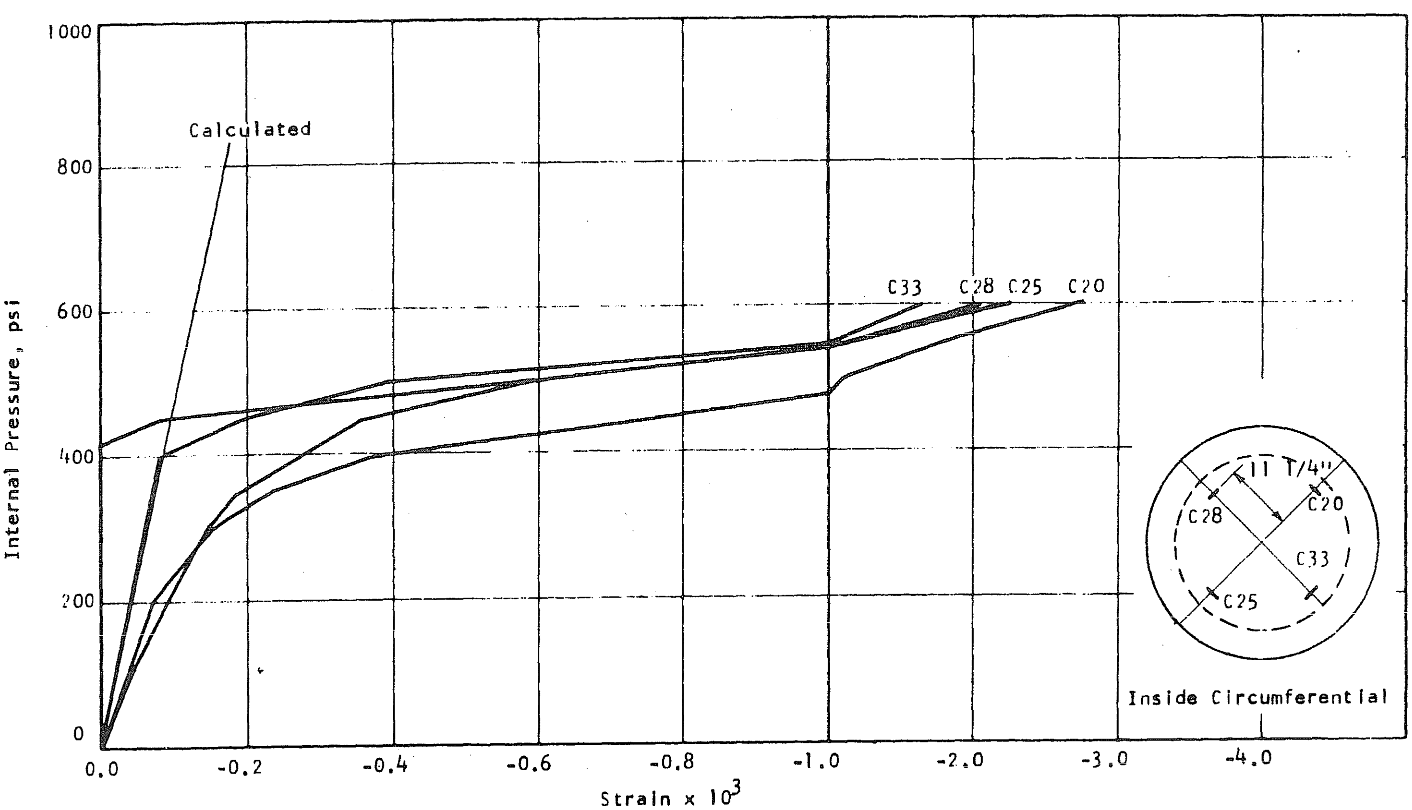


FIG. B8.13 (cont'd) CONCRETE STRAINS, VESSEL PV8

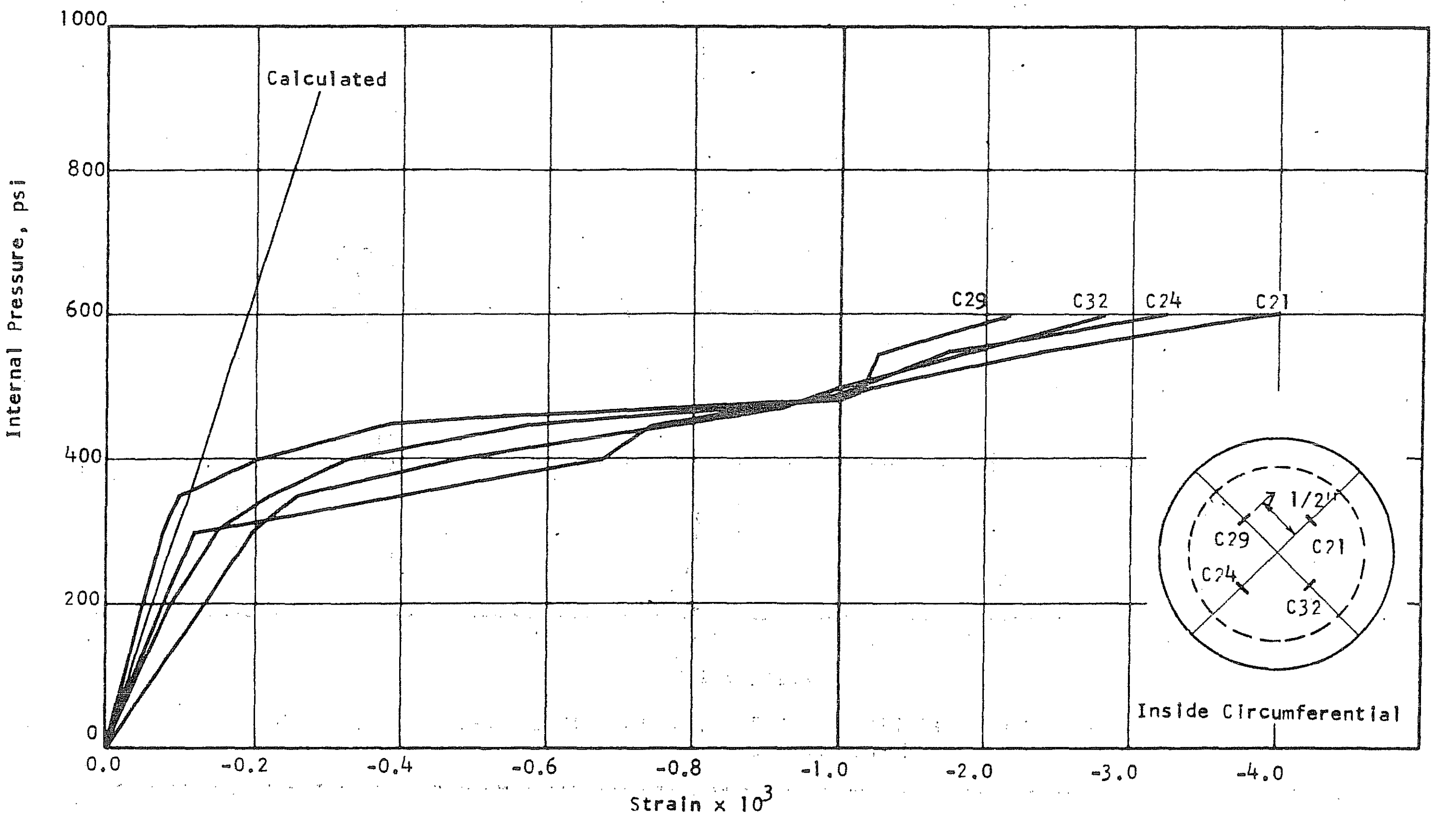


FIG. B8.13 (cont'd) CONCRETE STRAINS, VESSEL PV8

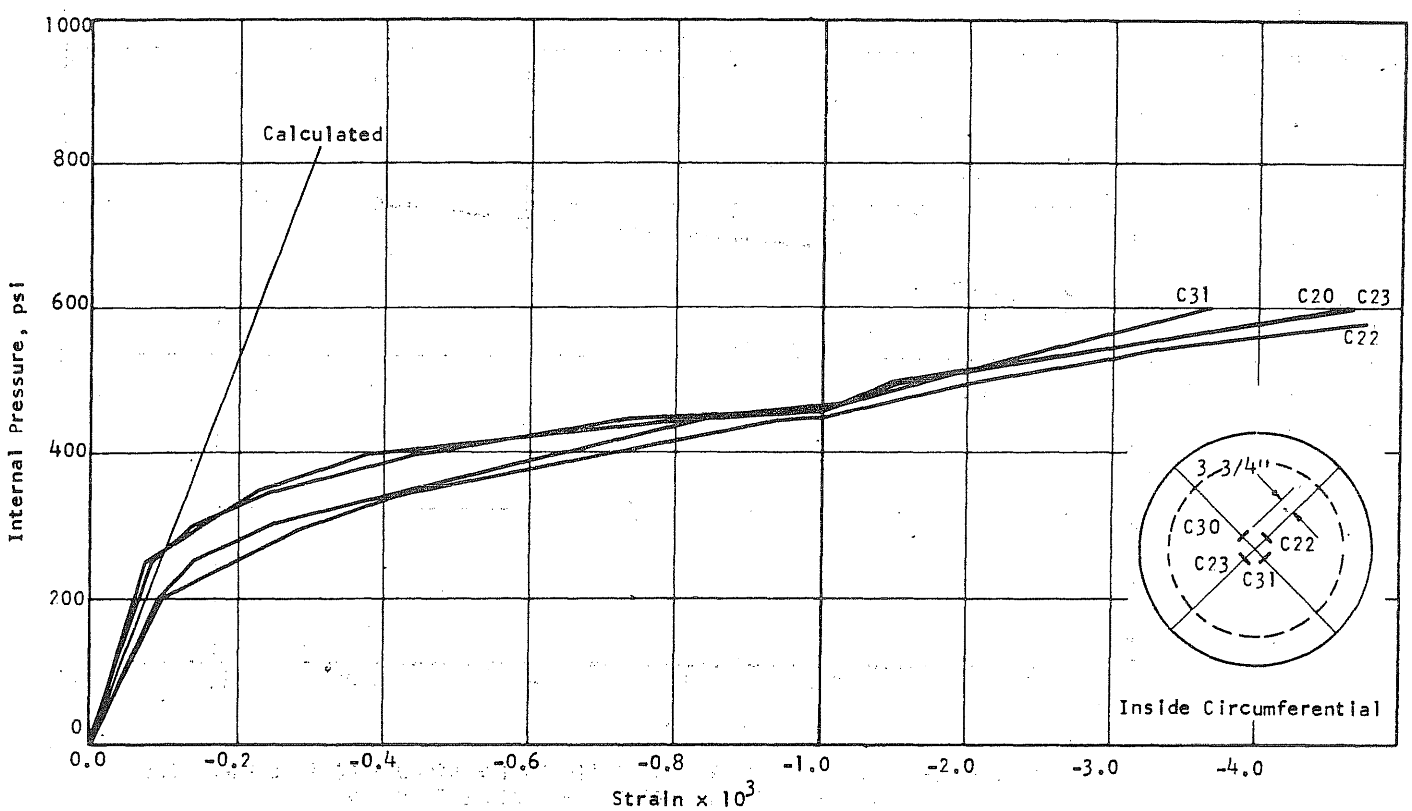


FIG. B8.13 (cont'd) CONCRETE STRAINS, VESSEL PV8

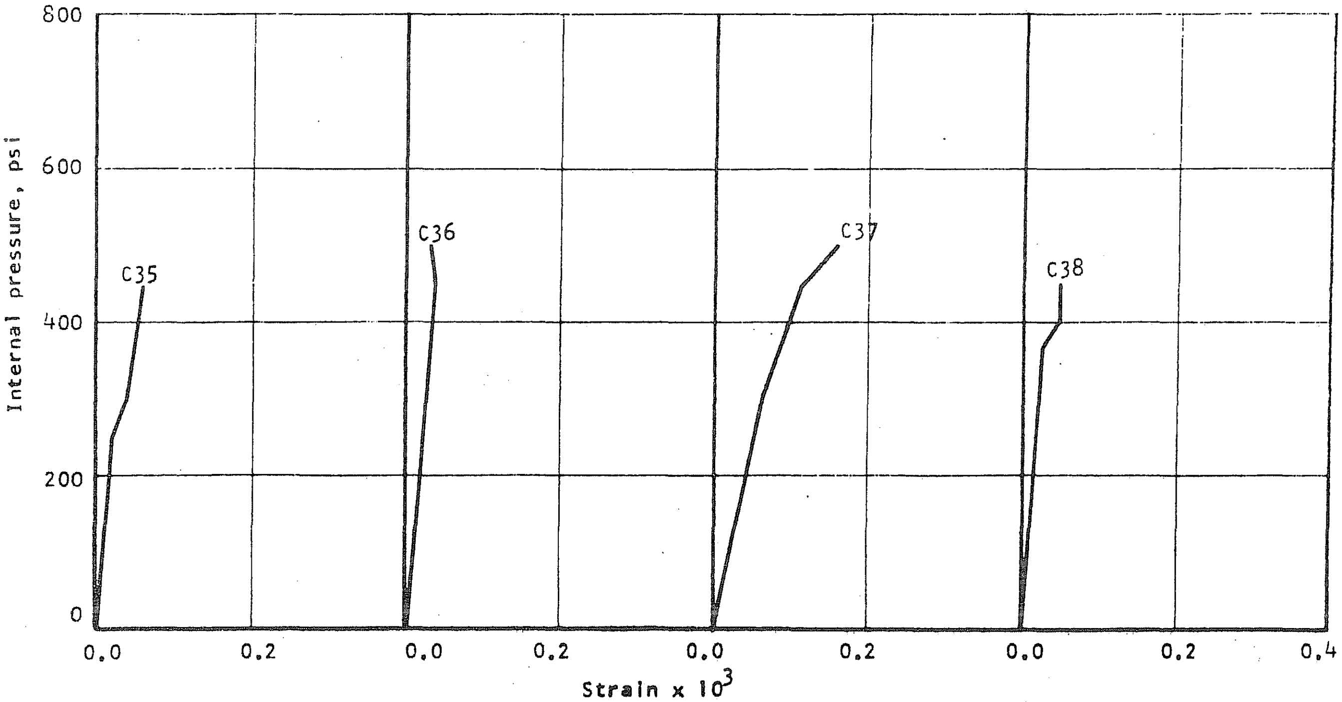


FIG. B8.14 APPLIED PRESSURE vs LONGITUDINAL STRAIN ON THE INSIDE OF THE WALL OF PV8

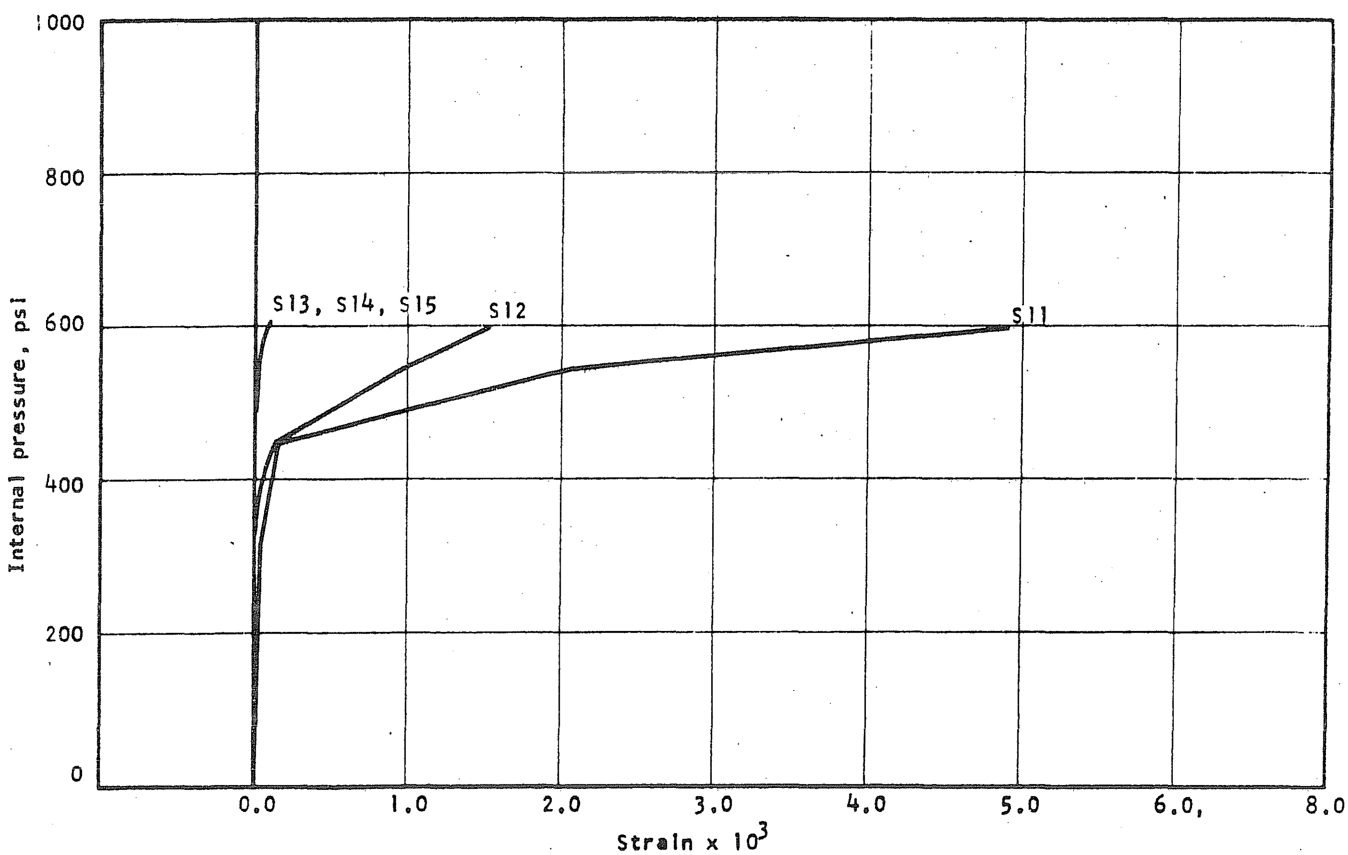


FIG. B8.15 APPLIED PRESSURE vs STRAIN IN THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE S-END OF THE N-S DIAMETER OF PV8

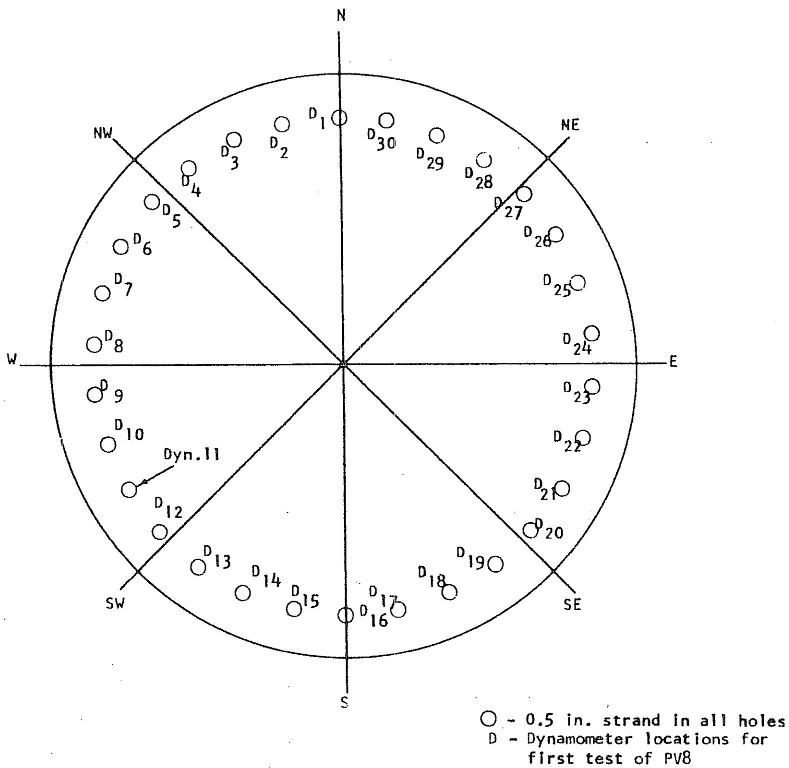


FIG. B8.16 LOCATION OF LONGITUDINAL REINFORCEMENT

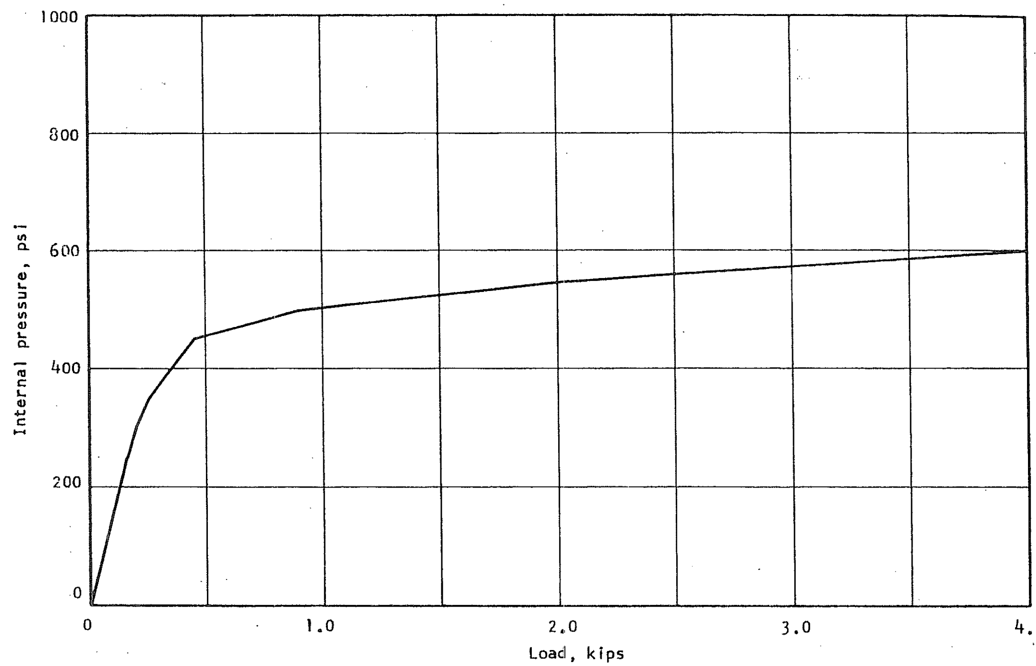


FIG. B8.17 APPLIED PRESSURE vs INCREASE IN LOAD IN DYNAMOMETER NO. 11 FOR FIRST TEST OF PV8

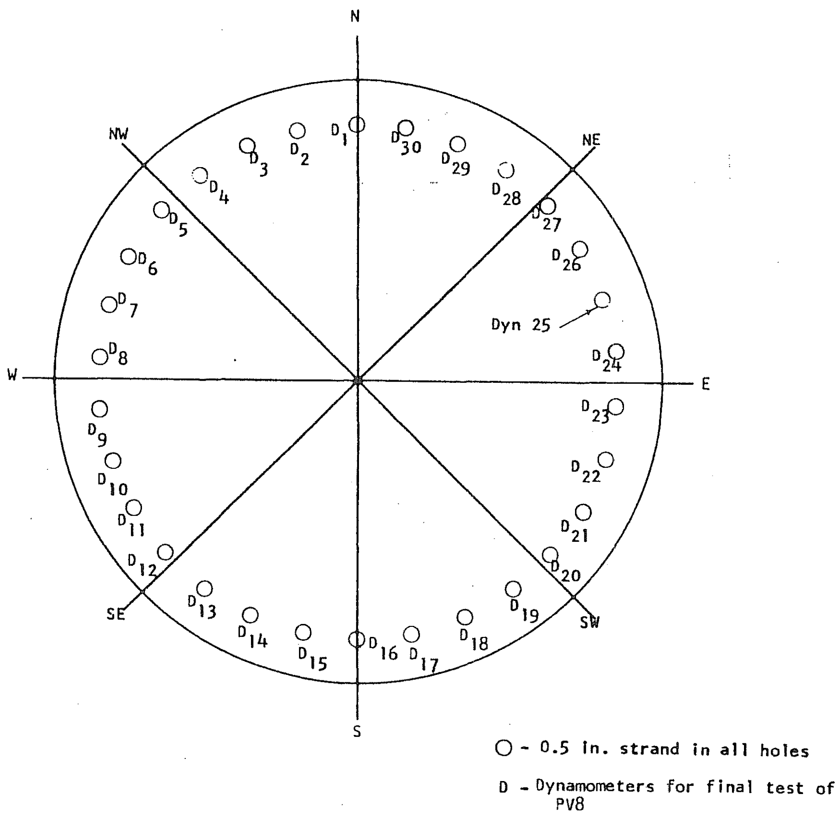


FIG. B8.18 LOCATION OF LONGITUDINAL REINFORCEMENT

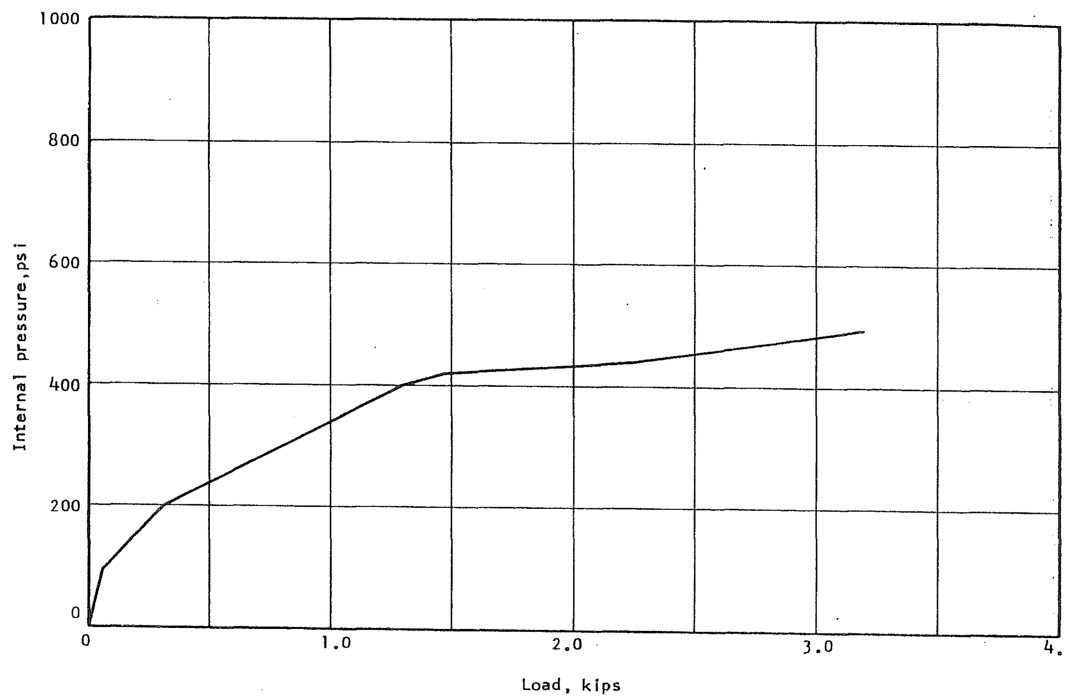


FIG. B8.19 APPLIED PRESSURE vs INCREASE IN LOAD IN DYNAMOMETER NO. 25 ON FINAL TEST OF PV8

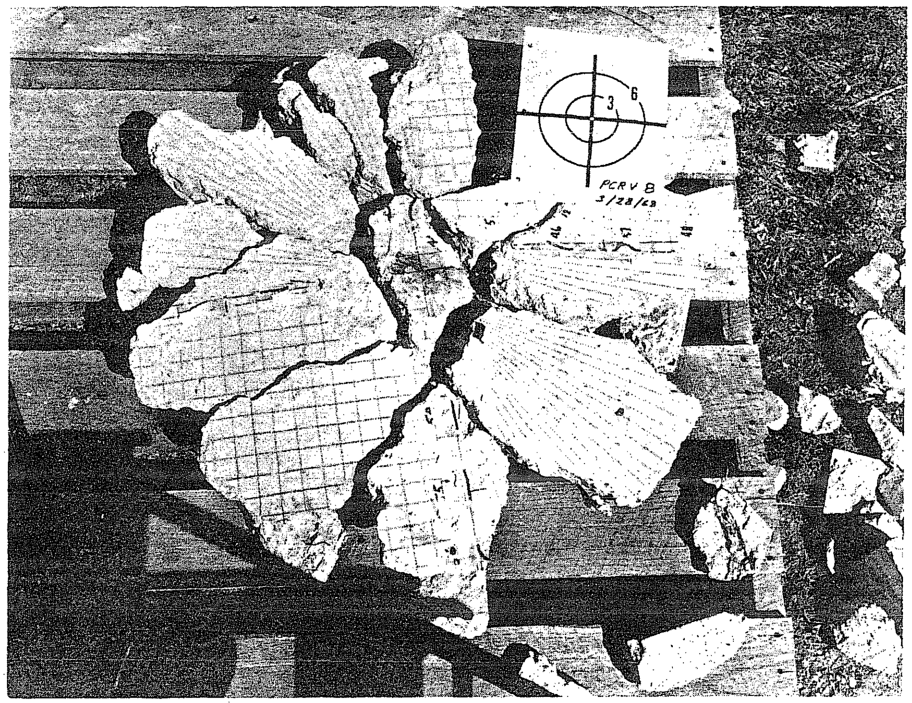


FIG. B8.20 REASSEMBLED END SLAB OF PV8

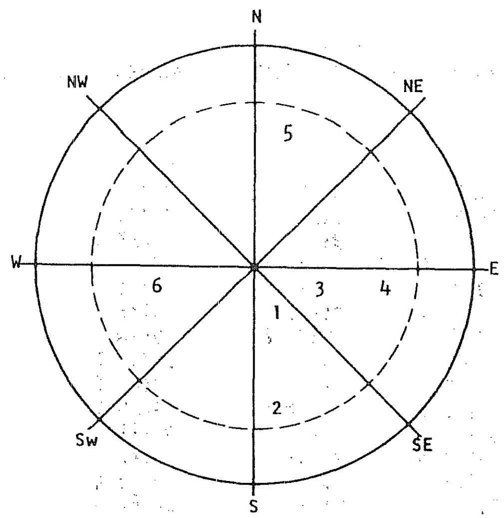
B9 Test Vessel PV9 (t = 9 in., s = 1/3 in.)

Test vessel PV9 was cast in the laboratory and was uncracked prior to prestressing. After circumferential prestressing a crack was observed on the inside of the vessel from five to six in. below the end slab and seven to nine in. below the top on the outside.

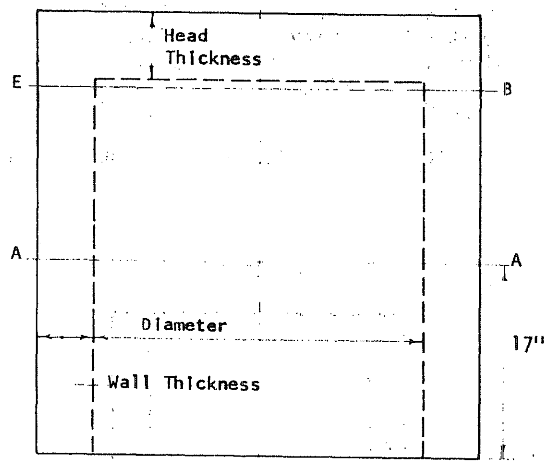
A detail of the liner is shown in Fig. B9.2 and is similar to the sealing detail successfully employed in vessel PV10, which was tested before PV9. The longitudinal prestressing force was provided by thirty strands.

This vessel was filled completely with water. The water pressure was increased by pumping oil into a buffer tank which was connected to the cavity of the vessel.

Pressure was increased in 50-psi increments to 850 psi and then in smaller increments until failure at 887 psi. Failure occurred when the circumferential wire broke. Advanced necking was observed in several wraps on opposite sides of the vessel. After failure the end slab was observed to be heavily cracked with vertical cracks on the side. The cracks at the center of the end slab were about one-half in. wide at the time of failure. The deflection at the center of the end slab reached 0.61 in. A photograph showing the crack pattern of the end slab after failure is shown in Fig. B9.14.



Head Thickness	
1	9 1/8
2	9 1/8
3	9 1/8
4	9 1/8
5	9 1/8
6	9 1/8
7	9''



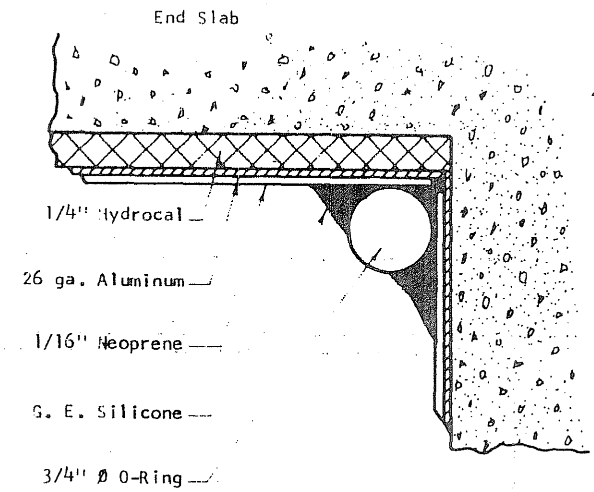
Wall Thickness, in.

Axis \ Plane	AA	BB
N	5.210	5.320
NE	5.240	5.270
E	5.044	5.014
SE	5.117	5.149
S	5.084	5.237
SW	5.139	5.216
W	5.049	5.061
NW	5.327	5.211

Inside Diameter, in.

Axis \ Plane	AA	BB
N-S	30 $\frac{2}{32}$	30 $\frac{2}{32}$
NE-SW	30	30
E-W	29 $\frac{30}{32}$	29 $\frac{31}{32}$
SE-NW	30	30 $\frac{30}{32}$

FIG. B9.1 DIMENSIONS OF PV9



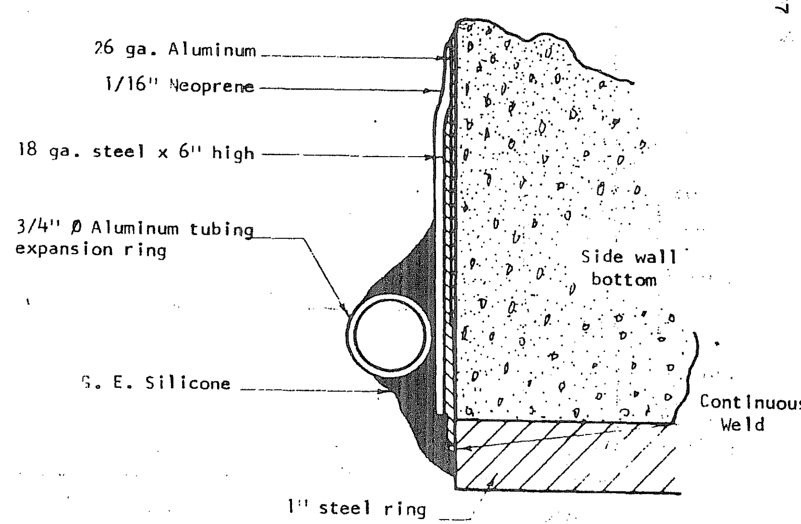
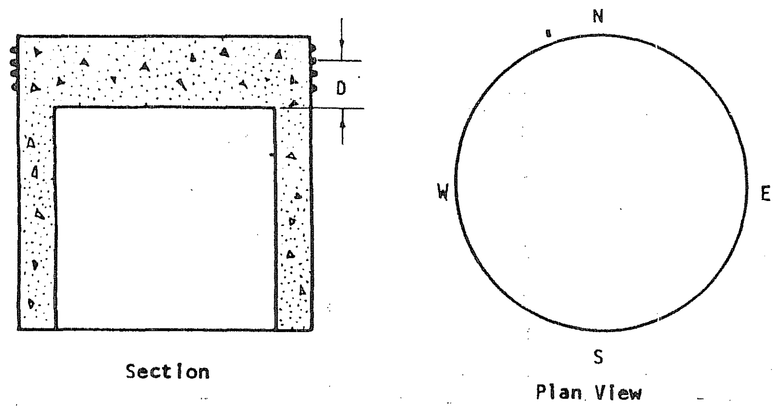


FIG. B9.2 SEALING DETAIL FOR PV9



Wrap No.	DN	DE	DS	DW
1	8 5/6	8 2/16	8 2/16	8 5/16
2	7 13/16	7 14/16	7 14/16	7 15/16
3	7 10/16	7 9/16	7 10/16	7 11/16
4	7 6/16	7 4/16	7 4/16	7 5/16
5	7 2/16	7 15/16	7 6/16	7 6/16
6	6 13/16	6 11/16	6 12/16	6 12/16
7	6 9/16	6 6/16	6 6/16	6 7/16
8	6 4/16	6 0/16	6 1/16	6 2/16
9	5 15/16	5 11/16	5 12/16	5 13/16
10	5/11/16	5 5/16	5 6/16	5 7/16
11	5 3/16	4 15/16	5 0/16	5 1/16
12	4 13/16	4 10/16	4 11/16	4 11/16
13	4 8/16	4 4/16	4 5/16	4 6/16
14	4 3/16	3 15/16	4 0/16	4 0/16
15	3 13/16	3 9/16	3 10/16	3 11/16
16	3 8/16	3 4/16	3 5/16	3 6/16
17	3 3/16	2 15/16	3 0/16	3 0/16
18	2 13/16	2 9/16	2 10/16	2 11/16
19	2 8/16	2 3/16	2 5/16	2 5/16
20	2 3/16	1 14/16	1 15/16	2 0/16
21	1 13/16	1 9/16	1 9/16	1 10/16
22	1 7/16	1 3/16	4 1/10	1 5/16
23	1 2/16	14/16	14/16	1 0/16
24	12/16	9/16	9/16	10/16
25	7/16	3/16	4/16	5/16
26	2/16	-	-	0/16

FIG. B9.3 MEASURED LOCATION OF THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE ENDS OF THE N-S AND E-W DIAMETERS ON PV9

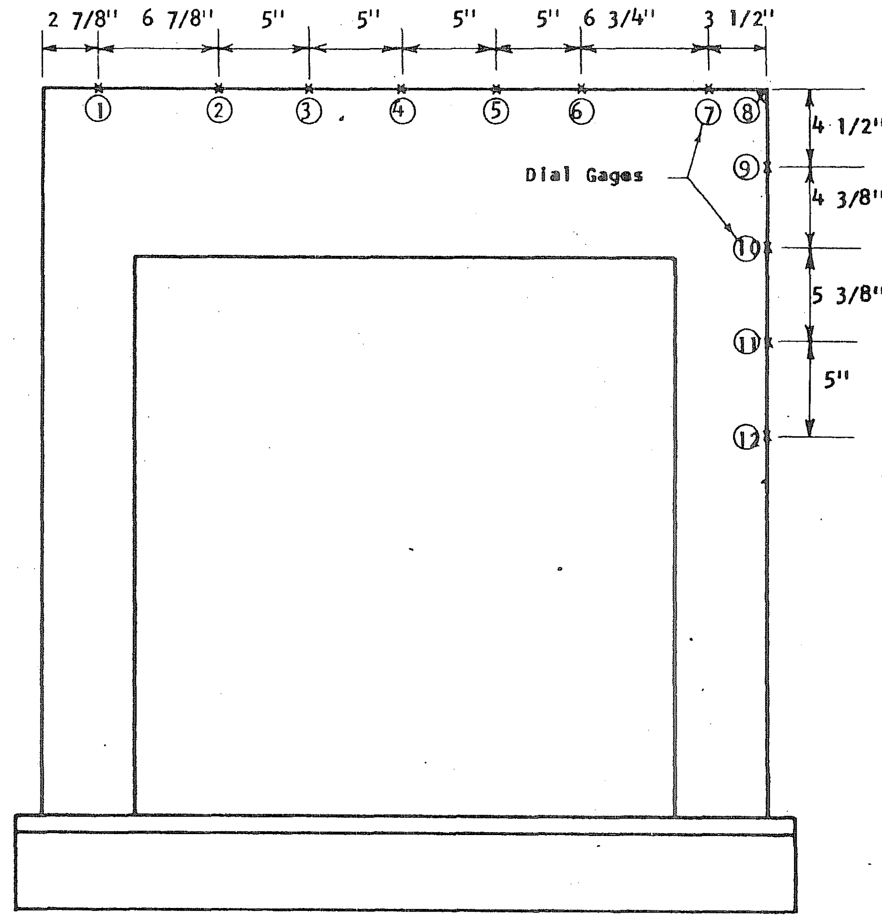


FIG. B9.4 LOCATION OF DEFLECTION GAGES ON PV9

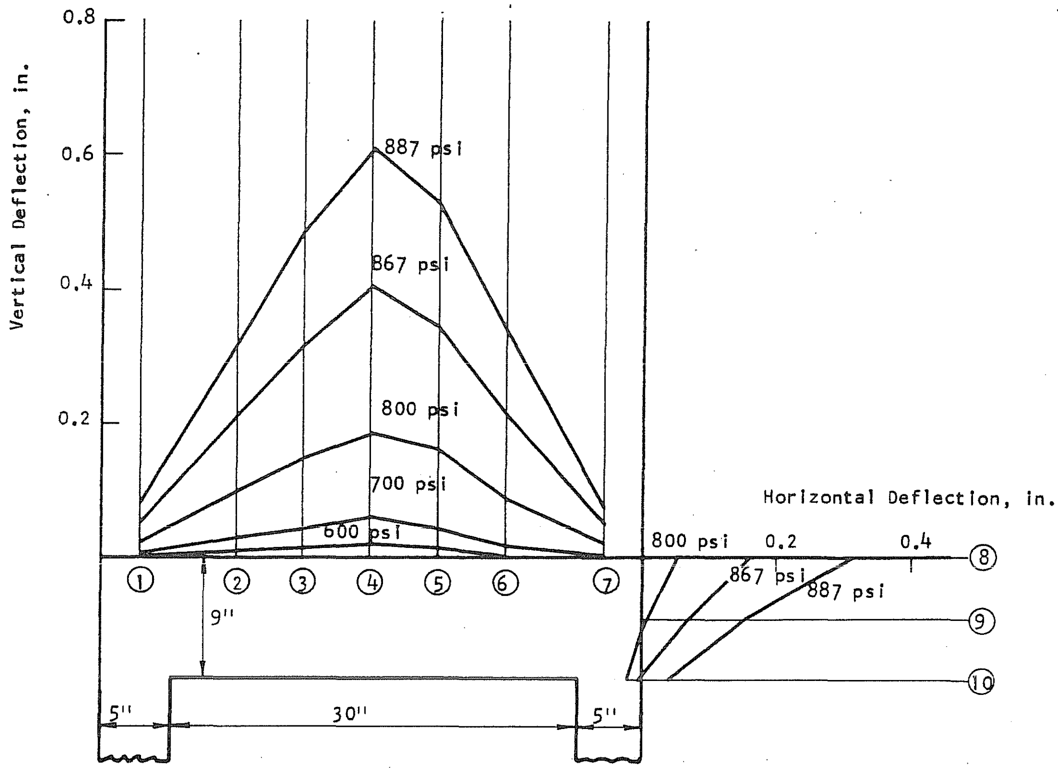


FIG. B9.5 DEFLECTION PROFILES OF THE END SLAB ALONG THE N-S DIAMETER OF VESSEL PV9

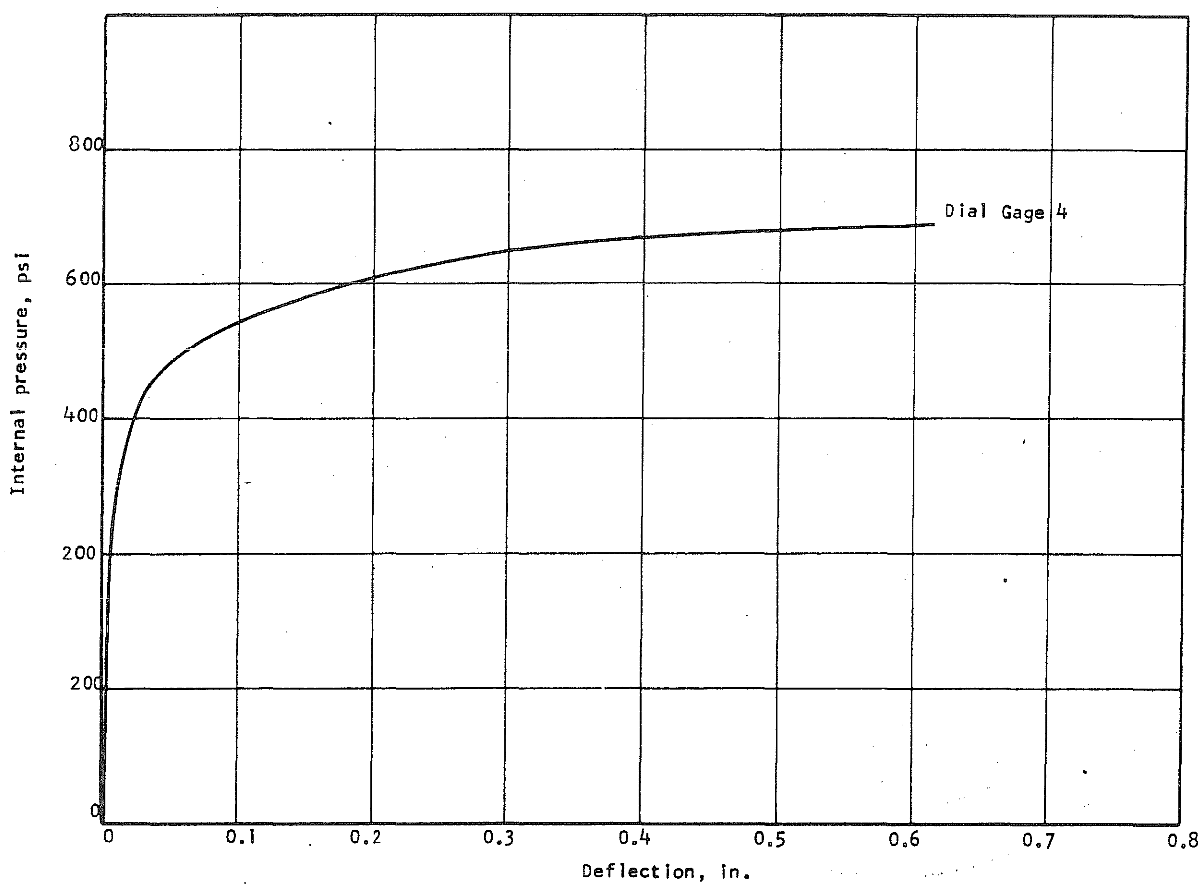


FIG. 9.6 APPLIED PRESSURE vs DEFLECTION AT MIDSPAN OF PV9

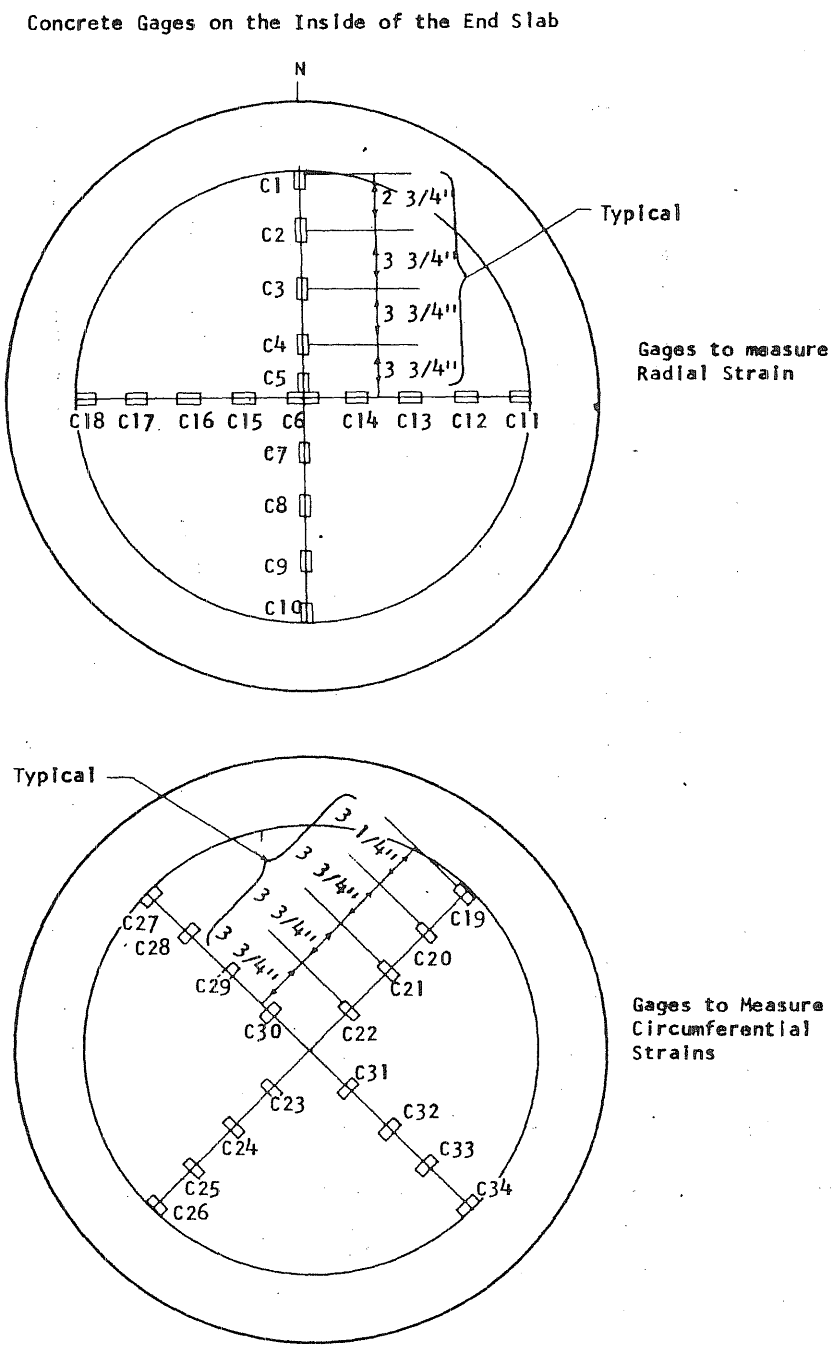
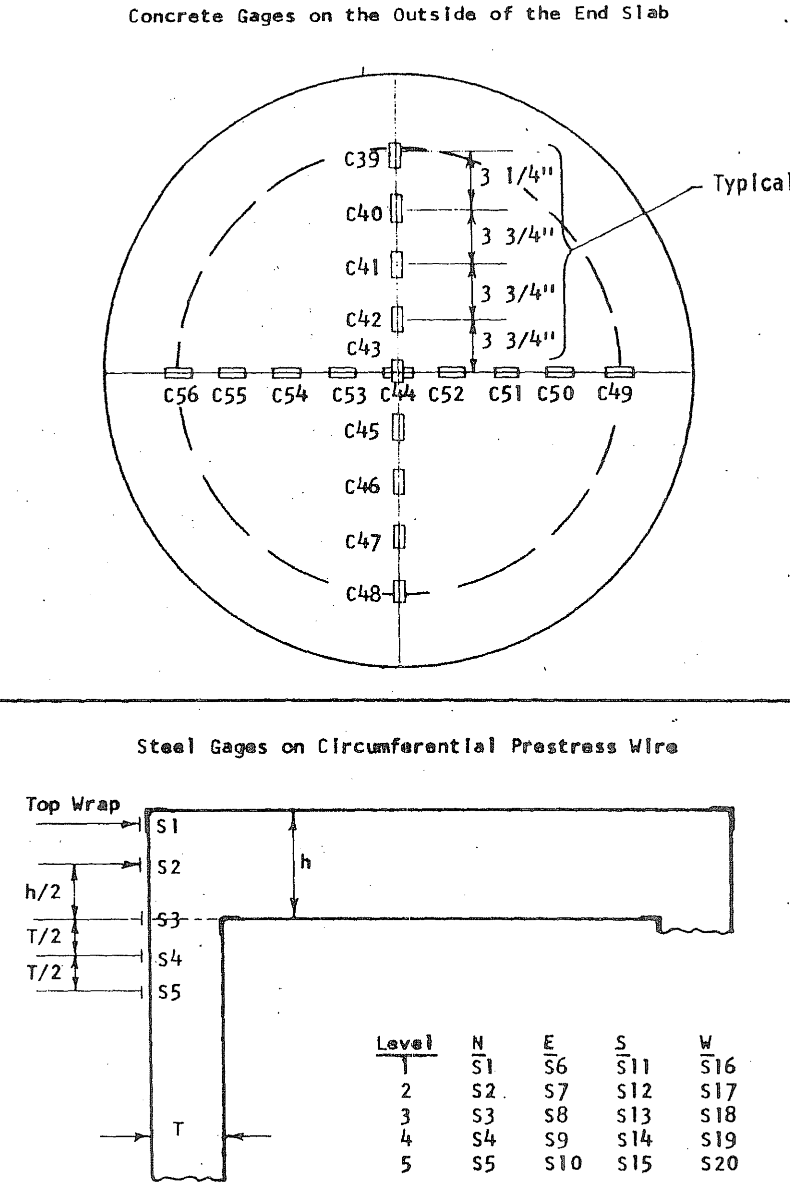


FIG. B9.7 STRAIN GAGE LOCATIONS ON PV9



Level	N	E	S	W
1	S1	S6	S11	S16
2	S2	S7	S12	S17
3	S3	S8	S13	S18
4	S4	S9	S14	S19
5	S5	S10	S15	S20

FIG. B9.7 (cont'd) STRAIN GAGE LOCATIONS ON PV9

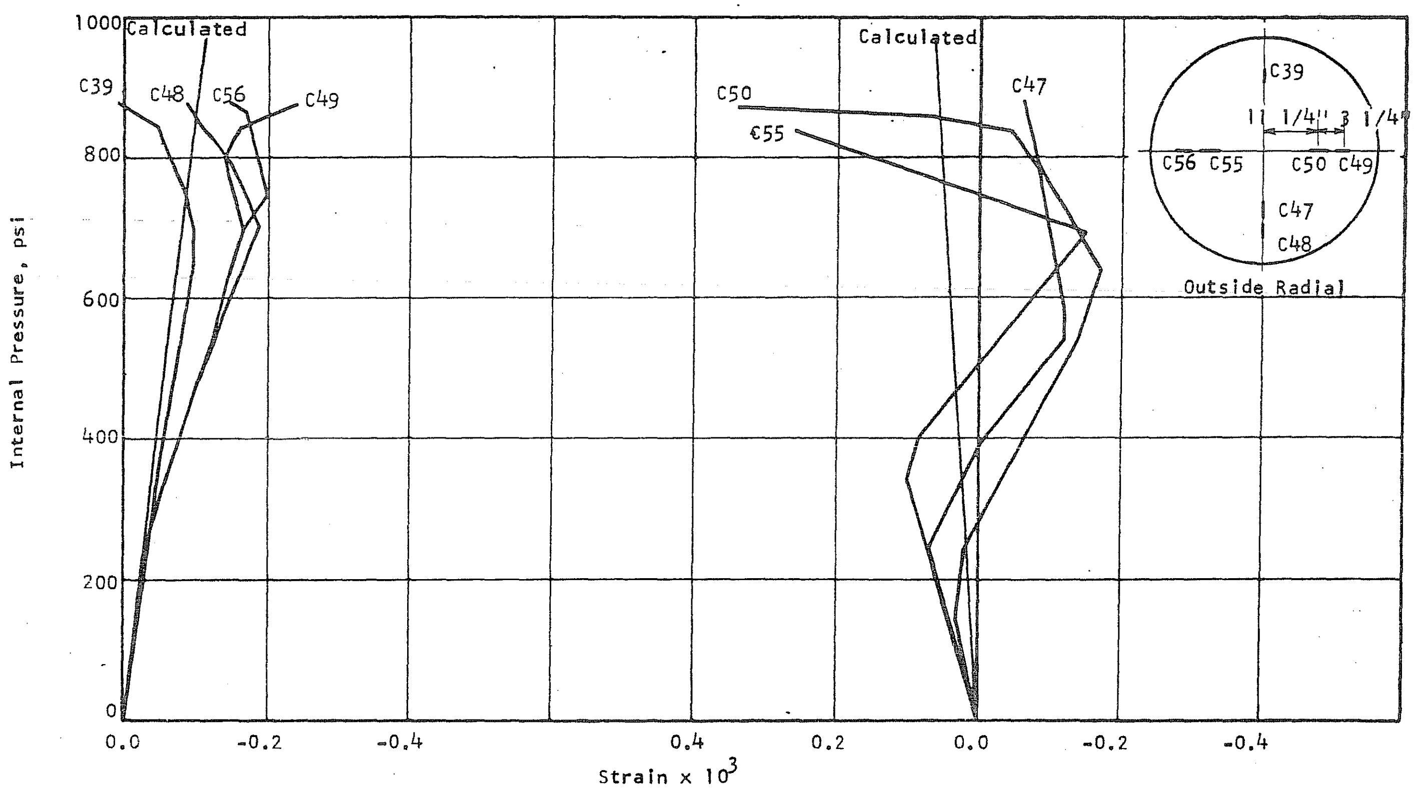


FIG. B9.8 CONCRETE STRAINS, VESSEL PV9

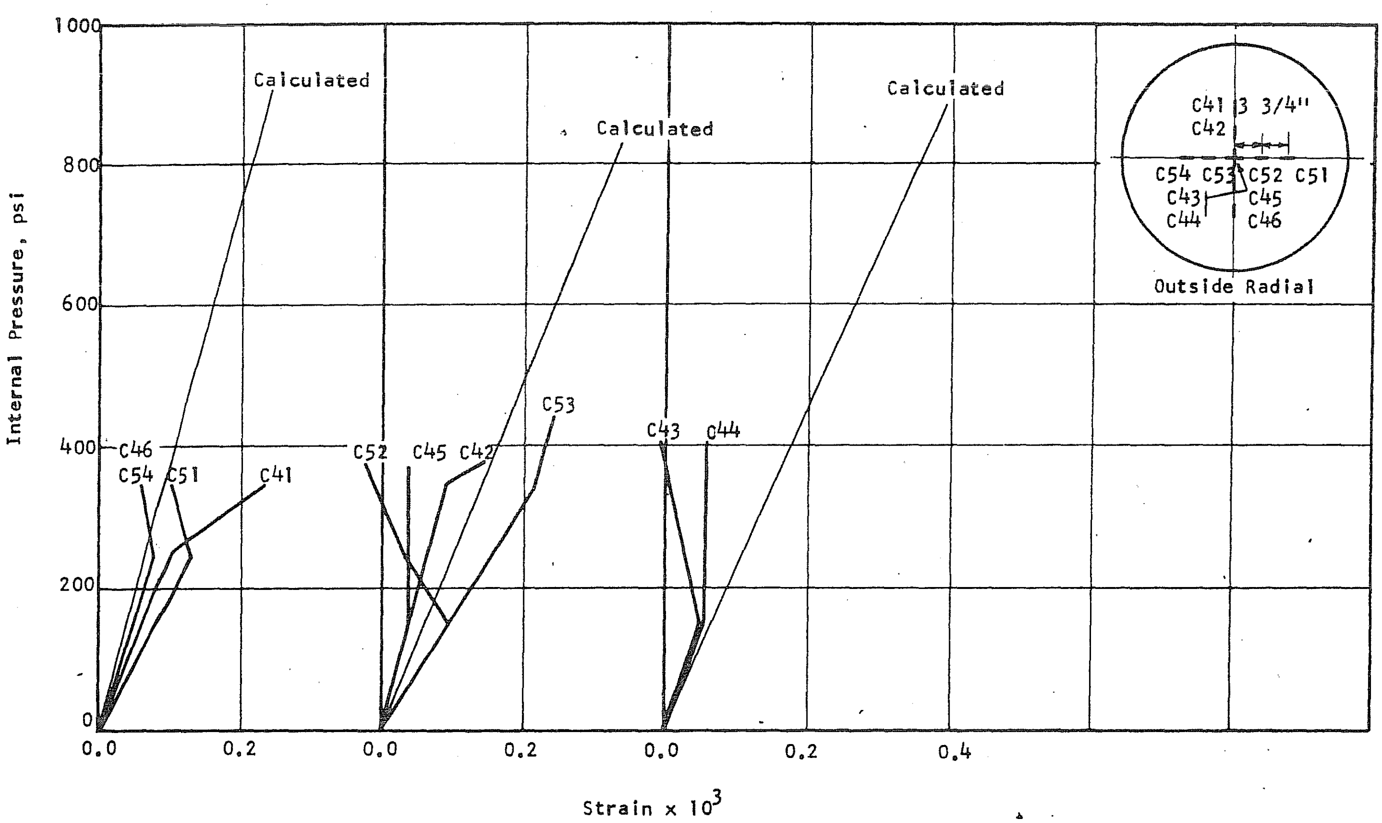


FIG. B9.8 (cont'd) CONCRETE STRAINS, VESSEL PV9

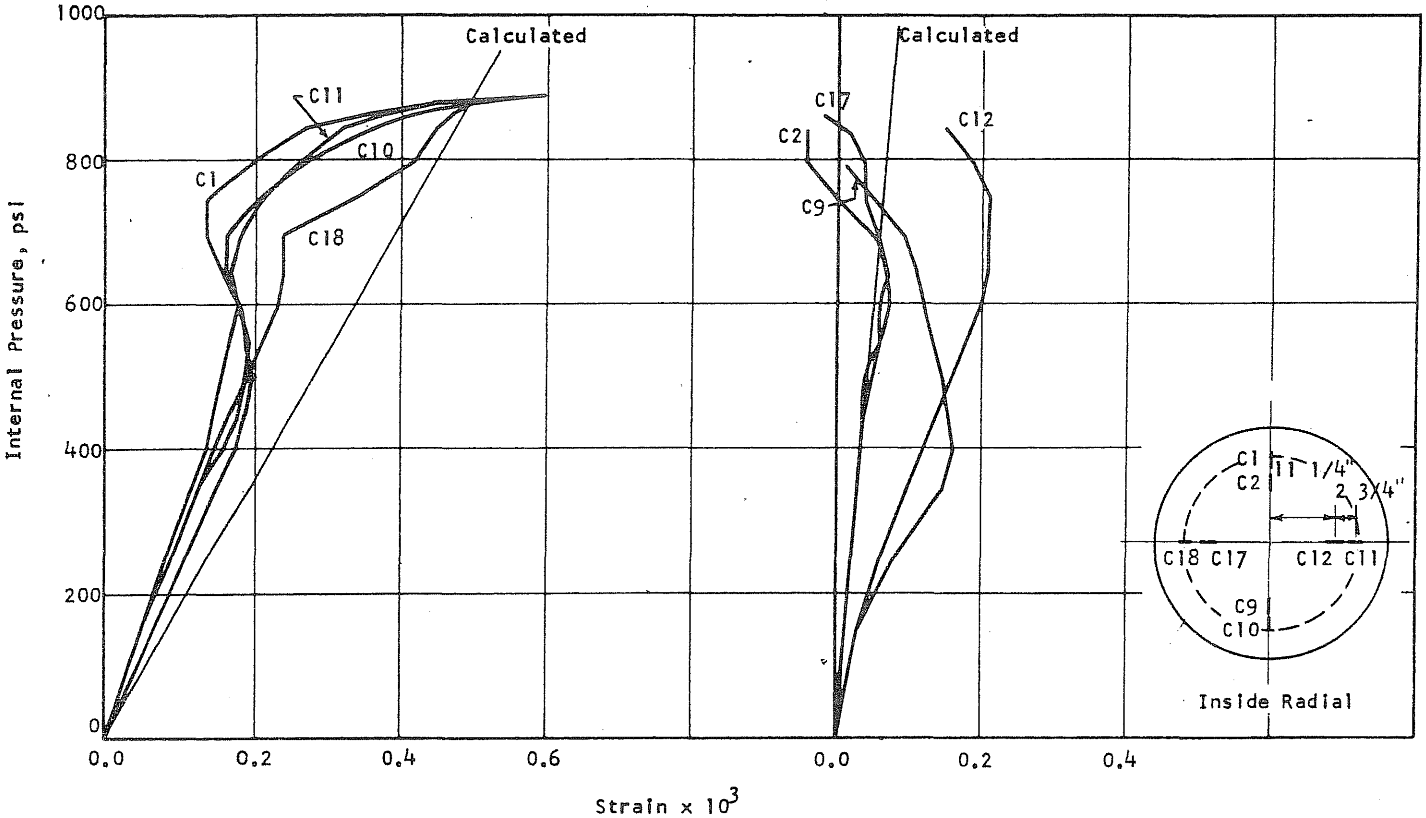


FIG. B9.9 CONCRETE STRAINS, VESSEL PV9

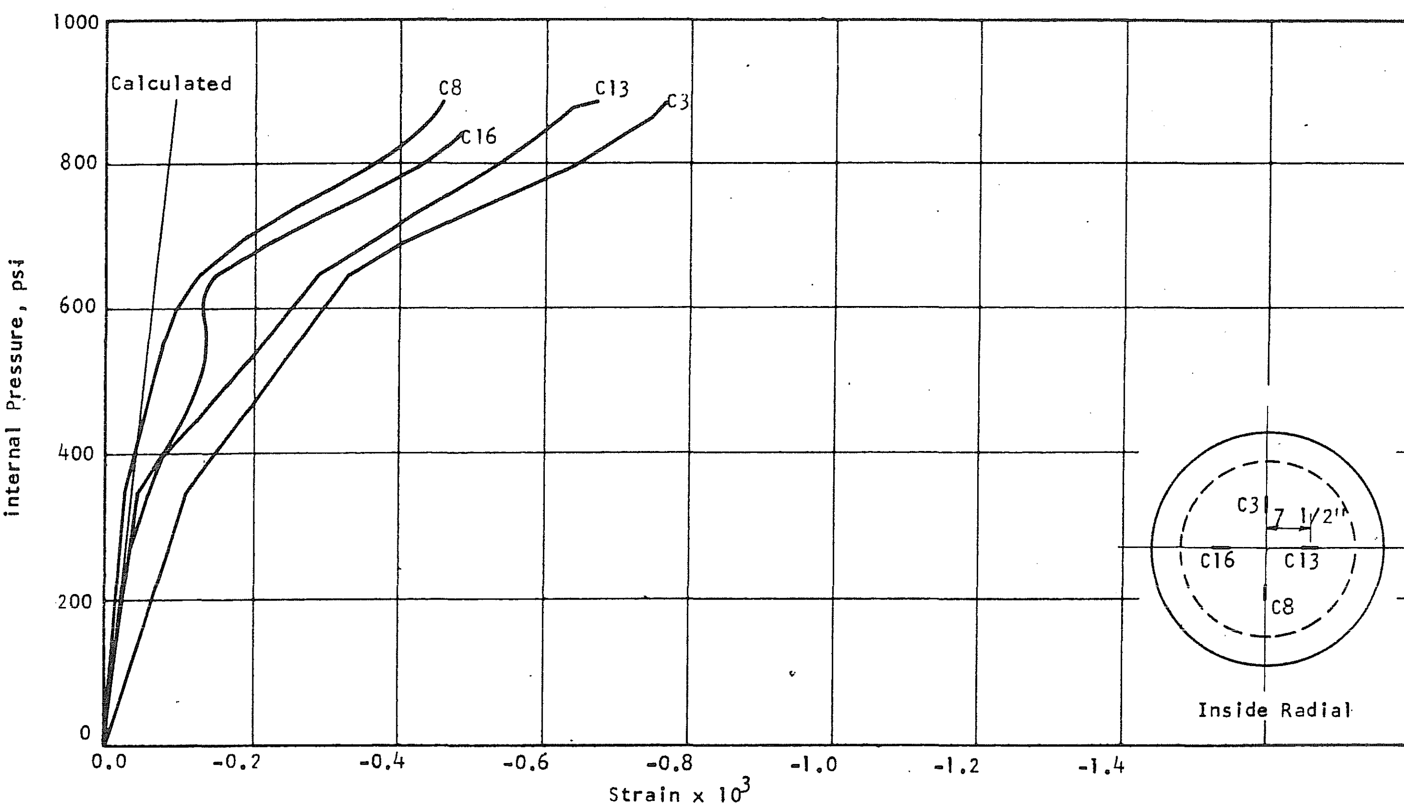


FIG. B9.9 (cont'd) CONCRETE STRAINS, VESSEL PV9

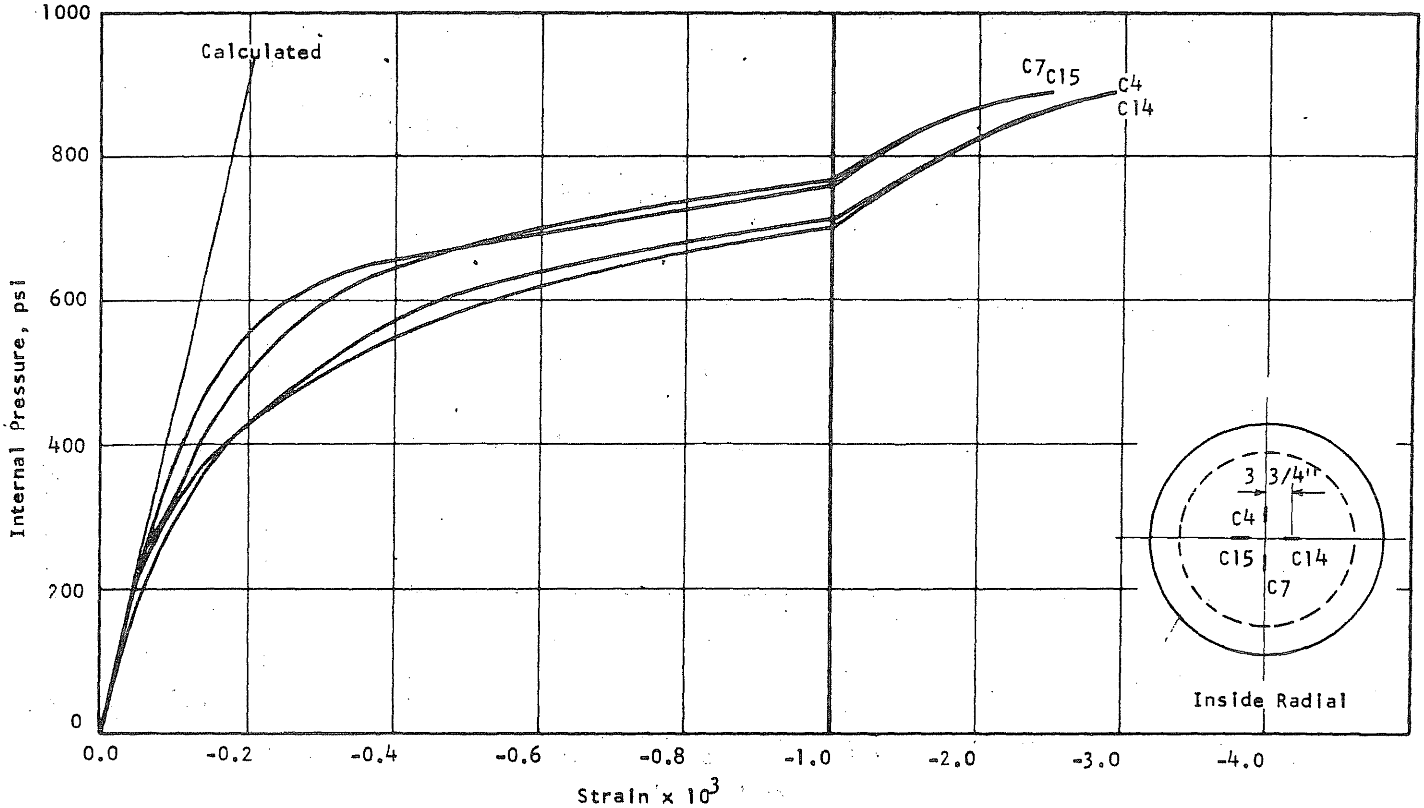


FIG. B9.9 (cont'd) CONCRETE STRAINS, VESSEL PV9

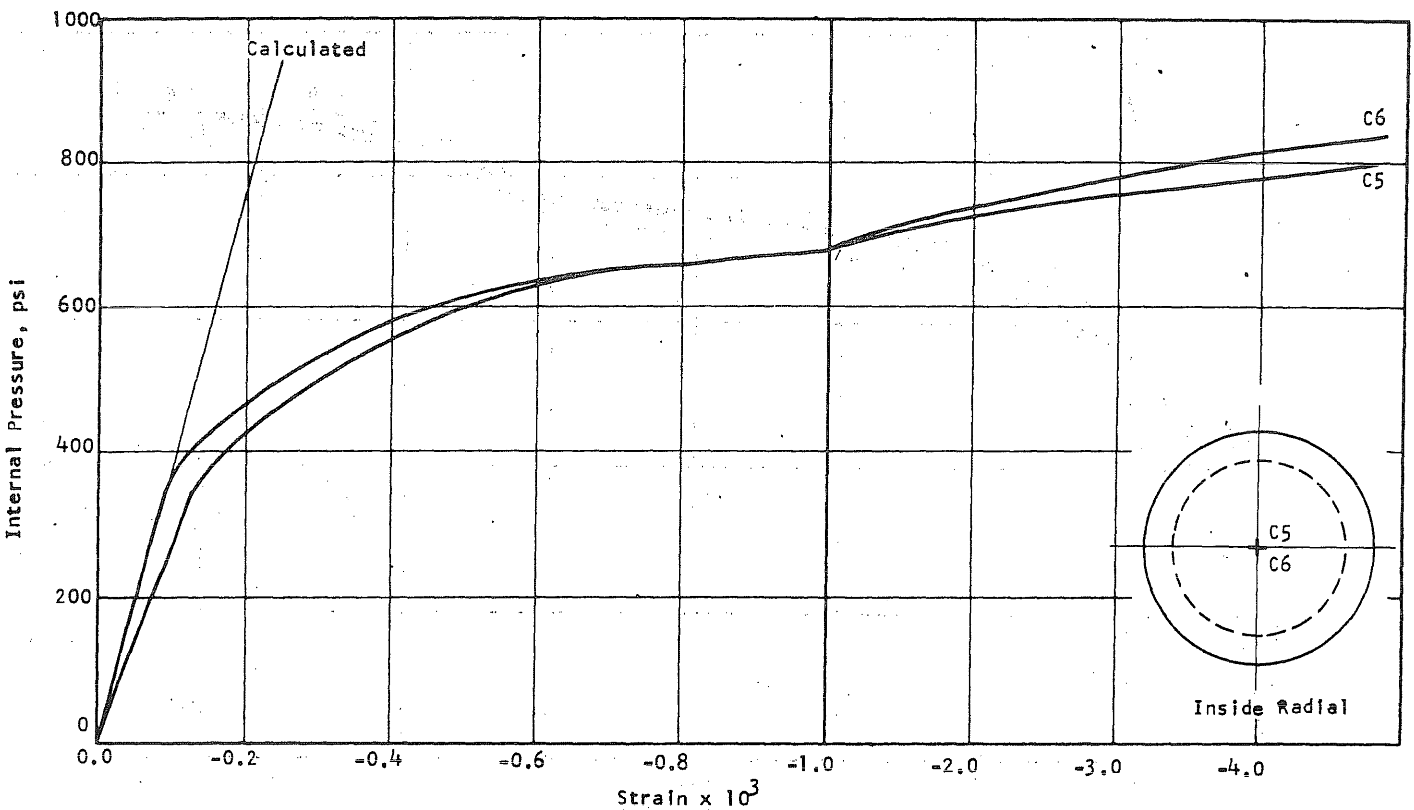


FIG. B9.9 (cont'd) CONCRETE STRAINS, VESSEL PV9

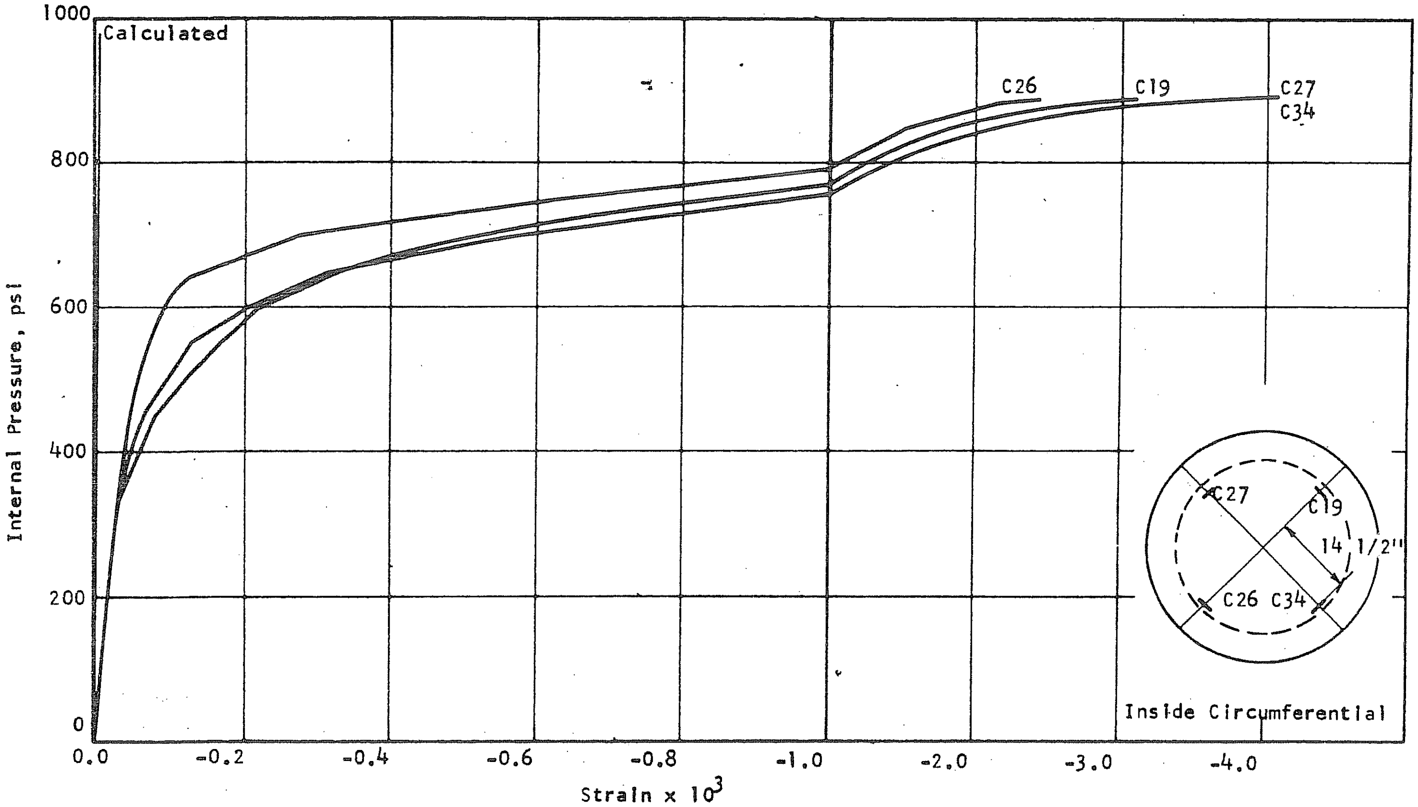


FIG. B9.10 CONCRETE STRAINS, VESSEL PV9

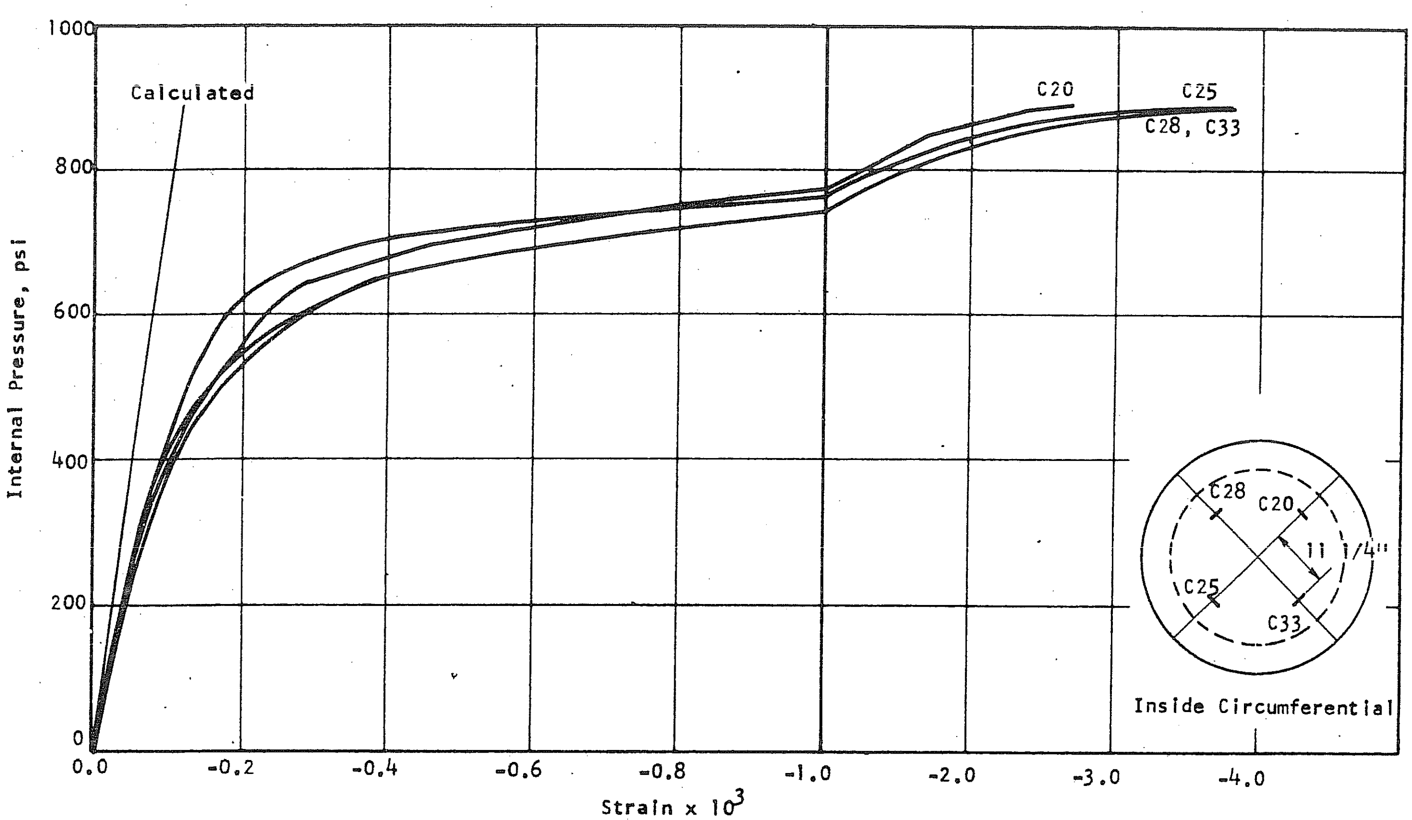


FIG. B9.10 (cont'd) CONCRETE STRAINS, VESSEL PV9

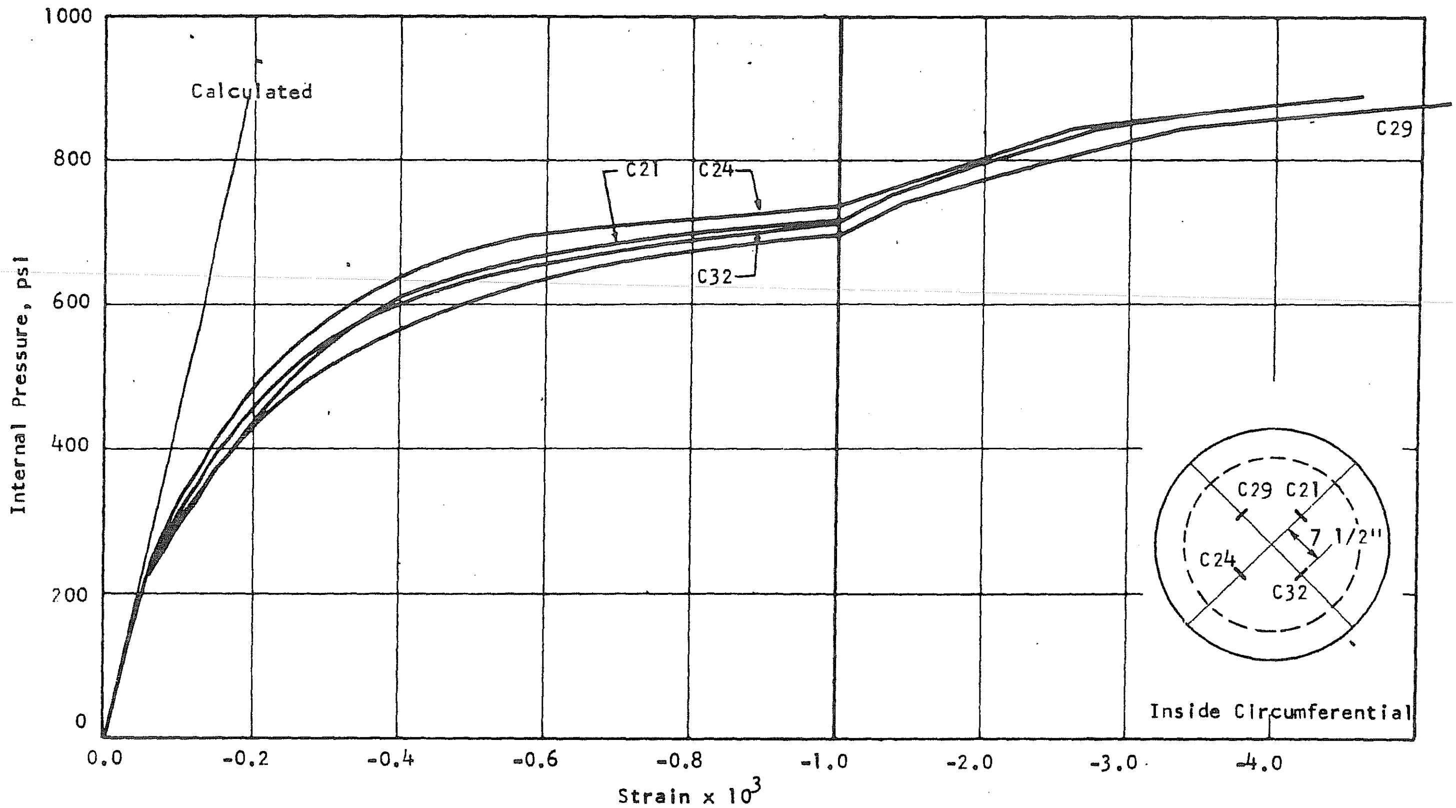


FIG. B9.10 (cont'd) CONCRETE STRAINS, VESSEL PV9

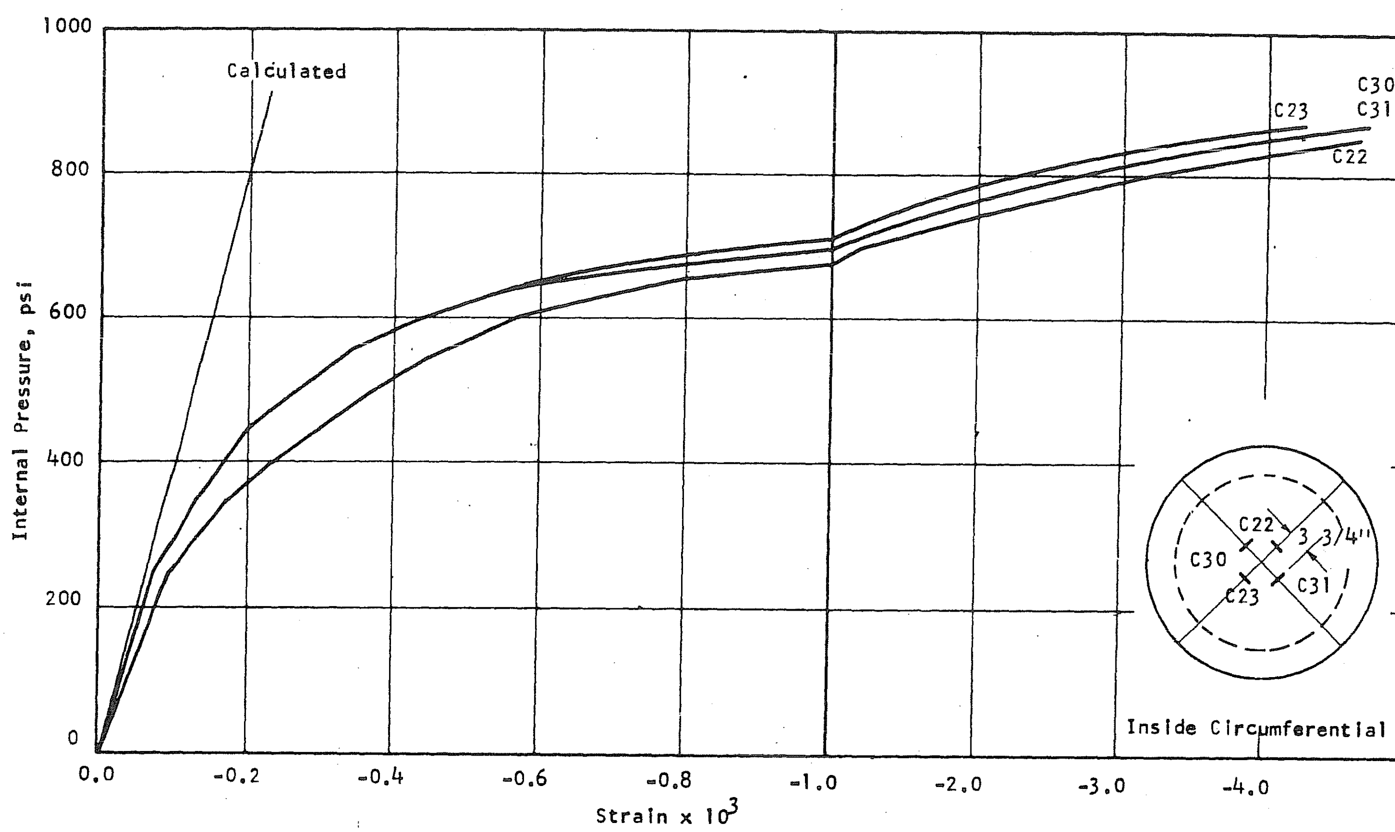


FIG. B9.10 (cont'd) CONCRETE STRAINS, VESSEL PV9

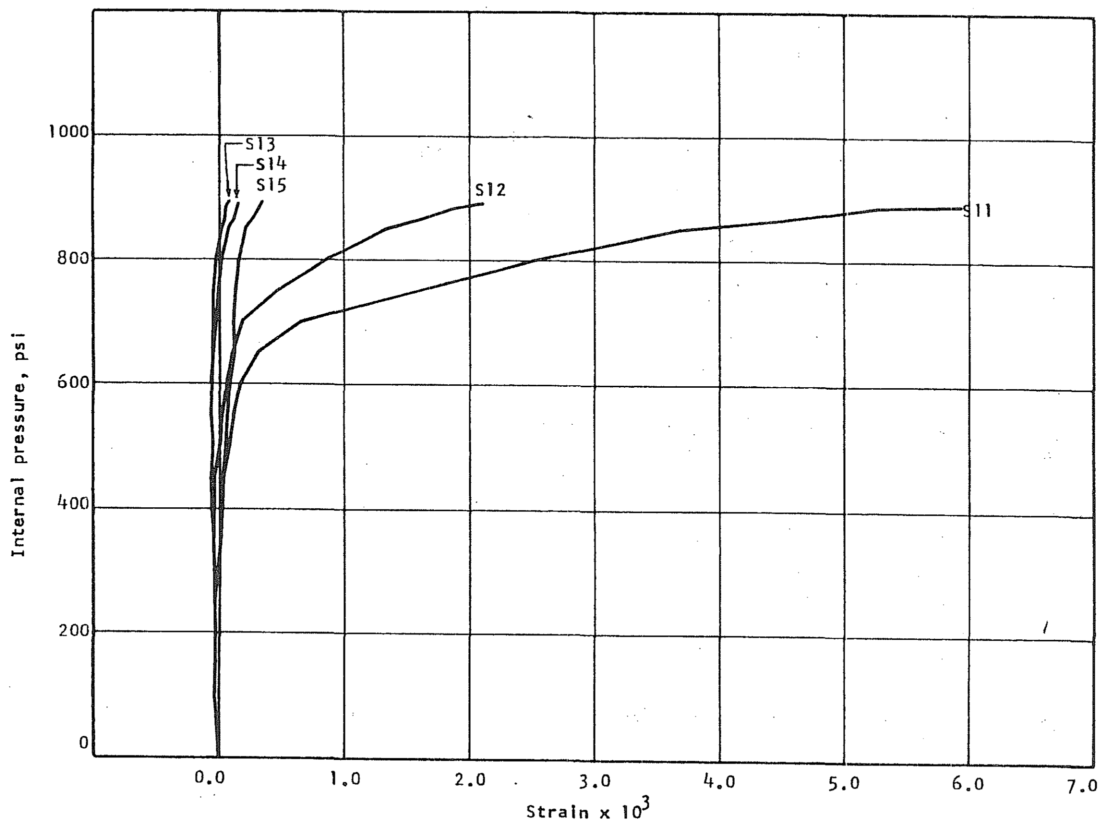


FIG. B9.11 APPLIED PRESSURE vs STRAIN IN CIRCUMFERENTIAL PRESTRESS WIRE AT THE S-END OF THE N-S DIAMETER OF PV9

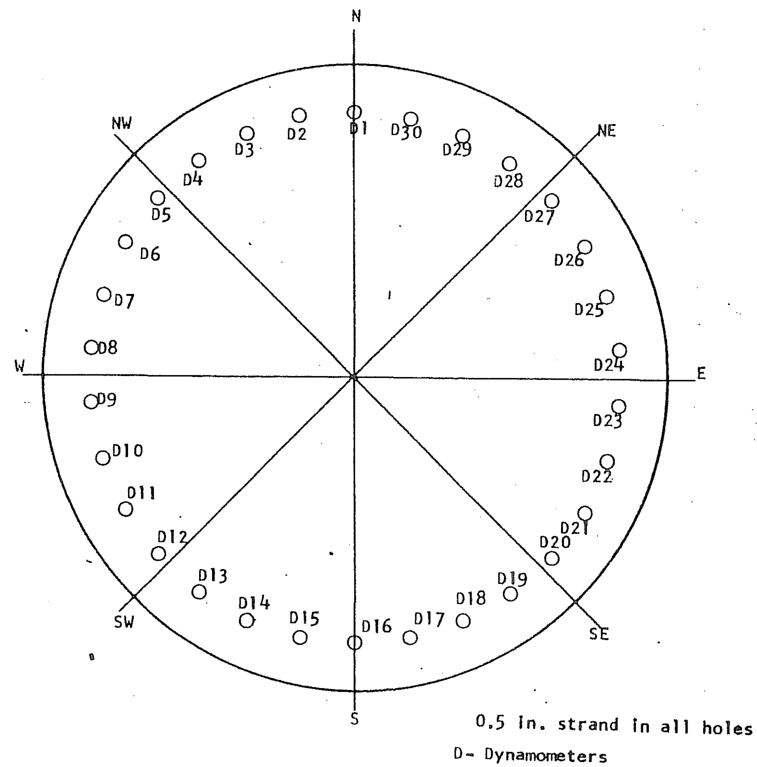


FIG. B9.12 LOCATION OF LONGITUDINAL REINFORCEMENT FOR PV9

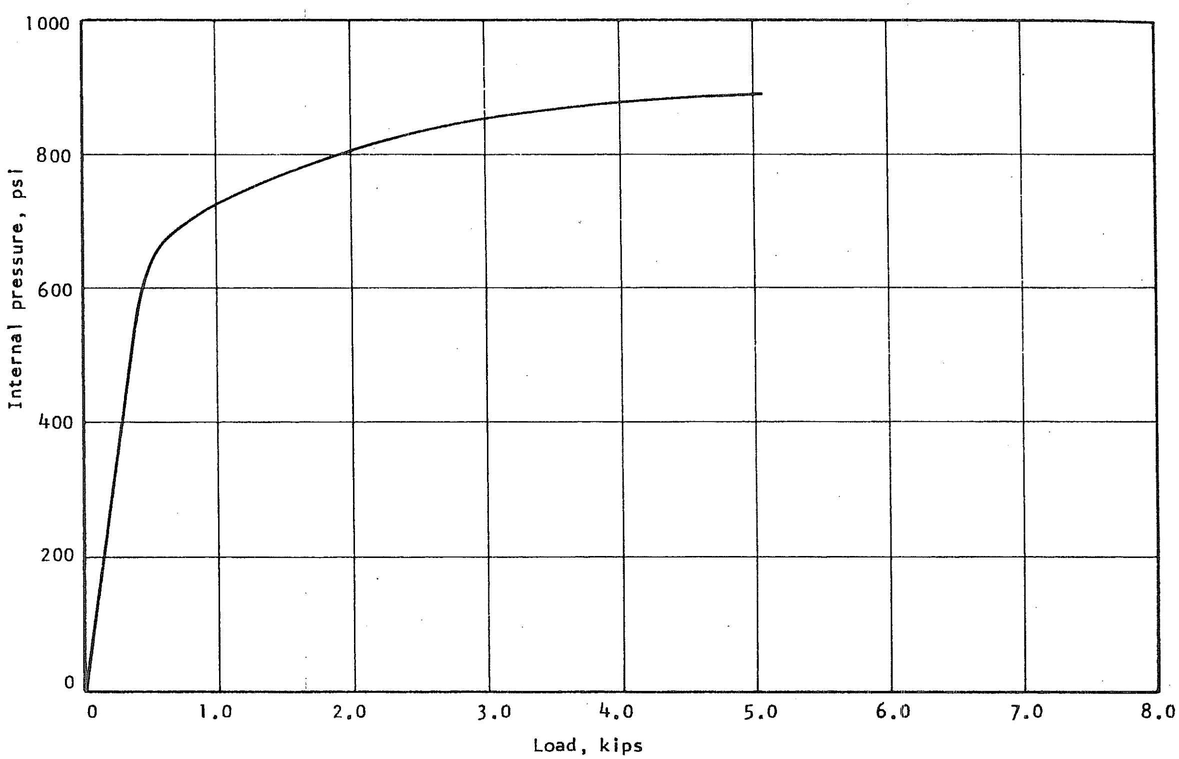


FIG. B9.13 APPLIED PRESSURE vs INCREASE IN LOAD IN DYNAMOMETER NO. 10

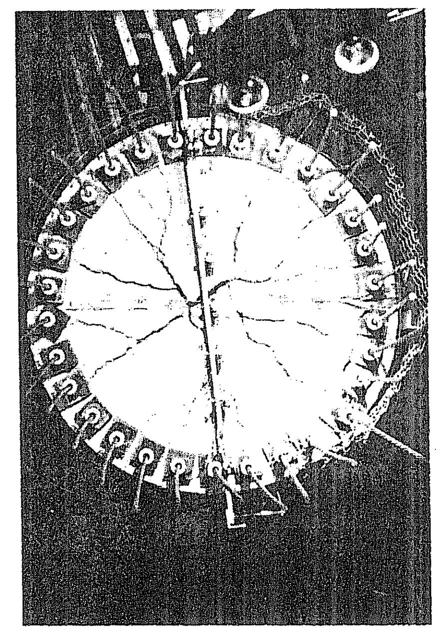


FIG. B9.14 END SLAB AFTER FAILURE

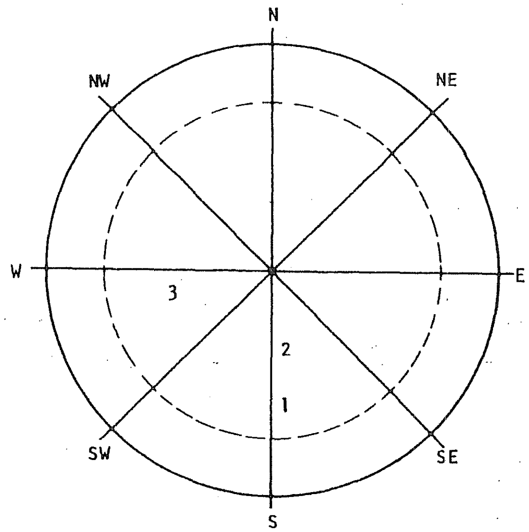
B10 Test Vessel PV10 (t = 7.5 in., s = 1/3 in.)

Test vessel PV10 was cast without any visible flaws. After circumferential prestressing, it developed two cricumferential cracks. One was on the outside approximately seven in. from the top. The other was on the inside approximately ten in. from the top.

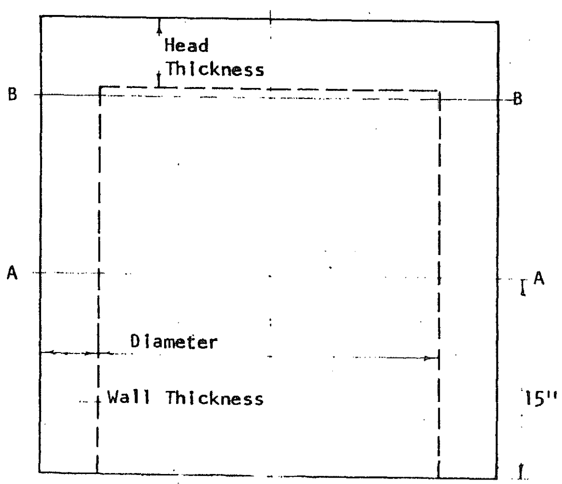
Vessel PV10 was the first specimen tested hydraulically. The vessel was pressurized with a hydraulic pump connected to the vessel through a buffer tank. The vessel cavity was filled with water before the test.

The liner detail was changed significantly from PV8 and is shown in Fig. B10.2. The aluminum liner was assembled outside the vessel and then dropped in place. A mechanical interlock was made at the end slab joint and at the lap in the wall. Both joints were tinned flat. A neoprene liner and a 0.75-in. neoprene O-ring was added as in previous vessels. The neoprene wall and end slab pieces butted at the end slab joint but did not lap. Thirty strands were used for longitudinal reinforcement.

Pressure was increased in 50-psi increments to 600 psi. The vessel began to leak slightly at 600 psi but it was still possible to pressurize the vessel using the vertical deflection of the end slab as a loading criterion. The load decreased during the reading of the gages but the deflections did not change significantly. Failure occurred at 737 psi when the prestressing wire failed. A photograph showing the crack pattern of the end slab after failure is given in Fig. B10.14.



Head Thickness	
Point No.	inches
1	$7\frac{11}{16}$
2	$7\frac{6}{8}$
3	$7\frac{10}{16}$
-	$7\frac{8}{16}$
-	$7\frac{11}{16}$
-	$7\frac{8}{16}$



Wall Thickness		
Axis \ Plane	AA	BB
N	4.950	5.118
NE	5.100	5.170
E	5.232	5.178
SE	5.307	5.323
S	5.209	5.277
SW	5.127	5.147
W	4.982	
NW	4.915	4.890

Inside Diameter, in.		
Axis \ Plane	AA	BB
N-S	$30\frac{1}{32}$	$29\frac{27}{32}$
NE-SW	$29\frac{31}{32}$	$29\frac{30}{30}$
E-W	$29\frac{31}{32}$	30
SE-NW	$29\frac{31}{32}$	$29\frac{30}{32}$

FIG. B10.1 DIMENSIONS OF PV10

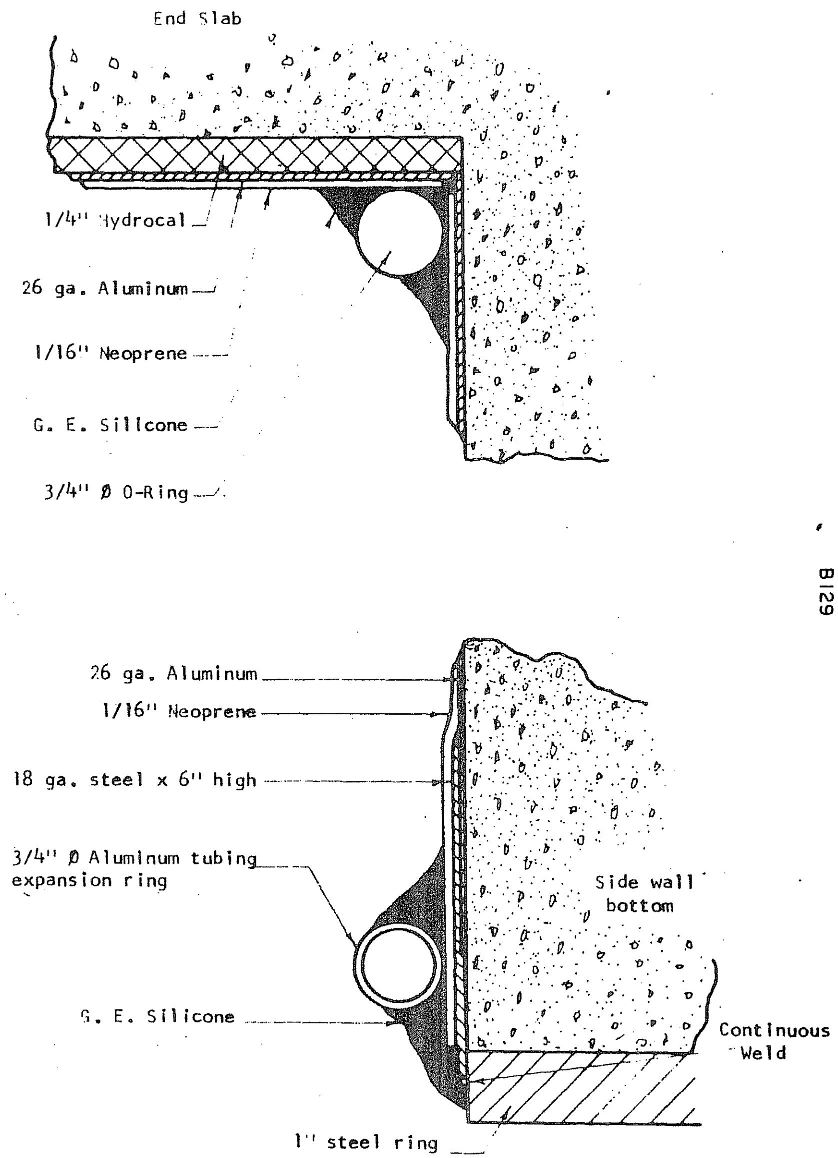
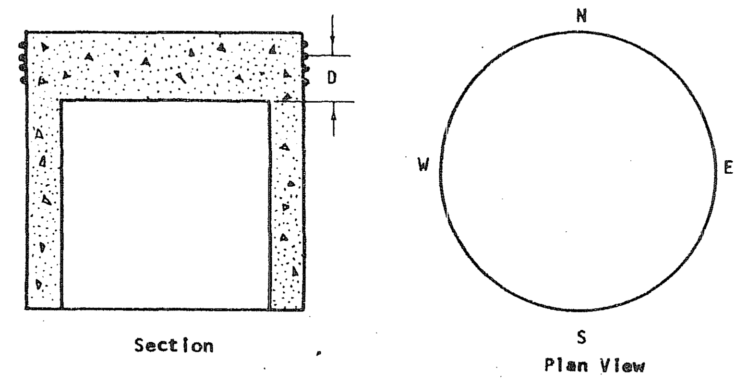


FIG. B10.2 SEALING DETAIL FOR PV10



Wrap No.	DN	DE	DS	DW
1	6 13/16	7 0/16	7 0/16	6 14/16
2	6 8/16	6 11/16	6 11/16	6 8/16
3	6 5/16	6 7/16	6 7/16	6 4/16
4	5 13/16	6 3/16	6 2/16	5 15/16
5	5 9/16	5 14/16	5 14/16	5 11/16
6	5 3/16	5 9/16	5 9/16	5 4/16
7	4 13/16	5 3/16	5 2/16	4 14/16
8	4 9/16	4 14/16	4 14/16	4 11/16
9	4 6/16	4 10/16	4 10/16	4 7/16
10	4 0/16	4 6/16	4 5/16	4 2/16
11	3 10/16	4 1/16	4 0/16	3 13/16
12	3 5/16	3 11/16	3 5/16	3 7/16
13	3 0/16	3 6/16	3 1/16	3 3/16
14	2 11/16	3 1/16	2 11/16	2 14/16
15	2 6/16	2 11/16	2 6/16	2 8/16
16	2 1/16	2 6/16	2 1/16	2 3/16
17	1 11/16	2 1/16	1 12/16	1 13/16
18	1 6/16	1 12/16	1 6/16	1 2/16
19	1 1/16	1 7/16	1 1/16	1 2/16
20	12/16	1 1/16	12/16	13/16
21	7/16	12/16	6/16	9/16
22	1/16	7/16	1/16	4/16

FIG. B10.3. MEASURED LOCATION OF THE CIRCUMFERENTIAL PRESTRESS WIRE AT THE ENDS OF THE N-S and E-W DIAMETERS ON PV10

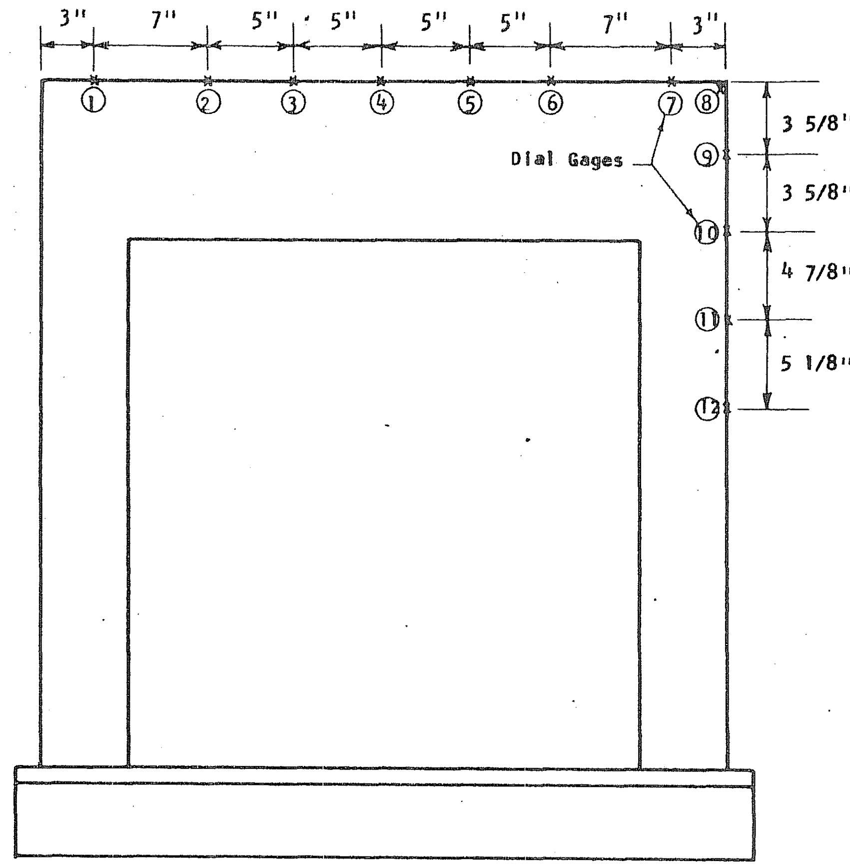


FIG. B10.4 LOCATION OF DEFLECTION GAGES ON PV10

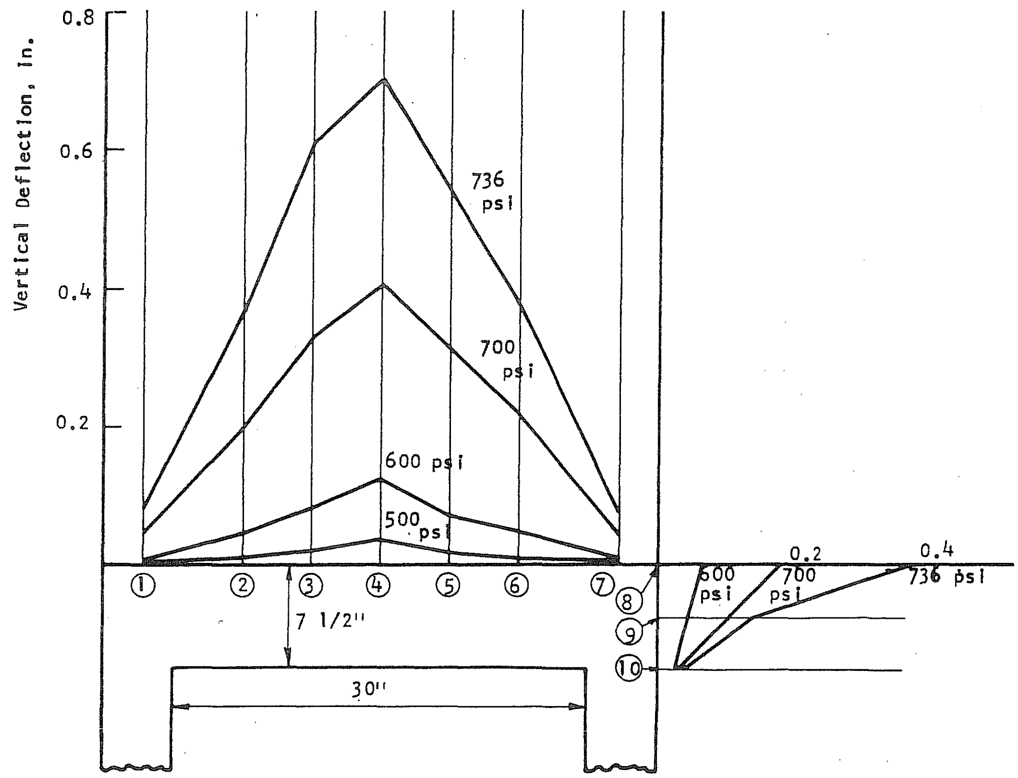


FIG. B10.5 DEFLECTION PROFILES OF THE END SLAB ALONG THE N-S DIAMETER OF PV10

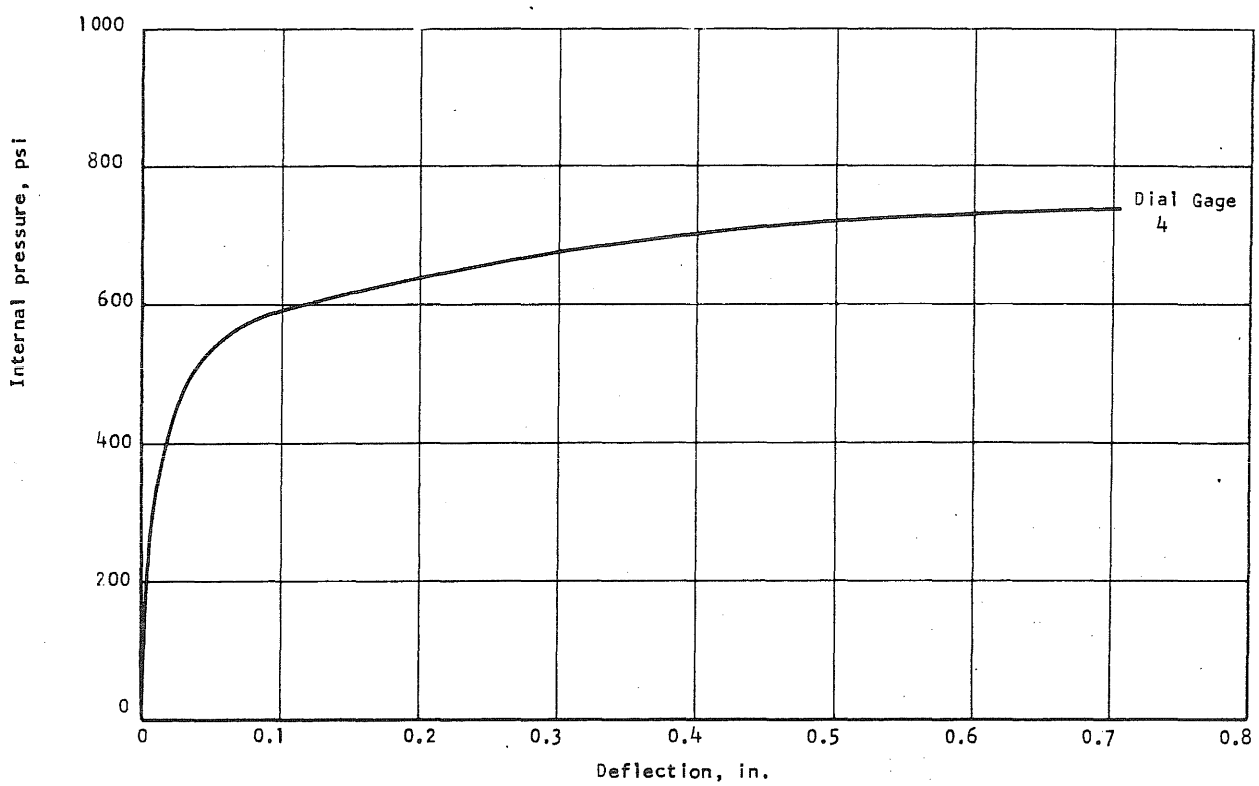
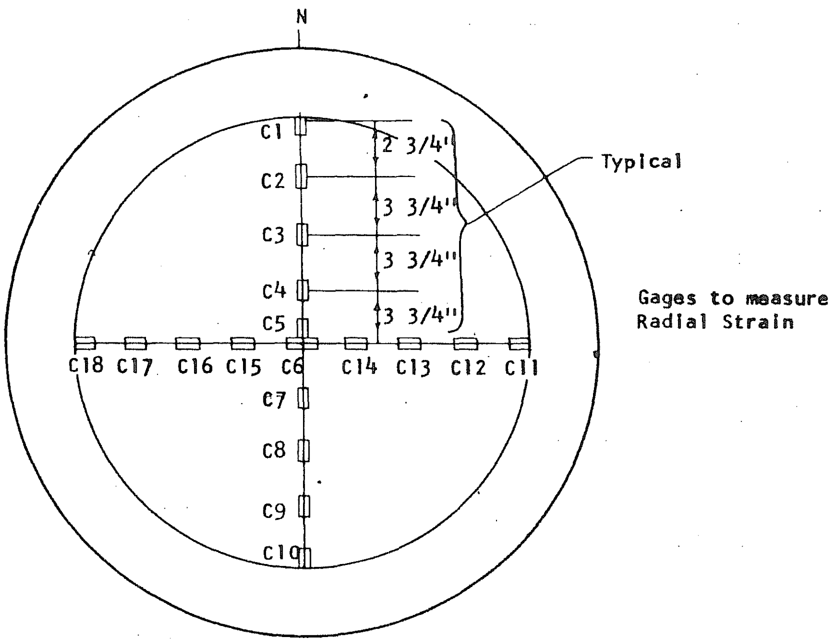
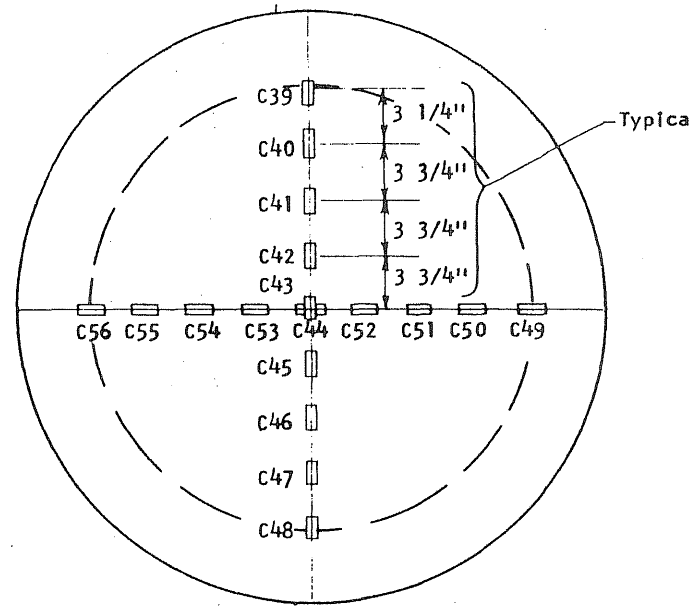


FIG. B10.6 APPLIED PRESSURE vs DEFLECTION AT MIDSPAN OF PV10

Concrete Gages on the Inside of the End Slab



Concrete Gages on the Outside of the End Slab



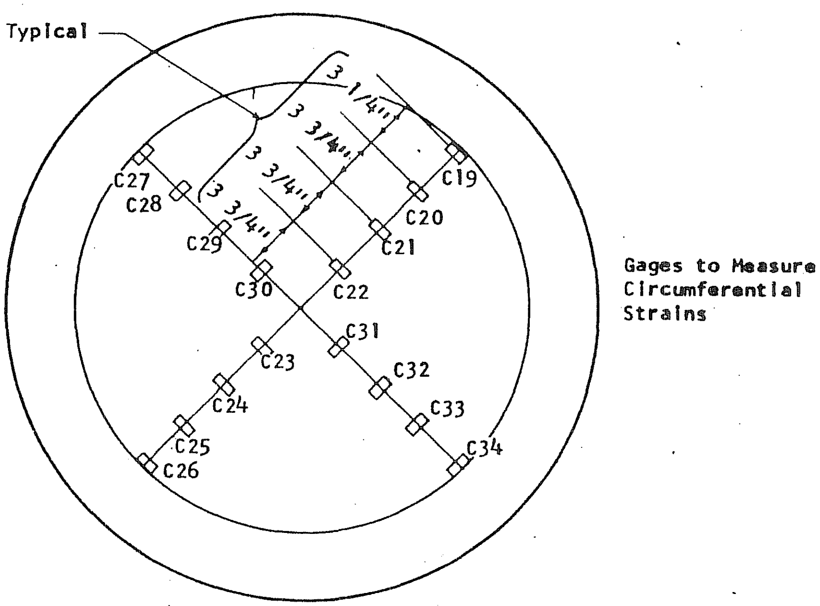
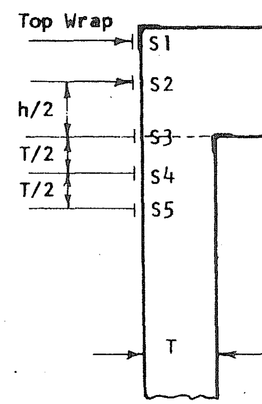


FIG. B10.7 STRAIN GAGE LOCATION ON PV10

Steel Gages on Circumferential Prestress Wire



Level	N	E	S	W
1	S1	S6	S11	S16
2	S2	S7	S12	S17
3	S3	S8	S13	S18
4	S4	S9	S14	S19
5	S5	S10	S15	S20

FIG. B10.7 (cont'd) STRAIN GAGE LOCATIONS ON PV10

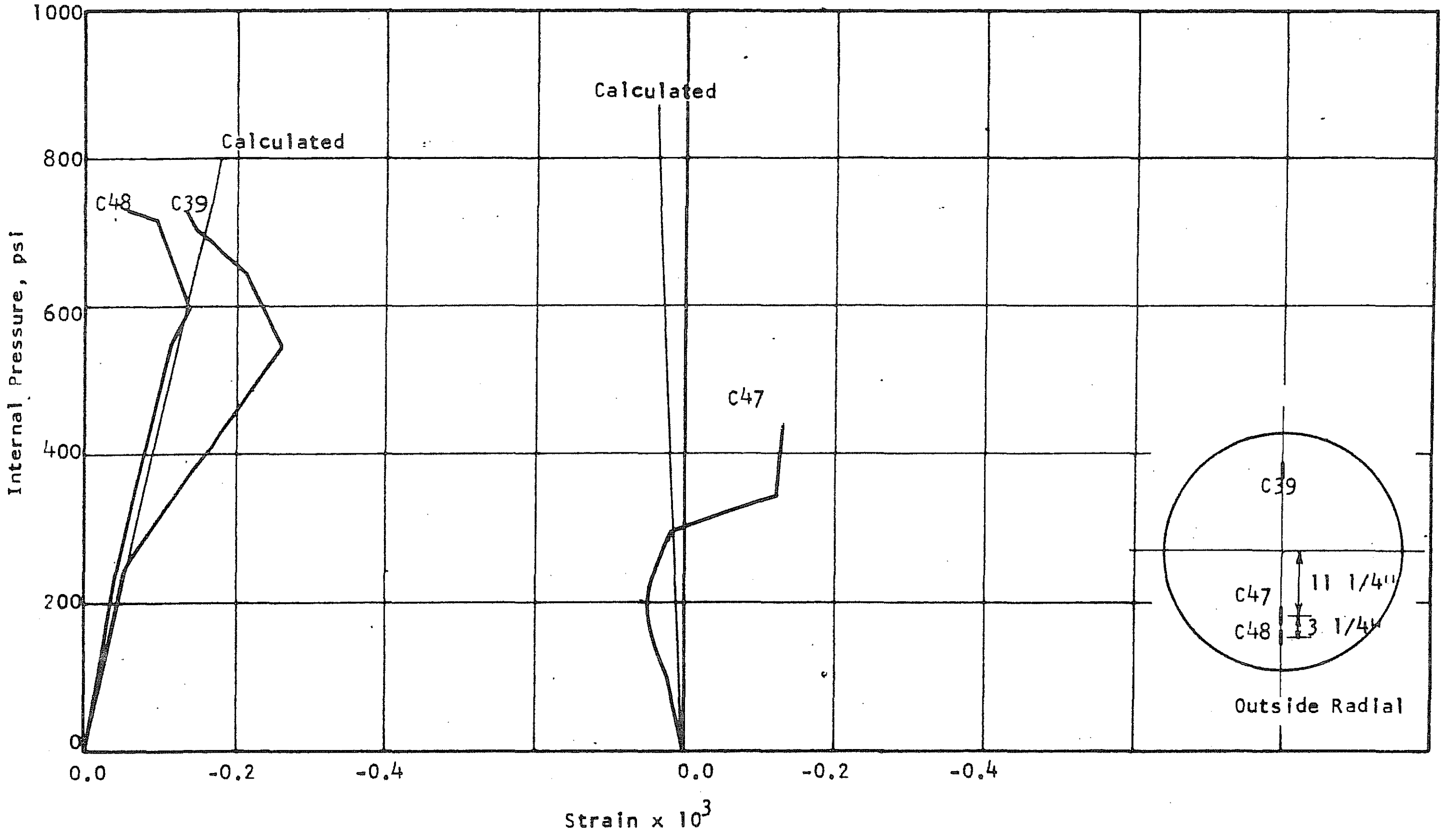


FIG. B10.8 CONCRETE STRAINS, VESSEL PV10

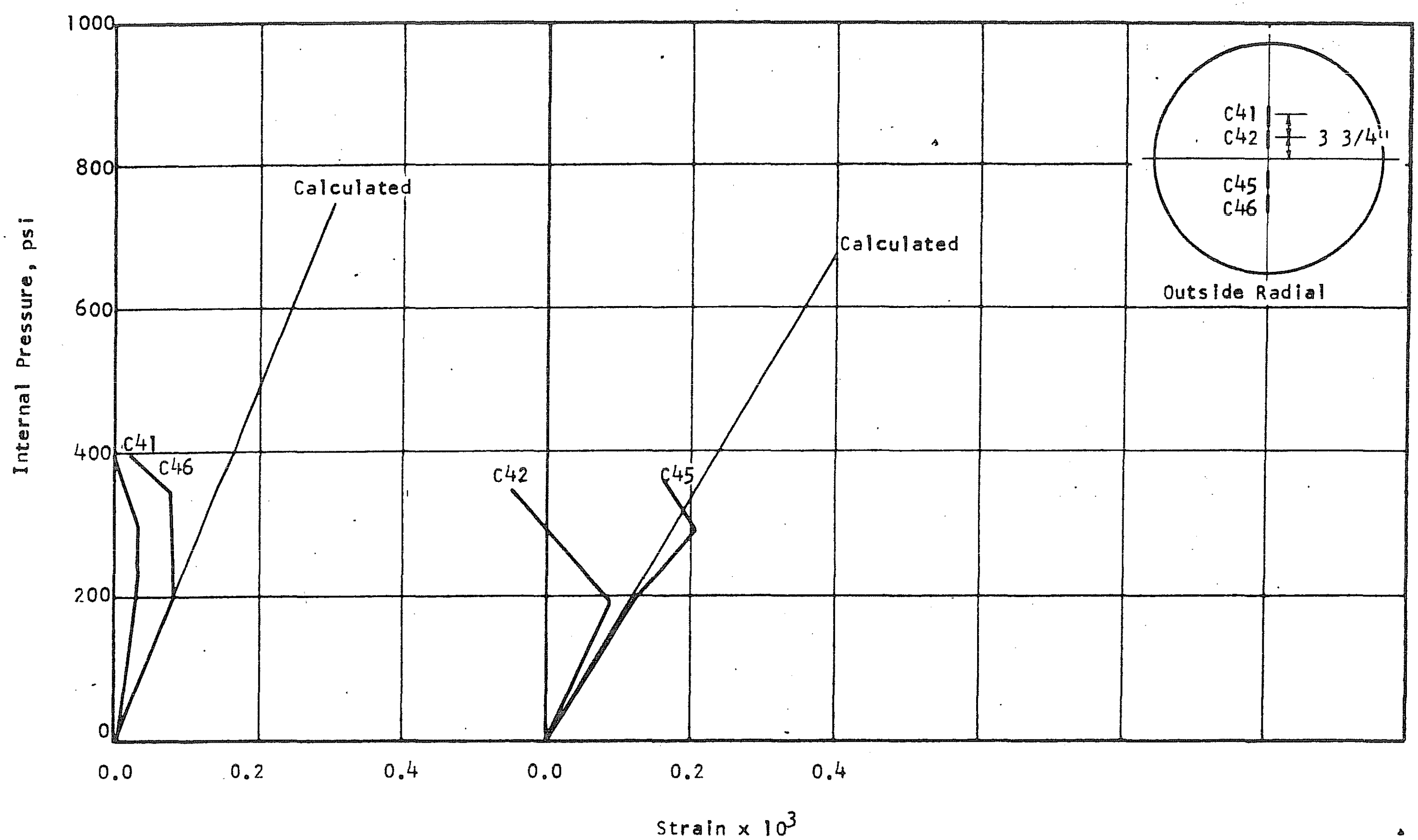


FIG. B10.8 (cont'd) CONCRETE STRAINS, VESSEL PV10

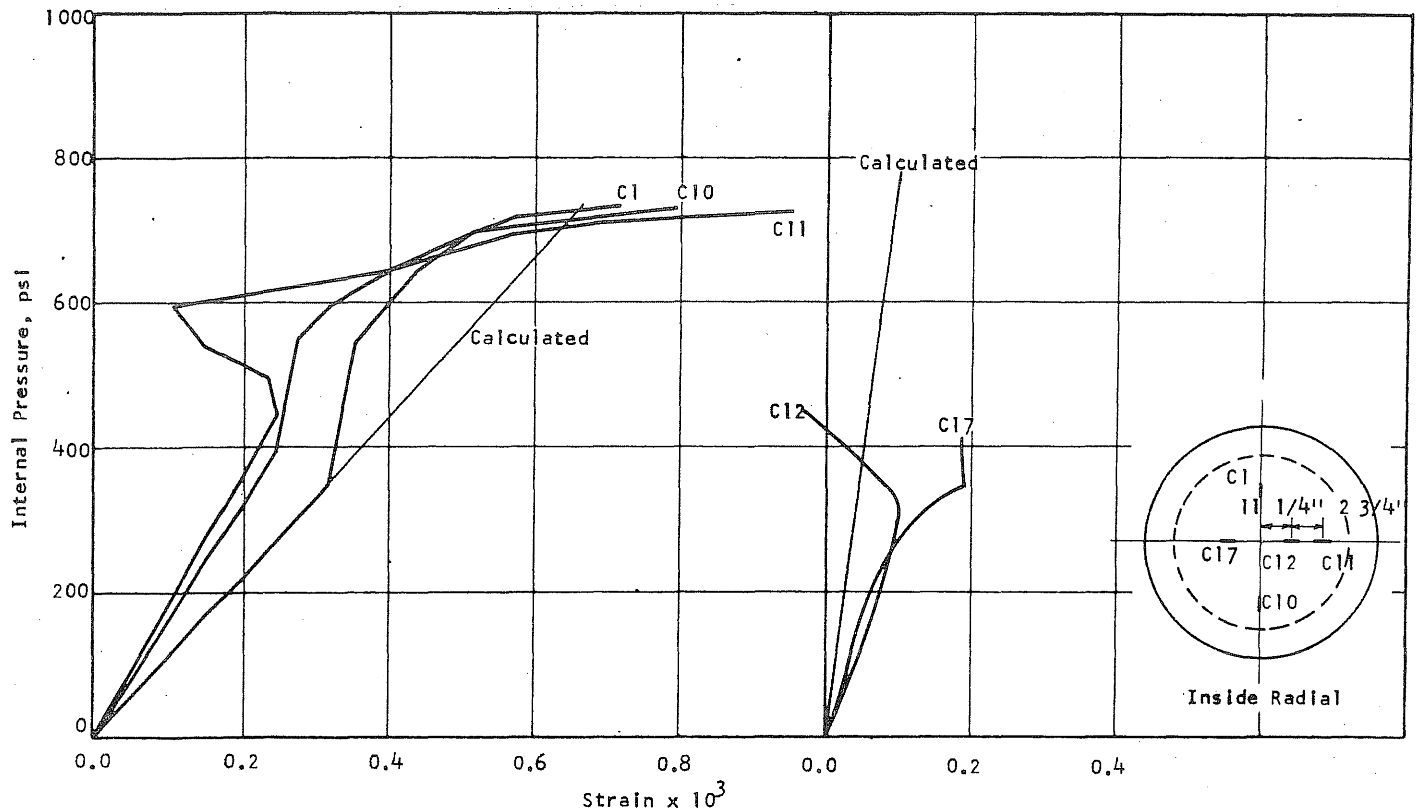


FIG. B10.9 CONCRETE STRAINS, VESSEL PV10

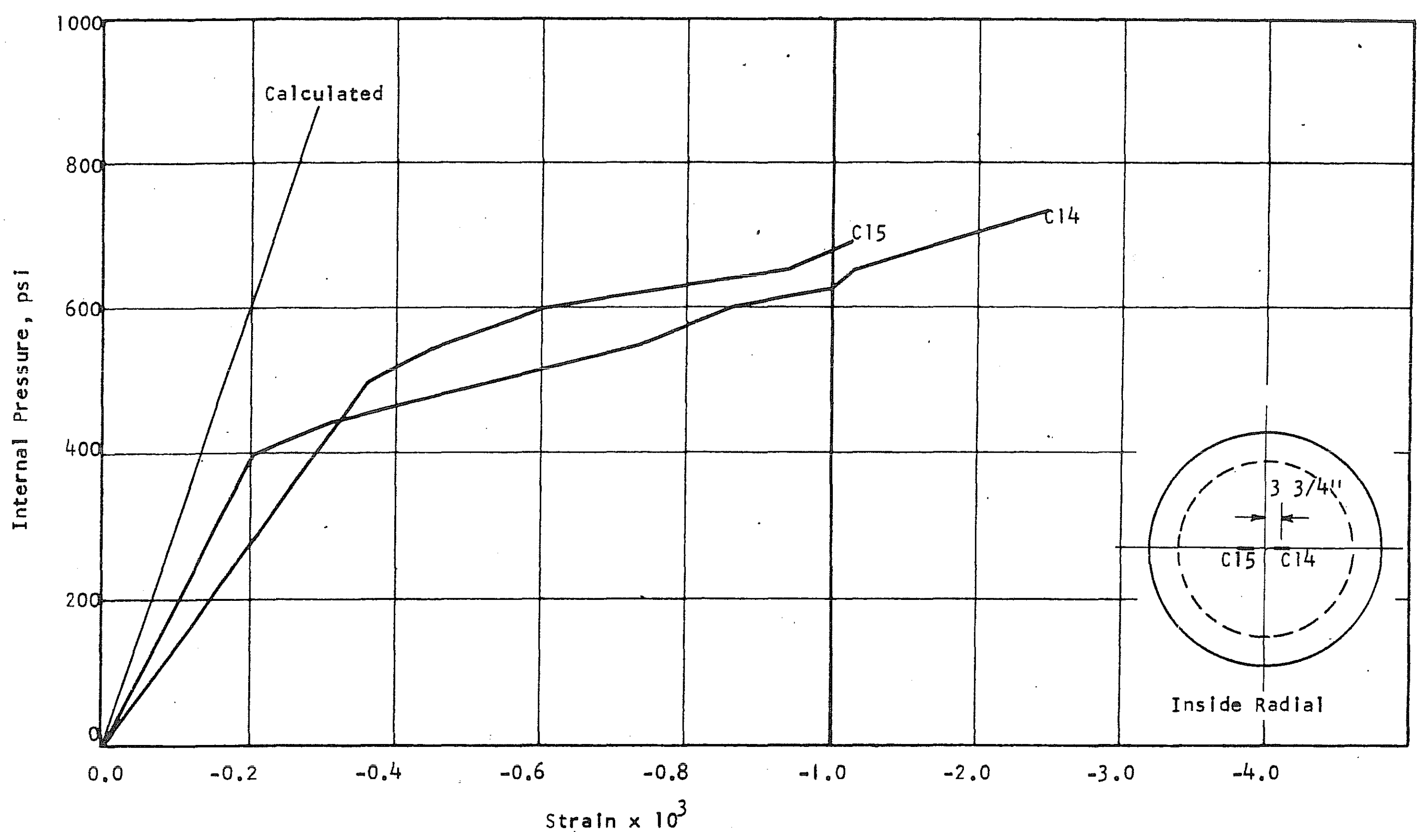


FIG. B10.9 (cont'd) CONCRETE STRAINS, VESSEL PV10

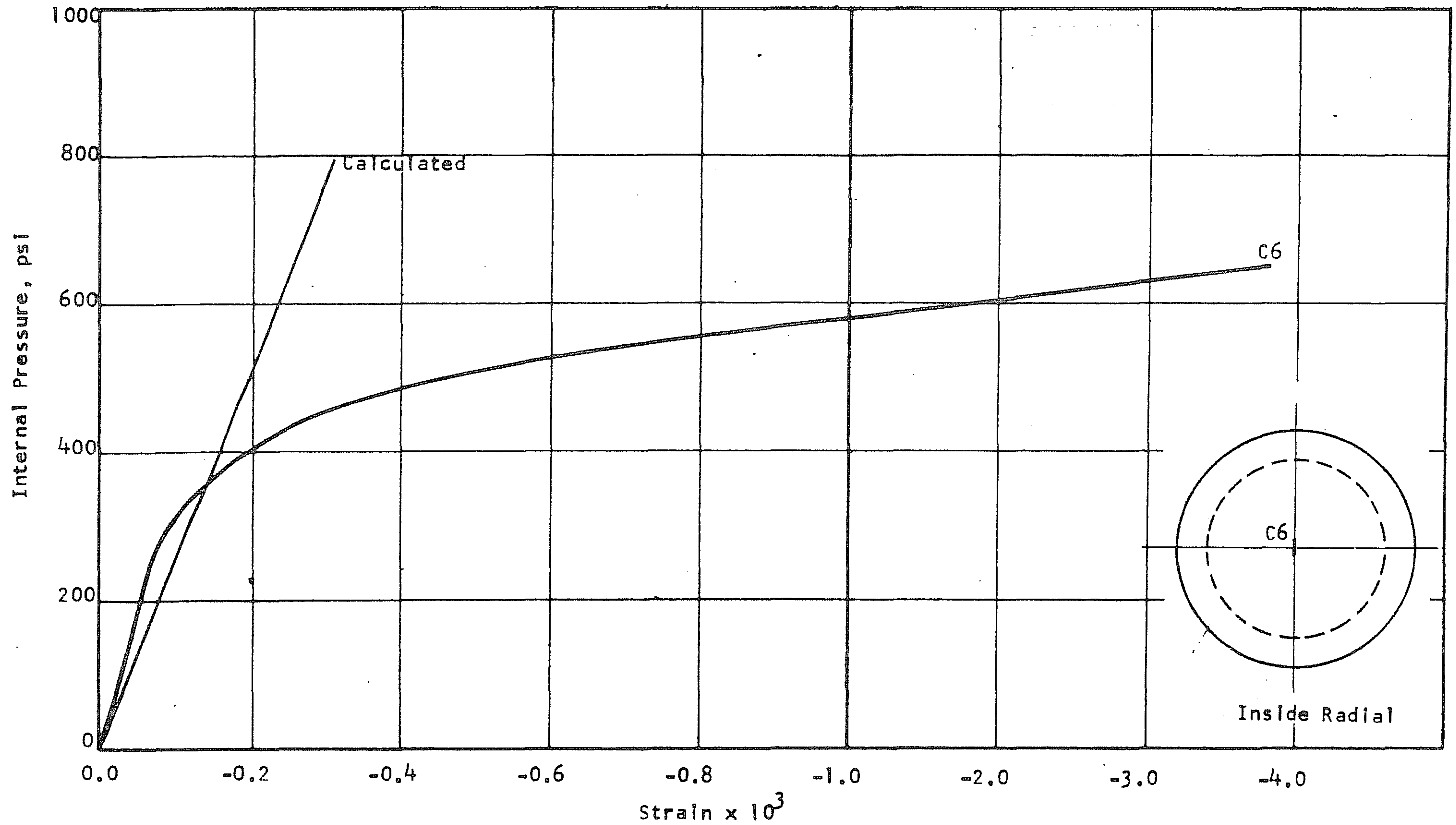


FIG. B10.9 (cont'd) CONCRETE STRAINS, VESSEL PV10

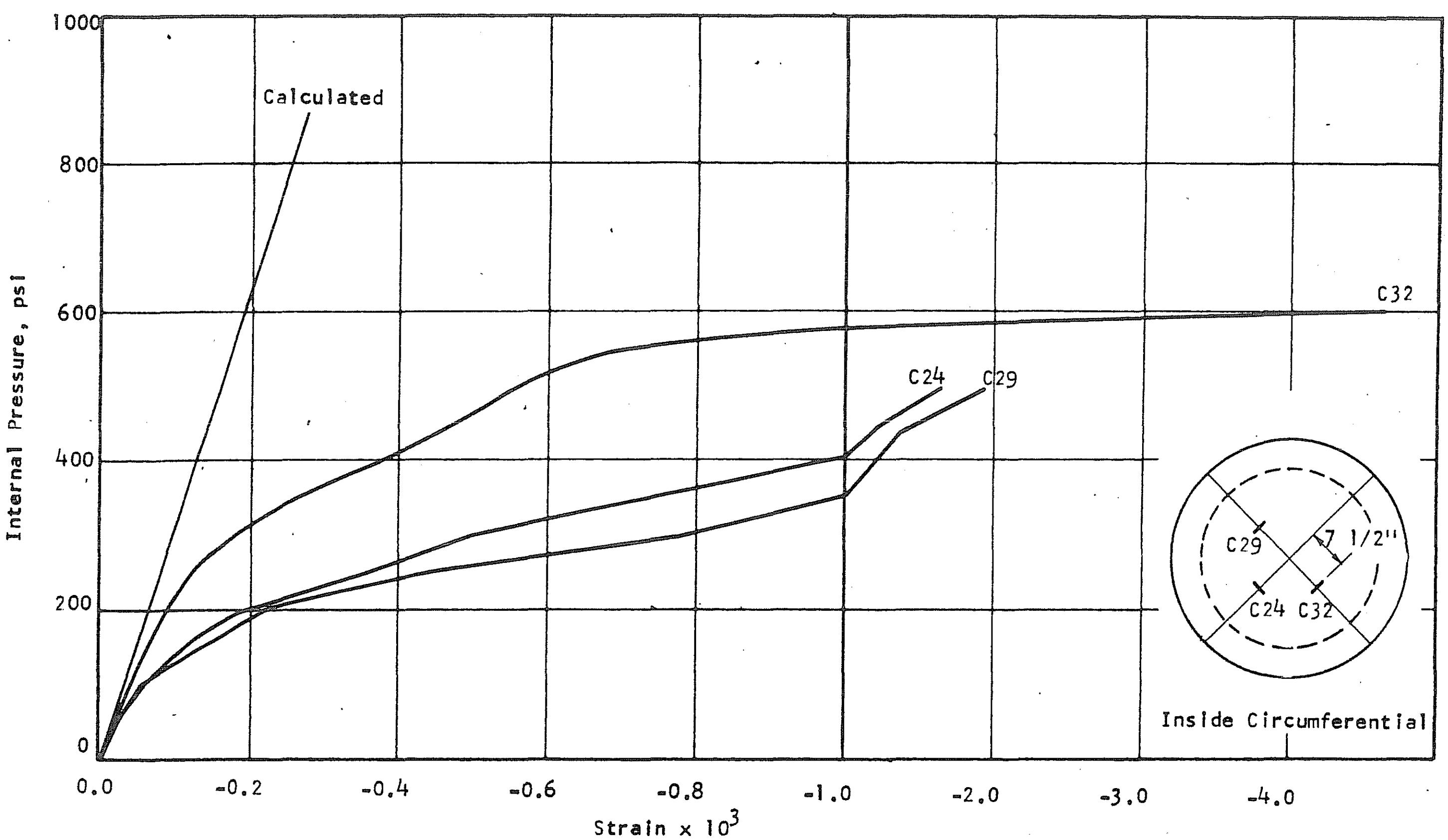


FIG. B10.10 CONCRETE STRAINS, VESSEL PV10

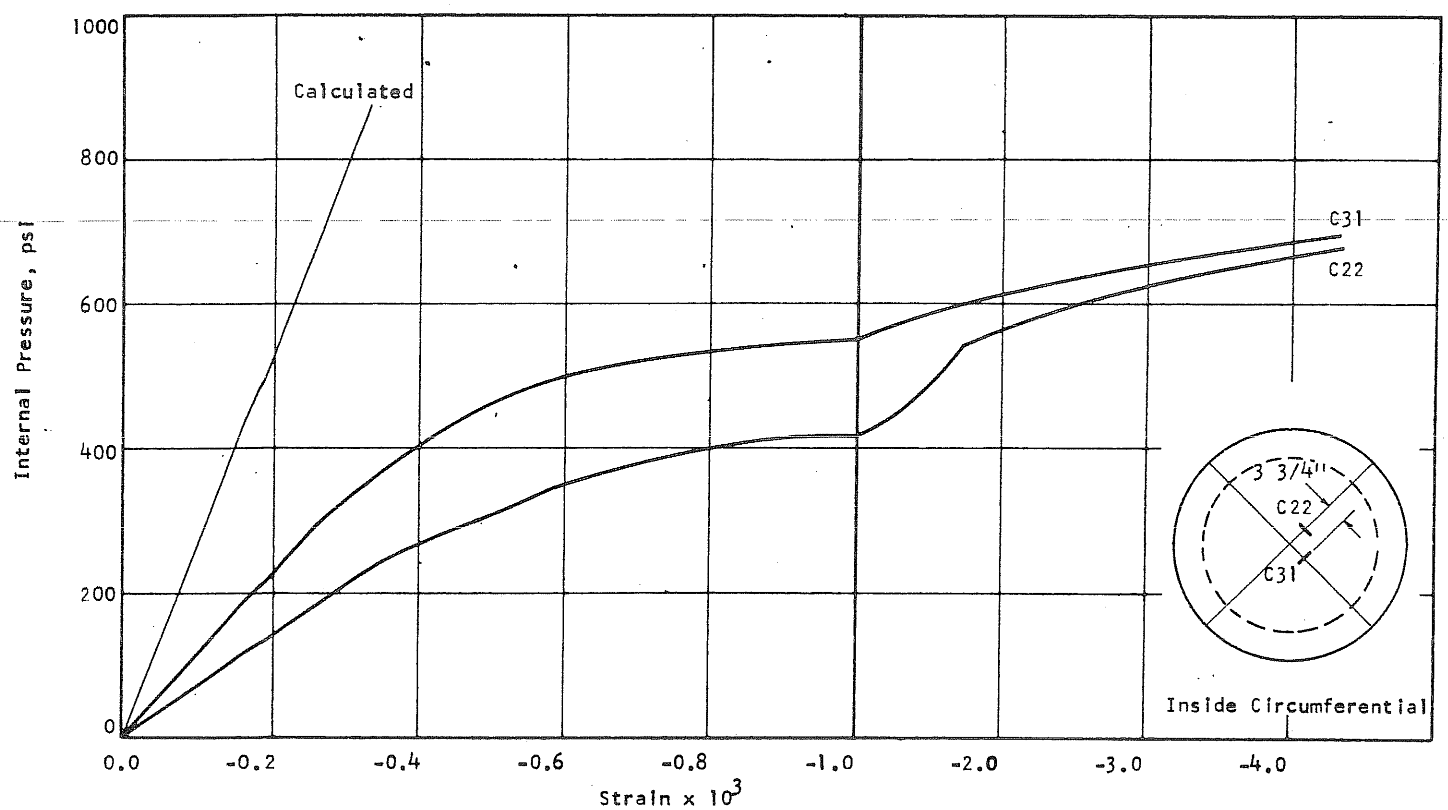


FIG. B10.10 (cont'd) CONCRETE STRAINS, VESSEL PV10

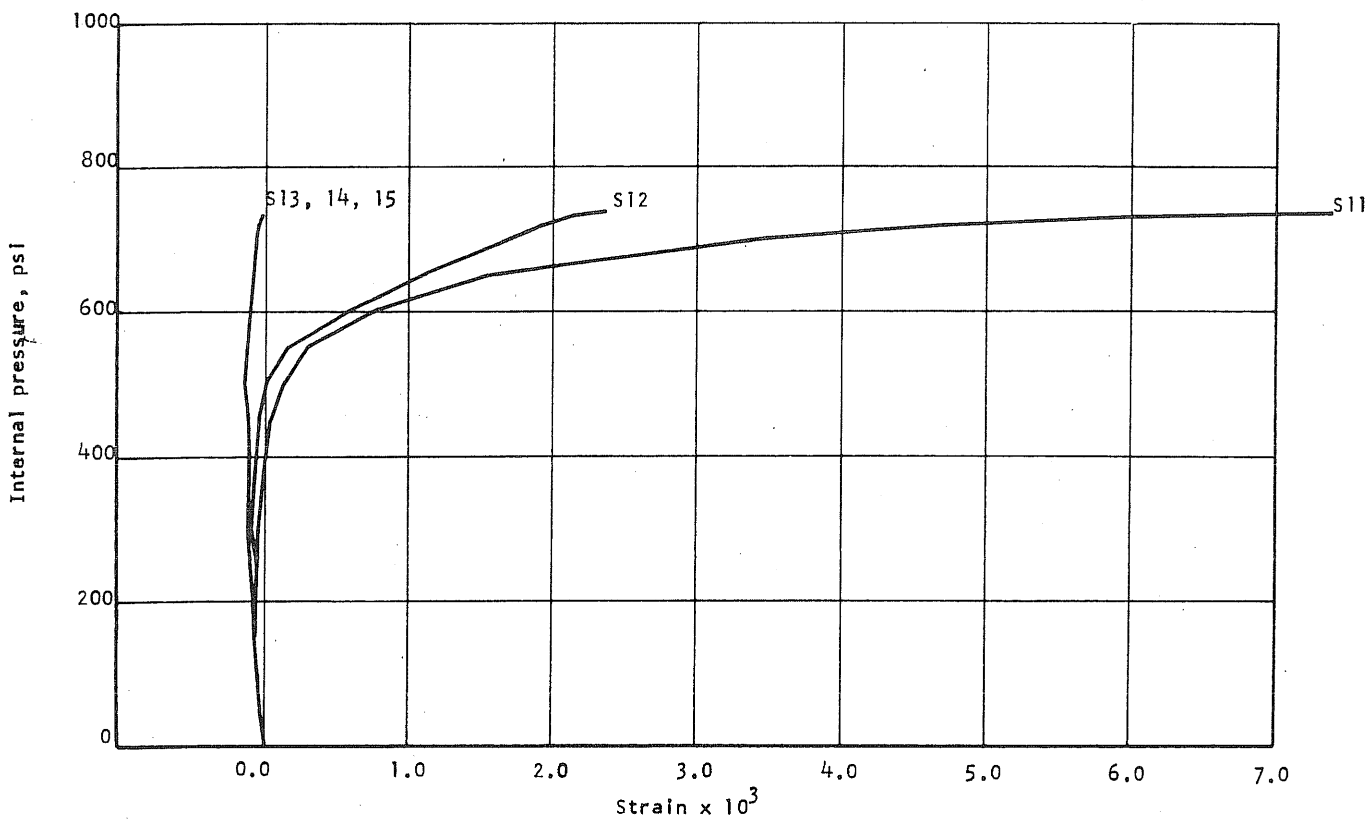
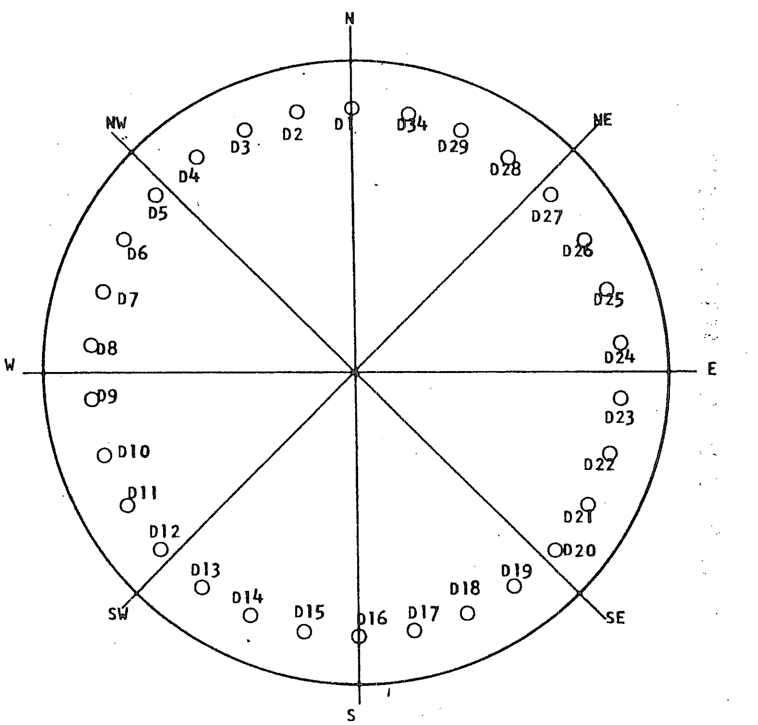


FIG. B10.11 APPLIED PRESSURE vs STRAIN IN CIRCUMFERENTIAL PRESTRESS WIRE AT THE S-END OF THE N-S DIAMETER OF PV10



0.5 in. Strand in all holes

D-Dynamometer

FIG. B10.12 LOCATION OF LONGITUDINAL REINFORCEMENT

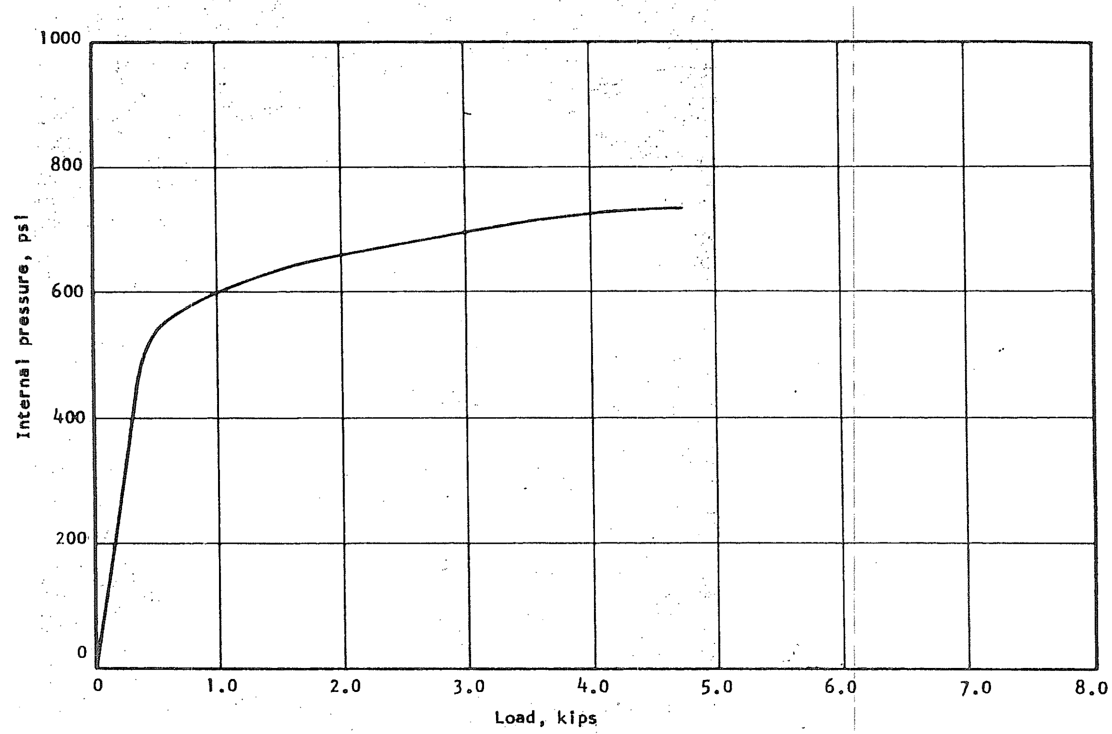


FIG. B10.13 APPLIED PRESSURE vs INCREASE IN LOAD IN DYNAMOMETER NO. 26

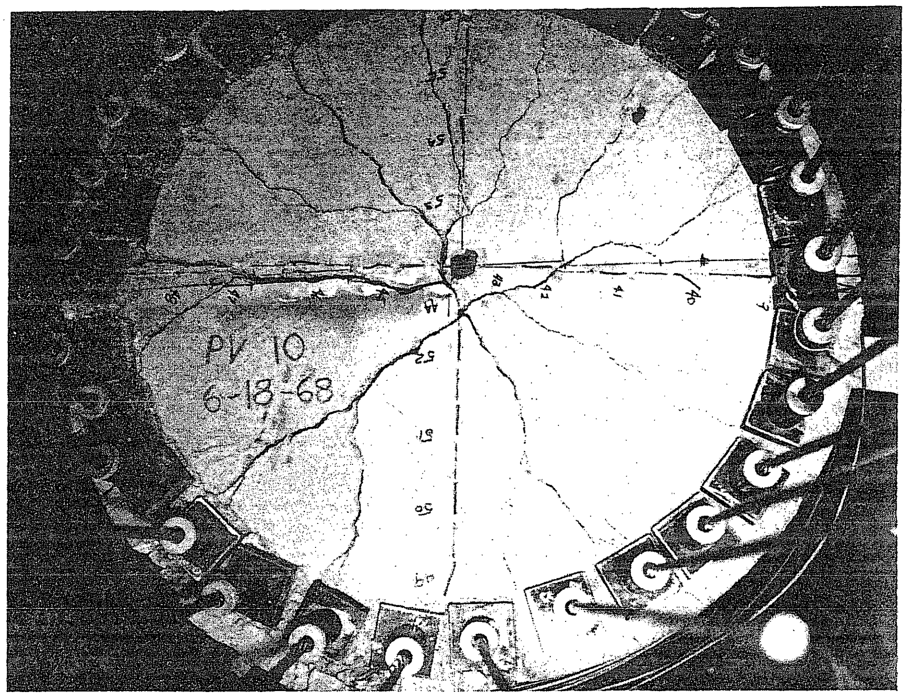


FIG. B10.14 END SLAB AFTER FAILURE

B11 Test Vessel PV11 (t = 7.5 in., s = 1/4 in.)

Test vessel PV11 was cast in the laboratory and was uncracked prior to prestressing. After circumferential prestressing a crack was observed on the inside of the vessel at 13.5 in. from the top. The 1/4-in. circumferential prestressing wire was wrapped continuously so that cracking on the outside could not be observed.

The liner detail was similar to the one used for PV9 and PV10. The aluminum liner was temporarily sealed and pressed into place with 70 psi air pressure before the neoprene was put on. A combination of 28 stressteel rods and two strands were used for the longitudinal prestressing.

Pressure was increased in 100-psi increments up to 1600 psi, when a seal blew in the gas regulator causing a leak. The pressure decreased to 250 psi while a higher capacity regulator was being installed. When repressurizing was attempted, it was found that the sealing in the vessel had failed. The vessel had a well developed system of radial cracks. A new 3/4-in. O-ring was installed after the old O-ring and caulking were removed. A second test was attempted and a pressure of 1830 psi was reached over a period of about 2 hours. At that pressure a leak in the liner became so severe that further increase in pressure was impossible. Center deflection was about 0.15 in.

The vessel was resealed which involved removing the O-ring and neoprene from the end slab surface and pouring a one-in. thick layer of hydrocal over the exposed aluminum. This hydrocal was covered with aluminum and neoprene and a new 3/4-in. O-ring was installed. It was hoped that the additional hydrocal would move the corner seal away from the actual corner of the vessel and minimize deformations in the seal. This time 30 stressteel rods were used for prestressing.

The vessel was again tested and reached 1980 psi in 45 minutes with only deflection readings being taken. The vessel leaked again. The leak was determined to be in the end slab since no water was being expelled. It was a small leak. The regulator was bypassed and the gas supply flowed directly from a 2600 psi nitrogen bottle into the specimen. The vessel failed at 2040 psi in about five minutes while reading the center deflection. A photograph showing the type of failure is shown in Fig. B11.13. Data from only the first test is presented with the exception of the load deflection curve for the center of the end slab for the final test.

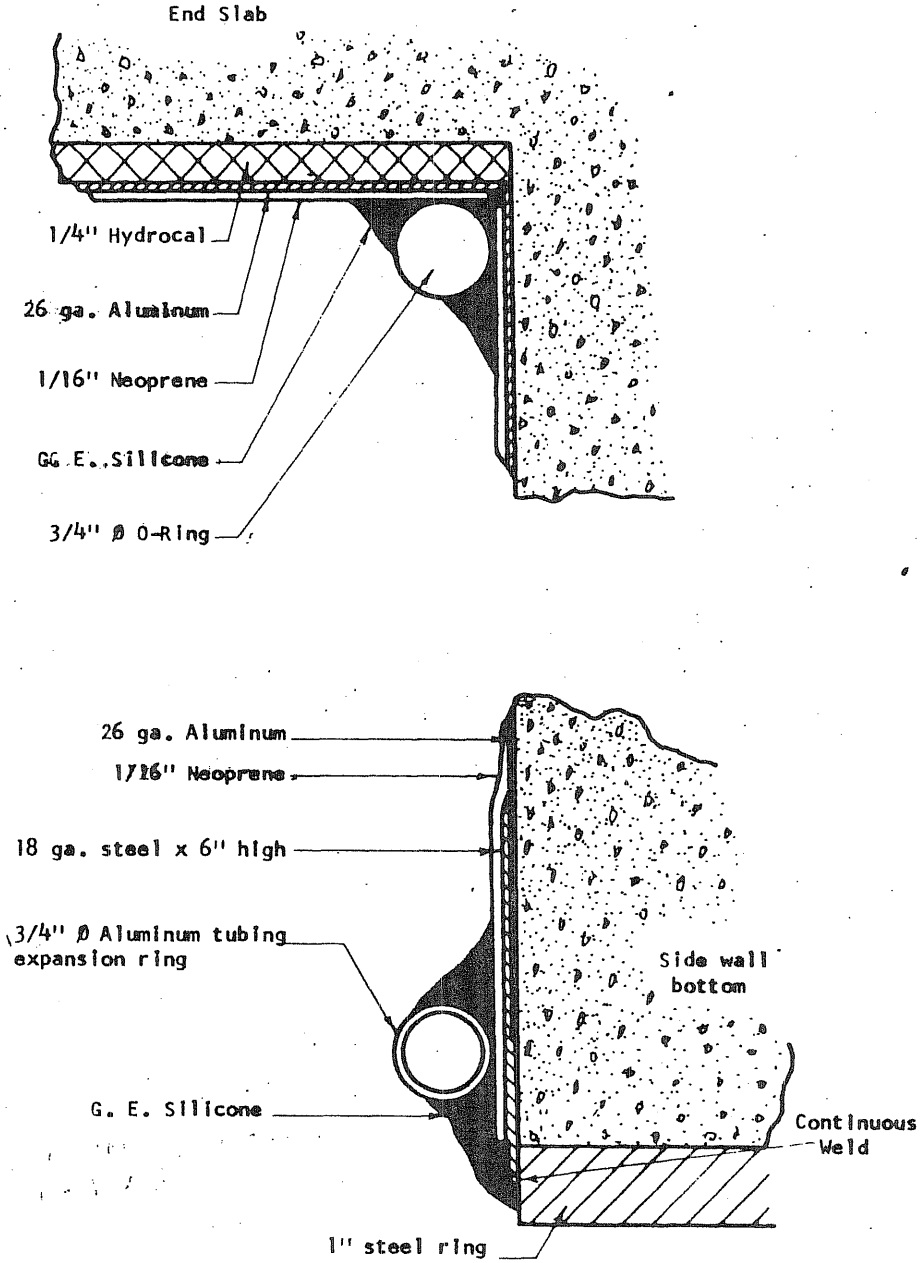


FIG. B11.1 SEALING DETAIL FOR PV11

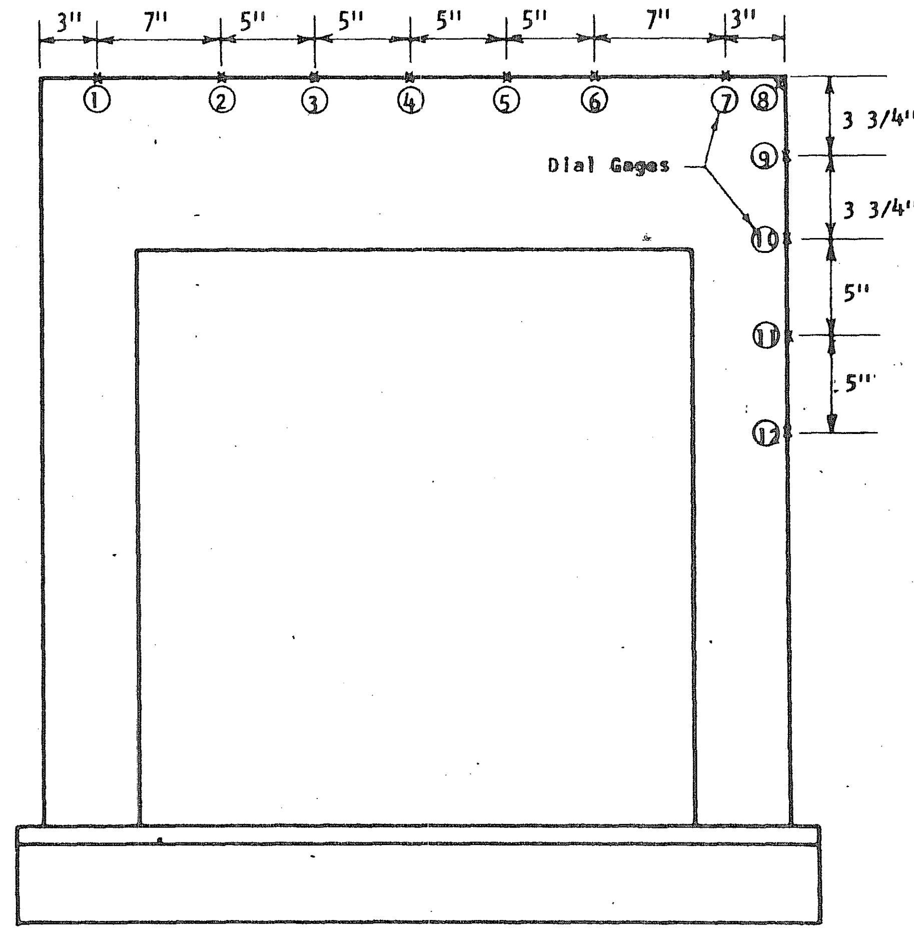


FIG. B11.2 LOCATION OF DEFLECTION GAGES ON PV11

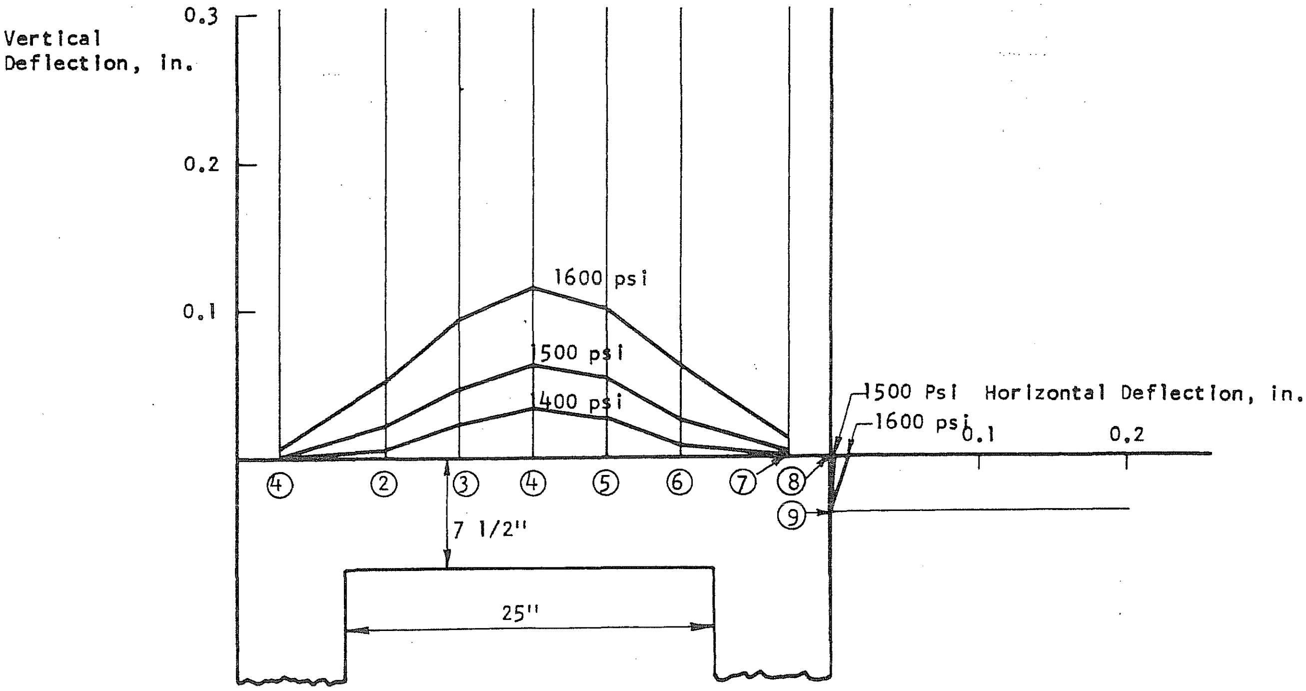


FIG. B11.3 DEFLECTION PROFILES OF THE END SLAB ALONG THE N-S DIAMETER OF PV11

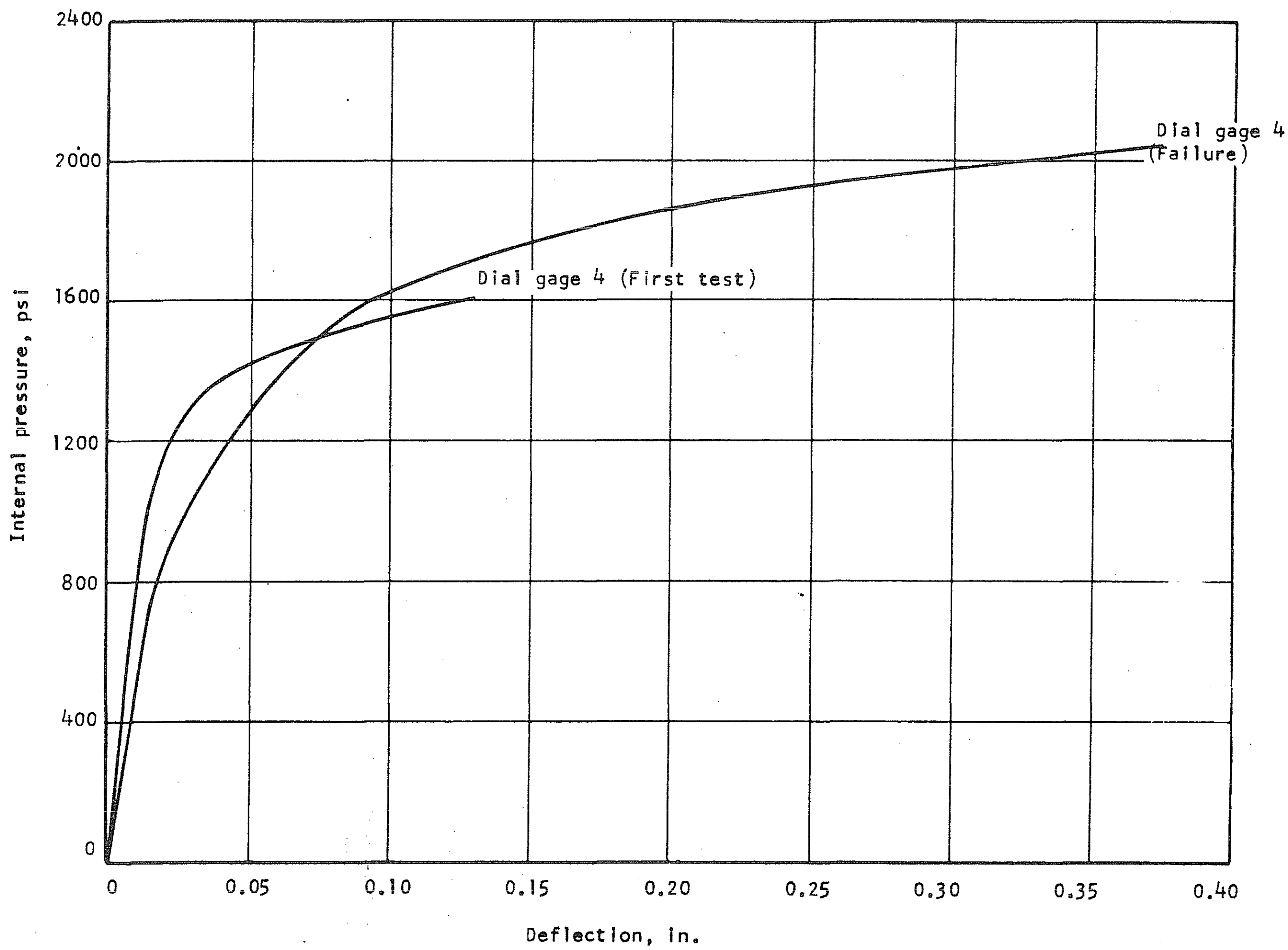
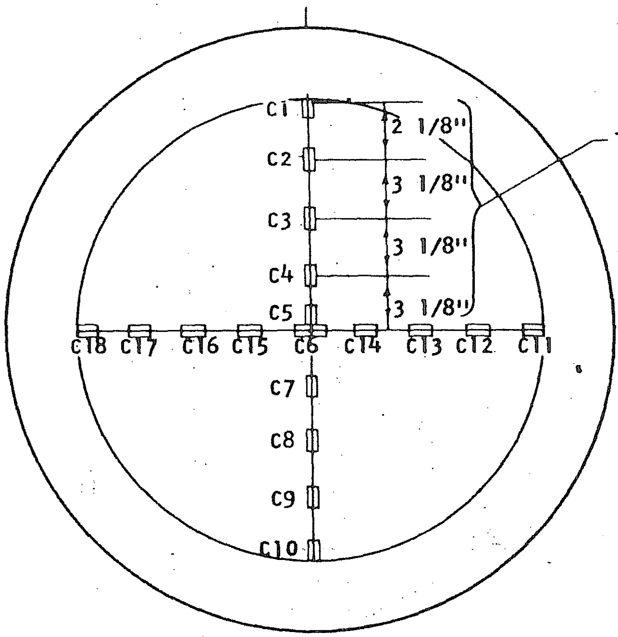


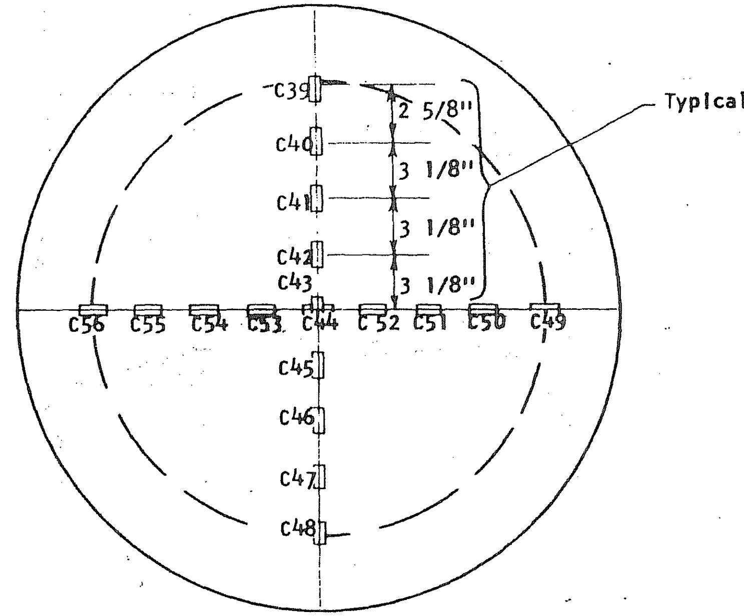
FIG. B11.4 APPLIED PRESSURE vs DEFLECTION AT MIDSPAN OF PV11

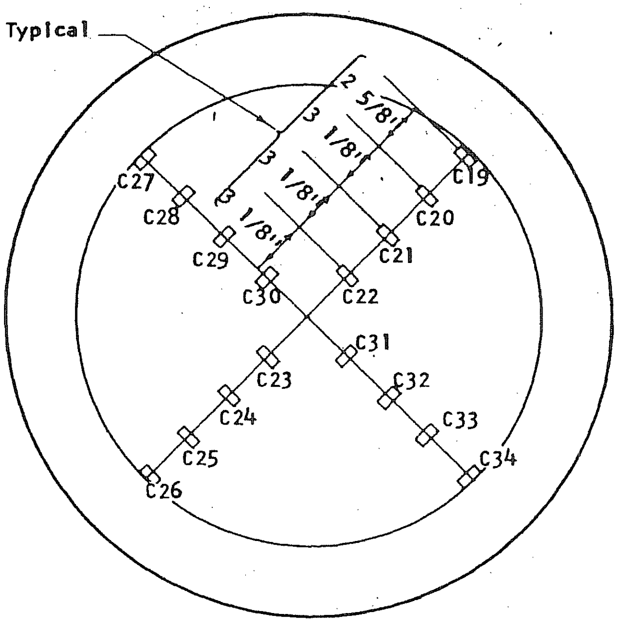
Concrete Gages on the Inside of the End Slab



Gages to Measure Radial Strain

Concrete gages on the Outside of the End Slab

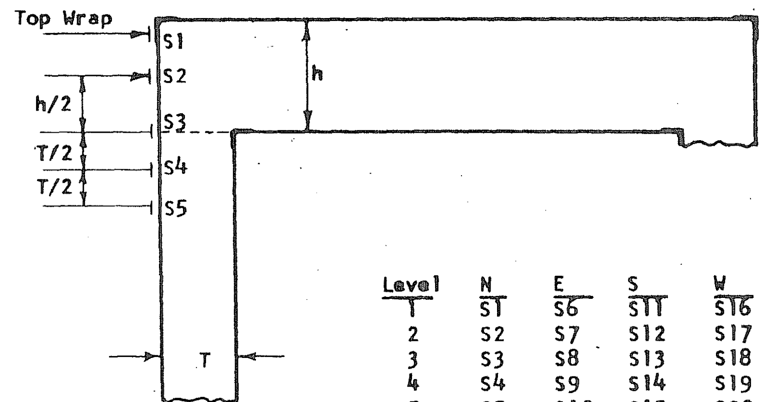




Gages to Measure Circumferential Strains

FIG. B11.5 STRAIN GAGE LOCATIONS ON PV11

Steel Gages on Circumferential Prestress Wire



Level	N	E	S	W
1	S1	S6	S11	S16
2	S2	S7	S12	S17
3	S3	S8	S13	S18
4	S4	S9	S14	S19
5	S5	S10	S15	S20

FIG. B11.5 (cont'd) STRAIN GAGE LOCATIONS ON PV11

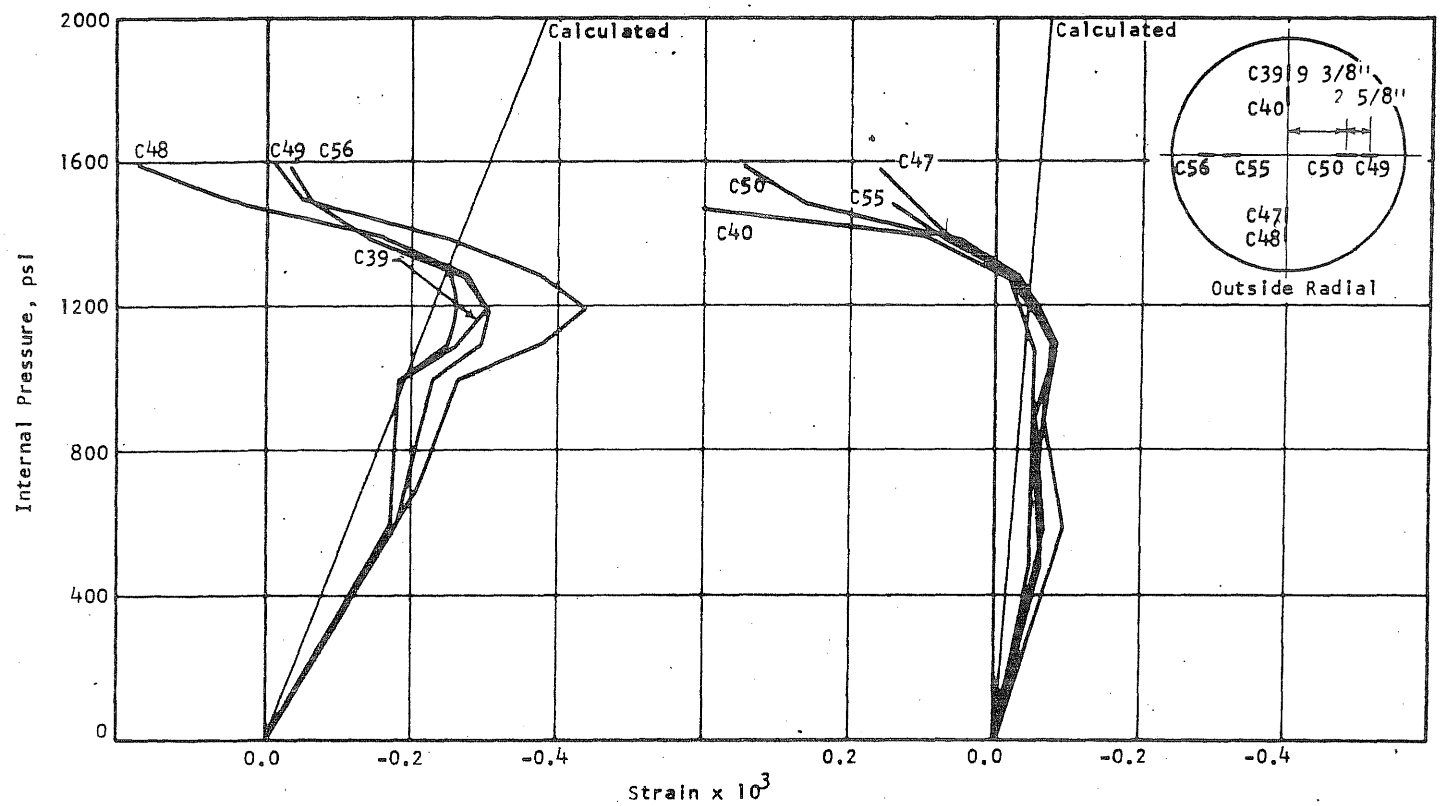


FIG. B11.6 CONCRETE STRAINS, VESSEL PV11

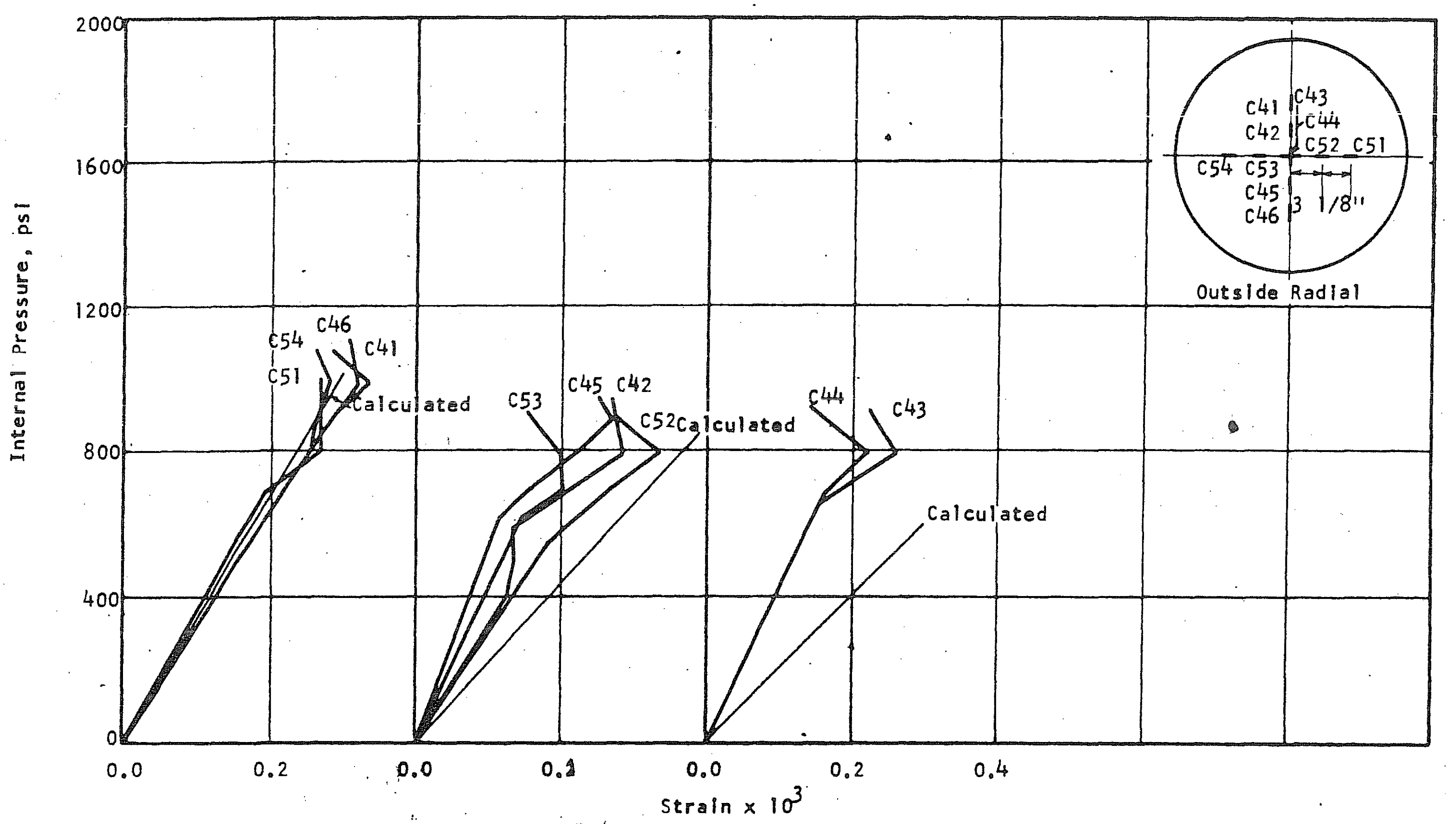


FIG. B11.6 (cont'd) CONCRETE STRAINS, VESSEL PV11

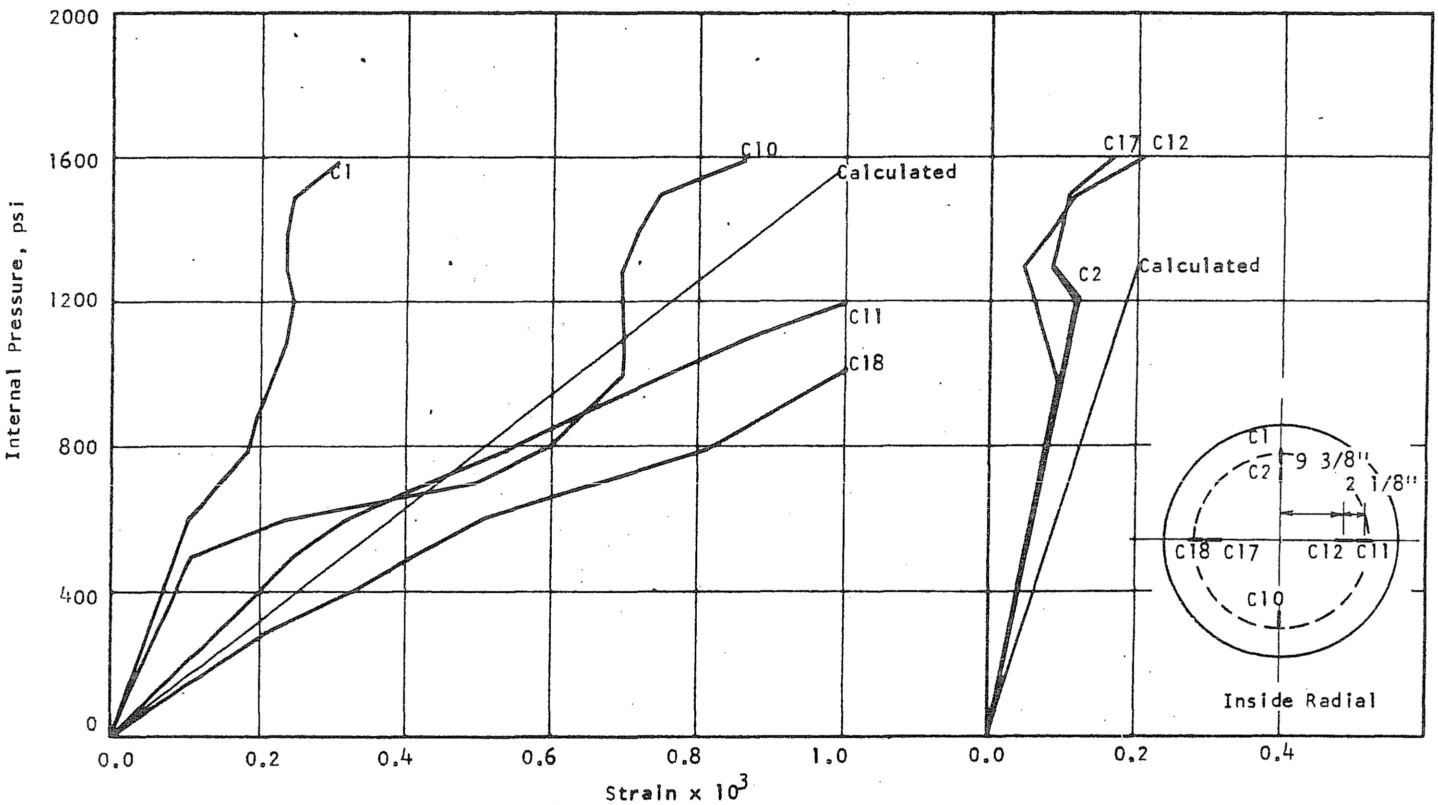


FIG. B11.7 CONCRETE STRAINS, VESSELS PV11

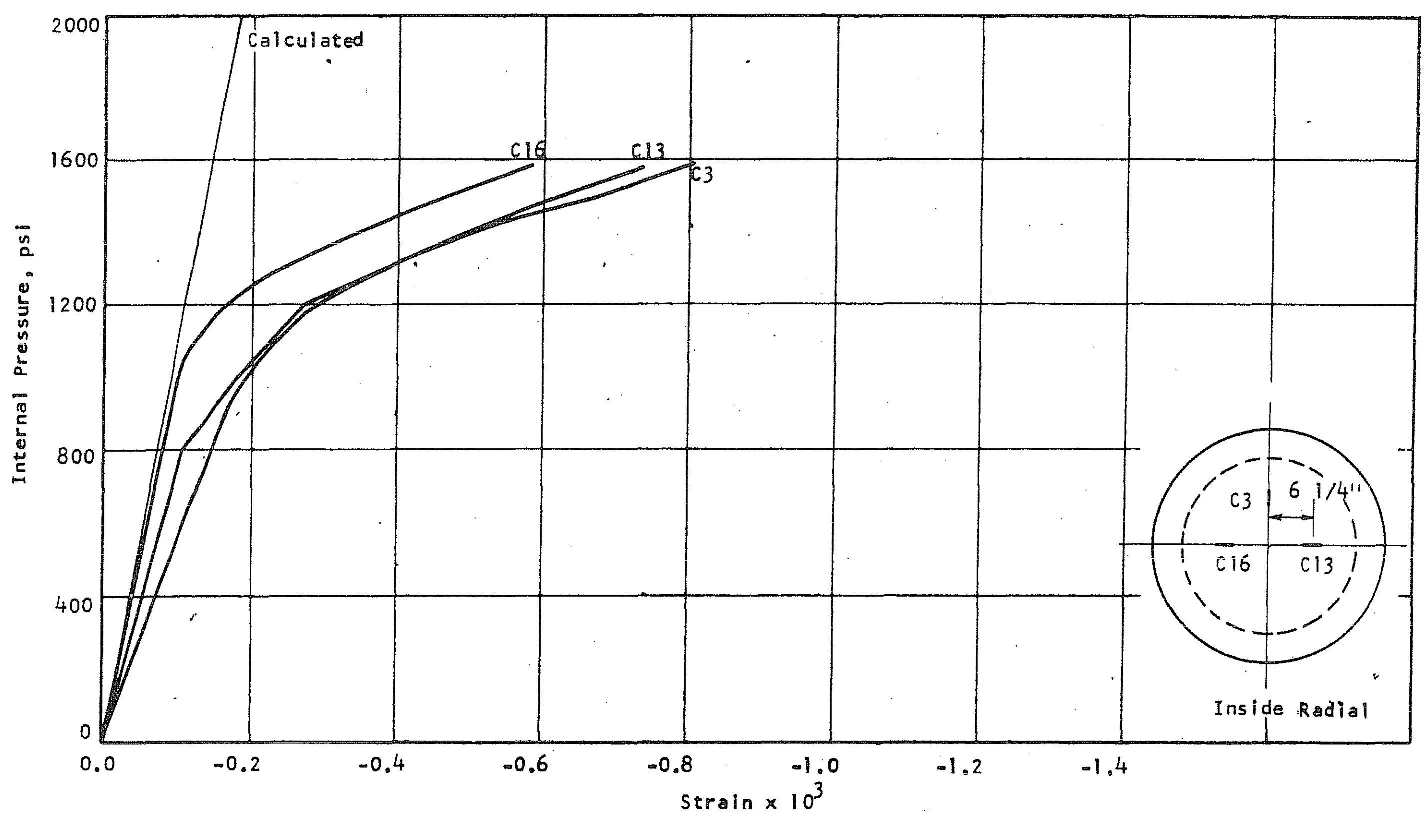


FIG. B11.7 (cont'd) CONCRETE STRAINS, VESSELS PV11

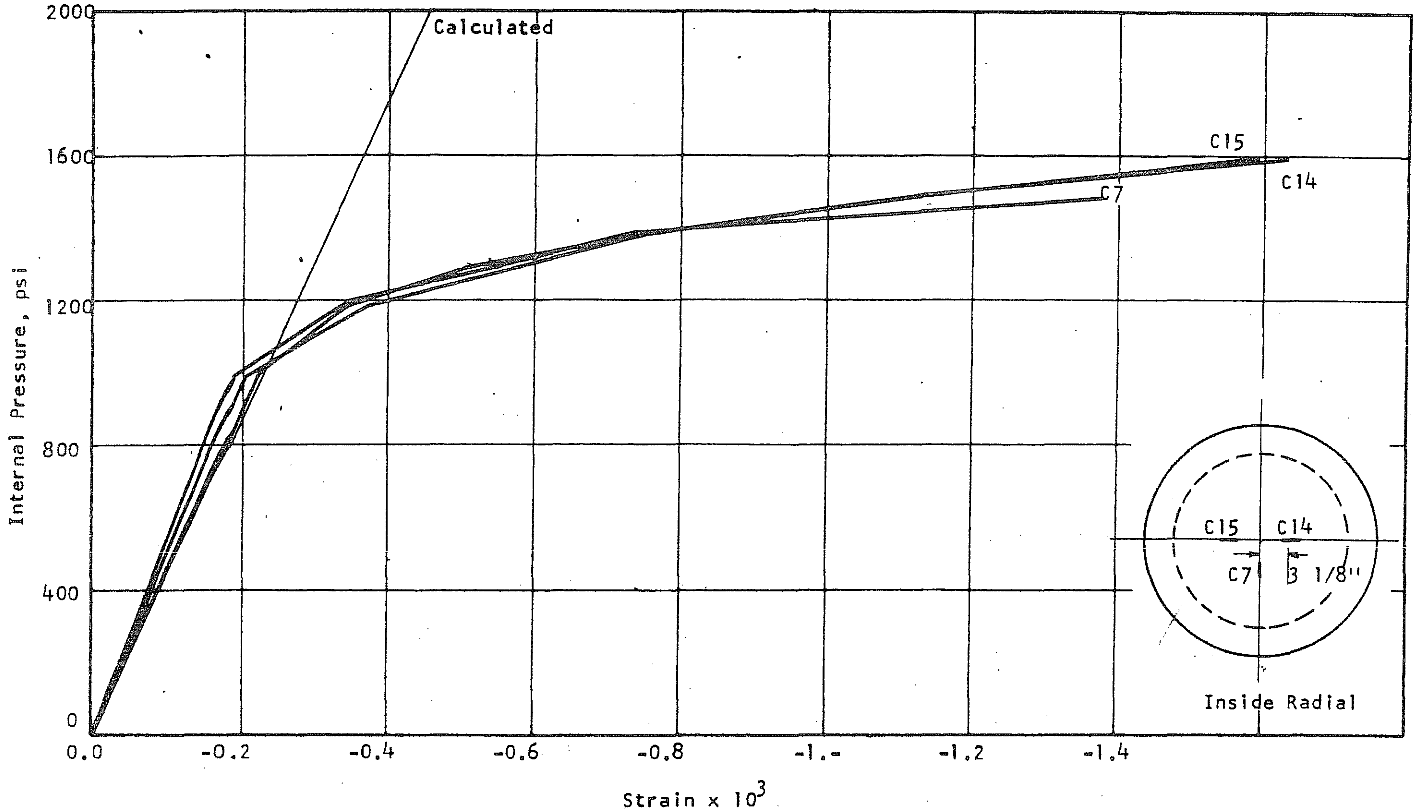


FIG. B11.7 (cont'd) CONCRETE STRAINS, VESSELS PV11

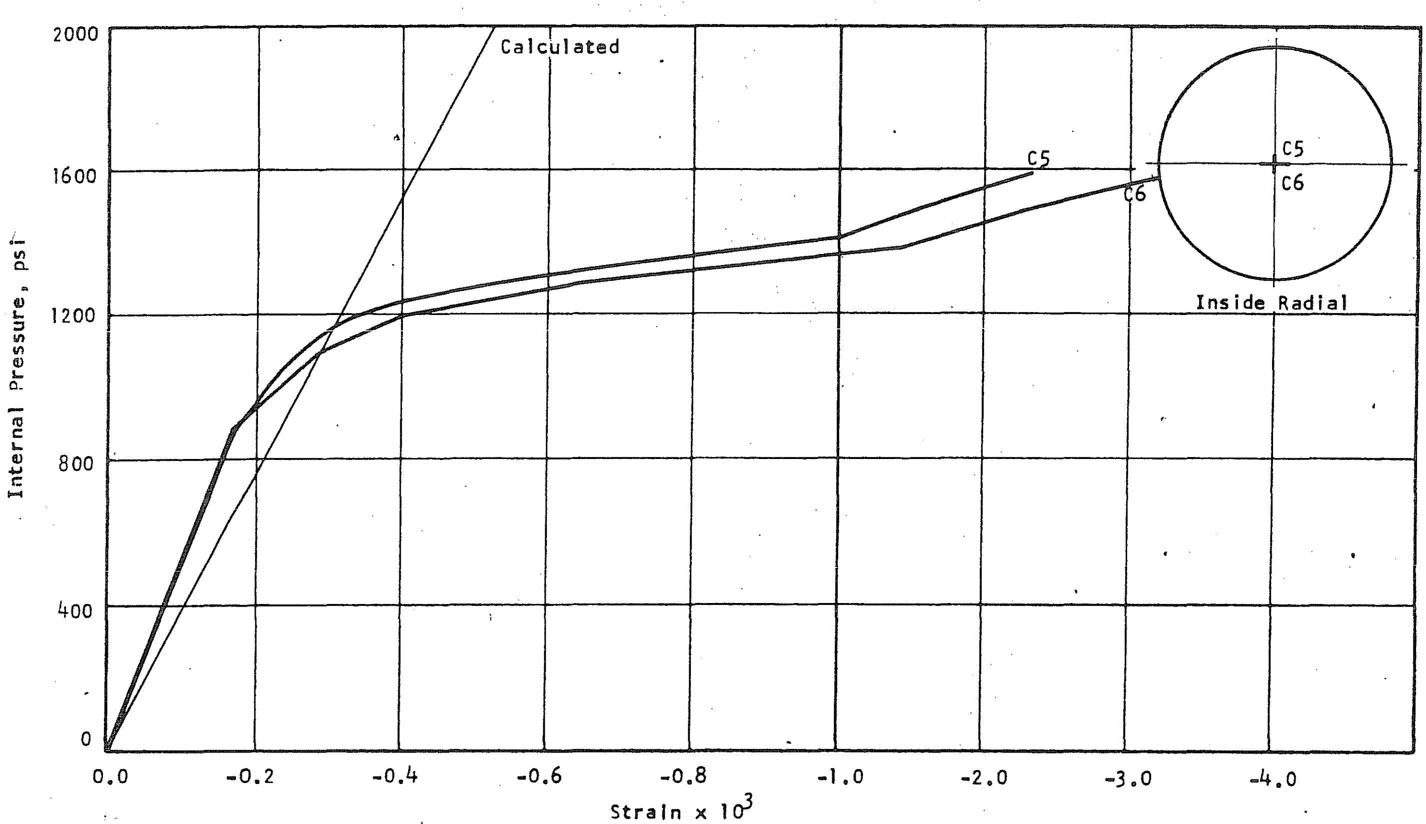


FIG. B11.7 (cont'd) CONCRETE STRAINS, VESSELS PV11

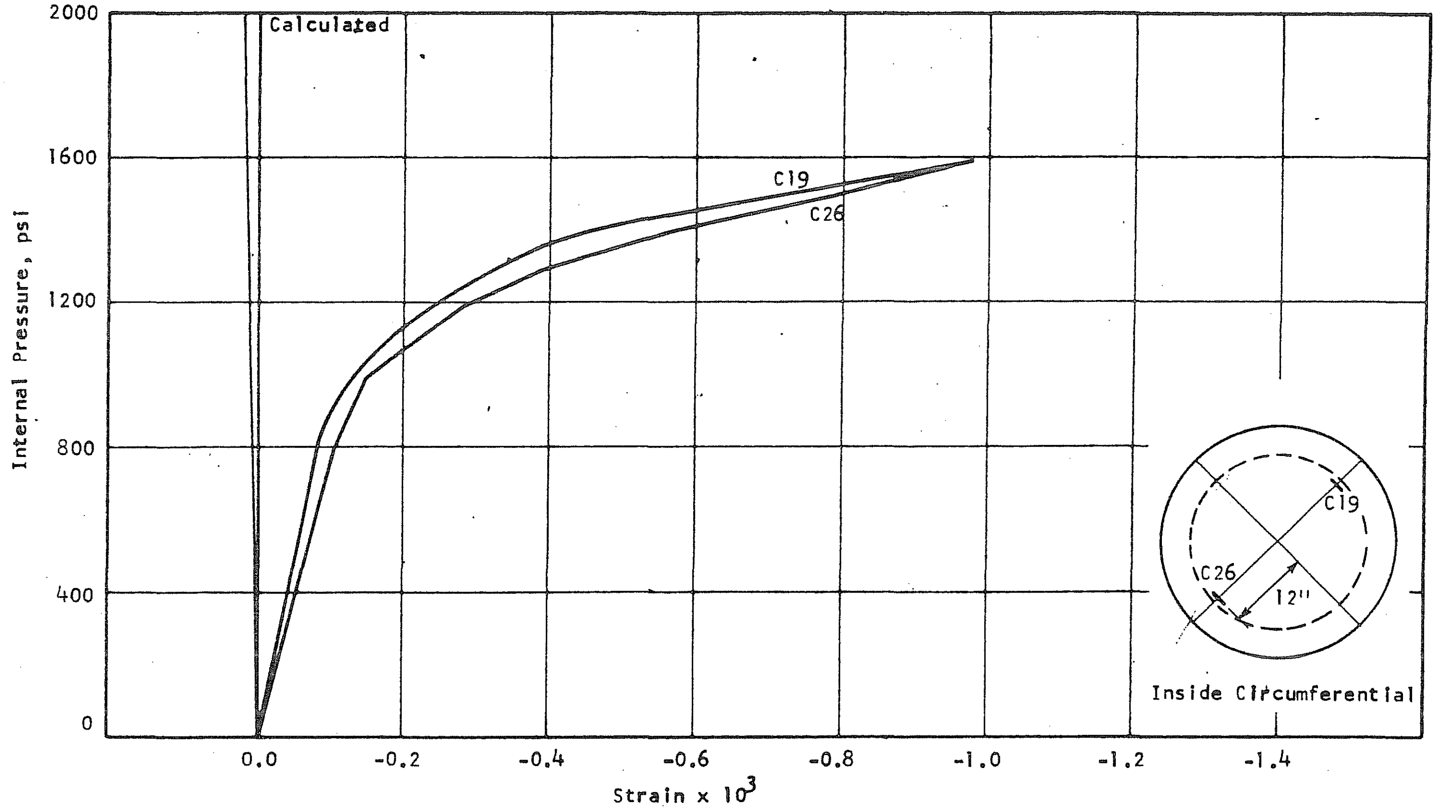


FIG. B11.8 CONCRETE STRAINS, VESSEL PV11

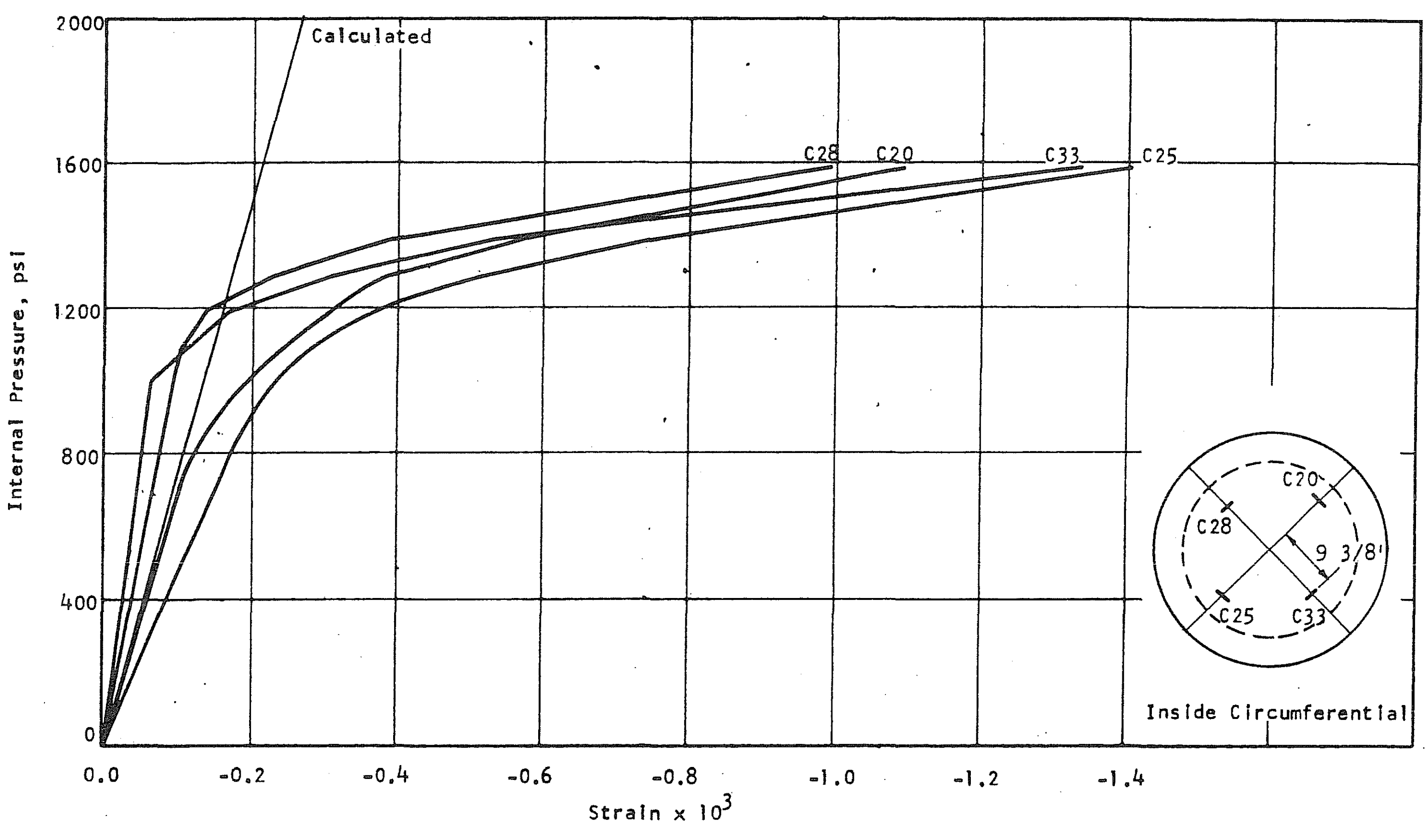


FIG. B11.8 (Cont'd) CONCRETE STRAINS, VESSEL PV11

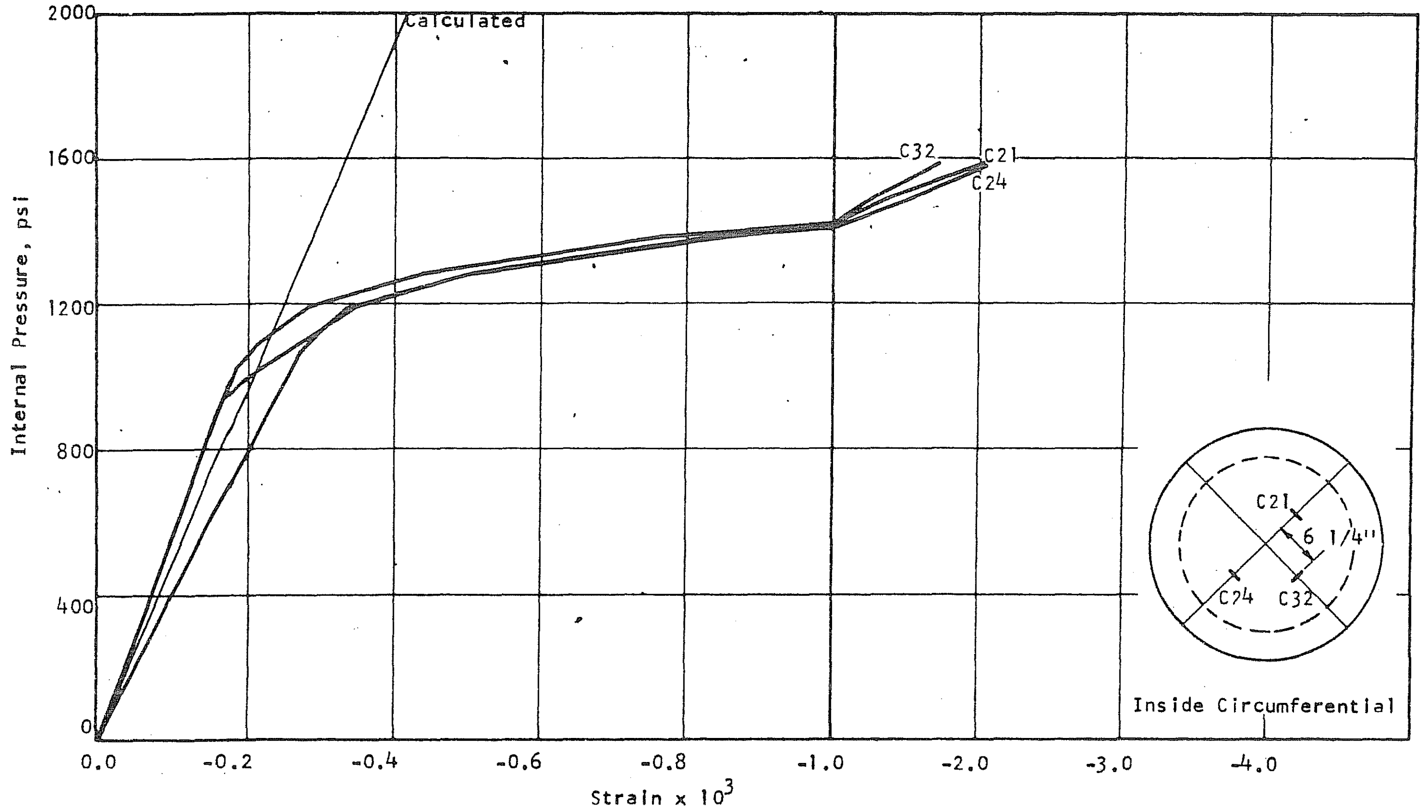


FIG. B11.8 (cont'd) CONCRETE STRAINS, VESSEL PV11

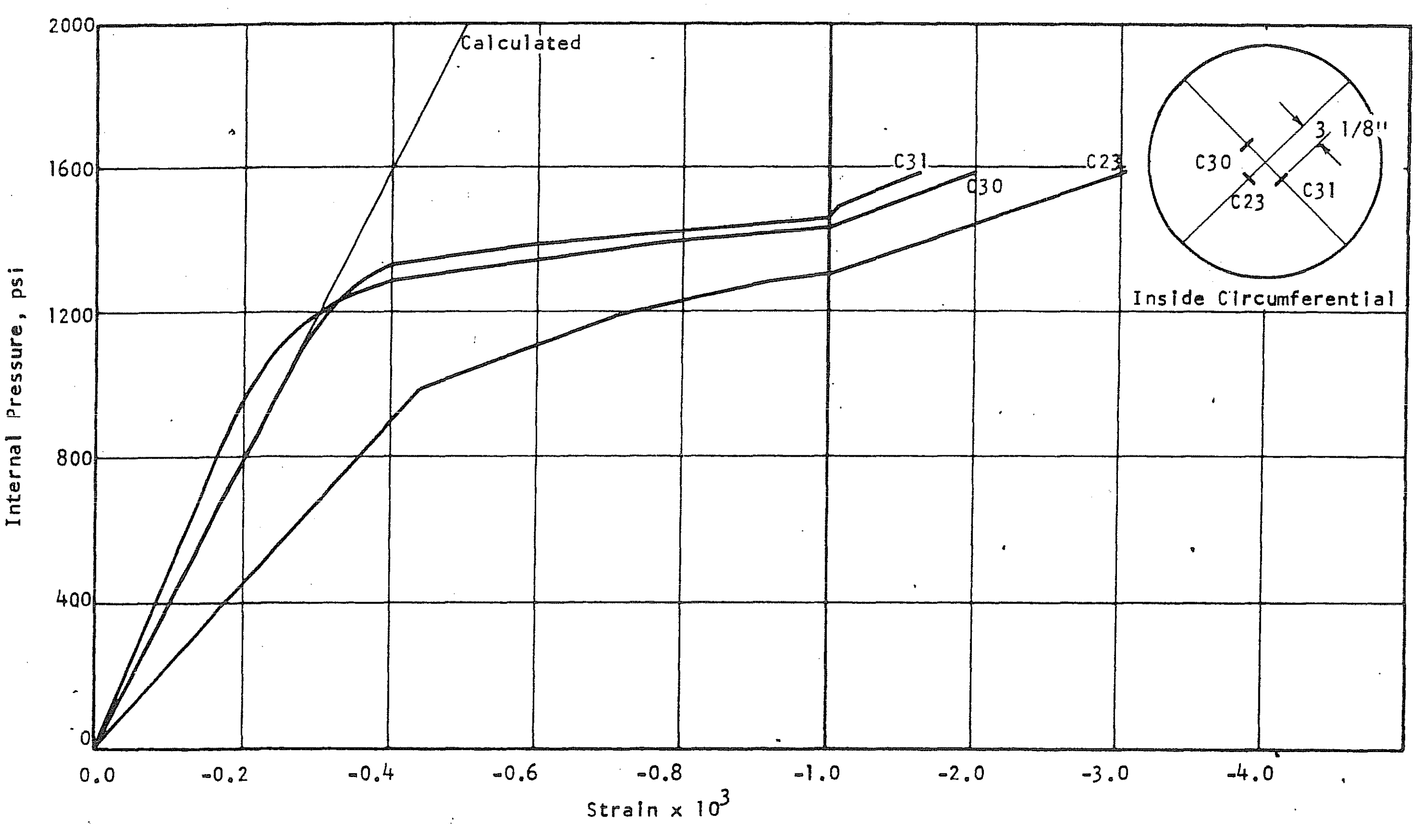


FIG. B11.8 (cont'd) CONCRETE STRAINS, VESSEL PV11

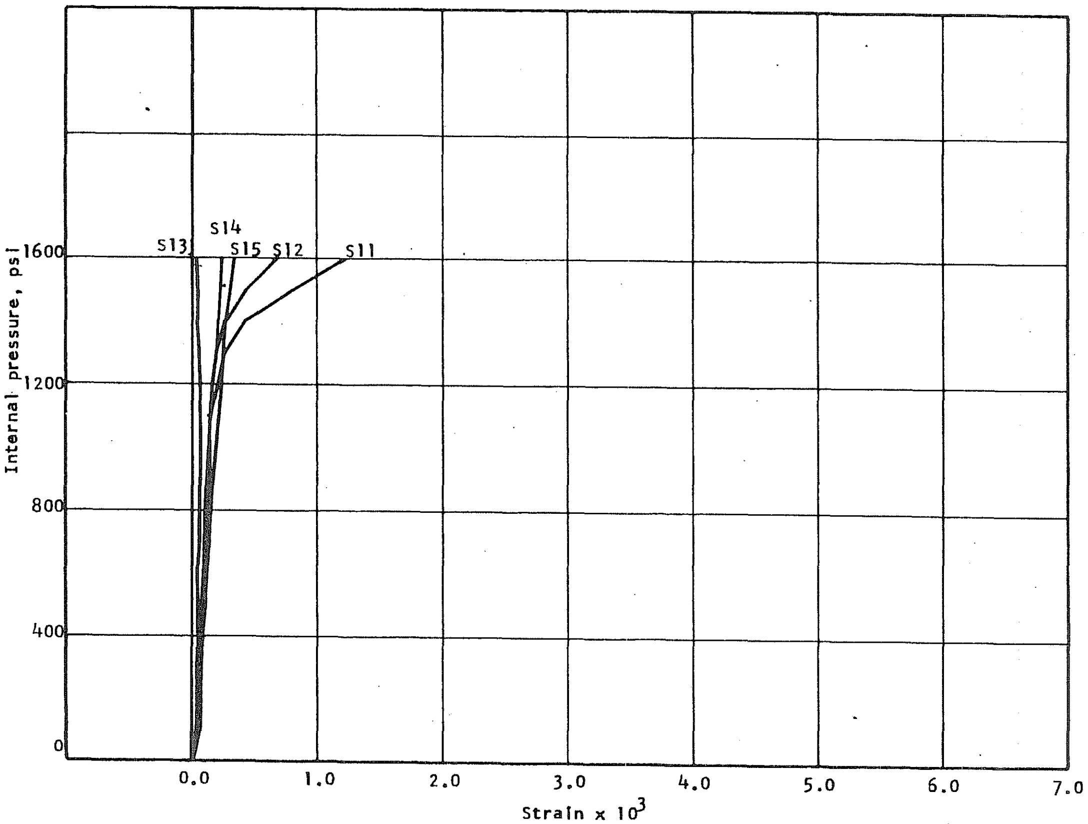


FIG. B11.9 APPLIED PRESSURE vs STRAIN IN CIRCUMFERENTIAL PRESTRESS WIRE AT THE S-END OF THE N-S DIAMETER OF PV11

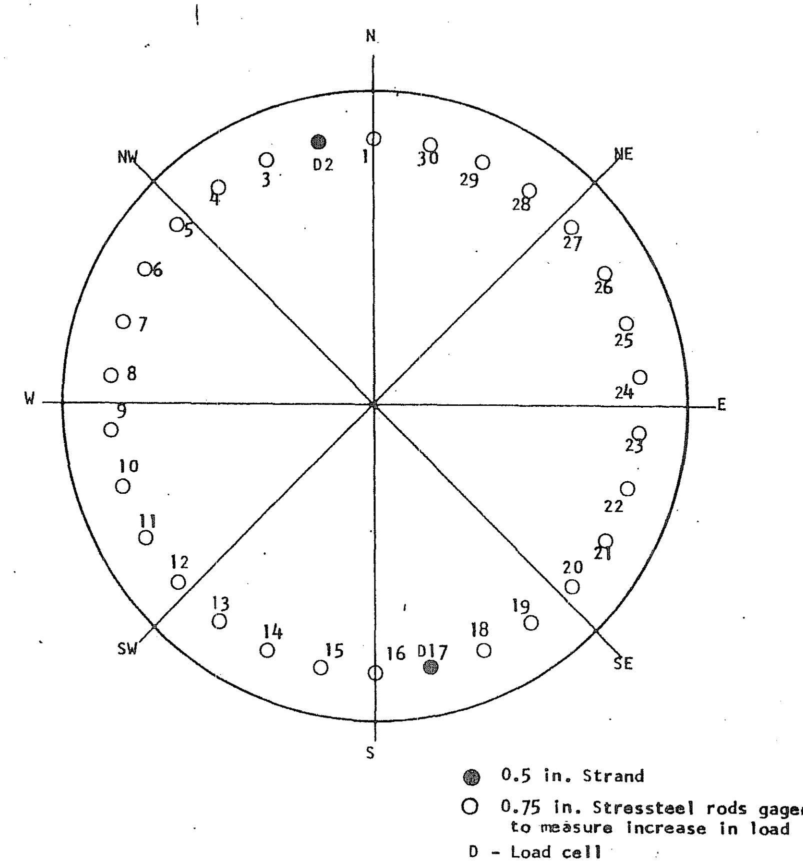


FIG. B11.10 LOCATION OF LONGITUDINAL REINFORCEMENT

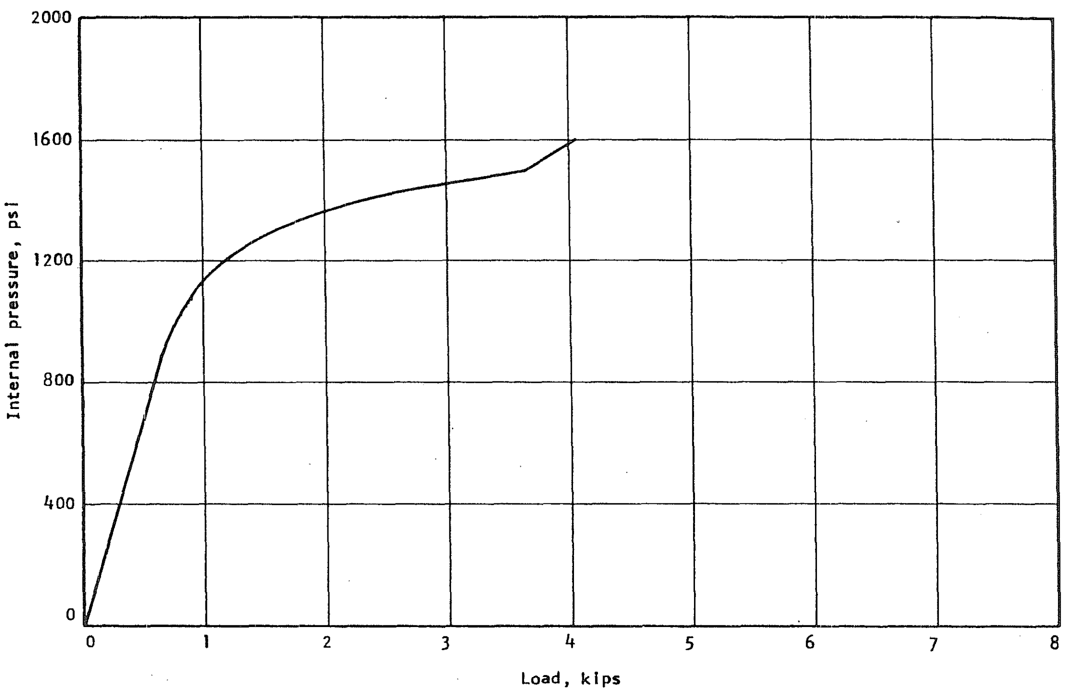


FIG. B11.11 APPLIED PRESSURE vs INCREASE IN LOAD IN STRESSTEEL ROD NO. 4

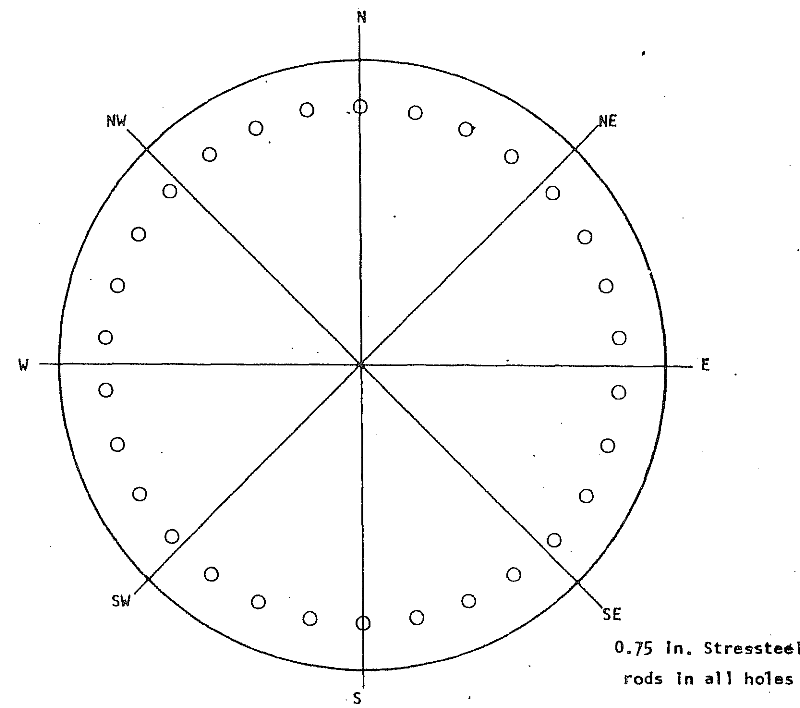


FIG. B11.12 LOCATION OF LONGITUDINAL REINFORCEMENT

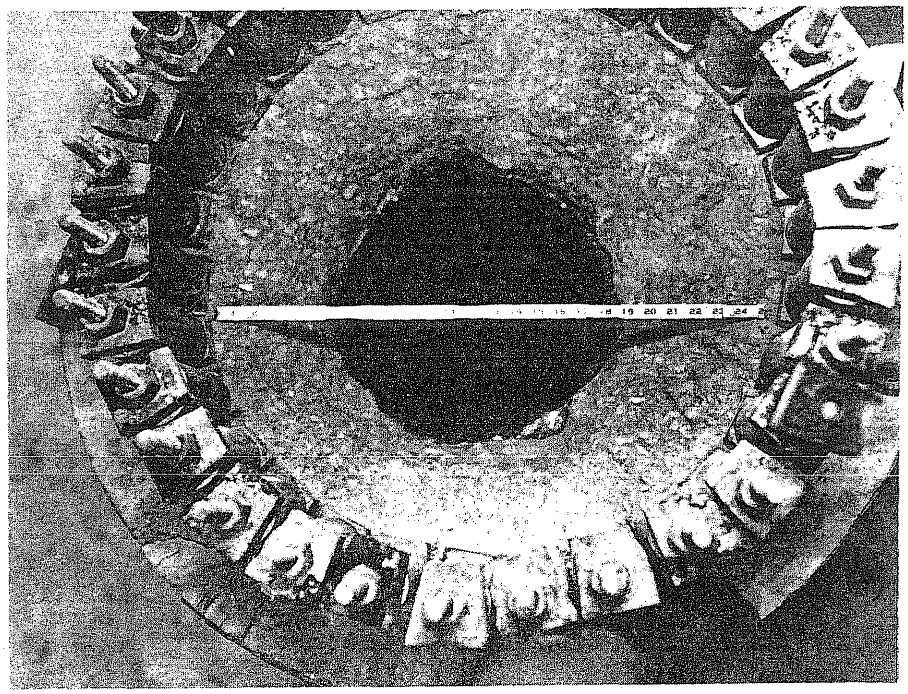


FIG. B11.13 END SLAB AFTER FAILURE

B12 Test Vessel PV12 (t = 10 in., s = 1/4 in.)

Test vessel PV12 was cast in the laboratory and was uncracked prior to prestressing. After circumferential prestressing a crack was observed on the inside of the vessel at 19 in. below the top.

The liner detail was changed significantly for this vessel and the resulting sealing detail was used on all the following tests. The sealing detail is shown in Fig. B12.1 The longitudinal prestressing was provided by 30 stressteel rods.

Nitrogen gas was used to pressurize the vessel in 250-psi increments up to 2250 psi. Since the nitrogen gas bottles used had a maximum pressure of 2600 psi, they had a limited capacity above 2000 psi. Therefore, oil pressure was used above 2250 psi with the help of a fully charged gas bottle. The pressure was increased to 2650 psi at which time the seal in the base was broken. It was found that a one-in. long piece of the small O-ring in the base had been extruded and the remainder had been partially extruded as shown in Fig. B12.12a. Figure B12.12b shows the crack pattern of the end slab after the test.

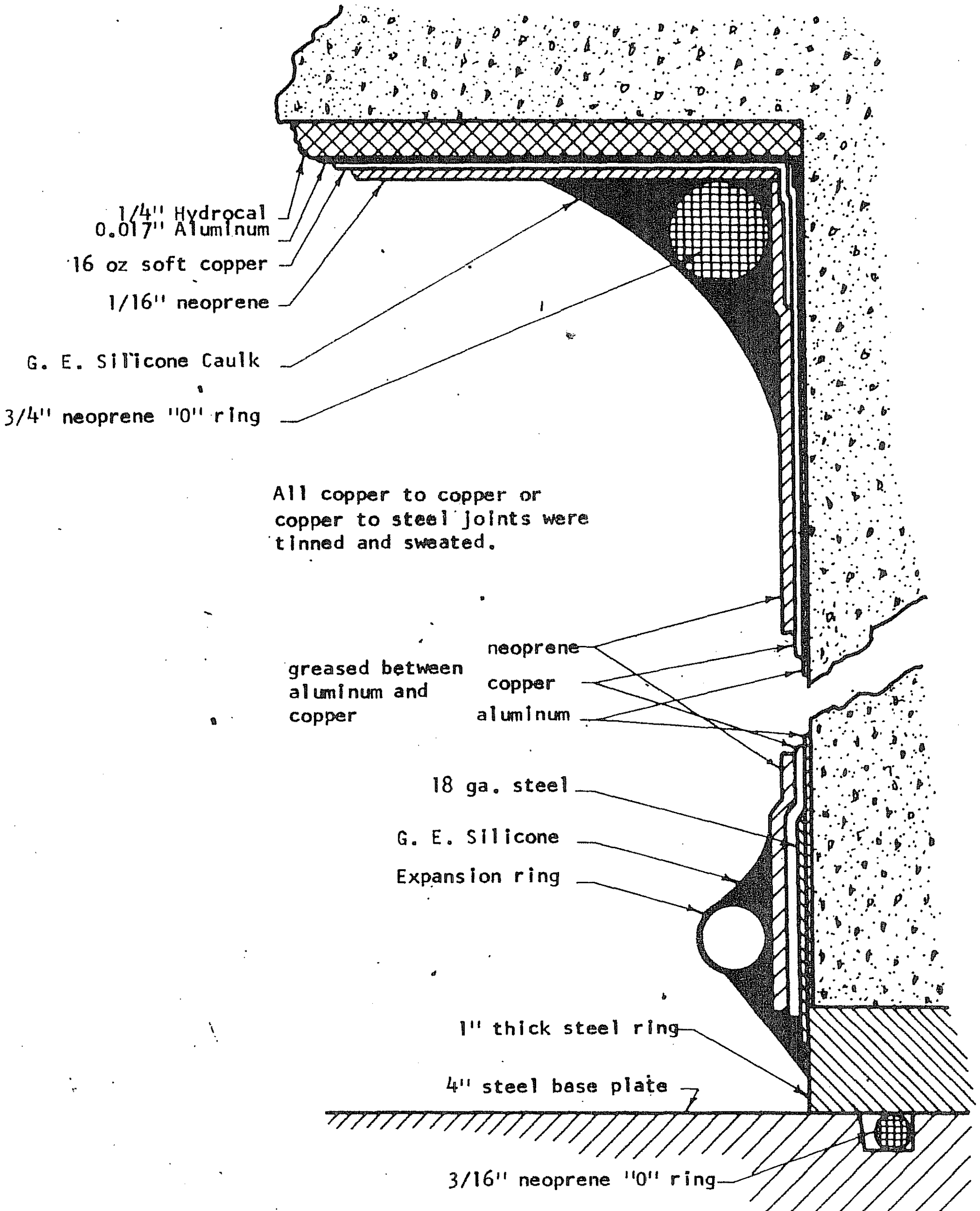


FIG. B12.1 SEALING DETAIL FOR PV12

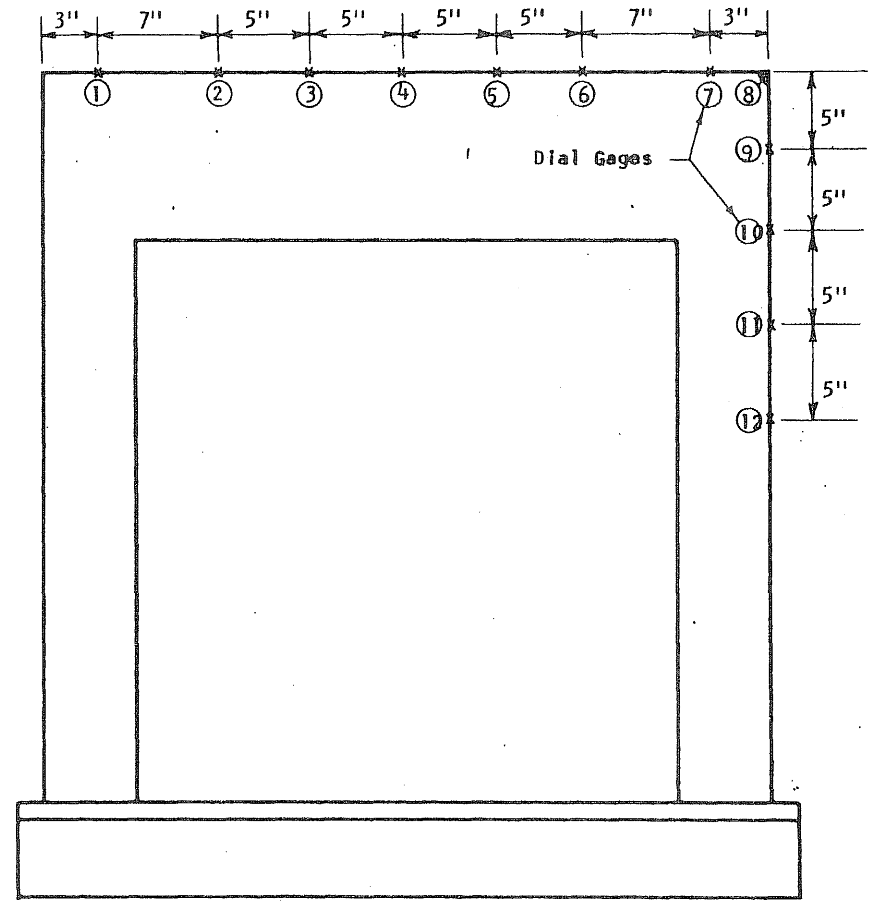


FIG. B12.2 LOCATION OF DEFLECTION GAGES ON PV12

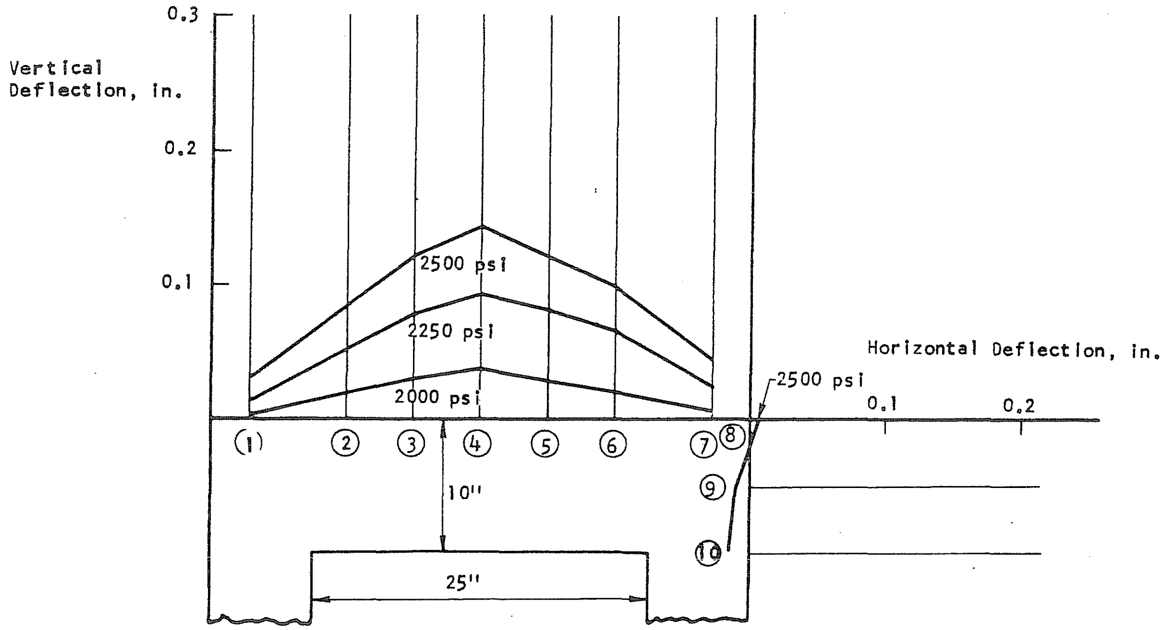


FIG. B12.3 DEFLECTION PROFILES OF THE END SLAB ALONG THE N-S DIAMETER OF PV12

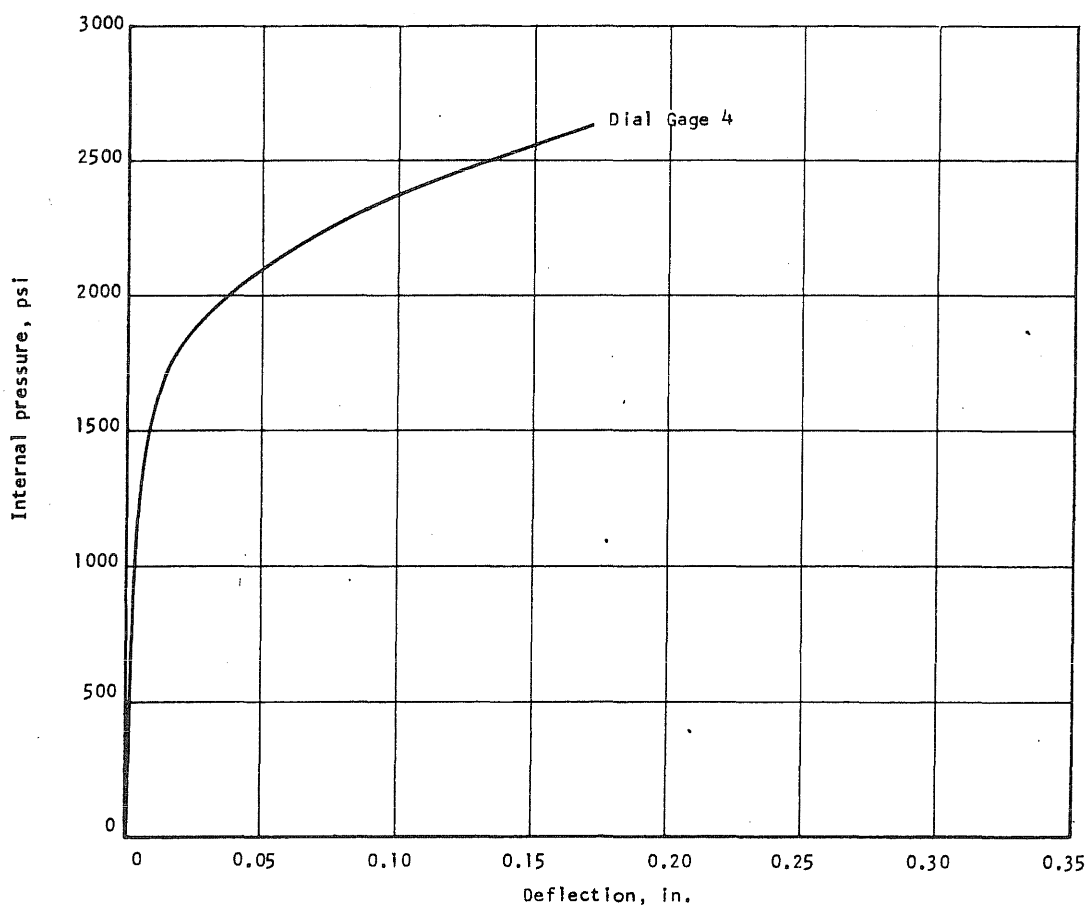
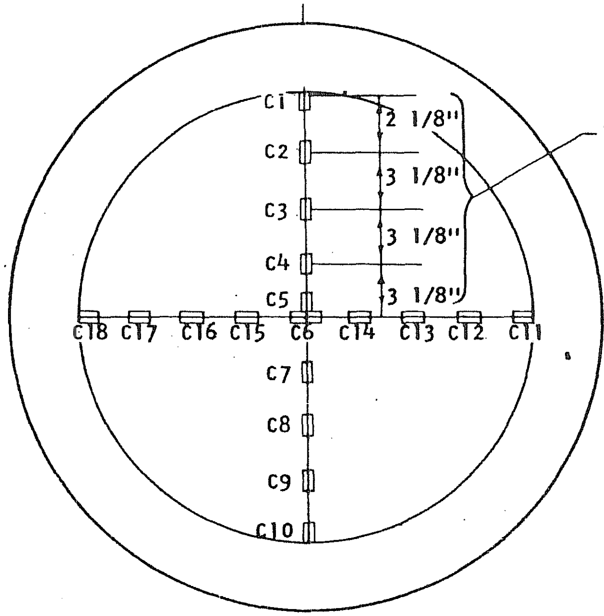
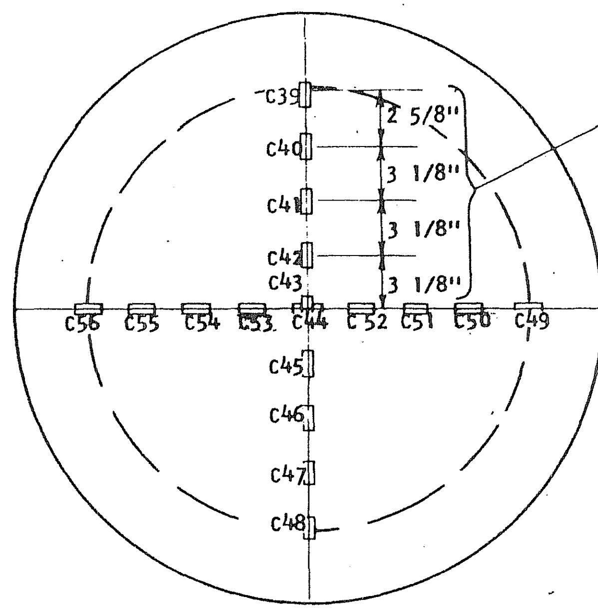


FIG. B12.4 APPLIED PRESSURE vs DEFLECTION AT MIDSPAN OF PV12

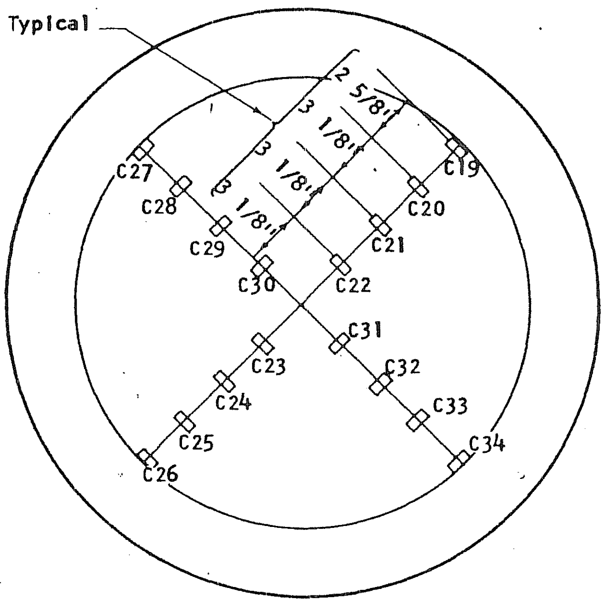
Concrete Gages on the Inside of the End Slab



Concrete gages on the Outside of the End Slab



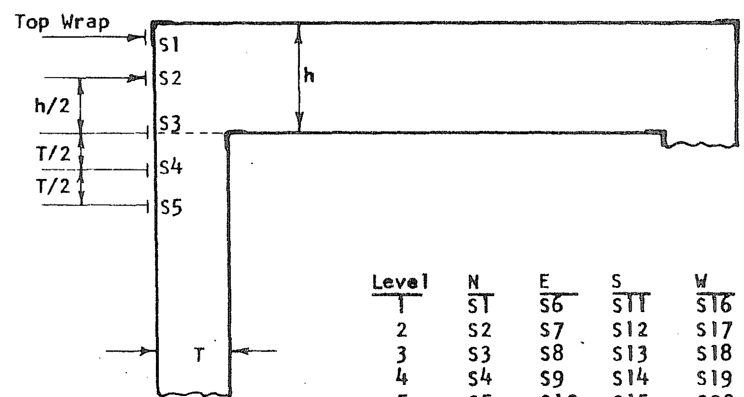
Gages to Measure Radial Strain



Gages to Measure Circumferential Strains

FIG. B12.5 STRAIN GAGE LOCATIONS ON PV12

Steel Gages on Circumferential Prestress Wire



Level	N	E	S	W
1	S1	S6	S11	S16
2	S2	S7	S12	S17
3	S3	S8	S13	S18
4	S4	S9	S14	S19
5	S5	S10	S15	S20

FIG. B12.5 (cont'd) STRAIN GAGE LOCATIONS ON PV12

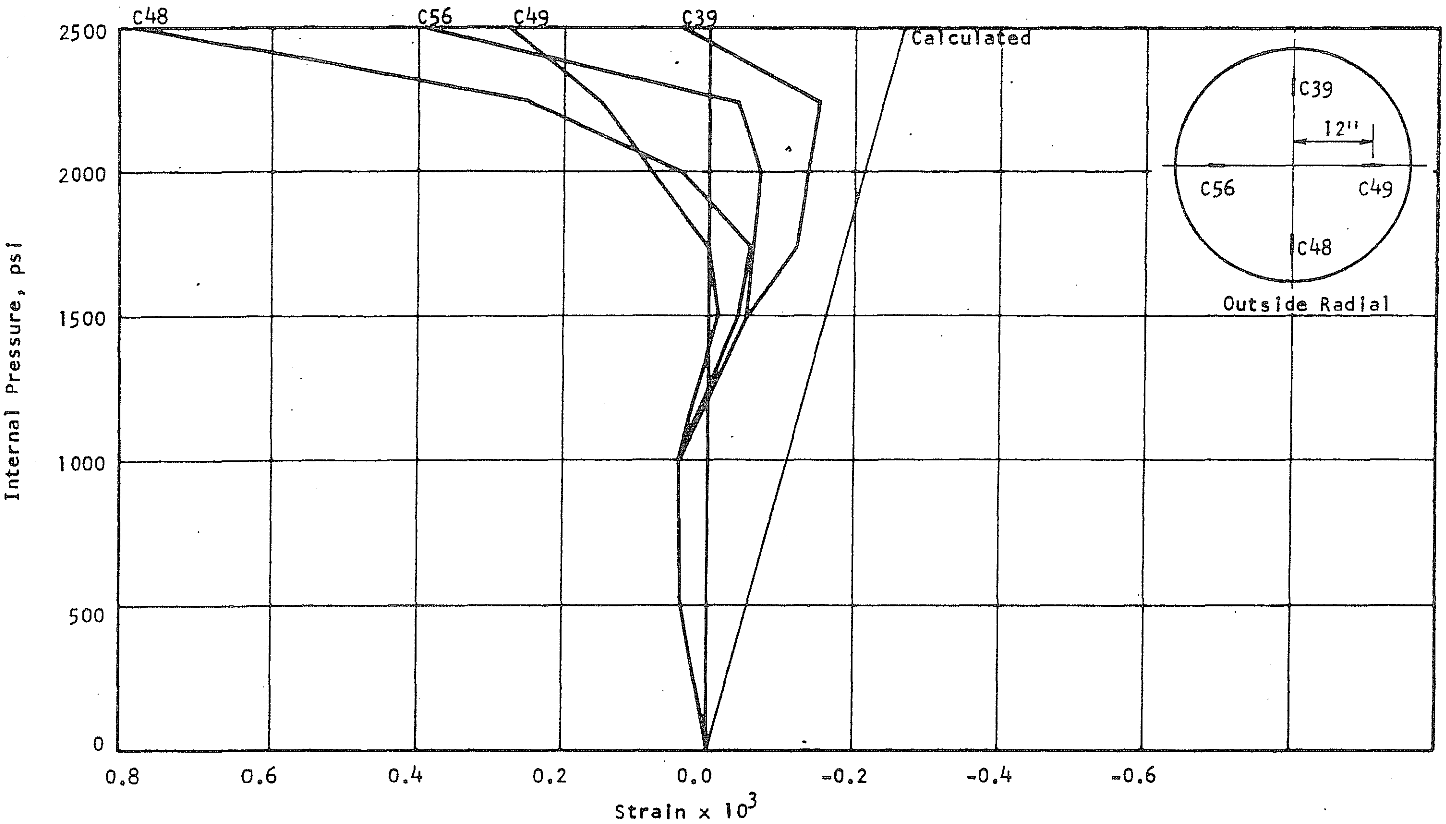


FIG. B12.6 CONCRETE STRAINS, VESSEL PV12

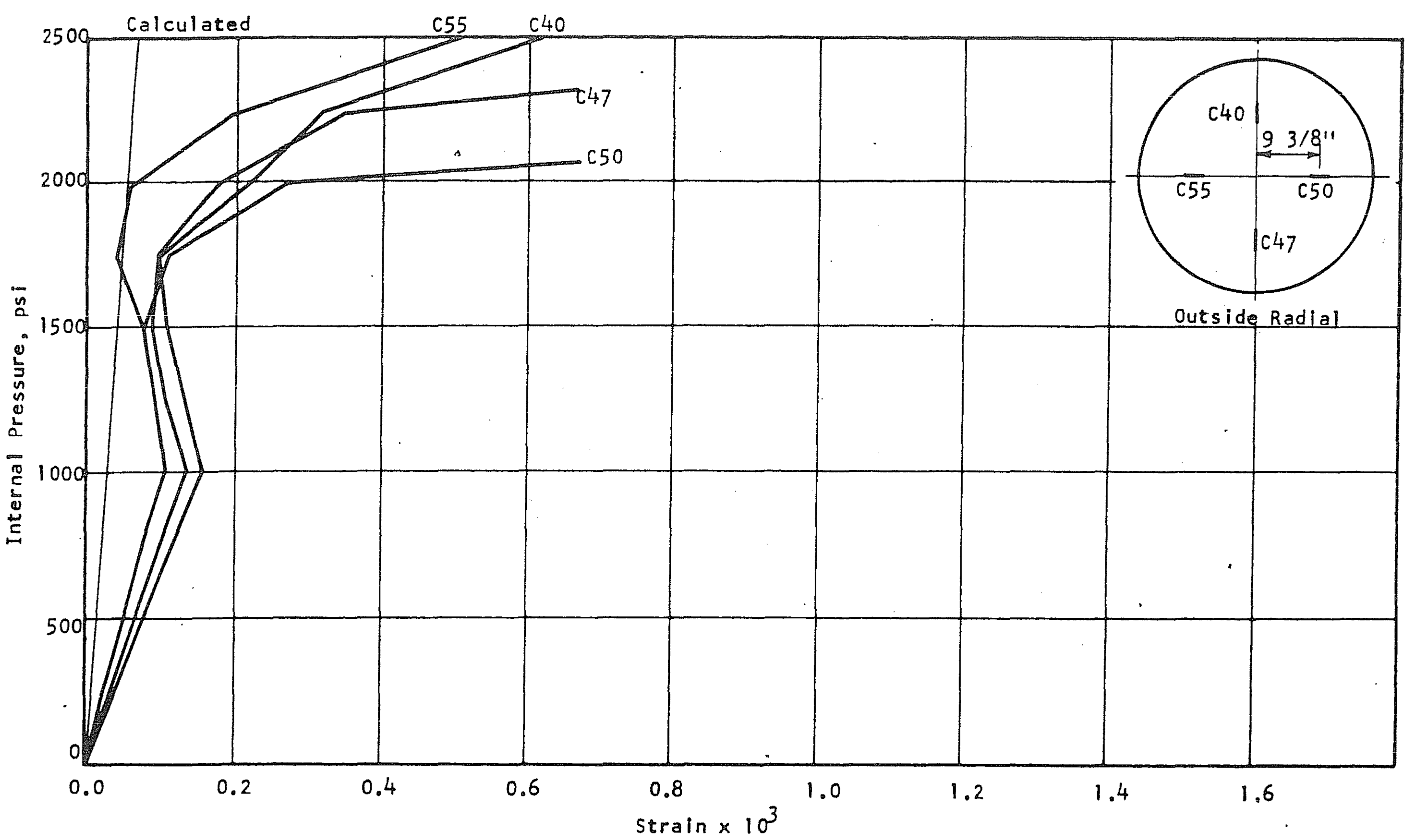


FIG. B12.6 (cont'd) CONCRETE STRAINS, VESSEL PV12

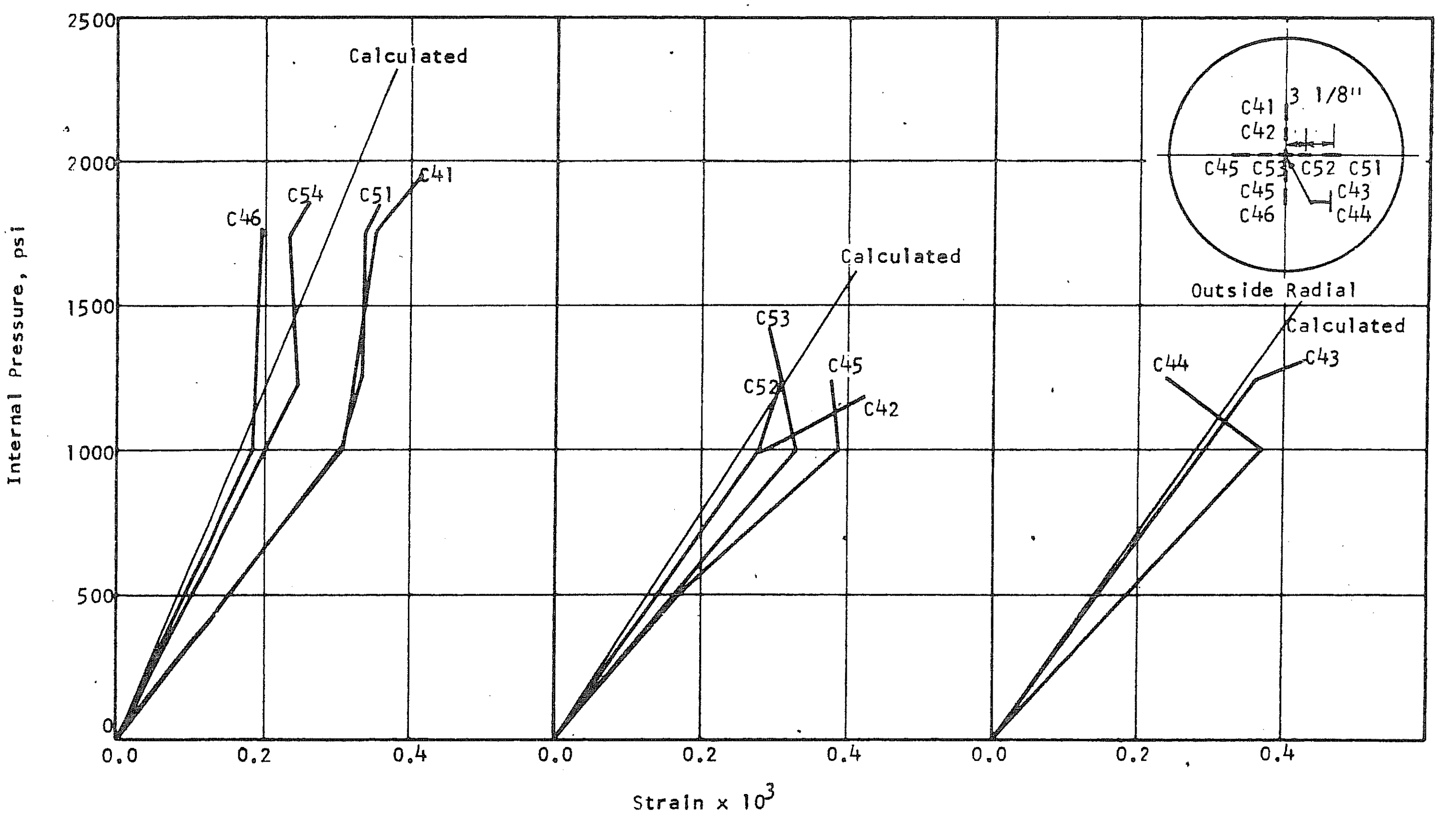


FIG. B12.6 (cont'd) CONCRETE STRAINS, VESSEL PV12

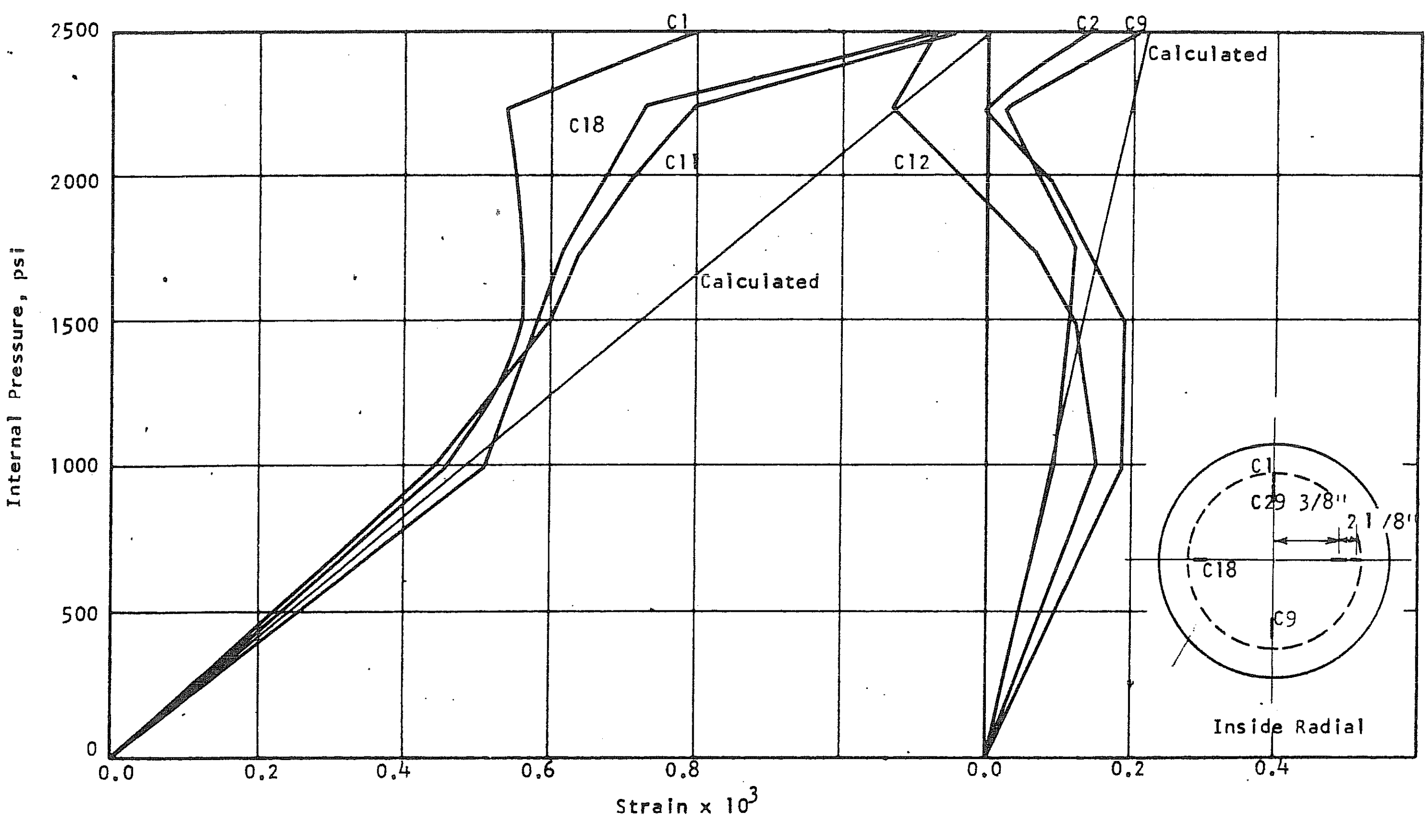


FIG. B12.7 CONCRETE STRAINS, VESSEL PV12

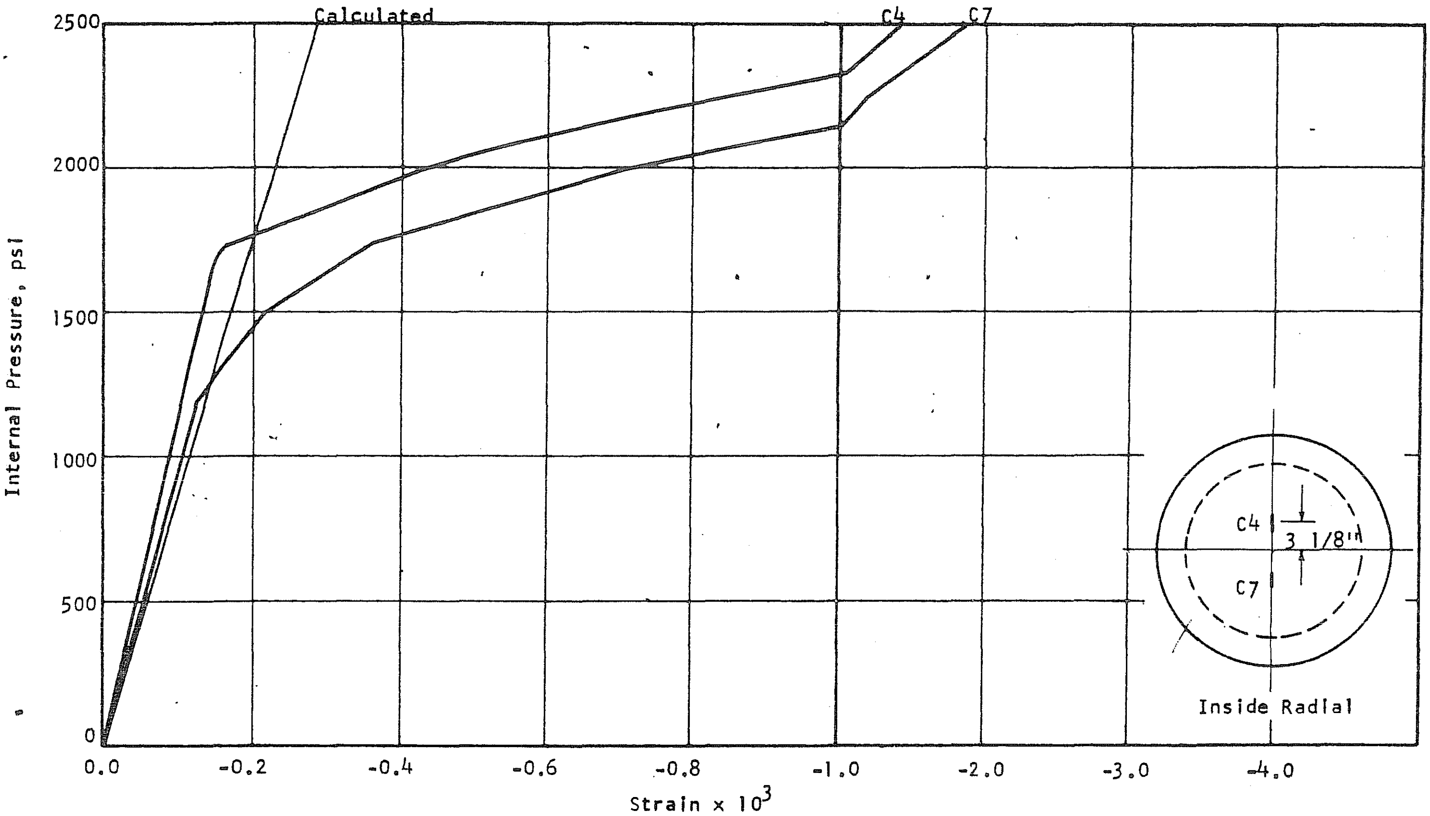


FIG. B12.7 (cont'd) CONCRETE STRAINS, VESSEL PV12

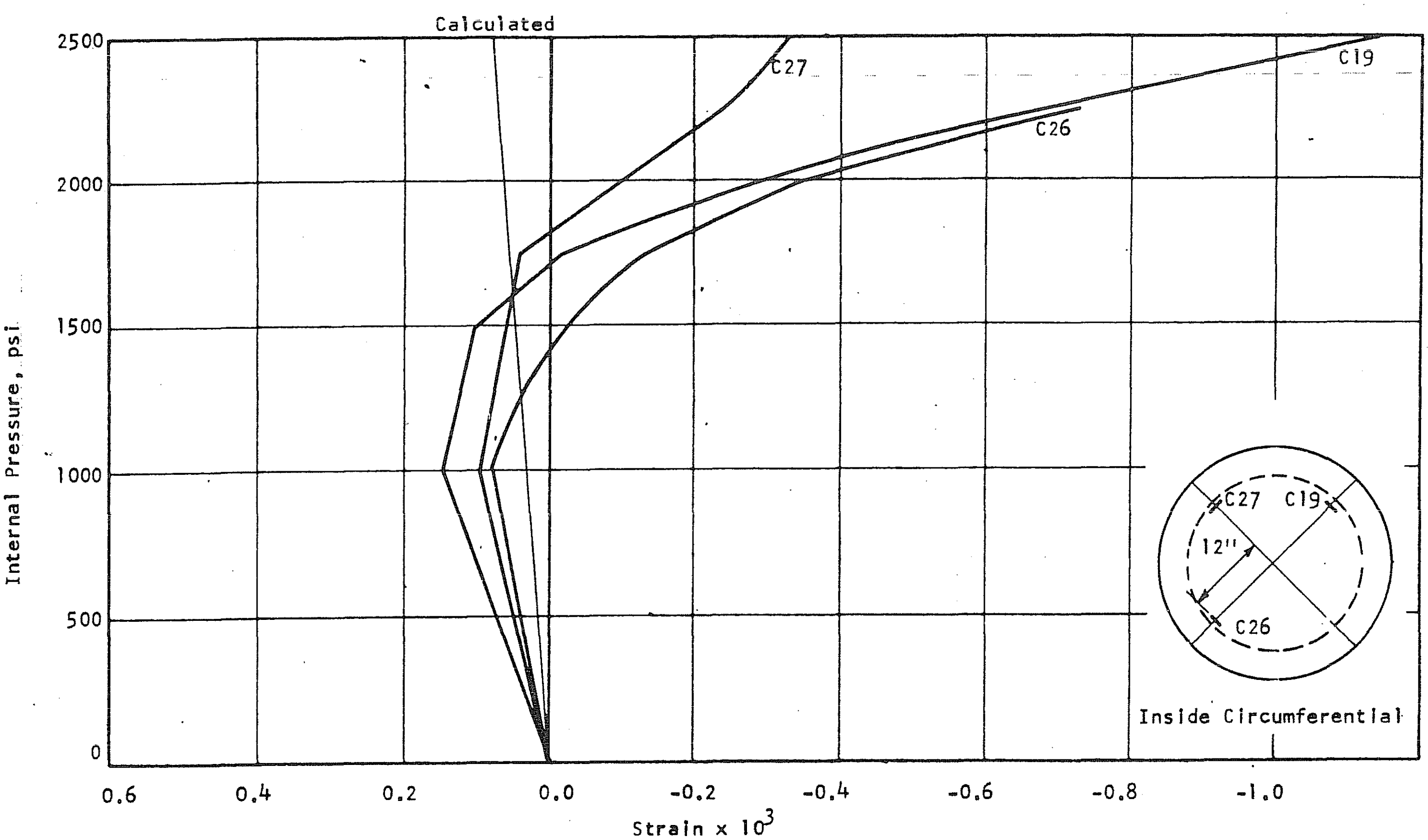


FIG. B12.8 CONCRETE STRAINS, VESSEL PV12

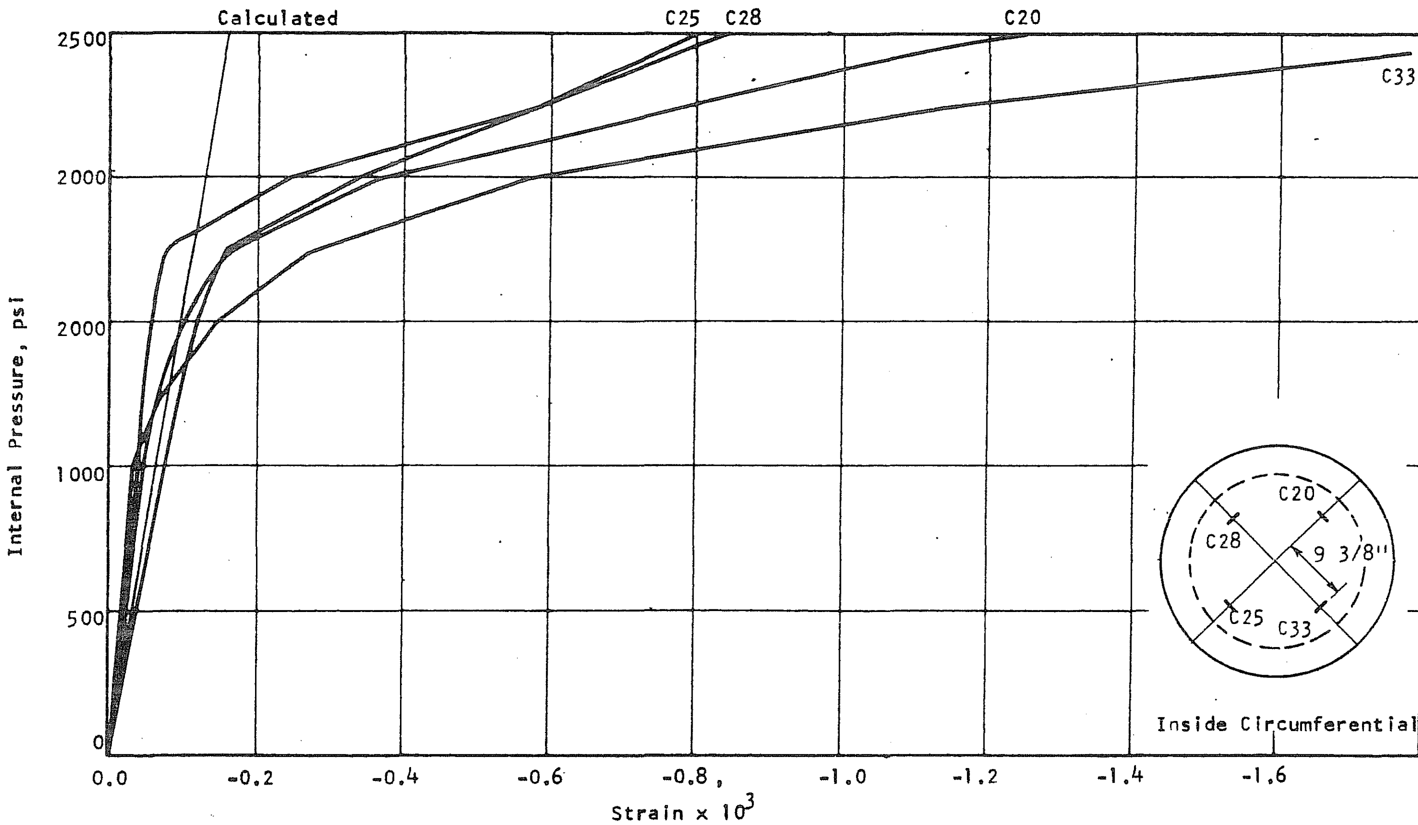


FIG. B12.8 (cont'd) CONCRETE STRAINS, VESSEL PV12

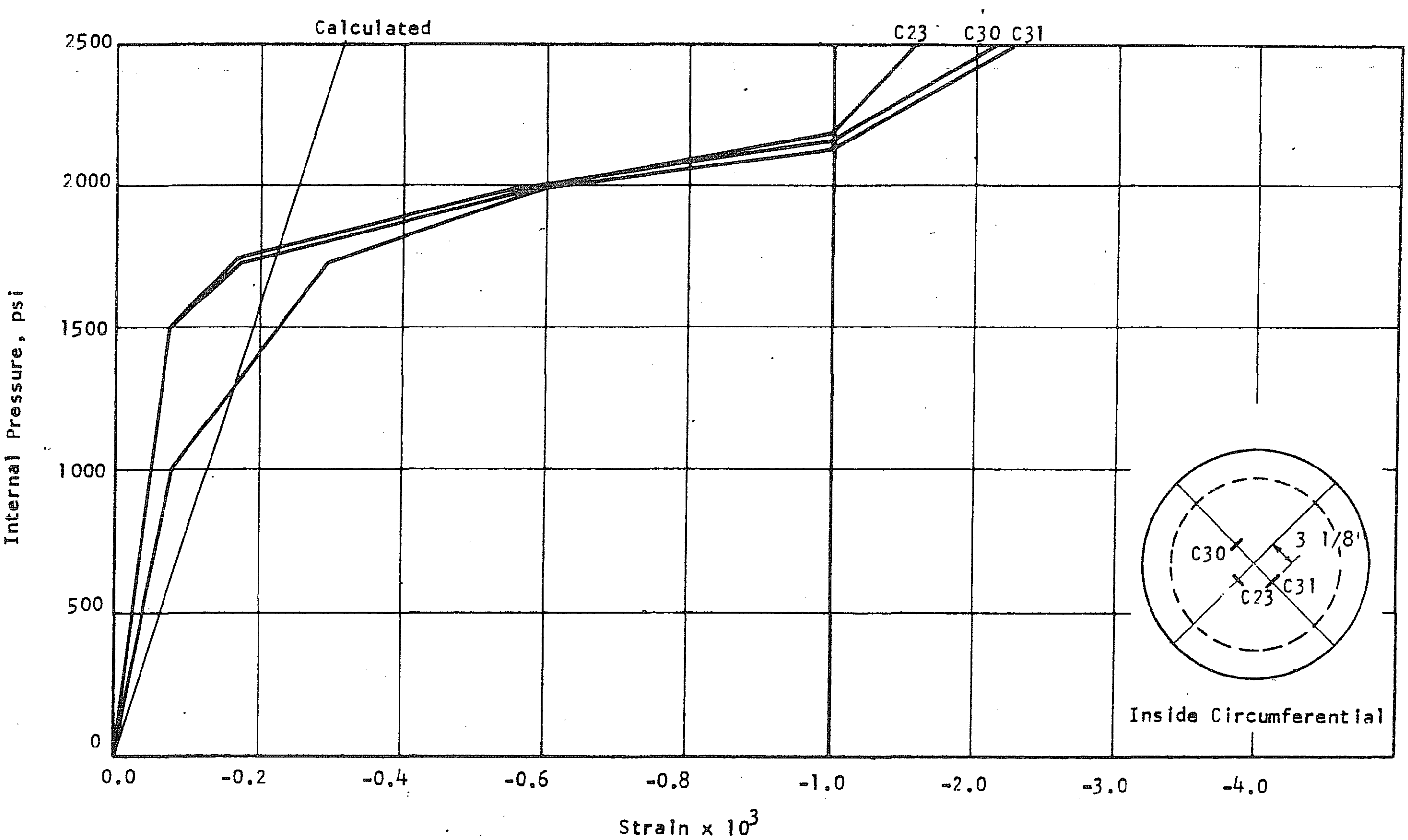


FIG. B12.8 (cont'd) CONCRETE STRAINS, VESSEL PV12

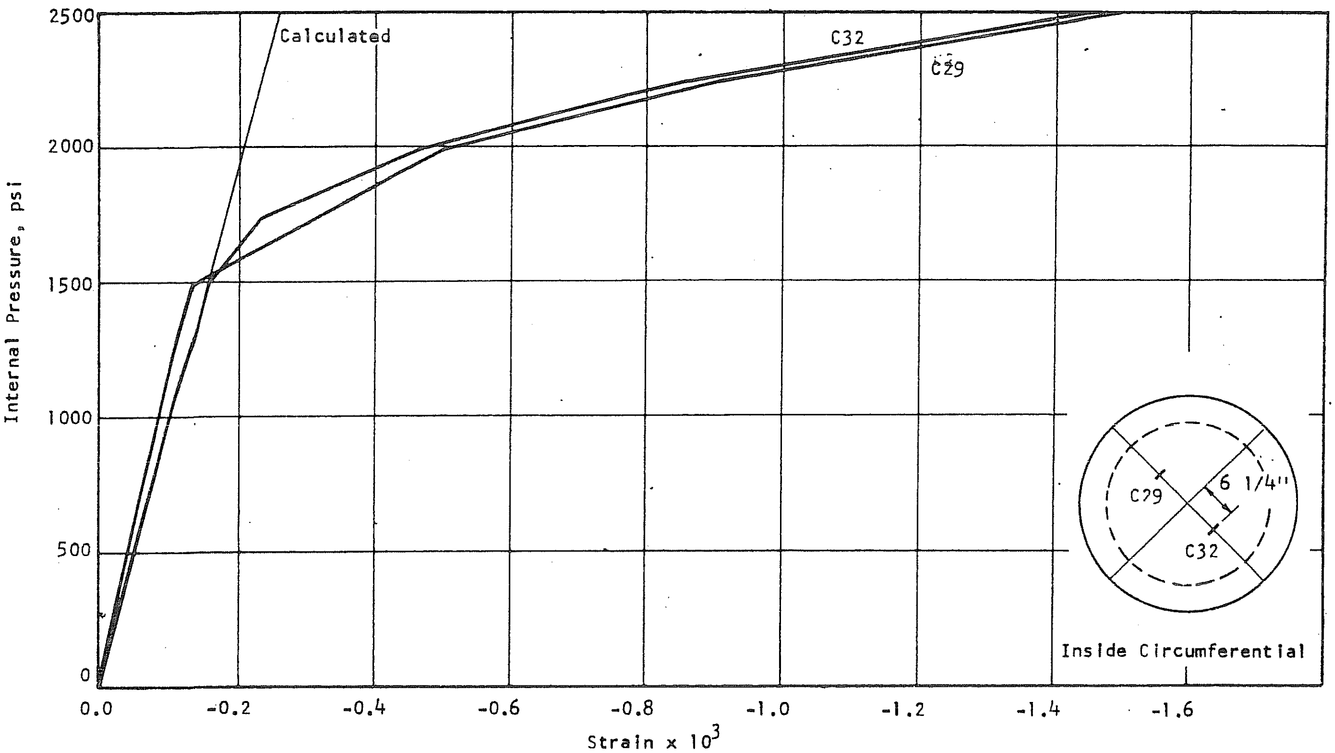
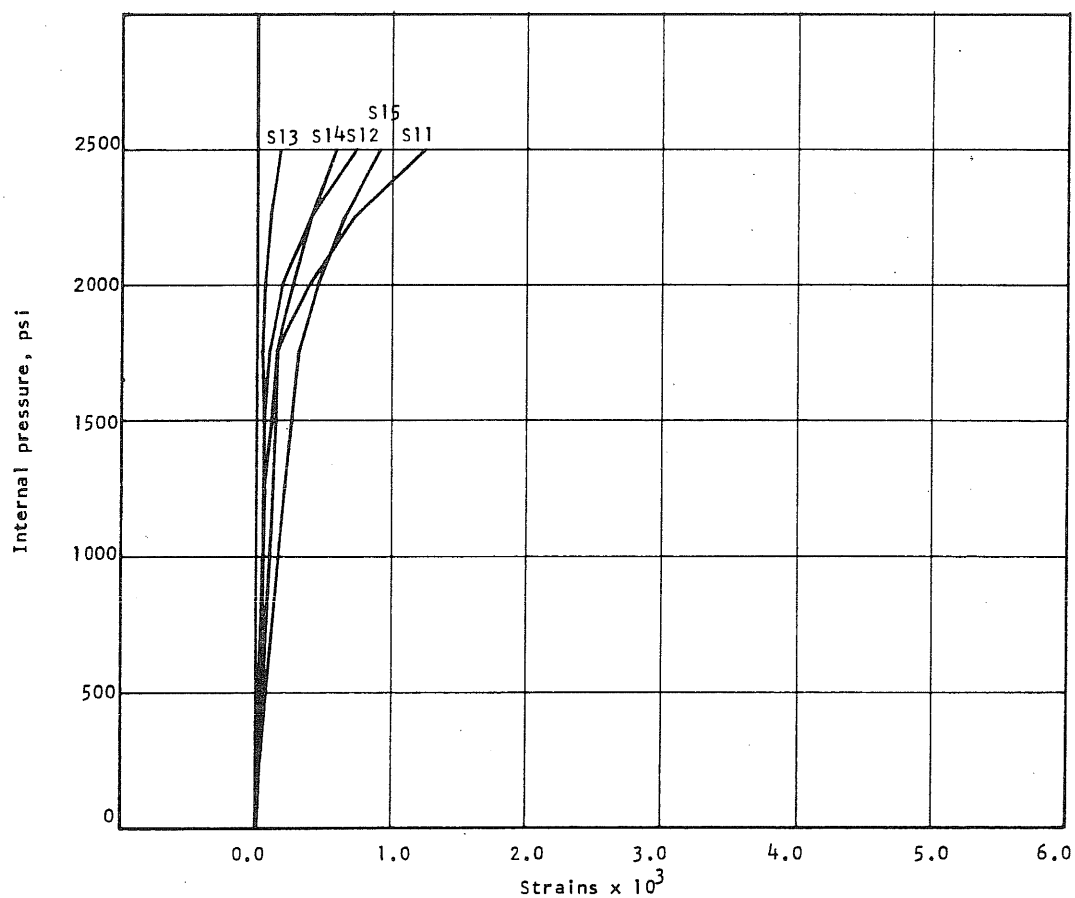
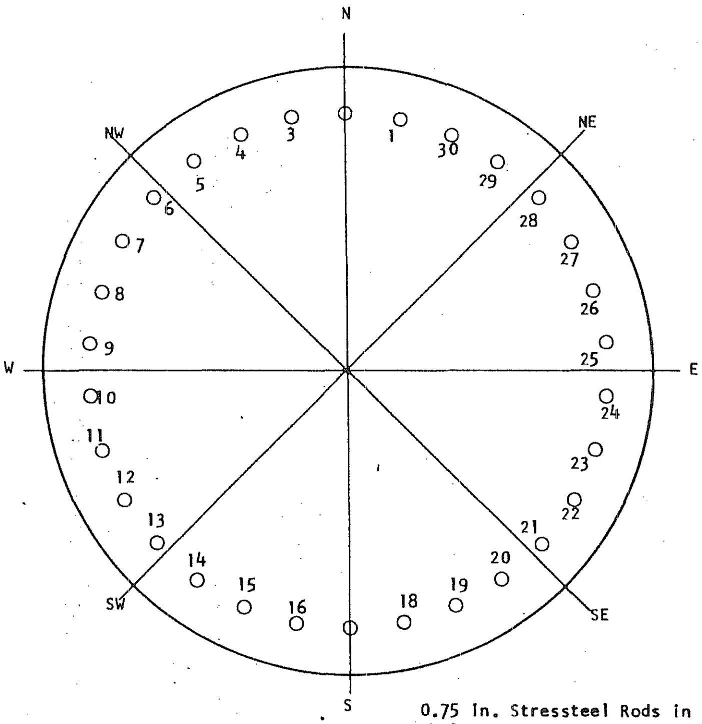


FIG. B12.8 (cont'd) CONCRETE STRAINS, VESSEL PV12



FIB. B12.9 APPLIED PRESSURE vs STRAINS IN CIRCUMFERENTIAL PRESTRESS WIRE AT THE S-END OF THE N-S DIAMETER OF PV12



0.75 in. Stressteel Rods in all holes

Numbered Rods are gaged to measure increase in load

FIG. 12.10 LOCATION OF LONGITUDINAL REINFORCEMENT

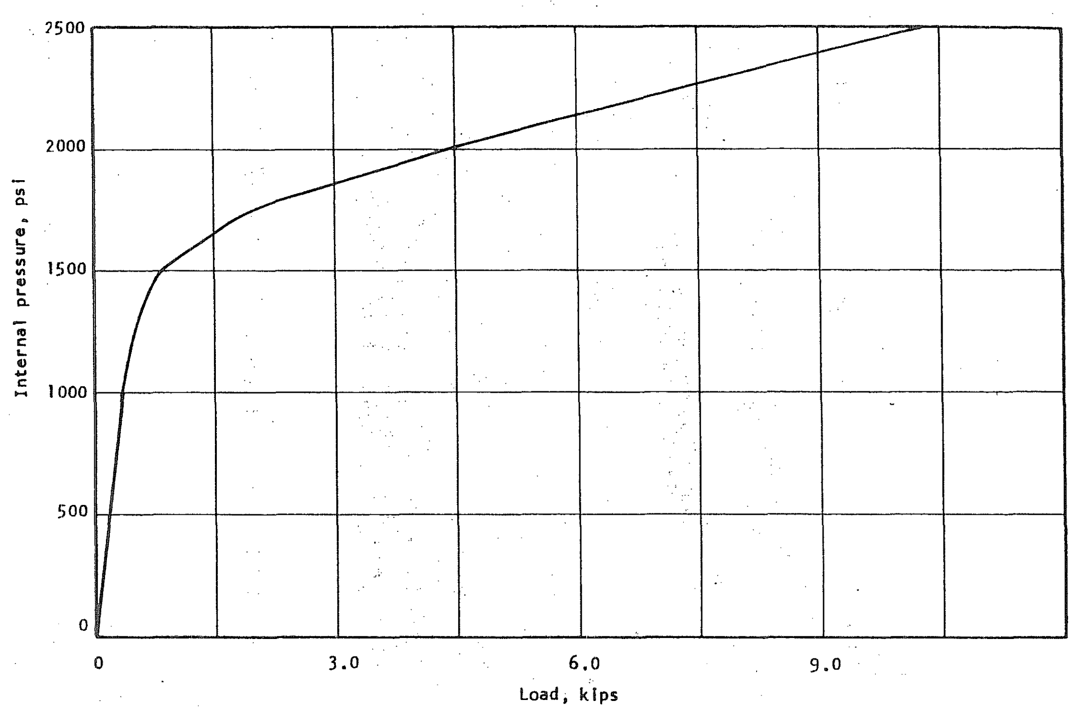


FIG. B12.11 APPLIED PRESSURE vs INCREASE IN LOAD IN STRESSTEEL ROD NO. 22

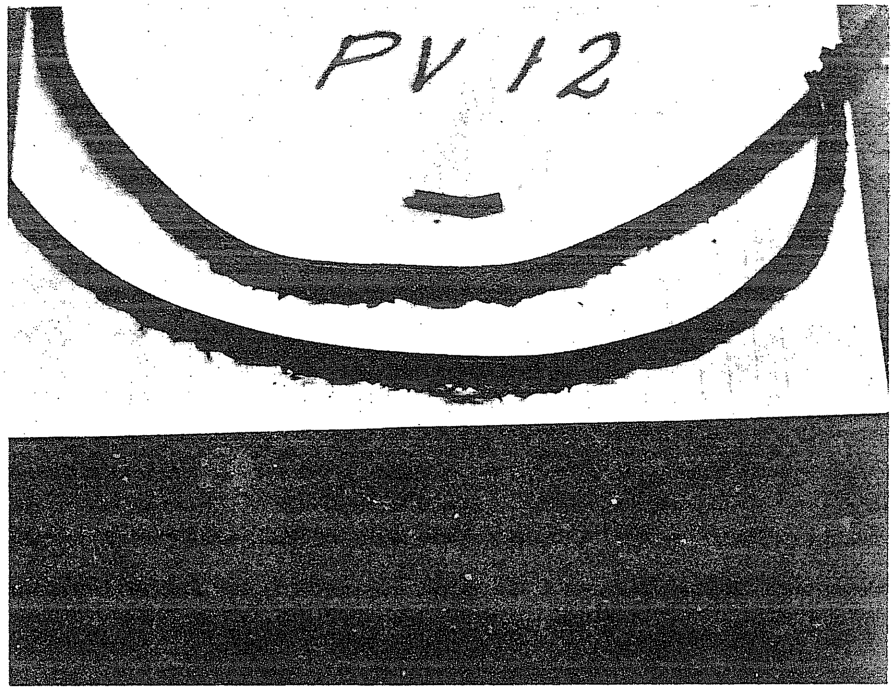


FIG. B12.12a EXTRUDED O-RING AFTER TEST

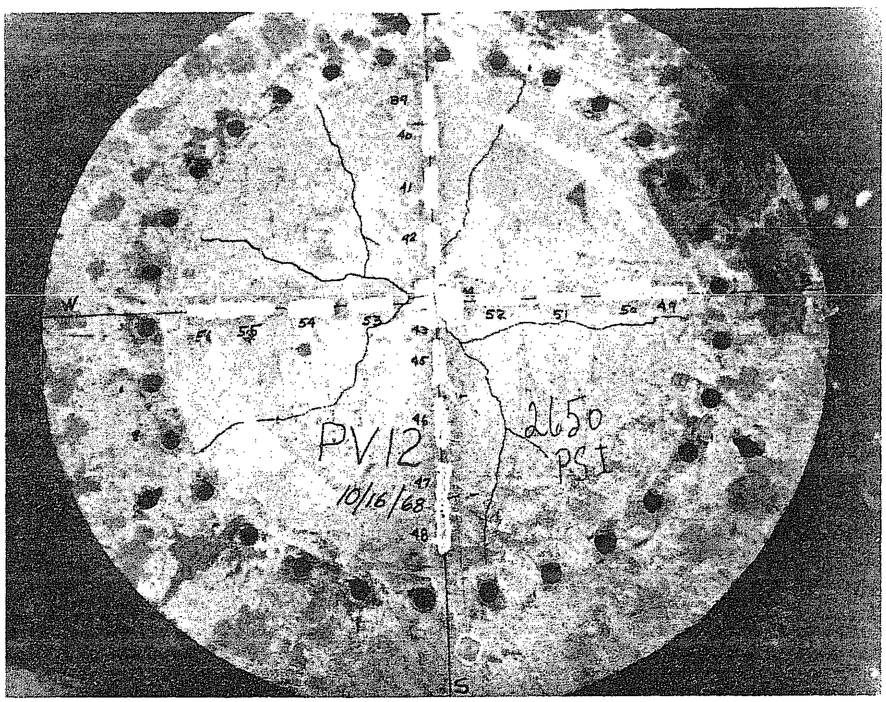


FIG. B12.12b END SLAB AFTER TEST OF PV12

B13 Test Vessel PV13 (t = 12.5 in., s = 1/4 in.)

This vessel was provided with an additional row of longitudinal reinforcement (Fig. 1.2). To accommodate the second row of reinforcement, two donut shaped plates of 1 1/4-in. thick steel were cut and drilled for two circles of rods. Centerlines of the rod circles were at diameters of 29 in. and 43-3/8 in. The inner diameter of the plate was 26 in. and the outer diameter was 45 in. One plate was placed on top of the specimen and one below the four-in. steel closure plate. The plate on the top was bedded in Hydrocal to provide a smooth bearing surface. Longitudinal prestressing was provided with 60 stressteel rods. Figure B13.10 shows PV13 in the test shed before the test.

A detail of the liner is shown in Fig. B13.1 and is basically the same as for PV12 except that two expansion ridges were formed into the copper liner near the joint with the end slab piece.

The vessel was tested with nitrogen gas and reached a pressure of 3450 psi before the seal between the base plate and one-in. seal ring was lost. (After testing PV12, 6000-psi gas bottles were used.) After the vessel was taken apart, the O-ring in the closure plate was found to be feathered as in PV12. Radial cracks were visible in the end of the side wall. Twenty-three of the rod holes had cracks running through them. These cracks were visible for about 10 to 15 in. up the side wall. There were 3 rings of circumferential cracks at about 12 in., 18 in., and 23 in. from the base of the side wall on the inside. The dial gages on the top of the vessel did not record any significant deflections. Gage 12, located 17.5 in. from the base, indicated a deflection of 0.158 in. at failure. Deflection-pressure curves and deflection profiles are therefore not shown for this test.

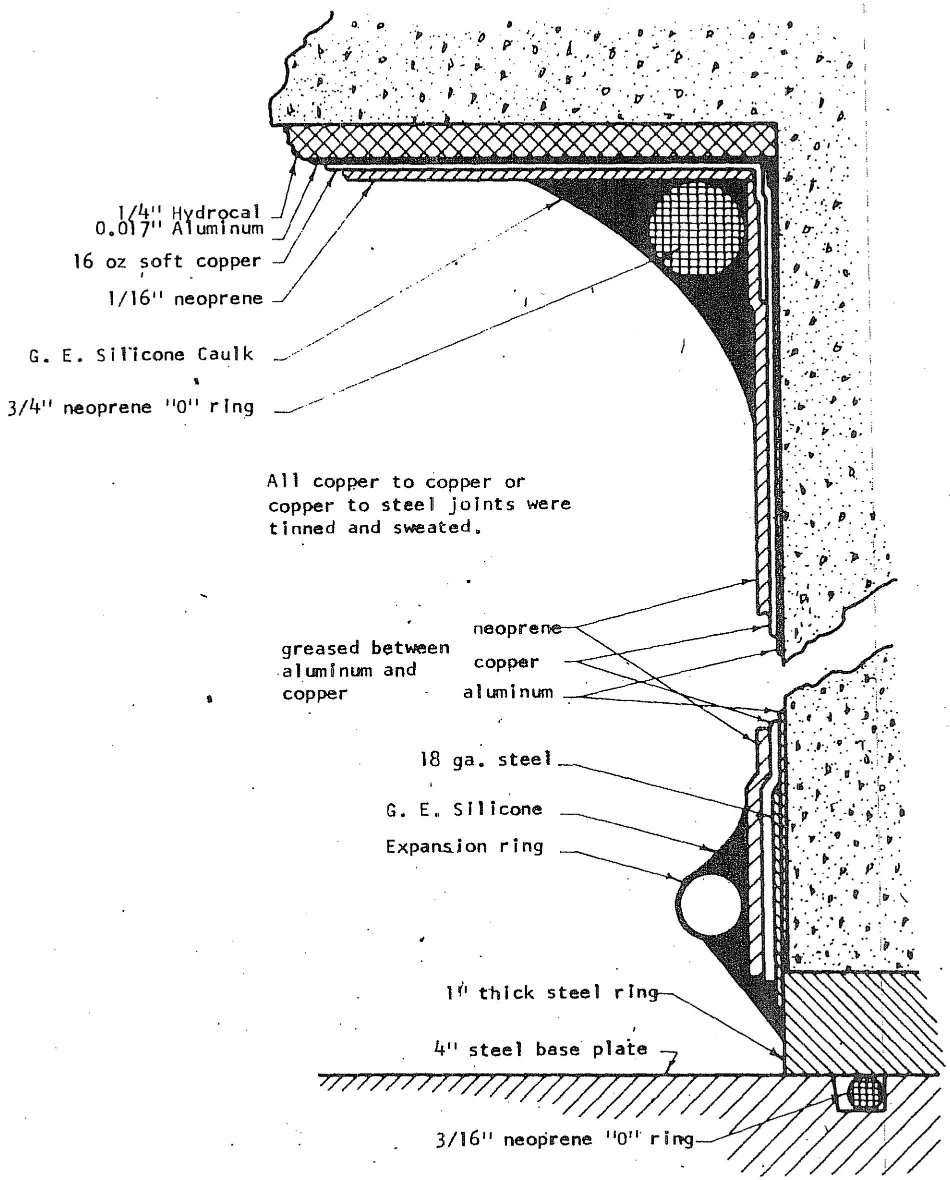


FIG. B13.1 SEALING DETAIL FOR PV13

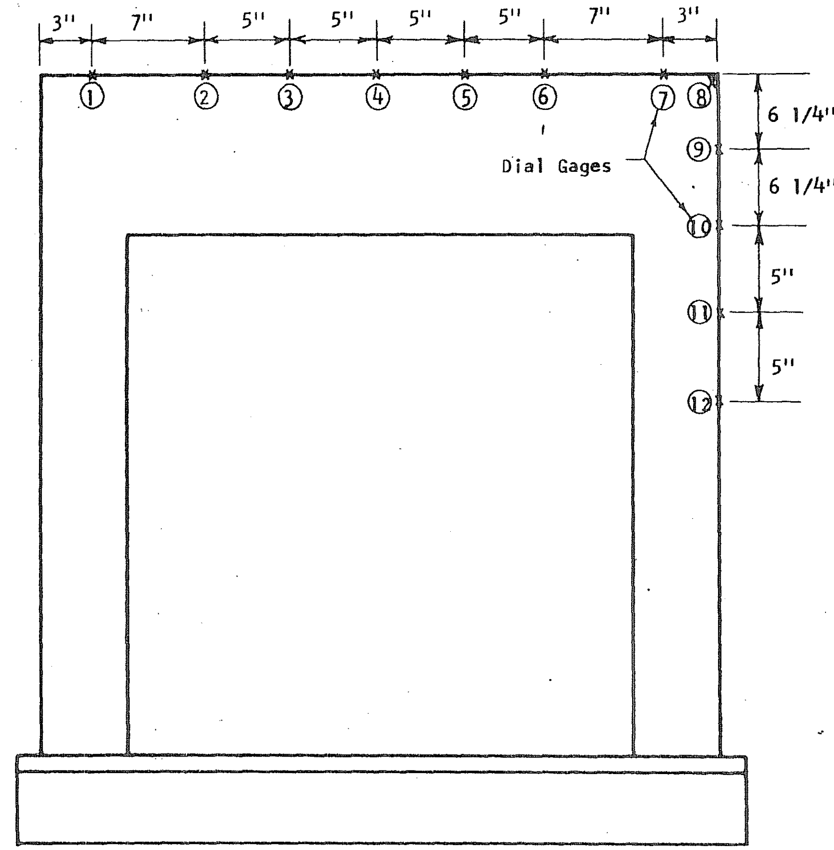


FIG. B13.2 LOCATION OF DEFLECTION GAGES ON PV13

Concrete Gages on the Inside of the End Slab

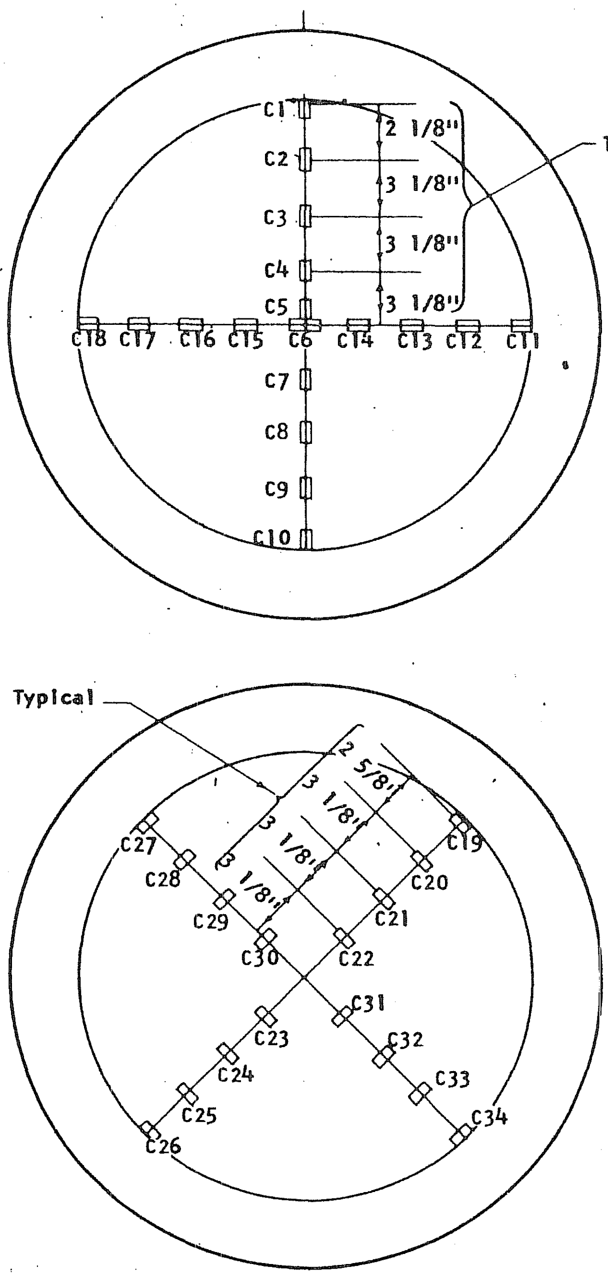
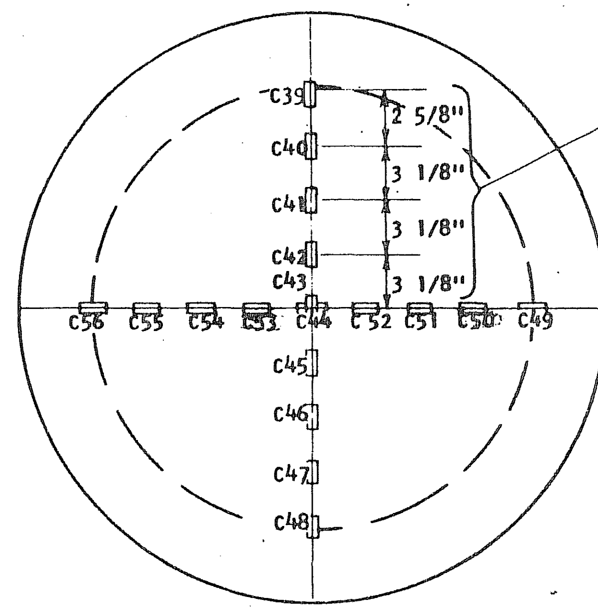
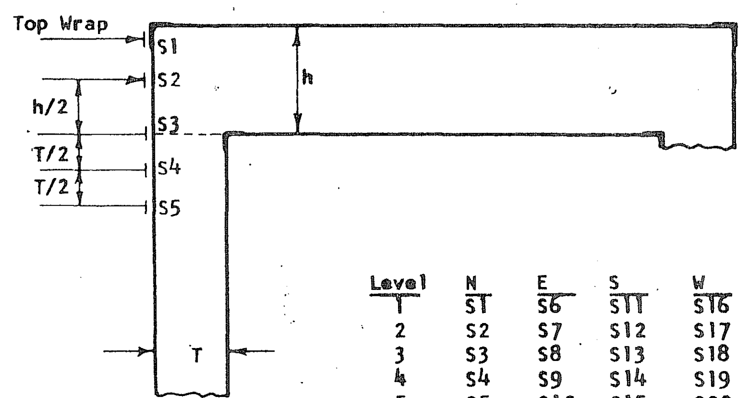


FIG. B13.3 STRAIN GAGE LOCATIONS ON PV13

Concrete gages on the Outside of the End Slab



Steel Gages on Circumferential Prestress Wire



Level	N	E	S	W
1	S1	S6	S11	S16
2	S2	S7	S12	S17
3	S3	S8	S13	S18
4	S4	S9	S14	S19
5	S5	S10	S15	S20

FIG. B13.3 (cont'd) STRAIN GAGE LOCATIONS ON PV13

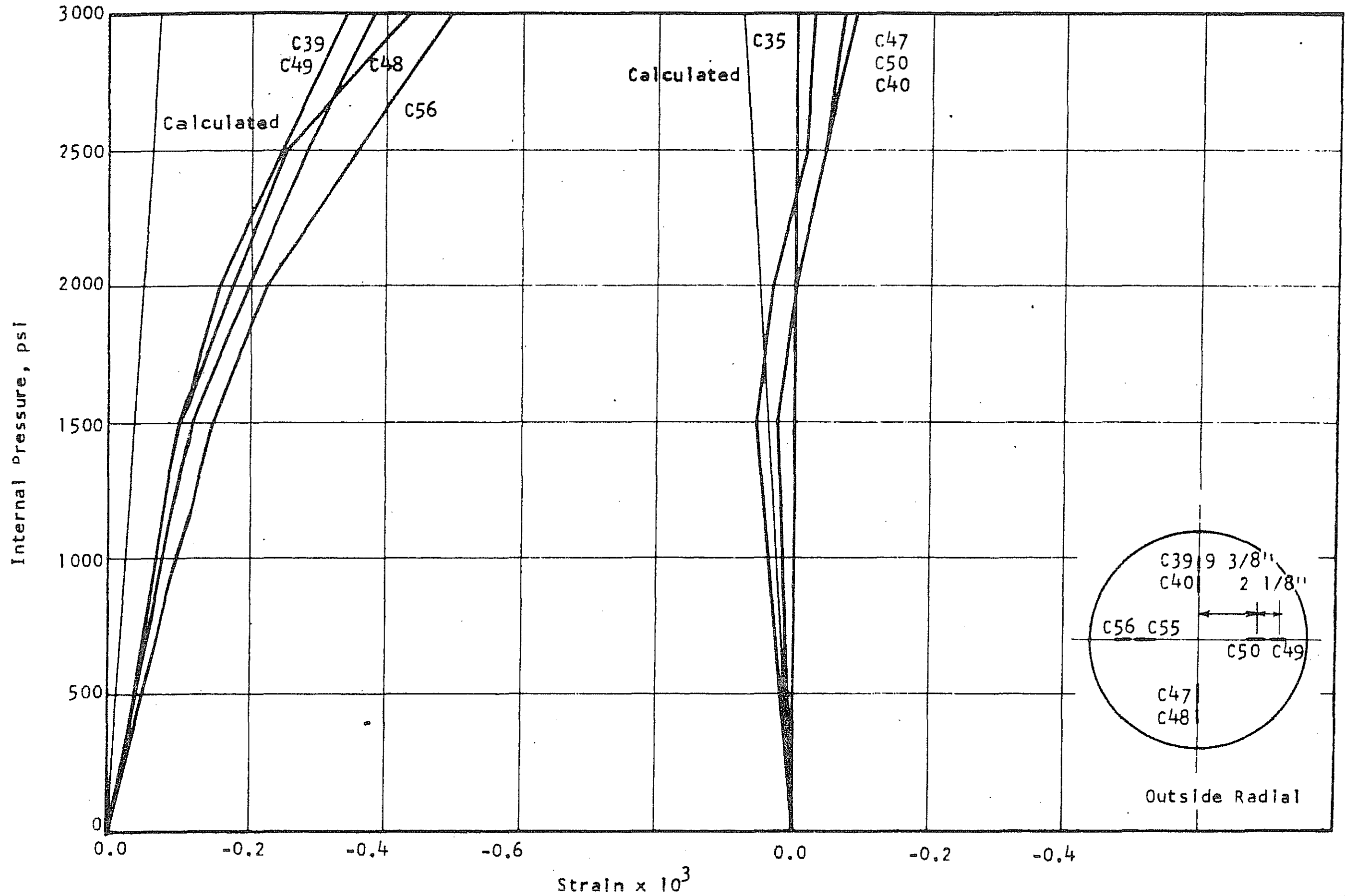


FIG. B13.4 CONCRETE STRAINS, VESSEL PV13

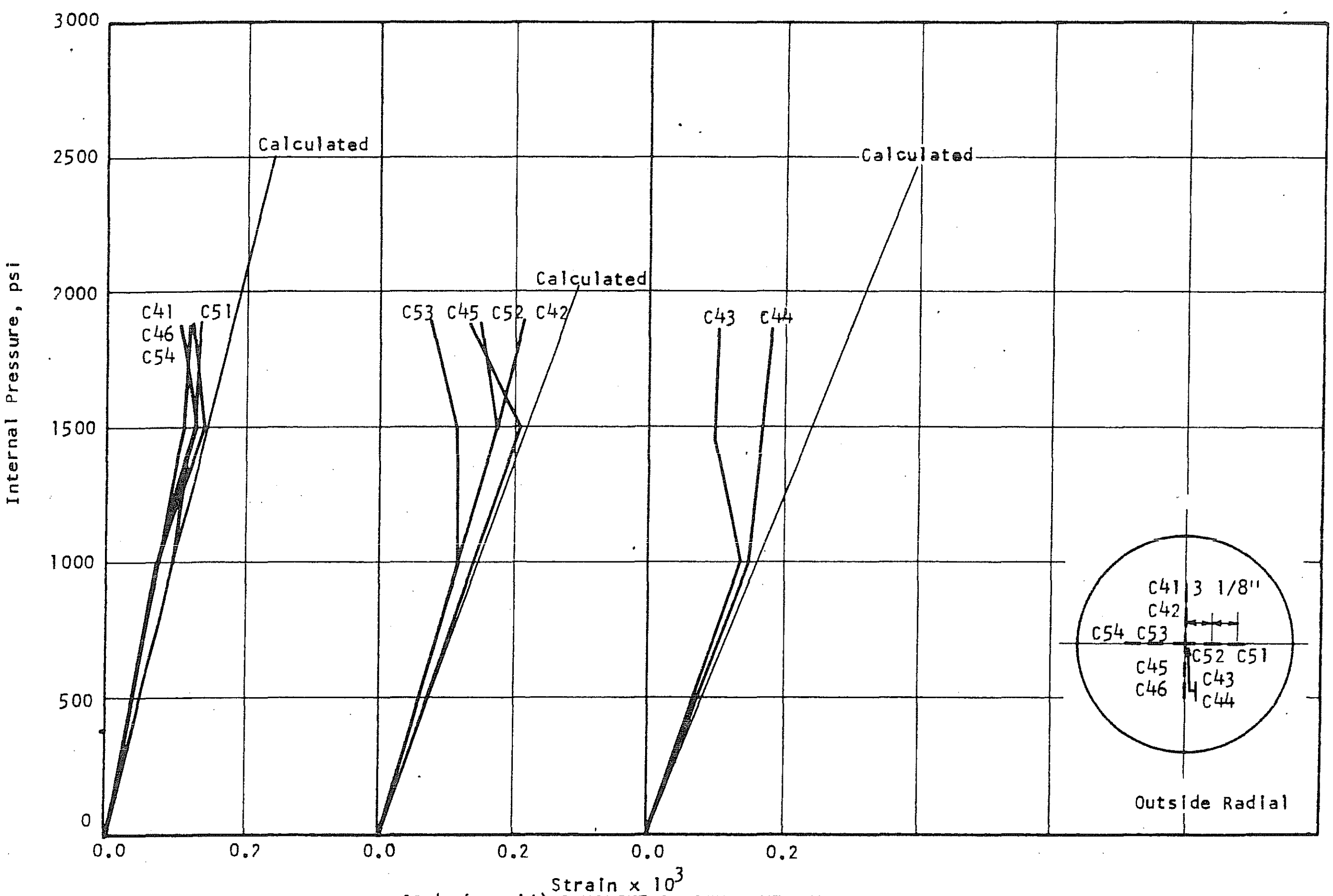


FIG. B13.4 (cont'd) CONCRETE STRAINS, VESSEL PV13

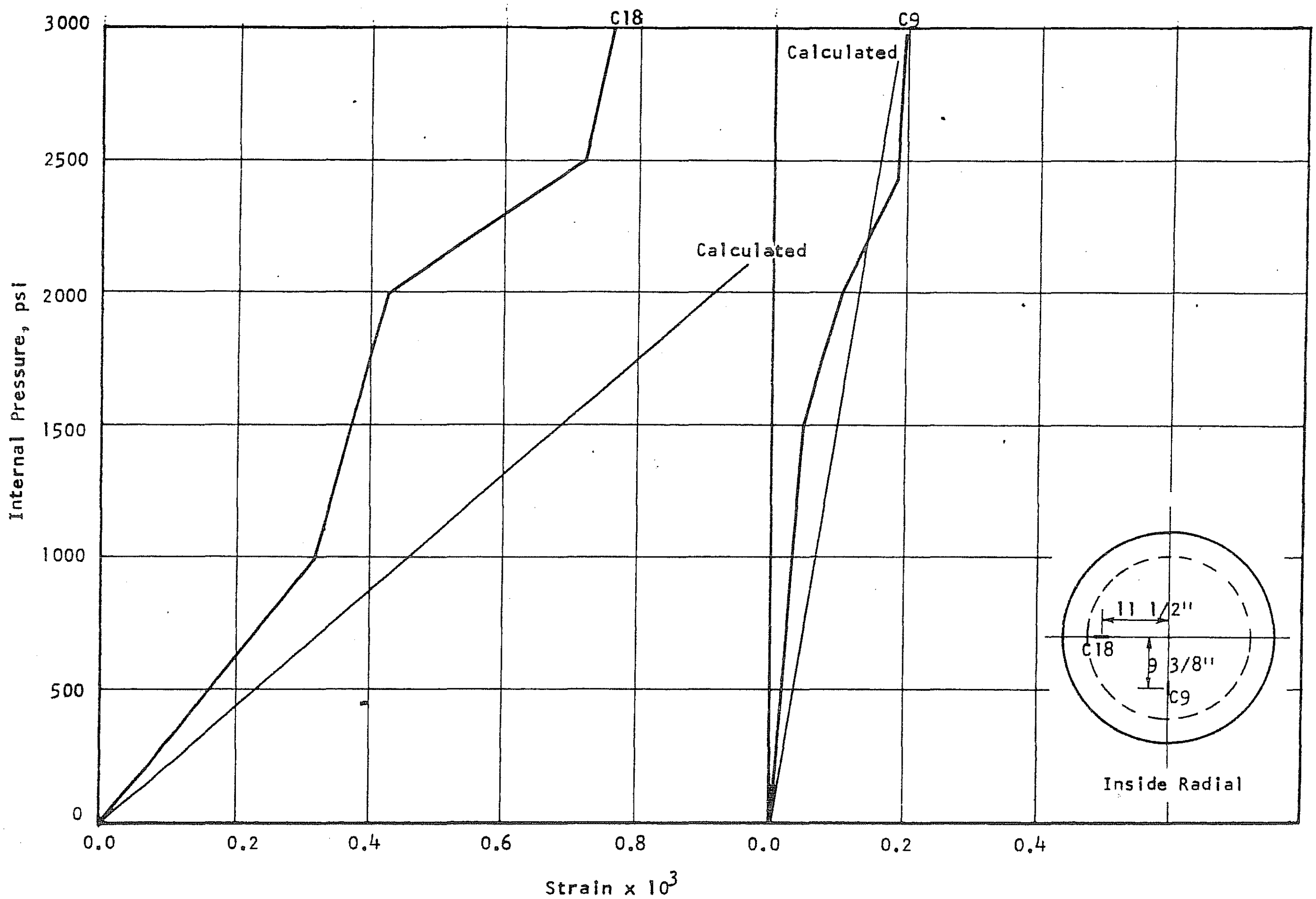


FIG. B13.5 CONCRETE STRAINS, VESSEL PV13

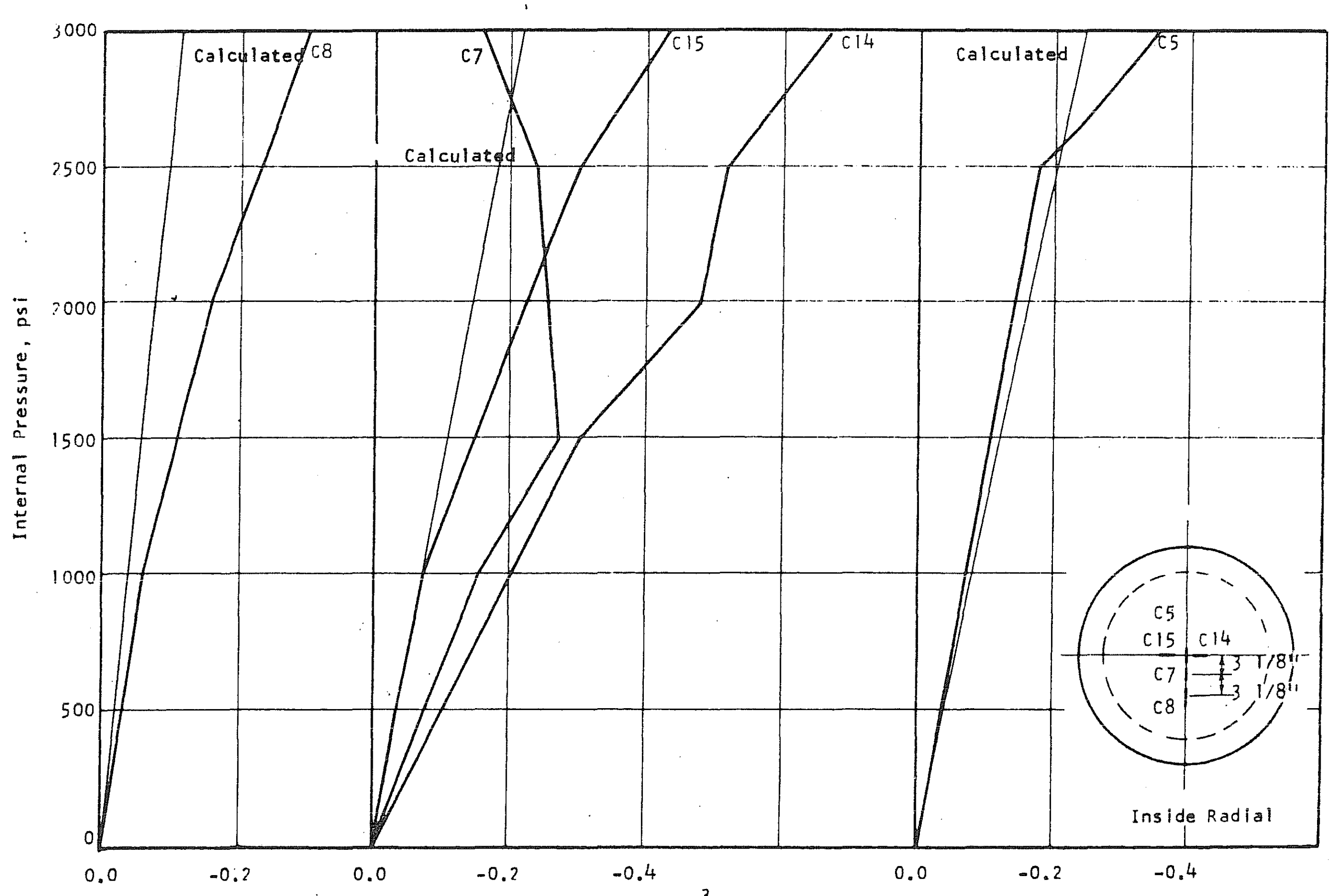


FIG. B13.5 (cont'd) CONCRETE STRAINS, VESSEL PV13

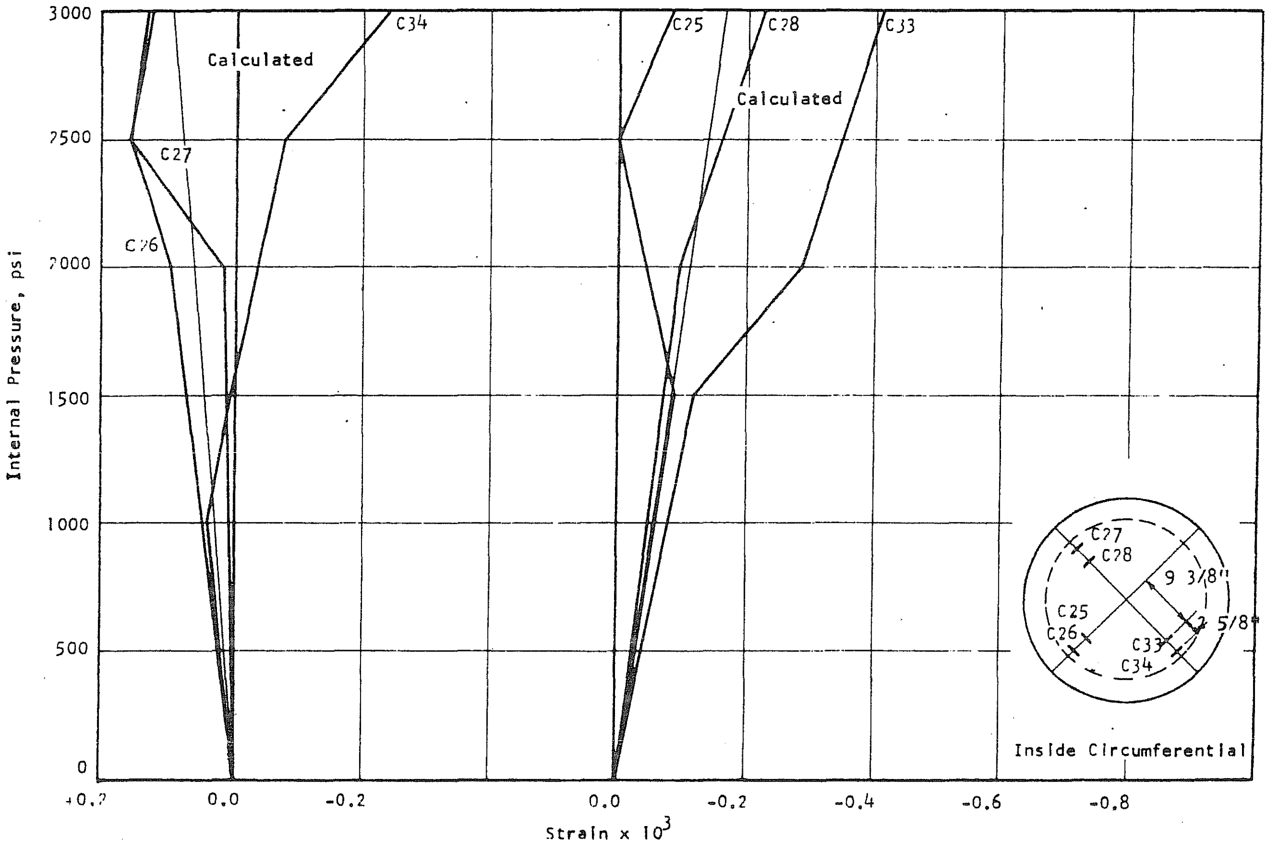


FIG. B13.6 CONCRETE STRAINS, VESSEL PV13

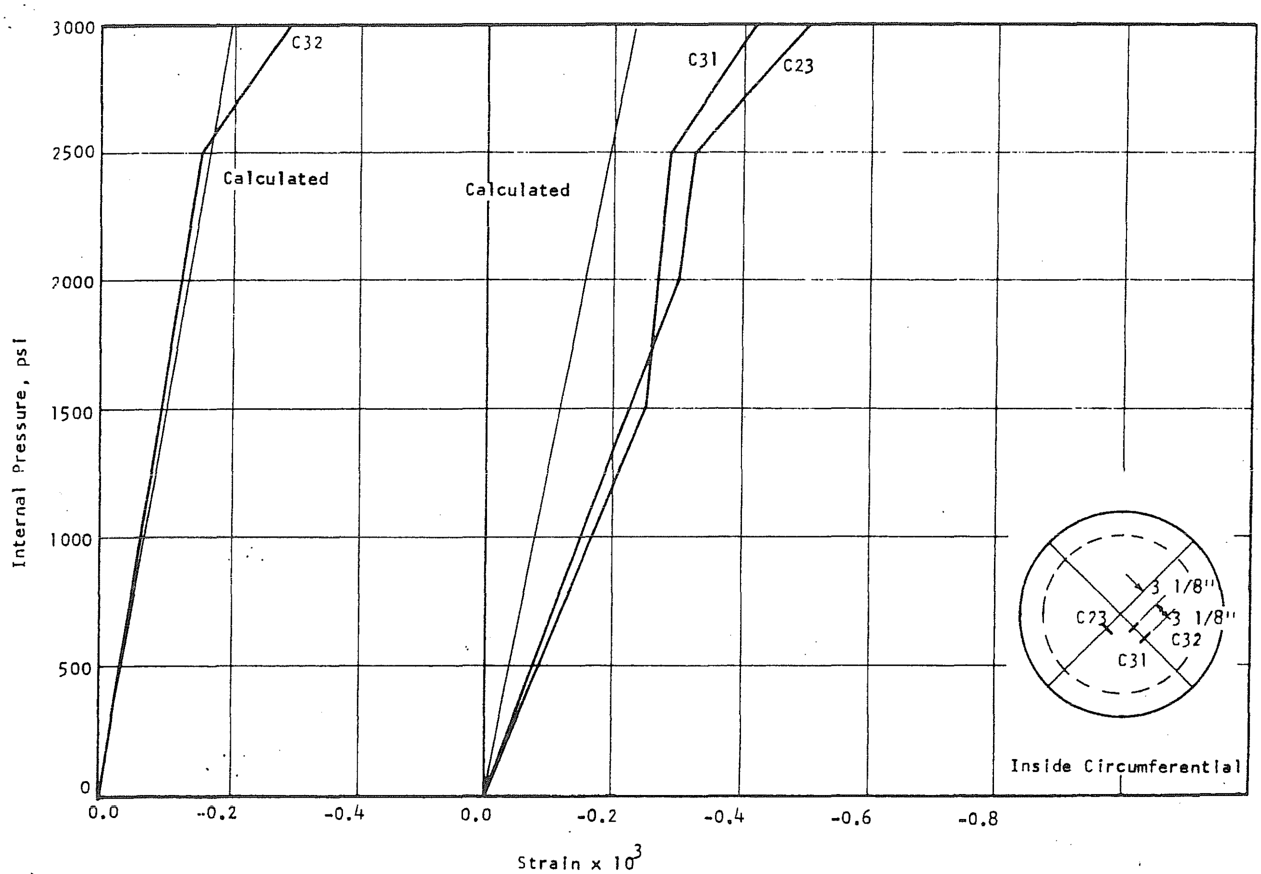


FIG. B13.6 (cont'd) CONCRETE STRAINS, VESSEL PV13

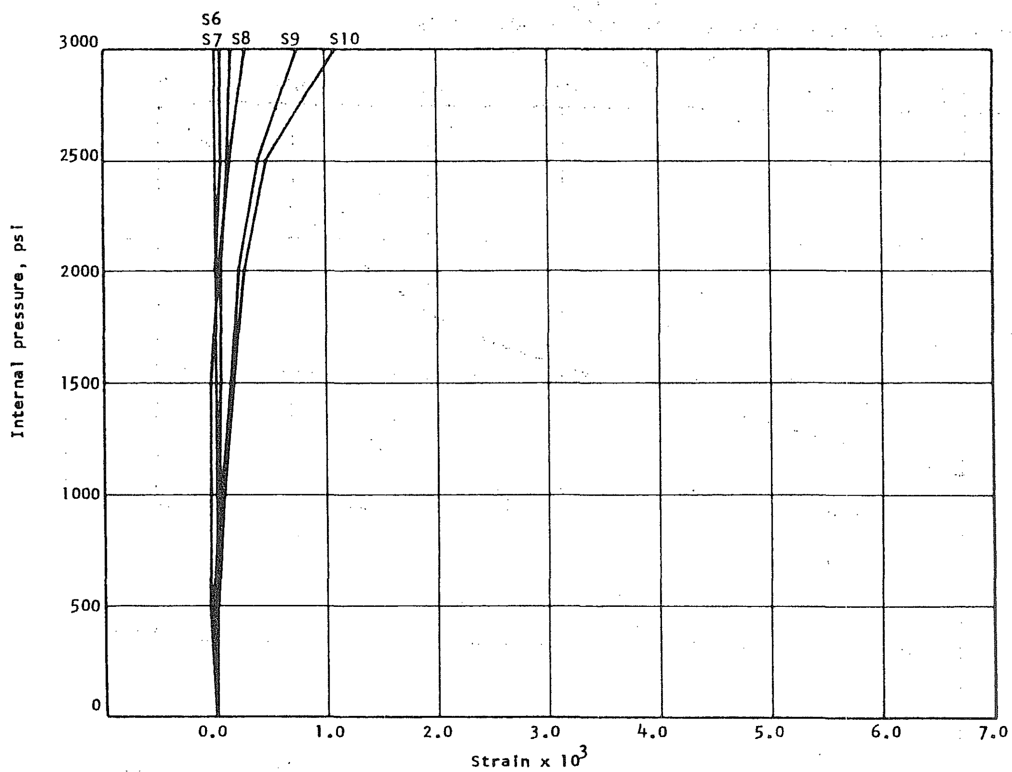


FIG. B13.7 APPLIED PRESSURE vs STRAIN IN CIRCUMFERENTIAL PRESTRESS WIRE AT THE E-END OF THE E-W DIAMETER OF PV13

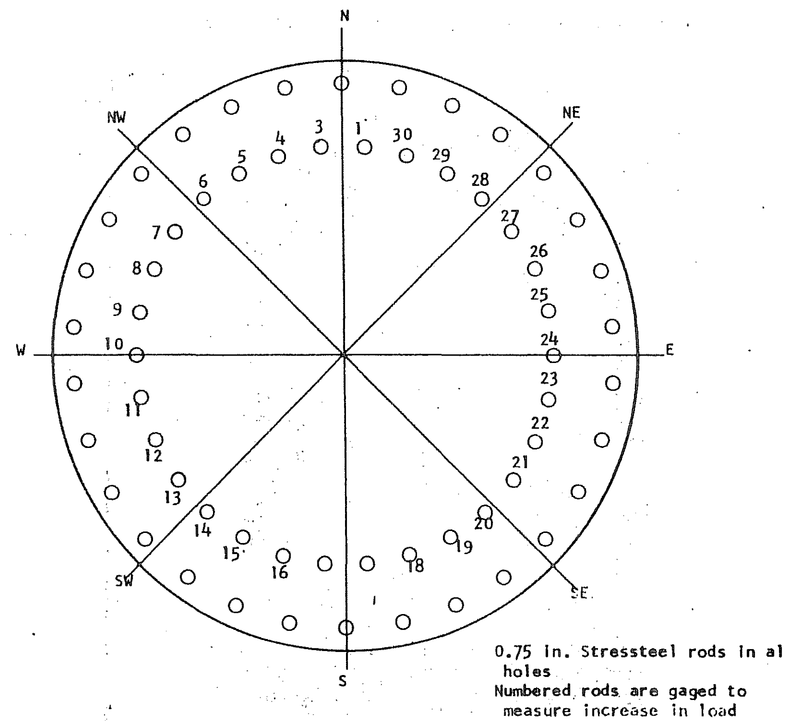


FIG. B13.8 LOCATION OF LONGITUDINAL REINFORCEMENT

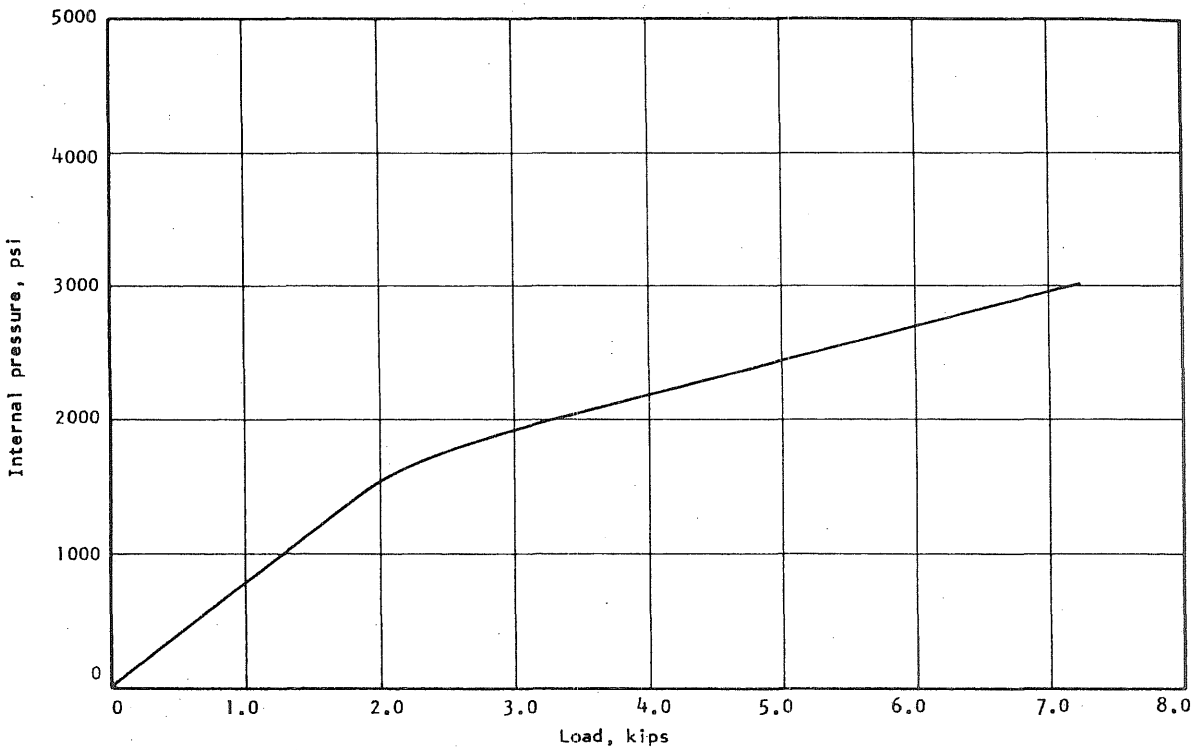


FIG. B13.9 APPLIED PRESSURE vs INCREASE IN LOAD IN STRESSTEEL ROD NO. 11

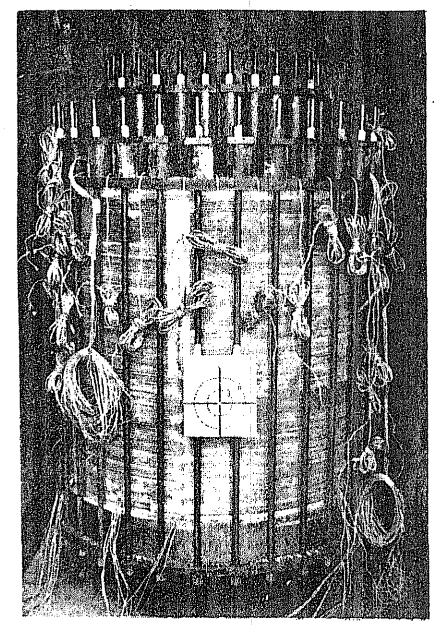


FIG. B13.10 VESSEL PV13 READY TO BE TESTED

B14 Test Vessel PV14 (t = 15 in., s = 1/4 in.)

Since PV13 had not developed an end slab failure, PV14 was used to test the circumferential prestress wire and the side wall capacity.

Two vertical grooves (3/4 in. x 3/8 in.) were cut in the inside of the side wall at 180° apart and were intended to be crack initiators. Small grooves were made across the main grooves at 2 in., 9 in., 17 in., and 24 in. from the base of the side wall. A-12 concrete gages were located in these grooves perpendicular to the main crack. The locations of gages on the circumferential reinforcement are shown in Fig. B14.3 and Fig. B14.4. The gages on the west half of the vessel were at the same level as the concrete gages. Deflection measurements were taken on the side of the vessel at nine locations as shown in Fig. B14.2 None were taken on the top. The longitudinal prestressing was similar to that of vessel PV13.

The vessel was pressurized in increments of 250 psi up to 2000 psi, increased to 500-psi increments up to 3000 psi, and reduced increments up to failure. A small leak occurred at the beginning of the test up to 3000 psi but then suddently stopped and there was no more leakage until failure occurred at 3690 psi.

After the test, the vessel was observed to be heavily cracked and five of the rod holes had collapsed onto the rods. Small radial cracks were visible through all of the rod holes after the vessel was broken up, but many of these were not visible on the side of the vessel. A circumferential crack with a diameter of 35 in. was visible in the end of the side wall. No cracks were visible in the top of the end slab.

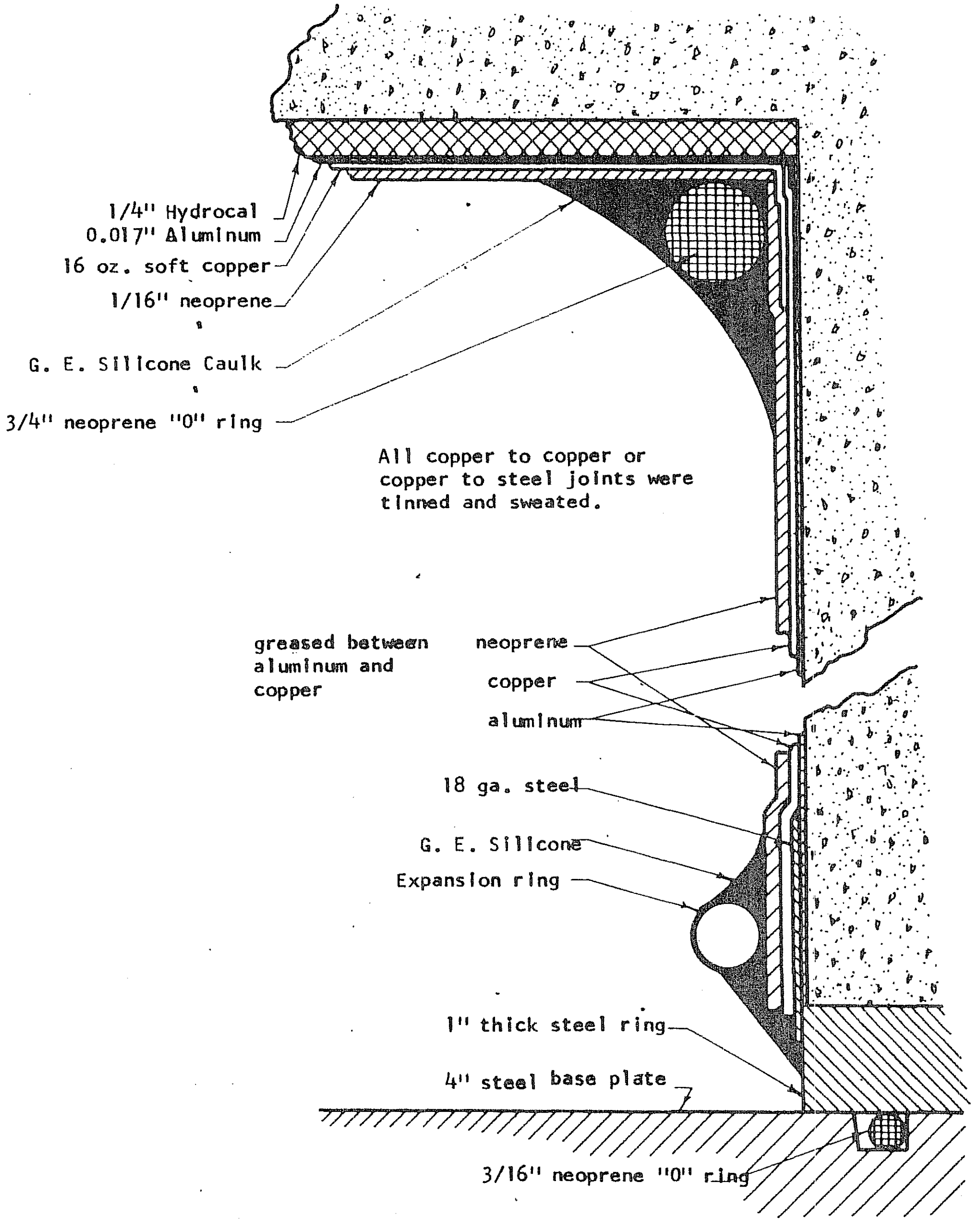


FIG. B14.1 SEALING DETAIL FOR PV14

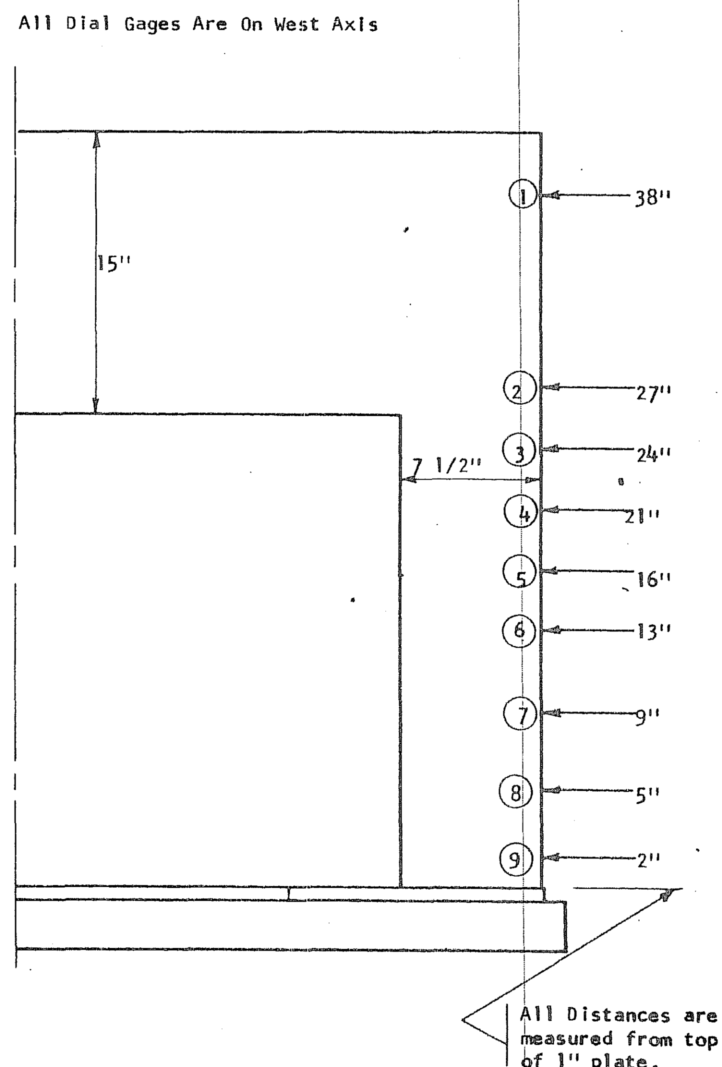


FIG. B14.2 LOCATION OF DEFLECTION GAGES ON PV14

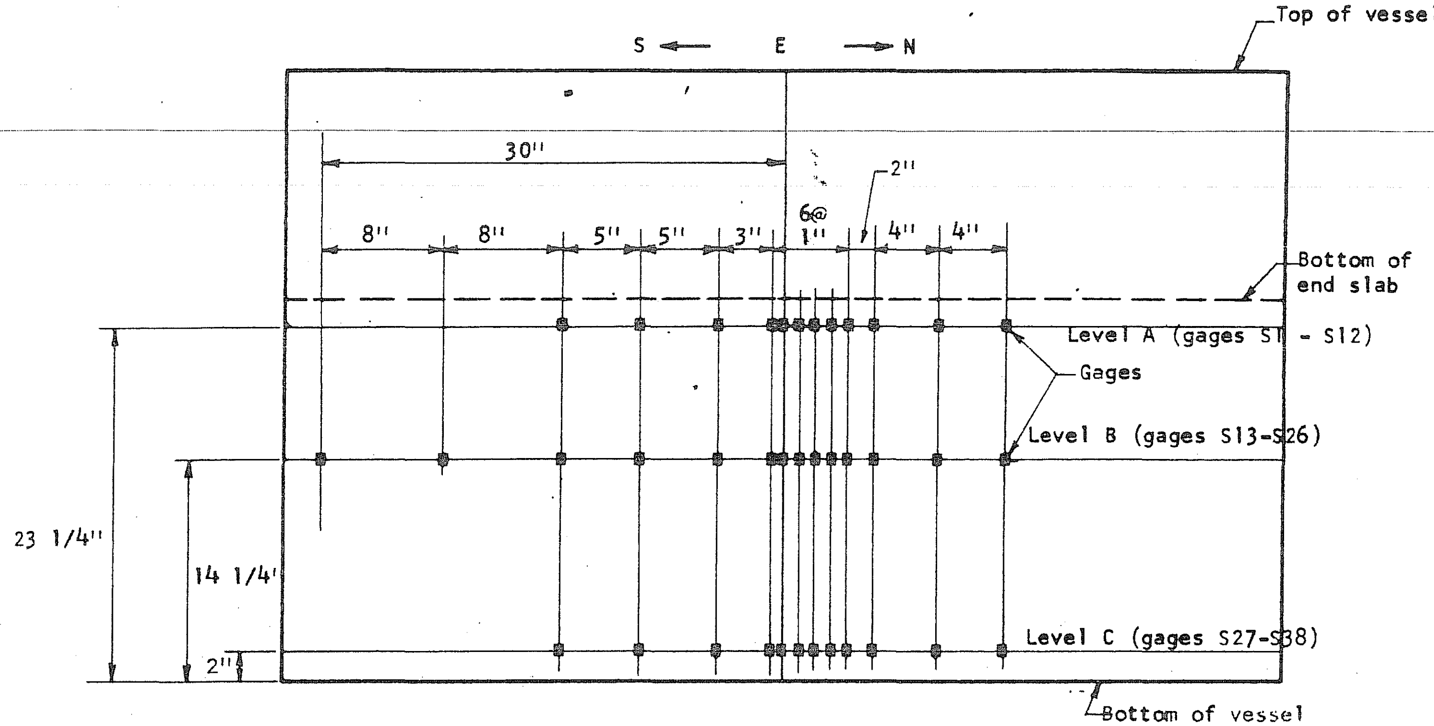


FIG. B14.3 LOCATION OF CIRCUMFERENTIAL REINFORCEMENT GAGES FOR EAST HALF OF PV14

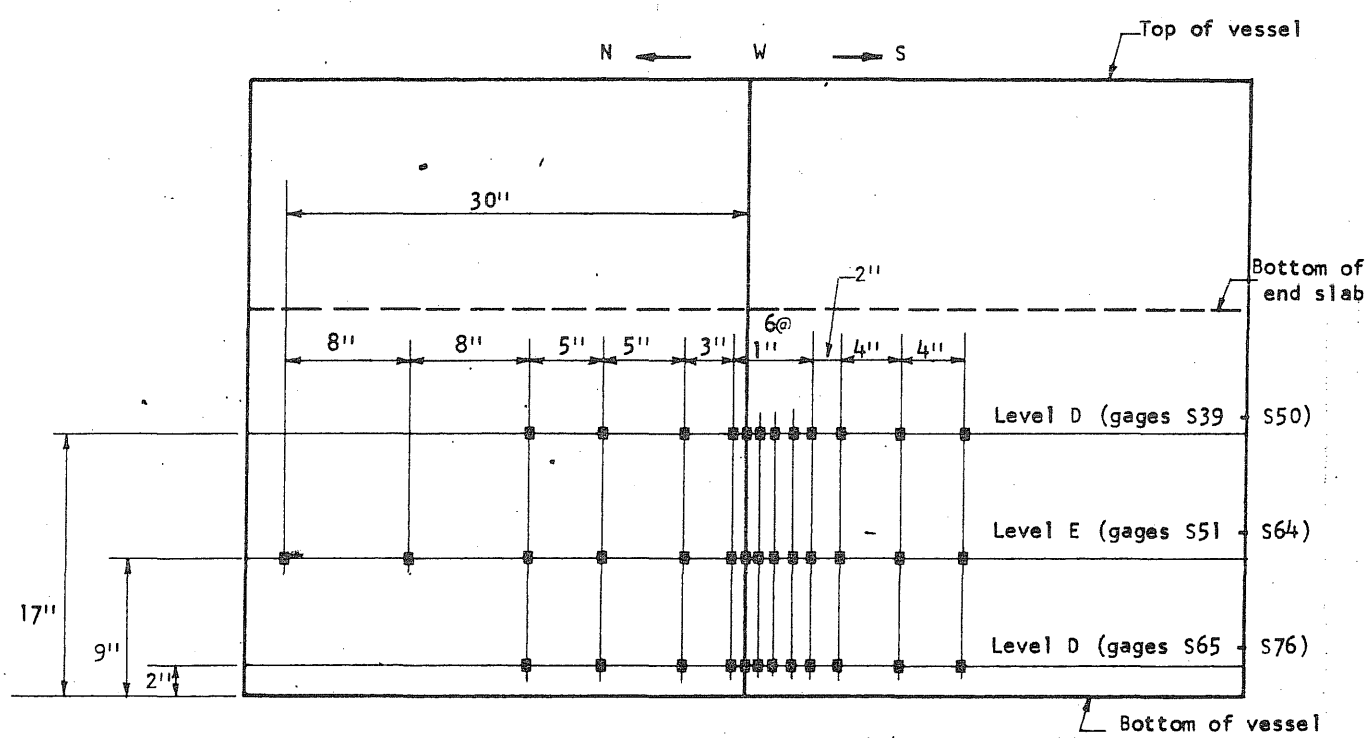


FIG. B14.3 (cont'd) LOCATION OF CIRCUMFERENTIAL REINFORCEMENT GAGES FOR WEST HALF OF PV14

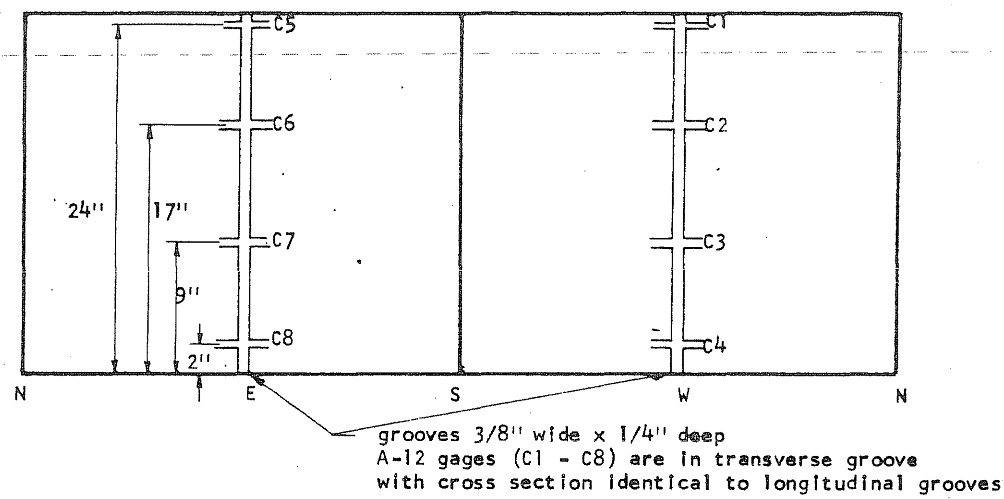


FIG. B14.4 LOCATION OF CONCRETE GAGES ON INSIDE SIDE WALL OF PV14

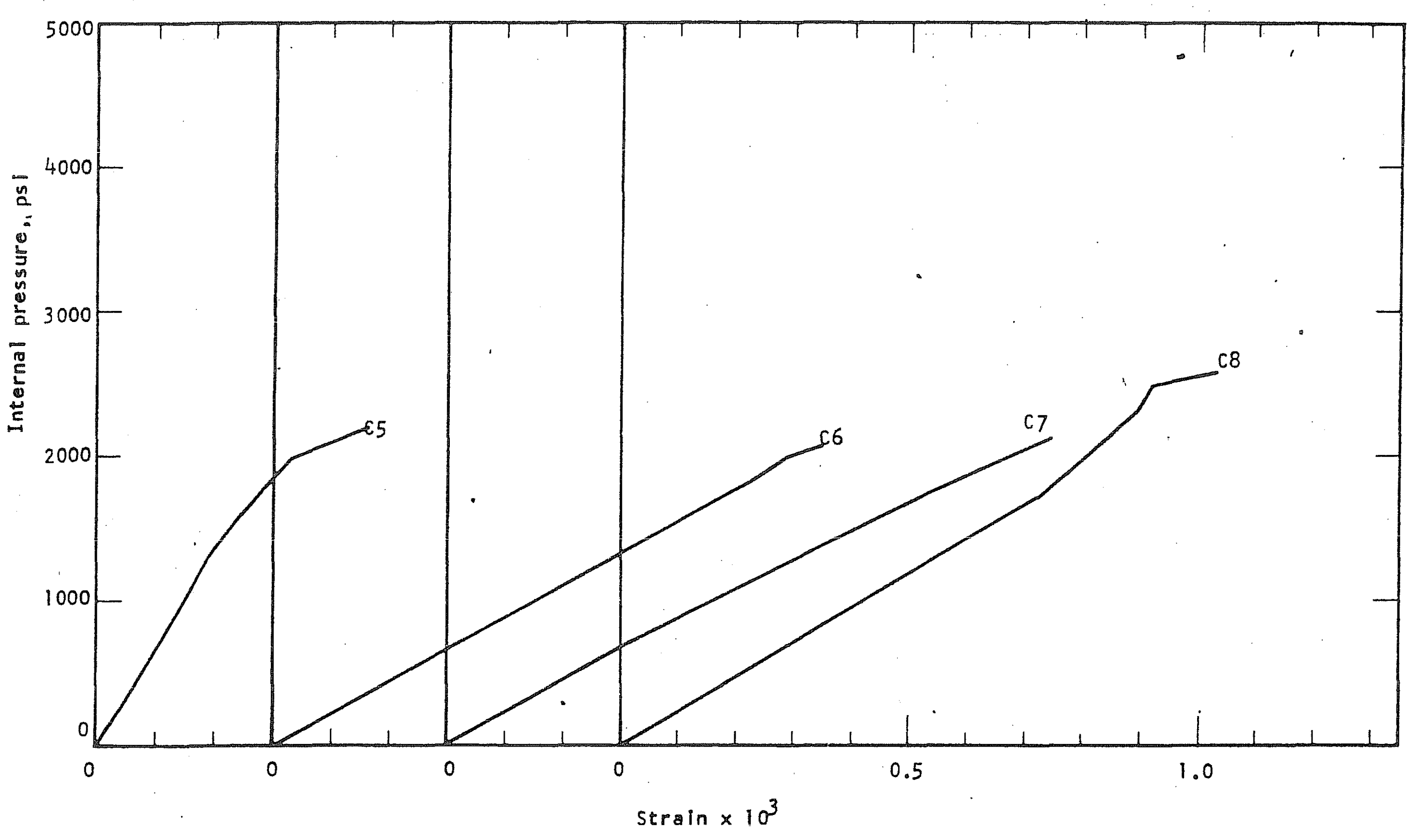


FIG. B14.5 CONCRETE STRAINS, VESSEL PV14

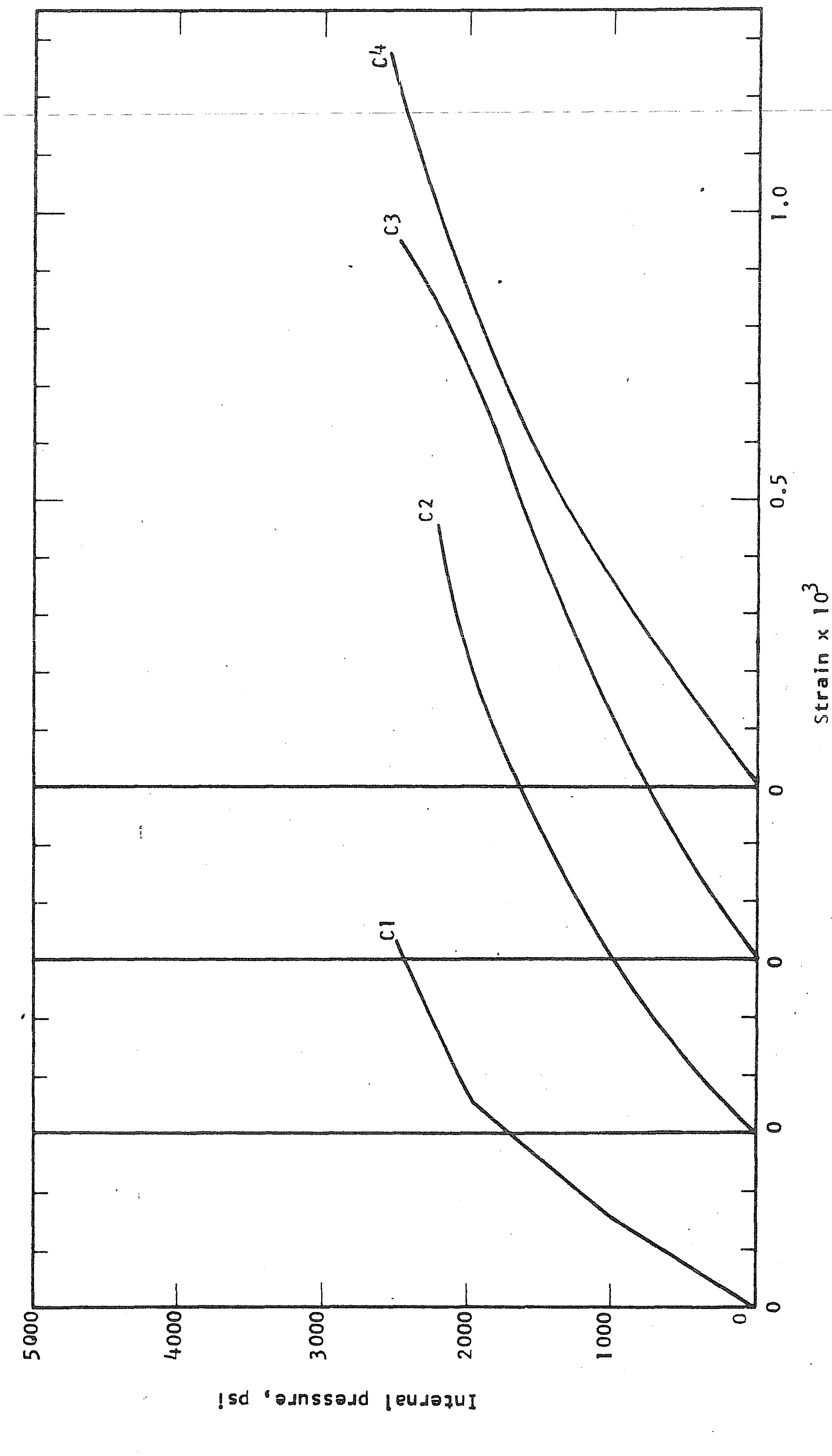


FIG. B14.6 CONCRETE STRAINS, VESSEL PV14

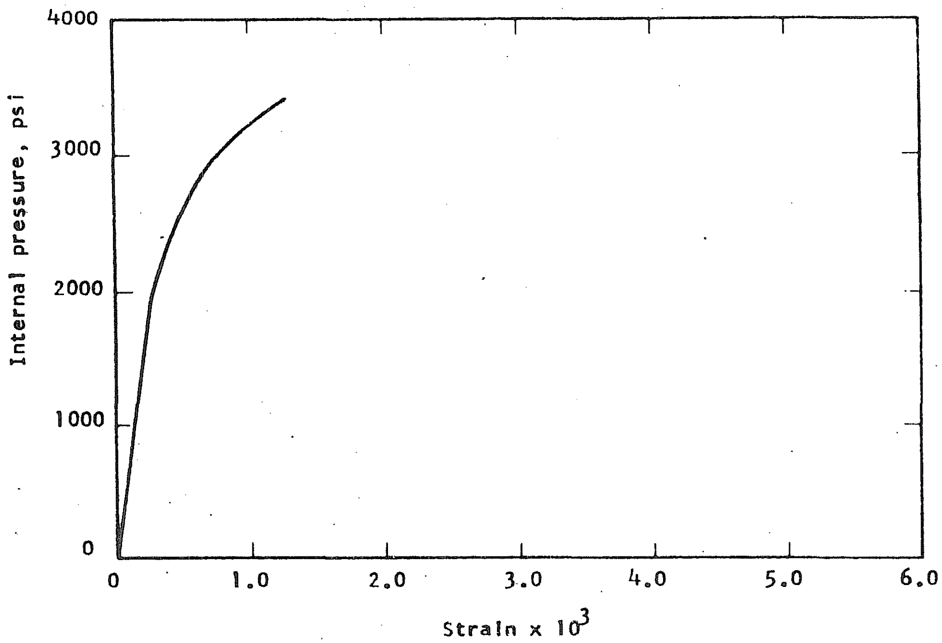


FIG. B14.7 APPLIED PRESSURE vs AVERAGE STRAIN IN CIRCUMFERENTIAL PRESTRESS WIRE AT LEVEL A

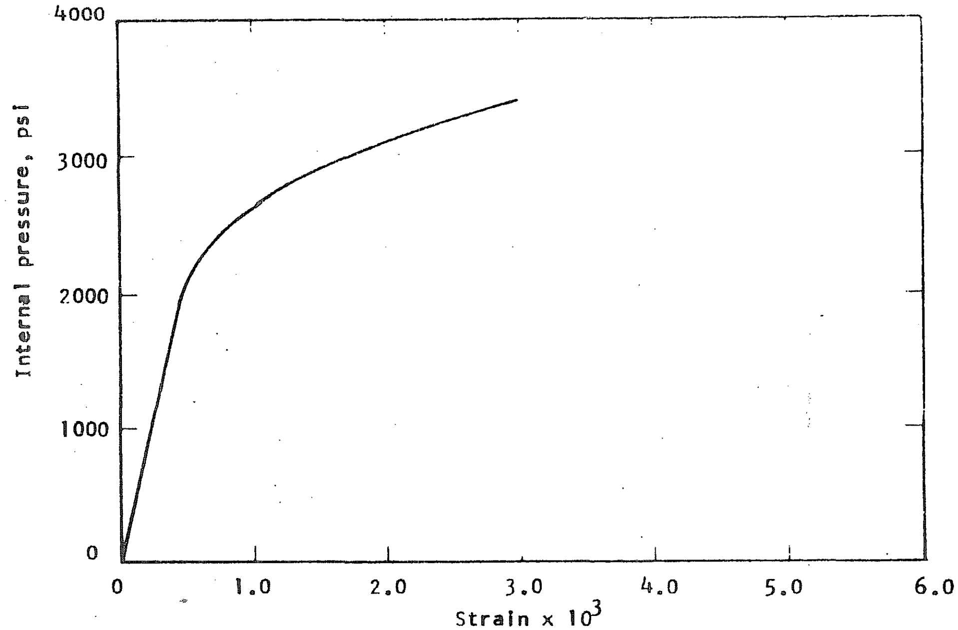


FIG. B14.8 APPLIED PRESSURE vs AVERAGE STRAIN IN CIRCUMFERENTIAL PRESTRESS WIRE AT LEVEL B

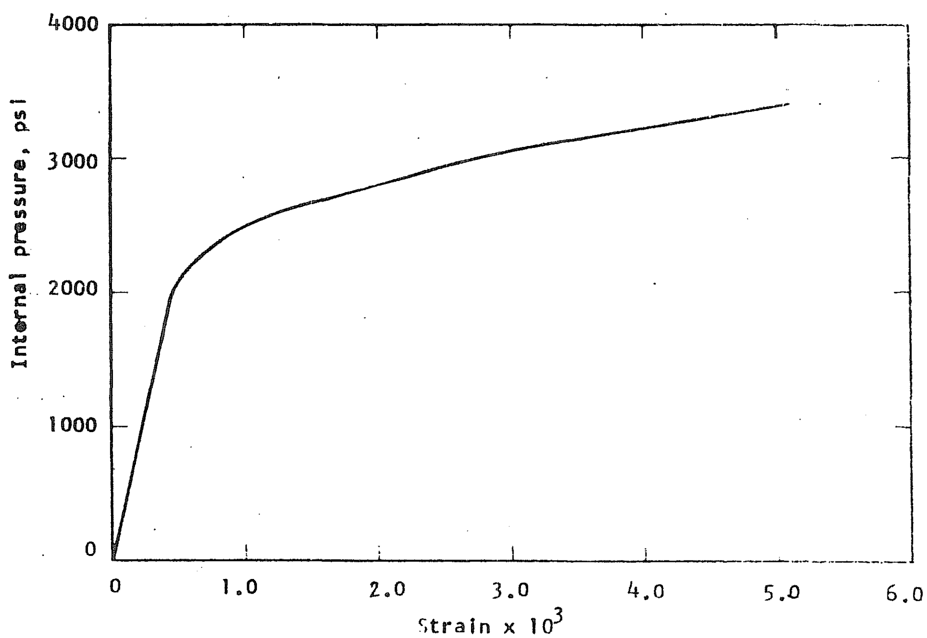


FIG. B14.9 APPLIED PRESSURE vs AVERAGE STRAIN IN CIRCUMFERENTIAL PRESTRESS WIRE AT LEVEL C

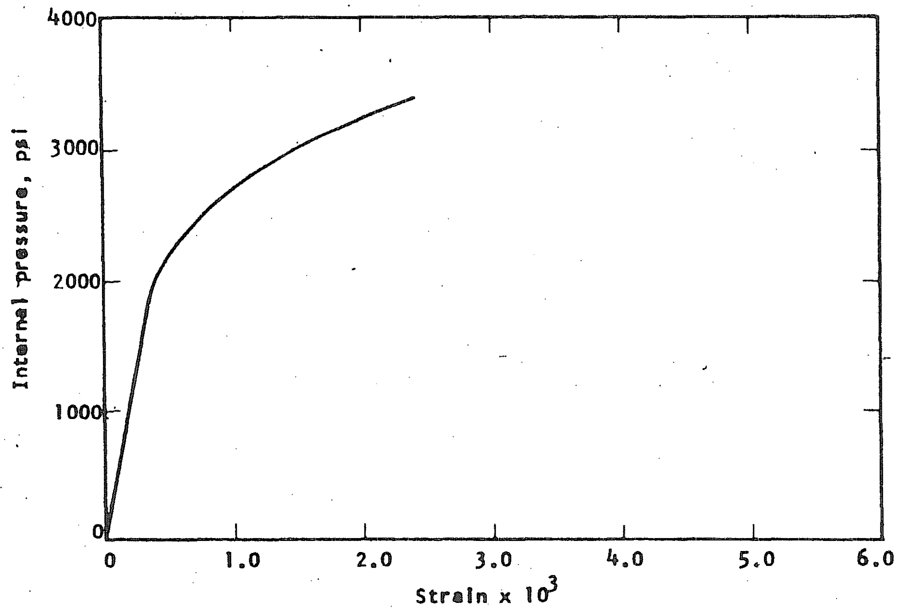


FIG. B14.10 APPLIED PRESSURE vs AVERAGE STRAIN IN CIRCUMFERENTIAL PRESTRESS WIRE AT LEVEL D

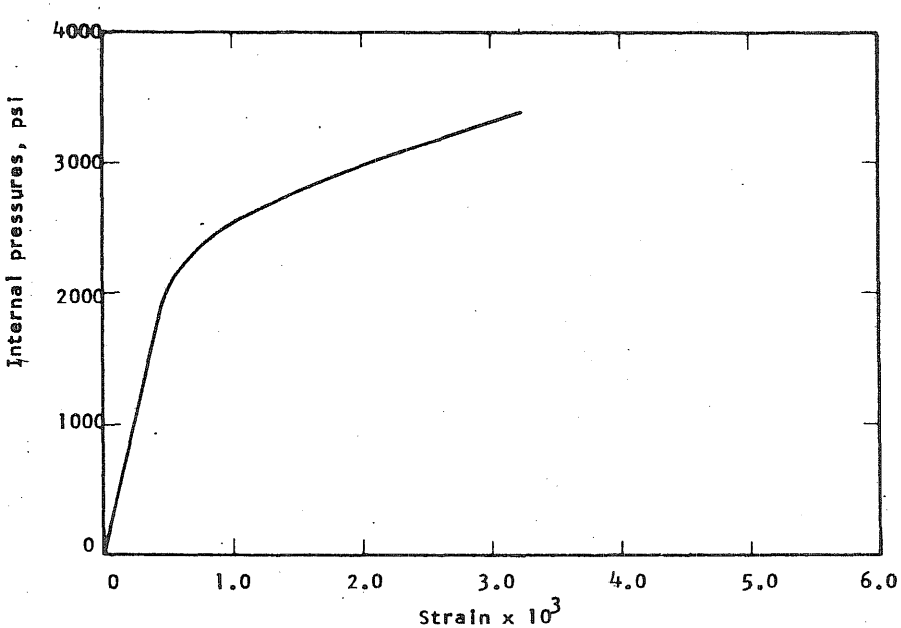


FIG B14.11 APPLIED PRESSURE vs AVERAGE STRAIN IN CIRCUMFERENTIAL PRESTRESS WIRE AT LEVEL E

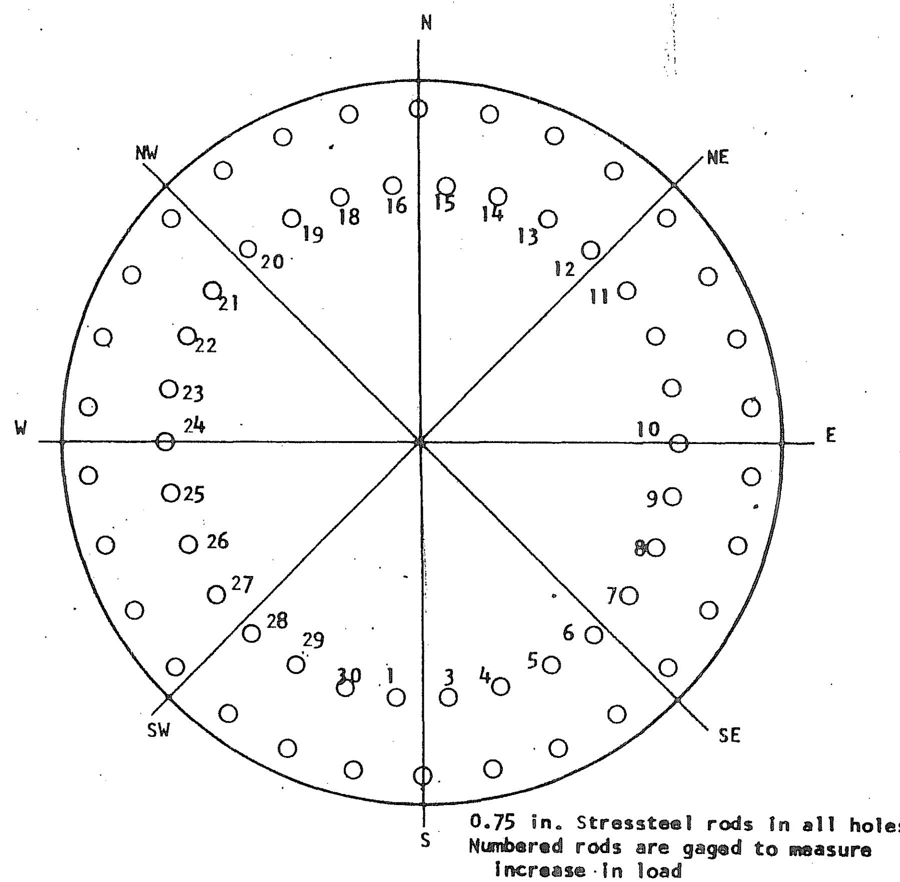


FIG. B14.12 LOCATION OF LONGITUDINAL REINFORCEMENT

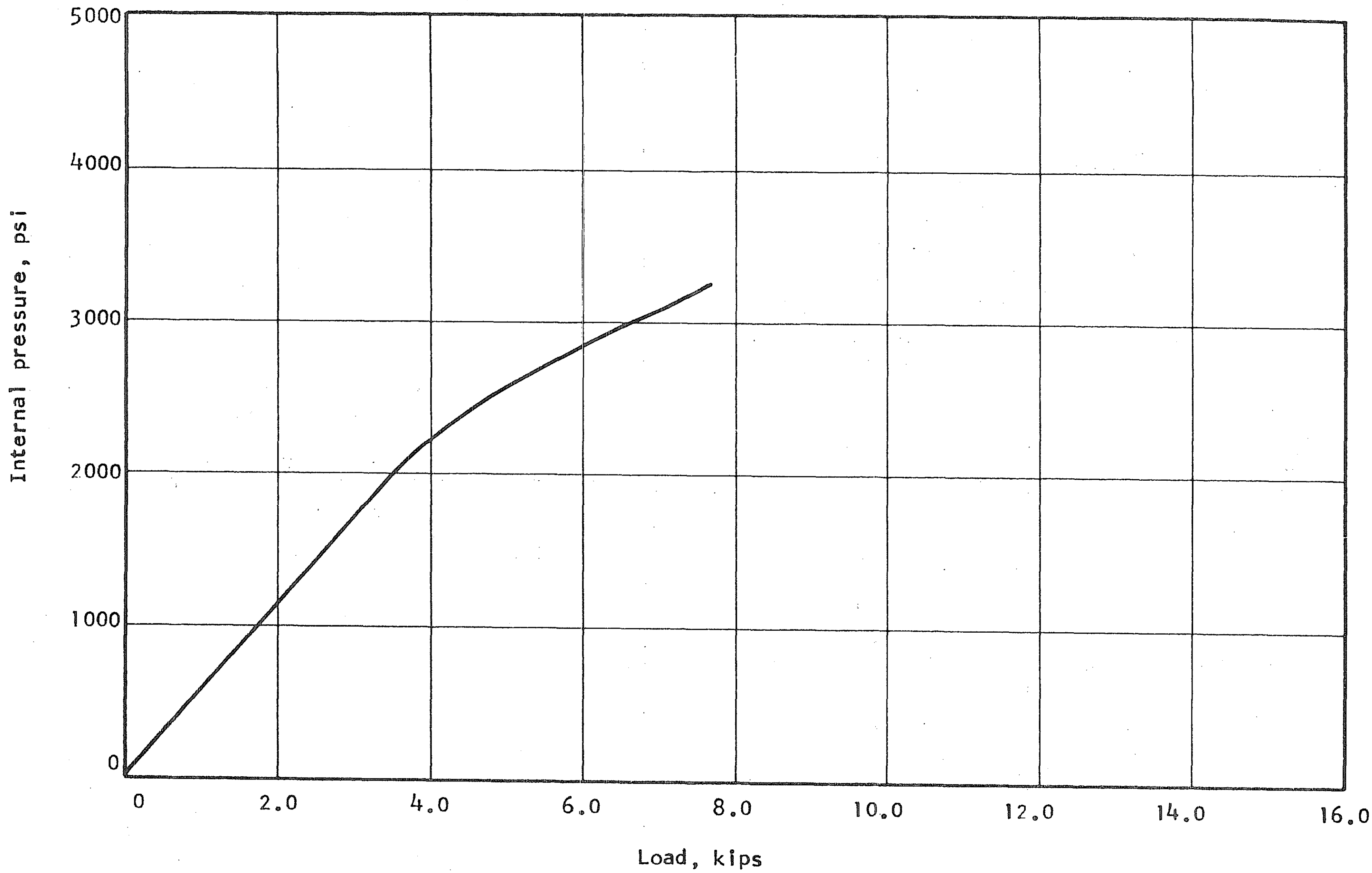


FIG. B14.13 APPLIED PRESSURE vs INCREASE IN LOAD IN STRESSTEEL ROD No. 9

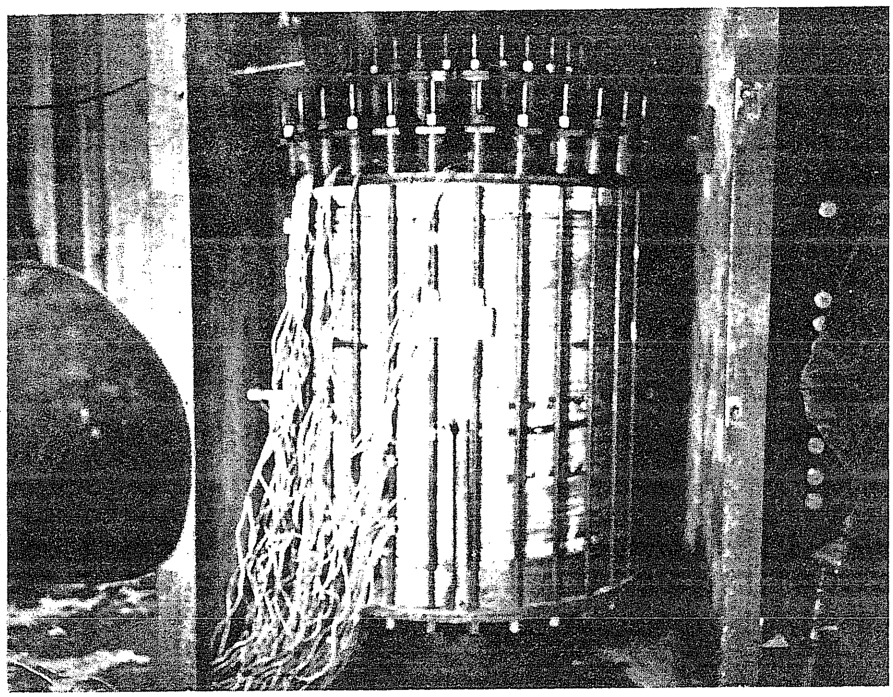


FIG. B14.14 VESSEL PV14 READY TO BE TESTED

B15 Test Vessel PV15 (t = 7.5 in., s = 1/4 in.)

Test vessel PV15 was cast with two rows of rod holes with diameters of 29 in. and 34 in. Due to the congestion of vertical prestressing on the end slab, it was impossible to use the three in. by three in. bearing plates. Instead, the 1-1/4 in. thick steel plates used for PV13 and PV14 was used. It was necessary to drill another set of holes for the outside set of rods. The top plate was slotted between the rod holes to reduce the radial restraint from the steel ring when the end slab segments rotated.

Sixty stressteel rods were used for the longitudinal prestressing. Dial gages 1 and 7 were omitted. PV15 was sealed in the same manner as the previous three vessels.

The vessel was loaded in 200-psi increments up to a pressure of 1600 psi and then the increments were reduced to 100 psi until failure occurred at 2300 psi. The vessel failed about five minutes after loading had stopped at this pressure. Cracks were clearly visible in the end slab at 1800 psi as seen via the closed circuit TV. The center of the end slab punched out in a shear failure with all three liners in the end slab sheared along the circumference of the hole as shown in Fig. B15.12.

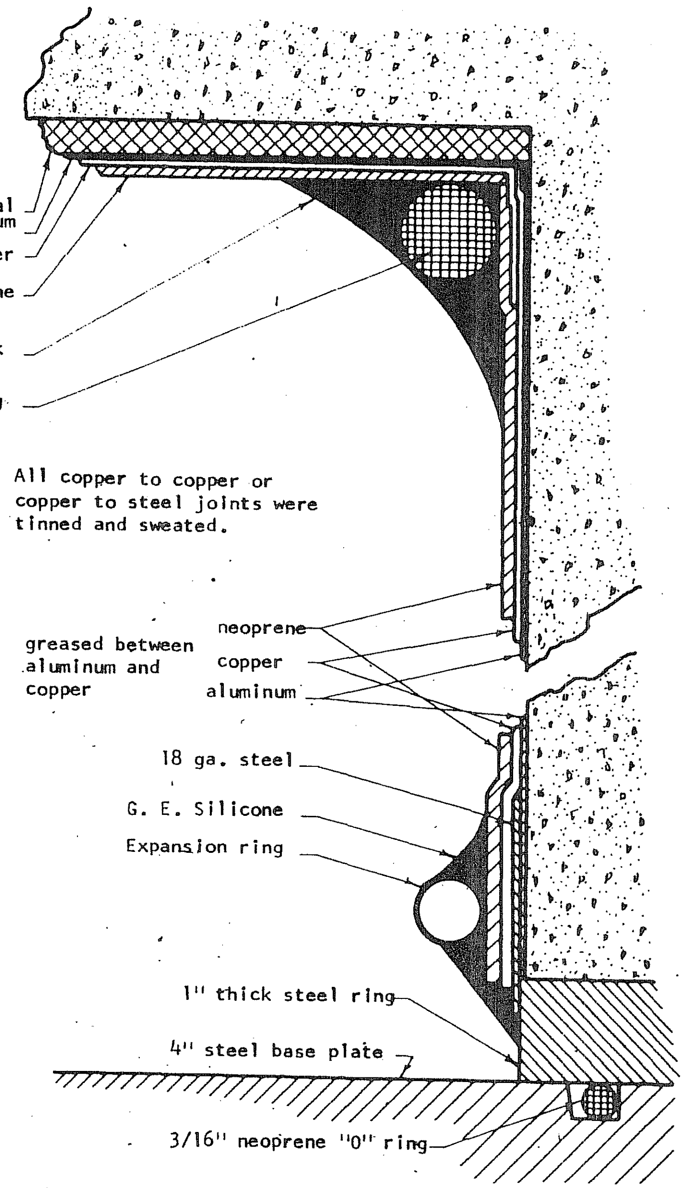


FIG. 15.1 SEALING DETAIL FOR PV15

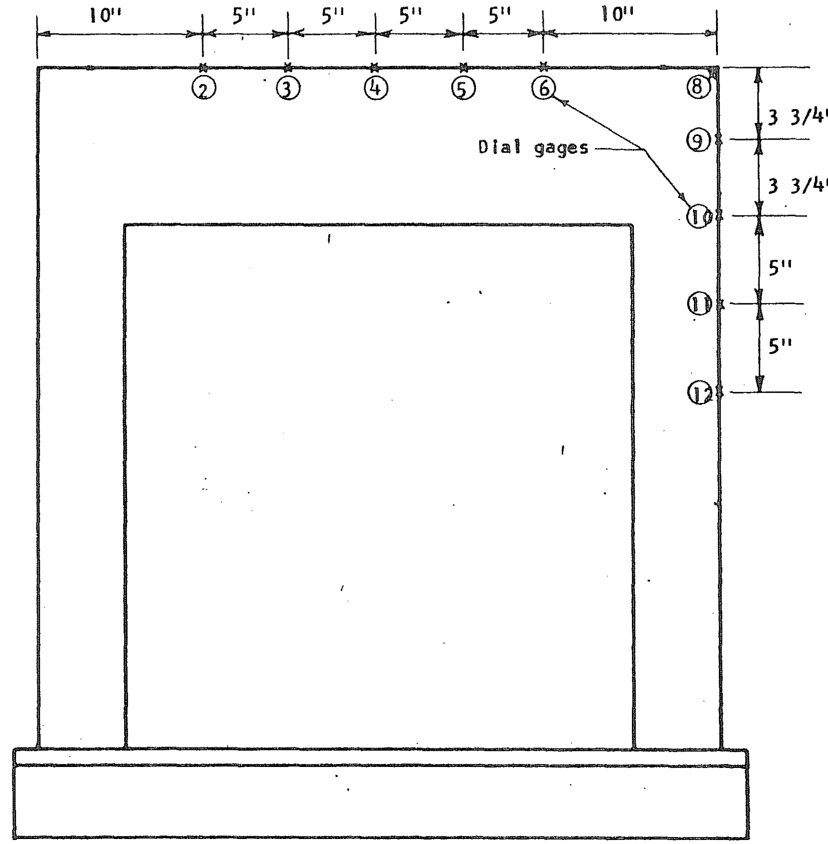


FIG. B15.2 LOCATION OF DEFLECTION GAGES ON PV15

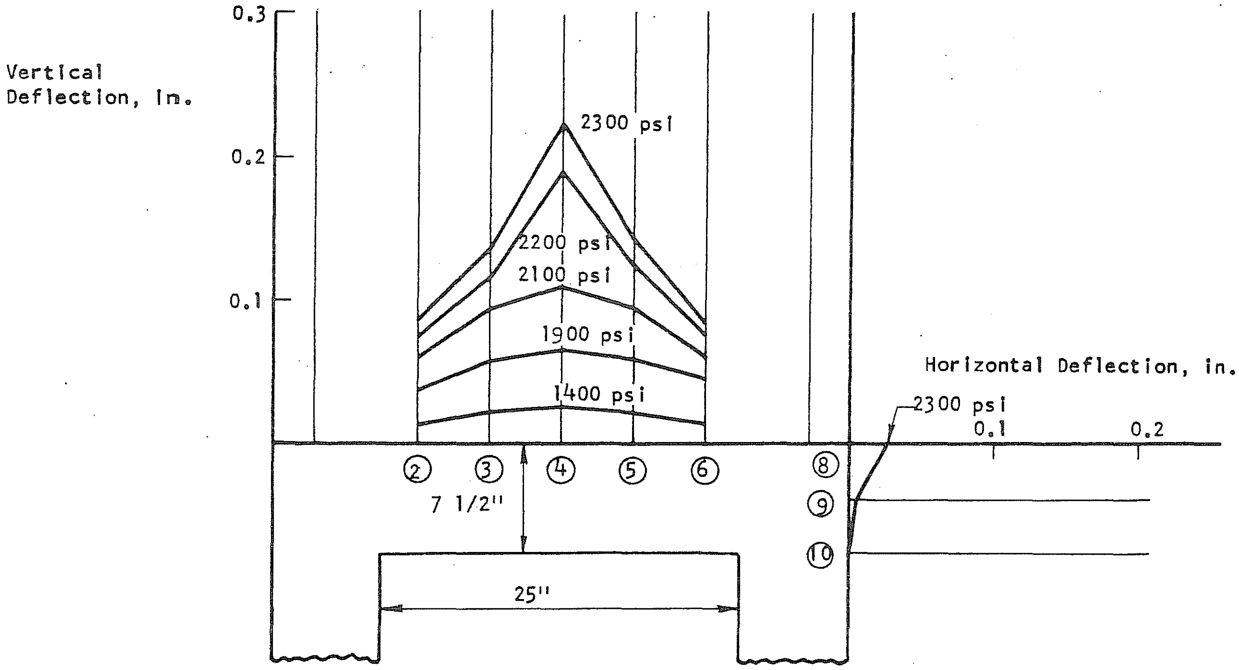


FIG. B15.3 DEFLECTION PROFILES OF THE END SLAB ALONG THE N-S DIAMETER OF PV15

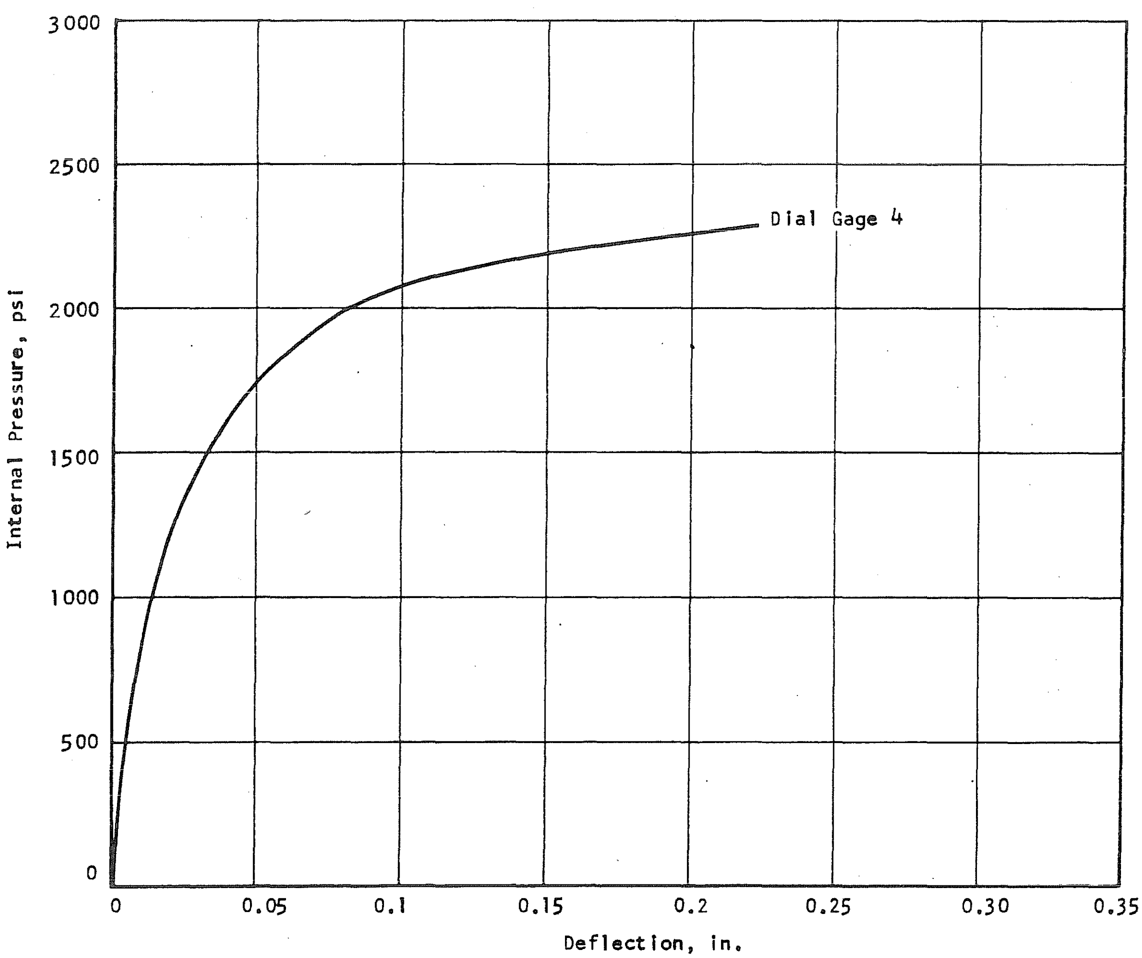
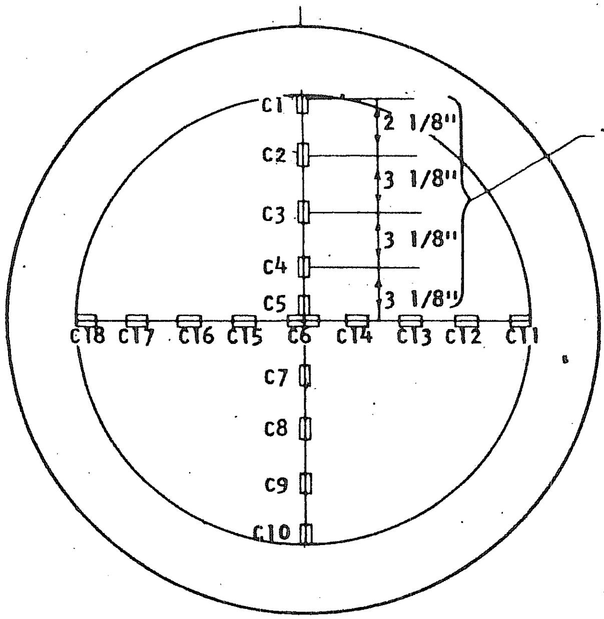


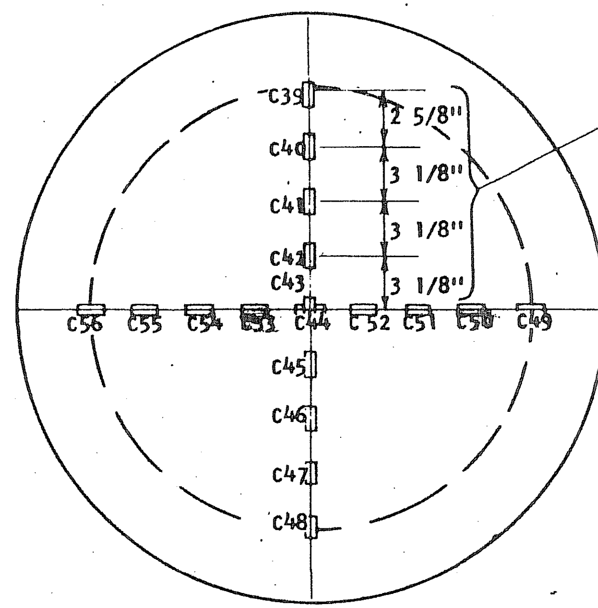
FIG. B15.4 APPLIED PRESSURE vs DEFLECTION AT MIDSPAN OF PV15

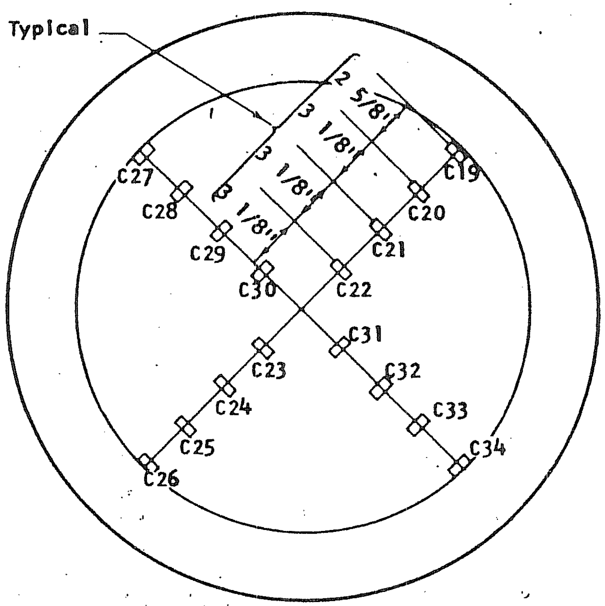
Concrete Gages on the Inside of the End Slab



Gages to Measure Radial Strain

Concrete gages on the Outside of the End Slab

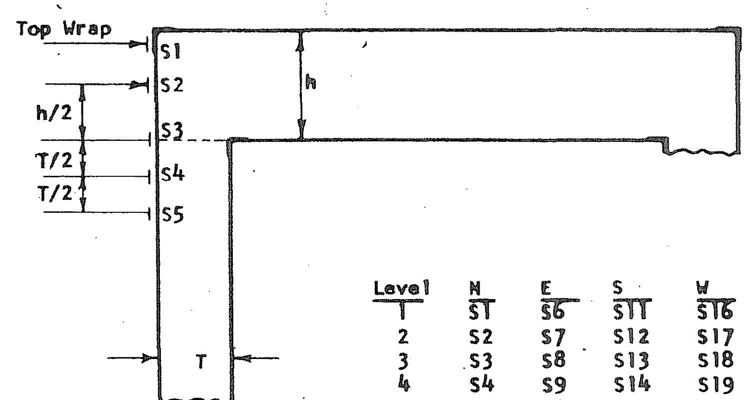




Gages to Measure Circumferential Strains

FIG. B15.5 STRAIN GAGE LOCATIONS ON PV15

Steel Gages on Circumferential Prestress Wire



Level	N	E	S	W
1	S1	S6	S11	S16
2	S2	S7	S12	S17
3	S3	S8	S13	S18
4	S4	S9	S14	S19
5	S5	S10	S15	S20

FIG. B15.5 (cont'd) STRAIN GAGE LOCATIONS ON PV15

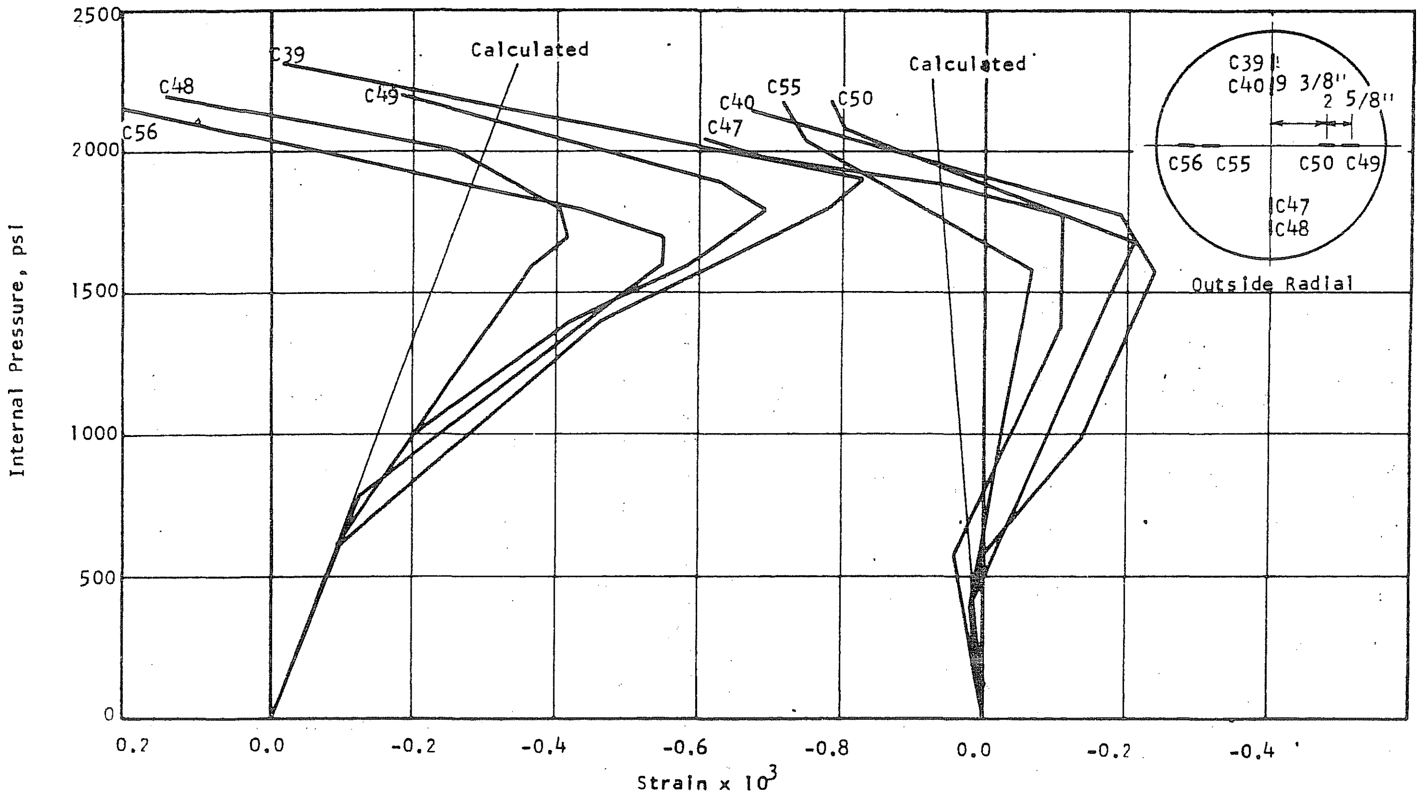


FIG. B15.6 CONCRETE STRAINS, VESSEL PV15

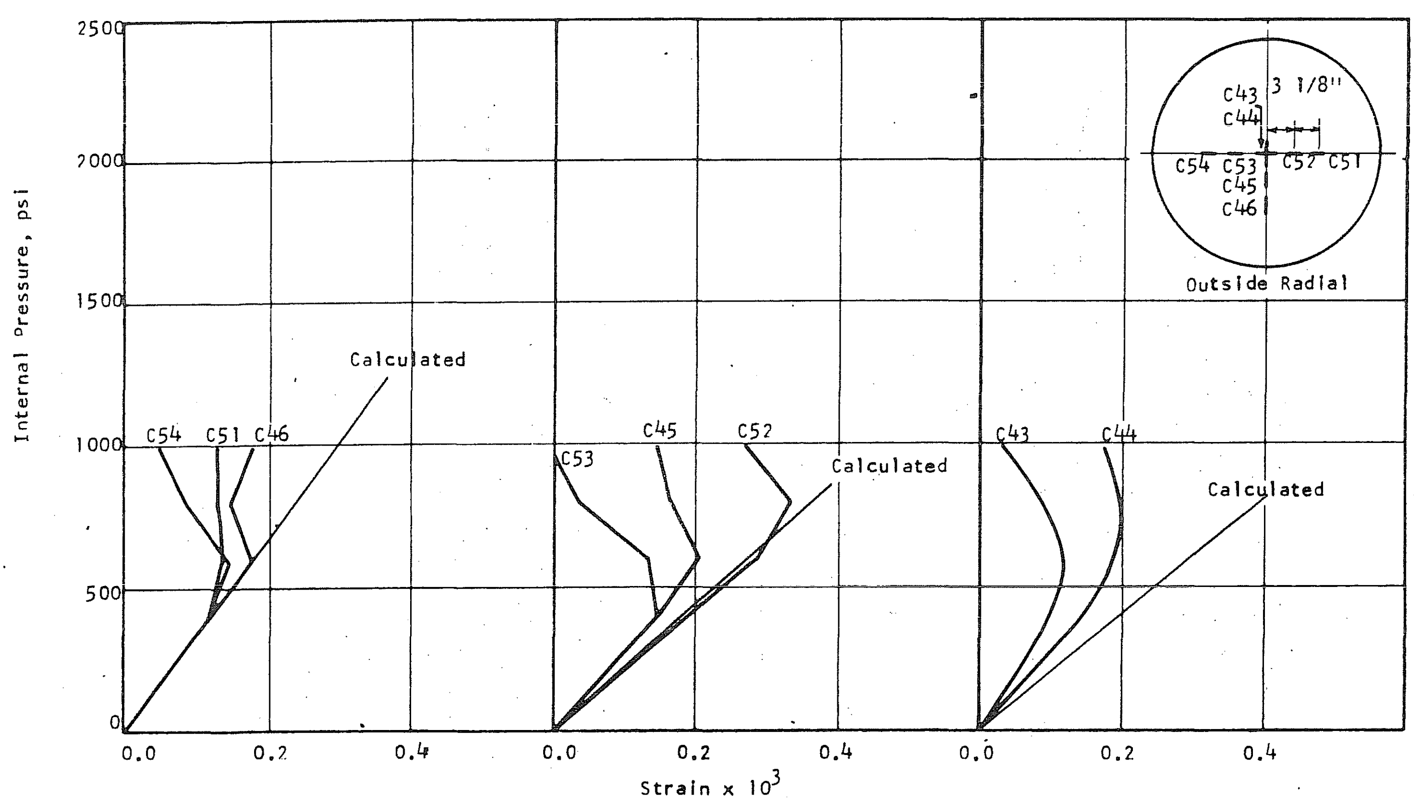


FIG. B15.6 (cont'd) CONCRETE STRAINS, VESSEL PV15

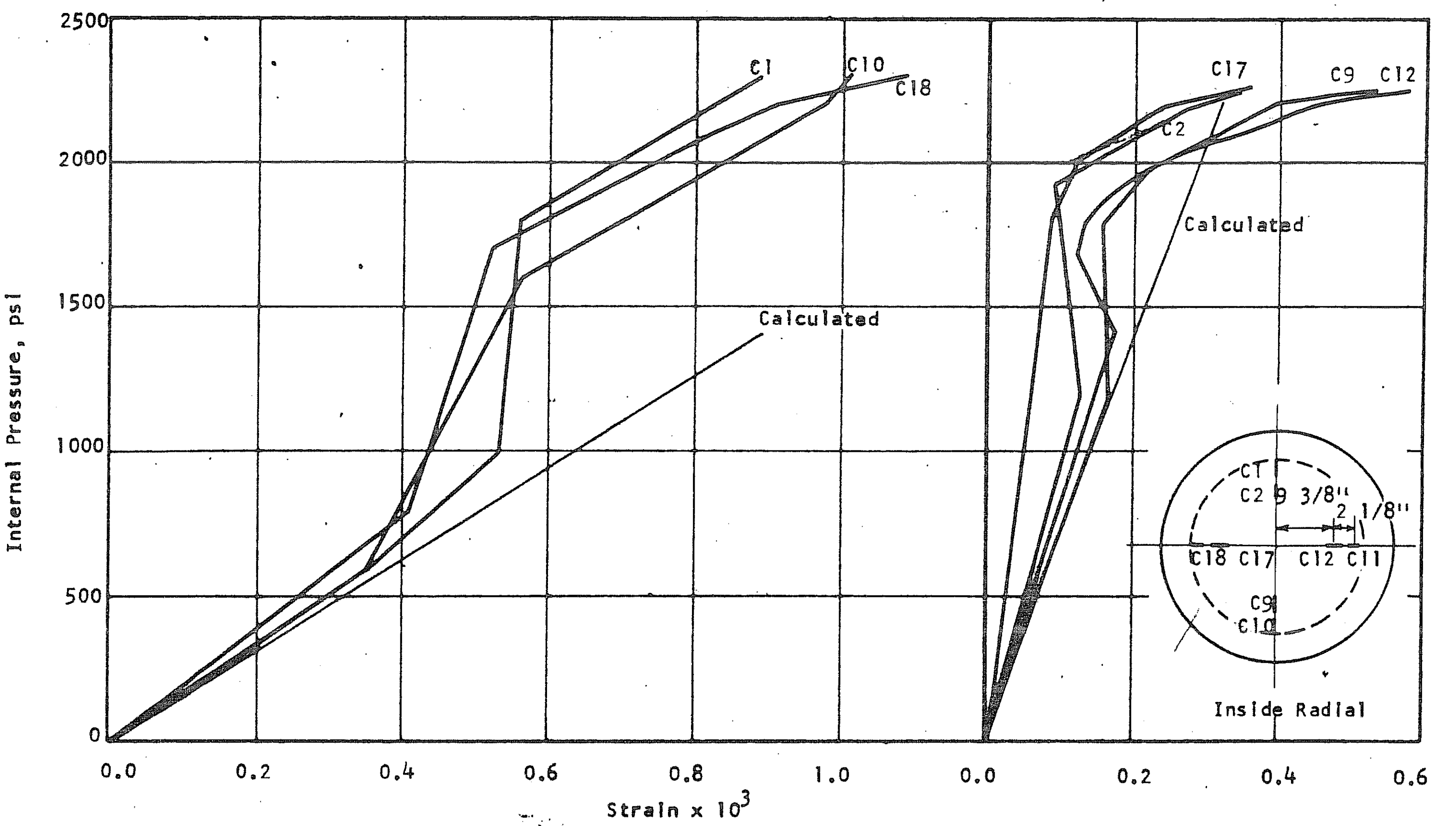


FIG. B15.7 CONCRETE STRAINS, VESSEL PV15

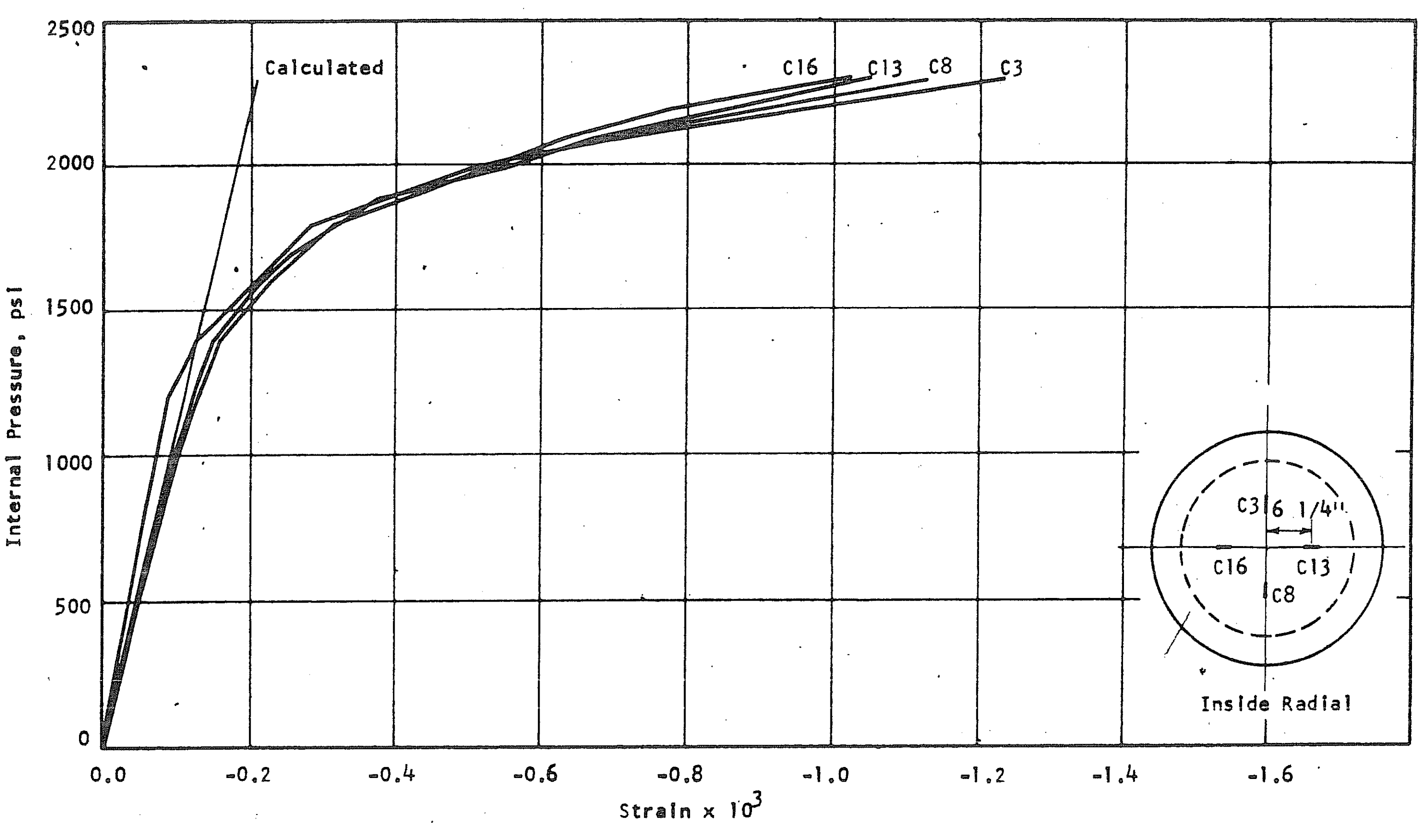


FIG. B15.7 (cont'd) CONCRETE STRAINS, VESSEL PV15

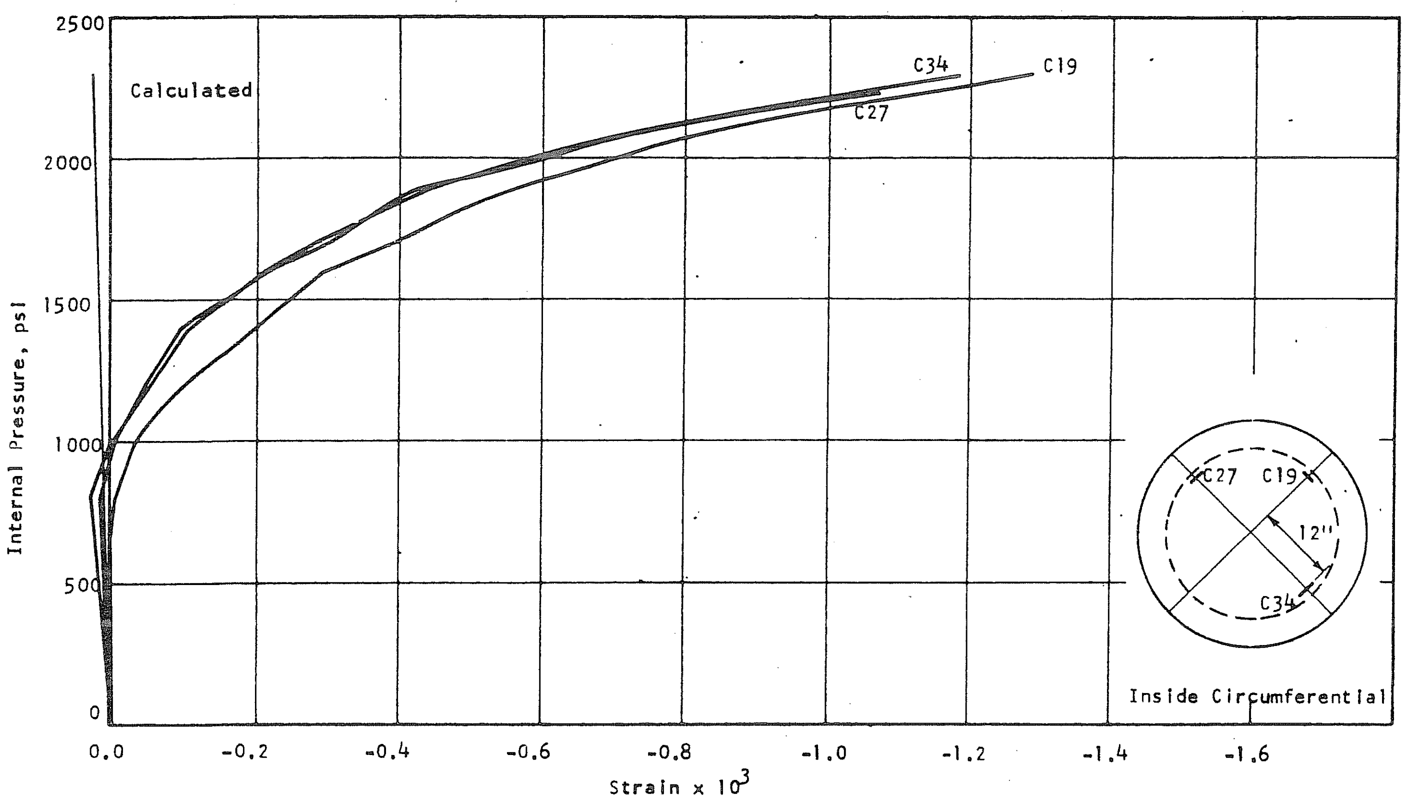


FIG. B15.8 CONCRETE STRAINS, VESSEL PV15

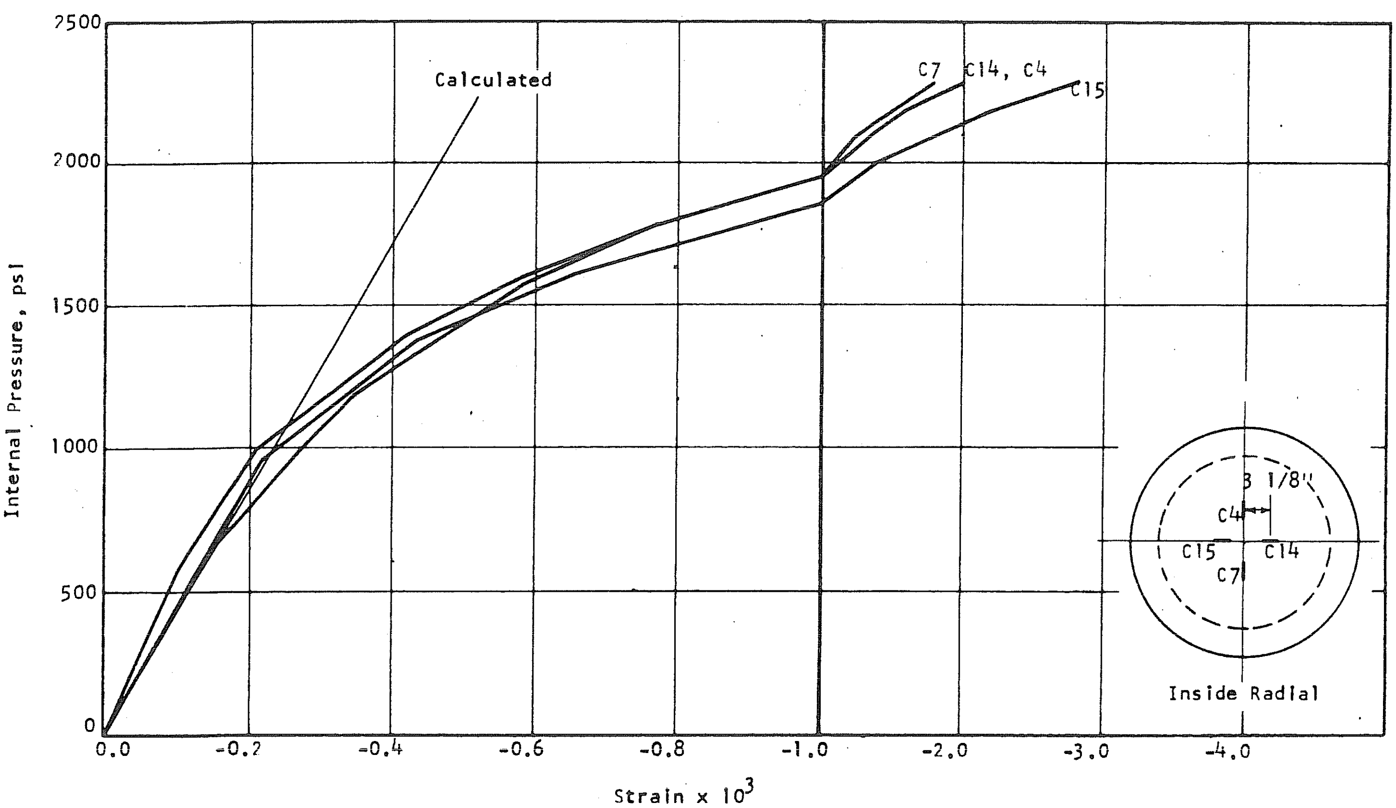


FIG. B15.8 (cont'd) CONCRETE STRAINS, VESSEL PV15

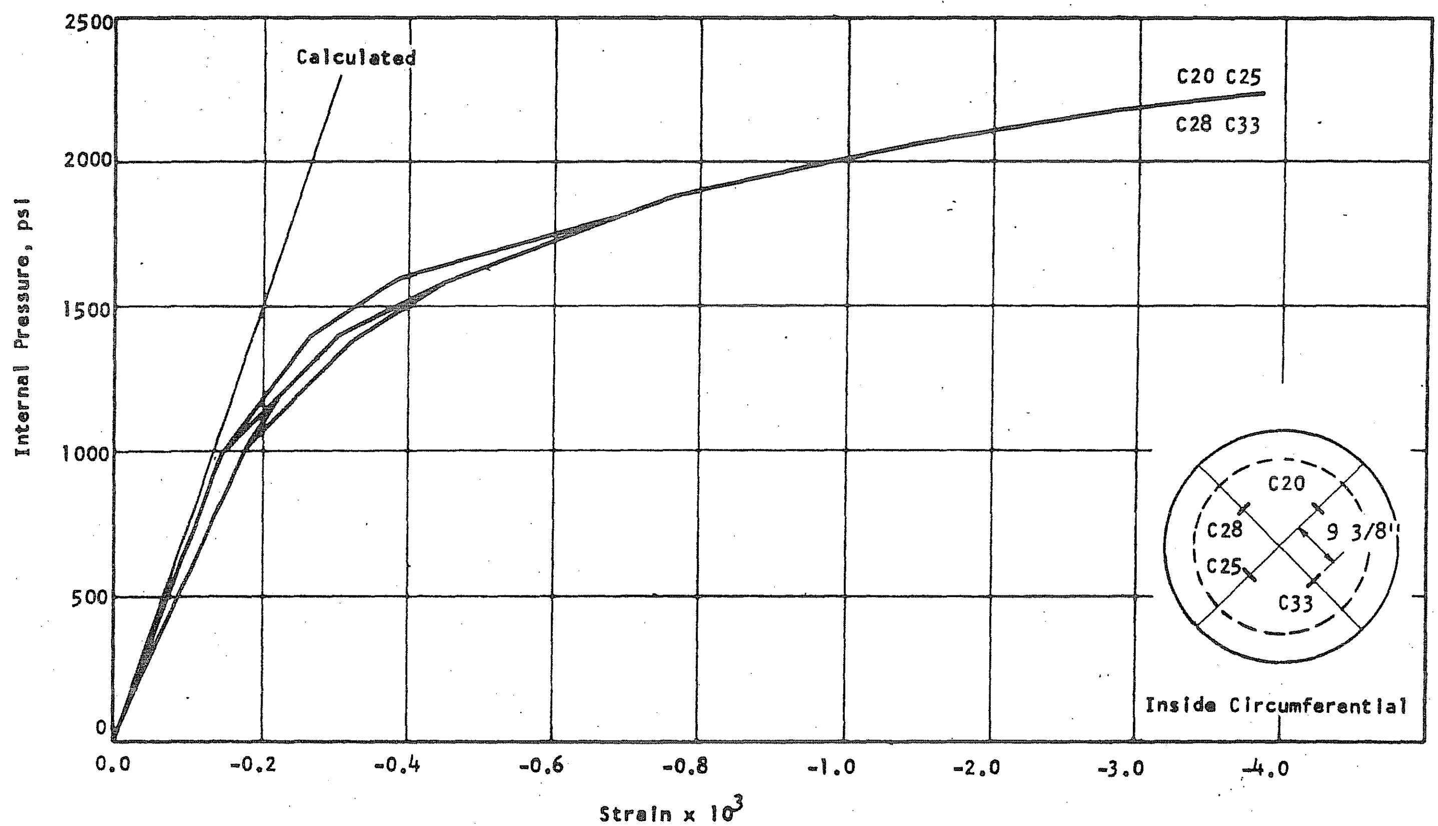


FIG. B15.8 (cont'd) CONCRETE STRAINS, VESSEL PV15

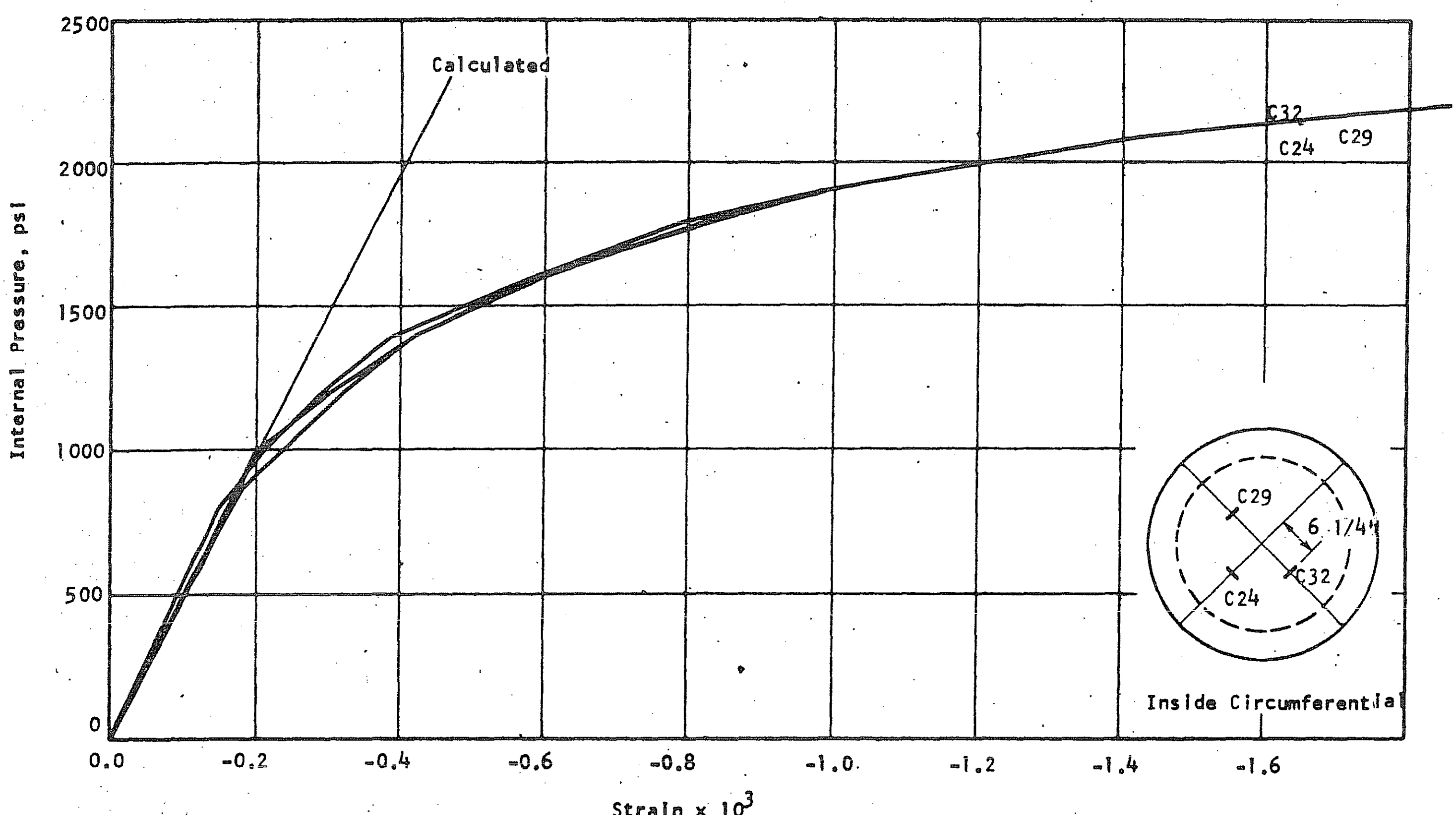


FIG. B15.8 (cont'd) CONCRETE STRAINS, VESSEL PV15

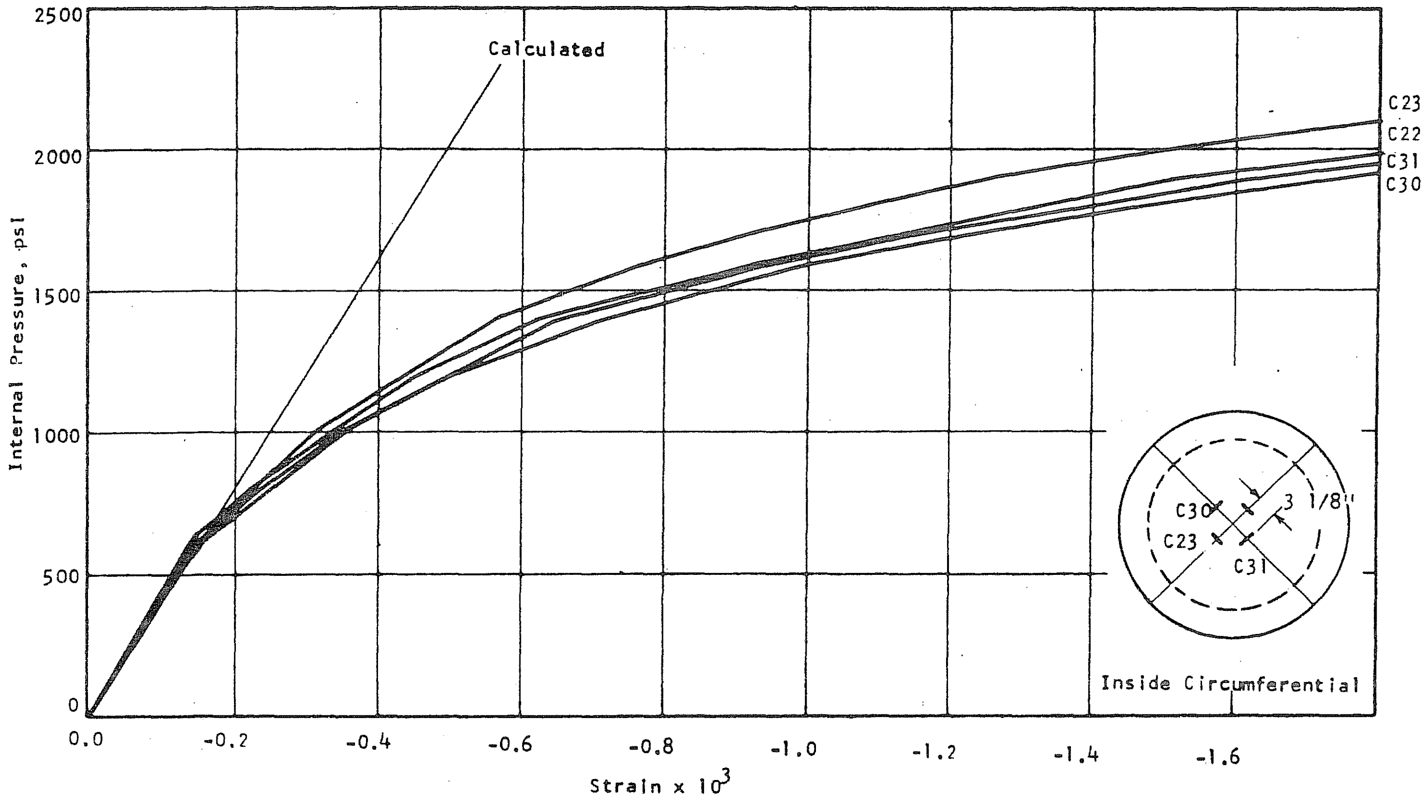


FIG. B15.8 (cont'd) CONCRETE STRAINS, VESSEL PV15

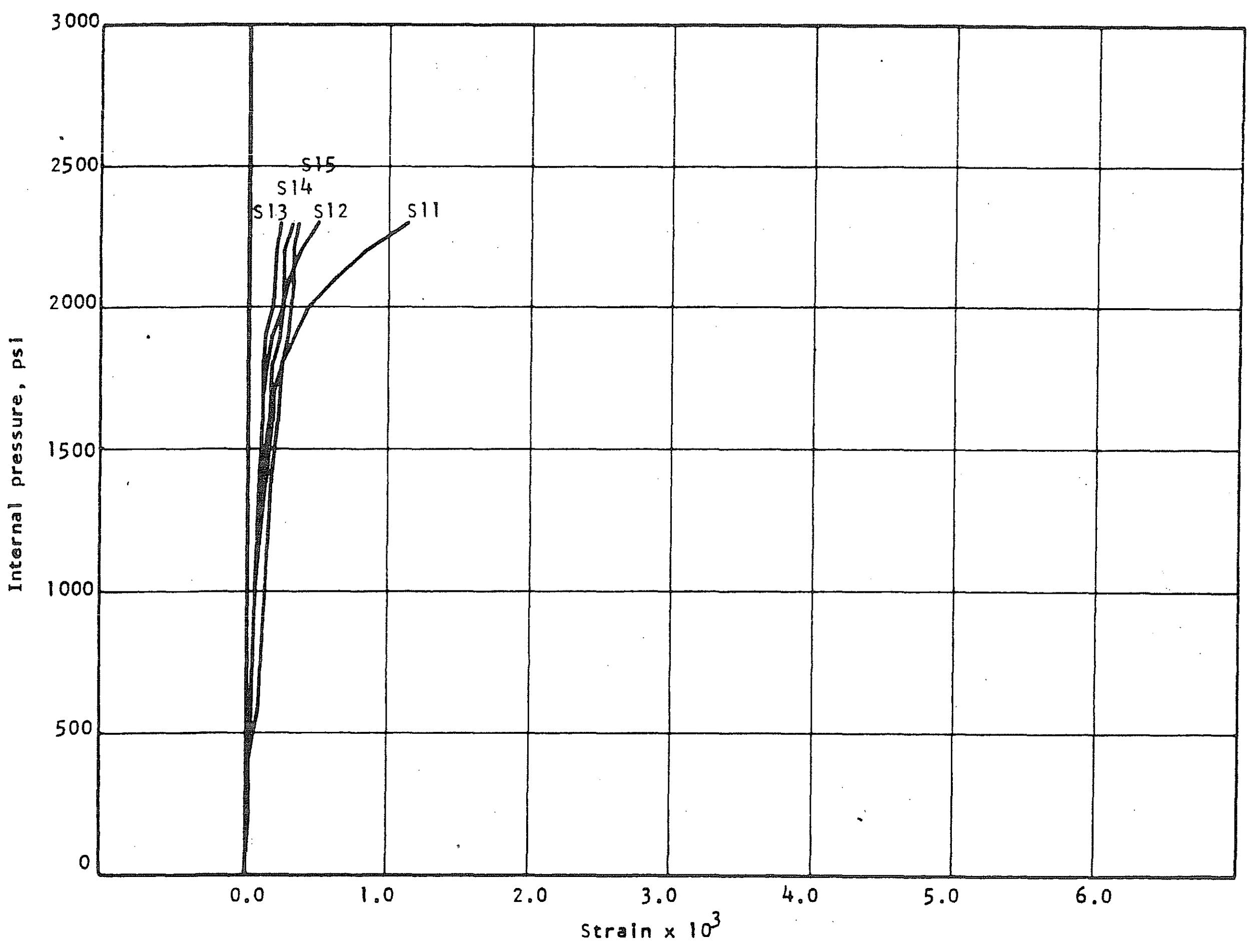


FIG. B15.9 APPLIED PRESSURE vs STRAIN IN CIRCUMFERENTIAL PRESTRESS WIRE AT THE S-END OF THE N-S DIAMETER OF PV15

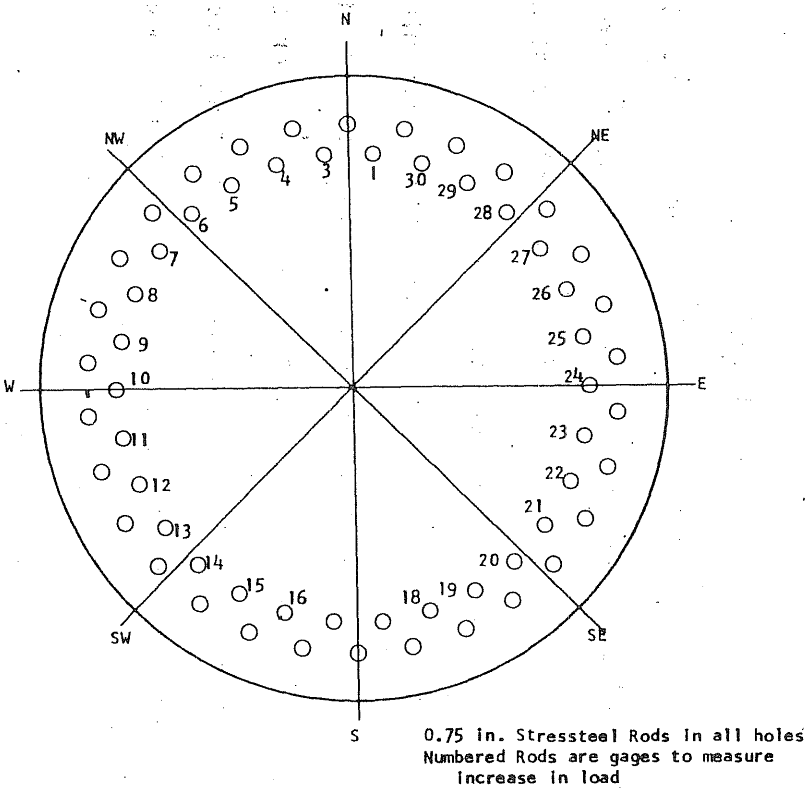


FIG. B15.10 LOCATION OF LONGITUDINAL REINFORCEMENT

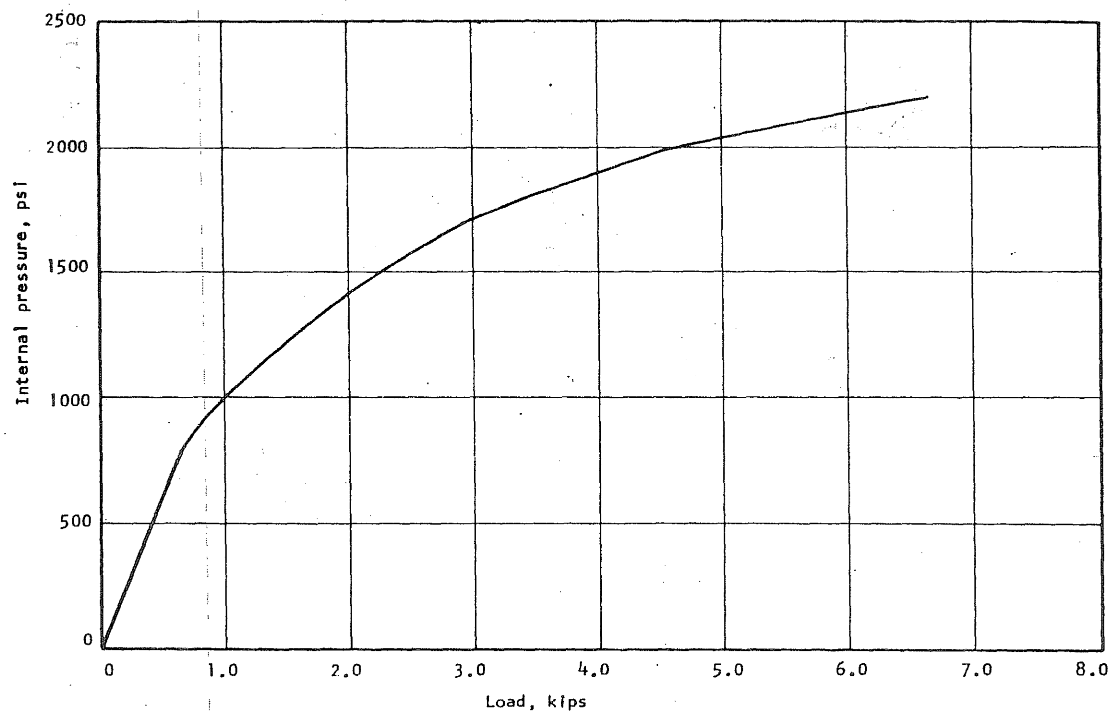


FIG. B15.11 APPLIED PRESSURE vs INCREASE IN LOAD IN STRESSTEEL ROD No. 13

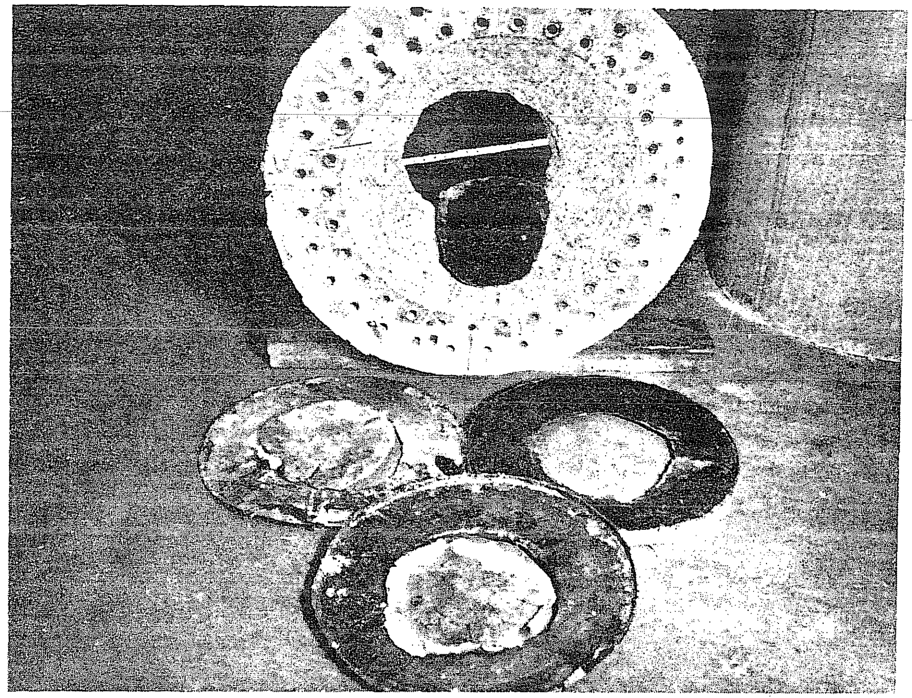


FIG. B15.12 END SLAB AND LINER AFTER FAILURE FOR PV15

B16 Test Vessel PV16 (t = 10 in., s = 1/4 in.)

Test vessel PV16 was cast in the same manner as PV15. The sealing details and longitudinal prestressing were also the same. Due to unforeseeable delays the vessel was prestressed 25 days before the test was conducted. During that period the vessel was represtressed twice.

The vessel was loaded with gas and failed about five minutes after a load of 3200 psi had been obtained. The creep in the vertical deflection gage at 3200 psi was quite large and increasing in speed. After the test it was noticed that two of the outer circle prestress rods stripped their threads during the latter stages of the test. Figure B16.12 shows the end slab after failure.

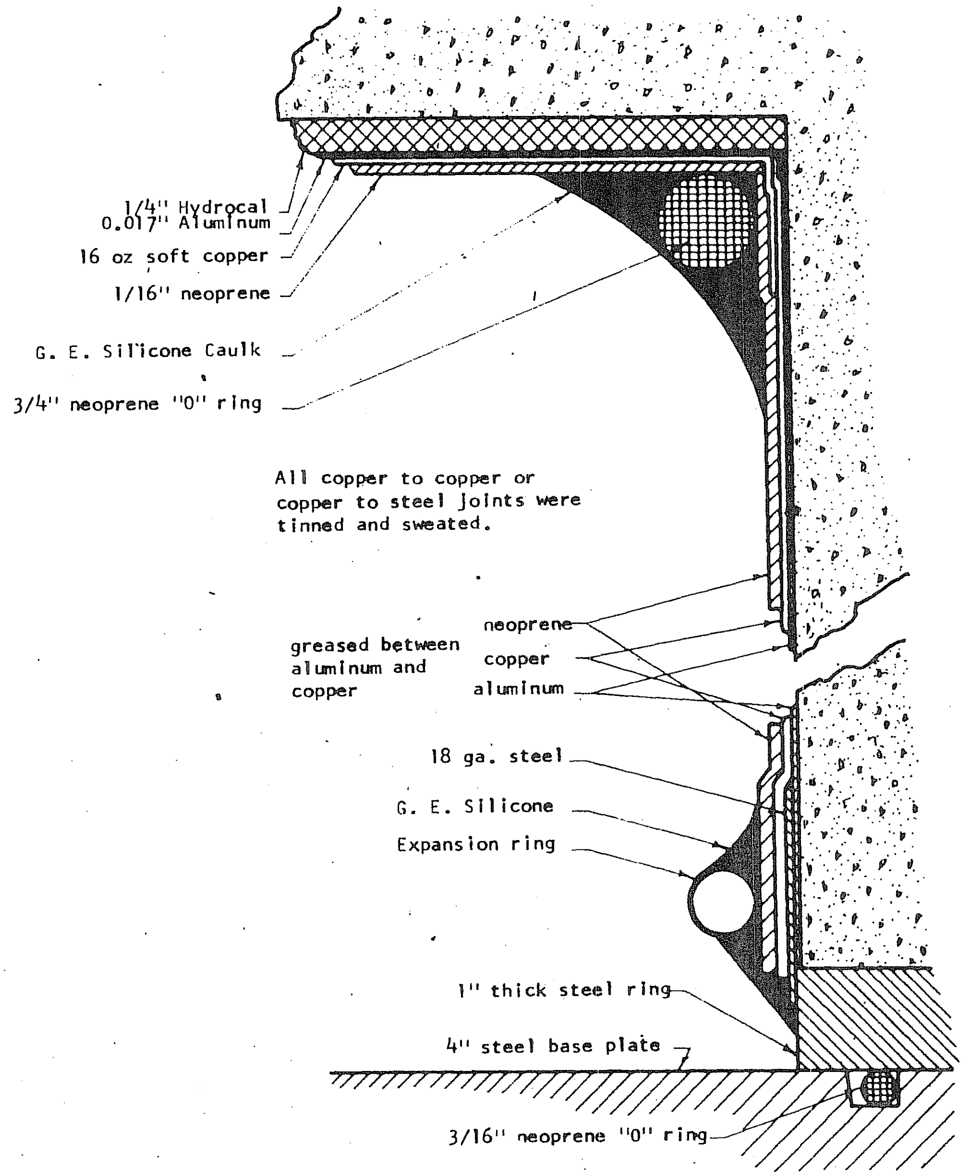


FIG. B16.1 SEALING DETAIL FOR PV16

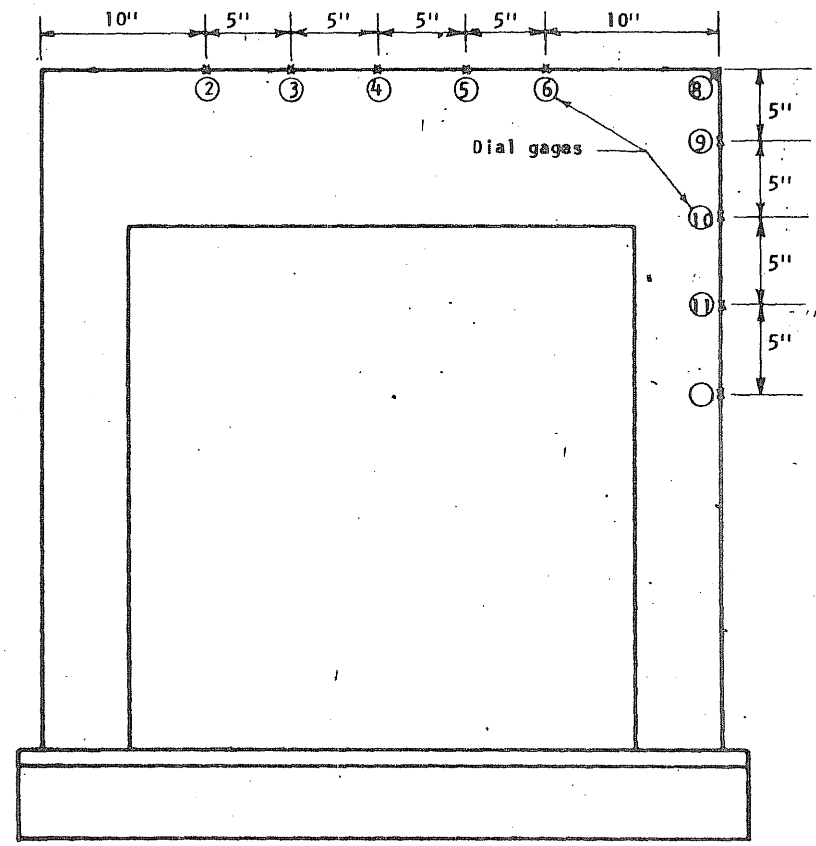


FIG. B16.2 LOCATION OF DEFLECTION GAGES ON PV16

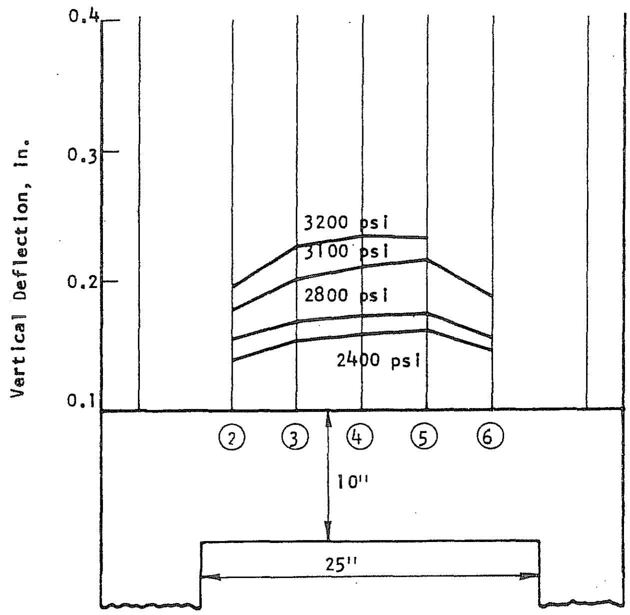


FIG. B16.3 DEFLECTION PROFILES OF THE END SLAB ALONG THE N-S DIAMETER OF PV16

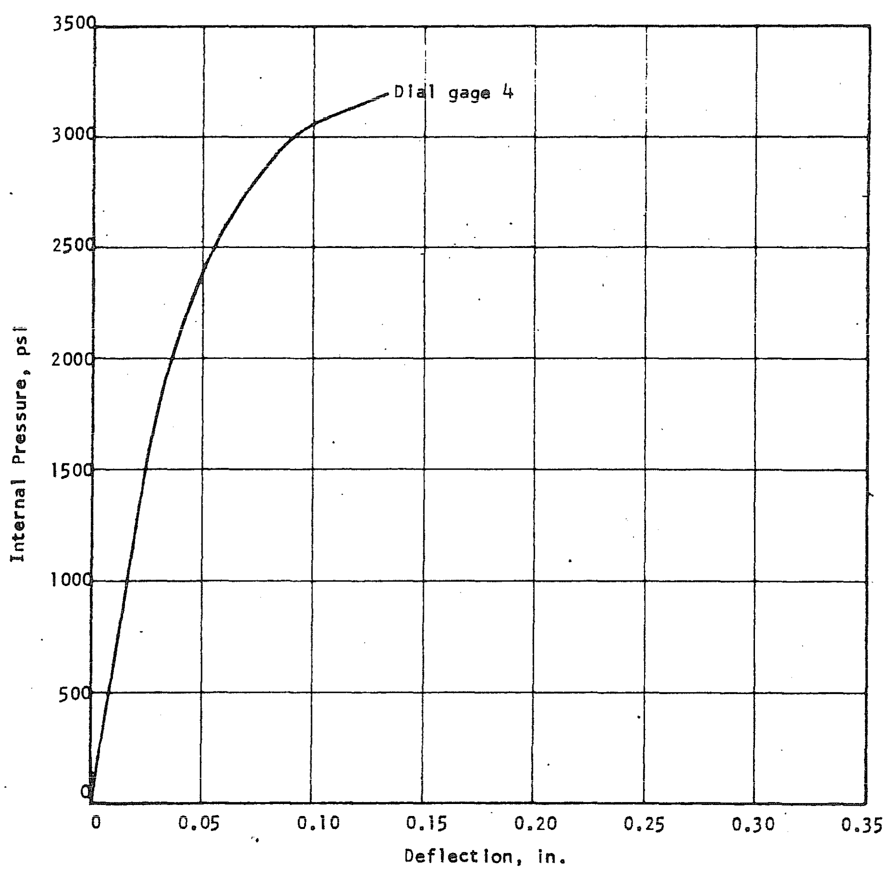
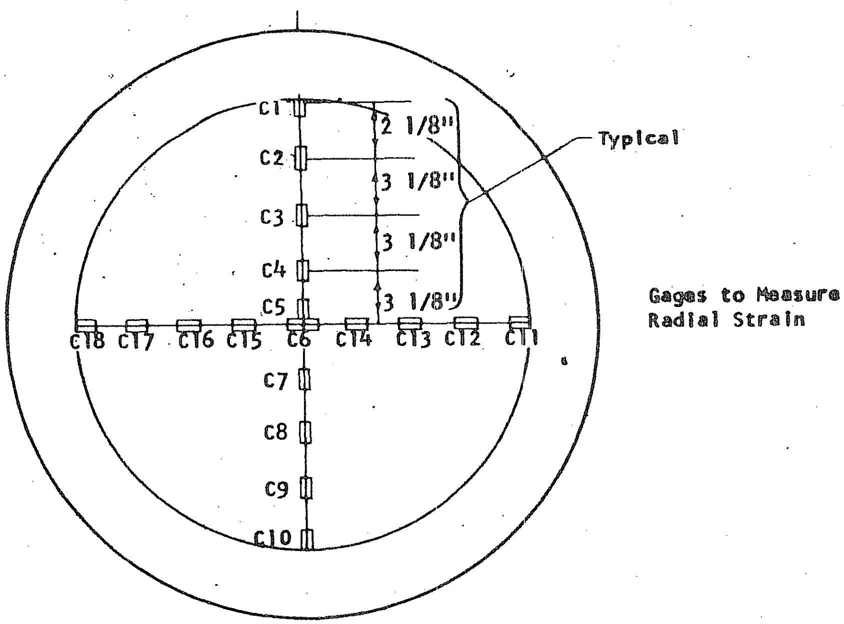
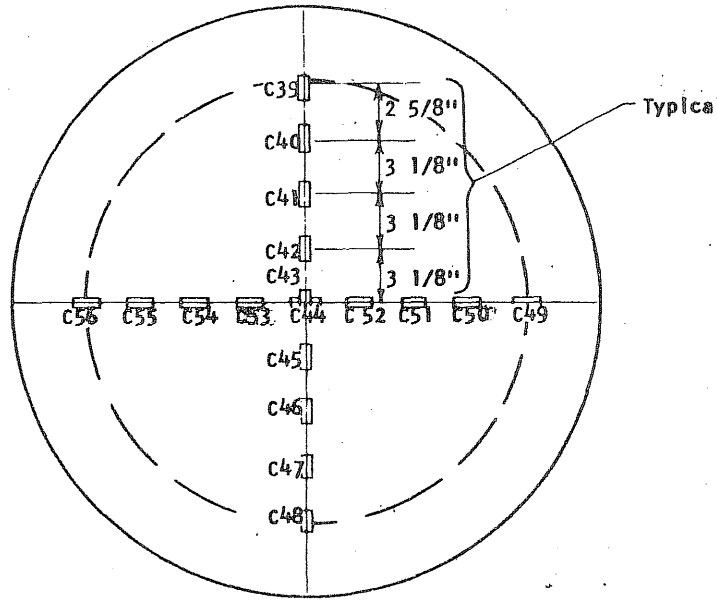


FIG. B16.4 APPLIED PRESSURE vs DEFLECTION AT MIDSPAN OF PV16

Concrete Gages on the Inside of the End Slab



Concrete gages on the Outside of the End Slab



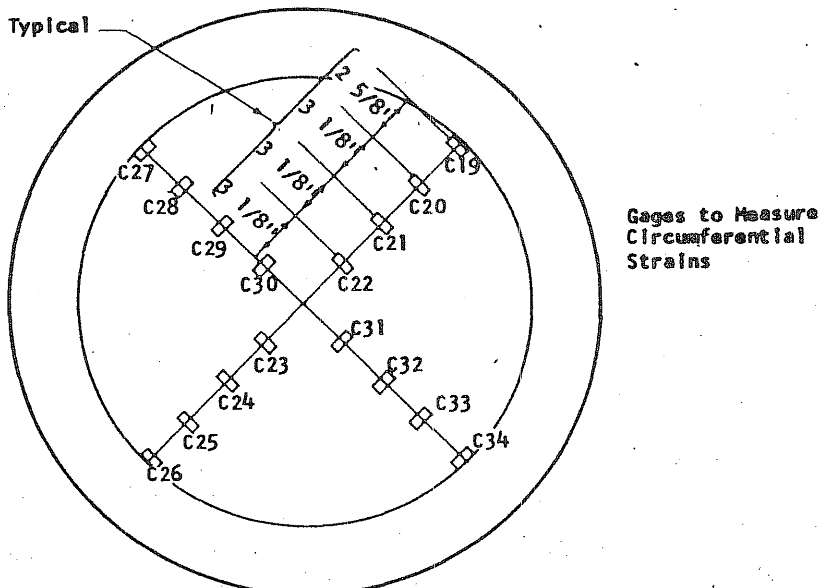
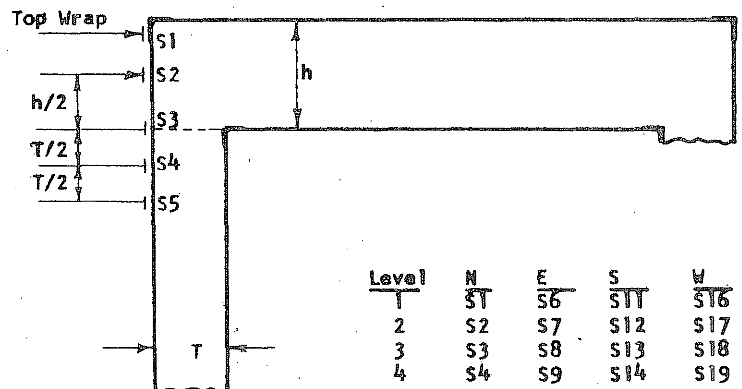


FIG. B16.5 STRAIN GAGE LOCATIONS ON PV16

Steel Gages on Circumferential Prestress Wire



Level	N	E	S	W
1	S1	S6	S11	S16
2	S2	S7	S12	S17
3	S3	S8	S13	S18
4	S4	S9	S14	S19
5	S5	S10	S15	S20

FIG. B16.5 (contd) STRAIN GAGE LOCATIONS ON PV16

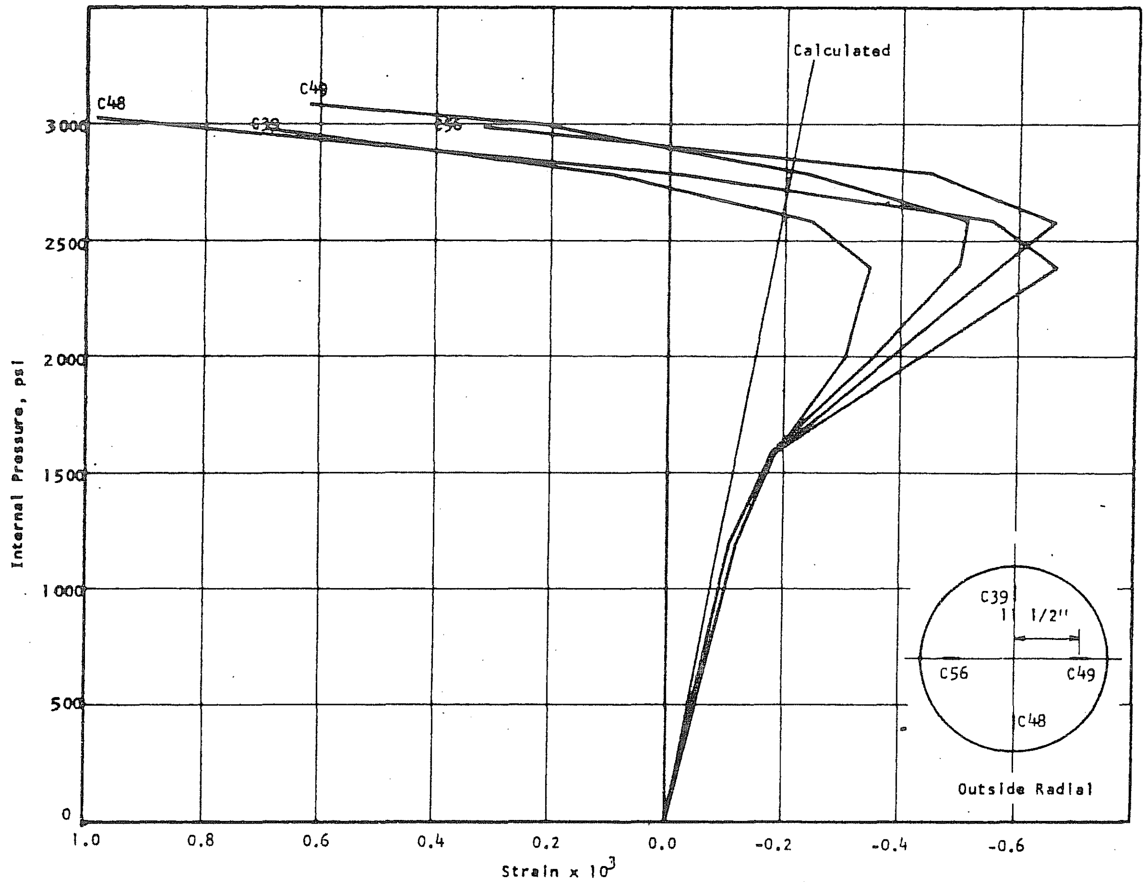


FIG. B16.6 CONCRETE STRAINS, VESSEL PV16

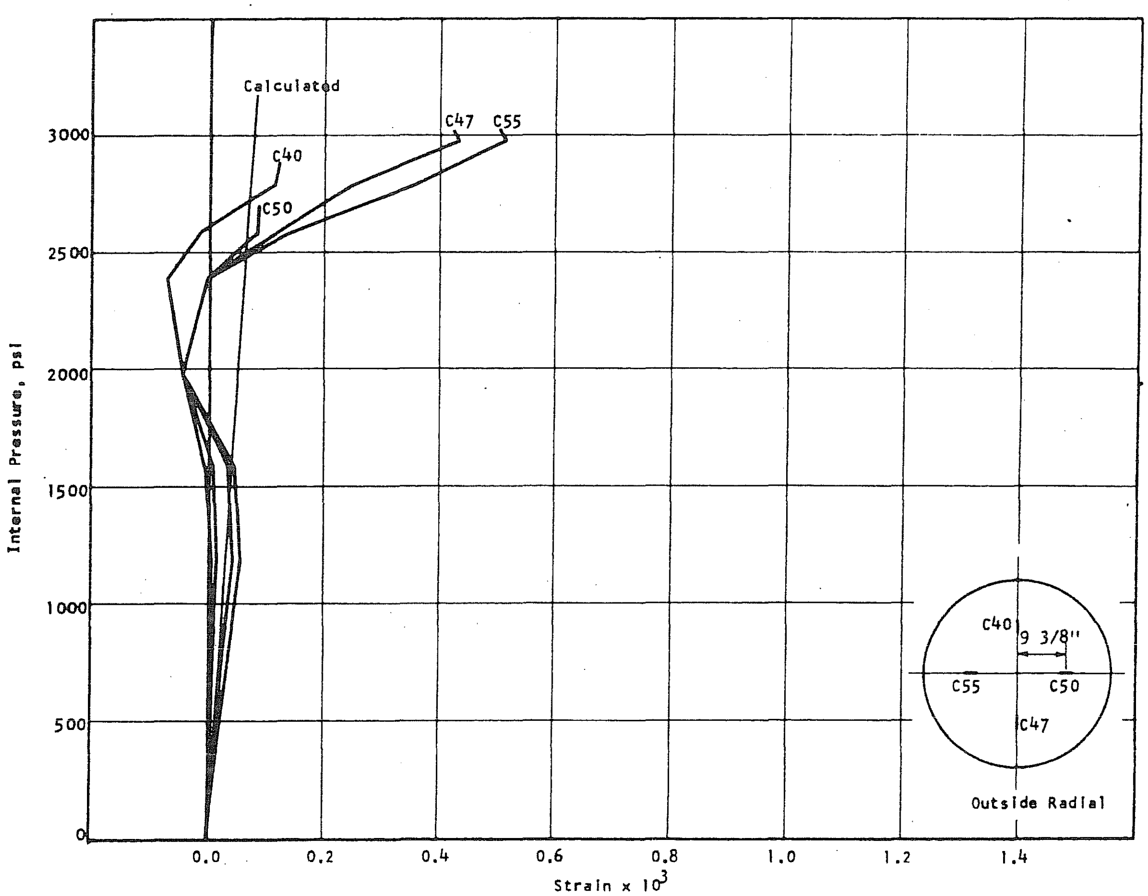


FIG. B16.6 (cont'd) CONCRETE STRAINS, VESSEL PV16

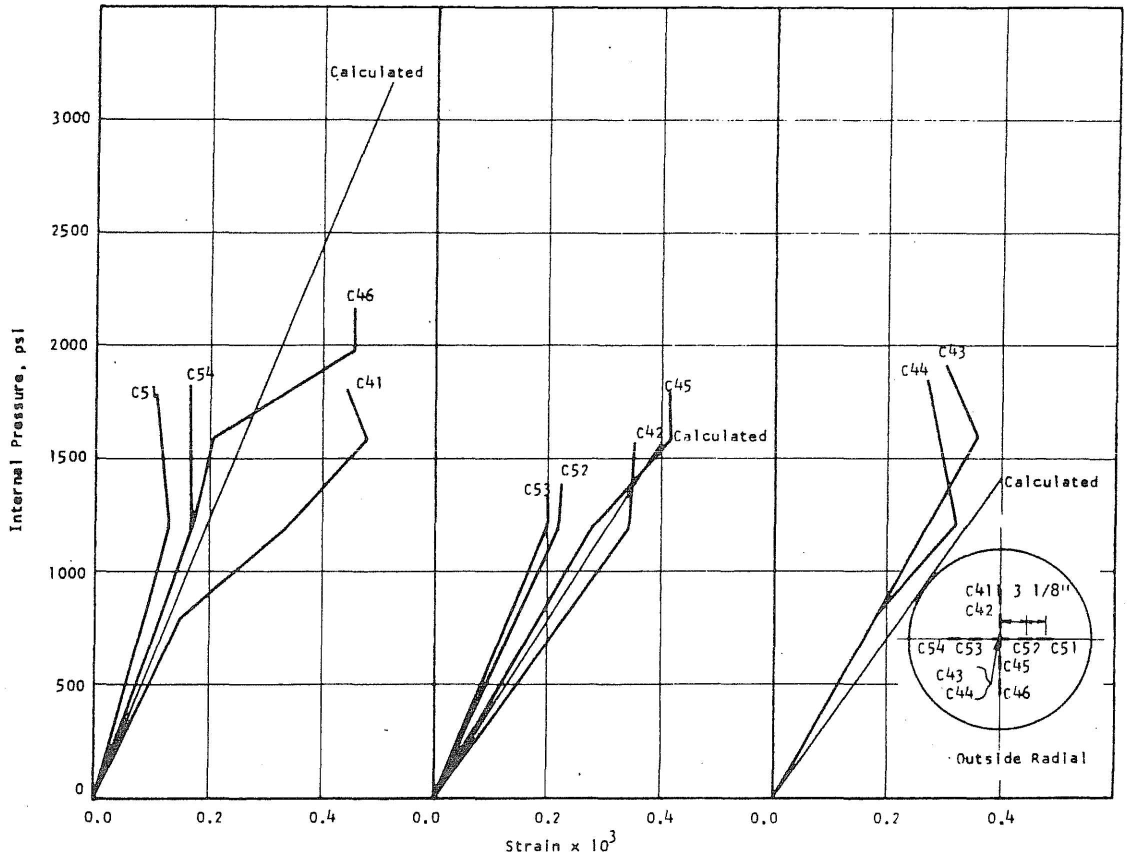


FIG. B16.6 (cont'd) CONCRETE STRAINS, VESSEL PV16

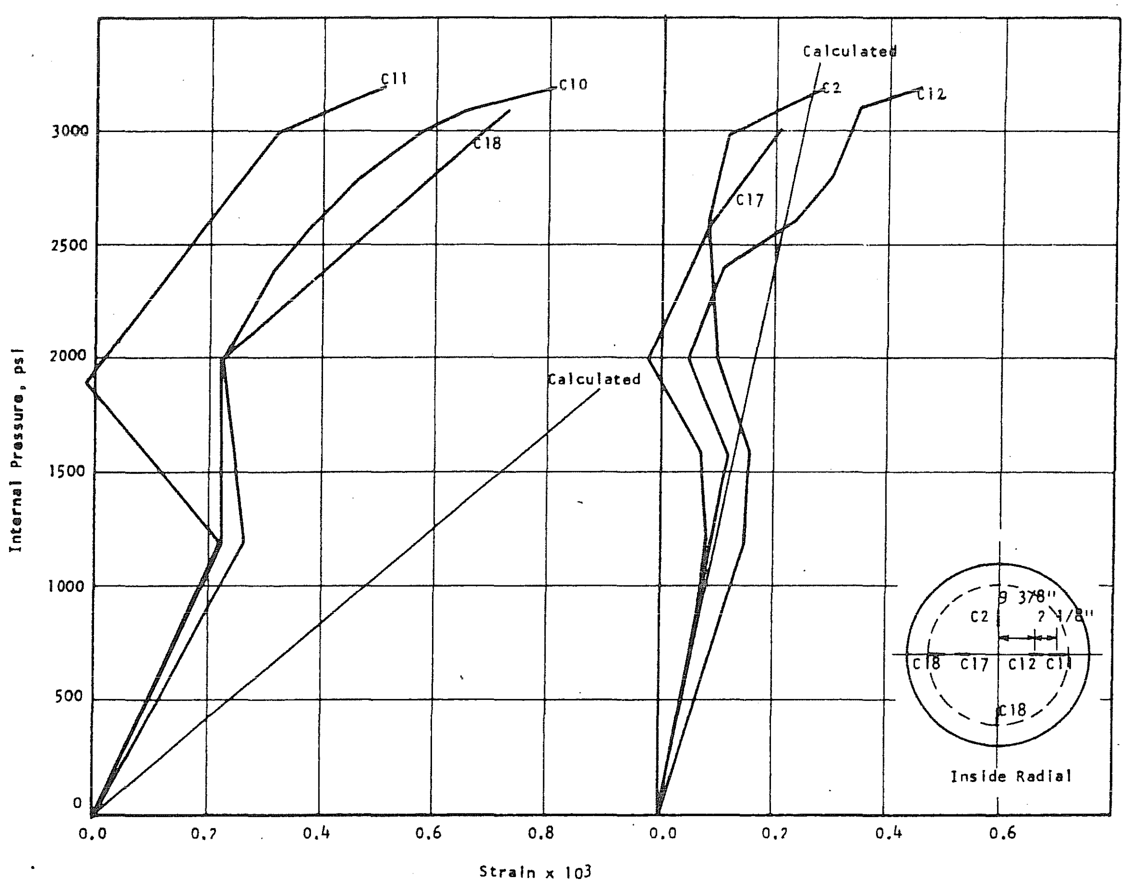


FIG. B16.7 CONCRETE STRAINS, VESSEL PV16

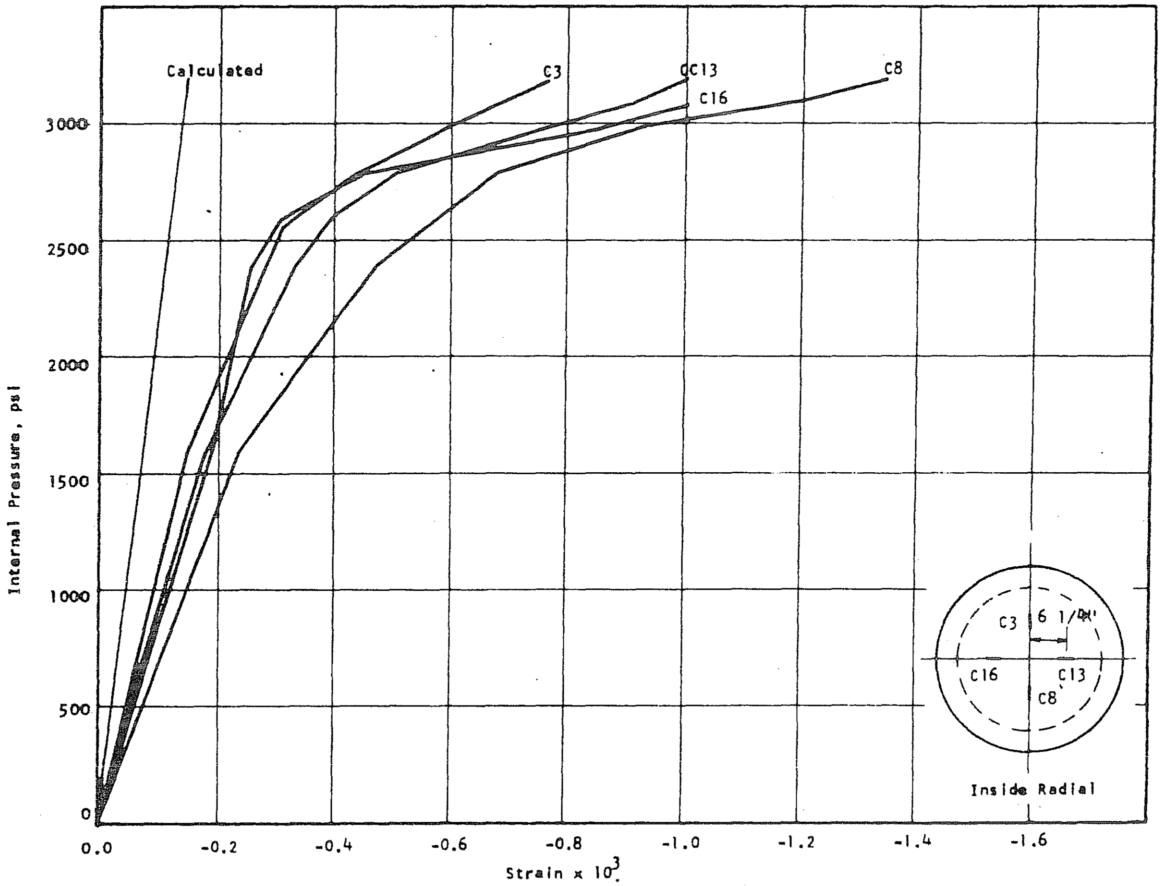


FIG. B16.7 (cont'd) CONCRETE STRAINS, VESSEL PV16

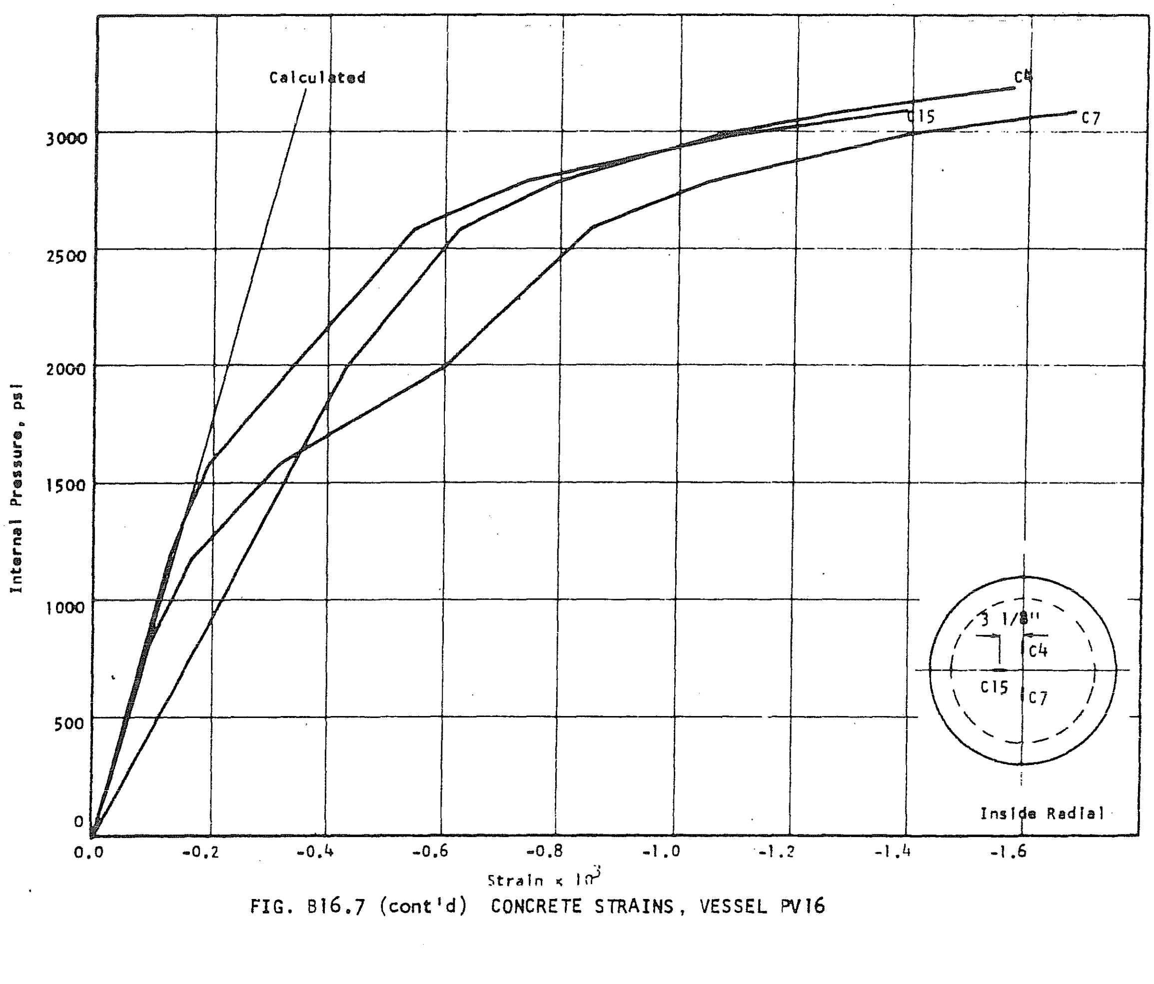


FIG. B16.7 (cont'd) CONCRETE STRAINS, VESSEL PV16

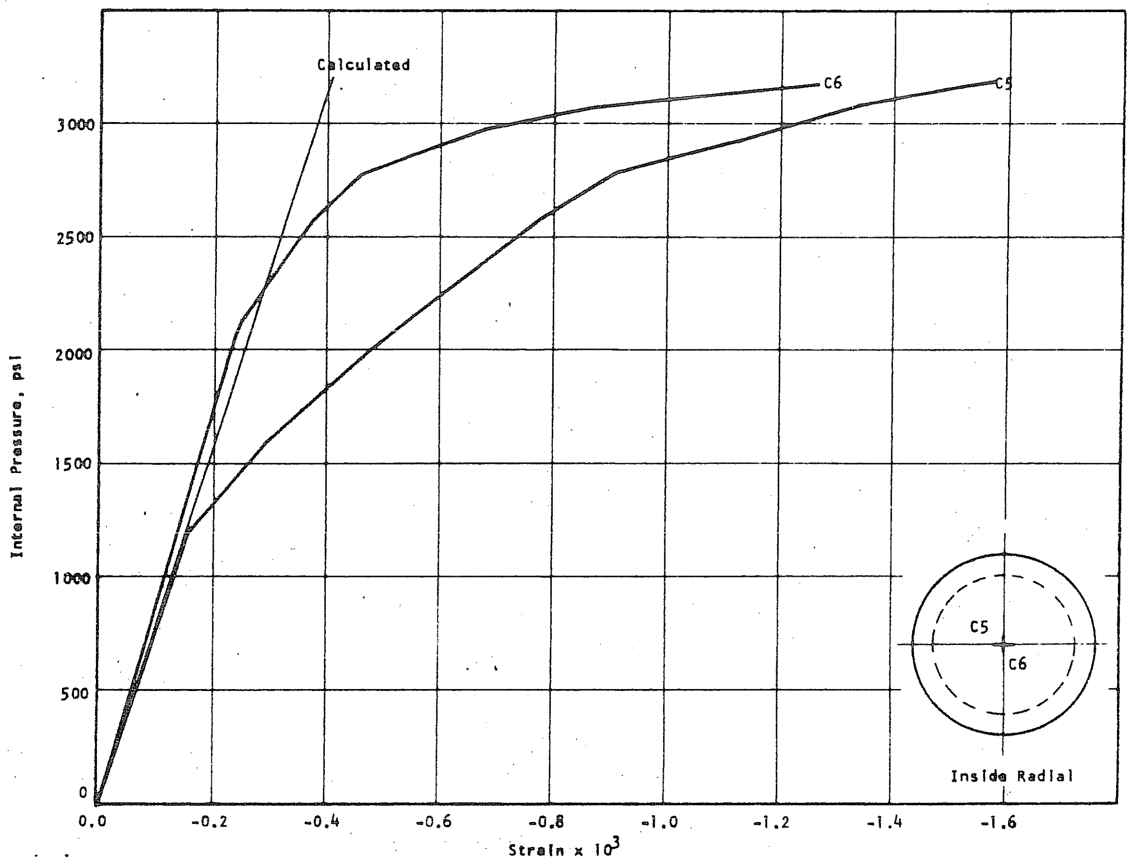


FIG. B16.7 (cont'd) CONCRETE STRAINS, VESSEL PV16

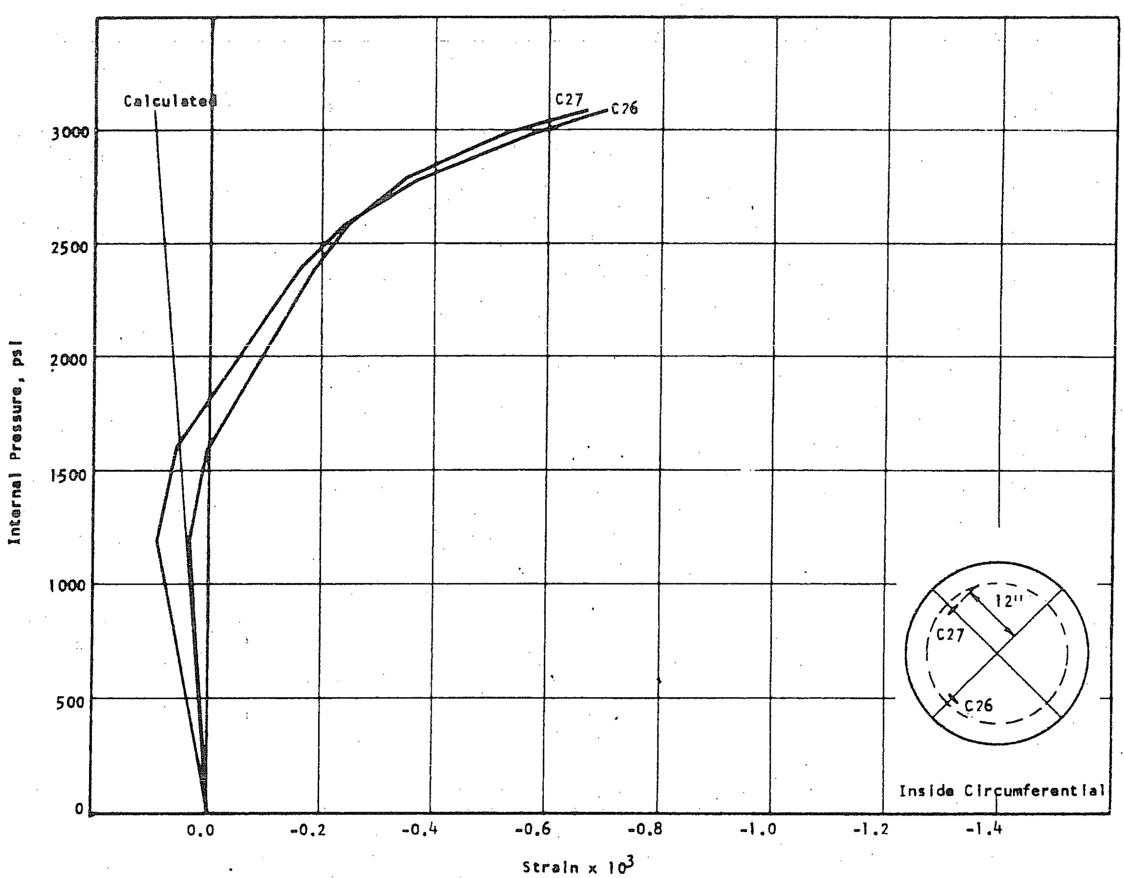


FIG. B16. 8 CONCRETE STRAINS, VESSEL PV16

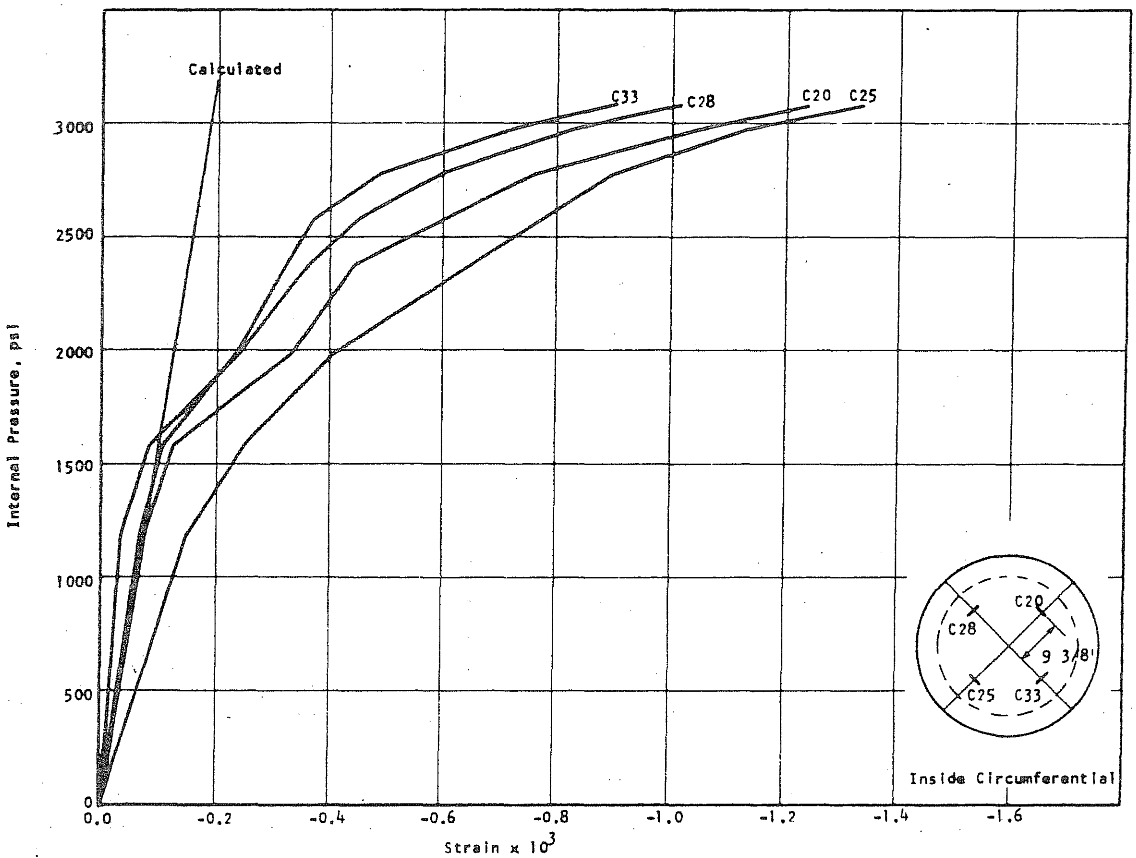


FIG. B16.8 (cont'd) CONCRETE STRAINS, VESSEL PV16

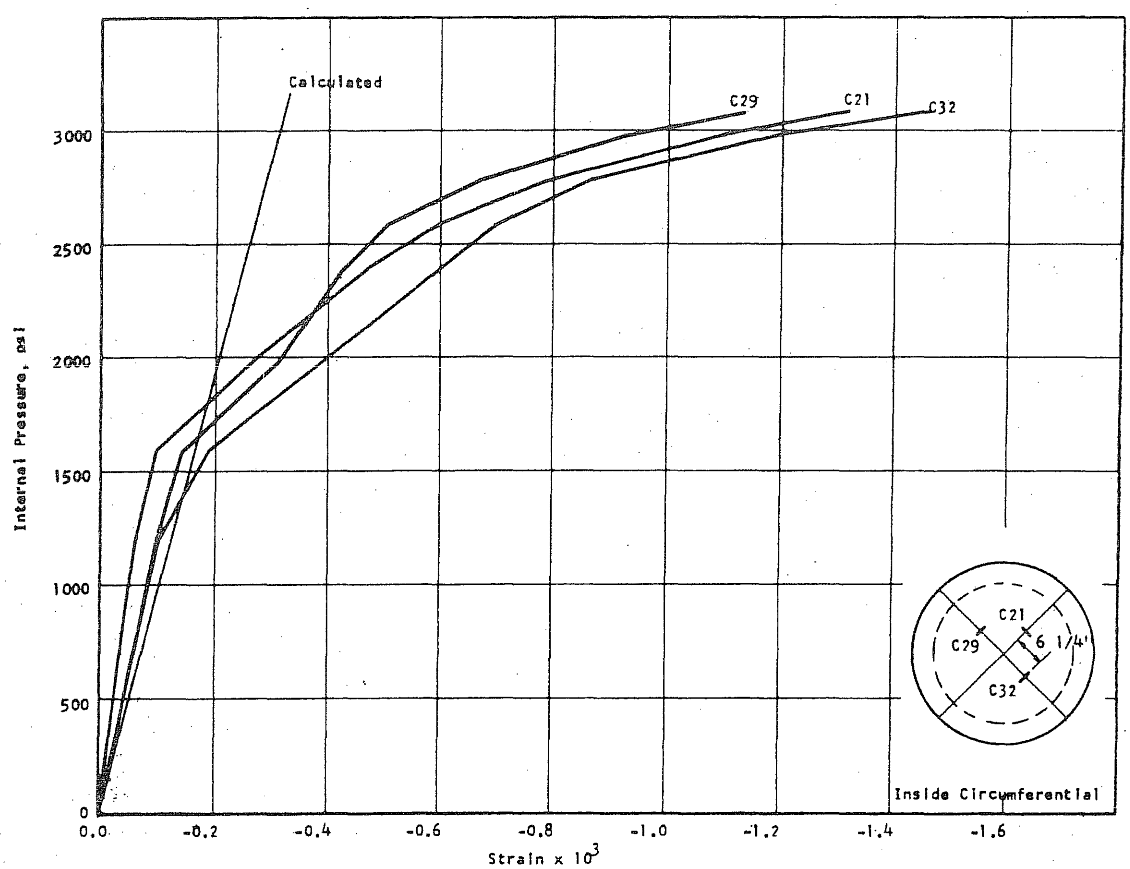


FIG. B16.8 (cont'd) CONCRETE STRAINS, VESSEL PV16

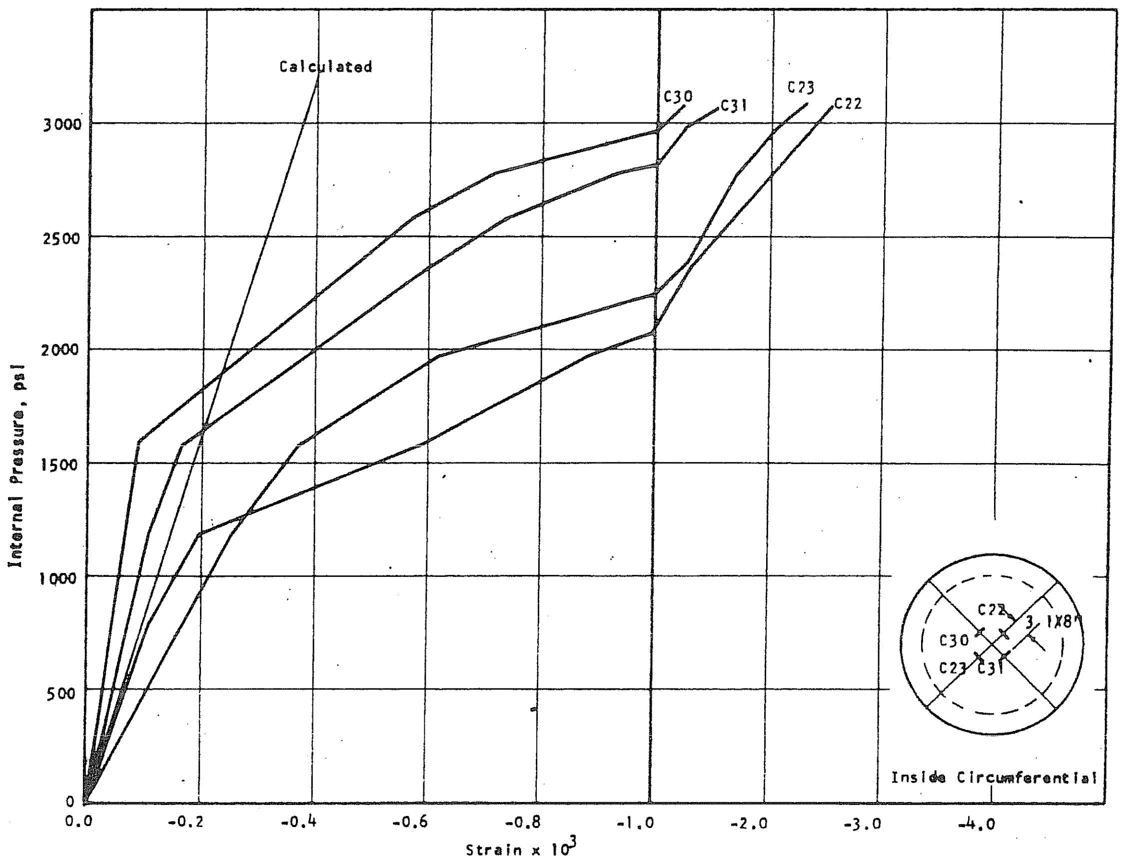


FIG. B16.8 (cont'd) CONCRETE STRAINS, VESSEL PV16

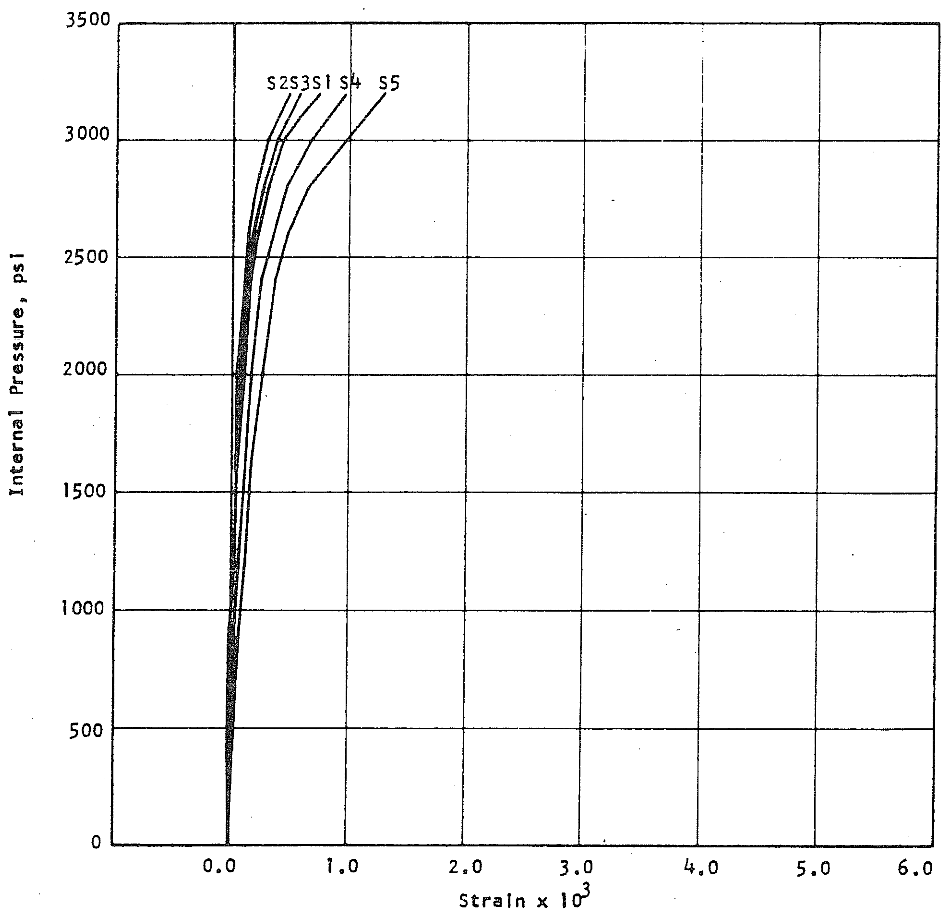


FIG. B16.9 APPLIED PRESSURE vs STRAIN IN CIRCUMFERENTIAL PRESTRESS WIRE AT THE N-END OF THE N-S DIAMETER OF PV16

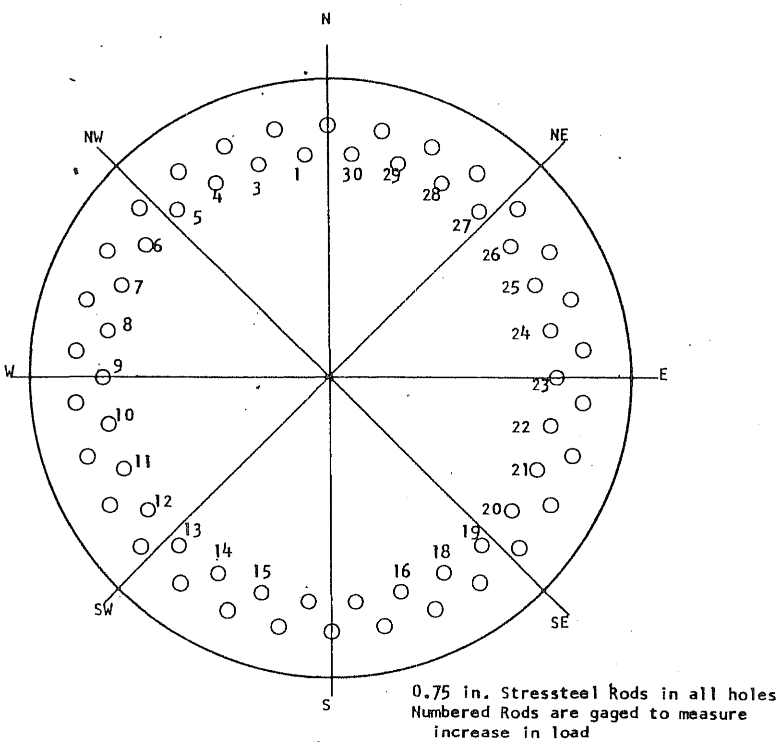


FIG. B16.10 LOCATION OF LONGITUDINAL REINFORCEMENT

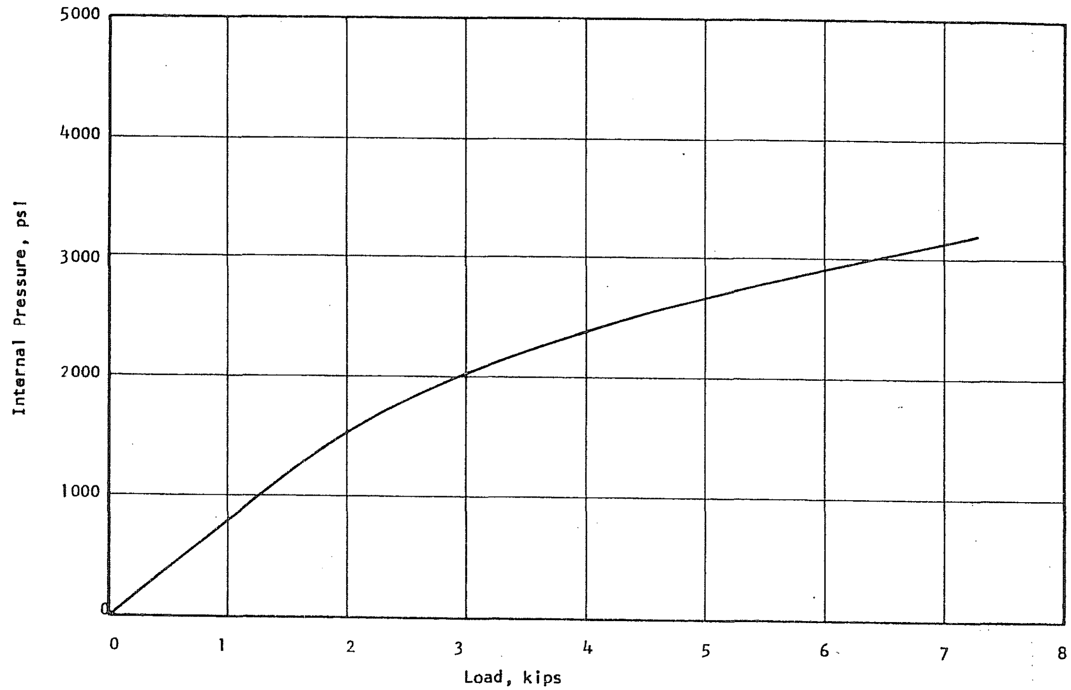


FIG. B16.11 APPLIED PRESSURE vs INCREASE IN LOAD IN STRESSTEEL ROD No. 13

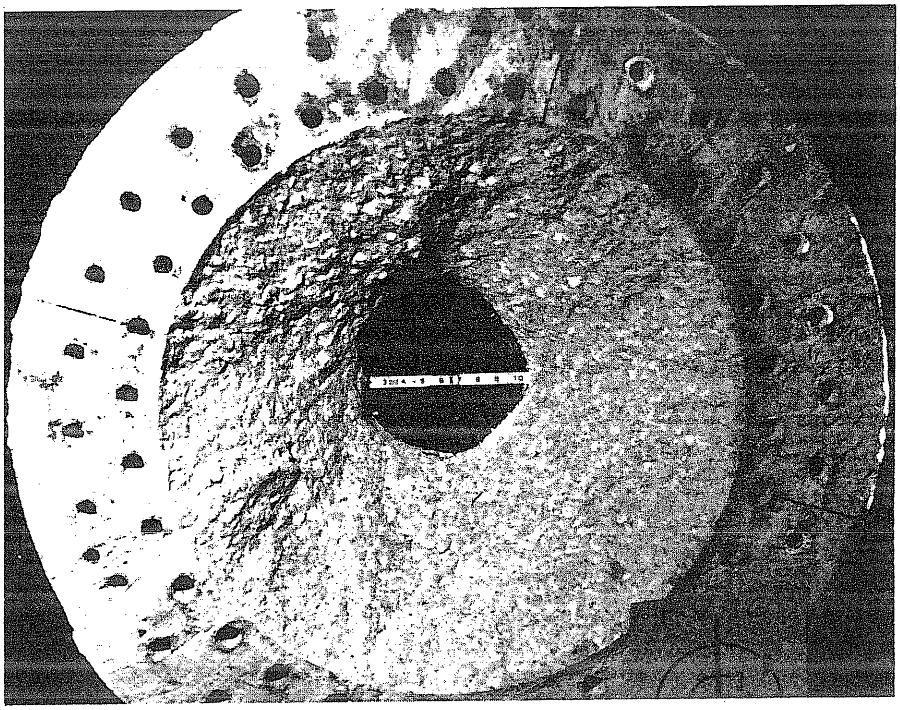


FIG. B16.12 END SLAB AFTER FAILURE

APPENDIX C

STRAIN DISTRIBUTION IN THE CIRCUMFERENTIAL REINFORCEMENT

C1 Description of the Tests

Analysis of the data from pressure tests of the vessels indicated that failure occurred in the circumferential prestress wire at an average strain much less than that which resulted in failure of wire specimens tested in direct tension. This premature wire fracture appeared to be caused by a concentration of strain at cracks in the concrete vessel walls. Tests were performed to check this observation.

A reinforced concrete disk was cast with a joint on a diameter to simulate a crack in the end slab of a test vessel. The concrete disk is shown in Fig. C1. Prestressing wire with a 0.192-in. diameter was wrapped around the disk, and the two halves of the disk were forced apart with a hydraulic jack, forcing the crack to open and at the same time imposing additional strain in the prestressing wire. During the tests the concrete disk lay on three-inch diameter pipe rollers to reduce friction between the disk and floor, and was held parallel to the floor with a steel channel section over the disk and loosely attached to the floor.

Opening of the crack was measured at both ends of the diameter with dial gages and the wire in the vicinity of the crack at one end of the diameter was instrumented with electrical resistance type strain gages. Also the force required to push the halves of the concrete disk apart was measured.

Three tests were performed with this arrangement. There was only one wrap of wire around the disk. A prestressing force was applied to the wire before the halves of the concrete disk were forced apart. This prestress force was applied with the arrangement shown in Fig. C2 and a load cell was used under the prestress jack to measure the force applied and the change of force at the ends of the wire during the test. The strain gages were placed on the wire after the prestressing force was applied. The jack used to force the halves of the concrete disk apart was placed off center 1/2 in. to assure that fracture of the wire occurred on the side which was instrumented.

C2. Shear Stress Between the Wire and Concrete

An analysis of the relation between shear force along the wire and variation of stress in the wire may be made if certain simplifying assumptions are made. Assume that there is some prestress in the wire which is applied without obtaining a shear stress between the wire and concrete so that the prestress force is uniform. The equilibrium of a section of wire between a crack and the point one-half the distance to the next crack, as shown in Fig. C3 is then investigated. Distance along the wire, x, is measured from the crack. Let F_x be the force at x in the wire, F_o the initial force in the wire, μ the coefficient of friction between the wire and concrete, and R_o the radius of the concrete disk about which the wire is wrapped. From Fig. C3 it is apparent that the rate of change in force at some distance x along the wire is

$$\frac{dF_x}{dx} = \mu \frac{F_x}{R_o} \qquad \text{(C1)}$$

where F_x is a function of x. This expression may be written

$$\frac{dF_x}{F_x} = \frac{\mu}{R_o} \, dx$$

Integration of this expression yields

$$\log F_x + C = \frac{\mu}{R_o} x$$

At x = o, F_x is equal to the force in the wire at the crack, F_o, which gives C = -log F_o. The above equation may then be written

$$\log \frac{F_x}{F_o} = \frac{\mu}{R_o} x \text{ or } \mu = \frac{R_o}{x} \log \frac{F_x}{F_o} \qquad \text{(C2)}$$

The wire on the test vessel approaches the conditions assumed in this analysis more nearly than does that in the wire friction tests described in the last section. In the wire friction tests the opening of the cracks was much larger so that the movement between the wire and concrete was greater. One would expect this to affect the friction coefficient between the two surfaces since the movement would alter the surface characteristics of the concrete. The wire in these tests was prestressed by pulling the ends of the wire around the concrete disk as explained earlier. This prestress caused a friction force between the wire and concrete in the direction opposite to that which would occur when the two halves of the disk are pushed apart on the section of wire which was gaged. As the halves of the disk are pushed apart, this initial shear stress must be relieved before any strain can be applied to the wire. Since the strain gages are applied with this reversed shear stress in the wire, the initial wire strain will appear to be a compression, though it is actually a slight relief of some of the initial tension in the wire.

The difference in force in the wire at a crack and away from the crack must result from friction between the wire and concrete. The maximum value of this force depends upon the coefficient of friction between the two surfaces and the distance between the cracks since the friction force will build up only over one-half the distance to the next crack. If the shear force is sufficient to cause the strainat the crack to be in the plastic range while that away from the crack is still below this range, then additional strain will be concentrated at the crack.

C3 Results of the Tests

Though there are certain basic differences between the conditions at the crack in the wire test and in the vessel tests, the pertinent basic information for understanding the wire behavior at a crack can be obtained from the wire tests. It is seen from Fig. C4, C5, and C6 that there is a definite strain concentration in the vicinity of a crack. In these graphs the variation of strain with distance from the crack is shown for several load increments for the three tests. The magnitude of strain concentration at the crack recorded in these tests depends to a large measure on whether a strain gage was located very near the failure region in the wire. The magnitude is sufficient, however, to cause failure of the wire to occur at the crack, and in Fig. C6 for example, when the load was maximum the highest strain read near the crack was 0.022 while that read at 7 in. from the crack was 0.0066.

Any numerical value of strain concentration given must be based on an arbitrary definition of what is meant by strain concentration; that is, on what level of strain the concentration is based since the strain is varying continuously along the wire. Also, the concentration of strain will depend on the spacing of cracks, the force in the wire, and on the coefficient of friction between the wire and concrete. In the test vessels the cracks were closely spaced so the results obtained from these friction tests probably represent an upper limit on the concentration factors, but the coefficient of friction should be representative of that in the test vessel.

In Fig. C4, C5, and C6 the curves are labeled with the forces at the crack found from the difference in the load cell forces. If these forces are assumed to be correct and a straight line is drawn to average the points from the crack out to 31 in. to the right for the curve labeled 4400 lb in Fig. C4, the difference in force can be found from this strain difference. This force difference is found to be 2100 lb and the force at 31 in. from the crack is then 2300 lb. Substitution of these forces into Eq. C2 gives

$$\mu = \frac{20 \text{ in.}}{31 \text{ in.}} \log \frac{2300 \text{ lb}}{4400 \text{ lb}} = 0.42$$

This value appears high. In Ref. C1 a value of approximately 0.33 is reported. Figure A7 shows the stress-strain curve for the 0.192 in. prestress wire. A stress of 230 ksi is well within the yield range while 220 ksi is well below the flat portion of the curve. This difference of 10 ksi represents a force difference of 290 lb. If a force of 4400 lb is assumed at the crack (certainly a lower limit) and a value of $\mu = 0.33$, then the distance required to obtain this force difference may be found from Eq. C2

$$0.33 = \frac{20 \text{ in.}}{x} \log \frac{4110}{4400}$$

$$x = 4.1 \text{ in.}$$

It is apparent that sufficient force difference could be developed in the wire to cause an appreciable strain concentration.

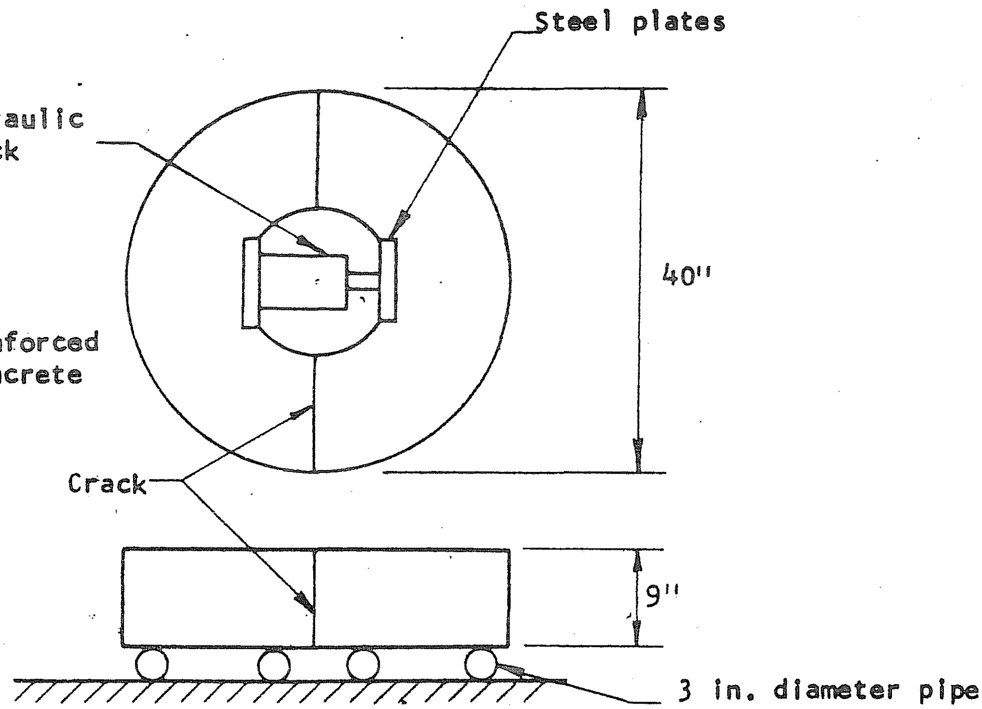


FIG. C1 TEST ARRANGEMENT FOR FRICTION TESTS OF PRESTRESS WIRE

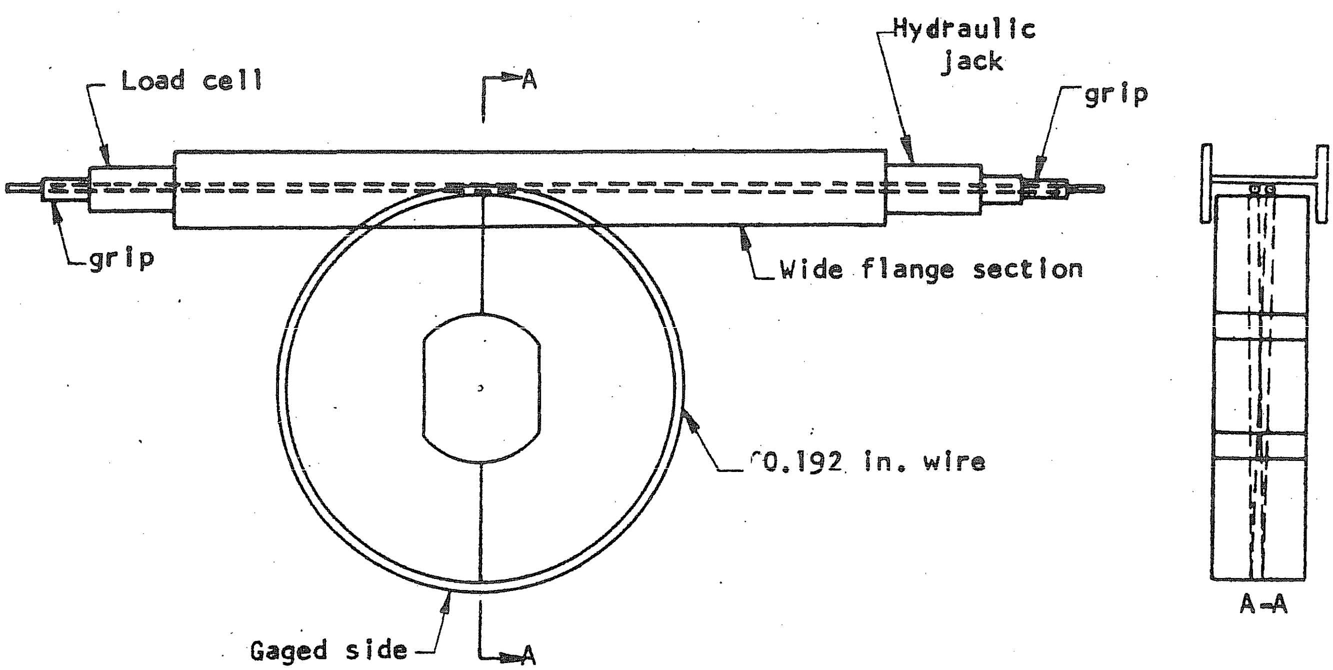


FIG. C2 ARRANGEMENT FOR PRESTRESSING THE WIRE FOR THE FRICTION TESTS

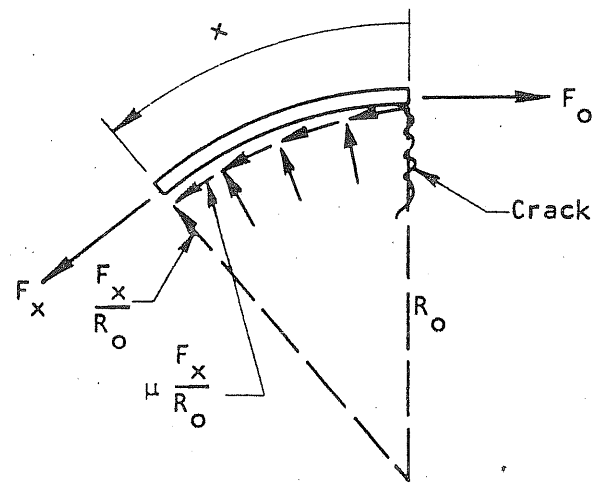


FIG. C3 FORCES ACTING ON A SECTION OF PRESTRESS WIRE AT A CRACK

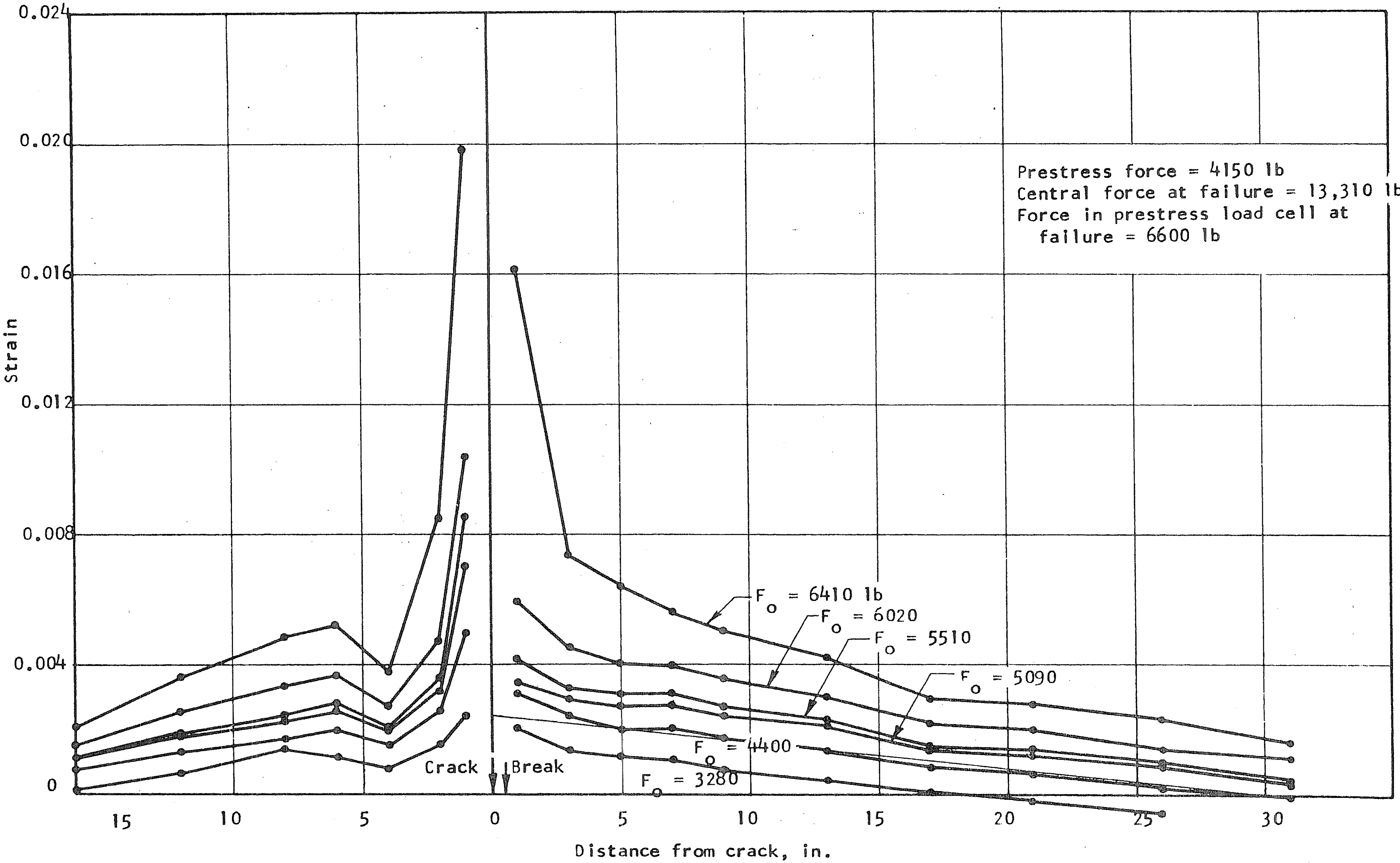


FIG. C4 STRAINS MEASURED ABOVE PRESTRESS STRAINS vs DISTANCE FROM THE CRACK AT SEVERAL LOADS FOR TEST No. 1

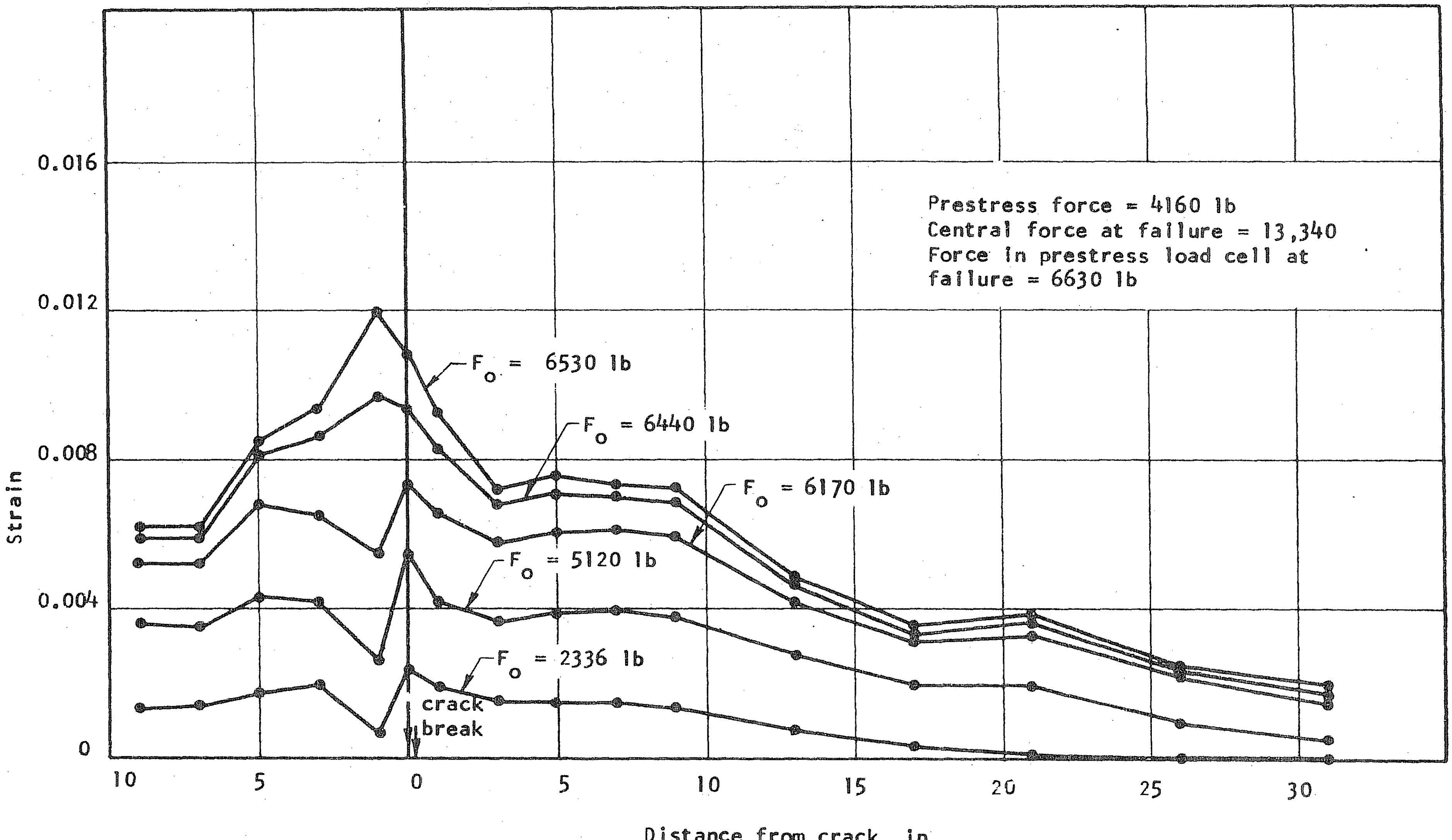


FIG. C5 STRAINS MEASURED ABOVE PRESTRESS STRAINS vs DISTANCE FROM THE CRACK AT SEVERAL LOADS FOR TEST No. 2

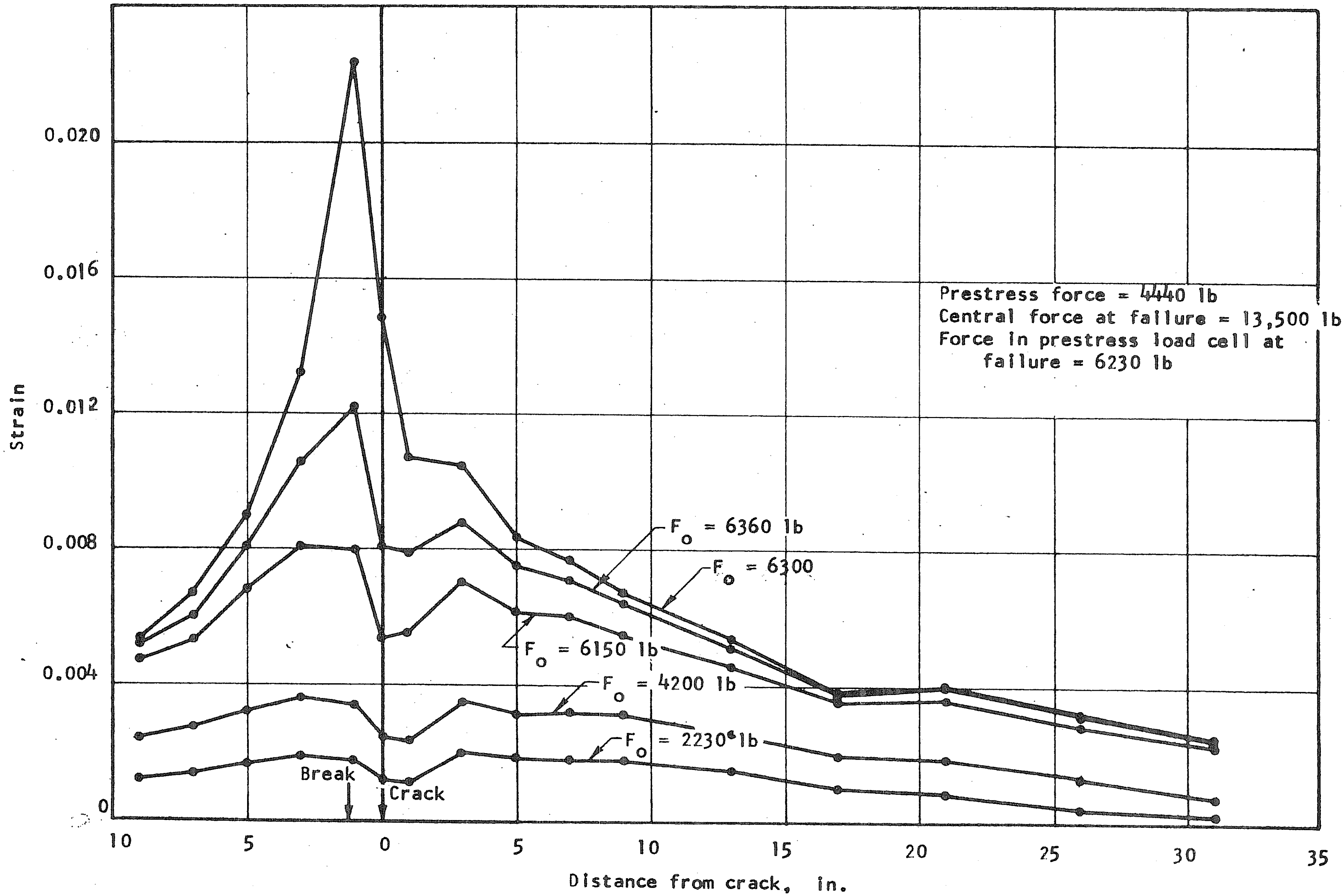


FIG. C6 STRAINS MEASURED ABOVE PRESTRESS STRAINS vs DISTANCE FROM THE CRACK AT SEVERAL LOADS FOR TEST No. 3

APPENDIX D

STIFFNESS MATRIX FOR LUMPED-PARAMETER ELEMENT

The stiffness matrix for a typical node m is

$$[\bar{k}_m] = 2\pi r_m \ (L_r L_z/2 \ [k_m]$$

The element of the symmetric matrix k_m are given by

$$k_{11} = (1/L_z^2)c_{44}$$

$$k_{21} = 0$$

$$k_{22} = (1/L_z^2)c_{22}$$

$$k_{31} = 0$$

$$k_{32} = (1/L_r L_z)c_{12} - (1/2r_m L_z)c_{23}$$

$$k_{33} = (1/L_r^2)c_{11} - 2(1/2r_m L_r)c_{13} + (1/4r_m^2)c_{33}$$

$$k_{41} = (1/L_r L_z)c_{44}$$

$$k_{42} = k_{43} = 0$$

$$k_{44} = (1/L_r^2)c_{44}$$

$$k_{51} = -k_{11}$$

$$k_{52} = k_{53} = 0$$

$$k_{54} = -(1/L_r L_z)C_{44}$$

$$k_{55} = k_{11}$$

$$k_{61} = 0$$

$$k_{62} = -k_{22}$$

$$k_{63} = -k_{32}$$

$$k_{64} = k_{65} = 0$$

$$k_{66} = k_{22}$$

$$k_{71} = 0$$

$$k_{72} = -(1/L_r L_z)C_{12} - (1/2r_m L_z)C_{23}$$

$$k_{73} = -(1/L_r^2)C_{11} + (1/4r_m^2)C_{33}$$

$$k_{74} = k_{75} = 0$$

$$k_{76} = -k_{72}$$

$$k_{77} = (1/L_r^2)C_{11} + 2(1/2r_m L_r)C_{13} + (1/4r_m^2)C_{33}$$

$$k_{81} = -(1/L_r L_z)C_{44}$$

$$k_{82} = k_{83} = 0$$

$$k_{84} = -(1/L_r^2)C_{44}$$

$$k_{85} = -k_{81}$$

$$k_{86} = k_{87} = 0$$

$$k_{88} = -k_{84}$$

APPENDIX E

COMPUTER PROGRAM LISTING

The computer program used in this study consists of a MAIN routine and a number of SUBROUTINES and FUNCTIONS. The MAIN routine is the control routine of the program in which various SUBROUTINES for reading of input parameters, computation of topological informations, assigning of joint displacement unknown numbers, generation of the stiffness matrix for the complete structure (equilibrium equations), calculation of joint loads for a specified pressure level, solution of equilibrium equations, computation of strains and stresses, etc. are called in. Calculation of various pressure levels corresponding to the cracking stress or the cracking strain at a flexible node is also performed in the MAIN routine.

The computation of the stiffness matrix for the complete structure which is an intermediate major step in the program is performed by the use of several SUBROUTINES. These SUBROUTINES generate the material property matrix (in elastic or in cracking state), the boundary condition matrix (if the node is on the boundary), and the element stiffness matrix for each flexible node. The individual stiffness matrices are then assembled in appropriate manner to obtain the stiffness matrix (equilibrium equations) of the complete structure. The terms in each row of the stiffness matrix between the first and the last non-zero columns are then stored on the DRUM (an auxiliary storage device).

When a crack is initiated at a flexible node or when it is propagated to another node, the equilibrium equations which are affected by the presence of the crack are regenerated and restored on the DRUM for subsequent use. The program maintains a table of information regarding the state of cracking at the flexible nodes (cracking history). This table is updated at the end of each pressure level and it is printed in order to provide the cracking sequence throughout the study. In addition to this table, the displacements, the strains, and the stresses are also updated at the end of each pressure level.

The program is coded in FORTRAN IV language and it is used on the IBM System 360/75 of the University of Illinois. The number of equilibrium equations which can be solved naturally depends on the storage capacity of the computer. However, due to repeated modification and solution of the equilibrium equations, solution of a large number of equations is not economical.

(a)

```
*******************************************************************************
      MAIN
*******************************************************************************
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHP,MW,NW,AK,ITOTI,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
     4        EXCF,SIGICR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
     1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
     3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
     4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
     5            (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
      EXTERNAL DUMP
      DEFINE FILE 2(1400,10,U,IREC)
      CALL ERRSET (200,1,0,2,DUMP,210)
   50 READ (5,100) IIC,IEC,JIP,JEP,N,ICABLE,LRC,LR,LCYC,LG,LPO,LPRCSS,
     1     AHP,FHP,ALR,ALZ,D,EST,EC,PR,ECRIT
  100 FORMAT (12I4,12X,F8.5,F12.2/3F10.5,2E12.4,2F12.6)
      H =         (JEP-1)*ALZ/2.
      TPLATE =          (JEP-JIP)*ALZ/2.
      TCYLDR =          (IEC-IIC)*ALR/2.
      ICBLR = ICABLE-IIC+2
      DOE = TCYLDR-(ICBLR-2)*ALR/2.
      PRF1 = EC/((1.+PR)*(1.-2.*PR))
      PRF2 = (1.-PR)*PRF1
      PRF3 = PR*PRF1
      PRF4 = EC/(2.*(1.+PR))
      IICM1 = IIC-1
      R(1) = 0.
      M = IEC-1
      DO  1 I=1,M
      R(I+1) = R(I)+ALR/2.
      SUMR(I+1) = 1./ALR+0.5/R(I+1)
    1 DIFFR(I+1) = 1./ALR-0.5/R(I+1)
      DIAM = 2.*R(IEC)
      CI = 1.+ALR/(8.*R(IIC))
      CE = 1.-ALR/(8.*R(IEC))
      PHP=FHP/(D*R(IEC))
      MW = JEP-JIP+1
      NW = IEC-IIC+1
      ITOT1 = 2*(((IIC-1)/2)*MW+(2*(IIC/2)-IIC+1)*((MW-1+LRC)/2))
      ITOT = ITOT1+2*(((JIP-1)/2)*NW+(2*(JIP/2)-JIP+1)*((NW-1+LRC)/2)+
     1       (MW/2)*NW+(MW-2*(MW/2))*((NW+2*((LRC+1)/2)-LRC)/2))
      READ (5,101) (ALP(I),FLP(I),I=1,20)
  101 FORMAT (5(F8.5,F8.0))
      IF (JEP-2*(JEP/2)) 24,31,24
```

(b)

```
   24 IF (JIP+LRC-2*((JIP+LRC)/2)) 32,33,32
   31 LADD = 0
      GO TO 37
   32 LADD = -1+2*(LRC/2)
      GO TO 37
   33 LADD = 1-2*(LRC/2)
   37 LCLI = LRC+IIC+JEP-JIP
      IF (LCLI-2*(LCLI/2)) 38,39,38
   38 LCL = 1
      GO TO 40
   39 LCL = 0
   40 L = 0
      K = 1
      I = 2+LCL
      J = JEP+1
      DO 16 II = 1,ITOT
   16 NR(II) = 0
   13 I = I-1
      J = J-1
      IF (I-1) 20,20,21
   21 IF (I-IEC) 14,14,15
   14 L = L + 1
      CALL NMBR(I,J,L)
      IF ( J-JIP) 17,18,13
   20 L = L+1
      CALL NMBR(I,J,L)
   19 K = K+1
      I = 2*K+LCL
      J = JEP+1
      GO TO 13
   18 IF (I-IIC) 19,19,13
   15 I = IEC
      J = JEP-(2*K-1+LCL-IEC)
      L = L+1
      CALL NMBR(I,J,L)
      IF (IEC-2*(IEC/2)) 13,11,13
   11 IF (I-IEC) 13,30,30
   30 IF (J-1) 25,25,13
   17 IF (J-1) 22,22,23
   23 IF (I-IIC) 13,19,13
   22 IF (I-2*(IEC/2)) 19,25,25
   25 CONTINUE
      DO 28 L=1,ITOT
      M = NR(L)
   28 NC(M) = L
      SUMPZP = 0.
      SUMALP = 0.
      NLP = IEC-IIC+2
      DO 4 I=1,NLP
      SUMALP = SUMALP + ALP(I)
    4 SUMPZP = SUMPZP+FLP(I)
      WRITE (6,102) TPLATE,TCYLDR,H,DIAM,IIC,IEC,JIP,JEP,ALR,ALZ
  102 FORMAT (1H1,'STRUCTURE DIMENSIONS'//6X,'PLATE THICKNESS',14X,'=',
     1     F8.3,'  IN.'/6X,'WALL THICKNESS',15X,'=',F8.3,'  IN.'/6X,'SEMI
     2-HEIGHT OF VESSEL',8X,'=',F8.3,'  IN.'/6X,'DIAMETER OF VESSEL',11X
     3,'=',F8.3,'  IN.'///' MODEL GEOMETRY'//6X,'I-LINE CORRESPONDING TO
     4 INTERIOR OF CYLINDER =',I5/6X,'I-LINE CORRESPONDING TO EXTERIOR O
```

(c)

```
     5F CYLINDER =',I5/6X,'J-LINE CORRESPONDING TO BOTTOM OF PLATE',6X,'
     6=',I5/6X,'J-LINE CORRESPONDING TO TOP OF PLATE',9X,'=',I5/6X,'PANE
     7L SPACING IN R-DIRECTION =',F8.3,'  IN.'/6X,'PANEL SPACING IN Z-DI
     8RECTION =',F8.3,'  IN.'//)
      GO TO (3,6),LRC
    3 WRITE (6,103)
  103 FORMAT (6X,'DISPLACEMENT NODE AT RE-ENTRANT CORNER'///)
      GO TO 7
    6 WRITE (6,104)
  104 FORMAT (6X,'STRESS NODE AT RE-ENTRANT CORNER'///)
    7 WRITE (6,105) EC,PR,ECRIT
  105 FORMAT(' ELASTIC CONSTANTS OF MATERIAL'//6X,'MODULUS OF ELASTICITY
     1',8X,'=',E13.5,'  PSI.'/6X,'POISSON RATIO',16X,'=',F7.3/6X,'CRACKI
     2NG STRAIN',14X,'=',F9.5//)
      WRITE (6,113) AHP,EST,D,FHP,PHP,SUMALP,EST,N,SUMPZP,DOE
  113 FORMAT (' HOOP PRESTRESSING'//6X,'AREA OF CABLE',16X,'=',E13.5,
     2                                                '  SQ. IN.'/6X'MODU
     3LUS OF ELASTICITY',8X'=',E13.5,'  PSI.'/6X'SPACING'22X'=',E13.5,'
     4 IN.'/6X,'PRESTRESSING LOAD',12X,'=',E13.5,'  LB.'/6X,'EQUIVALENT
     5APPLIED PRESSURE  =',E13.5,'  PSI.'///' LONGITUDINAL PRESTRESSING'
     6//6X,'AREA OF CABLE',16X,'=',E13.5,'  SQ. IN.'/6X,'MODULUS OF ELAS
     7TICITY',8X,'=',E13.5,'  PSI.'/6X,'NUMBER OF CABLES',13X,'=',I5/6X,
     8'PRESTRESSING LOAD PER CABLE  =',E13.5,'  LB.'/6X,'DISTANCE FROM O
     9UTER EDGE      =',E13.5,'  IN.'//)
      GO TO (8,9),LG
    8 WRITE (6,106)
  106 FORMAT (6X,'LONGITUDINAL PRESTRESSING IS UNGROUTED'//)
      GO TO 10
    9 WRITE (6,107)
  107 FORMAT (6X,'LONGITUDINAL PRESTRESSING IS GROUTED'//)
   10 IICP1 = IIC+1
      IICLP = IICP1+16
      WRITE (6,108) (I,I=IICP1,IICLP),(ALP(I),I=3,19),(FLP(I),I=3,19),
     1     LRC,LR,LCYC,LG,LPO,LPRCSS,ITOT
  108 FORMAT (4X,'EQUIVALENT PRESTRESSING LOADS AND AREAS AS THEY INTERV
     1ENE IN THE MODEL'/6X,'AT I =',17I7//6X,'AREAS   ',17F7.[illegible]
     2   ',17F7.0///' SWITCHES AT START'/6X,'LRC =',I3,5X,'LR =',I3,5X,'
     3LCYC =',I3,5X,'LG =',I3,5X,'LPO =',I3,5X,'LPRCSS =',I3// ' NUMBER
     4OF EQUATIONS  =',I5//)
      ITOTH = ITOT/2
      LRC = LRC+(LRC+1)/2-2*(LRC/2)
      JTOT1 =     (((IIC-1)/2)*MW+(2*(IIC/2)-IIC+1)*((MW-1+LRC)/2))
      JTOT = JTOT1+    (((JIP-1)/2)*NW+(2*(JIP/2)-JIP+1)*((NW-1+LRC)/2)+
     1       (MW/2)*NW+(MW-2*(MW/2))*((NW+2*((LRC+1)/2)-LRC)/2)
      JDRUM = (JTOT+9)/10
      ITOT1 = 2*JTOT1
      IF (LR) 80,80,81
   81 REWIND 3
      READ (3) NL,LRC,LPRCSS,LCR,DELP,P,ICR,JCR,SIGICR,AK,PHP,AR,PZP,U,W
      LRC = LRC+(LRC+1)/2-2*(LRC/2)
      ITOT1 = 2*(((IIC-1)/2)*MW+(2*(IIC/2)-IIC+1)*((MW-1+LRC)/2))
      REWIND 4
      DO 93 L=1,ITOTH
      NQ = 2*L
      CALL COORD
   93 WRITE (4) U(I,J),W(I,J)
      LRC = LRC+(LRC+1)/2-2*(LRC/2)
```

(d)

```
      ITOT1 = 2*JTOT1
      DO 75 K=1,JDRUM
      READ  (3) ERPO,EZPO,ETPO,ERZPO,E1PO,S1PO,S2PO,E2PO,TAN1PO,TAN2PO,
     1      SRPO,SZPO,STPO,SRZPO
      DO 76 L=1,10
      NQ = 2*((K-1)*10+L)
      CALL COORD
      DER(I,J) = S2PO(L)
      ERPR(I,J) = ERPO(L)
      ERPO(L) = ERPR(I,J)+DER(I,J)
      DEZ(I,J) = E2PO(L)
      EZPR(I,J) = EZPO(L)
      EZPO(L) = EZPR(I,J)+DEZ(I,J)
      DET(I,J) = TAN1PO(L)
      ETPR(I,J) = ETPO(L)
      ETPO(L) = ETPR(I,J)+DET(I,J)
      DERZ(I,J) = TAN2PO(L)
      ERZPR(I,J) = ERZPO(L)
      ERZPO(L) = ERZPR(I,J)+DERZ(I,J)
      EPS1(I,J) = E1PO(L)
      DEPS1(I,J) = S1PO(L)
   76 CONTINUE
      WRITE (2'K) SRPO
      WRITE (2'100+K) ERPO
      WRITE (2'200+K) SZPO
      WRITE (2'300+K) EZPO
      WRITE (2'400+K) STPO
      WRITE (2'500+K) ETPO
      WRITE (2'600+K) SRZPO
      WRITE (2'700+K) ERZPO
   75 CONTINUE
      GO TO 41
   80 NL = 0
      DO 83 I=1,NLP
      I1 = I+IIC-2
      AR(I) = 0.
      PZP(I)=      (N)*FLP(I)/(3.14159*ALR*R(I1))
   83 CONTINUE
      AK = 0.
      DELP = 0.
      P = 0.
      LCR = 0
      ICR = IIC
      JCR = JIP
      DO 2 I=1,IEC
      DO 2 J=1,JEP
      LC(I,J) = 0
      IF (J-JIP) 71,2,2
   71 IF (I-IIC) 72,2,2
   72 LC(I,J) = 10000
    2 CONTINUE
   26 CONTINUE
      DO 313 I=1,IEC
      DO 313 J=1,JEP
      SIGR(I,J) = 0.
      SIGZ(I,J) = 0.
      SIGT(I,J) = 0.
```

(a)

```
      SIGRZ(I,J) = 0.
      ERPR(I,J) = 0.
      EZPR(I,J) = 0.
      ETPR(I,J) = 0.
      ERZPR(I,J) = 0.
[illegible] CONTINUE
      LRC = LRC+(LRC+1)/2-2*(LRC/2)
      ITOT1 = 2*((((IIC-1)/2)*MW+(2*(IIC/2)-IIC+1)*((MW-1+LRC)/2))
[illegible] REWIND 4
      DO 77 L=1,ITOTH
      NQ = 2*L
      CALL COORD
      U(I,J) = 0.
      W(I,J) = 0.
   77 WRITE (4) U(I,J),W(I,J)
   79 CONTINUE
      LRC = LRC+(LRC+1)/2-2*(LRC/2)
      ITOT1 = 2*JTOT1
      DO 5 L=1,JTOT
      NQ = 2*L
      CALL COORD
      L1 = L-((L-1)/10)*10
      SRPO(L1) = SIGR(I,J)
      ERPO(L1) = ERPR(I,J)
      SZPO(L1) = SIGZ(I,J)
      EZPO(L1) = EZPR(I,J)
      STPO(L1) = SIGT(I,J)
      ETPO(L1) = ETPR(I,J)
      SRZPO(L1) = SIGRZ(I,J)
      ERZPO(L1) = ERZPR(I,J)
      IF ((L1-10)*(L-JTOT)) 5,94,5
   94 L10 = (L+9)/10
      WRITE (2'L10) SRPO
      WRITE (2'100+L10) ERPO
      WRITE (2'200+L10) SZPO
      WRITE (2'300+L10) EZPO
      WRITE (2'400+L10) STPO
      WRITE (2'500+L10) ETPO
      WRITE (2'600+L10) SRZPO
      WRITE (2'700+L10) ERZPO
    5 CONTINUE
   41 LR = LR+1
      NL = NL+1
      IF (NL-2) 42,43,44
   42 CONTINUE
      LRC = LRC+(LRC+1)/2-2*(LRC/2)
      ITOT1 = 2*((((IIC-1)/2)*MW+(2*(IIC/2)-IIC+1)*((MW-1+LRC)/2))
   84 REWIND 1
      DO 99 L=1,ITOT
      NQ = NR(L)
      CALL COORD
      CALL BAND
      CALL EQUATN
      IF (NQ-2*(NQ/2)) 46,47,46
   46 IF (I-1) 48,48,49
   48 A(KDR) = 1.
      GO TO 45
```

(b)

```
   47 IF (J-1) 48,48,52
   49 CALL SIGRA
      CALL SIGRB
      CALL SIGRZC
      CALL SIGRZD
      CALL SIGTIJ
      GO TO 45
   52 CALL SIGZC
      CALL SIGZD
      CALL SIGRZA
      CALL SIGRZB
   45 WRITE (1) I,J,KLOW,KHIGH,A,CON
   99 CONTINUE
   60 CALL SOLVER
   85 DO 53 L=1,ITOT
      NQ = NR(L)
      CALL COORD
      IF (NQ-2*(NQ/2)) 54,55,54
   54 U(I,J) = S(L)
      GO TO 53
   55 W(I,J) = S(L)
   53 CONTINUE
      LRC = LRC+(LRC+1)/2-2*(LRC/2)
      ITOT1 = 2*JTOT1
      DO 51 K=1,JORUM
      READ (2'K) SRPO
      READ (2'100+K) ERPO
      READ (2'200+K) SZPO
      READ (2'300+K) EZPO
      READ (2'400+K) STPO
      READ (2'500+K) ETPO
      READ (2'600+K) SRZPO
      READ (2'700+K) ERZPO
      DO 51 L=1,10
      NQ = 2*((K-1)*10+L)
      CALL COORD
      SIGR(I,J) = SRPO(L)
      ERPR(I,J) = ERPO(L)
      SIGZ(I,J) = SZPO(L)
      EZPR(I,J) = EZPO(L)
      SIGT(I,J) = STPO(L)
      ETPR(I,J) = ETPO(L)
      SIGRZ(I,J)=SRZPO(L)
      ERZPR(I,J)=ERZPO(L)
      IF (NQ-2*JTOT) 51,95,95
   51 CONTINUE
   95 CONTINUE
      DO 58 L=1,JTOT
      NQ = 2*L
      CALL COORD
      IA = I
      JA = J
      CALL STRSTR
      L1 = L-((L-1)/10)*10
      CALL SIGEPS
      IF ((L1-10)*(L-JTOT)) 58,98,58
   98 L10 = (L+9)/10
```

(c)

```
      WRITE (2'L10) SRPO
      WRITE (2'100+L10) ERPO
      WRITE (2'200+L10) SZPO
      WRITE (2'300+L10) EZPO
      WRITE (2'400+L10) STPO
      WRITE (2'500+L10) ETPO
      WRITE (2'600+L10) SRZPO
      WRITE (2'700+L10) ERZPO
      WRITE (2'800+L10) S1PO
      WRITE (2'900+L10) E1PO
      WRITE (2'1000+L10) S2PO
      WRITE (2'1100+L10) E2PO
      WRITE (2'1200+L10) TAN1PO
      WRITE (2'1300+L10) TAN2PO
   58 CONTINUE
      LRC = LRC+(LRC+1)/2-2*(LRC/2)
      ITOT1 = 2*((((IIC-1)/2)*MW+(2*(IIC/2)-IIC+1)*((MW-1+LRC)/2))
      REWIND 4
      DO 91 L=1,ITOTH
      NQ = 2*L
      CALL COORD
      READ (4) SIG(I,J),EPS(I,J)
      U(I,J) = U(I,J)+SIG(I,J)
   91 W(I,J) = W(I,J)+EPS(I,J)
      REWIND 4
      DO 92 L=1,ITOTH
      NQ = 2*L
      CALL COORD
   92 WRITE (4) U(I,J),W(I,J)
      LRC = LRC+(LRC+1)/2-2*(LRC/2)
      ITOT1 = 2*JTOT1
      IF (LR-3) 87,87,90
   90 IF (LPRCSS-2) 88,87,88
   87 CALL OUTPUT
      IF (LR-3) 88,88,301
  301 IF (LPRCSS-1) 88,304,88
  304 P=P+DELP
      GO TO 42
   88 IF (LR-LCYC) 41,59,59
   43 IF (LR-2) 34,34,35
   34 DO 61 I=1,NLP
      I1 = I+IIC-2
      AR(I) = N*ALP(I)*EST/(3.14159*ALR*R(I1))
   61 PZP(I) = 0.
      AK = AHP*EST/(D*R(IEC))
      PHP = 0.
      DELP = 100.
      P = P+DELP
      GO TO 42
   35 DELP = P
      PHP = FHP/(D*R(IEC))
      DO 303 I=1,NLP
      I1 = I+IIC-2
  303 PZP(I) = N*FLP(I)/(3.14159*ALR*R(I1))
      GO TO 42
   44 IF (LPRCSS-2) 62,63,64
   62 CALL EXTRPL
```

(d)

```
      DELP = 100.*(EXCF-1.)
      LPRCSS = 2
      PT = P+DELP
      WRITE (6,114) PT
  114 FORMAT (///'0THE INTERNAL PRESSURE INCREASES TO',F8.1,' PSI.  BEFO
     1RE NEXT CRACK DEVELOPS'//)
   65 P = P+DELP
   69 LRC = LRC+(LRC+1)/2-2*(LRC/2)
      ITOT1 = 2*((((IIC-1)/2)*MW+(2*(IIC/2)-IIC+1)*((MW-1+LRC)/2))
      GO TO 84
   63 ICRT = IABS(ICR)
      JCRT = IABS(JCR)
      IF (LC(ICRT,JCRT)-1) 201,202,202
  201 IF (ICR) 204,204,205
  204 LC(ICRT,JCRT) = 2
      GO TO 200
  202 LC(ICRT,JCRT) = 3
      GO TO 200
  205 LC(ICR,JCR) = 1
  200 WRITE (6,109) (I,I=1,IEC,2)
  109 FORMAT (1H1,50X,'CRACKING TABLE'///15X,28(I4)//)
      DO 66 J=1,JEP
      J1 = JEP-J+1
      IF (J+LCL-2*((J+LCL)/2)) 67,68,67
   68 WRITE (6,111) J1,(LC(I,J1),I=1,IEC,2)
  111 FORMAT (10X,I3,2X,28(I4))
      GO TO 66
   67 WRITE (6,112) J1,(LC(I,J1),I=2,IEC,2)
  112 FORMAT (10X,I3,4X,27(I4))
   66 CONTINUE
      LPRCSS = 3
      NL = 1
      GO TO 26
   64 CALL CHECK
      IF (LCR) 87,87,63
   59 REWIND 3
      WRITE (3) NL,LRC,LPRCSS,LCR,DELP,P,ICR,JCR,SIGICR,AK,PHP,AR,PZP,U,
     1         W
      DO 73 L=1,JTOT
      NQ = 2*L
      CALL COORD
      L1 = L-((L-1)/10)*10
      ERPO(L1) = ERPR(I,J)
      EZPO(L1) = EZPR(I,J)
      ETPO(L1) = ETPR(I,J)
      ERZPO(L1) = ERZPR(I,J)
      E1PO(L1) = EPS1(I,J)
      S1PO(L1) = DEPS1(I,J)
      S2PO(L1) = DER(I,J)
      E2PO(L1) = DEZ(I,J)
      TAN1PO(L1) = DET(I,J)
      TAN2PO(L1) = DERZ(I,J)
      IF ((L1-10)*(L-JTOT)) 73,74,73
   74 L10 = (L+9)/10
      READ (2'L10) SRPO
      READ (2'200+L10) SZPO
      READ (2'400+L10) STPO
```

(a)

```
      READ (2'600+L10) SRZPO
      WRITE (3) ERPO,EZPO,ETPO,ERZPO,E1PO,S1PO,S2PO,E2PO,TAN1PO,TAN2PO,
     1     SRPO,SZPO,STPO,SRZPO
   73 CONTINUE
      GO TO 50
      END
C*********************************************************************
      SUBROUTINE NMBR(IN,JN,L)
C*********************************************************************
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
     4        EXCF,SIGICR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
     1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
     3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
     4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
     5            (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
      IF (IN-IIC) 1,2,2
    1 NR(L) = (IN/2)*2*((MW+1-LCL)/2)+((IN-1)/2)*2*((MW+LCL)/2)+
     2     ((JN-JIP)/2)*2+1
      GO TO 5
    2 NR(L) = ITOT1+((IN-IIC-LRC+2)/2)*(JEP+LADD)
     1     +((IN-IIC+LRC-1)/2)*(JEP-LADD)+((JN-1)/2)*2+1
    5 L = L+1
      NR(L) = NR(L-1)+1
      RETURN
      END
C*********************************************************************
      SUBROUTINE EQUATN
C*********************************************************************
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
     4        EXCF,SIGICR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
```

(b)

```
     1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
     3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
     4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
     5            (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
      KHR = KHIGH-KLOW+1
      KDR = KD-KLOW+1
      DO 10 K=1,KHR
   10 A(K) = 0.
      CON = 0.
      C1 = SUMR(I)
      C2 = -DIFFR(I)
      C3 = 1./ALZ
      C4 = -C3
      IF ((I-1)*(I-IEC)) 11,12,12
   11 IF (I-IIC) 13,14,15
   13 IF ((J-JIP)*(J-JEP)) 200,17,17
   16 IF (I-2) 17,200,17
   14 IF (J-JIP) 18,19,23
   23 IF (J-JIP-1) 24,24,13
   24 C4 = -0.5*(1.-ALR/(8.*R(I)))/ALZ
      GO TO 13
C     AT INTERIOR FACE OF CYLINDER
   18 C1 = 2.*C1
      C2 = -2./ALR
      C3 = C3*C1
      C4 = -C3
      IF (J-1) 200,17,200
   17 C3 = 2.*C3
      C4 = -C3
      GO TO 200
C     AT RE-ENTRANT CORNER
   19 C2 = 0.5*C2
      C4 = 0.5*C4*C1
      GO TO 200
   15 IF (I-IIC-1) 25,26,25
   26 IF (J-JIP) 25,27,25
   27 C2 = 0.5*C2
   25 IF ((J-1)*(J-JEP)) 200,17,200
   12 IF (I-1) 21,22,21
C     AT EXTERIOR FACE OF CYLINDER
   21 C1 = 2./ALR
      C2 = 2.*C2
      C3 = C3*CE
      C4 = -C3
      IF ((J-1)*(J-JEP)) 200,17,17
   22 C1 = 8./ALR
      IF ((J-JIP)*(J-JEP)) 200,17,17
  200 RETURN
      END
C*********************************************************************
      SUBROUTINE SIGRA
C*********************************************************************
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
```

(c)

```
     4        EXCF,SIGICR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
     1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
     3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
     4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
     5            (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
    1 IA = I+1
      JA = J
      IF ((I-1)*(I-IEC+1)*(I-IEC)*(J-1)*(J-2)*(J-JIP-1)*(J-JIP)*(J-JEP))
     6     221,202,221
  221 CALL STRSTR
C     TYPICAL NODE
  201 A(KHR-5) = (C(11)/ALR+C(13)/(2.*R(IA)))*C1
      A(KHR-4) = C(14)*C1/ALR
      A(KHR-3) = -C(14)*C1/ALZ
      A(KHR-2) = -C(12)*C1/ALZ
  220 A(KDR-2) = C(14)*C1/ALZ
      A(KDR-1) = C(12)*C1/ALZ
      A(KDR) = -(C(11)/ALR-C(13)/(2.*R(IA)))*C1
      A(KDR+1) = -C(14)*C1/ALR
      GO TO 250
  202 IF (I-IEC+1) 203,204,205
C     AT EXTERIOR FACE OF CYLINDER
  205 A(KDR) = -AK/R(I)*C1
      CON = CON-PHP*C1
      GO TO 250
C     HALF-SPACE FROM EXT. FACE OF CYLINDER
  204 CON = CON-PHP*C1
      IF ((J-2)*(J-JEP)) 206,207,207
  206 A(KDR-2) = -AK/(2.*R(IA))*C1
  217 A(KHR-3) = -AK/(2.*R(IA))*C1
      GO TO 250
  207 IF (J-2) 208,223,209
  208 A(KDR-2) = -AK/R(IA)*C1
      GO TO 250
  209 A(KDR) = -AK/(2.*R(IA))*C1
      GO TO 217
  223 A(KDR-2) = -AK/(2.*R(IA))*C1
      A(KHR-1) = A(KDR-2)
      GO TO 250
  203 IF (I-1) 210,211,210
C     EQUATION AT CENTERLINE
  211 A(KDR) = 1.
      CON = 0.
      RETURN
  210 CALL STRSTR
      IF (J-JIP) 222,213,214
```

(d)

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  222 IF (J-2) 212,216,216
  212 A(KDR) = -(C(11)/ALR-C(13)/(2.*R(IA)))*C1
      A(KHR-1) = (C(11)/ALR+C(13)/(2.*R(IA)))*C1
      A(KDR-1) = 2.*C(12)*C1/ALZ
      GO TO 250
  213 IF (I-IIC+1) 215,216,201
C     HALF-SPACE FROM LOWER FACE OF PLATE
  216 A(KHR-3) = (C(11)/ALR+C(13)/(2.*R(IA)))*C1
      A(KHR-2) = C(14)*C1/ALR
      A(KHR-1) = -C(14)*C1/ALZ
      A(KHR) = -C(12)*C1/ALZ
      GO TO 220
  214 IF (J-JIP-1) 218,218,215
  218 IF (I-IIC) 216,201,201
  215 LOCAT = 1
  219 CF = C(11)*C1
      SIGN = 1.
      CALL RSTRN
      CF = C(12)*C1
      CALL ZSTRN
      SIGN = -1.
      CF = C(13)*C1
      CALL RSTRN
      CF = C(14)*C1
      CALL RZSTRN
  250 RETURN
      END
C*********************************************************************
      SUBROUTINE SIGRB
C*********************************************************************
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
     4        EXCF,SIGICR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(1C),E2PO(10),TAN1PO(10),TAN2PO(10)
      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
     1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
     3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
     4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
     5            (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
  250 IA = I-1
      JA = J
      CALL STRSTR
      IF ((I-2)*(I-IIC)*(I-IIC-1)*(J-1)*(J-JIP)*(J-JEP+1)*(J-JEP))
     1     251,252,251
  251 A(3) = C(14)*C2/ALZ
      A(4) = C(12)*C2/ALZ
```

(a)

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      A(5) = -(C(11)/ALR-C(13)/(2.*R(IA)))*C2
      A(6) = -C(14)*C2/ALR
  253 A(KDR) = A(KDR)+(C(11)/ALR+C(13)/(2.*R(IA)))*C2
      A(KDR+1) = A(KDR+1)+C(14)*C2/ALR
      A(KDR+2) = -C(14)*C2/ALZ
      A(KDR+3) = -C(12)*C2/ALZ
      GO TO 300
  252 IF (J-JIP) 254,255,261
  254 IF (I-IIC-1) 257,257,258
  257 CON = CON-C2*DELP
      GO TO 300
  258 A(4) = 2.*C(12)*C2/ALZ
      A(KDR) = A(KDR)+(C(11)/ALR+C(13)/(2.*R(IA)))*C2
      A(5) = -(C(11)/ALR-C(13)/(2.*R(IA)))*C2
      GO TO 300
  255 IF (I-IIC) 260,259,262
  262 IF (I-IIC-1) 263,263,251
  263 CON = CON-C2*DELP
      GO TO 251
  259 CON = CON-C2*DELP
      GO TO 266
  260 IF (I-2) 300,300,266
  261 IF (I-2) 300,300,256
  256 IF (J-JEP+1) 251,265,266
  265 A(1) = C(14)*C2/ALZ
      A(2) = C(12)*C2/ALZ
      A(3) = -(C(11)/ALR-C(13)/(2.*R(IA)))*C2
      A(4) = -C(14)*C2/ALR
      GO TO 253
  266 LOCAT = 2
      CF = C(11)*C2
      SIGN = 1.
      CALL RSTRN
      CF = C(12)*C2
      CALL ZSTRN
      CF = C(13)*C2
      SIGN = -1.
      CALL RSTRN
      CF = C(14)*C2
      CALL RZSTRN
  300 RETURN
      END
*****************************************************************
      SUBROUTINE SIGRZC
*****************************************************************
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
     4        EXCF,SIGICR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
```

(b)

```
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
     1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
     3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
     4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
     5            (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
  300 IA = I
      JA = J+1
      IF ((I-IIC)*(I-IEC)*(J-JEP+1)*(J-JEP)) 301,302,301
  302 IF (J-JEP+1) 303,350,350
  303 IF (I-IEC) 304,350,350
  304 IF (J-JIP+1) 350,301,301
  301 CALL STRSTR
      A(1) = C(44)*C3/ALZ
      A(2) = C(42)*C3/ALZ
      A(3) = A(3)-(C(41)/ALR-C(43)/(2.*R(IA)))*C3
      A(4) = A(4)-C(44)*C3/ALR
      A(KDR-2) = A(KDR-2)+(C(41)/ALR+C(43)/(2.*R(IA)))*C3
      A(KDR-1) = A(KDR-1)+C(44)*C3/ALR
      A(KDR) = A(KDR)-C(44)*C3/ALZ
      A(KDR+1) = A(KDR+1)-C(42)*C3/ALZ
  350 RETURN
      END
*****************************************************************
      SUBROUTINE SIGRZD
*****************************************************************
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
     4        EXCF,SIGICR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
     1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
     3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
     4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
     5            (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
  350 IA = I
      JA = J-1
      IF ((I-IIC)*(I-IEC)*(J-1)*(J-2)*(J-JIP)*(J-JIP-1)) 351,352,351
  352 IF (I-IEC) 353,400,400
  353 IF (I-IIC) 400,354,355
  354 IF (J-JIP-1) 400,356,351
  356 C4 = -CI/(2.*ALZ)
      GO TO 351
  355 IF (J-2) 400,400,351
```

(c)

```
  351 CALL STRSTR
      A(KDR) = A(KDR)+C(44)*C4/ALZ
      A(KDR+1) = A(KDR+1)+C(42)*C4/ALZ
      A(KDR+2) = A(KDR+2)-(C(41)/ALR-C(43)/(2.*R(IA)))*C4
      A(KDR+3) = A(KDR+3)-C(44)*C4/ALR
      A(KHR-3) = A(KHR-3)+(C(41)/ALR+C(43)/(2.*R(IA)))*C4
      A(KHR-2) = A(KHR-2)+C(44)*C4/ALR
      A(KHR-1) = -C(44)*C4/ALZ
      A(KHR) = -C(42)*C4/ALZ
  400 RETURN
      END
*****************************************************************
      SUBROUTINE SIGTIJ
*****************************************************************
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
     4        EXCF,SIGICR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
     1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
     3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
     4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
     5            (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
  400 C5 = -0.5/R(I)
      SIGN = 1.
      C6 = -1./(4.*R(I)**2)
      C15 = C6
      C25 = C6
      C35 = C6
      C45 = C6
      IF (I-IIC-1) 411,412,413
  411 IF (J-JIP) 414,415,416
  414 IF (J-2) 417,442,442
  417 C15 = 2.*C6
      C35 = C15
      LOCAT = 1
      IA = I+1
      JA = J
      CALL STRSTR
      A(KDR) = A(KDR)+C(33)*C15
      CF = C(31)*C5
      CALL RSTRN
      CF = C(32)*C5
      CALL ZSTRN
      LOCAT = 3
      IA = I
```

(d)

```
      JA = J+1
      CALL STRSTR
      A(KDR) = A(KDR)+C(33)*C35
      CF = C(31)*C5
      CALL RSTRN
      CF = C(32)*C5
      CALL ZSTRN
      RETURN
  442 C15 = 2.*C6
      IA = I+1
      JA = J
      CALL STRSTR
      A(KDR) = A(KDR)+C(33)*C15
  418 LOCAT = 3
      IA = I
      JA = J+1
      CALL STRSTR
      CF = C(31)*C5
      CALL RSTRN
      LOCAT = 4
      JA = J-1
      CALL STRSTR
      CF = C(31)*C5
      CALL RSTRN
      GO TO 427
  415 IF (I-IIC) 443,419,419
  419 C5 = 0.75*C5
      C25 = 0.5*C6
      C45 = C25
      GO TO 421
  416 IF ((J-JIP-1)*(J-JEP+1)) 420,425,444
  420 IF (I-2) 425,425,421
  412 IF ((J-JIP+1)*(J-JEP+1)) 421,422,422
  421 IA = I
      JA = J+1
      CALL STRSTR
      A(KDR) = A(KDR)+C(33)*C35
      A(2) = A(2)+C(32)*C5/ALZ
      A(KDR+1) = A(KDR+1)-C(32)*C5/ALZ
      JA = J-1
      CALL STRSTR
      A(KDR) = A(KDR)+C(33)*C45
      A(KHR) = A(KHR)-C(32)*C5/ALZ
      A(KDR+1) = A(KDR+1)+C(32)*C5/ALZ
      JA = J
      IA = I-I
      CALL STRSTR
      A(KDR) = A(KDR)+C(33)*C25+C(31)*C5/ALR
      A(5) = A(5)-C(31)*C5/ALR
      IA = I+1
      CALL STRSTR
      A(KHR-5) = A(KHR-5)+C(31)*C5/ALR
      A(KDR) = A(KDR)+C(33)*C15-C(31)*C5/ALR
      RETURN
  413 IF (I-IEC+1) 423,422,424
  423 IF ((J-2)*(J-JEP+1)) 421,425,426
  422 IF ((J-2)*(J-JEP+1)) 425,425,426
```

(a)

```
425 IA = I+1
    JA = J
    LOCAT = 1
    CALL STRSTR
    A(KDR) = A(KDR)+C(33)*C15
    CF = C(31)*C5
    CALL RSTRN
    IA = I-1
    LOCAT = 2
    CALL STRSTR
    A(KDR) = A(KDR)+C(33)*C25
    CALL RSTRN
427 IA = I
    JA = J-1
    LOCAT = 4
    CALL STRSTR
    A(KDR) = A(KDR)+C(33)*C45
    CF = C(32)*C5
    CALL ZSTRN
    JA = J+1
    LOCAT = 3
    CALL STRSTR
    A(KDR) = A(KDR)+C(33)*C35
    CF = C(32)*C5
    CALL ZSTRN
    RETURN
426 IF (J-1) 443,443,444
443 C35 = 2.*C6
    IA = I
    JA = J+1
    CALL STRSTR
    A(KDR) = A(KDR)+C(33)*C35
    GO TO 445
444 C45 = 2.*C6
    IA = I
    JA = J-1
    CALL STRSTR
    A(KDR) = A(KDR)+C(33)*C45
445 LOCAT = 1
    IA = I+1
    JA = J
    CALL STRSTR
    A(KDR) = A(KDR)+C(33)*C15
    CF = C(31)*C5
    CALL RSTRN
    CF = C(32)*C5
    CALL ZSTRN
428 LOCAT = 2
    IA = I-1
    JA = J
    CALL STRSTR
    A(KDR) = A(KDR)+C(33)*C25
    CF = C(31)*C5
    CALL RSTRN
    CF = C(32)*C5
    CALL ZSTRN
    RETURN
```

(b)

```
424 C25 = 2.*C6
    IF (J-JEP) 429,430,430
429 IF (J-2) 431,446,446
446 IA = I-1
    JA = J
    CALL STRSTR
    A(KDR) = A(KDR)+C(33)*C25
    GO TO 418
431 LOCAT = 3
    IA = I
    JA = J+1
    CALL STRSTR
    C35 = C25
    A(KDR) = A(KDR)+C(33)*C35
    CF = C(31)*C5
    CALL RSTRN
    CF = C(32)*C5
    CALL ZSTRN
    GO TO 428
430 LOCAT = 4
    IA = I
    JA = J-1
    CALL STRSTR
    C45 = C25
    A(KDR) = A(KDR)+C(33)*C45
    CF = C(31)*C5
    CALL RSTRN
    CF = C(32)*C5
    CALL ZSTRN
    GO TO 428
    END
*************************************************************************
    SUBROUTINE SIGZC
*************************************************************************
    COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
   1        PHP,MW,NW,AK,ITOTI,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
   2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
   3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOTI,ECRIT,
   4        EXCF,SIGICR,TPLATE,TCYLDR,IICMI,IICPI,LI,JDRUM
    COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
   1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
   2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
   3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),SIPO(10),
   4        EIPO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
    DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
   1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPSI(53,81),
   2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
   3           EPSI(53,81),SIG(53,81),EPS(53,81),DET(53,81)
    EQUIVALENCE (U(1),LC(1)) , (B(1),EPSI(1)) ,
   1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
   2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
   3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
   4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPSI(1)),
   5            (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
  2 IA = I
    JA = J+1
    IF (I-IIC) 511,512,513
```

(c)

```
511 IF ((I-1)*(J-JEP+1)*(J-JEP)) 514,515,514
514 CALL STRSTR
    A(1) = C(24)*C3/ALZ
    A(2) = A(2)+C(22)*C3/ALZ
    A(3) = -(C(21)/ALR-C(23)/(2.*R(IA)))*C3
    A(4) = -C(24)*C3/ALR
    A(KDR-3) = (C(21)/ALR+C(23)/(2.*R(IA)))*C3
    A(KDR-2) = C(24)*C3/ALR
    A(KDR-1) = -C(24)*C3/ALZ
    A(KDR) = A(KDR)-C(22)*C3/ALZ
    GO TO 550
515 IF (J-JEP+1) 516,550,550
516 CALL STRSTR
    A(2) = C(22)*C3/ALZ
    A(KDR) = -C(22)*C3/ALZ
    A(KDR-3) = 2.*(C(21)+C(23))*C3/ALR
    GO TO 550
512 IF ((J-JIP+1)*(J-JEP+2)) 514,514,518
513 IF ((J-1)*(J-JEP+1)*(J-JEP)*(I-IEC)) 517,518,517
517 GO TO (514,510),LG
510 I1 = I-IIC+2
    A(2) = AR(I1)*C3/ALZ
    A(KDR) = -A(2)
    GO TO 514
518 IF (J-1) 519,519,520
519 A(KDR) = 1.0
    CON = 0.
    RETURN
520 IF (J-JEP+1) 521,522,523
521 CALL STRSTR
    A(2) = C(22)*C3/ALZ
    A(KDR) = -A(2)
    LOCAT = 3
    SIGN = 1.
    CF = C(21)*C3
    CALL RSTRN
    SIGN = -1.
    CF = C(23)*C3
    CALL RSTRN
    CF = C(24)*C3
    CALL RZSTRN
    GO TO 550
522 I1 = I-IIC+2
    CON = CON-PZP(I1)*C3
    GO TO (524,525),LG
524 A(KDR) = -AR(I1)*C3/(H-ALZ/2)
    GO TO 550
525 CF = AR(I1)*C3
    CALL STRSTR
    CALL ZSTRN
    GO TO 550
523 I1 = I-IIC+2
    CON = CON-PZP(I1)*C3
    GO TO (526,550),LG
526 A(KDR) = A(KDR)-AR(I1)*C3/H
550 RETURN
    END
```

(d)

```
*************************************************************************
    SUBROUTINE SIGZD
*************************************************************************
    COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
   1        PHP,MW,NW,AK,ITOTI,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
   2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
   3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOTI,ECRIT,
   4        EXCF,SIGICR,TPLATE,TCYLDR,IICMI,IICPI,LI,JDRUM
    COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
   1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
   2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
   3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),SIPO(10),
   4        EIPO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
    DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
   1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPSI(53,81),
   2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
   3           EPSI(53,81),SIG(53,81),EPS(53,81),DET(53,81)
    EQUIVALENCE (U(1),LC(1)) , (B(1),EPSI(1)) ,
   1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
   2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
   3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
   4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPSI(1)),
   5            (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
550 IA = I
    JA = J-1
    CALL STRSTR
    IF (I-IIC) 551,552,553
551 IF ((I-1)*(J-JIP)*(J-JIP-1)) 554,555,554
554 A(KDR-1) = A(KDR-1)+C(24)*C4/ALZ
    A(KDR) = A(KDR)+C(22)*C4/ALZ
    A(KDR+1) = -(C(21)/ALR-C(23)/(2.*R(I)))*C4
    A(KDR+2) = -C(24)*C4/ALR
    A(KHR-3) = (C(21)/ALR+C(23)/(2.*R(I)))*C4
    A(KHR-2) = C(24)*C4/ALR
    A(KHR-1) = -C(24)*C4/ALZ
    A(KHR) = A(KHR)-C(22)*C4/ALZ
    GO TO 600
555 IF (J-JIP-1) 556,556,557
556 CON = CON-DELP*C4
    GO TO 600
557 A(KDR) = A(KDR)+C(22)*C4/ALZ
    A(KHR) = -C(22)*C4/ALZ
    A(KHR-3) = 2.*(C(21)+C(23))*C4/ALR
    GO TO 600
552 IF (J-JIP-1) 558,559,554
558 IF (J-JIP) 560,561,561
560 LOCAT = 4
    SIGN = 1.
    CF = C(21)*C4
    CALL RSTRN
    CF = C(22)*C4
    CALL ZSTRN
    SIGN = -1.
    CF = C(23)*C4
    CALL RSTRN
    CF = C(24)*C4
    CALL RZSTRN
```

(a)

```
      GO TO 600
  561 CON = CON+(1.-ALR/(8.*R(I)))*DELP/(2.*ALZ)
      GO TO 560
  563 C4 = -C1/(2.*ALZ)
      CON = CON+(1.-ALR/(8.*R(I)))*DELP/(2.*ALZ)
      GO TO 554
  560 IF ((J-2)*(I-IEC)) 562,563,562
  562 GO TO (554,565),LG
  565 I1 = I-IIC+2
      A(KHR) = -AR(I1)*C4/ALZ
      A(KDR) = A(KDR)-A(KHR)
      GO TO 554
  564 IF (I-IEC) 566,560,560
  566 A(KDR) = A(KDR)+2.*C(22)*C4/ALZ
      A(KHR-1) = (C(21)/ALR+C(23)/(2.*R(I)))*C4
      A(KDR+1) = -(C(21)/ALR-C(23)/(2.*R(I)))*C4
  567 RETURN
      END
*******************************************************************
      SUBROUTINE SIGRZA
*******************************************************************
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
     4        EXCF,SIG1CR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44)
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
     1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
     3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1))
     4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1))
     5            (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
  600 IA = I+1
      JA = J
      IF ((I-IEC+1)*(I-IEC)*(J-JEP)) 611,650,611
  611 IF ((J-2)*(J-JIP)*(J-JIP-1)) 612,614,612
  612 CALL STRSTR
      A(KHR-5) =  (C(41)/ALR+C(43)/(2.*R(IA)))*C1
      A(KHR-4) = C(44)*C1/ALR
      A(KHR-3) = A(KHR-3)-C(44)*C1/ALZ
      A(KHR-2) = A(KHR-2)-C(42)*C1/ALZ
  613 A(KDR-3) = A(KDR-3)+C(44)*C1/ALZ
      A(KDR-2) = A(KDR-2)+C(42)*C1/ALZ
      A(KDR-1) = A(KDR-1)-(C(41)/ALR-C(43)/(2.*R(IA)))*C1
      A(KDR) = A(KDR)-C(44)*C1/ALR
      GO TO 650
  614 IF (J-JIP) 615,616,617
  615 CALL STRSTR
```

(b)

```
      A(KHR-3) = (C(41)/ALR+C(43)/(2.*R(IA)))*C1
      A(KHR-2) = C(44)*C1/ALR
      A(KHR-1) = A(KHR-1)-C(44)*C1/ALZ
      A(KHR) = A(KHR)-C(42)*C1/ALZ
      GO TO 613
  616 IF (I-IIC+1) 650,615,612
  617 IF (I-IIC) 615,612,612
  650 RETURN
      END
*******************************************************************
      SUBROUTINE SIGRZB
*******************************************************************
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
     4        EXCF,SIG1CR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
     1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
     3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
     4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
     5            (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
  650 IA = I-1
      JA = J
      CALL STRSTR
      IF ((I-1)*(I-2)*(J-JEP)) 651,652,651
  651 IF ((I-IIC)*(I-IIC-1)*(J-JIP)*(J-JEP+1)) 653,654,653
  653 CALL STRSTR
      A(3) = A(3)+C(44)*C2/ALZ
      A(4) = A(4)+C(42)*C2/ALZ
      A(5) = -(C(41)/ALR-C(43)/(2.*R(IA)))*C2
      A(6) = -C(44)*C2/ALR
  655 A(KDR-1) = A(KDR-1)+(C(41)/ALR+C(43)/(2.*R(IA)))*C2
      A(KDR) = A(KDR)+C(44)*C2/ALR
      A(KDR+1) = A(KDR+1)-C(44)*C2/ALZ
      A(KDR+2) = A(KDR+2)-C(42)*C2/ALZ
  652 RETURN
  654 IF (J-JEP+1) 656,657,657
  656 IF (J-JIP) 652,658,653
  658 IF (I-IIC-1) 652,653,653
  657 CALL STRSTR
      A(1) = A(1)+C(44)*C2/ALZ
      A(2) = A(2)+C(42)*C2/ALZ
      A(3) = -(C(41)/ALR-C(43)/(2.*R(IA)))*C2
      A(4) = -C(44)*C2/ALR
      GO TO 655
      END
```

(c)

```
*******************************************************************
      SUBROUTINE RSTRN
*******************************************************************
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
     4        EXCF,SIG1CR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
     1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
     3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
     4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
     5            (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
      DO 1 K=1,4
      UC(K) = 0.
    1 WC(K) = 0.
      IF (SIGN) 11,12,12
   11 CF1 = CF/(2.*R(IA))
      GO TO 13
   12 CF1 = CF/ALR
   13 IF ((IA-1)*(IA-IIC)*(IA-IEC)) 14,15,14
   14 UC(1) = CF1
      UC(2) = -SIGN*CF1
   21 CALL ASSIGN
   10 RETURN
   15 IF (IA-IIC) 16,17,18
   16 UC(1) = 2.*CF/ALR
      GO TO 21
   17 IF (JA-JIP) 19,14,14
   19 IF (C(44)) 20,22,20
   20 A1 = -C(14)*C(42)/C(44)
      A4 = -C(14)*(C(41)/ALR-C(43)/(2.*R(IA)))/C(44)
      A5 = -C(14)*(C(41)/ALR+C(43)/(2.*R(IA)))/C(44)
      GO TO 23
   22 A1 = 0.
      A4 = 0.
      A5 = 0.
   23 A4 = A4+(C(11)/ALR-C(13)/(2.*R(IA)))
      IF (A4) 24,10,24
   24 A5 = A5+C(11)/ALR+C(13)/(2.*R(IA))
      A1 = A1+C(12)
      UC(1) = (A4-A5*SIGN)*CF1/A4
      WC(3) = -A1*SIGN*CF1/(A4*ALZ)
      CON = CON-CF1*DELP*SIGN/A4
   25 IF (JA-1) 26,26,27
   26 WC(3) = 2.*WC(3)
      UC(3) = 2.*UC(3)
```

(d)

```
      GO TO 21
   27 WC(4) = -WC(3)
      UC(4) = UC(3)
      GO TO 21
   18 IF (JA-JEP) 28,29,29
   28 IF (C(44)) 30,31,30
   30 A1 = -C(14)*C(42)/C(44)
      A4 = -C(14)*(C(41)/ALR-C(43)/(2.*R(IA)))/C(44)
      A5 = -C(14)*(C(41)/ALR+C(43)/(2.*R(IA)))/C(44)
      GO TO 32
   31 A1 = 0.
      A4 = 0.
      A5 = 0.
   32 A5 = A5+C(11)/ALR+C(13)/(2.*R(IA))
      IF (A5) 33,10,33
   33 A4 = A4+(C(11)/ALR-C(13)/(2.*R(IA)))
      A1 = A1+C(12)
      UC(2) = (A4-A5*SIGN)*CF1/A5
      WC(3) = -A1*CF1/(A5*ALZ)
      CON = CON-CF1*PHP/A5
      UC(3) = -CF1*AK/(2.*R(IA)*A5)
      GO TO 25
   29 IF (C(44)) 34,35,34
   34 A10 = (C(14)*C(22)-C(12)*C(24))/(C(24)*C(42)-C(22)*C(44))
      A6 = -(C(42)*(C(21)/ALR+C(23)/(2.*R(IA)))-C(22)*(C(41)/ALR+
     1  C(43)/(2.*R(IA))))*A10
      A7 = -(C(42)*(C(21)/ALR-C(23)/(2.*R(IA)))-C(22)*(C(41)/ALR-
     1  C(43)/(2.*R(IA))))*A10
      A10 = C(42)*A10
      GO TO 36
   35 A6 = 0.
      A7 = 0.
      A10 = 0.
   36 A6 = A6+C(22)*(C(11)/ALR+C(13)/(2.*R(IA)))-C(12)*(C(21)/ALR+
     1  C(23)/(2.*R(IA)))
      IF (A6) 37,10,37
   37 I1 = IA-IIC+2
      A7 = A7+C(22)*(C(11)/ALR-C(13)/(2.*R(IA)))-C(12)*(C(21)/ALR -
     1  C(23)/(2.*R(IA)))
      UC(4) = -C(22)*AK*CF1/(A6*2.*R(IA))
      UC(2) = UC(4)+(A7-A6*SIGN)*CF1/A6
      CON = CON-CF1*(C(22)*PHP-(C(12)+A10)*PZP(I1))/A6
      GO TO 21
      END
*******************************************************************
      SUBROUTINE ZSTRN
*******************************************************************
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
     4        EXCF,SIG1CR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
```

(a)

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      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPSI(53,81),
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPSI(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPSI(1)) ,
     1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
     3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
     4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPSI(1)),
     5            (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
      DO 1 K=1,4
      UC(K) = 0.
    1 WC(K) = 0.
      IF ((JA-1)*(JA-JIP)*(JA-JEP)) 11,12,11
   11 WC(3) = CF/ALZ
      WC(4) = -WC(3)
   18 CALL ASSIGN
   10 RETURN
   12 IF (JA-JIP) 13,14,15
   13 WC(3) = 2.*CF/ALZ
      GO TO 18
   14 IF (IA-IIC) 16,11,11
   16 IF (C(44)) 19,20,19
   19 A2 = C(24)/C(44)
      A1 = C(22)-A2*C(42)
      GO TO 21
   20 A1 = C(22)
      A2 = 0.
   21 CON = CON-CF*DELP/A1
   22 IF (IA-1) 23,24,23
   23 UC(1) = -CF*((C(21)-A2*C(41))/ALR+(C(23)-A2*C(43))/(2.*R(IA)))/A1
      UC(2) = CF*((C(21)-A2*C(41))/ALR-(C(23)-A2*C(43))/(2.*R(IA)))/A1
      GO TO 18
   24 UC(1) = -2.*CF*(C(21)+C(23)-A2*(C(41)+C(43)))/(ALR*A1)
      GO TO 18
   15 IF (IA-IEC) 25,26,26
   25 IF (C(44)) 27,28,27
   27 A2 = C(24)/C(44)
      A1 = C(22)-A2*C(42)
      GO TO 29
   28 A1 = C(22)
      A2 = 0.
   29 IF (IA-IIC) 22,30,30
   30 I1 = IA-IIC+2
      GO TO (31,32),LG
   31 WC(4) = -CF*AR(I1)/(A1*(H-ALZ/2.))
      GO TO 33
   32 A1 = A1-AR(I1)
   33 CON = CON-CF*PZP(I1)/A1
      GO TO 23
   26 IF (C(44)) 34,35,34
   34 A10 = (C(14)*C(22)-C(12)*C(24))/(C(24)*C(42)-C(22)*C(44))
      A1 = C(22)-C(24)*C(42)/C(44)
      A6 = -(C(42)*(C(21)/ALR+C(23)/(2.*R(IA)))-C(22)*(C(41)/ALR+
     1  C(43)/(2.*R(IA))))*A10
      A7 = -(C(42)*(C(21)/ALR-C(23)/(2.*R(IA)))-C(22)*(C(41)/ALR-
     1  C(43)/(2.*R(IA))))*A10
```

(b)

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      A8 = -C(24)*(C(41)/ALR+C(43)/(2.*R(IA)))/C(44)
      A9 = -C(24)*(C(41)/ALR-C(43)/(2.*R(IA)))/C(44)
      A10 = C(42)*A10
      GO TO 36
   35 A1 = C(22)
      A6 = 0.
      A7 = 0.
      A8 = 0.
      A9 = 0.
      A10 = 0.
   36 A9 = A9+C(21)/ALR-C(23)/(2.*R(IA))
      I1 = IA-IIC+2
      CON = CON-CF*PZP(I1)/A1
      UC(2) = A9*CF/A1
      A6 = A6+C(22)*(C(11)/ALR+C(13)/(2.*R(IA)))-C(12)*(C(21)/ALR+
     1  C(23)/(2.*R(IA)))
      IF (A6) 37,10,37
   37 A7 = A7+C(22)*(C(11)/ALR-C(13)/(2.*R(IA)))-C(12)*(C(21)/ALR-
     1  C(23)/(2.*R(IA)))
      A8 = A8+C(21)/ALR+C(23)/(2.*R(IA))
      UC(4) = A8*C(22)*AK*CF/(A1*A6*2.*R(IA))
      UC(2) = UC(2)+UC(4)-A8*A7*CF/(A1*A6)
      CON = CON +A8*CF*(C(22)*PHP-(C(12)+A10)*PZP(I1))/(A1*A6)
      GO TO 18
      END
***********************************************************************
      SUBROUTINE RZSTRN
***********************************************************************
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
     4        EXCF,SIGICR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPSI(53,81),
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPSI(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPSI(1)) ,
     1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
     3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
     4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPSI(1)),
     5            (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
      DO 1 K=1,4
      UC(K) = 0.
    1 WC(K) = 0.
      IF ((IA-1)*(JA-1)*(IA-IIC)*(IA-IEC)*(JA-JIP)*(JA-JEP)) 11,12,11
   11 UC(3) = CF/ALZ
      UC(4) = -UC(3)
      WC(1) = CF/ALR
      WC(2) = -WC(1)
      GO TO 14
```

(c)

```
   12 IF ((IA-1)*(JA-1)) 13,10,13
   13 IF (IA-IIC) 15,16,17
   15 IF (C(42)) 35,36,35
   35 A2 = C(22)/C(42)
      A1 = C(24)-A2*C(44)
      GO TO 37
   36 A1 = C(24)
      A2 = 0.
   37 IF (A1) 18,10,18
   18 UC(1) = -CF*((C(21)-A2*C(41))/ALR+(C(23)-A2*C(43))/(2.*R(IA)))/A1
      UC(2) = CF*((C(21)-A2*C(41))/ALR-(C(23)-A2*C(43))/(2.*R(IA)))/A1
      IF (JA-JIP) 19,19,14
   19 CON = CON+CF*DELP/A1
      GO TO 14
   16 IF (JA-JIP) 20,11,21
   20 A4 = C(44)*(C(11)/ALR-C(13)/(2.*R(IA)))-C(14)*(C(41)/ALR-
     1      C(43)/(2.*R(IA)))
      IF (A4) 22,10,22
   22 UC(1) = CF*((C(11)/ALR+C(13)/(2.*R(IA)))*(C(41)/ALR-C(43)/(2.*
     1  R(IA)))-(C(41)/ALR+C(43)/(2.*R(IA)))*(C(11)/ALR-C(13)/(2.*R(IA))
     2  ))/A4
      WC(3) = CF*(C(12)*(C(41)/ALR-C(43)/(2.*R(IA)))-C(42)*(C(11)/ALR-
     1  C(13)/(2.*R(IA))))/(ALZ*A4)
      WC(4) = -WC(3)
      CON = CON+CF*(C(41)/ALR-C(43)/(2.*R(IA)))*DELP/A4
      GO TO 14
   21 IF (JA-JEP) 11,23,11
   17 IF ((JA-JIP)*(IA-IEC)) 23,24,23
   23 IF (C(42)) 38,39,38
   38 A2 = C(22)/C(42)
      A1 = C(24)-A2*C(44)
      GO TO 40
   39 A1 = C(24)
      A2 = 0.
   40 IF (A1) 25,10,25
   25 I1 = IA-IIC+2
      CON = CON+CF*PZP(I1)/A1
      GO TO (26,27),LG
   26 WC(4) = CF*AR(I1)/(A1*(H-ALZ/2.))
      GO TO 18
   27 A1 = A1-AR(I1)*A2*C(44)/C(22)
      GO TO 18
   24 IF (IA-IEC) 11,28,11
   28 IF (JA-JEP) 29,10,10
   29 A5 = C(44)*(C(11)/ALR+C(13)/(2.*R(IA)))-C(14)*(C(41)/ALR+
     1      C(43)/(2.*R(IA)))
      IF (A5) 31,10,31
   31 UC(2) = CF*((C(41)/ALR-C(43)/(2.*R(IA)))*(C(11)/ALR+C(13)/(2.*
     1  R(IA)))-(C(11)/ALR-C(13)/(2.*R(IA)))*(C(41)/ALR+C(43)/(2.*R(IA)
     1  ))/A5
      WC(3) = CF*(C(12)*(C(41)/ALR+C(43)/(2.*R(IA)))-C(42)*(C(11)/ALR
     1  +C(13)/(2.*R(IA))))/(ALZ*A5)
      WC(4) = -WC(3)
      UC(3) = CF*(C(41)/ALR+C(43)/(2.*R(IA)))*AK/(A5*2.*R(IA))
      UC(4) = UC(3)
      CON = CON + CF*(C(41)/ALR+C(43)/(2.*R(IA)))*PHP/A5
   14 CALL ASSIGN
```

(d)

```
   10 RETURN
      END
***********************************************************************
      SUBROUTINE ASSIGN
***********************************************************************
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
     4        EXCF,SIGICR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPSI(53,81),
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPSI(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPSI(1)) ,
     1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
     3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
     4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPSI(1)),
     5            (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
      LQ = 2*(NQ/2)-NQ+1
      KDR1 = KDR-LQ
      GO TO (1,2,3,4),LOCAT
C     RIGHT
    1 IF ((J-1)*(J-2)*(J-JIP)*(J-JIP-1)*(J-JEP)) 11,12,11
   11 A(KDR1-2) = A(KDR1-2)+UC(3)
      A(KDR1-1) = A(KDR1-1)+WC(3)
   13 A(KHR-5) = A(KHR-5)+UC(1)
      A(KHR-4) = A(KHR-4)+WC(1)
      A(KHR-3) = A(KHR-3)+UC(4)
      A(KHR-2) = A(KHR-2)+WC(4)
   14 A(KDR1) = A(KDR1)+UC(2)
      A(KDR1+1) = A(KDR1+1)+WC(2)
      RETURN
   12 IF (J-JIP-1) 15,15,13
   15 IF (I-IIC+1) 16,17,18
   16 IF (J-JIP) 19,19,17
   18 IF (J-2) 19,17,11
   17 A(KHR-3) = A(KHR-3)+UC(1)
      A(KHR-2) = A(KHR-2)+WC(1)
      A(KHR-1) = A(KHR-1)+UC(4)
      A(KHR) = A(KHR)+WC(4)
      GO TO 20
   19 A(KHR-1) = A(KHR-1)+UC(1)
      A(KHR) = A(KHR)+WC(1)
   20 A(KDR1-2) = A(KDR1-2)+UC(3)
      A(KDR1-1) = A(KDR1-1)+WC(3)
      GO TO 14
C     LEFT
    2 IF (J-JEP+1) 31,32,33
   31 A(3) = A(3)+UC(3)
      A(4) = A(4)+WC(3)
```

(a)

```
   A(5) = A(5)+UC(2)
   A(6) = A(5)+WC(2)
34 A(KDR1) = A(KDR1)+UC(1)
   A(KDR1+1) = A(KDR1+1)+WC( 1)
   A(KDR1+2) = A(KDR1+2)+UC( 4)
   A(KDR1+3) = A(KDR1+3)+WC( 4)
   RETURN
33 A(1) = A(1)+UC(2)
   A(2) = A(2)+WC(2)
   GO TO 34
32 A(1) = A(1)+UC(3)
   A(2) = A(2)+WC(3)
   A(3) = A(3)+UC(2)
   A(4) = A(4)+WC(2)
   GO TO 34
  ABOVE
 3 IF (J-JEP+1) 41,42,44
41 A(1) = A(1)+UC(3)
   A(2) = A(2)+WC(3)
   A(3) = A(3)+UC(2)
   A(4) = A(4)+WC(2)
43 A(KDR1-2) = A(KDR1-2)+UC( 1)
   A(KDR1-1) = A(KDR1-1)+WC( 1)
   A(KDR1) = A(KDR1)+UC(4)
   A(KDR1+1) = A(KDR1+1)+WC( 4)
44 RETURN
42 A(1) = A(1)+UC(2)
   A(2) = A(2)+WC(2)
   GO TO 43
  BELOW
 4 IF ((J-2)*(J-JIP-1)) 51,52,51
51 A(KHR-3) = A(KHR-3) +UC(1 )
   A(KHR-2) = A(KHR-2)+WC(1)
   A(KHR-1) = A(KHR-1)+UC(4)
   A(KHR) = A(KHR)+WC(4)
53 A(KDR1) = A(KDR1)+UC(3)
   A(KDR1+1) = A(KDR1+1)+WC( 3)
   A(KDR1+2) = A(KDR1+2)+UC( 2)
   A(KDR1+3) = A(KDR1+3)+WC( 2)
   RETURN
52 IF (J-JIP-1) 54,55,51
55 IF (I-IIC) 54,51,51
54 A(KHR-1) = A(KHR-1)+UC(1)
   A(KHR) = A(KHR)+WC(1)
   GO TO 53
   END
****************************************************************
   SUBROUTINE COORD
****************************************************************
   COMMON   ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
  1         PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
  2         JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
  3         ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
  4         EXCF,SIGICR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
   COMMON   A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
  1         S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
  2         FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
```

(b)

```
  3         EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
  4         E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
   DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
  1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
  2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
  3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
   EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
  1           (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
  2           (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
  3           (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
  4           (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
  5           (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
   IF (NQ-ITOT1) 1,1,2
 1 I = (NQ-1)/MW+1
   IF (MW-2*(MW/2)) 3,4,3
 4 IF (IIC+LRC-2*((IIC+LRC)/2)) 7,9,7
 3 IF (IIC+LRC-2*((IIC+LRC)/2)) 5,6,5
 5 IF (NQ-MW-(2*MW)*((I-1)/2)) 7,8,7
 8 I = I+1
 7 J=2*((NQ+1)/2)-((I-1)/2)*(2*((MW+1)/2)-1)-(I/2)*(2*(MW/2)+1)+JIP-1
   RETURN
 6 IF (NQ-MW-1-(2*MW)*((I-1)/2)) 9,10,9
10 I = I-1
 9 J=2*((NQ-1)/2)-(I/2)*(2*((MW+1)/2)-1)-((I-1)/2)*(2*(MW/2)+1)+JIP
   RETURN
 2 I = (NQ-ITOT1-1)/JEP+IIC
   IF (JEP-2*(JEP/2)) 11,12,11
12 IF (JIP+LRC-2*((JIP+LRC)/2)) 13,14,13
11 IF (JIP+LRC-2*((JIP+LRC)/2)) 17,16,17
16 IF (NQ-ITOT1-1-JEP-(2*JEP)*((I-IIC)/2)) 14,18,14
18 I = I-1
14 J=2*((NQ - ITOT1-1)/2)+1-((I-IIC)/2)*(2*(JEP/2)+1)-((I-IIC+1)/2)*(
  12*((JEP+1)/2)-1)
   RETURN
17 IF (NQ-ITOT1-JEP-(2*JEP)*((I-IIC)/2)) 13,15,13
15 I = I+1
13 J = 2*((NQ - ITOT1+1)/2)-((I-IIC+1)/2)*(2*(JEP/2)+1)-((I-IIC)/2)*(
  12*((JEP+1)/2)-1)
   RETURN
   END
****************************************************************
   SUBROUTINE BAND
****************************************************************
   COMMON   ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
  1         PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
  2         JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
  3         ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
  4         EXCF,SIGICR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
   COMMON   A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
  1         S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
  2         FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
  3         EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
  4         E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
   DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
  1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
  2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
  3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
```

(c)

```
   EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
  1           (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
  2           (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
  3           (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
  4           (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
  5           (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
   KDT = NC(NQ)
   NQT = NQ
   IF (NQ-2*(NQ/2)) 11,51,11
51 NQ = NQ-1
11 KD = NC(NQ)
   IF (I-IIC) 12,13,13
12 IF ((J-JEP+1)*(J-JIP-1)) 14,15,16
14 KLOW = NC(NQ+2)
   KHIGH = NC(NQ-1)
   GO TO 300
15 IF (J-JEP+1) 17,18,17
17 IF (I-IIC+1) 7,8,7
 7 NQ1 = NQ+2*(MW/2)+1
19 KHIGH = NC(NQ1)
20 KLOW = NC(NQ+2)
   GO TO 300
 8 NQ1 = NQ+2*(MW/2)+2*((JIP-1)/2)+1
   GO TO 19
18 IF (I-1) 21,22,21
21 NQ1 = NQ-2*(MW/2)
23 KLOW = NC(NQ1)
24 KHIGH = NC(NQ-1)
   GO TO 300
22 KLOW = KD-2
   GO TO 24
13 IF ((J-JEP+1)*(J-2)) 14,26,27
26 IF (J-2) 28,29,28
28 NQ1 = NQ-2*(JEP/2)
   GO TO 23
29 IF (I-IEC) 30,31,30
30 NQ1 = NQ+2*(JEP/2)+1
   GO TO 19
31 KHIGH = KD+3
   GO TO 20
16 IF (J-JEP) 32,33,32
33 IF (I-2) 34,34,35
34 KLOW = KD
   GO TO 24
35 NQ1 = NQ-2*(MW/2)-2*((MW+1)/2)
   GO TO 23
32 IF (I-IIC+2) 36,44,37
44 NQ1 = NQ+2*(MW/2)+2*((MW+1)/2)+2*((JIP-1)/2)+1
   GO TO 19
36 NQ1 = NQ+2*(MW/2)+2*((MW+1)/2)+1
   GO TO 19
37 NQ1 = NQ+2*((MW-1)/2)+2*(JIP/2)+1
   GO TO 19
27 IF (J-JEP) 38,39,38
39 IF (I-IIC) 40,41,40
41 NQ1 = NQ-2*(MW/2)-2*((JEP+1)/2)
   GO TO 23
```

(d)

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40 NQ1 = NQ-2*(JEP/2)-2*((JEP+1)/2)
   GO TO 23
38 IF (I-IEC+1) 43,42,42
42 KHIGH = KD+1
   GO TO 20
43 NQ1 = NQ+2*(JEP/2)+2*((JEP+1)/2)+1
   GO TO 19
300 KD = KDT
   NQ = NQT
   RETURN
   END
****************************************************************
   SUBROUTINE STRSTR
****************************************************************
   COMMON   ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
  1         PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
  2         JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
  3         ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
  4         EXCF,SIGICR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
   COMMON   A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
  1         S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
  2         FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
  3         EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
  4         E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
   DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
  1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
  2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
  3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
   EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
  1           (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
  2           (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
  3           (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
  4           (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
  5           (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
   C(31) = PRF3
   C(32) = PRF3
   C(33) = PRF2
   C(34) = 0.
   IF (LC(IA,JA)-1) 11,12,13
13 IF (LC(IA,JA)-3) 14,12,16
14 C(31) = 0.
   C(32) = 0.
   C(33) = 0.
   C(34) = 0.
   GO TO 11
16 GO TO 11
C     HERE, VARIOUS TYPES OF CLOSED CRACKS CAN BE TAKEN INTO ACCOUNT
11 C(11) = PRF2
   C(12) = PRF3
   C(44) = PRF4
   C(13) = C(31)
   C(14) = 0.
   C(21) = C(12)
   C(22) = C(11)
   C(23) = C(32)
   C(24) = 0.
   C(41) = 0.
```

(a)

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      C(42) = 0.
      C(43) = 0.
      RETURN
   10 IF (I-IIC) 21,21,22
   21 IF (J-JIP-1) 23,23,22
   23 IF (ABS(TAN(W(IA,JA)))-1.2) 22,22,24
   24 IF (LC(IA,JA)-1) 11,11,14
   22 ERCF = PRF2*SIN(W(IA,JA))**2
      EZCF = PRF2*COS(W(IA,JA))**2
      ETCF = C(32)
      ERZCF = -0.5*PRF2*SIN(2.*W(IA,JA))
      SRCF = SIN(W(IA,JA))**2
      SZCF = COS(W(IA,JA))**2
      SRZCF = -0.5*SIN(2.*W(IA,JA))
      C(11) = ERCF*SRCF
      C(12) = EZCF*SRCF
      C(14) = ERZCF*SRCF
      C(21) = ERCF*SZCF
      C(22) = EZCF*SZCF
      C(24) = ERZCF*SZCF
      C(41) = ERCF*SRZCF
      C(42) = EZCF*SRZCF
      C(44) = ERZCF*SRZCF
      IF (LC(IA,JA)-2) 17,14,18
   17 C(13) = ETCF*SRCF
      C(23) = ETCF*SZCF
      C(34) = ETCF*SRZCF
      GO TO 19
   18 C(13) = 0.
      C(23) = 0.
      C(33) = 0.
      C(34) = 0.
   19 C(31) = C(13)
      C(32) = C(23)
      C(43) = C(34)
      RETURN
      END
*****************************************************************************
      SUBROUTINE EXTRPL
*****************************************************************************
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
     4        EXCF,SIGICR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
     1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
```

(b)

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     3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
     4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
     5            (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
      EXCF = 100000.
      DO 40 L=1,JTOT
      NQ = 2*L
      CALL COORD
      IF (LC(I,J)-1) 11,10,28
   11 IF (DEPS1(I,J)) 10,10,12
   12 D = 4.*DER(I,J)*DEZ(I,J)-DERZ(I,J)**2
      F = 4.*ECRIT**2-4.*ECRIT*(ERPR(I,J)+EZPR(I,J))+4.*ERPR(I,J)*EZPR(I
     1,J)-ERZPR(I,J)**2
      E = -2.*ECRIT*(DER(I,J)+DEZ(I,J))+2.*DER(I,J)*EZPR(I,J)+2.*DEZ(I,J
     1)*ERPR(I,J)-DERZ(I,J)*ERZPR(I,J)
      IF (D) 13,21,13
   21 IF (DEZ(I,J)) 22,24,22
   22 ROOT = F/(4.*DEZ(I,J)*(ECRIT-ERPR(I,J)))
      GO TO 7
   24 ROOT = F/(4.*DER(I,J)*(ECRIT-EZPR(I,J)))
    7 IF (ROOT) 10,9,9
   13 IF (ABS(E/D)-1.E 05) 8,8,21
    8 CONTINUE
      DISCR = E**2-D*F
      IF (DISCR) 23,14,14
   23 WRITE (6,101) I,J
  101 FORMAT ('0CRACK HAS ALREADY PROPAGATED TO NODE AT I =',I3,' , J ='
     1       ,I3/)
      GO TO 10
   14 F1 = (-E+SQRT(DISCR))/D
      F2 = (-E-SQRT(DISCR))/D
      X1 = ERPR(I,J)+F1*DER(I,J)
      Y1 = EZPR(I,J)+F1*DEZ(I,J)
      Z1 = ERZPR(I,J)+F1*DERZ(I,J)
      PRSTR1 = 0.5*(X1+Y1+SQRT((X1-Y1)**2+Z1**2))
      X2 = ERPR(I,J)+F2*DER(I,J)
      Y2 = EZPR(I,J)+F2*DEZ(I,J)
      Z2 = ERZPR(I,J)+F2*DERZ(I,J)
      PRSTR2 = 0.5*(X2+Y2+SQRT((X2-Y2)**2+Z2**2))
      IF (ABS(PRSTR1-ECRIT)-.1E-05) 15,15,16
   15 ROOT = F1
      IF (ROOT) 16,25,25
   25 CONTINUE
      IF (ABS(PRSTR2-ECRIT)-.1E-05) 17,17,9
   16 IF (ABS(PRSTR2-ECRIT)-.1E-05) 18,18,23
   17 IF (F2) 9,26,26
   26 IF (F1-F2) 9,9,18
   18 ROOT = F2
      IF (ROOT) 10,10,9
    9 IF (ROOT-EXCF) 20,20,10
   20 EXCF = ROOT
      ICR = I
      JCR = J
   10 IF (I-1) 40,40,29
   29 IF (LC(I,J)-1) 27,27,40
   27 IF (DET(I,J)) 40,40,31
   31 ROOT = (ECRIT-ETPR(I,J))/DET(I,J)
      IF (ROOT) 40,40,38
```

(c)

```
   38 IF (ROOT-EXCF) 30,32,40
   30 EXCF = ROOT
   34 ICR = -I
      JCR = -J
      GO TO 40
   32 IF (I-IABS(ICR)) 33,34,33
   33 WRITE (6,103) I,J,ICR,JCR
  103 FORMAT ('OWE ARE IN THE PRESENCE OF THE RARE CASE WHERE TWO NODES
     1APPART FROM EACH OTHER CRACK SIMULTANEOUSLY I =',I3,' J =',I3,' AN
     2D I =',I3,' J =',I3///)
      GO TO 40
   28 IF (LC(I,J)-3) 11,40,39
   39 CONTINUE
C     HERE - CLOSED CRACKS CAN BE CONSIDERED
   40 CONTINUE
      RETURN
      END
*****************************************************************************
      SUBROUTINE CHECK
*****************************************************************************
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
     4        EXCF,SIGICR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
     1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
     3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
     4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
     5            (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
      LCR = 0
      ETEMP = 0.
      DO 10 L=1,JTOT
      NQ = 2*L
      CALL COORD
      ET = ETPR(I,J)+DET(I,J)
      IF (LC(I,J)-1) 31,32,33
   31 IF (EPS1(I,J)-ECRIT) 34,37,37
   34 IF (ET-ECRIT) 10,38,38
   38 ICRT = -I
      JCRT = -J
      ETEMP1 = ET
      GO TO 39
   36 IF (ET-EPS1(I,J)) 35,40,40
   40 IF (I-1) 35,35,38
   37 IF (ET-ECRIT) 35,36,36
   35 ICRT = I
```

(d)

```
      JCRT = J
      ETEMP1 = EPS1(I,J)
   39 LCR = LCR+1
      IF (ETEMP1-ETEMP) 10,11,12
   11 WRITE (6,103) I,J,ICRT,JCRT
  103 FORMAT ('OWE ARE IN THE PRESENCE OF THE RARE CASE WHERE TWO NODES
     1APPART FROM EACH OTHER CRACK SIMULTANEOUSLY I =',I3,' J =',I3,' AN
     2D I =',I3,' J =',I3///)
      GO TO 10
   32 IF (ET-ECRIT) 10,42,42
   42 IF (I-1) 43,43,38
   43 LC(I,J) = 3
      GO TO 10
   33 IF (LC(I,J)-2) 44,44,10
   44 IF (EPS1(I,J)-ECRIT) 10,35,35
   12 ETEMP = ETEMP1
      ICR = ICRT
      JCR = JCRT
   10 CONTINUE
      IF (LCR) 15,15,16
   15 CONTINUE
      WRITE (6,113)
  113 FORMAT ('-THE CRACK DOES NOT PROPAGATE'///)
      DELP = 100.
      LPRCSS = 1
      PHP = 0.
      NLP = IEC-IIC+2
      DO 90 I=1,NLP
   90 PZP(I) = 0.
      RETURN
   16 WRITE (6,114) LCR
  114 FORMAT ('-THE CRACK SEEMS TO PROPAGATE INSTANTANEOUSLY THROUGH',
     1       I3,' STRESS NODES'///)
      RETURN
      END
*****************************************************************************
      SUBROUTINE SOLVER
*****************************************************************************
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
     4        EXCF,SIGICR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
     1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
     3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
     4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
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(a)

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5             (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
      REWIND 1
      CALL TRI
      IF (ERR) 1, 2, 3
    1 WRITE (6,4) ERR
    4 FORMAT (16H TOO MANY TERMS ,F10.0)
      GO TO 6
    2 CALL BACK
      WRITE (6,7) MS(ITOT)
    7 FORMAT (' SIZE OF VECTOR B IS',I6)
      RETURN
    3 WRITE (6,5) ERR
    5 FORMAT (20H ZERO DIAGONAL TERM ,F10.0)
    6 CONTINUE
      RETURN
      END
************************************************************************
      SUBROUTINE BACK
************************************************************************
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
     4        EXCF,SIGICR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
     1           (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2           (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
     3           (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
     4           (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
     5           (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
      N2 = ITOT-1
      DO 1 I = 1, N2
      JE = ITOT-I
      JL = MS(JE)
      JU = MS(JE+1)-1
      J2 = JE
      DO 1 J = JL, JU
      J2 = J2+1
    1 S(JE) = S(JE)+B(J)*S(J2)
      RETURN
      END
************************************************************************
      SUBROUTINE TRI
************************************************************************
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
```

(b)

```
     4        EXCF,SIGICR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
     1           (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2           (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
     3           (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
     4           (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
     5           (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
    8 MS(1) = 1
      LIMIT = 53000
      DO 1 IS=1,ITOT
      KD = IS
      READ(1) I,J,KLOW,KHIGH,A,CON
      NQ = NR(IS)
      KL = KLOW
      KH = KHIGH+1-KLOW
      KU = IS-1
      IF (KU) 4,4,3
    3 K1 = 0
      IF (KU-KL) 4,2,2
    2 DO 5 K = KL, KU
      K1 = K1+1
      LL = MS(K)
      LU = MS(K+1)-1
      L1 = K1
      DO 6 L = LL, LU
      L1 = L1+1
      A(L1) = A(L1)+B(L)*A(K1)
      IF (L1-KH) 6,6,14
   14 IF (A(L1)) 15,6,15
   15 KH = L1
    6 CONTINUE
    5 CON = CON+A(K1)*S(K)
    4 K1 = IS+1-KLOW
      KL = K1+1
      L = MS(IS)-1
      DO 7 K = KL, KH
      IF (A(K1)) 10,11,10
   11 ERR = IS
      RETURN
   10 CONTINUE
      L = L+1
    7 B(L) = -A(K)/A(K1)
      MS(IS+1) = L+1
      S(IS) = -CON/A(K1)
      IF (L-LIMIT) 1,13,13
   13 ERR = -IS
      RETURN
    1 CONTINUE
```

(c)

```
      ERR = 0.
  501 RETURN
      END
************************************************************************
      SUBROUTINE SIGEPS
************************************************************************
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
     4        EXCF,SIGICR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
     1           (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2           (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
     3           (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
     4           (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
     5           (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
      DEFINE FILE 2(1400,10,U,IREC)
      IF ((I-1)*(I-IIC)*(I-IEC)*(J-1)*(J-JIP)*(J-JEP)) 11,12,11
   11 ER = (U(I+1,J)-U(I-1,J))/ALR
      EZ = (W(I,J+1)-W(I,J-1))/ALZ
      ET = (U(I+1,J)+U(I-1,J))/(2.*R(I))
      ERZ = (U(I,J+1)-U(I,J-1))/ALZ+(W(I+1,J)-W(I-1,J))/ALR
      GO TO 300
   12 IF (I-IIC) 13,14,15
   13 IF (I-1) 16,17,16
   16 ER = (U(I+1,J)-U(I-1,J))/ALR
      ET= (U(I+1,J)+U(I-1,J))/(2.*R(I))
      EZ = 0.
      IF (C(42)) 18,19,18
   18 A2 = C(22)/C(42)
      A1 = C(24)-A2*C(44)
      GO TO 20
   19 A1 = C(24)
      A2 = 0.
   20 IF (A1) 21,22,21
   21 ERZ = -((C(21)-A2*C(41))*ER+(C(23)-A2*C(43))*ET)/A1
      IF (J-JIP) 23,24,23
   23 IF (I-IIC) 25,26,26
   26 ERZ = ERZ+PZP(I1)/A1
      GO TO 25
   24 ERZ = ERZ+DELP/A1
      GO TO 25
   17 ER = 2.*U(2,J)/ALR
      ET = ER
      EZ = 0.
      ERZ = 0.
      IF ((J-JIP)*(J-JEP)) 10,25,25
```

(d)

```
   10 EZ = (W(I,J+1)-W(I,J-1))/ALZ
      GO TO 300
   22 ERZ = 0.
   25 IF (C(44)) 27,28,27
   27 A2 = C(24)/C(44)
      A1 = C(22)-A2*C(42)
      GO TO 29
   28 A1 = C(22)
      A2 = 0.
   29 IF (J-JIP) 30,31,30
   30 IF (I-IIC) 32,33,33
   33 GO TO (34,35),LG
   34 EZ = -(PZP(I1)+AR(I1)*W(I,J-1)/(H-ALZ/2.))/A1
      GO TO 32
   35 A1 = A1-AR(I1)
      EZ = 0.
      GO TO 32
   31 EZ = EZ-DELP/A1
   32 EZ = EZ-((C(21)-A2*C(41))*ER+(C(23)-A2*C(43))*ET)/A1
      GO TO 300
   14 IF (J-JIP) 36,11,37
   37 IF (J-JEP) 11,49,49
   36 IF (J-1) 38,38,39
   38 EZ = 2.*W(1,2)/ALZ
      GO TO 40
   39 EZ = (W(I,J+1)-W(I,J-1))/ALZ
   40 IF (C(44)) 41,42,41
   41 A1 = -C(14)*C(42)/C(44)
      A4 = -C(14)*(C(41)/ALR-C(43)/(2.*R(I)))/C(44)
      A5 = -C(14)*(C(41)/ALR+C(43)/(2.*R(I)))/C(44)
      GO TO 43
   42 A1 = 0.
      A4 = 0.
      A5 = 0.
   43 A4 = A4+C(11)/ALR-C(13)/(2.*R(I))
      IF (A4) 44,45,44
   45 ER = 0.
      EZ = 0.
      ERZ = 0.
      GO TO 300
   44 A5 = A5+C(11)/ALR+C(13)/(2.*R(I))
      A1 = A1+C(12)
      UFICT = (A5*U(I+1,J)+A1*EZ+DELP)/A4
      ER = (U(I+1,J)-UFICT)/ALR
      ET = (U(I+1,J)+UFICT)/(2.*R(I))
      ERZ = (((C(11)/ALR+C(13)/(2.*R(I)))*(C(41)/ALR-C(43)/(2.*R(I)))-
     1 (C(41)/ALR+C(43)/(2.*R(I)))*(C(11)/ALR-C(13)/(2.*R(I))))*U(I+1,
     2J)+(C(12)*(C(41)/ALR-C(43)/(2.*R(I)))-C(42)*(C(11)/ALR-C(13)/(2.*R
     3(I))))*EZ+(C(41)/ALR-C(43)/(2.*R(I)))*DELP)/A4
      GO TO 300
   15 IF (I-IEC) 46,47,46
   46 IF (J-JIP) 48,11,49
   48 EZ = 2.*W(I,2)/ALZ
      ER = (U(I+1,J)-U(I-1,J))/ALR
      ET = (U(I+1,J)+U(I-1,J))/(2.*R(I))
      ERZ = 0.
      GO TO 300
```

(a)

```
49 I1 = I-IIC+2
   GO TO 16
47 IF (J-JEP) 50,51,51
50 IF (J-1) 52,52,53
52 EZ = 2.*W(I,2)/ALZ
   GO TO 54
53 EZ = (W(I,J+1)-W(I,J-1))/ALZ
54 IF (C(44)) 55,56,55
55 A1 = -C(14)*C(42)/C(44)
   A4 = -C(14)*(C(41)/ALR-C(43)/(2.*R(I)))/C(44)
   A5 = -C(14)*(C(41)/ALR+C(43)/(2.*R(I)))/C(44)
   GO TO 57
56 A1 = 0.
   A4 = 0.
   A5 = 0.
57 A5 = A5+C(11)/ALR+C(13)/(2.*R(I))
   IF (A5) 58,59,58
59 ER = 0.
   ET = 0.
   ERZ = 0.
   GO TO 300
58 A4 = A4+C(11)/ALR-C(13)/(2.*R(I))
   A1 = A1+C(12)
   IF (J-1) 60,60,61
60 PHPF = PHP+AK*U(I,J+1)/R(I)
   ERZ = 0.
   GO TO 62
61 PHPF = PHP+AK*(U(I,J+1)+U(I,J-1))/(2.*R(I))
   ERZ = (((C(41)/ALR-C(43)/(2.*R(I)))*(C(11)/ALR+C(13)/(2.*R(I)))-
  1    (C(11)/ALR-C(13)/(2.*R(I)))*(C(41)/ALR+C(43)/(2.*R(I))))*
  2    U(I-1,J)+(C(12)*(C(41)/ALR+C(43)/(2.*R(I)))-C(42)*(C(11)/ALR+
  3    C(13)/(2.*R(I))))*EZ+(C(41)/ALR+C(43)/(2.*R(I)))*PHPF)/A5
62 UFICT = (A4*U(I-1,J)-A1*EZ-PHPF)/A5
   ER = (UFICT-U(I-1,J))/ALR
   ET = (UFICT+U(I-1,J))/(2.*R(I))
   GO TO 300
51 I1 = I-IIC+2
   IF (C(42)) 63,64,63
63 A11 = C(24)-C(22)*C(44)/C(42)
   A12 = 1./(C(24)*C(42)-C(22)*C(44))
   GO TO 65
64 A11 = C(24)
   A12 = 0.
65 ERZ = 0.
   IF (A11) 66,67,66
66 ERZ = -PZP(I1)/A11
67 A4 = C(42)*(C(21)/ALR+C(23)/(2.*R(I)))-C(22)*(C(41)/ALR+C(43)/
  1      (2.*R(I)))
   A5 = C(42)*(C(21)/ALR-C(23)/(2.*R(I)))-C(22)*(C(41)/ALR-C(43)/
  1     (2.*R(I)))
   IF (C(44)) 68,69,68
68 A1 = C(22)-C(24)*C(42)/C(44)
   A10 = (C(14)*C(22)-C(12)*C(24))/(C(24)*C(42)-C(22)*C(44))
   A6 = -A4*A10
   A7 = -A5*A10
   A8 = -C(24)*(C(41)/ALR+C(43)/(2.*R(I)))/C(44)
   A9 = -C(24)*(C(41)/ALR-C(43)/(2.*R(I)))/C(44)
```

(b)

```
   A10 = C(42)*A10
   GO TO 70
69 A1 = C(22)
   A12 = C(24)*C(42)
   A6 = 0.
   A7 = 0.
   A8 = 0.
   A9 = 0.
   A10 = 0.
70 A9 = A9+C(21)/ALR-C(23)/(2.*R(I))
   EZ = -(PZP(I1)-A9*U(I-1,J))/A1
   A6 = A6+C(22)*(C(11)/ALR+C(13)/(2.*R(I)))-C(12)*(C(21)/ALR+
  1      C(23)/(2.*R(I)))
   IF (A6) 71,72,71
72 ER = 0.
   ET = 0.
   GO TO 73
71 A7 = A7+C(22)*(C(11)/ALR-C(13)/(2.*R(I)))-C(12)*(C(21)/ALR-
  1      C(23)/(2.*R(I)))
   A8 = A8+C(21)/ALR+C(23)/(2.*R(I))
   UFICT = (A7*U(I-1,J)-C(22)*(PHP+AK*(U(I-1,J)+U(I,J-1))/(2.*R(I)))+
  1      PZP(I1)*(C(12)+A10))/A6
   ER = (UFICT-U(I-1,J))/ALR
   ET = (UFICT+U(I-1,J))/(2.*R(I))
   EZ = EZ-A8*(A7*U(I-1,J)-C(22)*(PHP+AK*(U(I-1,J)+U(I,J-1))/(2.*R(I)
  1      ))+PZP(I1)*(C(12)+A10))/(A1*A6)
   ERZ = ERZ-A12*(A7*A4*U(I-1,J)+C(22)*A4*(PHP+AK*(U(I-1,J)+U(I,J-1))
  1      /(2.*R(I))) +A4*PZP(I1)*(C(12)+A10))/A6
73 ERZ = ERZ+A12*A5*U(I-1,J)
300 DSIGR = C(11)*ER+C(12)*EZ+C(13)*ET+C(14)*ERZ
   DSIGZ = C(21)*ER+C(22)*EZ+C(23)*ET+C(24)*ERZ
   DSIGT = C(31)*ER+C(32)*EZ+C(33)*ET+C(34)*ERZ
   DSIGRZ= C(41)*ER+C(42)*EZ+C(43)*ET+C(44)*ERZ
   SIGRT = SIGR(I,J)+DSIGR
   SIGZT = SIGZ(I,J)+DSIGZ
   SIGTT = SIGT(I,J)+DSIGT
   SIGRZT=SIGRZ(I,J)+DSIGRZ
   EPSR = ERPR(I,J)+ER
   EPSZ = EZPR(I,J)+EZ
   EPST = ETPR(I,J)+ET
   EPSRZ=ERZPR(I,J)+ERZ
   E1 = 0.5*(ER+EZ+SQRT((ER-EZ)**2+ERZ**2))
   EPS1(I,J) = 0.5*(EPSR+EPSZ+SQRT((EPSR-EPSZ)**2+EPSRZ**2))
   EPS2      = 0.5*(EPSR+EPSZ-SQRT((EPSR-EPSZ)**2+EPSRZ**2))
   IF (LC(I,J)-1) 97,520,520
520 IF (I-IIC) 521,521,96
521 IF (J-JIP-1) 523,523,96
523 IF (LC(I,J)-2) 524,96,524
524 IF (ABS(TAN(W(I,J)))-1.2) 96,97,97
96 SIGRT = C(11)*EPSR+C(12)*EPSZ+C(13)*EPST+C(14)*EPSRZ
   SIGZT = C(21)*EPSR+C(22)*EPSZ+C(23)*EPST+C(24)*EPSRZ
   SIGTT = C(31)*EPSR+C(32)*EPSZ+C(33)*EPST+C(34)*EPSRZ
   SIGRZT= C(41)*EPSR+C(42)*EPSZ+C(43)*EPST+C(44)*EPSRZ
   IF (LC(I,J)-2) 200,97,200
200 CONTINUE
   SIG1 = SIGRT*COS(W(I,J))**2+SIGZT*SIN(W(I,J))**2+
  1      SIGRZT*SIN(2.*W(I,J))
```

(c)

```
   SIG2 = SIGRT*SIN(W(I,J))**2+SIGZT*COS(W(I,J))**2-
  1      SIGRZT*SIN(2.*W(I,J))
   TAN1 = TAN(W(I,J))
   IF (TAN1) 98,99,98
98 TAN2 = -1./TAN1
   GO TO 93
99 TAN2 = 10000.
   GO TO 93
97 CONTINUE
   SIG1 = 0.5*(SIGRT+SIGZT+SQRT((SIGRT-SIGZT)**2+4.*SIGRZT**2))
   SIG2 = 0.5*(SIGRT+SIGZT-SQRT((SIGRT-SIGZT)**2+4.*SIGRZT**2))
   IF (SIGRT-SIGZT) 81,82,83
82 IF (SIGRZT) 85,86,87
85 TAN1 = -1.
   TAN2 =   1
   GO TO 84
86 TAN1 = 0.
   TAN2 = 10000.
   GO TO 84
87 TAN1 =   1.
   TAN2 = -1.
   GO TO 84
83 ANGLE = 0.5*ATAN(ABS(2.*SIGRZT/(SIGRT-SIGZT)))
   IF (ABS(1.5708-ANGLE)-.1E-03) 89,91,91
91 TAN1 = TAN(ANGLE)
   IF (SIGRZT) 88,86,90
81 ARG = 2.*SIGRZT/(SIGRT-SIGZT)
   IF (SIGRZT) 80,89,80
80 ANGLE = 0.5*ATAN(ABS(ARG))
   ANGLE = 1.5708-ANGLE
   IF (ABS(1.5708-ANGLE)-.1E-03) 89,92,92
92 TAN1 = TAN(ANGLE)
   IF (ARG) 90,89,88
89 TAN1 = 10000.
   TAN2 = 0.
   GO TO 84
88 TAN1 = -TAN1
90 TAN2 = -1./TAN1
84 W(I,J) = ATAN(TAN1)
   IF (ICR) 201,201,202
201 IF (I+ICR) 93,204,93
204 IF (J+JCR) 93,205,93
205 SIG1CR = SIGTT
   GO TO 93
202 IF (I-ICR) 93,94,93
94 IF (J-JCR) 93,95,93
95 SIG1CR = SIG1
93 DER(I,J) = ER
   DEZ(I,J) = EZ
   DET(I,J) = ET
   DERZ(I,J)= ERZ
   DEPS1(I,J) = E1
   SRPO(L1) = SIGRT
   ERPO(L1) = EPSR
   SZPO(L1) = SIGZT
   EZPO(L1) = EPSZ
   STPO(L1) = SIGTT
```

(d)

```
   ETPO(L1) = EPST
   SRZPO(L1) = SIGRZT
   ERZPO(L1) = EPSRZ
   S1PO(L1) = SIG1
   E1PO(L1) = EPS1(I,J)
   S2PO(L1) = SIG2
   E2PO(L1) = EPS2
   TAN1PO(L1) = TAN1
   TAN2PO(L1) = TAN2
   RETURN
   END
*************************************************************************
   SUBROUTINE OUTPUT
*************************************************************************
   COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
  1        PHP,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
  2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
  3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
  4        EXCF,SIG1CR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
   COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
  1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
  2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
  3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
  4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
   DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
  1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
  2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
  3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
   EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
  1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
  2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
  3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
  4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
  5            (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
   DEFINE FILE 2(1400,10,U,IREC)
   DO 331 KD=1,8
   GO TO (1,2,3,4,5,6,7,8),KD
 1 DO 11 I=1,IEC
   DO 11 J=1,JEP
   SIG(I,J) = U(I,J)
11 EPS(I,J) = W(I,J)
   LCL = LCL+1
   LRC = LRC+1
   GO TO 9
 2 LCL = LCL-1
   LRC = LRC-1
   DO 12 K=1,JDRUM
   READ (2'K) SRPO
   READ (2'100+K) ERPO
   DO 12 L=1,10
   NQ = 2*((K-1)*10+L)
   CALL COORD
   SIG(I,J) = SRPO(L)
   EPS(I,J) = ERPO(L)
   IF (NQ-2*JTOT) 12,12,9
12 CONTINUE
 3 DO 13 K=1,JDRUM
```

(a)

```
      READ (2'200+K) SZPO
      READ (2'300+K) EZPO
      DO 13 L=1,10
      NQ = 2*((K-1)*10+L)
      CALL COORD
      SIG(I,J) = SZPO(L)
      EPS(I,J) = EZPO(L)
      IF (NQ-2*JTOT) 13,13,9
   13 CONTINUE
    4 DO 14 K=1,JDRUM
      READ (2'400+K) STPO
      READ (2'500+K) ETPO
      DO 14 L=1,10
      NQ = 2*((K-1)*10+L)
      CALL COORD
      SIG(I,J) = STPO(L)
      EPS(I,J) = ETPO(L)
      IF (NQ-2*JTOT) 14,14,9
   14 CONTINUE
    5 DO 15 K=1,JDRUM
      READ (2'600+K) SRZPO
      READ (2'700+K) ERZPO
      DO 15 L=1,10
      NQ = 2*((K-1)*10+L)
      CALL COORD
      SIG(I,J) = SRZPO(L)
      EPS(I,J) = ERZPO(L)
      IF (NQ-2*JTOT) 15,15,9
   15 CONTINUE
    6 DO 16  K=1,JDRUM
      READ (2'800+K) S1PO
      READ (2'900+K) E1PO
      DO 16 L=1,10
      NQ = 2*((K-1)*10+L)
      CALL COORD
      SIG(I,J) = S1PO(L)
      EPS(I,J) = E1PO(L)
      IF (NQ-2*JTOT) 16,16,9
   16 CONTINUE
    7 DO 17 K=1,JDRUM
      READ (2'1000+K) S2PO
      READ (2'1100+K) E2PO
      DO 17 L=1,10
      NQ = 2*((K-1)*10+L)
      CALL COORD
      SIG(I,J) = S2PO(L)
      EPS(I,J) = E2PO(L)
      IF (NQ-2*JTOT) 17,17,9
   17 CONTINUE
    8 DO 18 K=1,JDRUM
      READ (2'1200+K) TAN1PO
      READ (2'1300+K) TAN2PO
      DO 18 L=1,10
      NQ = 2*((K-1)*10+L)
      CALL COORD
      SIG(I,J) = TAN1PO(L)
      EPS(I,J) = TAN2PO(L)
```

(b)

```
      IF (NQ-2*JTOT) 18,18,9
   18 CONTINUE
    9 CALL TITLES
      WRITE (6,100) (I,I=1,17)
  100 FORMAT (9X,17(I7)///)
      DO 131 J=1,MW
      J1 = JEP-J+1
      IF (J+LCL-2*((J+LCL)/2)) 132,133,132
  133 WRITE (6,101) J1,(SIG(I,J1),I=1,17,2)
  101 FORMAT (1H0,1X,I2,3X,9E14.5)
      WRITE (6,102) (EPS(I,J1),I=1,17,2)
  102 FORMAT (7X,9E14.5)
      GO TO 131
  132 WRITE (6,103) J1,(SIG(I,J1),I=2,17,2)
  103 FORMAT (1H0,1X,I2,10X,8E14.5)
      WRITE (6,104) (EPS(I,J1),I=2,17,2)
  104 FORMAT (14X,8E14.5)
  131 CONTINUE
      IF (IIC-18) 129,129,128
  128 IF (IIC-34) 127,127,126
  127 II = 17
      III = IICM1
      GO TO 130
  126 II = 17
      III = 33
  130 CALL TITLES
      WRITE (6,100) (I,I=II,III)
      IIP1 = II+1
      DO 231 J=1,MW
      J1 = JEP-J+1
      IF (J+LCL-2*((J+LCL)/2)) 232,233,232
  233 WRITE (6,101) J1,(SIG(I,J1),I=II,III,2)
      WRITE (6,102) (EPS(I,J1),I=II,III,2)
      GO TO 231
  232 WRITE (6,103) J1,(SIG(I,J1),I=IIP1,III,2)
      WRITE (6,104) (EPS(I,J1),I=IIP1,III,2)
  231 CONTINUE
      IF (III-IICM1) 125,129,129
  125 II = 33
      III = IICM1
      GO TO 130
  129 CALL TITLES
      WRITE (6,100) (I,I=IIC,IEC)
      DO 331 J=1,JEP
      J1 = JEP-J+1
      IF (J+LRC+MW-2*((J+LRC+MW)/2)) 332,333,332
  332 WRITE (6,101) J1,(SIG(I,J1),I=IIC,IEC,2)
      WRITE (6,102) (EPS(I,J1),I=IIC,IEC,2)
      GO TO 331
  333 WRITE (6,103) J1,(SIG(I,J1),I=IICP1,IEC,2)
      WRITE (6,104) (EPS(I,J1),I=IICP1,IEC,2)
  331 CONTINUE
      RETURN
      END
C*********************************************************************
      SUBROUTINE TITLES
C*********************************************************************
```

(c)

```
      COMMON  ALR,ALZ,IIC,IEC,JIP,JEP,EC,H,DELP,LRC,LR,LG,LPO,LCYC,PR,
     1        PHR,MW,NW,AK,ITOT1,ITOT,NQ,KD,KLOW,KHIGH,KHR,KDR,I,J,IA,
     2        JA,NL,CON,ERR,CF,PRF1,PRF2,PRF3,PRF4,LOCAT,LADD,LCL,SIGN
     3        ,CI,CE,C1,C2,C3,C4,ICR,JCR,LPRCSS,LCR,P,JTOT,JTOT1,ECRIT,
     4        EXCF,SIGICR,TPLATE,TCYLDR,IICM1,IICP1,L1,JDRUM
      COMMON  A(150),B(53000),U(53,81),W(53,81),NR(1800),NC(1800),C(44),
     1        S(1800),MS(1800),R(53),SUMR(53),DIFFR(53),AR(20),ALP(20),
     2        FLP(20),PZP(20),UC(4),WC(4),SRPO(10),ERPO(10),SZPO(10),
     3        EZPO(10),STPO(10),ETPO(10),SRZPO(10),ERZPO(10),S1PO(10),
     4        E1PO(10),S2PO(10),E2PO(10),TAN1PO(10),TAN2PO(10)
      DIMENSION  LC(53,81),SIGR(53,81),SIGZ(53,81),SIGT(53,81),SIGRZ(53,
     1           81),DER(53,81),DEZ(53,81),DERZ(53,81),DEPS1(53,81),
     2           ERPR(53,81),EZPR(53,81),ETPR(53,81),ERZPR(53,81),
     3           EPS1(53,81),SIG(53,81),EPS(53,81),DET(53,81)
      EQUIVALENCE (U(1),LC(1)) , (B(1),EPS1(1)) ,
     1            (B( 4301),ERPR(1)) , (B( 8601),EZPR(1)) ,
     2            (B(12901),ETPR(1)) , (B(17201),ERZPR(1)) ,
     3            (B(21501),SIGR(1),DER(1)),(B(25801),SIGRZ(1),DERZ(1)),
     4            (B(30101),SIGZ(1),DEZ(1)),(B(34401),SIGT(1),DEPS1(1)),
     5            (B(38701),SIG(1)),(B(43001),EPS(1)),(B(47301),DET(1))
      WRITE (6,100) TPLATE,TCYLDR,P
  100 FORMAT ('1STRUCTURE'/11X,F4.1,' IN. SLAB,',F8.1,' IN. SKIRT  VESSE
     1L'/'0LOADING'/11X,'PRESTRESSING AND INTERNAL PRESSURE =',F8.1,' PS
     2I.'///)
      GO TO (1,2,3,4,5,6,7,8),KD
    1 WRITE (6,101) LR
  101 FORMAT (' LR =',I4,45X,'TOTAL DISPLACEMENTS  U/W'///)
      RETURN
    2 WRITE (6,102)
  102 FORMAT (44X,'DIRECT  STRESSES/STRAINS  IN R-DIRECTION'///)
      RETURN
    3 WRITE (6,103)
  103 FORMAT (44X,'DIRECT  STRESSES/STRAINS  IN Z-DIRECTION'///)
      RETURN
    4 WRITE (6,104)
  104 FORMAT (44X,'DIRECT  STRESSES/STRAINS  IN T-DIRECTION'///)
      RETURN
    5 WRITE (6,105)
  105 FORMAT (46X,'SHEAR  STRESSES/STRAINS  IN RZ-PLANE'///)
      RETURN
    6 WRITE (6,106)
  106 FORMAT (45X,'MAXIMUM PRINCIPAL  STRESSES/STRAINS  -RZ-PLANE-'///)
      RETURN
    7 WRITE (6,107)
  107 FORMAT (45X,'MINIMUM PRINCIPAL  STRESSES/STRAINS   -RZ-PLANE-'///)
      RETURN
    8 WRITE (6,108)
  108 FORMAT (23X,'DIRECTION OF PRINCIPAL STRESSES  MAXIMUM/MINIMUM   GI
     1VEN THROUGH TANGENT FNCT OF ANGLE W/R TO R-DIRECTION '///)
      RETURN
      END
```