# REPORT

# ON

# CONSOLIDATED EDISON'S

# INDIAN POINT UNIT NO. 2

## CONTAINMENT VESSEL

## STRUCTURAL INTEGRITY TEST

## FOR

## WESTINGHOUSE ELECTRIC CORPORATION

PREPARED BY

UNITED ENGINEERS & CONSTRUCTORS INC.

PHILADELPHIA, PENNSYLVANIA 19105

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# FIGURES

## I PURPOSE

The purpose of this report is to present the results, observations, comparisons with expected responses and comparison with limiting responses for the Reactor Containment Vessel during the Structural Integrity Test on March 4, 1971 to March 6, 1971 and during the subsequent depressurization which was concluded on March 13, 1971.

The Structural Integrity Test (SIT) was performed to verify that the structural response of the Containment to pressure loads is in accordance with design assumptions and provides assurance that the structure was constructed in accordance with the design to resist pressure loads.

Interpretation of data and conclusions concerning response of the structure are based primarily on the structural behavior of the Containment Vessel when subjected to a maximum internal pressure of 54 psig (115 percent of the design pressure of 47 psig).

## II CONCLUSIONS

Most of the SIT Instrumentation performed well and their recorded data is valid. Some discrepancies in the data were observed and are discussed herein. The number of discrepancies were small compared with the amount of data recorded. Results were recorded at 117 points or 91% of the 129 points installed.

The discussion of the results of the SIT was based primarily on measurements at 54 psig. To put the magnitude of this pressure in perspective, 54 psig represents approximately 117,000,000 pounds of upward thrust at the springline of the dome of the Containment Vessel. This is equivalent to the thrust required to launch 16 Apollo XII rockets. To look at this in another way, approximately 600,000 pounds of air was required to pressurize the Containment to 54 psig. With these in mind, we present the following results:

a) All "Gross Deformation Acceptance Criteria" (Appendix C) met the predicted acceptable limits with the exception of the criteria for structural recovery. We believe this recovery criteria is too restrictive for reinforced concrete structures as discussed in Section VIII-6 of this report.

b) The predictions in the "Criteria of Structural Integrity of The Containment Structure During Structural Proof Test" (Appendix B) were generally

II CONCLUSIONS (continued)

b) (continued)

met and the limiting values were not exceeded in any instance. For discussion of these results, see Section IX.

c) The structural concrete generally showed greater tensile strength than expected, therefore, cracking was not as extensive as predicted. The rebar responded as predicted in cracked areas as evidenced by a deflection of 1-3/8" in the membrane region where 1-1/2" was predicted. The liner did not appear to exceed actual yield except at one local spot and no distress was evidenced at the conclusion of the test.

On the basis of the data taken and the detailed information which follows, the Containment Vessel behaved as expected in design and in all cases was well within limiting behavior or acceptance bounds.

## III DESCRIPTION OF REACTOR CONTAINMENT STRUCTURE

### 1. LOCATION

Indian Point Unit No. 2 is located adjacent to and north of Unit No. 1 on a site of approximately 239 acres of land on the east bank of the Hudson River at Indian Point, Village of Buchanan in upper Westchester County, New York. The site is about 24 miles north of the New York City boundary line.

### 2. GENERAL DESCRIPTION OF STRUCTURE

The Reactor Containment structure is a reinforced concrete vertical right cylinder with a flat base and hemispherical dome. A welded steel liner is attached to the inside face of the concrete shell to insure a high degree of leak-tightness. All plate-to-plate welds are covered with pressurization channels to assure all leakage will be into the Containment during a Design Basis Accident (DBA).

The structure consists of side walls measuring 148-feet from the liner on the base to the springline of the dome, and an inside diameter of 135-feet. The side walls of the cylinder and the dome are 4'-6" and 3'-6" thick respectively. The inside radius of the dome is equal to the inside radius of the cylinder so that the discontinuity at the springline due to the change in thickness is on the outer surface. The flat concrete base mat is 9-feet thick with the bottom liner plate located on top of this mat. The bottom liner plate will be covered with 3-feet of concrete, the top of which forms the

2. GENERAL DESCRIPTION OF STRUCTURE (continued)

floor of the Containment. The base mat is directly supported on rock and the vector sum of the pressure forces is zero, therefore, no mechanical anchors are required between the mat and the rock.

Two (2) large openings are provided for access into the Containment structure. The Personnel Lock is located in the south east quadrant with a centerline elevation of 83'-6" and an opening size of 8'-6" diameter. The Equipment Hatch is located in the north east quadrant of the Containment with a centerline elvation of 101'-6" and opening size of 16'-0" diameter. The Equipment Hatch has a Personnel Lock insert attached to the Hatch cover. Eight (8) penetrations for Main Steam and Feedwater Piping, 43 for Mechanical Piping, 60 for Electrical requirements, two (2) for Containment Ventilation Purge Ducts, and one (1) for the Fuel Transfer Tube are also provided in the concrete cylinder wall.

Internal structures consist of Equipment Supports, Shielding, Reactor Cavity, Canal for Fuel Transfer, and miscellaneous concrete and steel for floors and stairs. All internal structures are supported on the mat with the exception of fans and other equipment supported on intermediate floors.

A 3-foot thick concrete ring wall serving as a secondary radiation shield surrounds the Reactor Coolant system components and supports the 175-ton polar-type Reactor Containment crane. A 2-foot thick reinforced concrete floor covers the Reactor

III DESCRIPTION OF REACTOR CONTAINMENT STRUCTURE (continued)

2. GENERAL DESCRIPTION OF STRUCTURE (continued)

Coolant system with removable gratings in the floor provided for crane access to the Reactor Coolant Pumps. The four (4) Steam Generators, Pressurizer and various piping penetrate the floor. A standard stairway and a spiral stairway provide access to the areas below the operating floor.

The Refueling Canal connects the Reactor Cavity with the Fuel Transfer Tube to the Spent Fuel Pool in the Fuel Storage Building. The 4'-0" thick concrete floor and 6'-0" thick concrete walls of the canal provide shielding during the fuel handling operation. The concrete walls and floor are lined with 1/4-inch thick stainless steel plate. The linings provide a leakproof membrane that is resistant to abrasion and damage during fuel handling operation.

For a complete description of the Containment structure, see Chapter 5 in the Indian Point Unit No. 2 FSAR Docket 50-247.

3. DESIGN BASIS

The Containment structure completely encloses the entire Reactor and Reactor Coolant system and ensures that essentially no leakage of radioactive materials to the evironment would result even if gross failure of the Reactor Coolant system were to occur. The liner and penetrations are designed to attain a sensitive and accurate means of monitoring and detecting any leakage through the Containment. The structure provides biological shielding for both normal and accident situations.

III DESCRIPTION OF REACTOR CONTAINMENT STRUCTURE (continued)

3. DESIGN BASIS (continued)

The basic structural elements considered in the design of the Containment structure are the base slab, side walls and dome acting as one structure under all possible loading conditions. The liner is anchored to the concrete shell by means of stud anchors so that it forms an integral part of the entire composite structure under all loadings. During the SIT, the reinforcing in the structure has an elastic response which limits the maximum strains to insure the integrity of the steel liner. The lower portions of the cylindrical liner are insulated to avoid deformation of the liner due to restricted radial growth caused by the fixed wall to slab connection, when subjected to a rise in temperature.

For a complete description of the design basis, see Chapter 5 of the Indian Point Unit No. 2 FSAR Docket 50-247 and the Containment Design Report in Supplement 6 in Volume 6 of the Unit No. 2 FSAR Docket 50-247.

4. MATERIAL SPECIFICATIONS

a) CONCRETE

Concrete is a dense, durable mixture of sound coarse aggregate, fine aggregate, cement, and water. Aggregates conform to American Society for Testing Materials Specification C-33-64 "Standard Specifications for Concrete

III DESCRIPTION OF REACTOR CONTAINMENT STRUCTURE (continued)

4. MATERIAL SPECIFICATIONS (continued)

a) CONCRETE (continued)

Aggregates." Aggregates consist of inert materials that are clean, hard and durable, free from organic matter and uncoated with clay or dirt. Fine aggregates consist of natural sand and the coarse aggregates of crushed stone. Portland Cement conforms to American Society for Testing and Materials (ASTM) Specification C-150-65 "Standard Specification for Portland Cement, Type II (moderate heat of hydration requirements). Water is free from any injurious amounts of acid, alkali, salts, oil, sediment or organic matter. The concrete has a minimum density of 150 $lb/ft^3$. The 28-day standard compressive strength of the concrete is 3,000 psi. Adequate means of control were used in the manufacture of the concrete to assure minimum strength requirements, placement and curing.

All design and testing of concrete samples was done by an independent testing laboratory.

b) REINFORCING STEEL

Reinforcing steel for the dome, cylindrical walls and base mat is high-strength deformed billet steel bars conforming to ASTM Designation A-432 (Designation later revised to A-615 Grade 60)

III DESCRIPTION OF REACTOR CONTAINMENT STRUCTURE (continued)

4. MATERIAL SPECIFICATIONS (continued)

b) REINFORCING STEEL (continued)

Standard "Specification for Deformed Billet Steel Bars for Concrete Reinforcement." This steel has a minimum yield strength of 60,000 psi, a minimum tensile strength of 90,000 psi, and a minimum elongation of 7 percent in an 8-inch specimen or 9 percent in 2 inches. Reinforcing bars No. 11 and smaller in diameter were lapped spliced or spliced by the Cadweld process. Bars No. 14S and 18S were spliced by the Cadweld process. A certification of physical properties and chemical content of each heat of reinforcing steel delivered to the job site was required from the steel supplier. The splices used to join reinforcing bars were tested to assure they will develop at least 125% of the minimum yield point stress of the bar. The test program required cutting out, at random, completed splices and testing to determine their breaking strength. The capacity of splices is in accordance with American Concrete Institute (ACI) Code 318-63.

c) STEEL LINER

The plate steel liner is carbon steel conforming to ASTM Designation A442-65 "Standard Specification

III DESCRIPTION OF REACTOR CONTAINMENT STRUCTURE (continued)

4. MATERIAL SPECIFICATIONS (continued)

c) STEEL LINER (continued)

for Carbon Steel Plates with Improved Transition Properties," Grade 60. This steel has a minimum yield strength of 32,000 psi and a minimum tensile strength of 60,000 psi with an elongation of 22 percent in an 8 inch gage length at failure. The liner is 1/4-inch thick at the bottom, 1/2-inch thick in the first three courses except 3/4-inch thick at penetrations and 3/8-inch thick for the remaining portion of the cylindrical walls and 1/2-inch thick in the dome. The liner material was impact tested at a temperature 30$^{\circ}$F below the service temperature (50$^{\circ}$F) of the liner material. Impact testing was done in accordance with Section N331 of Section III of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code.

The liner anchors are 1/2-inch diameter bent welding studs at a 14 inch vertical spacing and 24 inch horizontal spacing in the region of the 3/8-inch liner plate. In the 1/2-inch liner plate region, a 28-inch vertical and 24-inch horizontal spacing was used. The first course of studs is an Elevation 44'-7 3/4". The studs are centered on vertical bars. In the dome 5'-0" by 5'-0" panels

III DESCRIPTION OF REACTOR CONTAINMENT STRUCTURE (continued)

4. MATERIAL SPECIFICATION (continued)

c) STEEL LINER (continued)

are anchored in the center by studs and by T-bars at the edges. The 1/2-inch diameter bent welding studs are 9 inches long minimum and 9-1/2 inches long maximum with a 2" - 90° hook at the end. Tests show the studs have a yield value of approximately 52,000 psi and a tensile strength of 65,000 psi and they can accommodate a shearing deflection of over.1" before failure. A 100% visual inspection of liner anchors is made prior to pouring concrete.

d) LINER INSULATION

To protect approximately 18'-0" of the lower portion of the Containment liner from severe temperature changes under accident conditions, the liner is covered with insulation. The basic insulation is 1-1/4-inch thick polyvinylchloride covered with a 0.019 inch thick stainless steel jacket.

## IV CONSTRUCTION

In order to evaluate and determine "as-built" conditions, which are necessary to provide a basis for evaluating the results of the SIT, the following discusses construction procedures and problems encountered during construction.

The Containment liner in the cylinder and dome was erected independant of the placement of the concrete shell and subjected to survey control during erection to maintain erection tolerances for out-of-roundness, plumbness and local buckling within the requirements of United Engineers & Constructors Inc. (UE&C) Specification 9321-01-225-3. All deviations from the specification were subsequently corrected before placement of concrete. The most serious discrepancy in the liner was a local deformation which occurred in the vicinity of the Fuel Transfer Penetration. It was repaired by jacking the liner back into place and adding additional studs on the concrete side of the liner.

Concrete was placed in 5'-0" lifts. During pouring of concrete, the cylinder portion of the liner was braced against deflection from concrete loads by a circular truss on the inside of the liner. The dome portion of the liner was restrained from buckling during dome concrete pouring by the addition of stiffeners on the concrete side of the liner. Thus, at completion of liner-concrete construction the inside liner tolerances were within the specification. To insure that there was no out-of-roundness at locations where inside diameter changes of the Containment structure were measured during the SIT, a survey was performed to ascertain the pre test Containment diameters at these locations. The results of this survey are shown in Figure 4.

In removing various appurtenances from the inside surface of the Containment liner, locations were discovered where weld grinding had extended into the parent liner metal. Since the discovery of this non-conformance was discovered just prior to the start of the SIT, it was decided to continue with test plans for the following reasons:

a) The imperfections were ground smoothly to avoid stress risers.

b) The depth (1 measured .1" at deepest point) and areas were small enough such that the integrity of the liner was not jepordized.

c) In the unlikely event that overstress did occur at one spot on the liner the ductility of the liner is such that the stress could readily be redistributed to the understressed rebar and the structure would not be compromised during the SIT.

At the conclusion of the SIT, all spots were dye penetrant tested to check for indications. On two (2) of the spots indications appeared, however, these were only surface indications and they were removed after minimal grinding (to maximum depth of .080") and then dye penetrant tested to assume all indications were removed. Since the most severe liner tensile loads are experienced during the pressure test and the liner imperfections passed the test

IV CONSTRUCTION (continued)

with no apparent distress, it is felt these imperfections did not affect the results of the SIT or the ability of the liner to function as designed during accident conditions.

Three (3) temporary windgirders (See Figure 9) on the inside face of the liner were left in place to facilitate construction efforts related to piping in the upper portion of the Containment. It was determined analytically that the stiffness added to the structure by the presence of these windgriders would not affect the response of the structure during the SIT or during design conditions. The lowest windgirder (Elevation 134'-0") was in the membrane region of the cylinder, thus no windgirders were in a region affected by the base discontinuity caused by the base mat-cylinder junction. The above assumption that the membrane type response of the structure is not affected by the windgirders is substantiated by the fact that no liner distortions were observed at the conclusion of the test and Figure 7 of Reference 1 shows the windgirder at Elevation 134'-0" to be in approximately the location of maximum diameter change during the SIT. This indicates that the extra stiffness added to the structure by the windgirders did not significantly affect the membrane type response of the cylinder to pressure loads.

There were two areas of the Containment structure where proper concrete cover over the outside layer of rebar could not be realized by holding to the proper outside dimension of the concrete wall. In one area, at the temporary construction opening in the northwest quadrant of the Containment, the forms were adjusted to provide for

IV CONSTRUCTION (continued)

a bulge in the structure at areas where improper cover would result. This was done with a smooth transition from the proper dimension to avoid any stress risers or discontinuities. In the Equipment Hatch area it was discovered after concrete was poured, that there were several areas where improper cover was present over the outer layer of rebar. The areas in question were located and then patched with concrete in accordance with applicable UE&C Specifications to achieve the proper concrete cover. Again a smooth transition from proper dimension to proper cover was used. The justification of proper application of the above procedures was evidenced during the pressure test when no excessive cracking or spalling of concrete was observed in these areas. These fixes were instituted only for appearance of the completed structure (without proper cover rebar rust stain may appear on the outer concrete surface) since the concrete cracks during the SIT and, therefore, is not critical for structural considerations.

A major problem encountered during construction concerned Cadweld Splicing. In April of 1967 a decline was noticed in average tensile strength of Cadweld Test Samples due to eight (8) failures. The overall samples still exhibited average strengths in excess of 125% of rebar yield (the specification requirements) however, in June of 1967 it was decided to stop Cadwelding to determine the cause of this disturbing trend. Additional testing showed that there were three major causes of low results.

IV CONSTRUCTION (continued)

a) Off centering of bars

b) Mill marks on portion of bar in sleeve

c) Bars scarfed or nicked adjacent to the sleeve.

UE&C procedures for Cadwelding rebar were written to eliminate the above causes of unsatisfactory splices. In addition, all Cadweld splices presently in the structure were visually inspected and about 1/3 were radiographed. Any bars displaying any of the three defects noted were cut out of the structure and replaced with new splices. The above procedure insured that all Cadwelds in the structure would be sound. This was substantiated by the pressure test where the gross deformations of the structure were in agreement with expected values from design thereby showing that rebar and splices were responding as designed.

## V TEST PROCEDURES

### 1. GENERAL DESCRIPTION

After completion of the construction of the entire Containment Vessel, a SIT was performed. The maximum pressure attained during the test was 54 psig (maintained for approximately one (1) hour). This pressure represented 115% of the design pressure of 47 psig. Readings and measurements required for the SIT were taken at 0 psig, 14 psig, 36 psig, 47 psig and 54 psig while pressurization took place and at 47 psig, 24.4 psig and 0 psig during depressurization. In conjunction with the SIT an Integrated Leak Rate Test (ILRT) was also performed. The discussion of results of the ILRT or the Sensitive Leak Rate Test performed at the conclusion of the SIT and ILRT, is not within the scope of this report.

The general requirement for the furnishing of all labor, tools, supervision and equipment necessary to install all equipment and record and interpret results for the SIT is found in UE&C Specification 9321-01-5-6 dated June 24, 1968 and revised June 10, 1969 and Addenda 1 through 4 which are located in Appendix A.

Criteria of Structural Integrity of the Containment Structure during Structural Proof Test can be found in Appendix B. This document contains the calculated reading of rebar strain gages, rosettes, invar wires and dial gages for 54 psig based on theoretical design procedures used for sizing structural elements during the design of the

V TEST PROCEDURES (continued)

1. GENERAL DESCRIPTION (continued)

Containment structure. These numbers were used as a guide for interpretating Wiss, Janney, Elstner & Associates (WJE) instrumentation readings and ascertaining whether the structure could be safely pressurized to the next level. The criteria strains are based on yield strain of the rebar or liner and are not to be confused with the Gross Deformation Acceptance Criteria discussed in Section VIII. These criteria strains were included as a guide for making the decision to proceed to the next pressure level.

Appendix C contains the Acceptance Criteria for the test and was based on gross deformations of the structure. The primary function of this criteria is to evaluate the performance of the structure during the test by comparison with observed and measured test data. The primary considerations include:

a) The increase in Containment Diameter (Limited by minimum yield stress of liner which is 32, 000 compared to 60,000 psi yield for the rebar).

b) Equipment Hatch deformations (Expected deformation + 30%).

c) Vertical elongation of Containment wall at Elevation 191'-0" (Expected value + 20%).

d) Maximun concrete crack width.

e) Minimum crack spacing.

V TEST PROCEDURES (continued)

1. GENERAL DESCRIPTION (continued)

f) Gage readings at return to 0 psig.

g) Post Test inspection.

It should be noted that although strain gages are placed on the rebar and rosettes on the liner, the analytically derived strains, although included in Reference B, are not part of the acceptance criteria for the structure. Values obtained are used to evaluate design of the structure and for guidence in future designs, however, the Gross Deformations are considered a more reliable yardstick for determining acceptance of the structure since they are more accurately measured and they are determined by more accurate design procedures. Strain gages are provided to get as much information from a test of this type as possible which can be used in future designs. The above is in accordance with the PSAR and FSAR and commitments in Appendix C which were accepted prior to the commencement of the SIT

The conclusions reached in comparing acceptance criteria with test data are discussed in Section VIII.

2. PREPARATION

Prior to the start of the test, the following steps were taken to insure successful acquisition of meaningful test data and obtain all required base data for the test:

a) Strain gages were cemented on reinforcing bars after proper cleaning of bar. Lead wires were connected and they received a coat

V TEST PROCEDURES (continued)

2. PREPARATION (continued)

a) (continued)

silicone lacquer, an overcoat of epoxy and a final coat of waterproof compound then wrapped with vinyl plastic electrical tape. Care was taken during placing of concrete in these areas to protect gages and wires. A representative of WJE was present during pouring of concrete in the Equipment Hatch area to prevent gage and wire damage. In addition, WJE provided redundancy in strain gages on rebar and liner, above that required on contract drawings, where they thought this was required to insure good data.

b) Rosettes were installed on the inside of the Containment Liner in a mannar similar to the above installation of rebar strain gages. Redundancy was provided on the liner rosettes on Azimuth 130$^{o}$ to compensate for any that may be damaged before the test.

c) Dial gages were installed in two areas on the outside of the Containment structure near the base and attached to rigid structural supports which do not move during the test.

V TEST PROCEDURES (continued)

2. PREPARATION (continued)

d) Invar wires for measuring Gross Deformations were installed inside the Containment and properly wired to readout equipment. All of the wiring inside the Containment was brought to the outside of the Containment by connection to a space Electrical Penetration at Elevation 54'-0" on Azimuth 191°-15'.

e) Specified areas were whitewashed to facilitate detailed test crack inspections.

f) The entire structure was surveyed with binoculars, temporary platforms and movable scaffolds to map cracks in the concrete and determine if any significant cracks were present which should be watched carefully during the test. Particular attention was paid to whitewashed areas. The results of this pre test crack inspection are found in Reference 1. WJE reported no significant cracks were present. Small surface cracks are expected in a reinforced concrete structure from thermal and drying shrinkage. Cracks found were surface cracks with very few extending beyond the outer layer of reinforcing.

g) Strain gages and Gross Deformation instruments were continuously monitored for some time to

V TEST PROCEDURES (continued)

2. PREPARATION (continued)

g) (continued)

establish electrical stability and determine ambient temperature effects if any.

h) Within an hour of the start of the pressure test, a complete set of zero reading were recorded for all WJE instruments. This provided a base for all readings taken during the test. Gages recorded electrical readings in volts at various pressure levels which were related to zero readings to obtain changes which occurred. With the exception of dial gage readings, all readout was done remotely, and the results transmitted to a time sharing computer which converted voltage readouts to stresses or deflections.

3. DURING TEST

At each pressure level the data required for the SIT, including strain gage readings, rosette readings, and invar wire readings were obtained by WJE on punched tape from their VIDAR digital data acquisition system. Dial gage readings and observation of crack patterns were visually obtained by WJE. Punched tapes were used in conjunction with a time sharing computer system to obtain stresses and deformations.

The data was interpretated jointly by WJE and UE&C. Before

3. DURING TEST

proceeding with pressurization to the next pressure level, the test director consulted UE&C to assure that all required structural data was obtained and that there were no indications that the structure was not responding as designed. At no time during the test was there any cause, related to the SIT, to delay pressurization to the next level. For a further description of WJE's equipment and function during the SIT, see Reference 1. A complete description of the instrumentation used during the test is given in Section VI.

In addition to the above, the structure was observed at various pressure levels with binoculars, temporary platforms and movable scaffolding to insure that no extreme behavior, including cracking, was occurring during pressurization which would indicate a problem in structural response to the internal pressure load. No problems were encountered during the test that caused any concern relative to the SIT.

4. AFTER TEST

Following completion of the test, all data secured was recorded and reported by WJE. All equipment was checked for electrical stability after final readings were taken at 0 psig and removed except for those items embedded in the concrete. A final inspection was made to determine crack widths and check for any visual distortion of the liner plate. Most cracks returned to their original width and there was no visual distortion of the liner plate.

V TEST PROCEDURES (continued)

5. DEVIATIONS FROM PREVIOUS COMMITMENTS

UE&C drawings showing areas of Containment and Liner which were instrumented during the SIT appear in the answer to Question 5.13 of Supplement No. 1 to the Indian Point Unit No. 2 FSAR. Since that time, several changes have been made to improve the acquisition of data during the SIT or conform to "as-built" conditions. These changes are reflected in the latest UE&C revisions to the drawings and include the following:

a) Figure 5.13-1

1. Radial shear bars were added in the Equipment Hatch Boss running parallel to the Equipment Hatch at approximately the 3rd points of the boss. These bars were added at the recommendation of UE&C's Structural Consultant, Professor Holley of Massachusettes Institute of Technology, as a result of his review of the Equipment Hatch design, to provide added assurance that a diagonal crack from pressure on the inside head of the Hatch would not propagate through the boss section. Further description of reinforcing in the Equipment Hatch area is located in the Containment Design Report Volume 6 of the Unit No. 2 FSAR. Five (5) strain gages were added to

V TEST PROCEDURES (continued)

5. DEVIATIONS FROM PREVIOUS COMMITMENTS (continued)

a) Figure 5.13-1 (continued)

1. (continued)

the radial shear bars discussed above.

2. Miscellaneous gage locations were changed slightly to reflect "as-built" conditions of the rebar.

b) Figure 5.13-2

1. Strain gages on rebar adjacent to the liner at the base were raised approximately 2 feet in elevation to clear rebar which was installed prior to placement of the gages. The information obtained from the gages would reveal structural behavior at either elevation and it was considered a prudent solution to cut the liner and install the gages 2'-0" above the elevation shown on the drawing rather than take the risks associated with cutting and reinstalling rebar in this congested area in order to install the gages as shown on drawing. The liner was replaced, welded, tested and seams covered with pressurization channels consistent with all other liner installation.

V TEST PROCEDURES (continued)

5. DEVIATIONS FROM PREVIOUS COMMITMENTS (continued)

c) Figure 5.13-3

1. In Section A-A dial gages to measure radial growth of the Equipment Hatch area were replaced by invar wires. The line end of the invar wire was attached to the inside face of the Containment Liner and the dead end was attached to a fixed structure such as the polar crane, pressurizer shield wall or crane wall concrete as necessary to locate invar wire as close as possible to the original locations shown for the dial gages. This change was necessitated due to a change in the construction schedule. The Retaining Wall outside the Equipment Hatch, which was to be used for supporting the dial gages, was not complete at the time of the pressure test. In any case the use of invar wire is more desirable than dial gages for the following reasons:

   1) Remote recording of data is possible with invar wire while dial gages must be read manually.

   2) The invar wire is inside the building thus eliminating weather conditions

V TEST PROCEDURES (continued)

5. DEVIATIONS FROM PREVIOUS COMMITMENTS (continued)

c) Figure 5.13-3 (continued)

1. (continued)

2) (continued)

and human factors from considerations.

2. The location of dial gages and supports in the electrical tunnel and Shield Wall area changed slightly due to field conditions, however, these changes did not affect the results of data obtained during the SIT

d) Figure 5.13-4

1. All Gross Deformation data (diameter changes, radial growth and vertical growth) was obtained by use of invar wires inside the structure instead of using surveying instruments (scale, transits etc.). This is considered a much more accurate method of measurement and again has the added advantages of remote recording and elimination of weather and human conditions.

2. Invar wires were added to measure the diameter change in the Equipment Hatch at azimuths 135° and 225°. This is in accordance with Dr. N. Newmark's request at the site meeting on May 2, 1969 to have this information made available for future considerations.

V TEST PROCEDURES (continued)

5. DEVAITIONS FROM PREVIOUS COMMITMENTS (continued)

d) Figure 5.13-4 (continued)

3. The field was instructed to perform a survey to determine "as-built" conditions at all elevations where Containment radial or diameter changes are to be measured by invar wires. The results of this survey are in Figure 4.

VI INSTRUMENTATION

1. GENERAL DESCRIPTION

Location and type of instrumentation used for the SIT is shown in Figures 1, 2, and 3. In addition, Table 1 contains further location details for all instrumentation. A summary of various types of instrumentation follows:

a) Rosettes on liner

b) Strain gages on rebar

c) Invar wire extensometers

d) Dial gages

2. ROSETTES

Strain gages attached to the steel liner plate were three element rosettes SR-4 BLH - type FABR - 50D - 1286. A three wire bridge circuit was used on each leg of the rossete to provide for temperature compensation. A total of eight (8) rosettes were placed near the Equipment Hatch. Four (4) were placed at 0°, 90°, 180° and 270° around the Hatch at approximately 1'-0" from the Hatch to measure liner strains in an area of the thickened boss influenced by the Equipment Hatch opening. The remaining four (4) rosettes were placed at 0°, 90°, 180° and 270° around the Hatch approximately 10'-6" from the Equipment Hatch to measure liner strains in the area of 4'-6" thick cylinder wall immediately adjacent to the 7'-6" thickened concrete boss around the Equipment Hatch. Redundant gages were not installed around the Equipment Hatch since they were placed symmetrically around the opening. This provided the necessary

VI INSTRUMENTATION (continued)

2. ROSETTES (continued)

redundancy. In addition, a total of eight (8) rosettes were placed on the liner at elevations in a typical area of the cylinder wall. These included a gage near the base of the structure, one at approximately the mid point of the wall, one just below and one just above the springline. The redundant gages for each of these gages were installed approximately 2" from the primary gage.

The rosettes measured liner strain in the vertical and horizontal directions and shear in the x-y plane. The measured values were input to the time sharing computer system and the output included stress in the x and y directions, shear in the x-y plane, two (2) principal stresses and the principal shear stress.

3. STRAIN GAGES

Strain gages mounted on reinforcing bars were two element (temperature - compensating) SR4 BLH - type FAET-12C-1256F encapsulated gages. A total of 68 strain gages were placed on rebar in and around the vicinity of the 7'-6" thickened concrete boss in the area of the Equipment Hatch. This included 46 instrument locations on cylinder wall, hoop, vertical and seismic bars, boss area hoop bars, radial shear and tie bars in the boss, and 22 redundant gages. In addition, rebar was instrumented in the approximately 24' x 24' construction opening near the base of the structure centered on azimuth $245^{\circ}$-50'-45" in the northwest

VI INSTRUMENTATION (continued)

3. STRAIN GAGES (continued)

quadrant of the Containment structure to record rebar strains in an area or the cylinder wall influenced by the discontinuity effect of the fixed wall - base mat junction. A total of seven (7) bars were instrumented including vertical and hoop bars near the inside face of the wall, vertical and hoop bars on the outside face of the wall and diagonal seismic bars in the mid plane of the wall. In addition, two (2) redundant gages were provided on vertical bars on the inside face of the wall. All strain gage readings are recorded on tape and the time sharing computer system yields stress in the rebar for each gage. For further information concerning strain gages on rebar, see Figure 3, Table 1 and Reference 1.

4. INVAR WIRE EXTENSOMETERS

Invar wire extensometers were used to measure Gross Deformations of the wall in the vicinity of the Equipment Hatch, the cylinder wall in the horizontal and vertical directions and the diameter change of the Equipment Hatch.

Each invar wire measuring device consists of an invar wire spanning the distance to be measured. The "dead" end is anchored to a fixed object inside the Containment for measuring vertical or radial changes, or in the case of wires measuring Containment diameter change, to the liner. The "live" end is attached to a spring loaded frame which is rigidly attached, in the direction of measurement, to the point where movement is being

4. INVAR WIRE EXTENSOMETERS (continued)

measured. The sensing device is a linear potentiometer positioned between the spring and actuated by relative movement between the fixed and free end of the spring loaded frame. The potentiometer is of the infinite resolution type with a total resistence of about 2000 ohms. A constant voltage of 2 volts was applied to each potentiometer. Voltage changes in the potentiometer are recorded on the external readout system. The data is input to the time sharing computer and deformations of the structure in inches are outputted. This method of measuring Gross Deformations was employed in the following areas:

a) At 15 locations in the thickened Equipment Hatch boss and the transition area from the thickened boss to the 4'-6" cylinder wall to measure radial deformation of the Containment wall. The live end of the invar wire was attached to the liner inside the Containment and the dead end was attached to a fixed object inside the building such as the polar crane, pressurizer shield wall concrete, or 3'-0" thick crane wall concrete.

b) At 10 locations, spaced at approximately 1'-0", in the Containment cylinder wall between elevation 101'-0" and 191'-0" to measure diameter

VI INSTRUMENTATION (continued)

4. INVAR WIRE EXTENSOMETERS (continued)

b) (continued)

change in the Containment structure. These wires are stretched across the diameter of the structure from Azimuth 135° to 315°.

c) At Azimuth 315° on the Containment cylinder wall at Elevation 91'-0" to measure radial deflection at this point. The "dead" end of the wire is attached to a 7'-0" high concrete shield wall around the steam generators.

d) At Elevations 95'-0", 143'-0" and 191'-0" on Azimuth 300° in the Containment cylinder wall to measure vertical deflection of the Containment at these elevations. The "live" end of the wire is located at the elevation to be measured and the "dead" end is located at Elevation 46'-0" on a 3'-0" thick concrete slab located inside the building and on top of the 9'-0" thick base mat.

e) Two (2) wires at Azimuths 300° and 120°, extending from the springline at Elevation 191'-0" to the apex of the dome at Elevation 258'-6", to measure the vertical growth at the apex of the dome. These were angular measurements and were converted to vertical measurements by the time sharing computer.

f) Two (2) wires in the Equipment Hatch stretching from Azimuth 45° to 225° and 135° to 315° to measure the diameter change in the Equipment Hatch.

VI INSTRUMENTATION (continued)

5. DIAL GAGES

Dial gages having 1" of travel and a 2" diameter reading face and graduated to read .001 inch changes in deformation were used to measure radial deformations at two locations of the Containment structure. Dial gage readings and crack observations were the only manual operations performed by WJE during the SIT, all other data is remotely recorded on electronic readout equipment. The dial gages are attached at one end to the outside of the Containment cylinder wall at the point where data is required. The other end is attached to a temporary steel structure which is rigidly supported by structural steel or concrete. The areas instrumented in the above manner include 16 gages on the outside of the Containment wall at Azimuth 230° in the Electrical Penetration Tunnel between Elevations 46'-6" and 61'-6". In addition, there were 16 gages at Azimuth 290° in area of the Shield Wall between Elevations 43'-6" and 58'-6". The dial gages provided information regarding the radial deformation pattern of the structure from the fixed base at Elevation 46'-0" to an elevation approaching the membrane region of the cylinder with unrestrained radial growth.

6. CONCRETE CRACK MEASUREMENTS

Prior to the test, the entire structure was surveyed by means of movable scaffolding. Patterns were mapped (See

VI INSTRUMENTATION (continued)

6. CONCRETE CRACK MEASUREMENTS (continued)

Reference 1) and cracks were measured using a 6 X comparator. The structure was carefully investigated to find any serious cracks which would require close attention during the test. During the test the total structure was surveyed at each pressure level with binoculars, movable scaffolding and temporary platforms to determine crack patterns and discover any large cracks which may appear. In addition, cursery inspections were made during periods of pressurization in the more easily accessible areas to insure that no problem areas were developing in the structure.

The most detailed crack measurements were made in three whitewashed areas which included:

a) A 10'-0" wide x 30' high strip on the Containment wall between Elevations 43'-0" and 75'-0" at Azimuth 310°.

b) The upper right hand quadrant (viewed from outside of building) of the Equipment Hatch Boss including a sector of the 4'-6" wall to boss junction area.

c) The upper right hand quadrant (viewed from outside of building) of the Personnel Lock Boss including a sector of the 4'-6" wall to boss junction area.

VI INSTRUMENTATION (continued)

6. CONCRETE CRACK MEASUREMENTS (continued)

c) (continued)

All crack survey information is found in Appendix C of Reference 1.

7. DATA ACQUISITION EQUIPMENT

All data, except cracking information and dial gage readings, were obtained using a VIDAR 5205 D-DAS digital data acquisition system. The data could be observed on the scanner, it was punched on tape and for permanent record a Digital Printing Recorder was added by WJE. The above provided sufficient redundancy to assure that data would not be lost during the test. The punched tapes were transmitted to the computer coupler for fast accurate reduction of data. This proved to be an excellent method of reviewing data as it was being retrieved and making decisions regarding the adequacy of structural response to the test pressures.

A resister calibrator box was used to check the reliability and accuracy of the data either during the test or when data was being reviewed. This had the advantage of not only checking the data acquisition system but determining if a gage had malfunctioned or was damaged, simply by checking it electrical stability. This proved advantageous. In the few instances where gages did malfunction it was determined immediately, leaving no doubt in the mind of anyone reviewing data.

VI INSTRUMENTATION (continued)

7. DATA ACQUISITION EQUIPMENT (continued)

For further discussion of all the equipment and gages discussed above, see Reference 1.

## VII TEST DATA

For additional description of test procedures, preparation and instrumentation and complete reporting of all test data, see the WJE report entitled "Structural Response of Secondary Containment Vessel During Structural Integrity Test at Indian Point Power Generating Station Unit No. 2 for WEDCO Corporation" attached herein as Reference 1.

## VIII COMPARISON OF TEST DATA WITH "GROSS DEFORMATION ACCEPTANCE CRITERIA"

The Gross Deformation Acceptance Criteria, in Appendix C, constitutes the criteria by which we will determine whether the test has properly demonstrated the ability of the structure to respond to pressure as intended. On the basis of this criteria, it can be seen that the structural design assumptions were reasonable and the structure has been constructed in accordance with the design to resist pressure loads. Each item in Appendix C will be discussed below with regard to the above considerations:

### 1. INCREASE IN CONTAINMENT DIAMETER

Appendix C requires that the maximum (limiting) increase in Containment Diameter shall not exceed 1.76" between Elevation 91'-0" and Elevation 191'-0" for the 54 psig internal pressure load when measured as an average of all readings. The value of 1.76" is determined by calculating the maximum expected diameter change based on the classical thin shell membrane theory using the reinforcing bar and liner area as the spring constant (i.e., concrete assumed cracked) and conservatively adding a factor of 13%. A factor of +20% could be applied to the calculated (expected) value to reflect all variables; including precision of measurements, design variables such as accuracy of design loads, analysis techniques, and material

VIII COMPARISON OF TEST DATA WITH "GROSS DEFORMATION ACCEPTANCE CRITERIA" (continued)

1. INCREASE IN CONTAINMENT DIAMETER (continued)

properties and construction variables such as variation of dimension.

From test data in Reference 1, Appendix B, Table 6, the maximum change in diameter occurred at Elevation 131'-0" in the cylinder wall and was equal to 1.48" (.740 radial deflection). This is within the limiting displacement of 1.76" and is very close to the calculated displacement of 1.56". On examining Figure 6, it can be seen that the maximum radial deflections occurred in the middle portions of the structure. This is in agreement with observation of crack patterns during the test in which it was discovered that the majority of all cracks opened up during the test were in the middle third of the structure. This accounts for the decrease in radial deflection in the cylinder wall as it approaches the springline.

A plot of diameter changes in the cylinder wall showing test data, expected deformations and limiting deformations is found in Figure 6. At no time does the test data exceed expected or limiting deformation.

VIII COMPARISON OF TEST DATA WITH "GROSS DEFORMATION ACCEPTANCE CRITERIA" (continued)

1. INCREASE IN CONTAINMENT DIAMETER (continued)

Based on the above, it can be concluded that for this phase of structural behavior, the structure has behaved very close to design assumptions and has considerable safety margin.

It is our opinion that the above criteria is the most significant with respect to judging the structural response of the Containment Building. It is the most reliable measured quantity, and is based on the most reliable theory and shows that the overall rebar configuration in the structure is capable of elastically carrying pressure load as designed. The pressure load is the major contributor to total rebar stress (See Containment Design Report in Supplement 6 of Volume 6 of the Indian Point Unit No. 2 FSAR).

2. EQUIPMENT HATCH DEFORMATIONS

Appendix C requires that Equipment Hatch deformations show the same trend as computed values and the maximum radial displacement shall not exceed .935". The value .935" is obtained by increasing the expected value of .720" by 30%. A factor of 30% includes all items for the 20% factor in Item 1 above and also

VIII COMPARISON OF TEST DATA WITH "GROSS DEFORMATION ACCEPTANCE CRITERIA" (continued)

2. EQUIPMENT HATCH DEFORMATIONS (continued)

accounts for the additional unknowns in the very complex Equipment Hatch area. The design method employed here was an approximate finite element computer analysis which necessitates dividing the area into small rectangular elements, and modeling concrete and rebar within the limits of the computer program to represent the actual structure. In addition, assumptions must be made concerning the amount of concrete which will crack during response to load. A complete description of this analysis is located in the Containment Design Report in Supplement 6 in Volume 6 of the Indian Point Unit No. 2 FSAR.

From test data in Table 7, Appendix B of Reference 1, the maximum value of radial deformation is .738". This is well within the limiting value of .935" and again is very close to the calculated value of .720". Of the 15 invar wires in the Equipment Hatch area, this gage exhibits the only value in excess of the expected .720" maximum (2.5% over).

Figure 8 shows expected, actual and limiting displacements in the Equipment Hatch area.

VIII COMPARISON OF TEST DATA WITH "GROSS DEFORMATION ACCEPTANCE CRITERIA" (continued)

3. VERTICAL ELONGATION

Appendix C requires that the total vertical elongation of the Containment wall at Elevation 191'-0" (the springline) shall not exceed .85". This value is based on the calculated .71" plus a 20% increase. The .71" is based on resisting strength of the rebar and liner (concrete assumed cracked). The 20% increase is for reasons outlined in Item 1 above. Test data in Table 8 Appendix B of Reference 1 shows a vertical deflection at Elevation 191'-0" at 54 psig equal to .2568. This is considerably below expected and limiting values. It is noted that all vertical deflections including the top of the dome are far below limiting values. This is attributed to the fact that no evidence of extensive horizontal concrete cracking occurred during the pressure test. No new horizontal concrete cracks were opened and shrinkage cracks documented prior to the test did not exhibit any further extension although concrete stresses were approximately 450 psi in the vertical direction at the 54 psig pressure load. Present

3. VERTICAL ELONGATION (continued)

theory would indicate the concrete would crack at this stress. However, reasons for lack of horizontal concrete cracking can be explained by the following:

1) Considerable variation in stresses which cause concrete to fail in tension.

2) Concrete trial mixes and test cylinders continually exhibiting compressive strength in excess of the specified 3000 psi during construction.

3) Vertical cracks from horizontal load (which is twice the vertical load and resisted by the same area of concrete) formed between 14 psig and 36 psig pressure levels indicating cracking stresses between 220 psi and 550 psi, both of which are above expected values due to the reasons stated in 1) and 2) above. This is less than the cracking stress in the vertical direction for two reasons:

a) The dead load adds compressive stress in the vertical direction.

3. VERTICAL ELONGATION (continued)

b) The concrete was in a state of uniaxial tension under high vertical loads since the concrete had already cracked from the greater horizontal loading. Before vertical cracking from horizontal loads occurred, the concrete was in a state of biaxial tension which could have lowered the ultimate tensile strength of the concrete in the horizontal direction.

Figure 7 shows a plot of test data, expected and limiting deflections.

The above results, which indicate little or no horizontal cracking of the concrete, and are far below design values, indicate a margin of safety exists in the structure. The rebar, which carries very little load until the concrete cracks, will be stressed far below design values; consequently, the test further demonstrates the ability of the structure to safely respond to pressure loading.

4. CRACK WIDTH

Appendix C requires that the maximum crack width shall not exceed .035" averaged over 20'-0" length of crack. The value .035" was determined by considering several approaches:

a) Recommendations in a paper entitled "Strength and Cracking Characteristics

VIII COMPARISON OF TEST DATA WITH "GROSS DEFORMATION ACCEPTANCE CRITERIA" (continued)

4. CRACK WIDTH (continued)

a) (continued)

of Beams with No. 14 and No. 18 Bars Spliced With Mechanical Splices" by Mete A. Sosen and William L. Gamble was used assuming the authors' maximum recommended slip in cadweld splices based on their test results.

b) Recommendations from paper entitled "Determination of Minimum Wall Thickness and Temperature Steel in Conventionally Reinforced Circular Concrete Silos" from American Concrete Institute (ACI) Journal July, 1970 by Sargis S. Safarian and Ernest C. Harris were used.

c) Considering the rebar stressed to $32^{ksi}$ (the maximum liner stress) crack spacing and width was determined to accommodate the total circumferential rebar strain.

d) Experience in testing of Reinforced Concrete Containment structures.

Of the approaches mentioned above, d) was considered the most reliable. Consequently, the crack spacing and width were chosen based on

VIII COMPARISON OF TEST DATA WITH "GROSS DEFORMATION ACCEPTANCE CRITERIA" (continued)

4. CRACK WIDTH (continued)

previous industry experience. The other approaches listed, for the most part, substantiated the conclusions drawn from d).

The crack width was averaged over a 20'-0" length to account for any spalling of concrete due to inadequate concrete cover or any other such event which could occur during the test which would not be detrimental to the structural integrity of the Containment.

The pre-test survey did not indicate any extensive cracking which needed careful watching during the test. During the test, most cracks were less than .005 inches in width. No new horizontal cracks opened during the test and the majority of the vertical cracks were in the middle third of the structure. The maximum crack width, measured anywhere on the structure, was .030 inches in width occurring at the interface of the Containment Wall; and the thickened boss at the Equipment Hatch, an area of discontinuity, and is not representative of the membrane behavior of the majority of the structure. It can be seen from the above that the crack criteria has been

4. CRACK WIDTH (continued)

satisfied. At no point during the test did cracks indicate that any rebar was near yield. For a complete discussion of crack surveys, see Reference 1. For pre-test and test crack pattern mapping, see Appendix C of Reference 1.

5. CRACK SPACING

Appendix C requires that average crack spacing be not less than 15" excluding crack patterns in areas affected by discontinuities. This criteria was established on experience with other Containment Vessel testing and was established in a manner similar to and in conjunction with the crack spacing discussed in 4 above. It was not considered practical to predict crack spacing at areas of discontinuity due to the many unknowns, previously discussed, that are associated with reinforced concrete in tension and the complicated stress patterns at discontinuities also mentioned in prior discussion.

In the membrane region, the vertical cracks were at approximately 15 inch spacing, therefore, it is concluded that the above criteria has been satisfied.

VIII COMPARISON OF TEST DATA WITH "GROSS DEFORMATION ACCEPTANCE CRITERIA" (continued)

6. STRUCTURAL RECOVERY

An additional requirement which was imposed in Appendix C is that all gage readings shall return to 10% of maximum gage readings when the Containment is depressurized to 0 psig. Two reasons why this criteria was too restrictive are:

a) The criteria was not satisfied as nearly all readings, as can be seen in Reference 1, returned to between 10% and 20% of their maximum readings. We feel that data taken at a future date would show further recovery, however, this was not within the scope of the SIT.

b) Further research has revealed that the above criteria is not reasonable for reinforced concrete structures as evidenced by the reference material in the following items:

1) Tests(1) have shown that reinforced concrete beams subjected to flexural loads show 80% recovery for high loads and only about 70% for loads in the working load range. It is

(1) ACI Journal - February 1956 - P.601, "Ultimate Flexural Strength of Prestressed and Conventionally Reinforced Concrete Beams" by J. Janney, E. Hognestad, D. McHenry.

VIII COMPARISON OF TEST DATA WITH "GROSS DEFORMATION ACCEPTANCE CRITERIA" (continued)

6. STRUCTURAL RECOVERY (continued)

b) (continued)

1) (continued)

hypothesized that lower loads show less recovery because of slip which takes place near tension cracks in the concrete before the bar deformations are firmly seated. The recovery for the Containment structure is greater than shown in the above tests. Rebar stresses are low, as indicated by strain gages and the maximum rebar stress is limited to about 1/2 the yield stress by the liner, thereby, indicating only 70% recovery would have been satisfactory.

2) Tests[2] show that when singly reinforced beams are subjected to cyclic bending loads the shakedown limit nearly coincides with the ultimate moment of the beam.

(2) ACI Journal - August 1964 - P. 1021, "Response of Singly Reinforced Beams to Cyclic Loading" by B. Sinha, K. Gerstle, L. Tulin.

VIII COMPARISON OF TEST DATA WITH "GROSS DEFORMATION ACCEPTANCE CRITERIA" (continued)

6. STRUCTURAL RECOVERY (continued)

b) (continued)

2) (continued)

The shakedown limit is the limit of reloading below which the load will not cause additional curvature of the beam. In other words, if the structure is loaded, then unloaded without complete recovery and then reloaded to a load lower than the shakedown limit, the structure will not experience curvature greater than the curvature during the first cycle of loading.

Since the Containment rebar was stressed well below ultimate strength during the SIT, the structure should respond to a DBA, where pressures are lower than those experienced during the SIT, with essentially the same loading and unloading characteristics measured and

VIII <u>COMPARISON OF TEST DATA WITH "GROSS DEFORMATION ACCEPTANCE CRITERIA"</u> (continued)

6. STRUCTURAL RECOVERY (continued)

b) (continued)

2) (continued)

documented during the SIT. This is presented as further evidence that the recovery criteria of Appendix C is not necessary to insure structural integrity of the Containment structure.

3) Further tests[3] performed on doubly reinforced beams indicated the same characteristics as (2) above for cyclic loading which did not include reverse loading. A reverse loading cycle includes loading in tension, unloading, loading in compression, unloading etc. This is not representative of the Containment which is a pressure vessel experiencing tension loads for all major loading except dead loads.

[3] ACI Journal - July 1965 - P. 823, "Response of Doubly Reinforced Concrete Beams to Cyclic Loading" by G. Agrawal, L. Tulin, K. Gerstle.

VIII COMPARISON OF TEST DATA WITH "GROSS DEFORMATION ACCEPTANCE CRITERIA" (continued)

6. STRUCTURAL RECOVERY (continued)

On the basis of research documented above, we conclude that the recovery criteria above was too severe for reinforced concrete structures, although probably applicable for prestressed concrete structures; however, the recovery indicated by test results is representative of tests on reinforced concrete structures. Although we have not satisfied this criteria, we do not feel that any indication of structural inadequacy is represented by the results we have obtained based on the above documentation.

## IX INTERPRETATION OF DATA NOT RELATED TO GROSS DEFORMATION ACCEPTANCE CRITERIA

The "Criteria of Structural Integrity of Containment Structure During Structural Proof Test" is located in Appendix B. This criteria was developed to provide a working document for reference during the test to aid in identifying any serious abnormalities in structural beahvior. It is not to be confused with the Gross Deformation Acceptance Criteria in Appendix C described in Section VIII. Appendix B is a table of predicted strains and deformations at 54 psi based on analytical models used in design, where many assumptions are approximate and conservative and consequently will not necessarily represent the exact behavior of the structure. Although all items contained in Appendix B are not included in the "Gross Deformation Acceptance Criteria" and are not considered in justifying the adequacy of the structural integrity of the Containment Vessel, the information is available and will be discussed below. It must be remembered that conservative analytical assumptions, variations in material properties such as modulus of elasticity of steel, compressive concrete strength, tensile concrete strength and construction variations all contribute to the final response of the structure; therefore, differences between measured values and predicted values are not used for reaching conclusions concerning structural integrity. If this data is viewed on the basis of trends for indications of structural response, it can provide meaningful conclusions. With this in mind, a brief review of each set of data will be discussed:

IX **INTERPRETATION OF DATA NOT RELATED TO GROSS DEFORMATION ACCEPTANCE CRITERIA** (continued)

1. STRAIN GAGES ON REBAR

a) IN EQUIPMENT HATCH AREA

The location of all gages in the Equipment Hatch area can be found in Table 1 and Figure 3. The calculated strains in Appendix B are based on the finite element computer analysis of the Equipment Hatch area discussed in Section VIII-2. As previously mentioned, this analysis depended on approximate modeling techniques and assumptions regarding cracking of concrete which affects both the load resisted and the structural elements which resist the load. The set of assumptions yielding the highest rebar stresses were used for design. As can been seen from the measured strains in Appendix B only three (3) gages (SG8, SG30, and SG43) exhibited tensile strains in excess of predicted values. Only SG30 showed an appreciable difference in excess of the predicted value (factor of 2), however, it was still well within the acceptance strains. More important is the fact that the majority of data showed general agreement with the predicted values. Although the data are generally lower, we can associate the smaller predicted values with the smaller measured data and the larger predicted values with the larger values measured. One reason why data was generally lower is that the amount of concrete cracking in the Equipment Hatch area was not as extensive as expected. The results indicate that conservative assumptions were used in design of rebar.

One notable exception to the above general agreement between the measured and predicted strains occurred in the seismic reinforcing where appreciable compressive strains were measured where analysis indicated tension. Although it is not clearly evident how this occurred, several theories are extended:

IX INTERPRETATION OF DATA NOT RELATED TO GROSS DEFORMATION ACCEPTANCE CRITERIA (continued)

1. STRAIN GAGES ON REBAR (continued)

a) IN EQUIPMENT HATCH AREA (continued)

1) The vertical and horizontal reinforcing, which is bent around the Equipment Hatch will compress the concrete at the bend points when the bar is under tension (the bar will attempt to straighten). This compressive load may be distributed through the concrete to the seismic rebar

2) The seismic rebar is at a $45^{o}$ angle to a horizontal plane through the Containment and thus the rebar follows a helical path in the wall. Some manifestation of torsion and bending from the axial loads could be measured if the gage was in a location to measure these effects.

3) Some effect from torsion of the Equipment Hatch boss could be felt by the seismic rebar. The fact that the two (2) layers of seismic rebar in opposite directions are located

IX INTERPRETATION OF DATA NOT RELATED TO GROSS DEFORMATION ACCEPTANCE CRITERIA (continued)

1. STRAIN GAGES ON REBAR (continued)

a) IN EQUIPMENT HATCH AREA (continued)

3) (continued)

side by side may have some effect. The seismic rebar is designed to resist shear from an earthquake by a combination of tension in one layer and compression in the other (see the Containment Design Report in Supplement 6 of Volume 6 of the Unit No. 2 FSAR). If in plane shear, torsion or bending from the thickened boss were resisted by the same mode of action, the results could all indicate compression since all seismic bars instrumented were in the same layer.

4) Non uniform cracking of concrete from location to location or from one rebar layer's zone of load resistence to the other could cause compression if a highly loaded rebar transmitted load to an uncracked block of concrete which in turn transmitted the load to the other rebar layer.

IX **INTERPRETATION OF DATA NOT RELATED TO GROSS DEFORMATION ACCEPTANCE CRITERIA** (continued)

1. **STRAIN GAGES ON REBAR** (continued)

a) **IN EQUIPMENT HATCH AREA** (continued)

5) The gages may have been improperly installed or wired in such a manner to give unreasonable results. A summation of forces in the horizontal direction indicates that tension in the seismic rebar would more nearly balance the resisting forces with the membrane forces acting on the cross section.

Regardless of cause there is no need for concern since the load is compressive and tensile stresses cause the most concern in rebar. Compressive strains in rebar surrounded by concrete which prevents buckling of the bar and resists most of the load, do not prevent the Containment from performing its main function (to resist pressure loads from a Design Basis Accident).

The acceptance strains for all bars are based on maintaing rebar stresses below yield (Ø fy) for the highest pressure considered in design (70.5 psig). This necessitated determining

IX INTERPRETATION OF DATA NOT RELATED TO GROSS DEFORMATION ACCEPTANCE CRITERIA (continued)

1. STRAIN GAGES ON REBAR (continued)

a) IN EQUIPMENT HATCH AREA (continued)

the stress at 54 psig, which when proportioned for the 70.5 psig pressure load, would be within the allowable rebar stress. From the data in Appendix B, it can be seen that no rebar strains exceeded the acceptance strains. The maximum stress of $20.6^{ksi}$ occurred in SG30 discussed above, which is located on a primary vertical bar outside the Equipment Hatch boss, where the predicted stress was approximately $10^{ksi}$. Most values for all primary vertical reinforcing were in the range of $5^{ksi}$. Most hoop reinforcing was stressed to about $20^{ksi}$ outside the boss and $5^{ksi}$ inside the boss. The stress in radial shear bars was low, showing less than $3^{ksi}$, indicating that a diagonal tension crack had not formed and the concrete was resisting most of the shear load. The low stresses in the shear bars indicate that assumptions concerning concrete cracking were conservative and low rebar stresses indicate

IX INTERPRETATION OF DATA NOT RELATED TO GROSS DEFORMATION ACCEPTANCE CRITERIA (continued)

1. STRAIN GAGES ON REBAR (continued)

a) IN EQUIPMENT HATCH AREA (continued)

that the thickened section did not draw loads from discontinuity as high as the analysis indicated.

To summarize, the strain gages on rebar in the Equipment Hatch area almost all were below predicted values, always below acceptance values and generally followed the trend of predicted values, indicating that the design assumptions used to size rebar were reasonably conservative.

b) NEAR BASE OF STRUCTURE AT TEMPORARY OPENING

The location of these gages can be found in Table I. The calculated strains are based on a beam on elastic foundation consideration to determine the effect of the fixed base. This analysis is highly dependent on whether the concrete is assumed cracked or uncracked. The concrete was considered uncracked at the base in determining the flexural rigidy, thus attracting high moments to the fully

IX INTERPRETATION OF DATA NOT RELATED TO GROSS DEFORMATION ACCEPTANCE CRITERIA (continued)

1. STRAIN GAGES ON REBAR (continued)

b) (continued)

fixed base. The resisting spring constant in the membrane region was based on rebar only thus creating a greater discontinuity at the fixed base. The loads determined above were resisted by rebar in a cracked concrete section. These assumptions were chosen to maximize the tensile stress in the inside vertical rebar. Acceptance values were determined as in a) above.

The vertical bar on the outside face of the Containment wall (SG-1A)indicated compression as expected. Although the compressive stress is higher than calculated,it is still well within acceptable limits. The value of this compressive stress depends on the amount of cracking in the concrete section, and for this reason, we did not expect exact agreement.

The stress in gage SG-2A on the secondary vertical bar bent across the Containment

IX INTERPRETATION OF DATA NOT RELATED TO GROSS DEFORMATION ACCEPTANCE CRITERIA (continued)

1. STRAIN GAGES ON REBAR (continued)

b) (continued)

wall to resist radial shear was much lower than predicted. This was expected since all shear reinforcing in the Containment was sized to resist the entire radial shear load with no help from the concrete. Since the outside of the wall showed compressive stress, we know concrete was available to resist radial shear. The inside hoop rebar exhibited compression which could be from the restraint placed on movement of the wall by the fixed base. The outside hoop showed a higher tensile value than expected although still only 5 psig. This could be explained by any small outward movement of the base mat from the shear load at the base of the Containment wall. Since the predicted value of hoop rebar stress was almost zero, this small outward base mat movement, which was not calculated before the test but would be approximately .06"

IX INTERPRETATION OF DATA NOT RELATED TO GROSS DEFORMATION ACCEPTANCE CRITERIA (continued)

1. STRAIN GAGES ON REBAR (continued)

b) (continued)

considering the concrete uncracked, could add a significant percentage increase in predicted value. However, the final stress still remained insignificant.

The strain gages on rebar in the temporary opening exhibited very low stresses and indicated a conservative design approach for the base of the Containment structure.

No results were obtained for the gages located on the inside vertical bars thereby affecting our interpretation of results on other gages in this area since the tensile stress in these bars would be a good indication of the degree of fixity at the base.

2. EQUIPMENT HATCH DIAMETER CHANGE

The Equipment Hatch diameter change was small (.0067) compared to the value from the finite element computer analysis (.017) and the acceptable value (.022"). This was probably due to the concrete

IX INTERPRETATION OF DATA NOT RELATED TO GROSS DEFORMATION ACCEPTANCE CRITERIA (continued)

2. EQUIPMENT HATCH DIAMETER CHANGE (continued)

in the boss not cracking to the degree expected.

3. ROSETTES ON LINER

Measurement of liner strains are the most difficult to interpret in relation to predicted values for the following reasons:

a) The bending stress in the liner in areas such as the Equipment Hatch and base of the structure is dependent on the moment transferred to liner through the horizontal shear carrying capacity of the studs which would vary with yield strength of the stud. Due to the great ductility of the studs, this is not of any particular importance to the stud-liner system integrity (see the Containment Design Report in Supplement 6 in Volume 6 to the Unit No. 2 FSAR).

b) Localized stress concentrations occur when small air voids occur between the steel plate and the concrete cylinder. This is quite common in reinforced concrete construction and will not effect the

IX INTERPRETATION OF DATA NOT RELATED TO GROSS DEFORMATION ACCEPTANCE CRITERIA (continued)

3. ROSETTES ON LINER (continued)

b) (continued)

integrity of the liner, however, it could significantly affect gage readings causing high local tensile and/or compressive stresses depending on the location of the gage relative to the void.

c) The predicted values for liner strain at the Equipment Hatch in Appendix B are based on the finite element computer analysis which contains the assumptions previously discussed in this report along with the additional assumption that the stud transfer all moment to the liner.

The test data in Appendix B shows general agreement with predicted values in some cases. In others there are significant differences. This is to be expected for the reasons stated above. One (1) rosette (R-2R) at Elevation 118'-0" on the Containment wall indicated liner yield. However, its redundant R2, which is within 2" of R-2R, showed values considerably below yield, indicating that the data for R-2R is

IX INTERPRETATION OF DATA NOT RELATED TO GROSS DEFORMATION ACCEPTANCE CRITERIA (continued)

3. ROSETTES ON LINER (continued)

d) (continued)

questionable, since stresses in R2 were less than R-2R at 54 psig. All other gages at the Equipment Hatch and at the base of the structure produce data below the yield point of the liner. On this basis and the fact that for isolated areas the liner can show strains as high as .5% according to criteria in Section 2.2.4 of the Containment Design Report in Supplement 6 in Volume 6 of the Unit No. 2 FSAR, we conclude that the integrity of the liner will not be violated during DBA conditions where temperature increases will cause compressive forces in the liner. To further support this conclusion, no permanent distortions of the liner were discovered at the conclusion of the SIT.

4. DIAL GAGES

The theoretical displacements for dial gages at the base of the structure were calculated by the beam on elastic foundation analytical procedure described in Section IX -2 of this report. In addition, theoretical displacements were calculated considering a flexural rigidity at the base for cracked concrete to

IX INTERPRETATION OF DATA NOT RELATED TO GROSS DEFORMATION ACCEPTANCE CRITERIA (continued)

4. DIAL GAGES (continued)

partially account for any cracking which may take place during the SIT. Using this approach, the base is still considered fixed against rotation which would not be the case if concrete cracked extensively, however, the calculated deflections are larger by this approach.

The dial gage data for radial deflections near the base of the structure is found in Figure 5. The displacements in the area of the Electrical Penetration Tunnel were less than the theoretical displacements for all cases with the data plot showing the same general shape as the plot of theoretical displacements. The results indicate that a degree of fixity did occur at the base of the cylinder (lower 20'-0") wall. Since the majority of cracking occurred in the middle third of the cylinder wall, the deflection about 20'-0" from the base of the structure did not approach the unrestrained radial growth at as low an elevation as the theoretical displacements indicated.

The radial displacements at the Shield Wall area show some deviation from the predicted values, however, the deflections at the base of the structure are very small. The maximum excess of measured deflection

IX INTERPRETATION OF DATA NOT RELATED TO GROSS DEFORMATION ACCEPTANCE CRITERIA (continued)

4. DIAL GAGES (continued)

over theoretical displacement for uncracked concrete is about .03". As the membrane region is approached the values again fall within the theoretical curves.

The deviation from theoretical deflection of .03" is considered unimportant for the following reasons:

a) A .03" deflection difference for a 135'-0" diameter structure is very small.

b) The predicted measurements are very small at the base. Any change caused by accuracy in instrumentation, assumptions in design or even a small outward movement in the base slab (see Section IX-1 for calculated outward movement) although very small would appear to be a large percentage change in the dimension being measured.

c) Greater deflections near the base mat are not indications of structural problems. The fixity at the base is reduced and the moment resisting rebar stresses at the inside of the wall are lowered. Increased hoop stresses

4. DIAL GAGES (continued)

c) are of no concern because hoop reinforcement is the same as in the membrane portion of the structure. In addition, thermal effects on the liner during accident conditions would be less severe. (Thermal effects on the liner are small since the lower portion is insulated).

In conclusion, the dial gage measurements show good agreement with theory in the Electrical Penetration area with small deviations (in magnitude) in the Shield Wall area.

TABLE 1

TABLE 1

INSTRUMENT LOCATION



1-1 EQUIPMENT HATCH AREA - REINFORCING BAR STRAIN

| STRAIN GAGE | HORIZONTAL LOCATION | ELEVATION | TYPE OF STRUCTURAL ELEMENT |
|---|---|---|---|
| SG 1 | On Centerline | 83'-4" | Vertical (Inside) |
| SG 2 | On Centerline | 82'-9" | Hoop (Inside) |
| SG 5 | On Centerline | 87'-3" | Hoop (Boss) |
| SG 7 | On Centerline | 92'-5" | Hoop (Boss) |
| SG 8 | On Centerline | 92'-6" | Hoop (Boss) |
| SG 9 | On Centerline | 90'-2" | Tie (Boss) |
| SG 10 | On Centerline | 86'-5" | Hoop (Boss) |
| SG 11 | Left of ℄ 0'-7" | 85'-11" | Tie (Boss) |
| SG 12 | On Centerline | 82'-7" | Vertical (Outside) |
| SG 13 | On Centerline | 82'-1" | Hoop (Outside) |
| SG 17 | Right of ℄ 15'-3" | 101'-6" | Hoop (Boss) |
| SG 18 | Right of ℄ 15'-4" | 100'-10" | Tie (Boss) |
| SG 19 | Right of ℄ 15'-2" | 101'-0" | Hoop (Boss) |
| SG 20 | Right of ℄ 12'-6" | 100'-5" | Tie (Boss) |
| SG 21 | Right of ℄ 8'-10" | 100'-8" | Hoop (Boss) |
| SG 22 | Right of ℄ 8'-7" | 101'-6" | Hoop (Boss) |
| SG 24 | Right of ℄ 21'-0" | 82'-9" | Hoop (Inside) |
| SG 25 | Right of ℄ 21'-0" | 83'-4" | Vertical (Inside) |
| SG 26 | Right of ℄ 22'-3" | 82'-7" | Vertical (Outside) |
| SG 27 | Right of ℄ 22'-0" | 82'-4" | Hoop (Outside) |
| SG 29 | Left of ℄ 21'-0" | 120'-3" | Hoop (Inside) |
| SG 30 | Left of ℄ 21'-0" | 120'-10" | Vertical (Inside) |
| SG 31 | Left of ℄ 21'-7" | 120'-9" | Hoop (Outside) |
| SG 32 | Left of ℄ 21'-5" | 121'-2" | Vertical (Outside) |
| SG 33 | On Centerline | 82'-9" | Seismic |
| SG 34 | On Centerline | 89'-9" | Seismic |
| SG 35 | Right of ℄ 13'-10" | 101'-6" | Seismic |
| SG 36 | Right of ℄ 17'-0" | 101'-6" | Seismic |
| SG 37 | Left of ℄ 21'-0" | 120'-3" | Seismic |
| SG 38 | Right of ℄ 21'-0" | 82'-9" | Seismic |
| SG 43 | On Centerline | 92'-6" | Hoop (Boss) |
| SG 44 | On Centerline | 85'-4" | Hoop (Boss) |
| SG 46 | Right of ℄ 8'-7" | 101'-6" | Hoop (Boss) |
| SG 47 | Right of ℄ 9'-6" | 101'-8" | Vertical (Boss) |
| SG 48 | Right of ℄ 11'-7" | 101'-1" | Vertical (Boss) |
| SG 49 | Right of ℄ 14'-1" | 101'-6" | Vertical (Boss) |
| SG 50 | Right of ℄ 15'-2" | 101'-5" | Vertical (Boss) |
| SG 51 | Right of ℄ 18'-5" | 101'-11" | Vertical (Outside) |
| SG 52 | Right of ℄ 0'-3" | 92'-0" | Hoop (Boss) |

1-1 EQUIPMENT HATCH AREA - REINFORCING BAR STRAIN (cont'd)

| STRAIN GAGE | HORIZONTAL LOCATION | ELEVATION | TYPE OF STRUCTURAL ELEMENT |
|---|---|---|---|
| SG 53 | Right of ℄ 0'-7" | 90'-5" | Hoop (Boss) |
| SG 54 | Right of ℄ 0'-8" | 88'-4" | Hoop (Boss) |
| SG 55 | Right of ℄ 1'-1" | 91'-6" | Radial Shear |
| SG 56 | Left of ℄ 0'-5" | 88'-9" | Radial Shear |
| SG 57 | Right of ℄ 12'-2" | 100'-10" | Radial Shear |
| SG 58 | Right of ℄ 9'-10" | 101'-3" | Radial Shear |
| SG 59 | Right of ℄ 10'-1" | 101'-4" | Radial Shear |

(Work This Table With Figure 3)

1-2 BASE OF CONTAINMENT STRUCTURE - REINFORCING BAR STRAIN

| STRAIN GAGE | HORIZONTAL LOCATION | ELEVATION | TYPE OF STRUCTURAL ELEMENT |
|---|---|---|---|
| SG 1A | Azimuth 345°, 26', 53" | 44'-2" | Vertical (Outside) |
| SG 2A | Azimuth 345°, 26', 53" | 44'-2" | Secondary Vertical (Inside) |
| SG 3A | Azimuth 345°, 26', 53" | 44'-2" | Seismic |
| SG 8A | Azimuth 345°, 26', 53" | 46'-6" | Secondary Vertical (Inside) |
| SG 8B | Azimuth 345°, 26', 53" | 46'-6" | Secondary Vertical (Inside) |
| SG 15A | Azimuth 345°, 26', 53" | 48'-0" | Hoop (Inside) |
| SG 16A | Azimuth 345°, 26', 53" | 45'-11" | Hoop (Outside) |
| SG 19A | Azimuth 345°, 26', 53" | 46'-6" | Vertical (Inside) |
| SG 19B | Azimuth 345°, 26', 53" | 46'-6" | Vertical (Inside) |

1-3 CYLINDER WALL AND DOME DISPLACEMENTS
INVAR WIRES STRUNG ACROSS DIAMETER OF
CONTAINMENT BUILDING

| INVAR WIRE | FROM AZIMUTH | TO AZIMUTH | ELEVATION | TO MEASURE |
|---|---|---|---|---|
| I.G. 16 | Crane Wall | 315°, 0'-0" | 91'-0" | Radial Displacement |
| I.G. 17 | S.G. Shield Wall | 315°, 0'-0" | 101'-0" | Radial Displacement |
| I.G. 18 | 135°, 0'-0" | 315°, 0'-0" | 111'-0" | Diameter Change |
| I.G. 19 | 135°, 0'-0" | 315°, 0'-0" | 121'-0" | Diameter Change |
| I.G. 20 | 135°, 0'-0" | 315°, 0'-0" | 131'-0" | Diameter Change |
| I.G. 21 | 135°, 0'-0" | 315°, 0'-0" | 141'-0" | Diameter Change |
| I.G. 22 | 135°, 0'-0" | 315°, 0'-0" | 151'-0" | Diameter Change |
| I.G. 23 | 135°, 0'-0" | 315°, 0'-0" | 161'-0" | Diameter Change |
| I.G. 24 | 135°, 0'-0" | 315°, 0'-0" | 171'-0" | Diameter Change |
| I.G. 25 | 135°, 0'-0" | 315°, 0'-0" | 181'-0" | Diameter Change |
| I.G. 26 | 135°, 0'-0" | 315°, 0'-0" | 191'-0" | Diameter Change |

(Work This Table With Figure 2)

INVAR WIRES CONNECTED TO BASE
AT ELEVATION 46'-0" AND CYLINDER WALL

| INVAR WIRE | AT AZIMUTH | ELEVATION | TO MEASURE |
|---|---|---|---|
| I.G. 29 | 300°, 0'-0" | 95'-0" | Vertical Displacement |
| I.G. 30 | 300°, 0'-0" | 143'-0" | Vertical Displacement |
| I.G. 31 | 300°, 0'-0" | 191'-0" | Vertical Displacement |

(Work This Table With Figure 2)

# TABLE 1 (cont'd)

## INSTRUMENT LOCATION (cont'd)



1-3 (cont'd)

### DOME DISPLACEMENT

| INVAR WIRE | FROM | TO |
|---|---|---|
| I.G. 27 | Apex @ El. 258'-6" | Springline @ El. 191'-0" Azimuth 300° 0'-0" |
| I.G. 28 | Springline @ El. 191'-0" Azimuth 120°, 0'-0" | Apex @ El. 258'-6" |

(Work This Table With Figure 2)

1-4

### EQUIPMENT HATCH - DIAMETER CHANGE

### INVAR WIRES STRUNG ACROSS DIAMETER OF EQUIPMENT HATCH

| INVAR WIRES | AZIMUTH OF EQUIPMENT HATCH |
|---|---|
| I.G. 33 | From 45°, 0'-0" to 225°,0'-0" |
| I.G. 34 | From 135°, 0'-0" to 315°,0'-0" |

(Work This Table With Figure 1)

1-5

### EQUIPMENT HATCH - RADIAL DISPLACEMENT INVAR WIRES STRUNG FROM FIXED POINT INSIDE THE CONTAINMENT BUILDING (CRANE WALL, PRESSURIZER SHIELD WALL, CRANE) TO THE FOLLOWING LOCATIONS ON THE INSIDE OF THE LINER (SHOWN ON OUTSIDE OF CONTAINMENT FOR CLARITY)

| INVAR WIRE | HORIZONTAL LOCATION (Viewed From Outside) | ELEVATION |
|---|---|---|
| I.G. 1 | Right of 24'-0" | 94'-0" |
| I.G. 2 | Right of 14'-0" | 94'-0" |
| I.G. 3 | Right of 14'-0" | 98'-6" |
| I.G. 4 | Left of 10'-6" | 100'-0" |

1-5 EQUIPMENT HATCH - RADIAL DISPLACEMENT
INVAR WIRES STRUNG FROM FIXED POINT INSIDE THE CONTAINMENT BUILDING (CRANE WALL, PRESSURIZER SHIELD WALL, CRANE) TO THE FOLLOWING LOCATIONS ON THE INSIDE OF THE LINER (SHOWN ON OUTSIDE OF CONTAINMENT FOR CLARITY) (cont'd)

| INVAR WIRE | HORIZONTAL LOCATION (Viewed From Outside) | ELEVATION |
|---|---|---|
| I.G. 5 | Left of ℄ 15'-6" | 100'-0" |
| I.G. 6 | Left of ℄ 24'-0" | 92'-6" |
| I.G. 7 | Right of ℄ 27'-3" | 116'-6" |
| I.G. 8 | Right of ℄ 14'-0" | 110"-6" |
| I.G. 9 | Right of ℄ 14'-0" | 106'-6" |
| I.G. 10 | Left of ℄ 10'-6" | 106'-6" |
| I.G. 11 | Left of ℄ 26'-0" | 110'-6" |
| I.G. 12 | Left of ℄ 26'-0" | 116'-6" |
| I.G. 13 | On Centerline | 110'-6" |
| I.G. 14 | On Centerline | 116'-6" |
| I.G. 15 | On Centerline | 127'-6" |

(Work This Table With Figure 1)

1-6 CYLINDER WALL - LINER STRAIN

| ROSETTE | AZIMUTH | ELEVATION |
|---|---|---|
| R 1 | 130°, 0'-0" | 46'-6" |
| R 2 | 130°, 0'-0" | 118'-6" |
| R 3 | 130°, 0'-0" | 190'-6" |
| R 4 | 130°, 0'-0" | 191'-6" |

(Work This Table With Figure 2)

1-7 EQUIPMENT HATCH AREA - LINER STRAIN

| ROSETTE | HORIZONTAL ELEVATION | ELEVATION |
|---|---|---|
| R 5 | On Centerline | 120'-0" |
| R 6 | On Centerline | 110'-6" |
| R 7 | Left of ℄ 21'-0" | 101'-6" |
| R 8 | Left of ℄ 9'-0" | 101'-6" |
| R 9 | On Centerline | 79'-6" |
| R 10 | On Centerline | 92'-6" |
| R 11 | Right of ℄ 21'-0" | 101'-6" |
| R 12 | Right of ℄ 9'-0" | 101'-6" |

(Work This Table with Figure 2)

1-8 CONTAINMENT STRUCTURE - RADIAL DISPLACEMENT

| DIAL GAGE @ ELECT. TUNNEL | AZIMUTH | ELEVATION |
|---|---|---|
| D.G. 1 | 230° 0'-0" | 46'-6" |
| D.G. 2 | 230° 0'-0" | 47'-6" |
| D.G. 3 | 230° 0'-0" | 48'-6" |
| D.G. 4 | 230° 0'-0" | 49'-6" |
| D.G. 5 | 230° 0'-0" | 50'-6" |
| D.G. 6 | 230° 0'-0" | 51'-6" |
| D.G. 7 | 230° 0'-0" | 52'-6" |
| D.G. 8 | 230° 0'-0" | 53'-6" |
| D.G. 9 | 230° 0'-0" | 54'-6" |
| D.G. 10 | 230° 0'-0" | 55'-6" |
| D.G. 11 | 230° 0'-0" | 56'-6" |
| D.G. 12 | 230° 0'-0" | 57'-6" |
| D.G. 13 | 230° 0'-0" | 58'-6" |
| D.G. 14 | 230° 0'-0" | 59'-6" |
| D.G. 15 | 230° 0'-0" | 60'-6" |
| D.G. 16 | 230° 0'-0" | 61'-6" |

| DIAL GAGE @ PIPE BRIDGE | AZIMUTH | ELEVATION |
|---|---|---|
| D.G. 1 | 290° 0'-0" | 43'-6" |
| D.G. 2 | 290° 0'-0" | 44'-6" |
| D.G. 3 | 290° 0'-0" | 45'-6" |
| D.G. 4 | 290° 0'-0" | 46'-6" |

(Work This Table with Figure 1)

## TABLE 1 (cont'd)

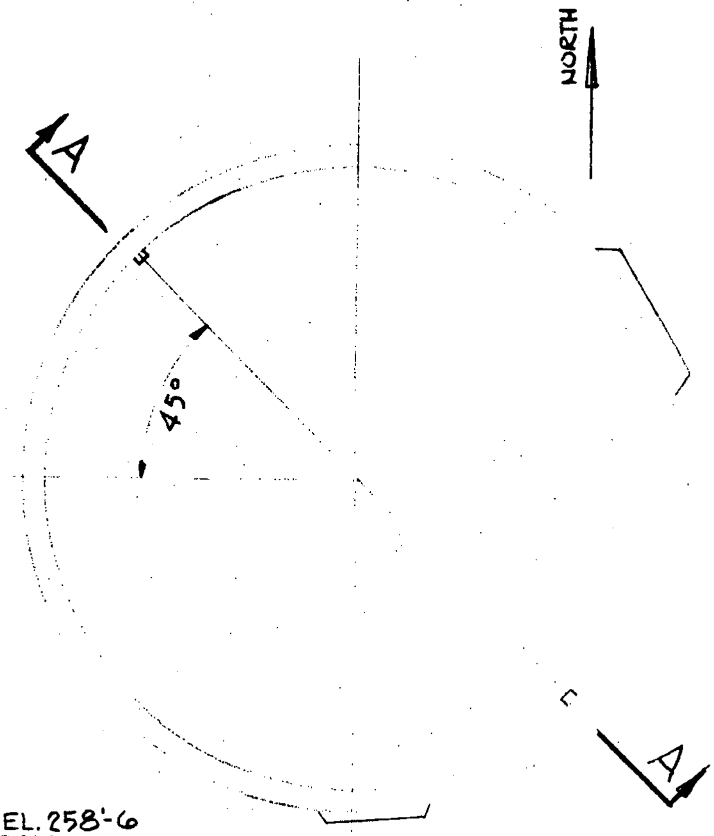


### 1-8 CONTAINMENT STRUCTURE - RADIAL DISPLACEMENT

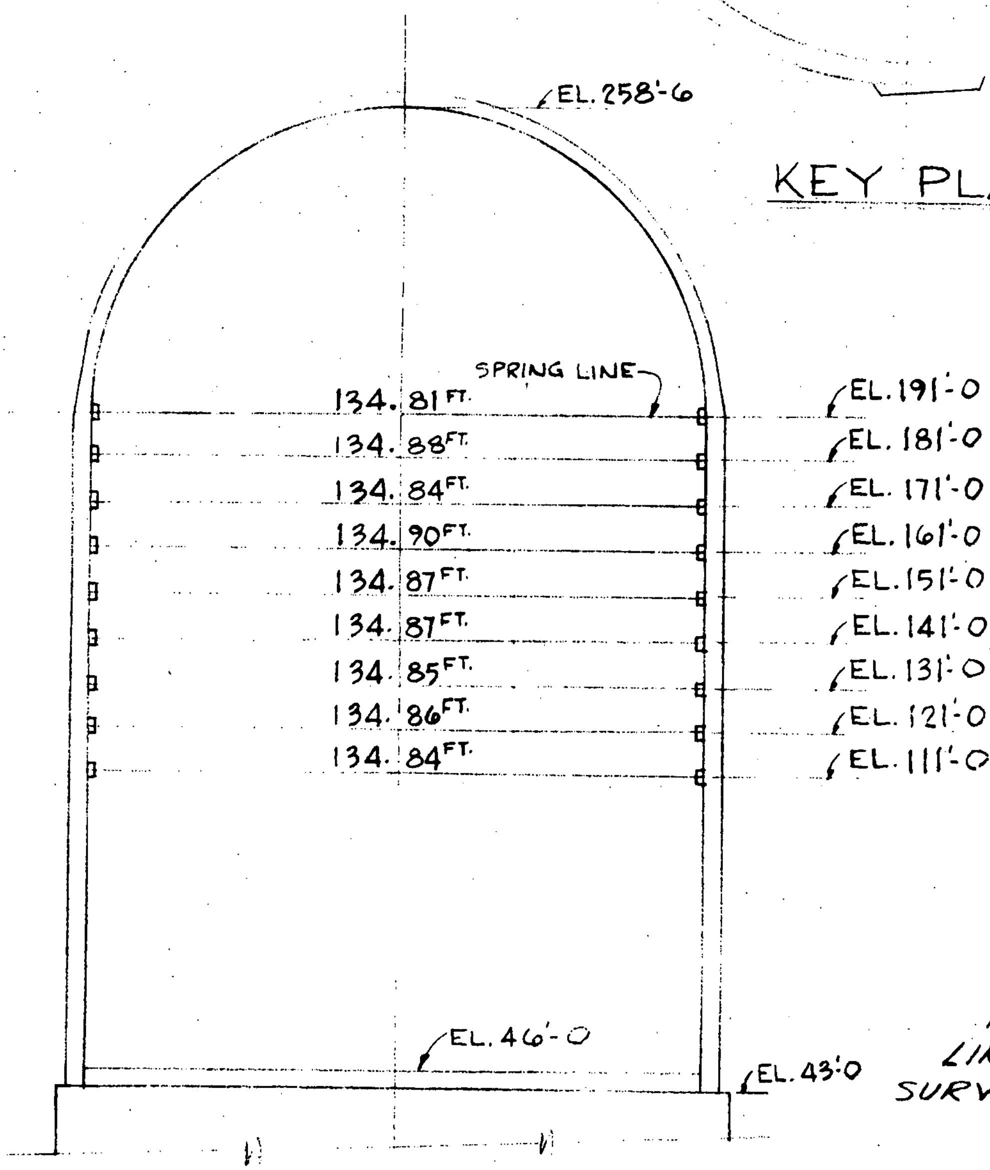
| DIAL GAGE @ PIPE BRIDGE | AZIMUTH | ELEVATION |
|---|---|---|
| D.G. 5 | 290° 0'-0" | 47'-6" |
| D.G. 6 | 290° 0'-0" | 48'-6" |
| D.G. 7 | 290° 0'-0" | 49'-6" |
| D.G. 8 | 290° 0'-0" | 50'-6" |
| D.G. 9 | 290° 0'-0" | 51'-6" |
| D.G. 10 | 290° 0'-0" | 52'-6" |
| D.G. 11 | 290° 0'-0" | 53'-6" |
| D.G. 12 | 290° 0'-0" | 54'-6" |
| D.G. 13 | 290° 0'-0" | 55'-6" |
| D.G. 14 | 290° 0'-0" | 56'-6" |
| D.G. 15 | 290° 0'-0" | 57'-6" |
| D.G. 16 | 290° 0'-0" | 58'-6" |

(Work This Table With Figure 1)

FIGURES

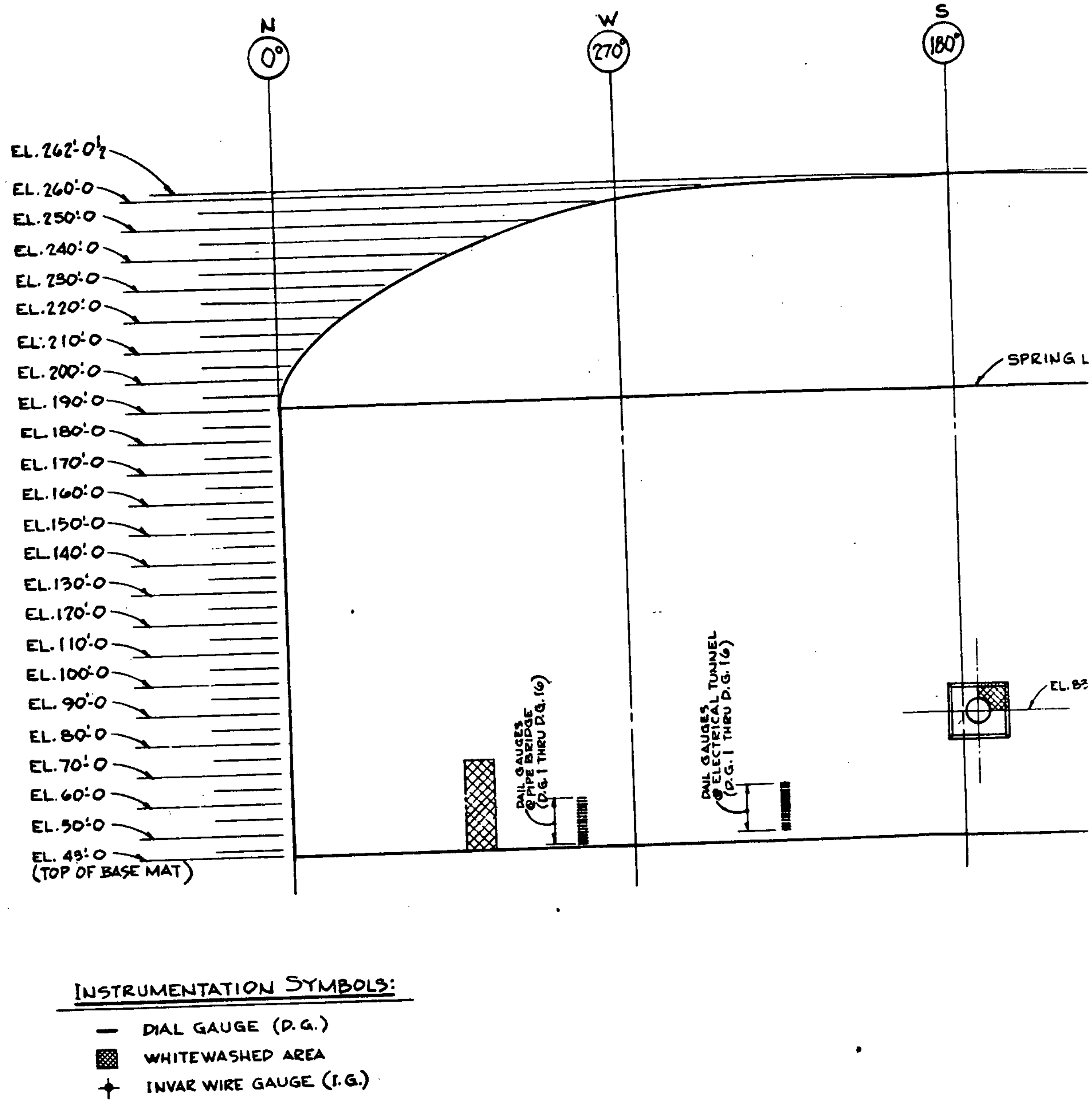


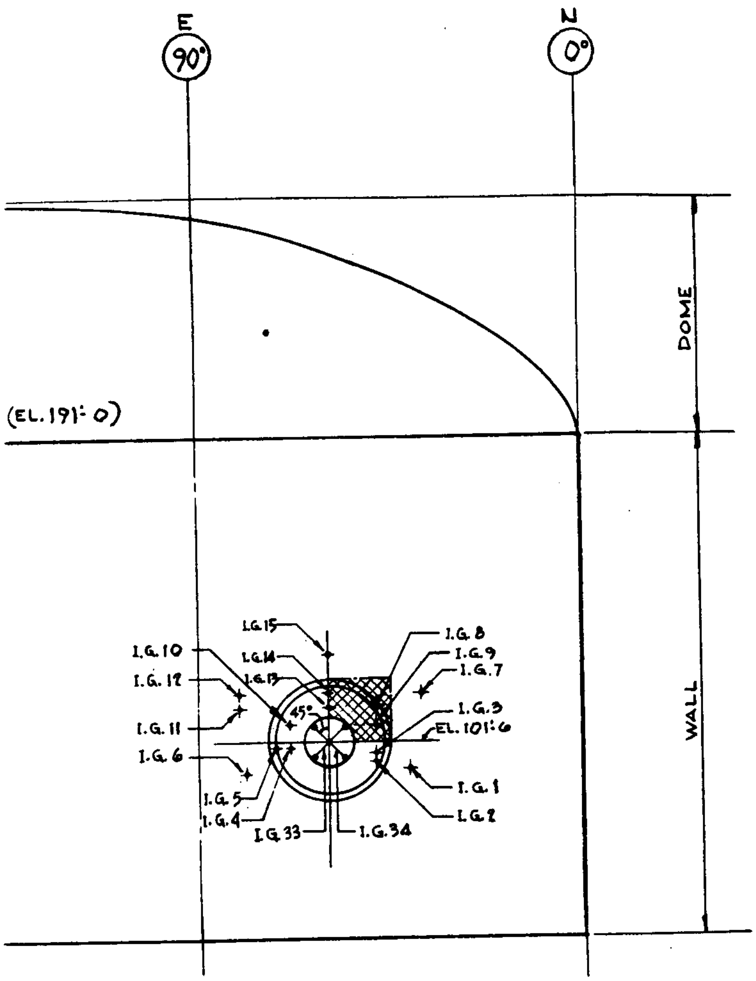

KEY PLAN

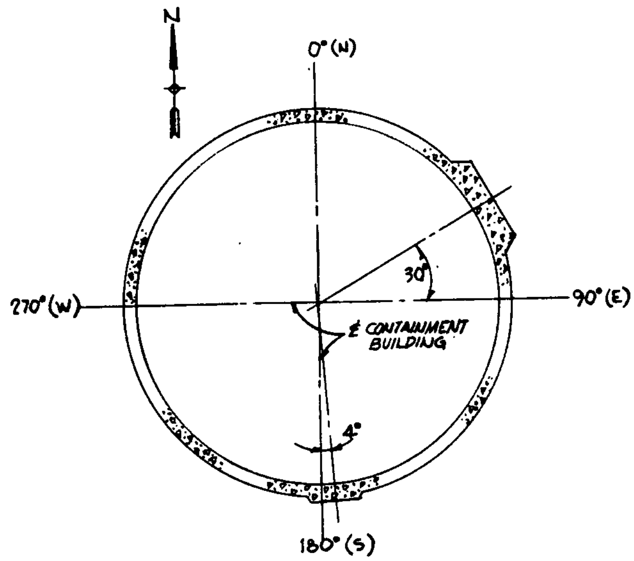



SECTION A-A

FIGURE 4
LINER DIAMETER
SURVEY AT INVAR WIRES


N
0°
W
270°
S
180°
EL. 262'-0½
EL. 260'-0
EL. 250'-0
EL. 240'-0
EL. 230'-0
EL. 220'-0
EL. 210'-0
EL. 200'-0
EL. 190'-0
EL. 180'-0
EL. 170'-0
EL. 160'-0
EL. 150'-0
EL. 140'-0
EL. 130'-0
EL. 170'-0
EL. 110'-0
EL. 100'-0
EL. 90'-0
EL. 80'-0
EL. 70'-0
EL. 60'-0
EL. 50'-0
EL. 49'-0
(TOP OF BASE MAT)
SPRING L
DAIL GAUGES @ PIPE BRIDGE (D.G. 1 THRU D.G. 16)
DAIL GAUGES @ ELECTRICAL TUNNEL (D.G. 1 THRU D.G. 16)
INSTRUMENTATION SYMBOLS:
DIAL GAUGE (D.G.)
WHITEWASHED AREA
INVAR WIRE GAUGE (I.G.)

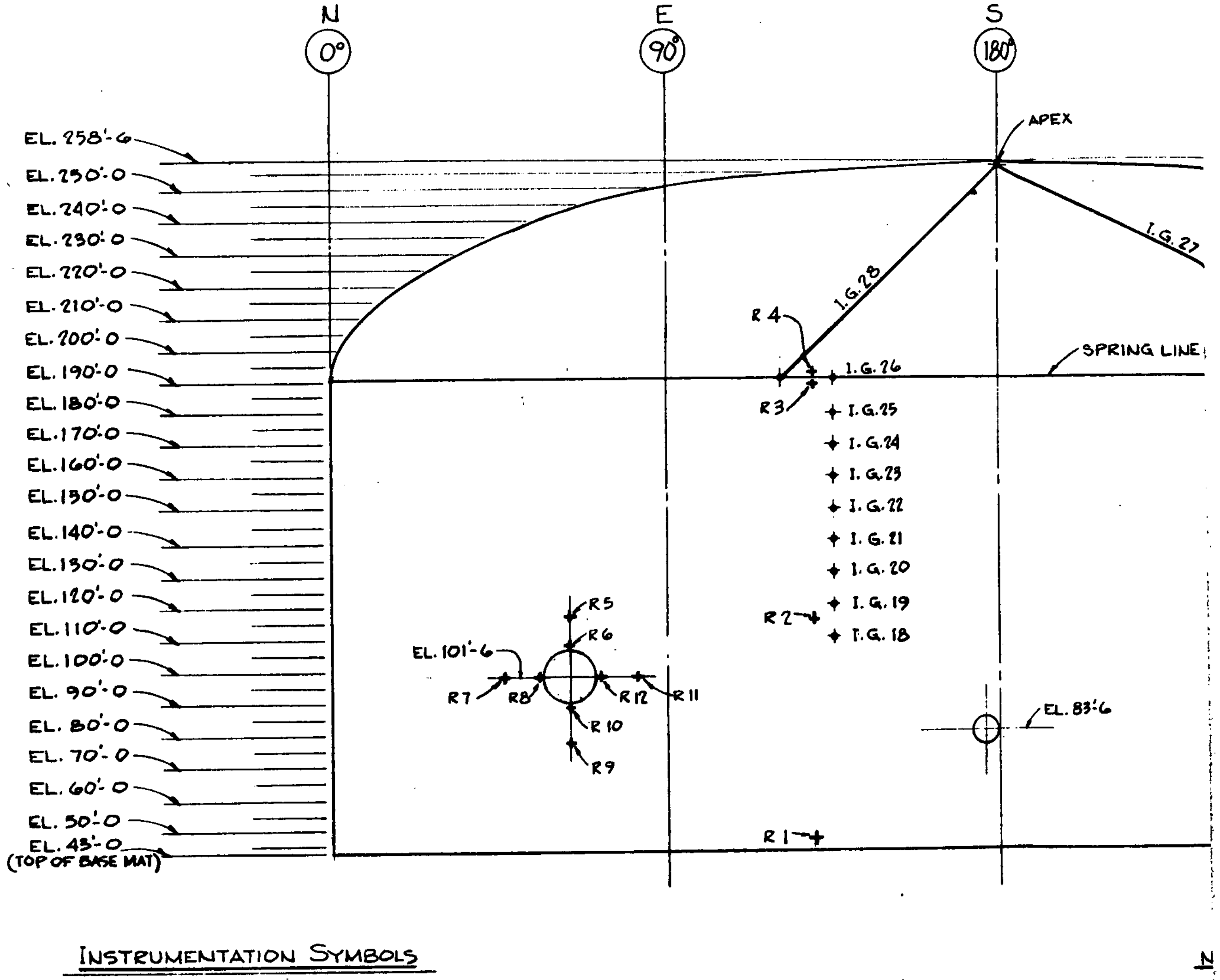



LOCATION PLAN

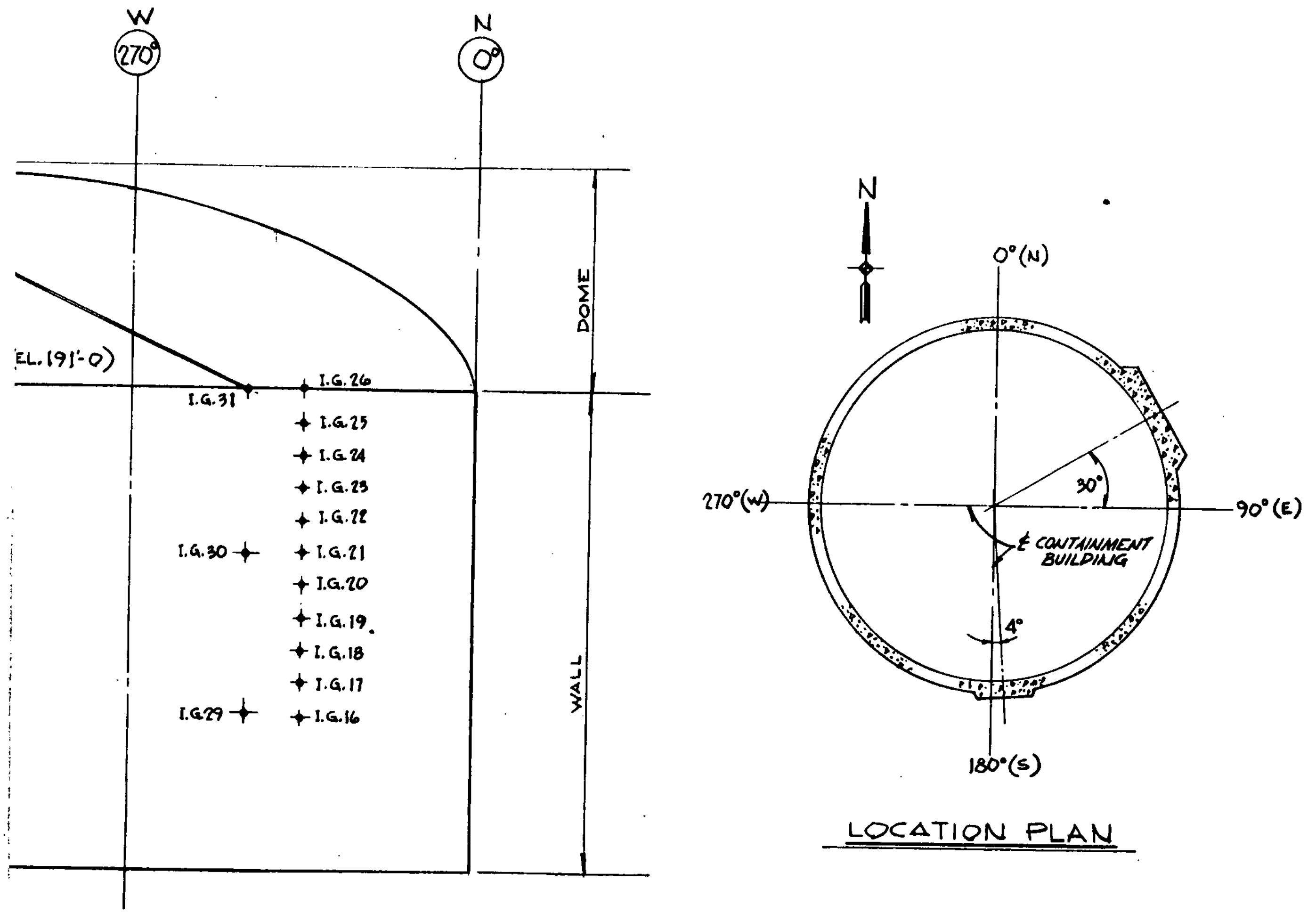
NOTE:
FOR INSTRUMENTATION LOCATION SEE TABLE I

FIGURE 1
STRETCH-OUT OF CONTAINMENT BUILDING
OUTSIDE INSTRUMENTATION




## Instrumentation Symbols

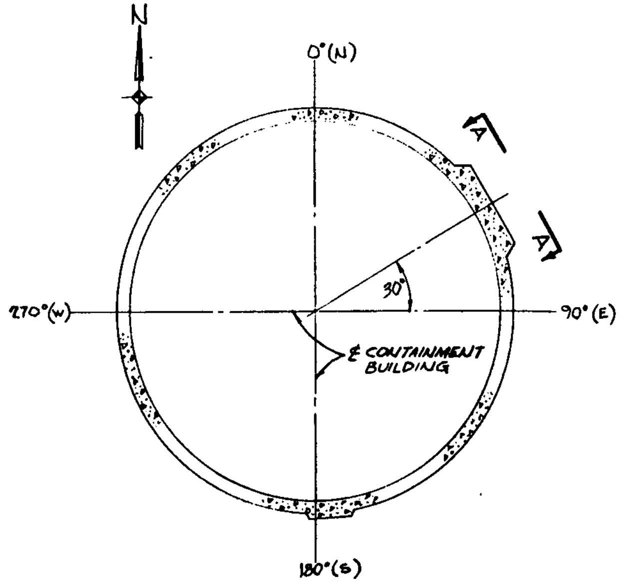
- STRAIN ROSETTES (R)
- INVAR WIRE GAUGE (I.G.)



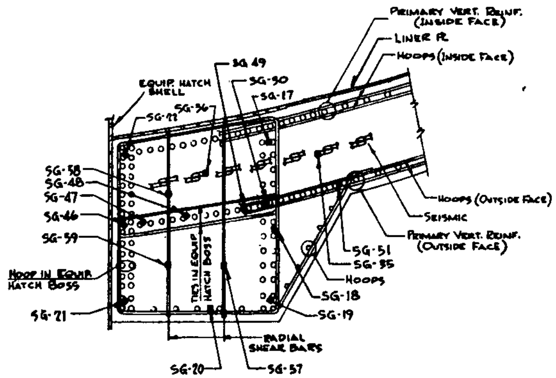

OTE:

FOR INSTRUMENTATION LOCATION SEE TABLE I

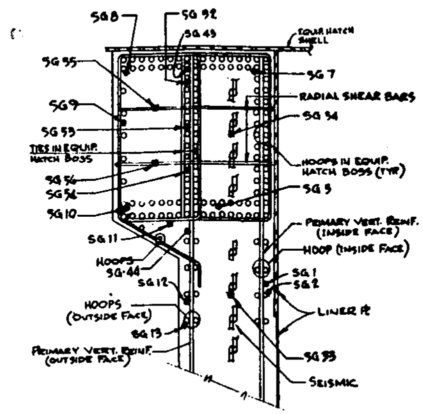
FIGURE 2
STRETCH-OUT OF CONTAINMENT BUILDING
INSIDE INSTRUMENTATION



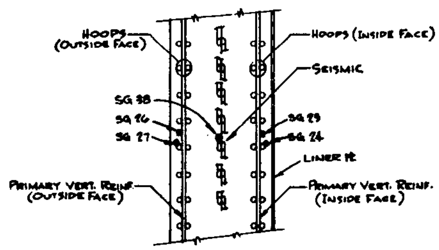

LOCATION PLAN



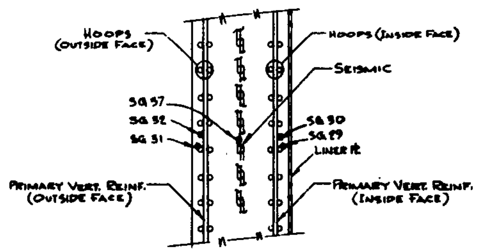

SECTION C-C



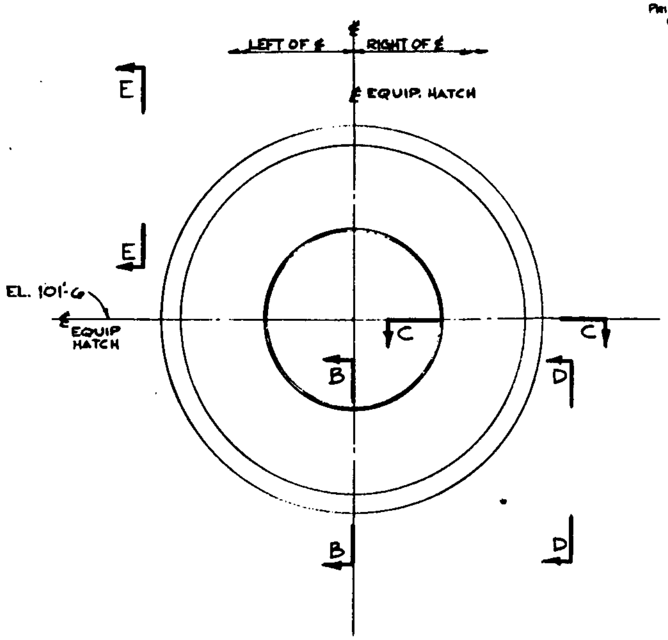

SECTION B-B




SECTION D-D




SECTION E-E

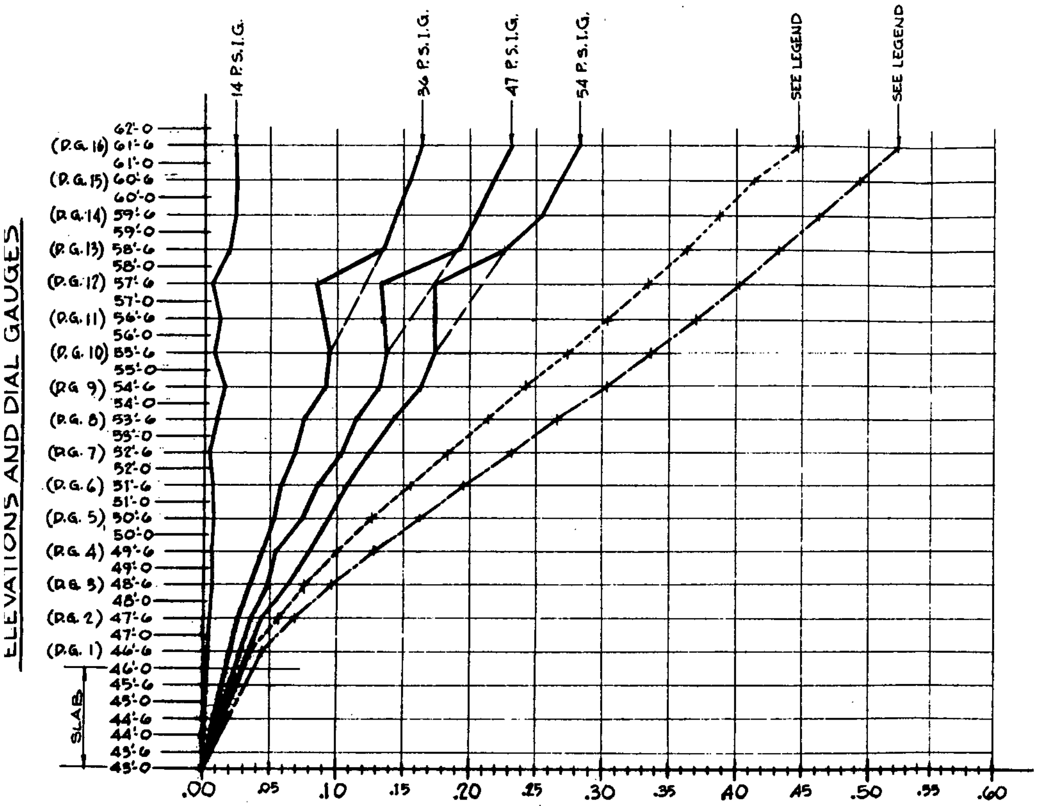



SECTION A-A (EQUIP. HATCH)

INSTRUMENTATION SYMBOLS:

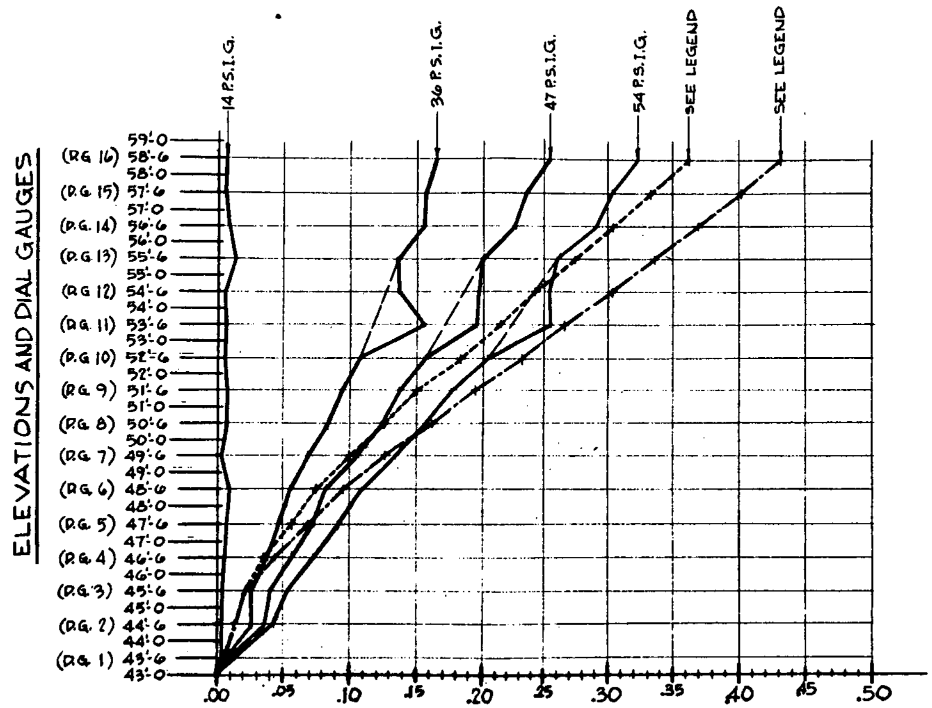
■ STRAIN GAUGES (SG)

FIGU
EQUIPME
RE-BAR INS




RADIAL DEFLECTION (INCHES)
AT ELECTRICAL PENETRATION TUNNEL
(AZIMUTH 230°)

NOTE:
D.G. 12- BAD GAGE




RADIAL DEFLECTION (INCHES)
AT SHIELD WALL AREA
(AZIMUTH 290°)

NOTE:
D.G. 11 - BAD

LEGEND:

- - - - - - - THEORETICAL DEFLECTION @ 54 P.S.I. (UNCRACKED CONCRETE @ BASE)

— - — THEORETICAL DEFLECTION @ 54 P.S.I. (CRACKED CONCRETE)

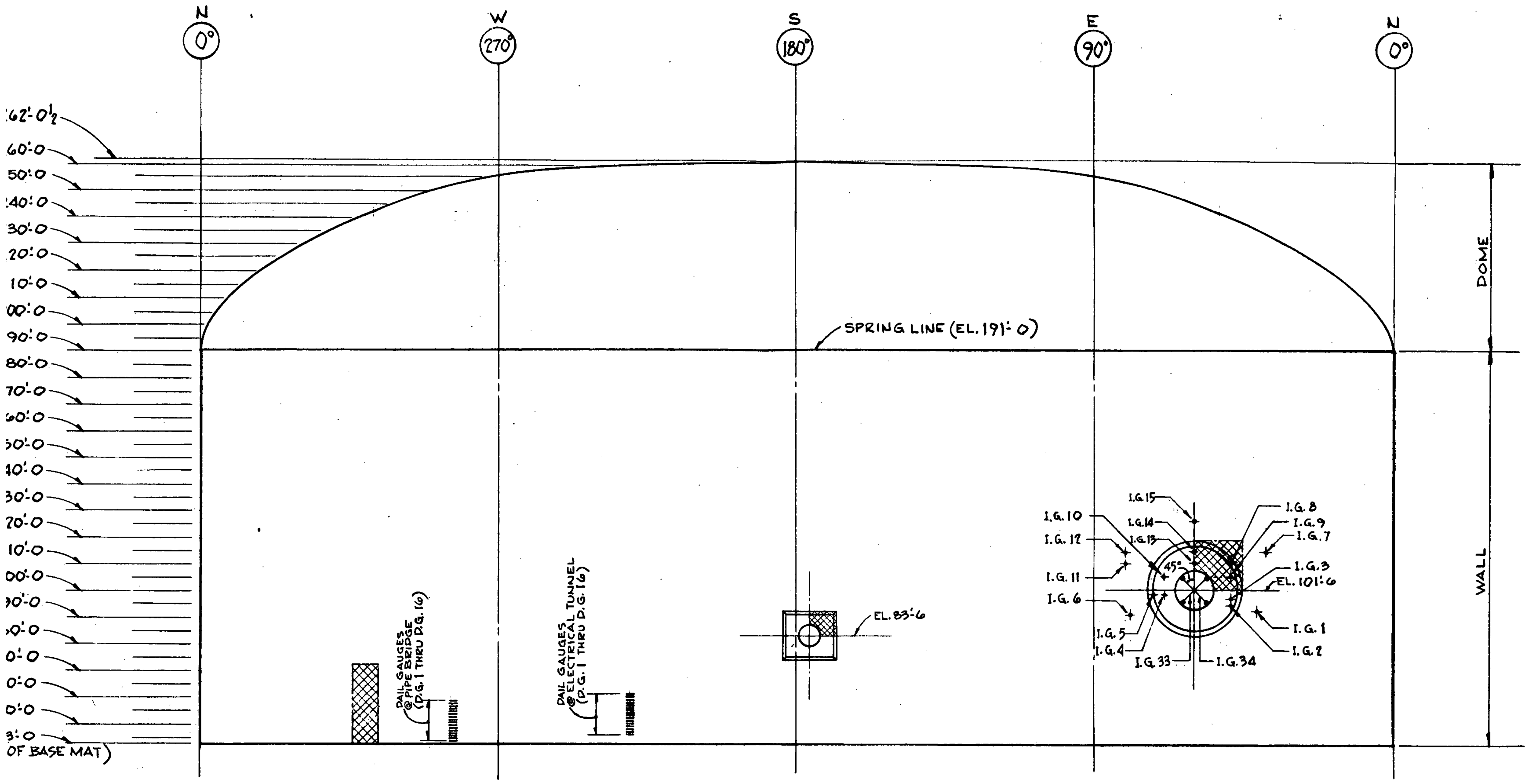
——— ACTUAL DEFLECTION MEASURED DURING PRESSURIZATION

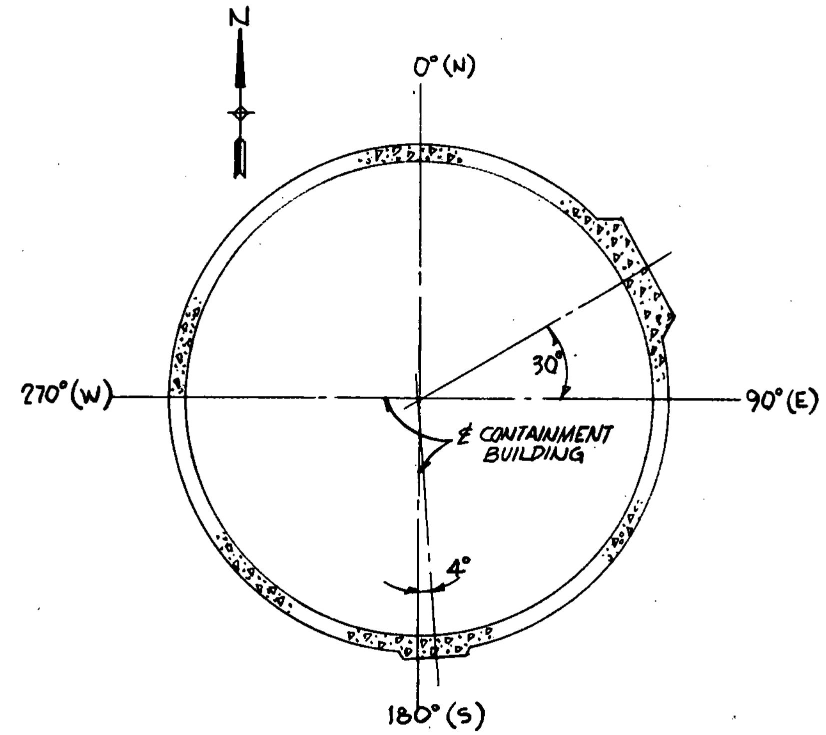
FIGURE 5
RADIAL DEFLEC
NEAR BASE OF CON
DIAL GAU

Do

Not

Film




LOCATION PLAN

INSTRUMENTATION SYMBOLS:

— DIAL GAUGE (D.G.)

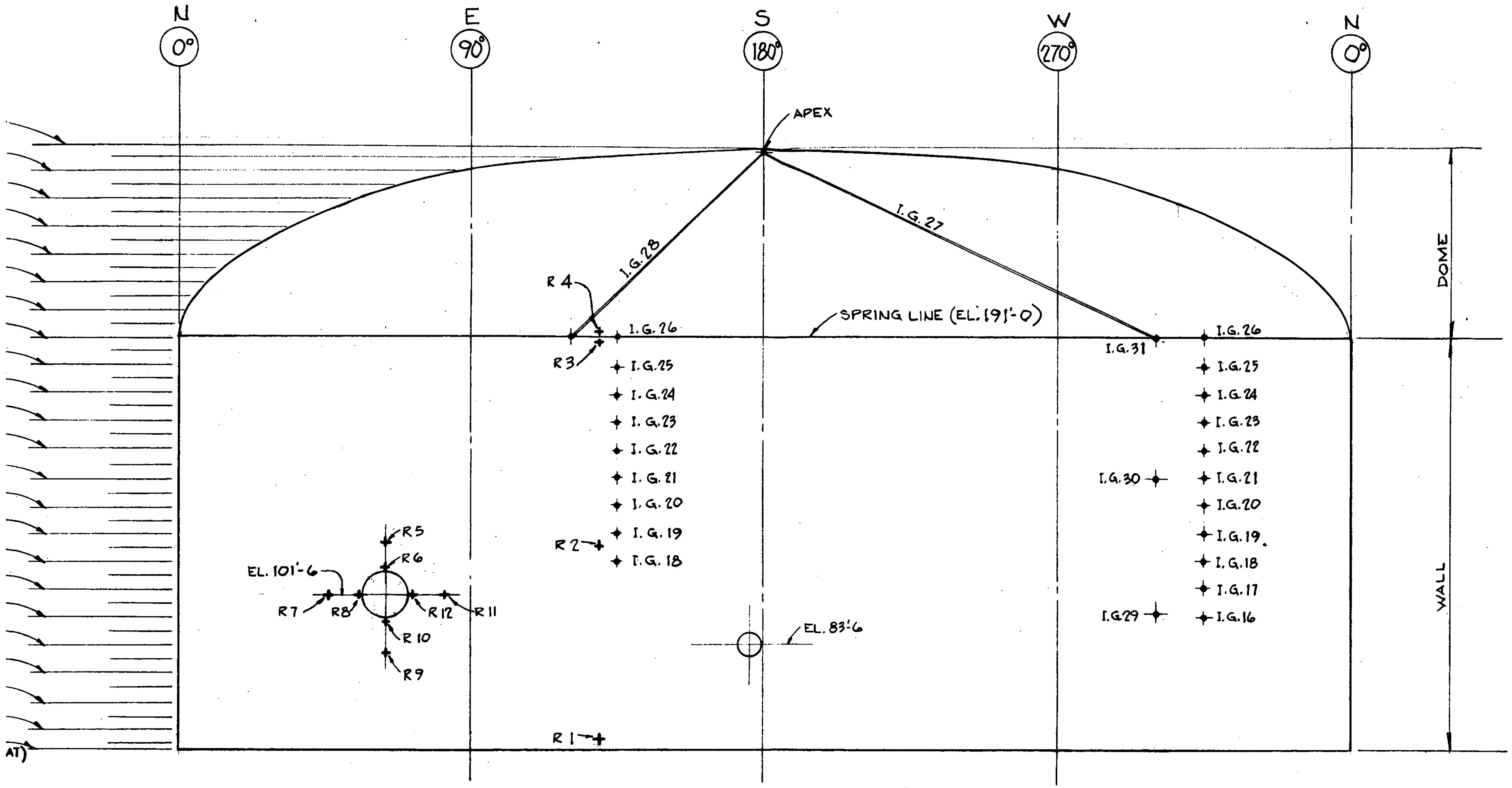
▩ WHITEWASHED AREA

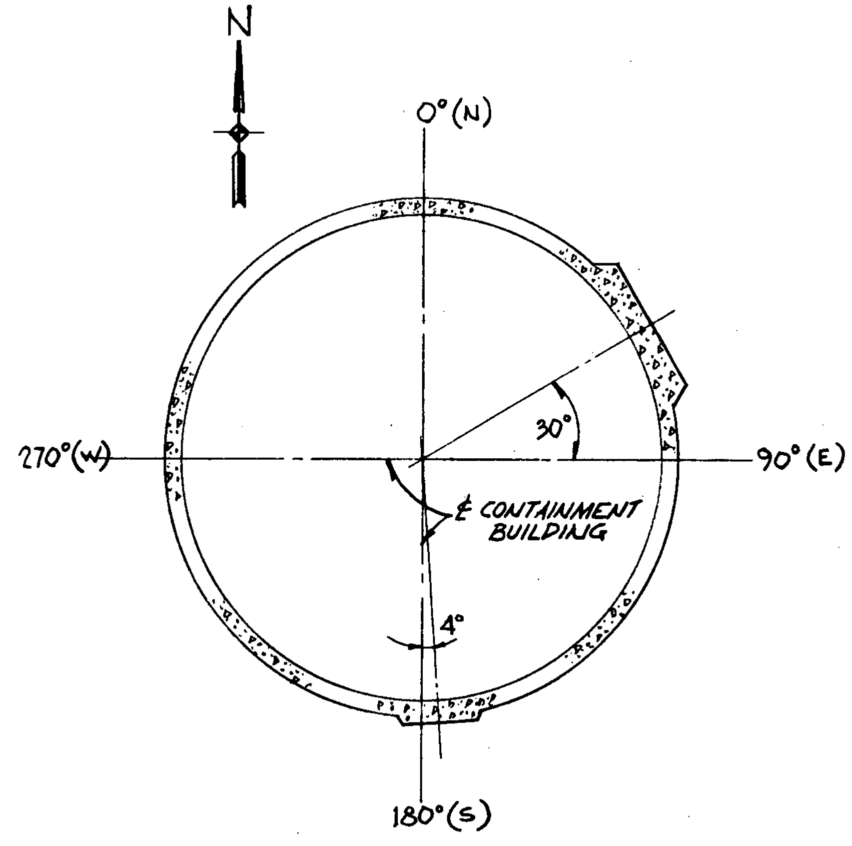
✛ INVAR WIRE GAUGE (I.G.)

NOTE:

FOR INSTRUMENTATION LOCATION SEE TABLE I

FIGURE 1
STRETCH-OUT OF CONTAINMENT BUILDING
OUTSIDE INSTRUMENTATION



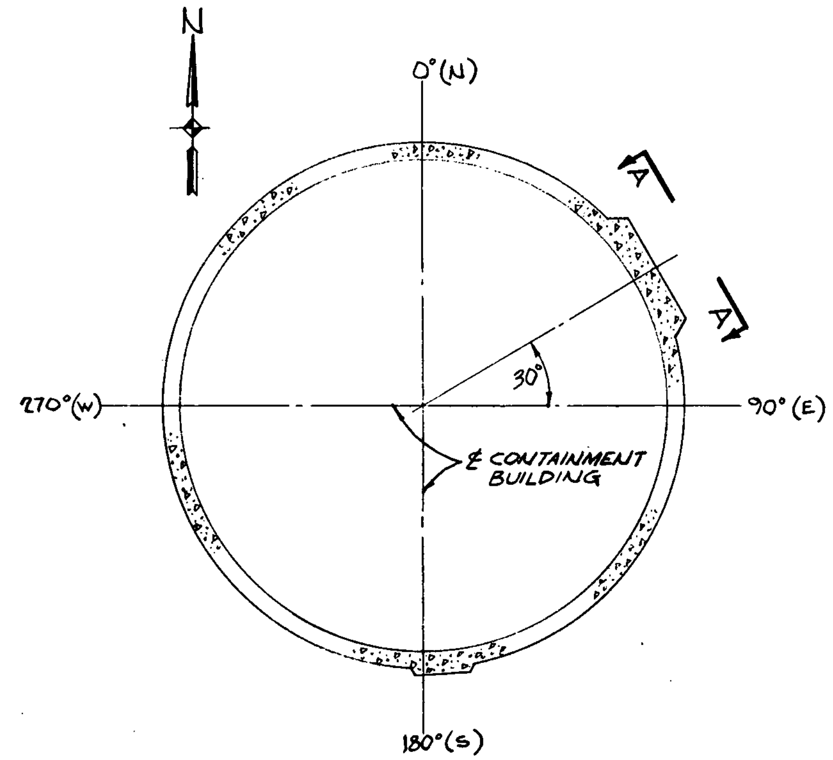

LOCATION PLAN

ZUMENTATION SYMBOLS

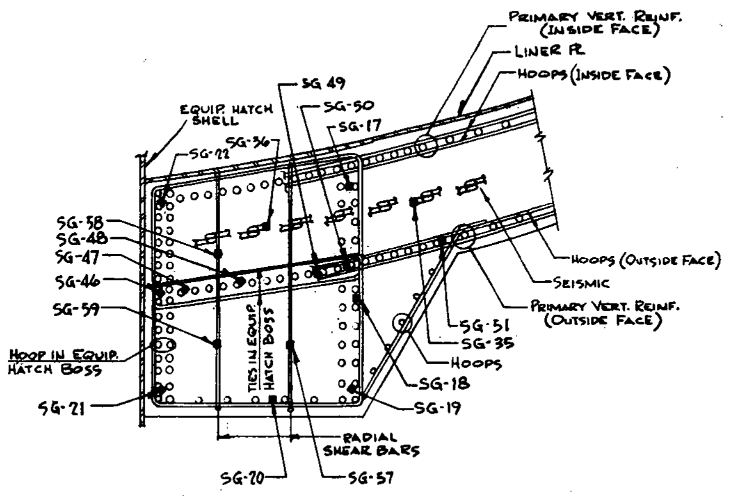
STRAIN ROSETTES (R)
INVAR WIRE GAUGE (I.G.)

NOTE:
FOR INSTRUMENTATION LOCATION SEE TABLE I

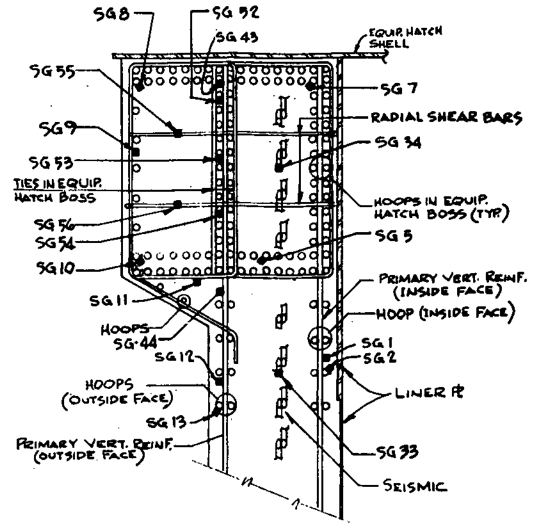
FIGURE 2
STRETCH-OUT OF CONTAINMENT BUILDING
INSIDE INSTRUMENTATION



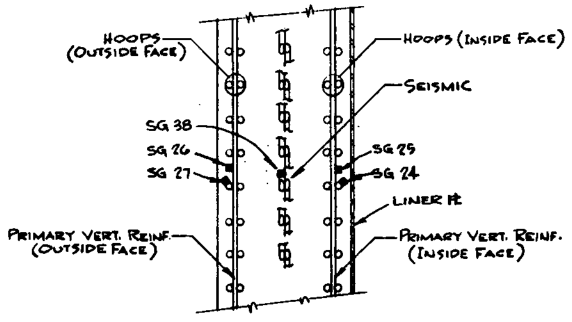

LOCATION PLAN



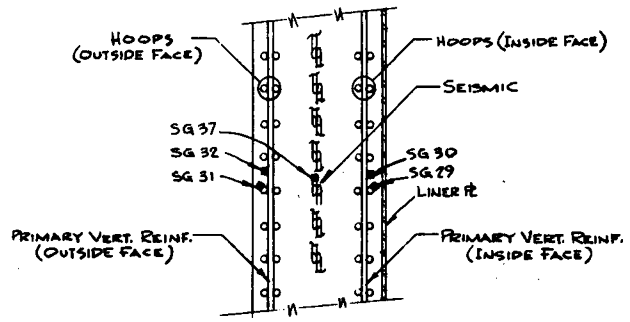

SECTION C-C



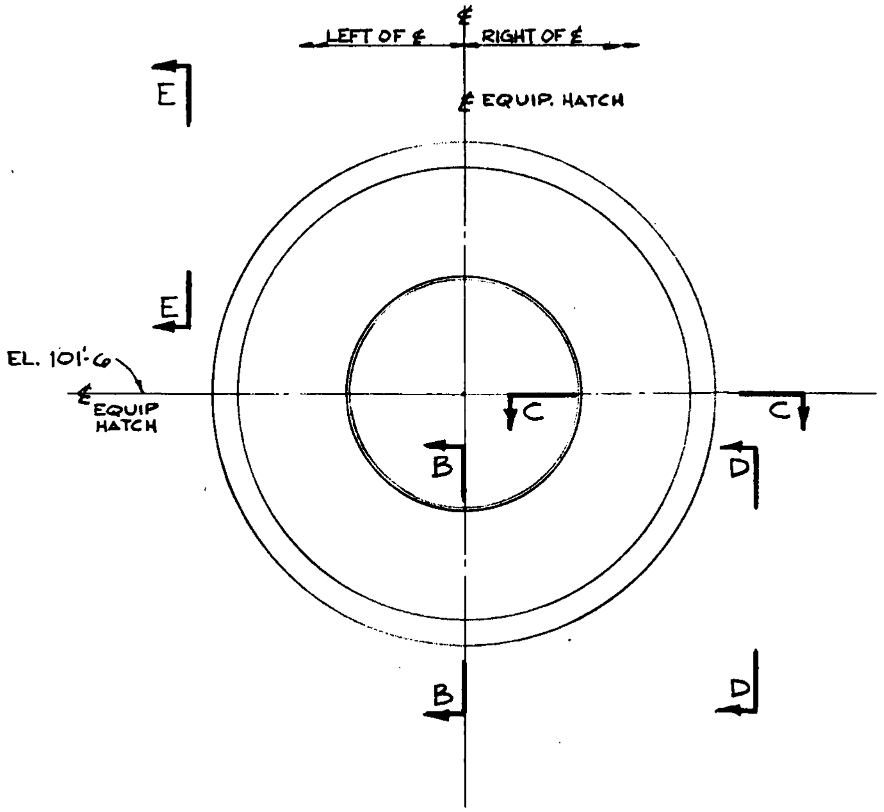

SECTION B-B




SECTION D-D




SECTION E-E

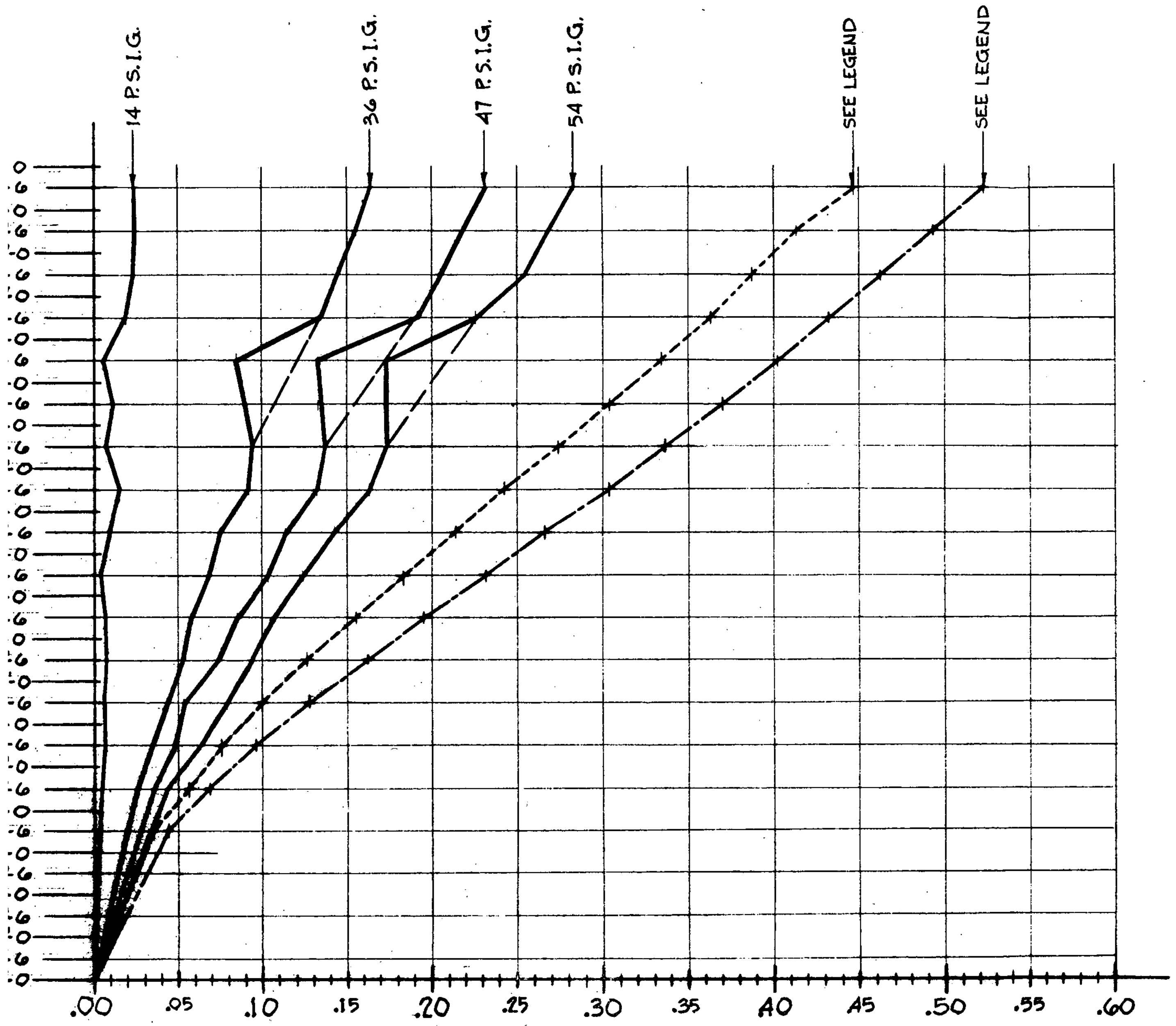



SECTION A-A (EQUIP. HATCH)

INSTRUMENTATION SYMBOLS:

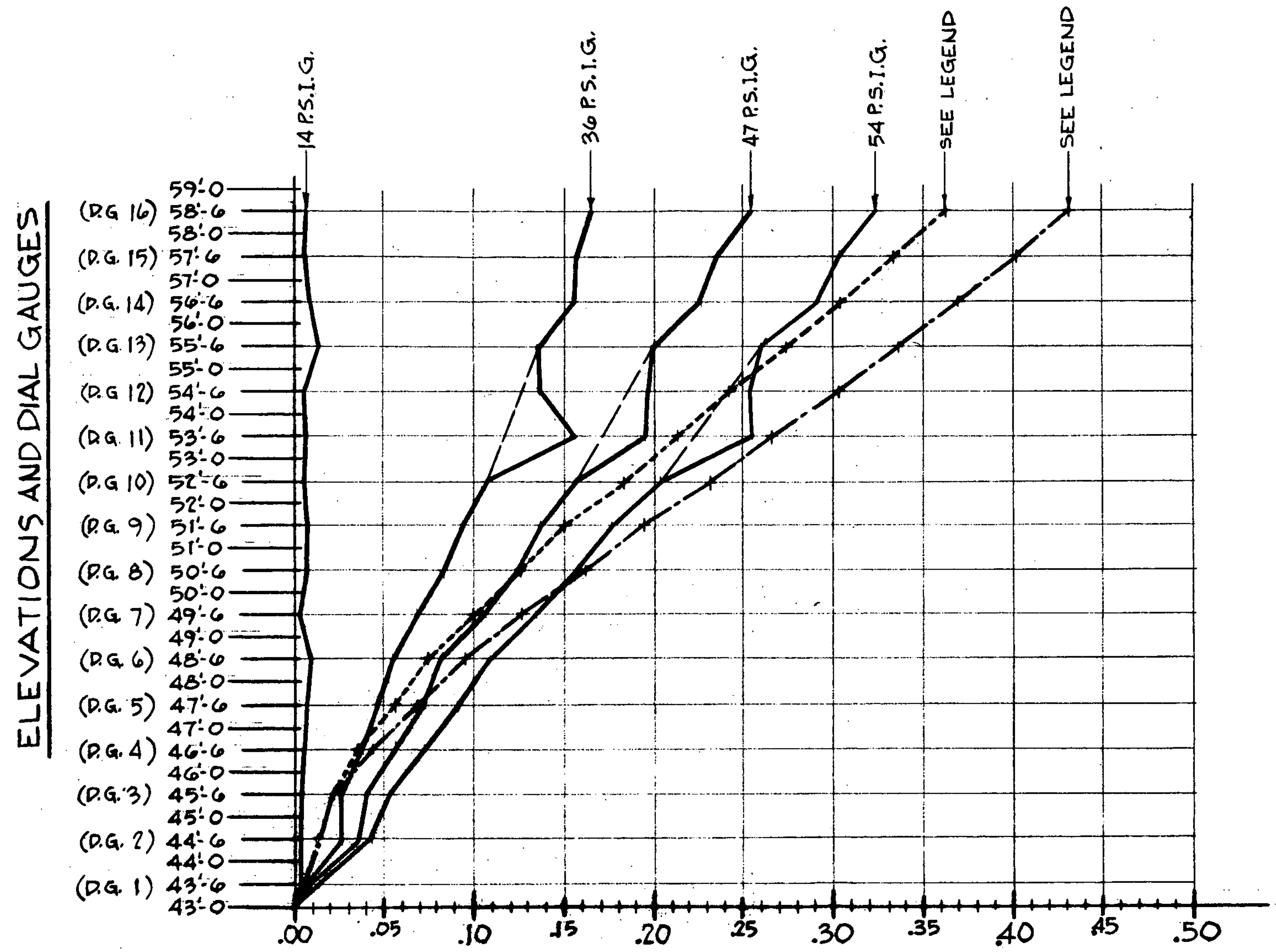
■ STRAIN GAUGES (SG)

*FIGURE 3*
*EQUIPMENT HATCH*
*RE-BAR INSTRUMENTATION*




RADIAL DEFLECTION (INCHES)
AT ELECTRICAL PENETRATION TUNNEL
(AZIMUTH 230°)

NOTE:
D.G. 12 - BAD GAGE




RADIAL DEFLECTION (INCHES)
AT SHIELD WALL AREA
(AZIMUTH 290°)

NOTE:
D.G. 11 - BAD GAGE

*LEGEND:*

- - - - - - THEORETICAL DEFLECTION @ 54 P.S.I. (UNCRACKED CONCRETE @ BASE)

— - — THEORETICAL DEFLECTION @ 54 P.S.I. (CRACKED CONCRETE)

——— ACTUAL DEFLECTION MEASURED DURING PRESSURIZATION

*FIGURE 5*
*RADIAL DEFLECTIONS*
*NEAR BASE OF CONTAINMENT BUILDING*
*DIAL GAUGES*

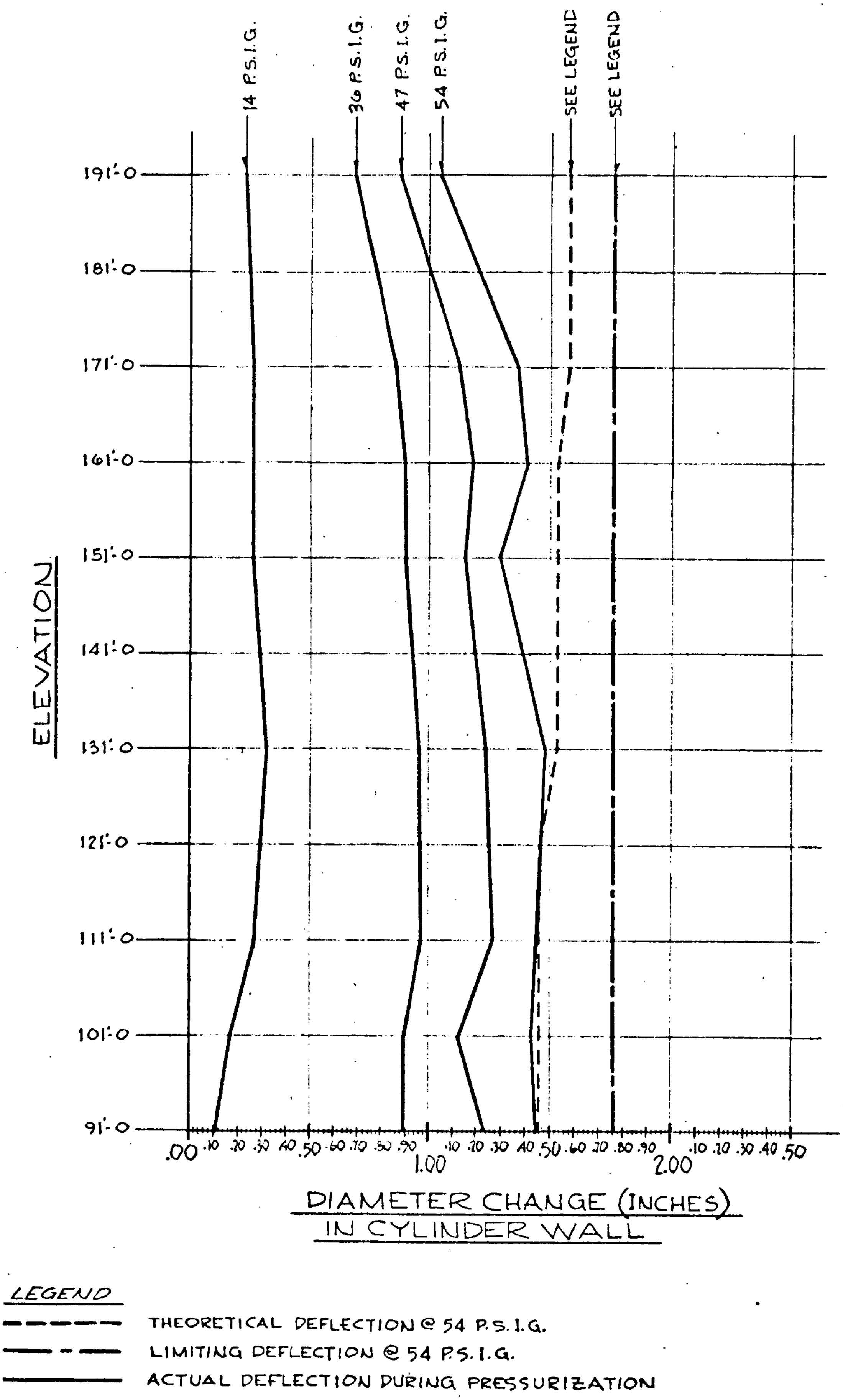



FIGURE 6
DIAMETER CHANGE OF
CYLINDER WALL

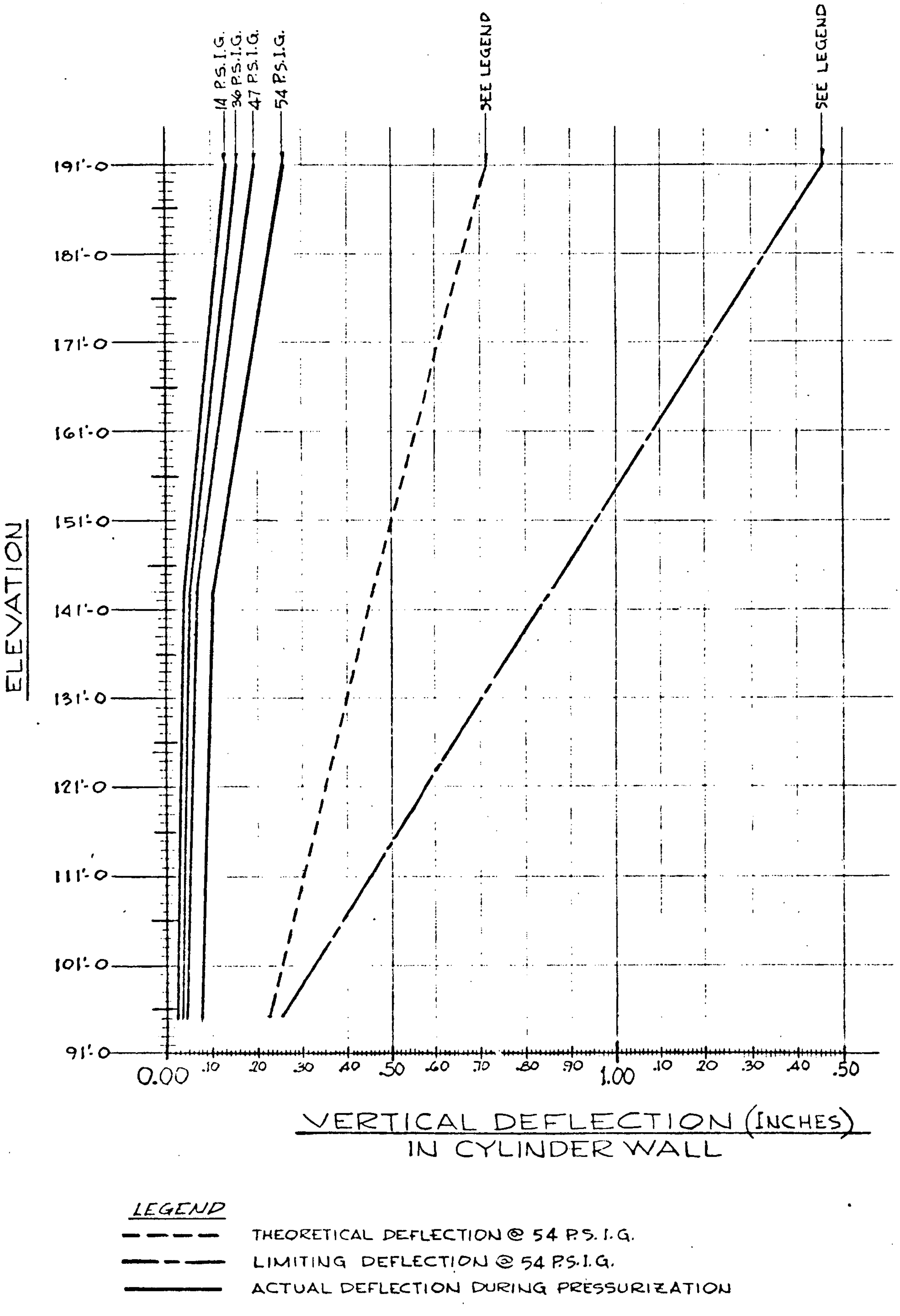
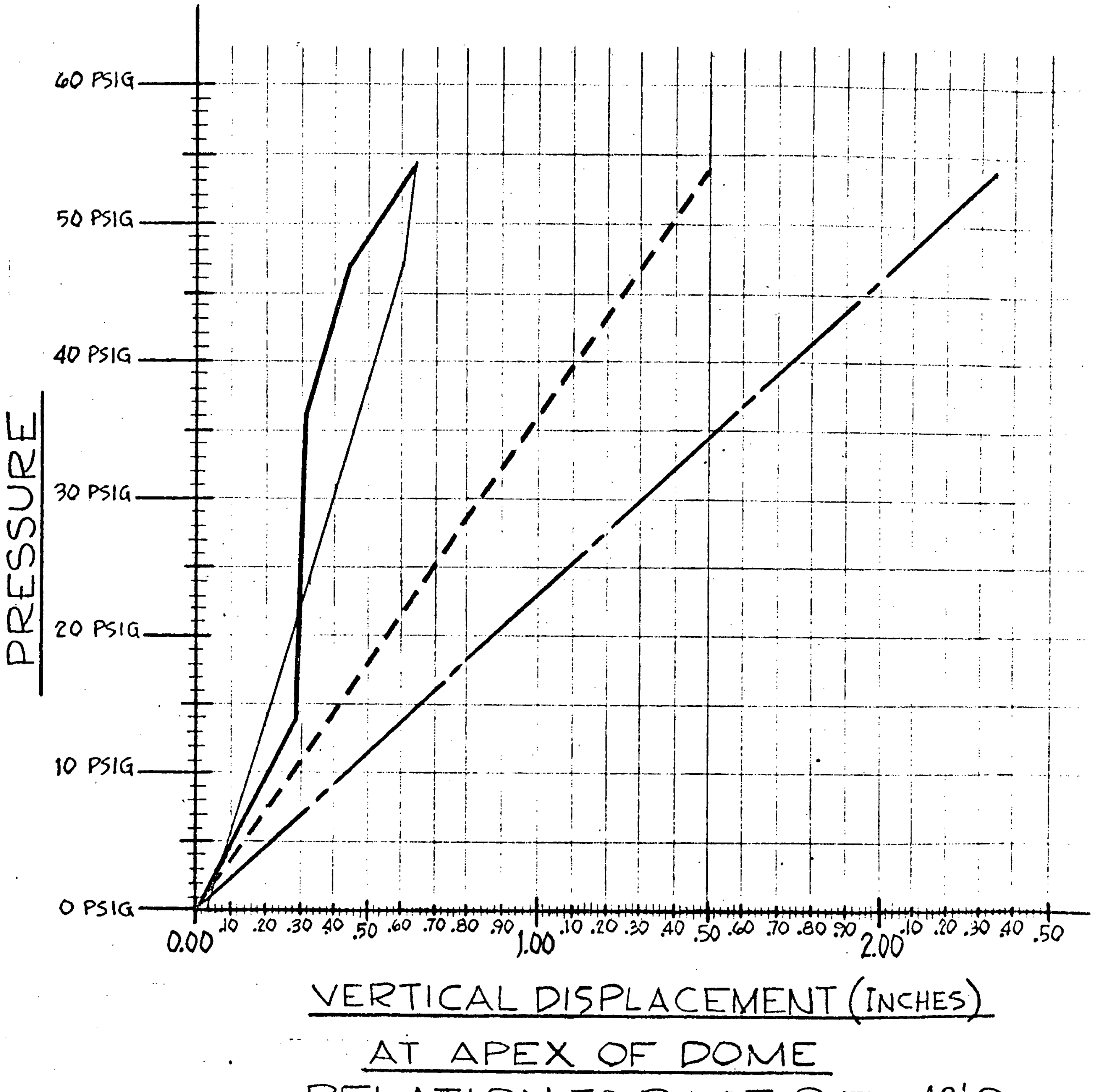



FIGURE 7
SHEET 1 OF 2
VERTICAL DEFLECTIONS
INVAR WIRE GAUGES




*LEGEND*

- - - - THEORETICAL DEFLECTION } BASED ON CRACKED CONC.
—— - —— LIMITING DEFLECTION } BASED ON CRACKED CONC.
——— ACTUAL DEFLECTION DURING PRESSURIZATION } UNCRACKED
——— ACTUAL DEFLECTION DURING DEPRESSURIZATION } UNCRACKED

*FIGURE 7*
*SHEET 2 OF 2*
*VERTICAL DEFLECTION*

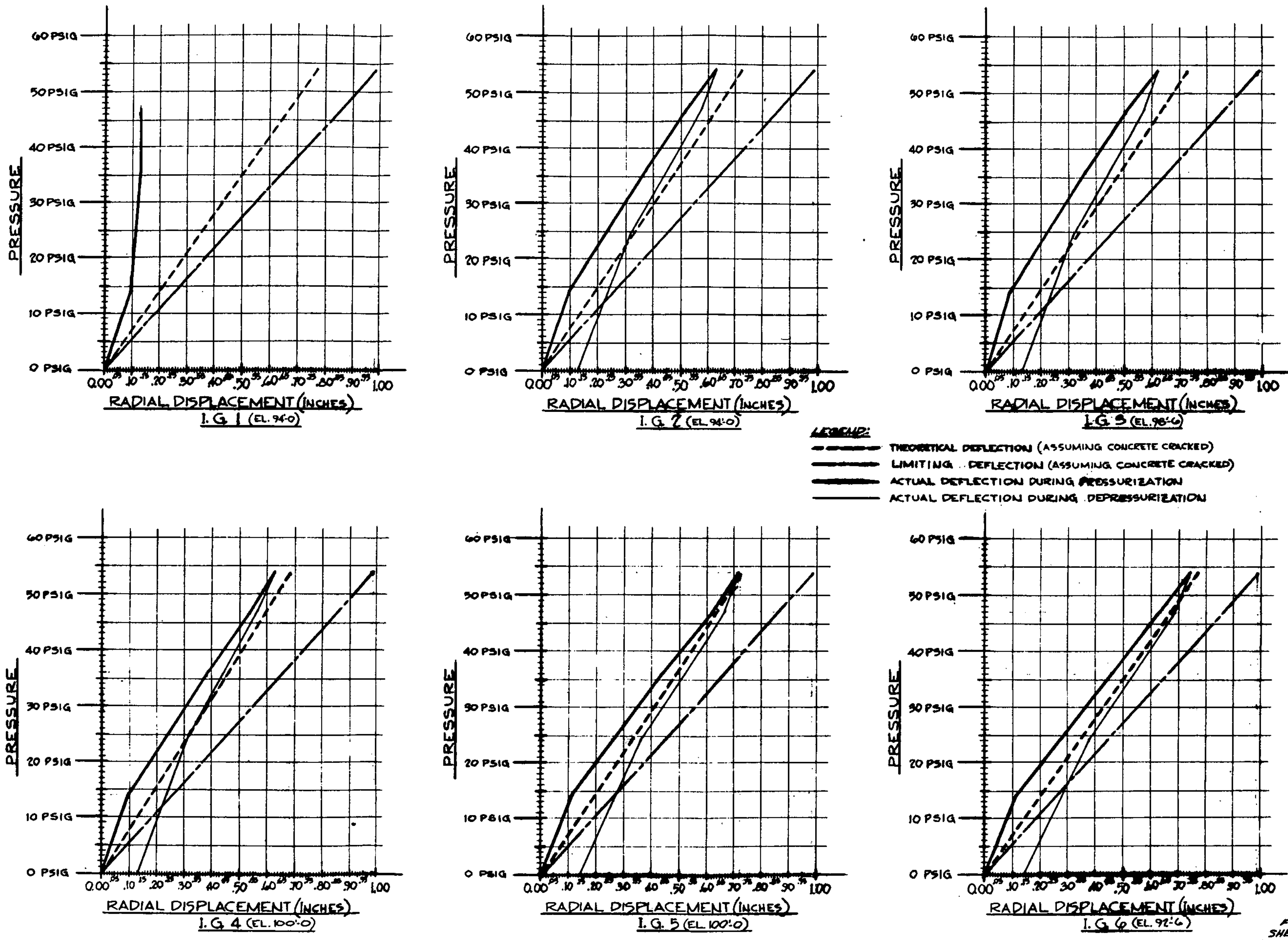
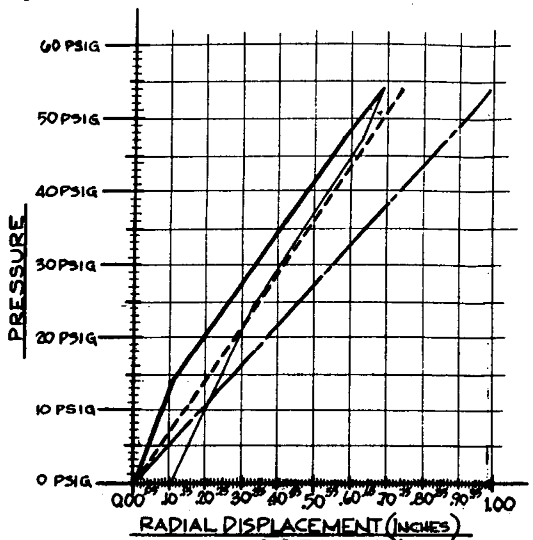
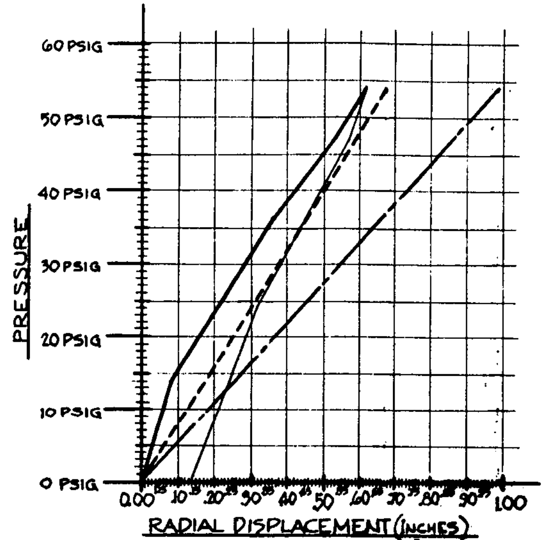


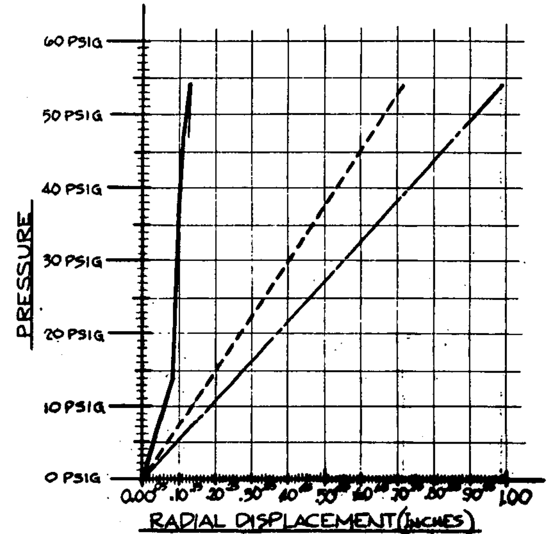

FIGURE 8
SHEET 1 OF 3
EQUIPMENT HATCH AREA
RADIAL GROWTH



I.G 7 (EL. 116'-6)

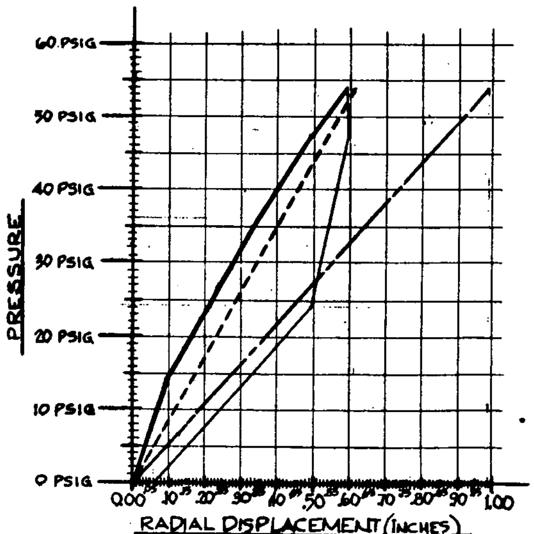


I.G 8 (EL. 110'-6)

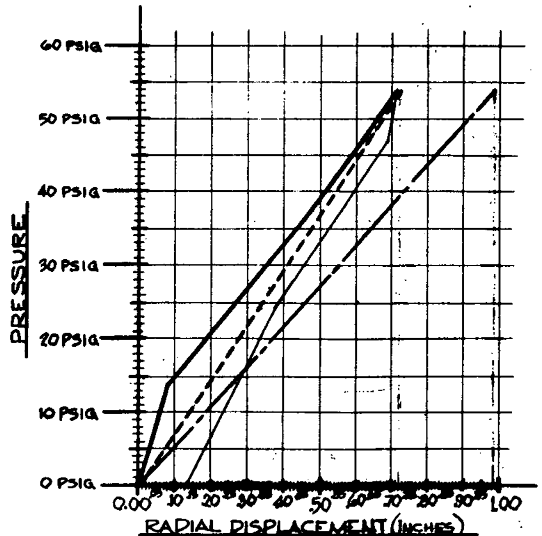


I.G 9 (EL. 106'-6)

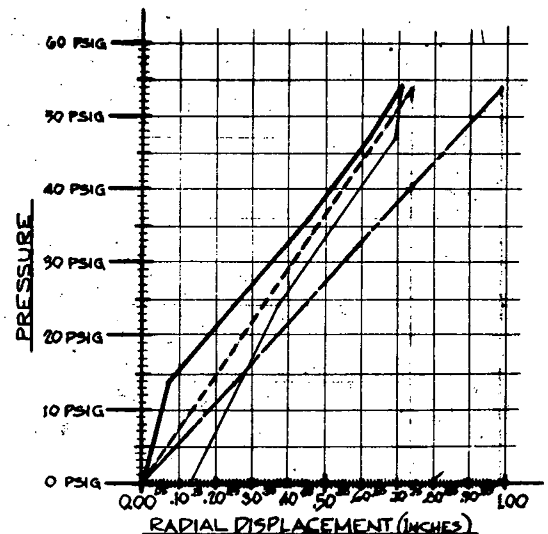
LEGEND:
- THEORETICAL DEFLECTION (ASSUMING CONCRETE CRACKED)
- LIMITING DEFLECTION (ASSUMING CONCRETE CRACKED)
- ACTUAL DEFLECTION DURING PRESSURIZATION
- ACTUAL DEFLECTION DURING DEPRESSURIZATION



I.G 10 (EL. 106'-6)

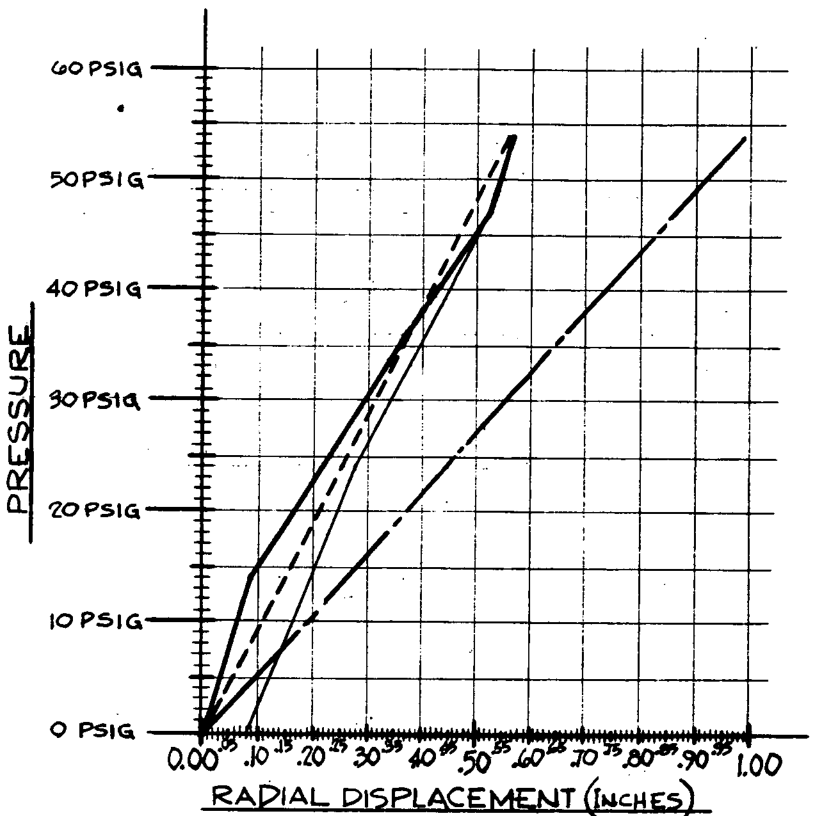


I.G 11 (EL. 110'-6)

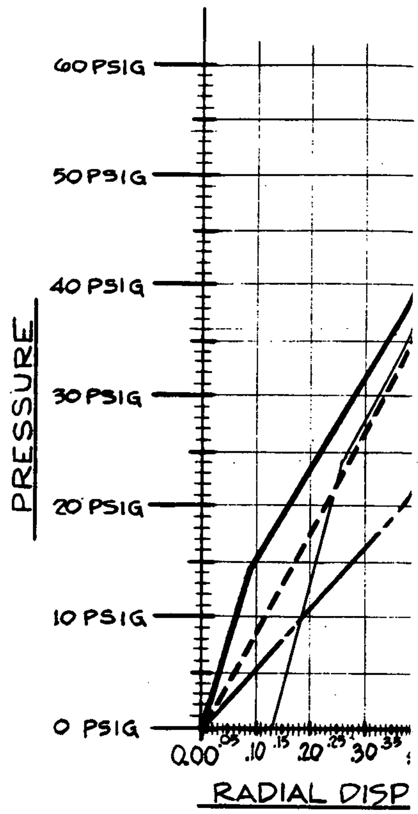


I.G 12 (EL. 116'-6)

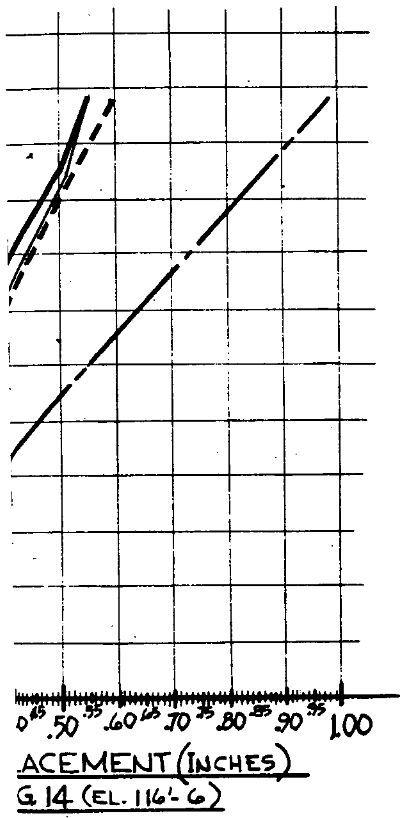
FIGURE 8
SHEET 2 OF 3
EQUIPMENT HATCH
RADIAL GROWTH

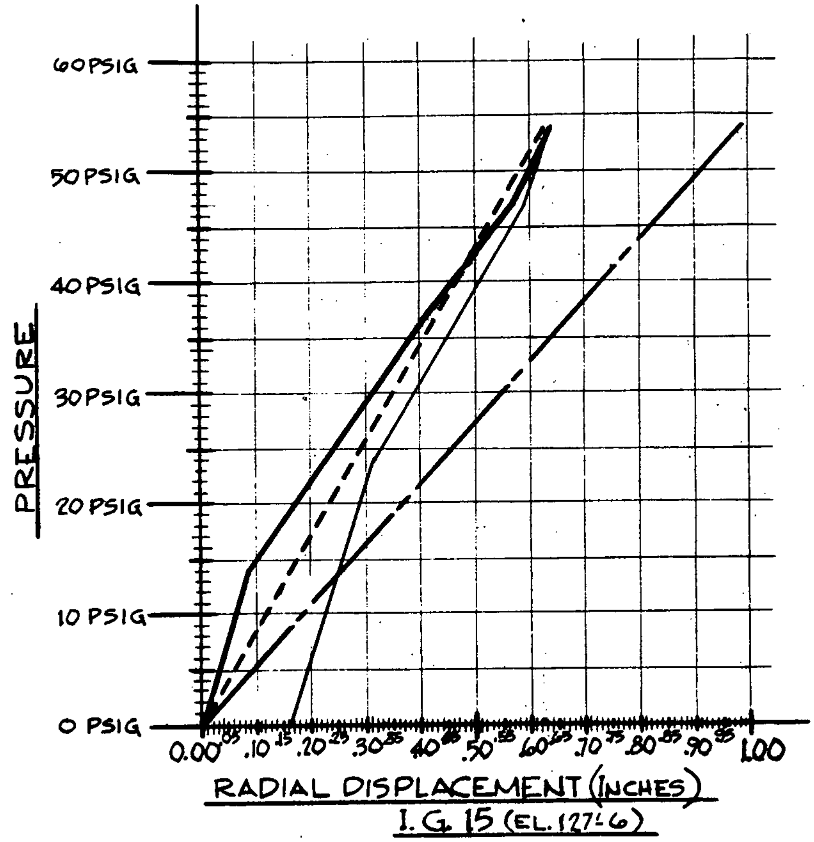



I.G. 13 (EL. 110'-6)




I.




*LEGEND:*

- — — — — THEORETICAL DEFLECTION (ASSUMING CONCRETE CRACKED)
- ——— — LIMITING DEFLECTION (ASSUMING CONCRETE CRACKED).
- ▬▬▬ ACTUAL DEFLECTION DURING PRESSURIZATION
- ——— ACTUAL DEFLECTION DURING DEPRESSURIZATION

*FIGURE 8*
*SHEET 3 OF 3*
*EQUIPMENT HATCH*
*RADIAL GROWTH*

Do
Not
Film

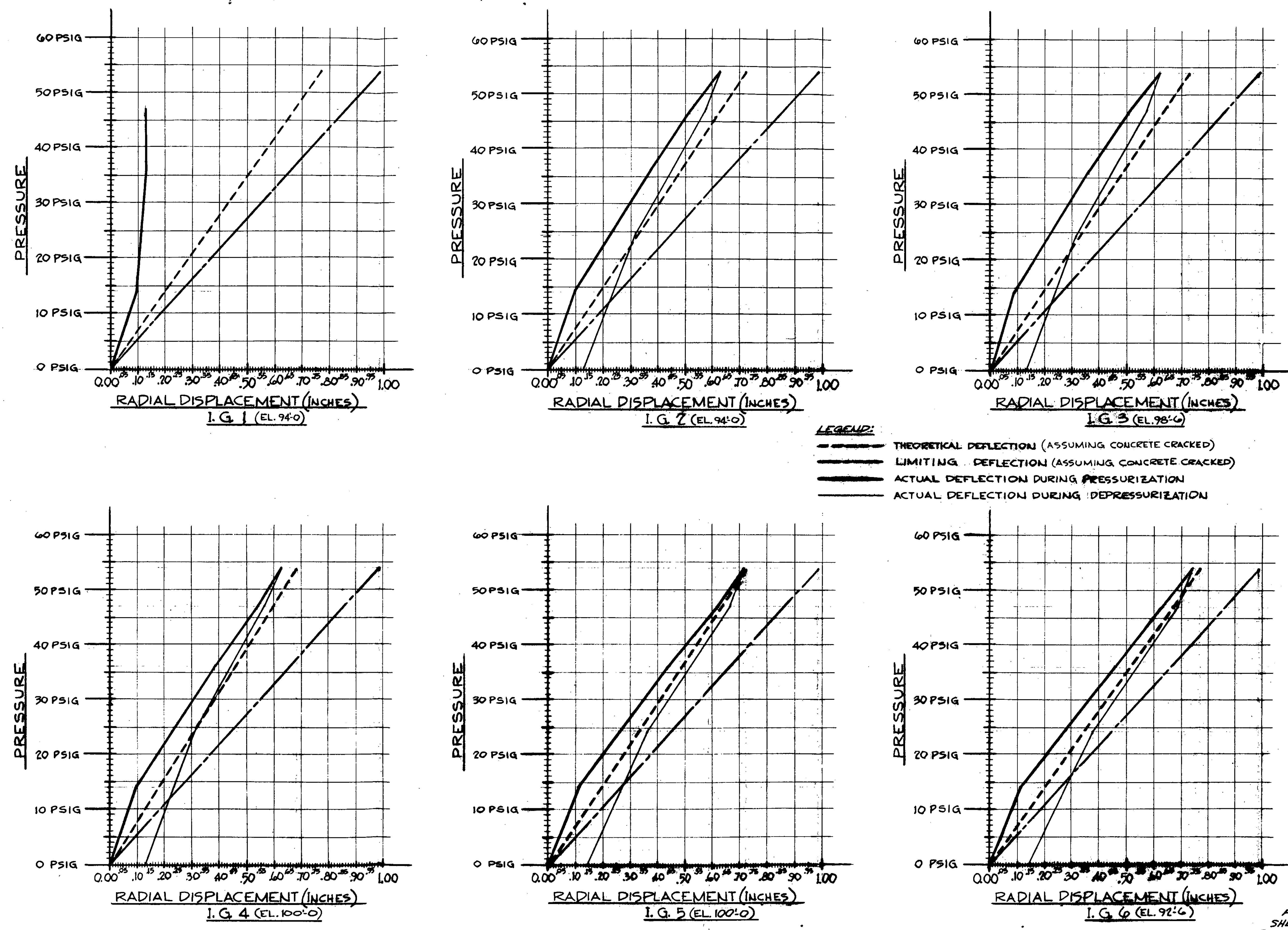



FIGURE 8
SHEET 1 OF 3
EQUIPMENT HATCH AREA
RADIAL GROWTH

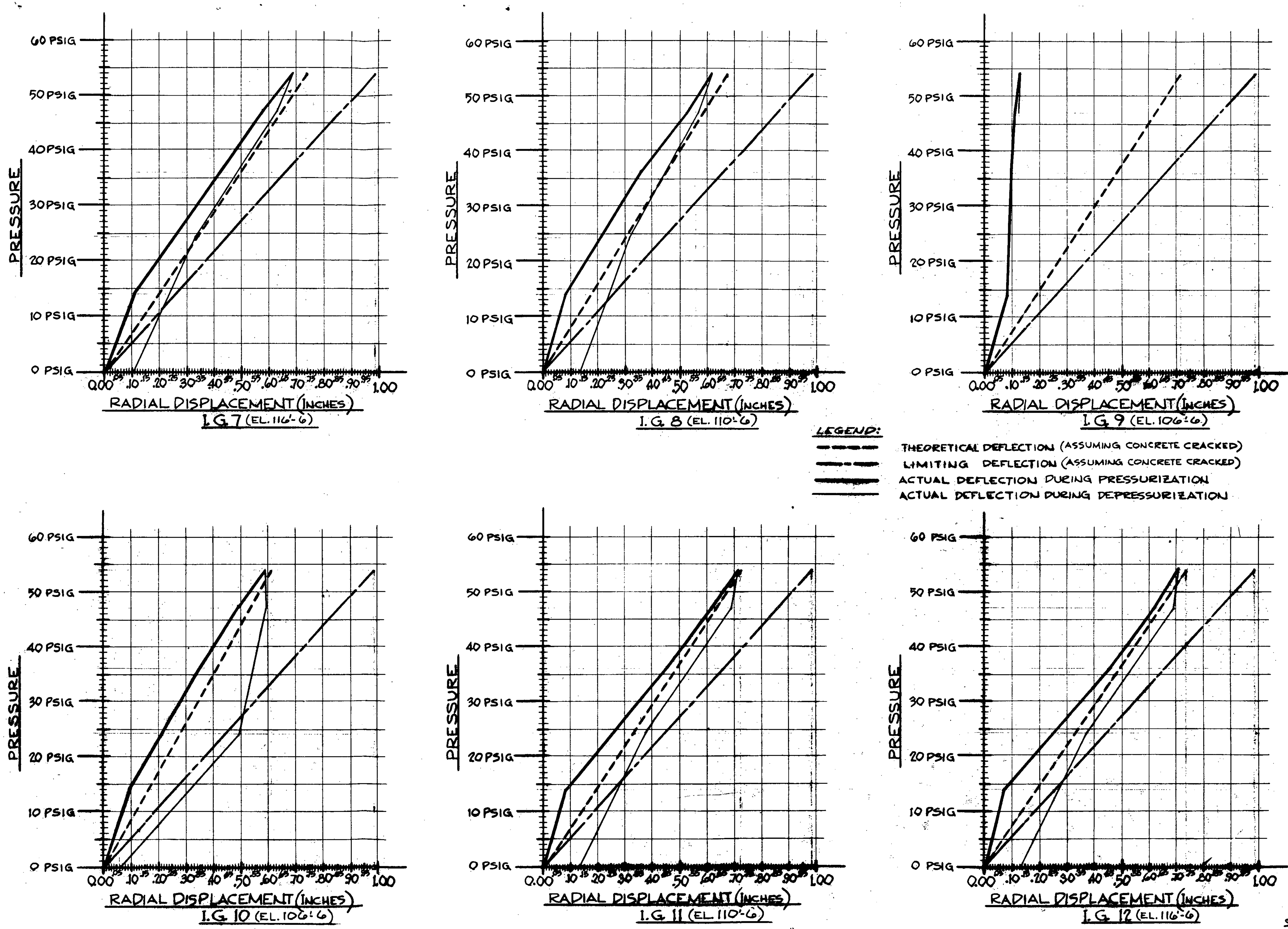



FIGURE 8
SHEET 2 OF 3
EQUIPMENT HATCH
RADIAL GROWTH

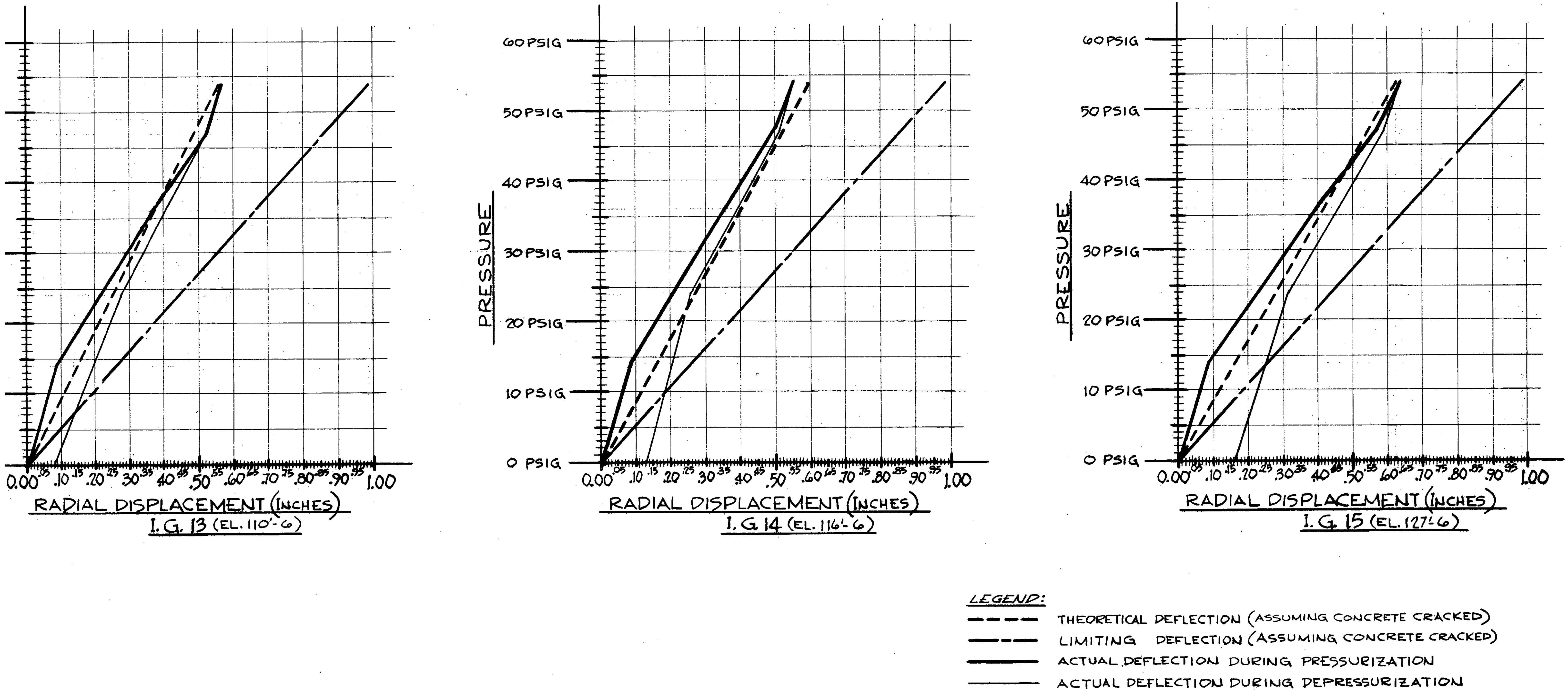



FIGURE 8
SHEET 3 OF 3
EQUIPMENT HATCH
RADIAL GROWTH

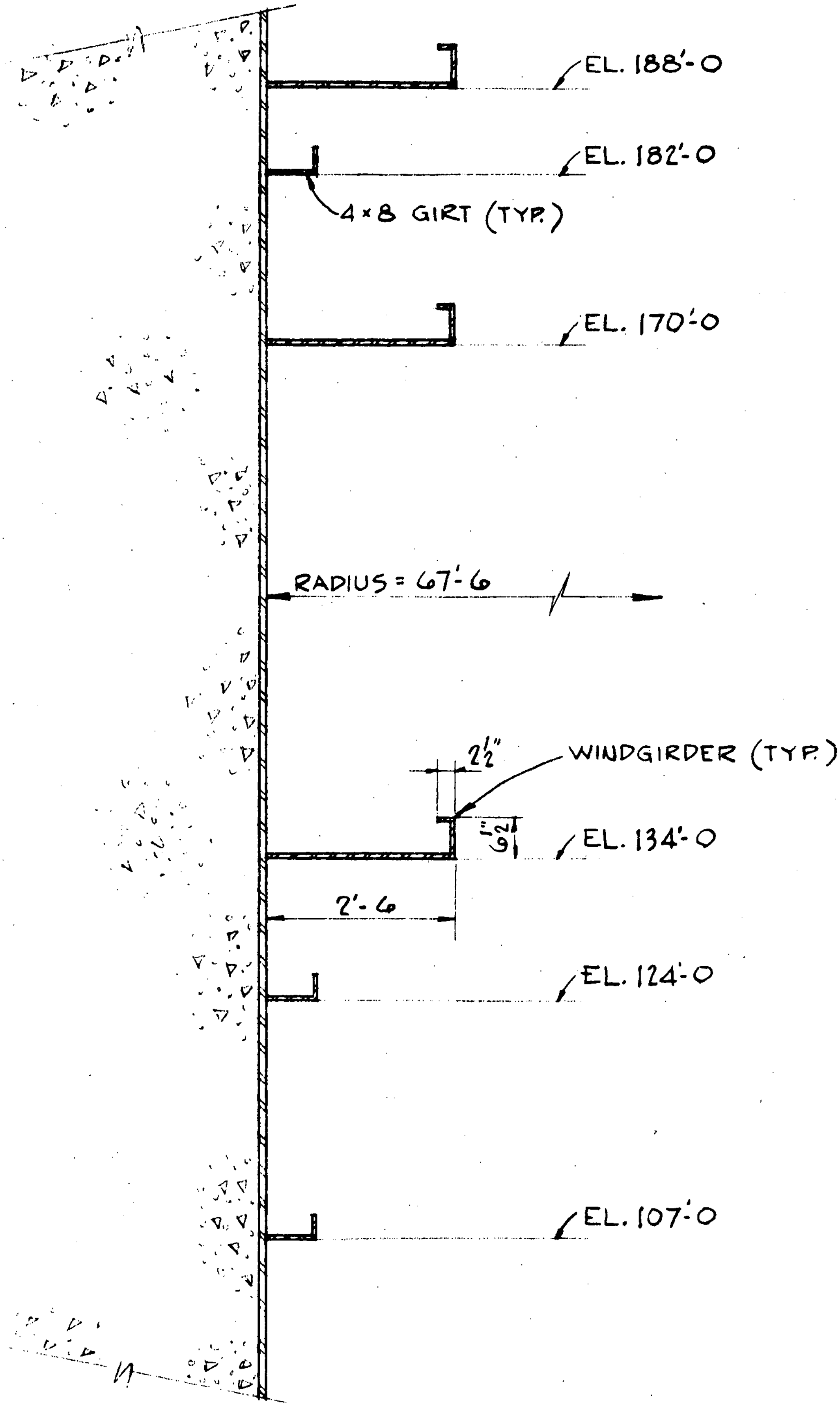



FIGURE 9
WINDGIRDERS ON INSIDE
OF CONTAINMENT LINER

UNITED ENGINEERS & CONSTRUCTORS INC.

PHILADELPHIA, PENNSYLVANIA 19105

# SPECIFICATION

for

# STRUCTURAL INTEGRITY

# TEST OF CONTAINMENT STRUCTURE

for

WESTINGHOUSE ELECTRIC CORPORATION

INDIAN POINT GENERATING STATION - UNIT NO. 2

CONSOLIDATED EDISON COMPANY OF NEW YORK

Date: June 24, 1968
Rev: September 26, 1969
Rev: November 7, 1968
Rev: June 10, 1969

Spec. No. 9321-01-5-6

WORK NOT INCLUDED (Continued)

4. Furnish and install liner insulation.

5. Furnishing and installing pressurization equipment and pressurizing containment.

6. Integrated leak test.

7. Fabrication and installation of supports pad etc.

8. Provide penetration with pigtails for strain gauge connections.

GENERAL

1. The tests will be performed when the containment structure is under the action of 0, 18, 36, 47, 54, 47, 18,~~4~~0 psig internal pressure. The strains and deformations shall be recorded at each of these pressures and the corresponding stresses calculated for the reinforcing and liner at each of these pressures. Time for pressurization and return to 0 psig is estimated as six (6) days.

2. Personnel other than those directly involved in the tests shall be excluded from the containment area during the pressure test. Test personnel are allowed to be at the outer surface of the containment while the structure is at pressures where measurements are recorded.

   The surface of the containment shell shall be 100% inspected prior to pressurization to establish any initial cracks, 100% visual inspection shall also be performed by this subcontractor to insure no local distress and to extablish crack patterns when the containment is pressurized to 36 psi.

   Before testing starts the following areas shall be inspected and cracks located and measured before these areas are whitewashed by Others.

   a) Quadrant of "boss" around Equipment Hatch and Personnel Lock.

   b) 10' width between elevation 43'-0" and elevation 73'-0".

   At 47 psig detailed measurements of crack width and spacing shall be taken to verify that they are within acceptable limits. Calculations of maximum expected measurements will be supplied by the Contractor prior to the test. The Subcontractor shall examine these locations in detail and locate and record any existing cracks.

   A mobile crane with an observation bucket attached will be provided by the contractor for the subcontractor's use in the above.

3. The method of attachment, placement and cable routing of all temporary gauges, junction boxes, cables, jigs, fixtures and etc., to any part of the containment structure, access ways, permanent structures or equipment shall be subject to the approval of the contractor.

GENERAL (Continued)

All reinforcing strain gauges shall be attached to the reinforcing bars indicated on the drawings.

4. Instrumentation shall have capability of measuring strains from 0 to .003 in/in. with accuracy of ± .00003 in/in. Prior to the test, the Subcontractor will be supplied with calculations predicting anticipated strains.

5. Instrumentation shall be chemically inert to concrete and shall remain functional after 6 months of installation. Means of accommodating above shall be subject to contractor's approval.

6. Since the pressurization of the structure will be performed by Others, the Subcontractor shall be required to coordinate his activities with the Subcontractor pressurizing the building.

7. Each gauge and redundant gauge shall be clearly marked and tagged with identifying number relating the number to the location in the structure.

8. All equipment used shall be checked and temperature recorded prior to taking actual measurements and the percent errors recorded and corrected in measurements taken during containment pressurization.

9. Temperature recording shall be taken during containment pressurization and containment measurements and corrections made from base established prior to containment pressurization.

10. Subcontractor shall prepare in detail and submit to the contractor for approval, a procedure outlining how all data is to be obtained, recorded and reduced to final form.

11. A minimum of 10% of all readings shall be reduced, interpreted and evaluated at the time of testing to insure that acceptable data is being obtained. At least 90% of all data taken must be valid data.

# ADDENDUM NO. 1

to

## SPECIFICATION NO. 9321-01-5-6

for

## STRUCTURAL INTEGRITY TEST OF CONTAINMENT STRUCTURE

United Engineers & Constructors
1401 Arch Street
Philadelphia, Pennsylvania 19105

Date: March 23, 1970

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Page 2 General Item No. 1

Revise first sentence to read:

"The tests shall be performed when the Containment structure is under the action of 0, 14, 36, 47, 54, 47, 23.5 and 0 psig internal pressure."

ADDENDUM NO. 2

to

SPECIFICATION NO. 9321-01-5-6

for

STRUCTURAL INTEGRITY TEST OF CONTAINMENT STRUCTURE

United Engineers & Constructors Inc.
Philadelphia, Pennsylvania 19105

Date: August 19, 1970

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Page 2 - General - Item No. 1

After last sentence add:

Both the concrete and liner shall be visually inspected after the test to insure there is no visual distortion of the liner plate and to determine the size and location of any residual concrete cracks.

Page 2 - General - Item No. 2

Revise the second paragraph to read:

The surface of the containment shell shall be 100% inspected with binoculars prior to pressurization to establish any initial cracks. Any significant cracks shall be documented and their behavior carefully observed during the test. Significant cracks shall be measured by the Subcontractor before and during the test if required to do so by the engineer. One hundred percent (100%) visual inspection shall also be performed by this subcontractor to insure no local distress and to establish crack patterns when the containment is pressurized to 36 psi.

ADDENDUM NO. 3

to

SPECIFICATION NO. 9321-01-5-6

for

STRUCTURAL INTEGRITY TEST OF CONTAINMENT STRUCTURE

United Engineers & Constructors Inc.
Philadelphia, Pennsylvania 19105

Issue For W Approval: October 23, 1970
Issue Date: December 15, 1970

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Page 2 - General - Item No. 2

Revise the second paragraph of the specification and the second paragraph of Addendum No. 2 dated August 19, 1970 to read:

"The surface of the Containment shell shall be 100% visually inspected prior to pressurization by the Contractor to establish any initial cracks. Any significant cracks shall be documented, the area surrounding the cracks whitewashed and their behavior carefully observed during the test. Significant cracks shall he measured by the Subcontractor before and during the test if required to do so by the engineer. A visual inspection shall also be performed by this Subcontractor to establish and document initial crack patterns (36, 47, or 54 psi depending on when initial crack patterns first appear)."

ADDENDUM NO. 4

to

SPECIFICATION NO. 9321-01-5-6

for

STRUCTURAL INTEGRITY TEST OF CONTAINMENT STRUCTURE

United Engineers & Constructors Inc.
Philadelphia, Pennsylvania 19105

Date: December 15, 1970

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Under WORK INCLUDED

Add Item No. 9

"Provide time sharing computer installation for reduction of data from remote recorders."

Under GENERAL

Add Item No. 12

"All gauges recording strains or deformations shall be zeroed while the interior of the Containment is at ambient temperature and again when the test temperature of 90°F has been reached. The 90°F reading shall provide the zero basis for test results."

# APPENDIX B

"CRITERIA OF STRUCTURAL INTEGRITY
OF
CONTAINMENT STRUCTURE DURING
STRUCTURAL PROOF TEST"

CRITERIA OF ACCEPTANCE OF STRUCTURAL INTEGRITY OF CONTAINMENT STRUCTURE DURING STRUCTURAL PROOF TEST

PURPOSE

To provide assurance of structural adequacy, the Indian Point Unit No. 2 Containment structure will be pressurized and various measurements will be taken to evaluate structural behavior. Testing will be performed under UE&C P.O. 9321-01-5-6.

The following lists specific items to be measured, pressure at which measurement will be taken, and acceptable deviation from anticipated values.

Drawing 9321-F-1053

| IDENT. | PRESSURE* | CALC. STRAIN** x $10^{-3}$ | ACCEPTANCE STRAIN x $10^{-3}$ | MEAS. STRAIN x $10^{-3}$ |
|---|---|---|---|---|
| SG-1 | 54 psig | .373 | 1.379 | --- |
| SG-2 | | .920 | 1.430 | .793 |
| SG-5 | | .761 | 1.430 | -.069 (-.034) |
| SG-7 | | .754 | 1.430 | .413 |
| SG-8 | | -.025 | 1.430 | .069 (.069) |
| SG-9 | | .426 | 1.230 | .069 |
| SG-10 | | .240 | 1.430 | -.034 (-.034) |
| SG-11 | | .220 | 1.350 | .069 (.034) |
| SG-12 | | .807 | 1.399 | .655 |
| SG-13 | | .735 | 1.430 | .413 (.413) |
| SG-17 | | .156 | 1.390 | .034 |
| SG-18 | | .651 | 1.350 | .034 (.104) |
| SG-19 | | .585 | 1.430 | .069 |
| SG-20 | | .582 | 1.230 | .034 (-.138) |
| SG-21 | | .117 | 1.430 | .034 |
| SG-22 | | .235 | 1.385 | .069 |
| SG-24 | | .906 | 1.500 | .861 |
| SG-25 | | .166 | 1.450 | .138 |
| SG-26 | | .402 | 1.459 | .276 (.207) |
| SG-27 | | .947 | 1.500 | .690 (.769) |
| SG-29 | | .868 | 1.500 | --- |
| SG-30 | | .290 | 1.468 | .725 |
| SG-31 | | .897 | 1.500 | .379 |
| SG-32 | | .303 | 1.468 | .104 (.104) |
| SG-33 | | .708 | 1.430 | -.413 |
| SG-34 | | .511 | 1.430 | -.526 |
| SG-35 | | .422 | 1.430 | -.069 (-.104) |
| SG-36 | | .260 | 1.402 | -.552 (-.759) |

* 0, 14, 36, 47, 54, 47, 24.4, 0 psig

** Value given for 54 psig; Factor for others (after concrete cracks)

--- Indicates strain gages inoperative during test

() Indicates reading on redundant gage

Drawing 9321-F-1053

| IDENT. | PRESSURE* | CALC. STRAIN** x $10^{-3}$ | ACCEPTANCE STRAIN x $10^{-3}$ | MEAS. STRAIN x $10^{-3}$ |
|---|---|---|---|---|
| SG-37 | 54 psig | .590 | 1.170 | -.448 |
| SG-38 | | .610 | 1.170 | -.689 (-.552) |
| SG-43 | | .364 | 1.430 | .448 (.586) |
| SG-44 | | .664 | 1.430 | .138 (.276) |
| SG-46 | | .172 | 1.411 | .069 |
| SG-47 | | .325 | 1.414 | .034 (.034) |
| SG-48 | | .376 | 1.416 | .034 (.034) |
| SG-49 | | .375 | 1.410 | .241 |
| SG-50 | | .375 | 1.410 | .379 |
| SG-51 | | .329 | 1.409 | .241 (.276) |
| SG-52 | | .334 | 1.430 | .138 (.207) |
| SG-53 | | .359 | 1.430 | - .241 (-.172) |
| SG-54 | | .505 | 1.430 | .276 |
| SG-55 | | .445 | 1.350 | -.034 |
| SG-56 | | .445 | 1.350 | -.034 (.069) |
| SG-57 | | .445 | 1.350 | .034 |
| SG-58 | | .445 | 1.350 | .034 |
| SG-59 | | .445 | 1.350 | .034 |

Drawing 9321-F-1054

| IDENT. | PRESSURE * | CALC. STRAIN** x $10^{-3}$ | ACCEPTANCE STRAIN x $10^{-3}$ | MEAS. STRAIN x $10^{-3}$ |
|---|---|---|---|---|
| SG-1A | 54 psig | -.147 | 1.430 | -.241 (-.241) |
| SG-2A | | 1.319 | 1.350 | .107 |
| SG-3A | | .179 | .888 | .107 |
| SG-8A | | .736 | 1.388 | --- |
| SG-15A | | .091 | 1.510 | -.172 (-.270) |
| SG-16A | | .034 | 1.510 | .172 (.069) |
| SG-19A | | .736 | 1.388 | --- |

Drawing 9321-F-1055

East Side (Sect. A-A)

| IDENT. | ELEV. | CALC. DIAMETER CHANGE (in) | ACCEPTANCE DEFLECTION |
|---|---|---|---|
| I.G. 16 | 91'-0" | .73 (Radial) | .88 |
| I.G. 17 | 101'-0" | .73 (Radial) | .88 |
| I.G. 18 | 111'-0" | 1.46 | 1.76 |
| I.G. 19 | 121'-0" | 1.46 | 1.76 |
| I.G. 20 | 131'-0" | 1.53 | 1.76 |
| I.G. 21 | 141'-0" | 1.53 | 1.76 |
| I.G. 22 | 151'-0" | 1.53 | 1.76 |
| I.G. 23 | 161'-0" | 1.53 | 1.76 |
| I.G. 24 | 171'-0" | 1.58 | 1.76 |
| I.G. 25 | 181'-0" | 1.58 | 1.76 |
| I.G. 26 | 191'-0" | 1.58 | 1.76 |

Equipment Hatch Dia. Change

| CALC. RADIAL DEFLECTION (in) | ACCEPTANCE DEFLECTION | MEAS. DEFLECTION |
|---|---|---|
| .017" | .022" | .0067 |

Vert. Deflection

| IDENT. | ELEV. | CALC. RADIAL DEFLECTION (in) | ACCEPTANCE DEFLECTION |
|---|---|---|---|
| I.G. 29 | 95'-0" | .222 | .250 |
| I.G. 30 | 143'-0" | .459 | .855 |
| I.G. 31 | 191'-0" | .711 | 1.460 |
| I.G. 27 & 28 | 262'-0" | 1.491 | 2.340 |

Drawing 9321-F-1066

Section A-A

| GAUGE NO. @ EQUIP. HATCH | CALC. RADIAL DEFLECTION (in) | ACCEPTANCE DEFLECTION |
|---|---|---|
| IG-1 | .768 | .985 |
| IG-2 | .720 | .985 |
| IG-3 | .727 | .985 |
| IG-4 | .682 | .985 |
| IG-5 | .726 | .985 |
| IG-6 | .768 | .985 |
| IG-7 | .734 | .985 |
| IG-8 | .674 | .985 |
| IG-9 | .713 | .985 |
| IG-10 | .605 | .985 |
| IG-11 | .721 | .985 |
| IG-12 | .731 | .985 |
| IG-13 | .557 | .985 |
| IG-14 | .595 | .985 |
| IG-15 | .625 | .985 |

Section B-B

| ROSETTES @ EQUIP. HATCH | CALC. (HOR) xx | MEASURED (HOR) | MEASURED (VERT) | CALC. VERT. yy |
|---|---|---|---|---|
| R-5 | .872 | 1.087 | .878 | .387 |
| R-6 | .933 | 1.082 | .506 | 0 |
| R-7 | .758 | .850 | -.095 | .184 |
| R-8 | .039 | .215 | .271 | .248 |
| R-9 | .881 | .839 | .471 | .219 |
| R-10 | .945 | .271 | .296 | 0 |
| R-11 | .758 | .231 | .010 | .184 |
| R-12 | .039 | -.525 | -.330 | .248 |

Isolated areas may be overstressed, therefore no limitations are given (within design criteria in Cont. Design Report).

Section C-C

| GAUGE NO. @ ELECT. TUNNEL | CALC. RADIAL DEFLECTION (in) | CRACKED* SECTION |
|---|---|---|
| | Uncracked Section* | |
| DG-1 El. 46'-6" | .035 | .044 |
| DG-2 | .056 | .069 |
| DG-3 | .075 | .096 |
| DG-4 | .100 | .128 |
| DG-5 | .126 | .161 |
| DG-6 | .155 | .195 |
| DG-7 | .182 | .231 |
| DG-8 | .213 | .266 |
| DG-9 | .243 | .302 |
| DG-10 | .273 | .337 |
| DG-11 | .303 | .370 |
| DG-12 | .333 | .401 |
| DG-13 | .362 | .431 |
| DG-14 | .388 | .461 |
| DG-15 | .413 | .492 |
| DG-16 El. 61'-6" | .448 | .522 |

Section D-D

| GAUGE NO. @ PIPE BRIDGE | CALC. RADIAL DEFLECTION* (in) | CRACKED* SECTION |
|---|---|---|
| | Uncracked Section | |
| DG-1 | .004 | .004 |
| DG-2 | .013 | .013 |
| DG-3 | .021 | .021 |
| DG-4 | .035 | .044 |
| DG-5 | .056 | .069 |
| DG-6 | .075 | .096 |
| DG-7 | .100 | .128 |
| DG-8 | .126 | .161 |
| DG-9 | .155 | .195 |
| DG-10 | .182 | .231 |
| DG-11 | .213 | .266 |
| DG-12 | .243 | .302 |
| DG-13 | .273 | .337 |
| DG-14 | .303 | .370 |
| DG-15 | .333 | .401 |
| DG-16 El. 58'-6" | .362 | .431 |

*These numbers serve as an upper and lower limit of Containment Deflections.

Section E-E

| IDENT. | ROSETTE ELEV. | $\epsilon_{xx}$ (HOR.) | $\epsilon_{yy}$ (VERT.) | MEASURED** (HOR.) | STRAINS** (VERT.) |
|---|---|---|---|---|---|
| R-1 | 46'-6" | .040 | .239 | .557 (.400) | .674 (.612) |
| R-2 | 118'-6" | .875 | .405 | .830 (Yield) | .468 (Yield) |
| R-3 | 190'-6" | 1.0 | .570 | .678 (.907) | .566 (.631) |
| R-4 | 191'-6" | .728 | .510 | .750 (.926) | -.052 (.589) |

**Local yielding of liner during pressure test is acceptable, since it will be loaded in compression during accident conditions and tension during the test. In addition, although instruments will be zeroed not to reflect temperature, the liner will be in compression due to the test temperature increase.

NOTE: Local spalling of concrete due to inadequate cover over reinforcing is acceptable. These areas shall be patched in accordance with approved procedures.

# APPENDIX C

## GROSS DEFORMATION ACCEPTANCE CRITERIA

GROSS DEFORMATION ACCEPTANCE CRITERIA 9/8/70

The following criteria are proposed as a measure of Containment structural performance during and after the strength test at 54 psig which represents 115% of the design pressure of 47 psig:

1. The increase in Containment diameter shall not exceed 1.56 in. + 13 percent, or 1.76 in. for invar tape measurements between El. 91'-0" and El. 191'-0" when measured as an average of all readings. This measurement is limited by the specified minimum yield stress of the Containment Liner which is 32,000 psi compared to 60,000 psi yield in the rebar.

2. Equipment Hatch distortions shall show the same trend as computed values and the maximum radial displacement shall not exceed .720" + 30% or .935".

3. The expected total vertical elongation of the Containment wall measured at El. 191'-0" shall not exceed .71 inches + 20 percent or .85 inches.

4. The maximum concrete crack width shall not exceed .035" averaged over a 20'-0" length of crack.

5. The average crack spacing for both the horizontal and vertical directions of the Containment cylindrical wall shall not be less than 15 inches. These two (2) averages shall exclude crack patterns in areas affected by discontinuities such as penetrations through the Containment wall.

GROSS DEFORMATION ACCEPTANCE CRITERIA 9/8/70 (continued)

6. At depressurization all gauge readings are to return to zero ± 10 percent of the maximum reading recorded at 54.0 psig.

Both concrete and liner will be visually inspected after the test. There shall be no visual distortion of the liner plate in excess of values presently recorded in construction surveys. Only very small, hairline cracks in the concrete ( .010") will be considered acceptable. However, it is fully expected there will be small residual cracks as a result of shrinkage in the concrete.

If any of the foregoing criteria is not met, an engineering evaluation of the test results will be performed to determine the reasons for failure to meet the criteria and the course of action required, if any.

Prior to the test, a table of predicted strains, deformations, crack widths and crack spacings will be developed for an internal pressure of 54 psig. These expected measurements will be predicted from the analytical model and are to be used as a basis for verifying satisfactory structural response. Although strain gauges are to be installed on designated areas of the liner and reinforcing, the analytically derived strains will not be used as acceptance figures for the actual values. Values obtained will be analyzed and evaluated to determine magnitude and direction of principal strains. Conclusions concerning the acceptance of the structural response will be based on the six (6) criteria given above.

REFERENCE 1

STRUCTURAL RESPONSE OF SECONDARY CONTAINMENT VESSEL
DURING STRUCTURAL INTEGRITY TEST AT
INDIAN POINT POWER GENERATING STATION UNIT NO. 2
CONSOLIDATED EDISON COMPANY

FOR

WEDCO CORPORATION

BY

WISS, JANNEY, ELSTNER &
ASSOCIATES INC.

# STRUCTURAL RESPONSE OF SECONDARY CONTAINMENT VESSEL DURING STRUCTURAL INTEGRITY TEST AT INDIAN POINT POWER GENERATING STATION UNIT NO. 2 CONSOLIDATED EDISON COMPANY

FOR

WEDCO CORPORATION

Submitted by

WISS, JANNEY, ELSTNER and ASSOCIATES
330 Pfingsten Road
Northbrook, Illinois 60062

April 22, 1971

9134

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### List of Figures and Tables



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Appendix C - Crack Surveys

# STRUCTURAL RESPONSE OF SECONDARY CONTAINMENT VESSEL
# DURING STRUCTURAL INTEGRITY TEST AT
# INDIAN POINT POWER GENERATING STATION UNIT NO. 2
# CONSOLIDATED EDISON COMPANY

FOR

WEDCO CORPORATION

April 22, 1971

## CONTRACTURAL REQUIREMENTS

The structural behavior testing described hereunder was performed during the structural integrity test of the secondary containment vessel, Unit No. 2, Indian Point Generating Station, Consolidated Edison Company. Wiss, Janney, Elstner and Associates were retained by WEDCO Corporation to install the prescribed instrumentation, monitor the response of the instruments, conduct crack surveys prior to and during structural integrity testing, and to report on the results of this structural behavior study.

The location of test instrumentation was planned by United Engineers and Constructors, Inc. The work was conducted in accordance with United Engineers and Constructors specification No. 9321-01-5-6, as modified by subsequent directions required by field conditions. All installation was performed or supervised by WJE personnel. That part of the work normal to their skills (routine installation of electrical lead wire, etc.) was performed by tradesmen.

## OBJECTIVES OF STRUCTURAL TESTING

The instrumentation was planned and installed to serve two purposes. First, the satisfactory response of the structure to specified test pressures would be confirmed; second, the criteria assumed in the structural design would be confirmed, or the measurements would indicate improvements in design criteria for future structures.

## DESCRIPTION OF THE SECONDARY CONTAINMENT VESSEL

The containment structure is a reinforced concrete, right-vertical cylinder with a flat base and hemispherical dome. The sidewalls rise 148 ft from the top of the base mat (Elev. 43 ft 0 in.) to the spring-line of the dome (Elev. 191 ft 0 in.). The sidewalls are 4 ft 6 in. thick and the dome is 3 ft 6 in. thick. The cylinder walls are rigidly connected to the 9 ft thick base mat.

Major discontinuities occur in the structure at the following locations:

A. At Azimuth 60°, thickened boss area around equipment hatch opening, centerline Elev. 101 ft 6 in.

B. At Azimuth 176°, a thickened boss area around the personnel lock, centerline Elev. 83 ft 6 in.

C. At penetrations located in the electrical tunnel and pipe bridge areas. These areas are not thickened.

The interior wall of the containment vessel is lined with a 3/8 in. thick steel plate, continuously welded to form an airtight seal. The liner plate is thickened to 3/4 in. around the equipment hatch.

## TEST PROGRAM

Test instrumentation was located to yield the following information:

1. Radial displacements at the equipment hatch
2. Radial displacements of the wall from the base mat to the springline at Azimuth 315°
3. Radial displacements at a typical penetration area (electrical tunnel)
4. Radial displacements at the base mat (pipe bridge)
5. Vertical growth and dome displacements of the structure
6. Stresses in liner plate around the equipment hatch and along a typical wall section
7. Stresses in reinforcing bars at the temporary opening and in the region of equipment hatch
8. Crack patterns at three locations:
   a. A typical wall section
   b. The discontinuity at the equipment hatch
   c. The discontinuity at the personnel hatch

In addition to the instrumentation above, a continuous visual inspection of the entire structure was made to monitor major cracking which might occur so that such could be evaluated by the design engineers.

## STRAIN GAGE INSTRUMENTATION

Strain gages mounted on reinforcing bars were two-element (temperature-compensation) SR4BLH-type FAET-12C-12S6F, encapsulated gages. The gages were cemented to the prepared bars using epoxy cement. After the lead wires were attached, the installation received a coat of silicone lacquer, an overlay of epoxy, and a final coat of waterproofing compound. Several layers of vinyl plastic electrical tape and several layers of rubberized electrical tape were then used to complete the protective coating.

In spite of extreme installation care and use of best waterproofing techniques, strain gages embedded in concrete are often rendered useless during concrete placement or by moisture. To minimize this loss of data, all strain gages on reinforcing steel were installed in duplicate. By this practice, steel stresses at only 3 places out of 55 were undetermined.

Strain gages attached to the steel liner plate were three-element rosettes SR-4 BLH-type FABR-50D-1286. After the lead wires were attached, the installation was waterproofed using the same techniques described for the reinforcing bars. A three-wire bridge circuit was used on each leg of the rosettes.

## DISPLACEMENT INSTRUMENTATION

Gross deformation measurements at the electrical penetration and the 290° meridian below Elev. 62 ft were obtained using dial gages having one inch of travel and an accuracy of 0.001 in. The dial gages were attached to a temporary support system at both locations (see Fig. 1).

DIAL GAGE INSTALLATION
IN ELECTRICAL TUNNEL

Fig. 1

Gross deformation measurements at the equipment hatch, radial displacements from Elev. 91 to 191, and all vertical displacements were obtained using invar wire extensometers.

The invar wire extensometers were located entirely inside the structure, and were connected to an external power supply and read-out equipment by electrical leads which extended through penetrations in the cylinder wall.

Each extensometer consisted of an invar wire spanning the distance to be measured. One end (the "dead" end) was fixed to the steel liner, and the "live"end of the wire was attached to a spring-loaded frame which was rigidly attached to the liner plate in the direction of measurement. Deformations of the structure were measured thus with a linear potentiometer mounted in each frame. (The spring and potentiometer arrangement is shown by Fig. 2.) The potentiometers are of the infinite resolution type with a total resistance of about 2000 ohms. A constant voltage of 2.00 volts was applied to each potentiometer. At each measurement, voltage is measured between the movable contact point and each end of the resistor. The voltage changes are recorded on the external read-out system.

Prior to shipment to the field, all the frames were calibrated in our laboratories. As a further check, calibrations were obtained on a number of the extensometers after they were installed in the structure just prior to the test. After completion of testing, a number of the frames were recalibrated in the laboratory to insure that the original calibration had not changed.

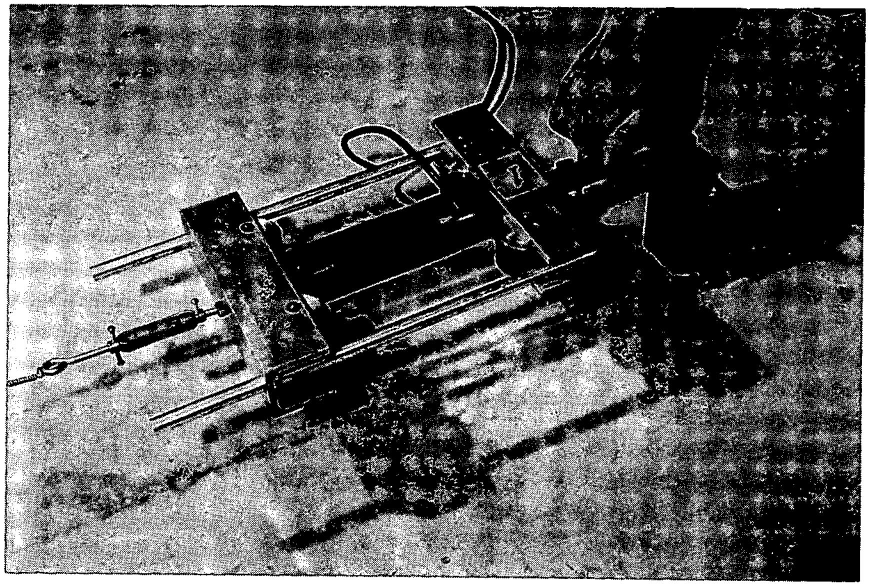


FIGURE 2

INVAR WIRE EXTENSOMETER

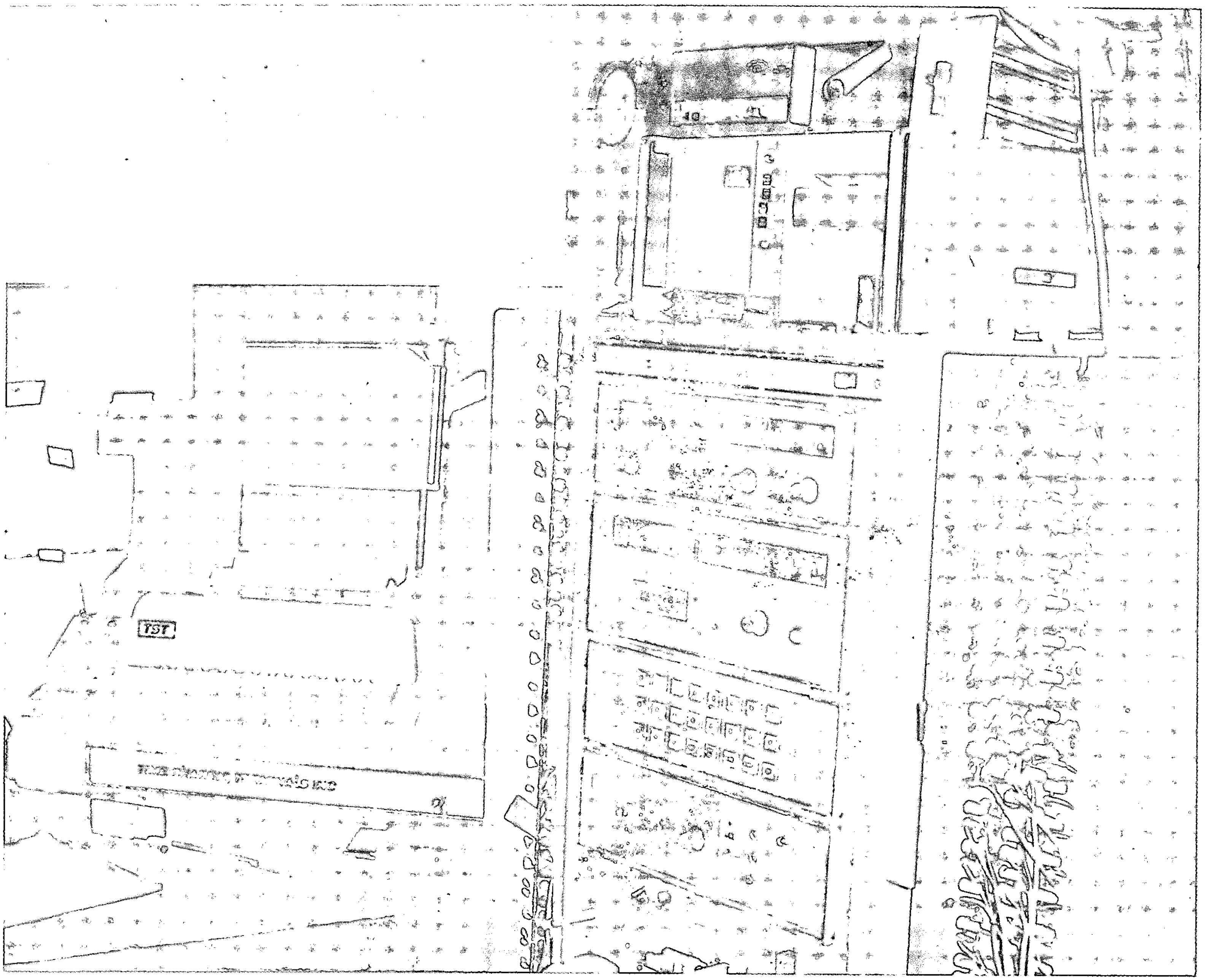
## DATA ACQUISITION EQUIPMENT

All data (except those obtained from the dial gages which were recorded manually) were obtained using a VIDAR 5205 D-DAS recording system. The system is a digital data acquisition system designed to collect rapidly and transform raw analog data into a permanent punched paper tape record. The system sequentially samples, measures and records data in the 10 millivolt to 300 volt range, the Hz to 2 MHz frequency range and the 40 microsecond to 10 second period range.

The VIDAR system includes a 604 Scanner, a 520 Integrated Digital Voltmeter, a 653-02 System Coupler, and a TALLEY Tape Punch. To provide a permanent record, as required by test specifications, the VIDAR System was modified to also include a Hewlett Packard 5050B Digital Printing Recorder. Fig. 3 shows an overall view of the total data acquisition system as it was installed at the test site.

The reliability and accuracy of the acquired data were checked periodically during the progress of the test with the aid of a resistor calibrator box. The calibrator incorporates a precision resistor of known magnitude which, when switched into the system, produces a known voltage change. Any significant deviation from the theoretical voltage change would indicate a malfunction in the system.

To facilitate the reduction of acquired data, the use of a computer was incorporated into the acquisition system. The punched tapes from each pressure level were transmitted to the computer via a teletype unit and acoustical coupler. The data were reduced and returned via the same system. The use of this sytem had two advantages. The primary advantage was that data could be obtained and reduced to stresses or



DATA ACQUISITION EQUIPMENT

Fig. 3

displacements within thirty minutes. The second advantage was that principals at the WJE office in Northbrook, Illinois were continually up-dated as to the progress of the test. Personnel in Northbrook could receive the computer output at any time, obtaining a full set of data. Thus, if questions arose regarding the indicated performance of the structure during the test, lengthy telephone transmission of data would be unnecessary to resolve such questions. This computer tie-in with Northbrook was used to advantage in connection with a few minor considerations of instrument behavior.

## CRACK INSPECTION

Prior to the structural integrity test, the entire structure was surveyed for cracks. The survey was made by traversing the surface of the structure on movable scaffolding, "Sky-Climber Model 55" and "TE Steeple Jenny" Model 59M. The records of existing cracking were reviewed to determine any significant cracks which would require close observation during the structural integrity test. Crack widths observed during this pretest survey were measured using a 6X comparator.

Visual observations of the total exterior surface were made at designated pressures during the test (14, 36, 47 and 54 psi) with the aid of variable power (7X to 15X) binoculars and a Redfield 60X spotting scope.

## STRUCTURAL INTEGRITY TEST

The structural integrity test was performed in conjunction with the integrated leak rate test. Complete sets of data, along with detailed crack inspections, were made at four pressure increments, during the loading cycle and at two pressure increments during depressurization (i.e., 14, 36, 47, 54, 47, 24.4 psig) and finally, at return to zero pressure.

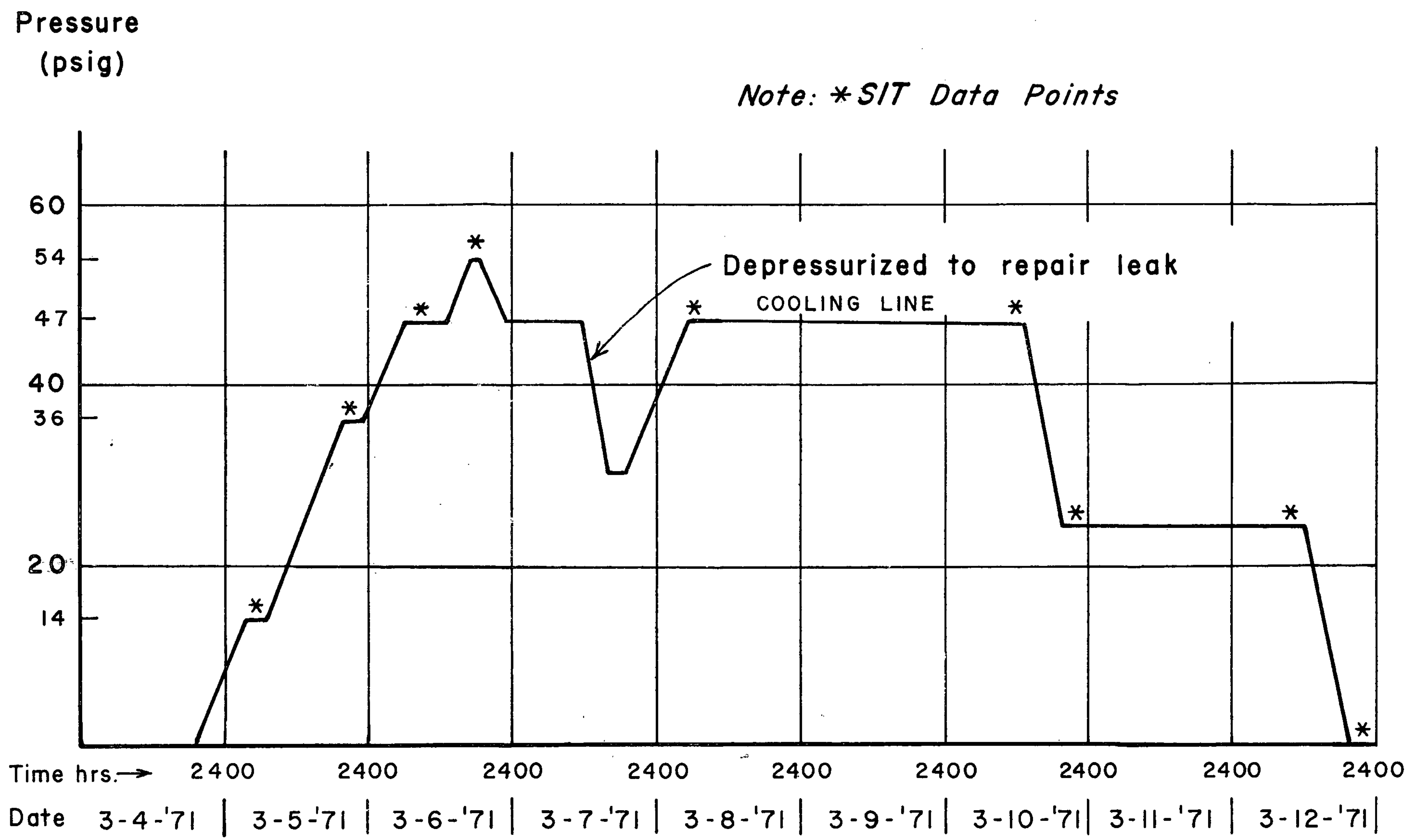
The data obtained at each pressure level were immediately transmitted to the computer where preliminary data-reduction was achieved. This preliminary data was reviewed jointly by personnel of United Engineers and Constructors and Wiss, Janney, Elstner and Associates before proceeding to the next pressure increment.

The structural integrity test was started on March 3, 1971, at 1840 hours and was terminated on March 12, 1971 at 2015 hours. A time pressure curve is presented in Fig. 4. Complete sets of structural data were obtained at 14, 36, 47, 54, 47, 24.4 and 0 pressures.

## TEST RESULTS

### Stresses in Reinforcing Steel

Fifty-four, two-element strain gages were mounted directly on main reinforcing steel around the equipment hatch and at the temporary opening. (A redundant gage was added at each location at the time of installation.) The gage locations are shown on Figs. 8 through 12 in Appendix A. Tabulated strain gage locations also are shown in Tables 1 and 2. Appendix A also contains graphs of stresses in the reinforcing steel as a function of the pressure applied to the containment vessel. These graphs are presented in numerical sequence according to gage number, and should be considered in connection with the location figures.




PRESSURE VERSUS TIME, STRUCTURAL INTEGRITY TEST

Fig. 4

The stresses in the reinforcing steel were converted from measured strains by the computer. The computer conversion was based on elastic properties of the steel as follows: modulus of elasticity - 30 x $10^6$ psi and Poisson's ratio - 0.30.

As indicated previously, the gages at three locations (including the redundants) exhibited excessive drift and instability. These were Gages SG1, SG29 and SG8A. The data from these gages and their redundants were unreliable and have been excluded from this report.

In general, the stresses in the reinforcement were found to be low. The maximum stress measured in the primary vertical reinforcement around the equipment hatch was 20.6 ksi, but most values obtained from this steel were less than 5 ksi. The hoop reinforcement around the equipment hatch, however, was stressed in most cases to about 20 ksi. The stresses in the radial shear steel and ties were quite low, most being less than 3 ksi. All of the gages on the seismic reinforcement indicated compressive stresses for reasons that are not clearly evident, but probably can be explained as a manifestation of torsion. The diagonal cracking which developed in the region of the equipment hatch during the test also could be arributed to torsion.

## Stresses in Liner Plate

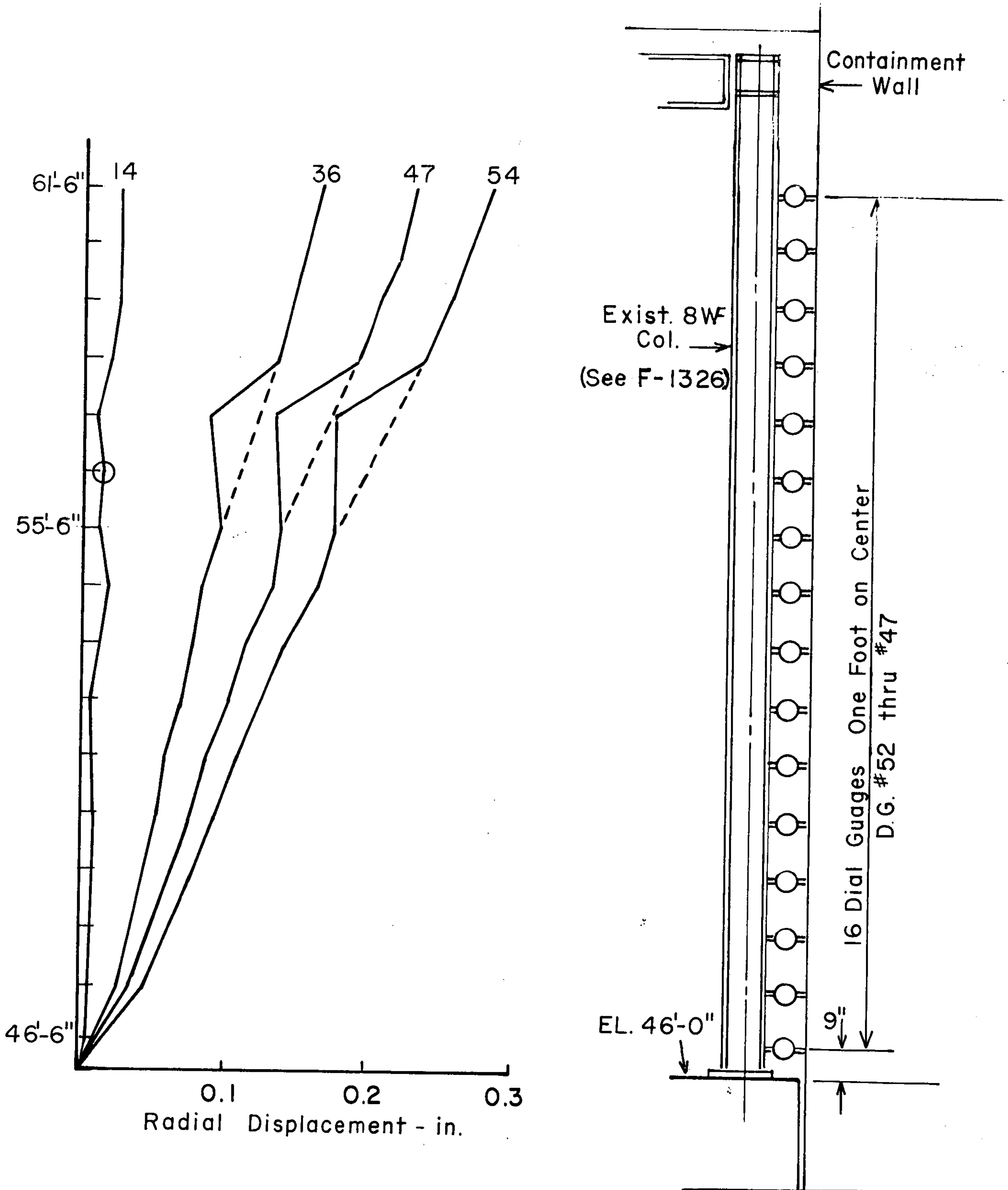
The rosette strain gage locations at Azimuth 130°, and also on the liner plate near the equipment hatch, are shown in Figs. 13, 14 and 15 of Appendix A, respectively. Strain data, obtained from each leg of the rosette, have been used to determine the principal stresses at each gage location. Fig. 16 indicates the key to the direction of the major and minor principal stresses and maximum shears as related to the vertical and horizontal direction of the rosettes. All these stresses are shown in Table 3 of Appendix A.

The maximum principal stresses found in the liner plate appear reasonable. In most instances, the orientation of these stresses was found to be either vertical or radial, as would be expected. Yielding apparently took place at gage location R2R as a rather erratic development of stress occurred during the pressure cycle. This strange stress-load relationship either can be attributed to faulty gage performance or to a highly localized stress concentration which should be expected when small air voids occur between the steel plate and the concrete cylinder. This should be viewed as completely normal and will not in any way be adverse to the performance of the liner.

## Radial Displacements of Cylinder Wall

Radial displacements of the cylinder wall were measured with external dial gages near the base and with invar wire extensometers at higher elevations. The radial displacements from the dial gages at Azimuths 230° and 290° are shown in Figs. 5 and 6, respectively, and the detailed data are tabulated in Tables 4 and 5 of Appendix B.

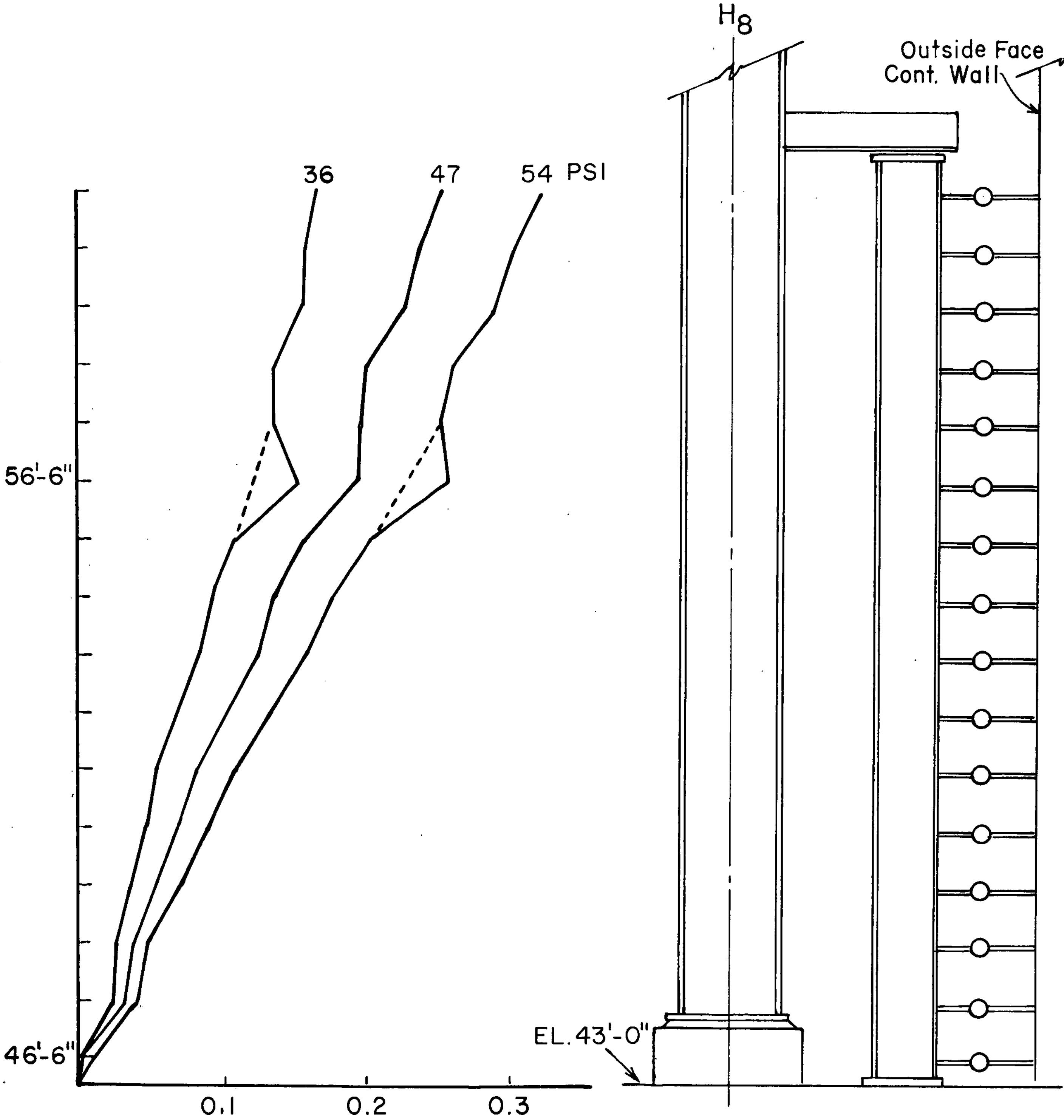
Near Elevation 56 ft 6 in. at both dial gage installations, the displacements are indicated as dashed lines; the recorded data near this elevation are either missing or considered questionable. In one case, the dial gage was stolen, and it is probable that other gages were




SECTION C-C

(REFER TO FIGURE 13)

Fig. 5 - RADIAL DISPLACEMENTS NEAR BASE, AZIMUTH 230°




SECTION D-D

(REFER TO FIGURE 13)

Fig. 6- RADIAL DISPLACEMENTS NEAR BASE, AZIMUTH 290°

tampered with. Regardless of this minor amount of missing data, the displacements of the cylinder wall have been well established by both the dial gages and the extensometers.

At elevations above 91 ft 0 in. to the springline, Elev. 191 ft 0 in., the radial displacements of the cylinder wall were monitored with the invar wire extensometers located at Azimuth 315°. Extensometers were located at 10 ft intervals. Table 6 of Appendix B provides the detailed data from these extensometers. Instruments P19, P21, and P25 were inoperative, but similar to the situation with respect to the dial gages discussed above, the total number of extensometers have provided an accurate record of the cylinder wall displacements at higher elevations.

The radial displacements of the cylinder wall measured at 10 ft intervals from Elevation 91 ft to the springline of the dome at Azimuth 315° have been combined with the data obtained from the dial gages located near the base slab at Azimuth 290° to develop the relationship shown in Fig. 7. The distortion of the cylinder wall throughout its entire height at this location can thus be seen at the various levels of test pressures.

## Radial Displacements near Equipment Hatch

Invar wire extensometers were used to monitor the radial displacements near the equipment hatch at fifteen locations, as shown in Fig. 17 of Appendix B. The detailed displacement data are provided in Table 7 of Appendix B. The radial displacements near the equipment hatch were only slightly less than those found in the uninterrupted cylinder wall (Table 6).

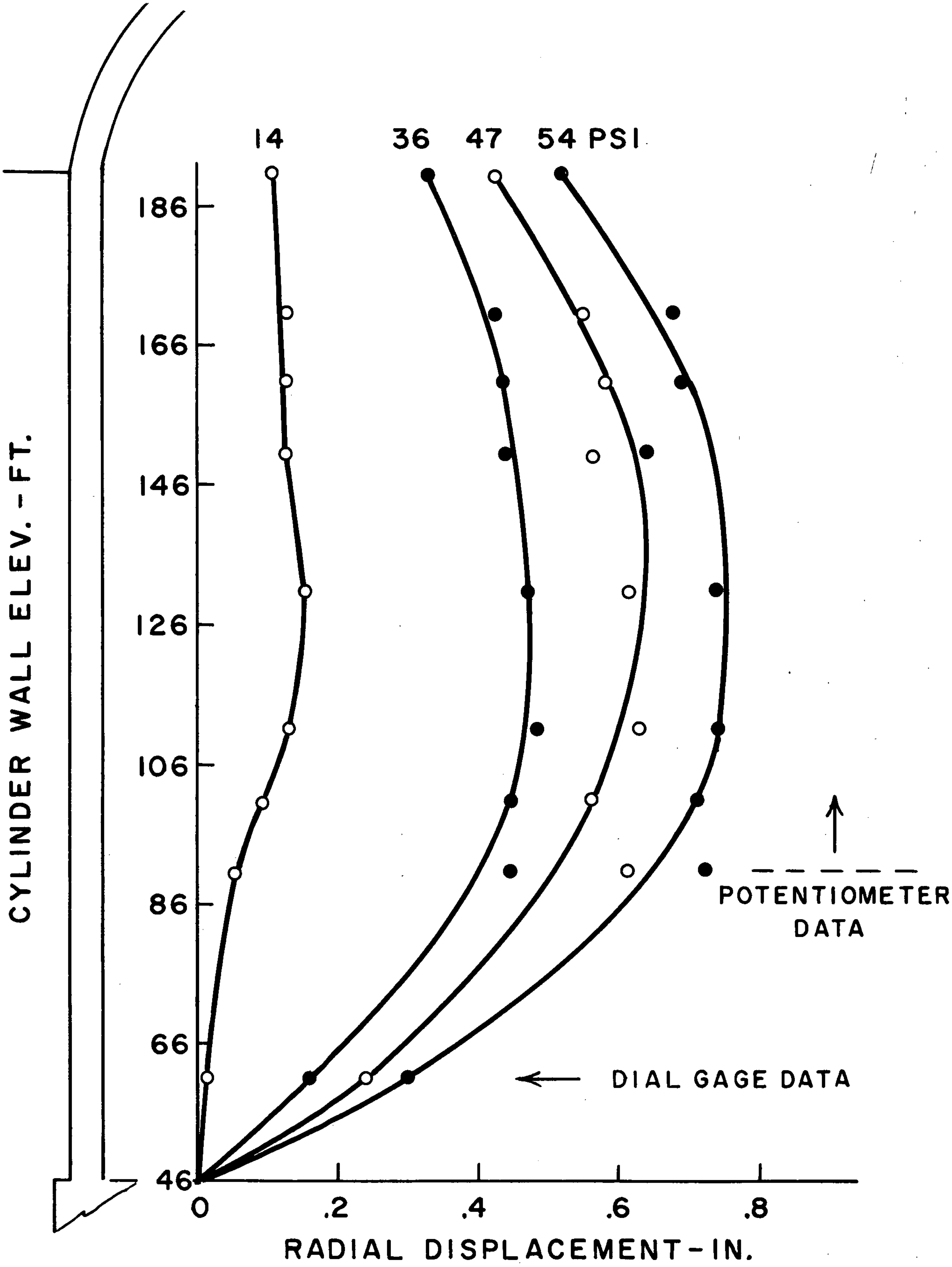



Fig.7 - RADIAL DISPLACEMENT OF CYLINDER WALL AT AZIMUTH 315°

## Cylinder Growth and Dome Displacement

The cylinder growth was measured relative to the base at three elevations of the wall, 95, 143 and 191 ft, at Azimuth 315°. The displacement of the apex of the dome was measured relative to two positions on the springline. These data, corrected to reflect vertical displacement relative to the base, are shown in Table 8 of Appendix B.

The data indicate that vertical growth of the cylinder is about one-third the radial displacement of the wall at maximum pressure. The vertical displacement of the apex of the dome relative to the springline is about half the radial displacement.

## Diameter Change of Equipment Hatch

The change in diameter of the equipment hatch during the pressure test was monitored across two diameters. The data is shown in Table 9 of Appendix B. These changes were small and less than 0.007 in.

## Crack Patterns

The total structure was intensively surveyed to reveal cracking which existed prior to the structural integrity test; and during the test, the total structure also was surveyed for any major cracking. Also during the test, specific attention was paid to:

1. The 10 by 30 ft white-washed area at Azimuth 310° and above Elevation 43 ft
2. The upper right-hand section of the equipment hatch boss

3. The upper right-hand sector of the personnel lock boss. The first nine charts of Appendix C provide the results of the pretest survey and the following eleven charts indicate the additional cracking which developed during the pressure test.

Pretest Survey. The pretest crack inspection revealed extensive but insignificant cracking. Cracking that was observed consisted of horizontal cracks, less than 0.005 inches in widths at construction joints. Spider cracking generally consisting of three or four cracks less than 0.005 in width and approximately eight to ten inches long was observed at almost all of the scaffolding insert holes.

Vertical cracking observed generally was random in nature and occurred to the greatest extent between Elevations 93 ft 0 in. and 168 ft 0 in. Below Elevation 93 ft and above Elevation 168 ft, cracking was found to be much less prevalent. About 99 per cent of all cracks observed were found to be less than 0.005 inches in width. Approximately 1 per cent of the cracks measured were greater than 0.005 inches in width and the maximum width found was 0.008 inches. None exceeded 4 ft in length. Vertical cracks usually began at one construction joint and terminated at the next construction joint.

Cracks observed in the dome, from the springline to the apex, were all less than 0.005 inches in width. Cracking generally occurred in all of the form crevices. All cracks observed during the pretest survey were those which we have come to associate with drying and/or thermal shrinkage. It is our opinion that they existed only as surface cracks and probably very few extended into the wall or dome beyond the outer layer of reinforcement.

Development of Cracks During Test. The crack patterns developed under imposed test load, at the locations which were whitewashed, are presented in Appendix C. The crack survey performed during the conduct of the test did not reveal any crack which exceeded the test criteria (crack width of 0.035 inches over a length of 20 ft). The majority of cracks observed generally were very fine and were less than 0.005 inches in width. The maximum crack width measured in a whitewashed was 0.020 inches over a 6 ft length. This crack occurred at the interface of the containment wall and the thickened boss section at the personnel hatch.

The maximum crack width measured anywhere on the structure was 0.030 inches in width, occurring at the interface of the containment wall and the thickened boss area at the equipment hatch. The cracks in the wall section, Azimuth 310°, were spaced approximately 15 inches apart, and the maximum measured width was 0.002 inches. New cracking which developed during the pressure test was vertical in direction. No new horizontal cracks were noted and old cracking did not increase perceptibly in width. The majority of cracks were concentrated in the middle third of the structure, with little or no new cracking being observed in the remaining portions of the structure.

At the conclusion of the test, the structure was surveyed again. Cracks which were "open" when the test load was at 54 psi closed to nearly their original width. The largest cracks observed (those at the equipment hatch boss) had closed to approximately one-third of the maximum reached at 54 psi.

SUMMARY

Interpretation of the data in light of the design concepts is not within the scope of our assignment. However, we feel that our many years of experience in observing the performance of reinforced concrete structures under many types of test loading requires that a general commentary be made as follows regarding the behavior of this structure under the application of the test loading:

1. The cracks which were noted closely prior to testing were fine and of the character that should be expected as resulting from thermal and drying shrinkage. They are believed to be surface cracks and very few probably extend beyond the outer layer of reinforcement.

2. The additional cracking, and the extension and widening of existing cracking which occurred during the application of test pressures, did not develop to the extent that yielding of reinforcement was indicated at any point on the structure.

3. None of the strain gages placed on reinforcement produced data which indicated that the structure was even approaching a condition of distress at any time during the test.

4. The response of most of the strain gages with respect to recovery after sustained loading was completely consistent with our experience with other nonprestressed reinforced concrete structures in which comparable levels of stresses have been developed. If it were within the scope of our task to have monitored these gages from some period after the conclusion of the test, further recovery would have been observed.

5. The overall performance of the structure was such that we believe that it could sustain internal pressures somewhat higher than the maximum test pressures without suffering permanent distress at any point.

Respectfully submitted,

WISS, JANNEY, ELSTNER and ASSOCIATES, INC.

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# APPENDIX A

## STRAIN GAGE DATA

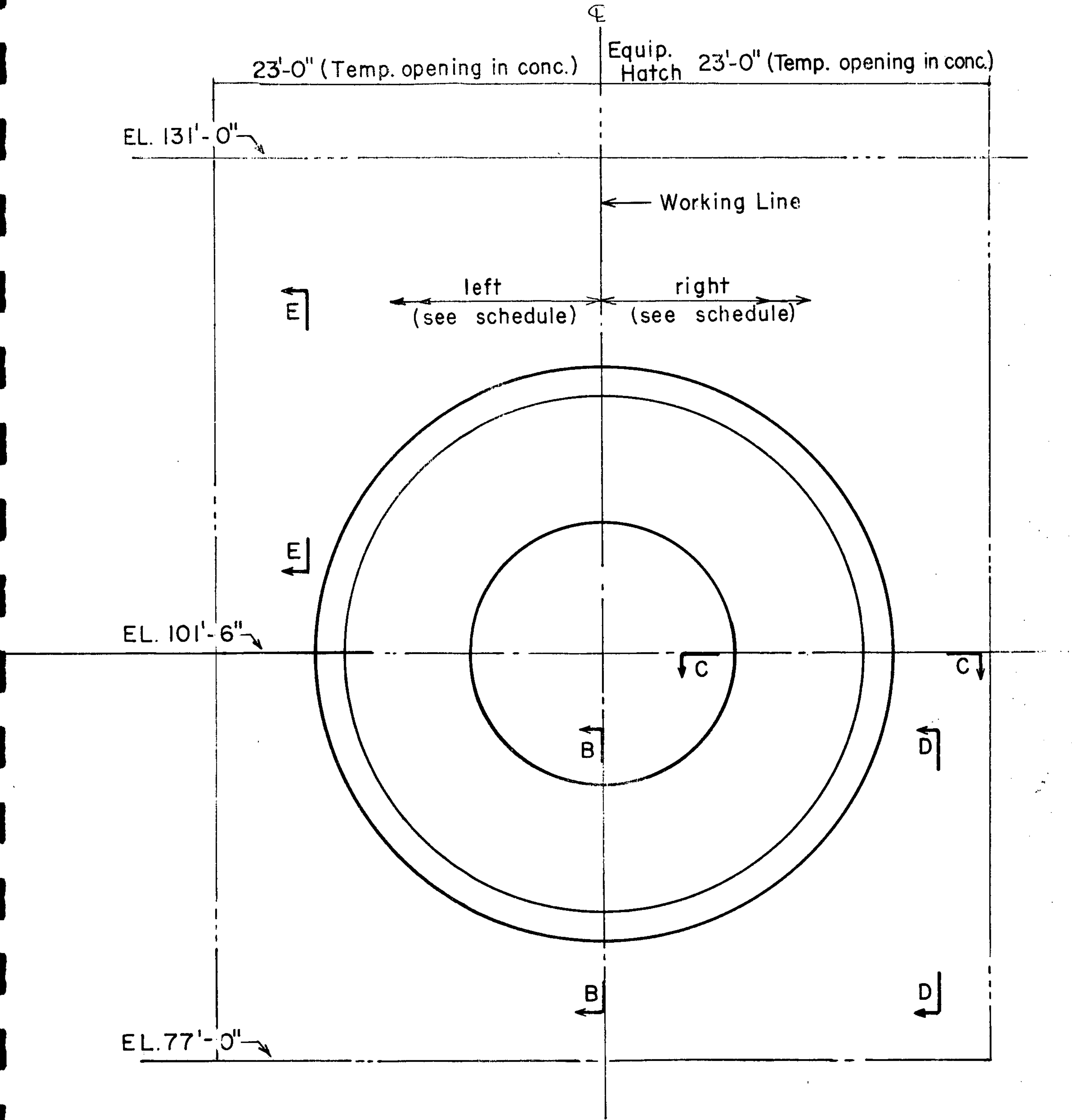
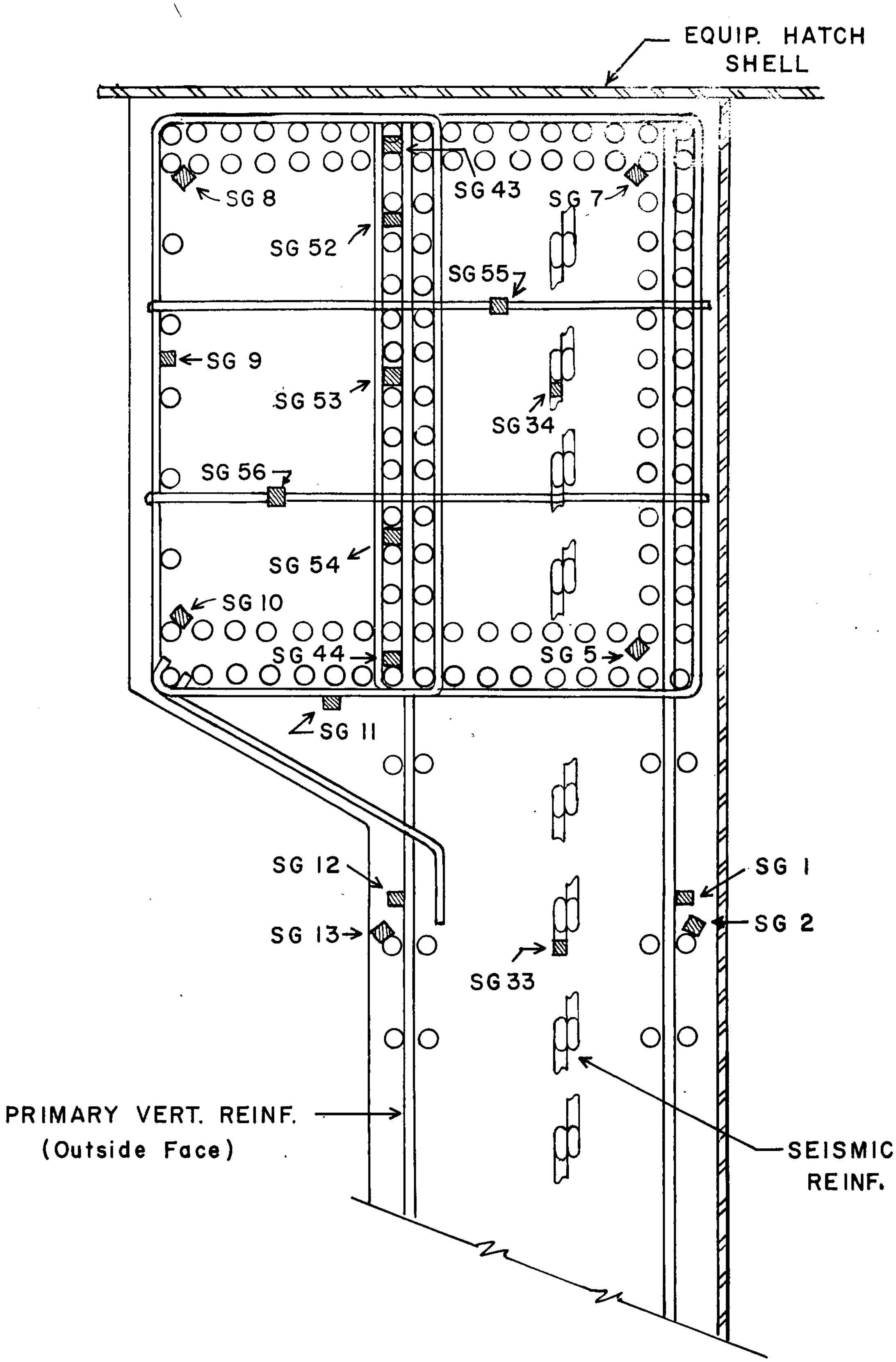


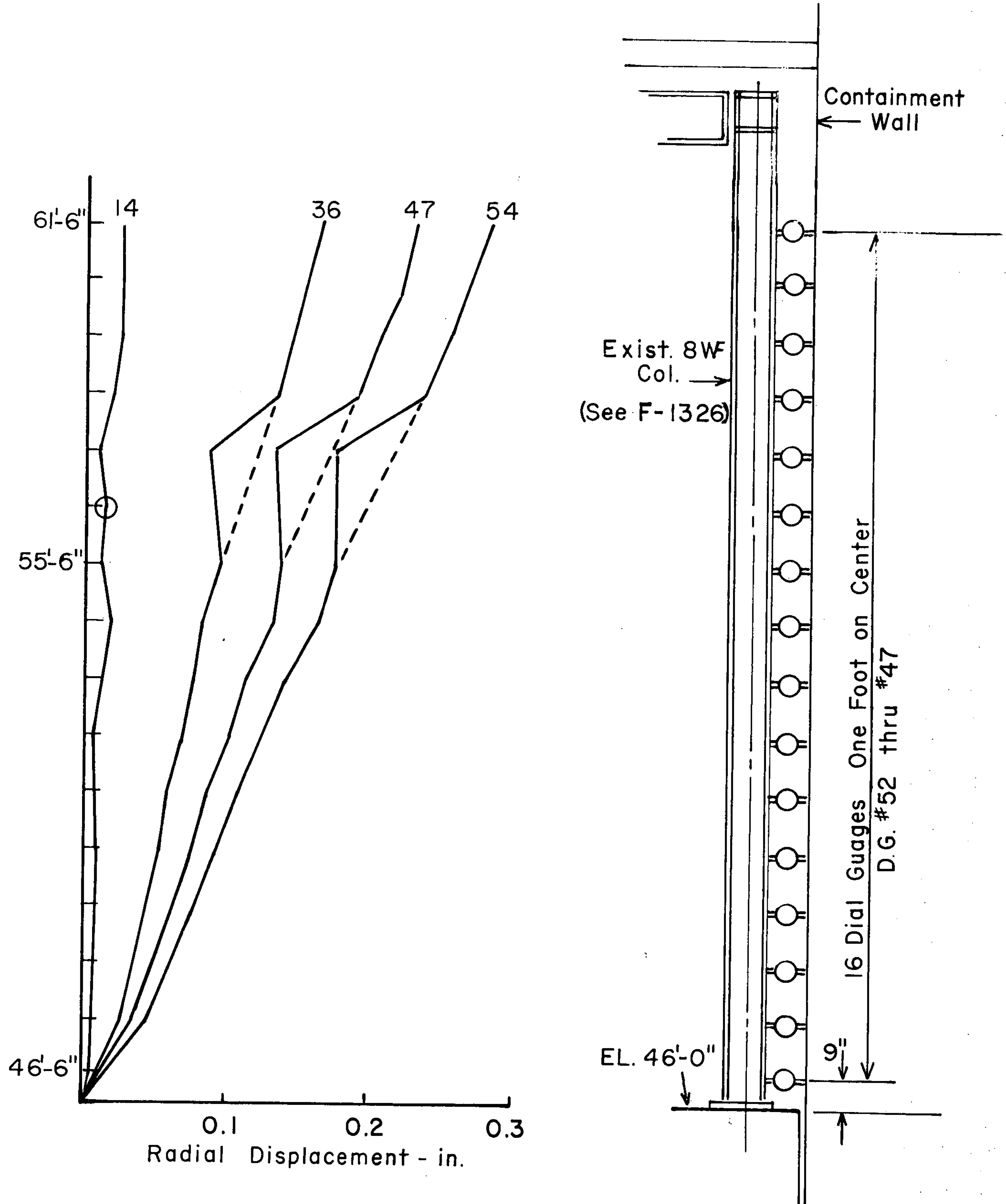

**Fig. 8 - KEY PLAN, STRAIN GAGES ON REINFORCING STEEL NEAR EQUIPMENT HATCH**




SECTION B-B

(REFER TO Fig. 8)

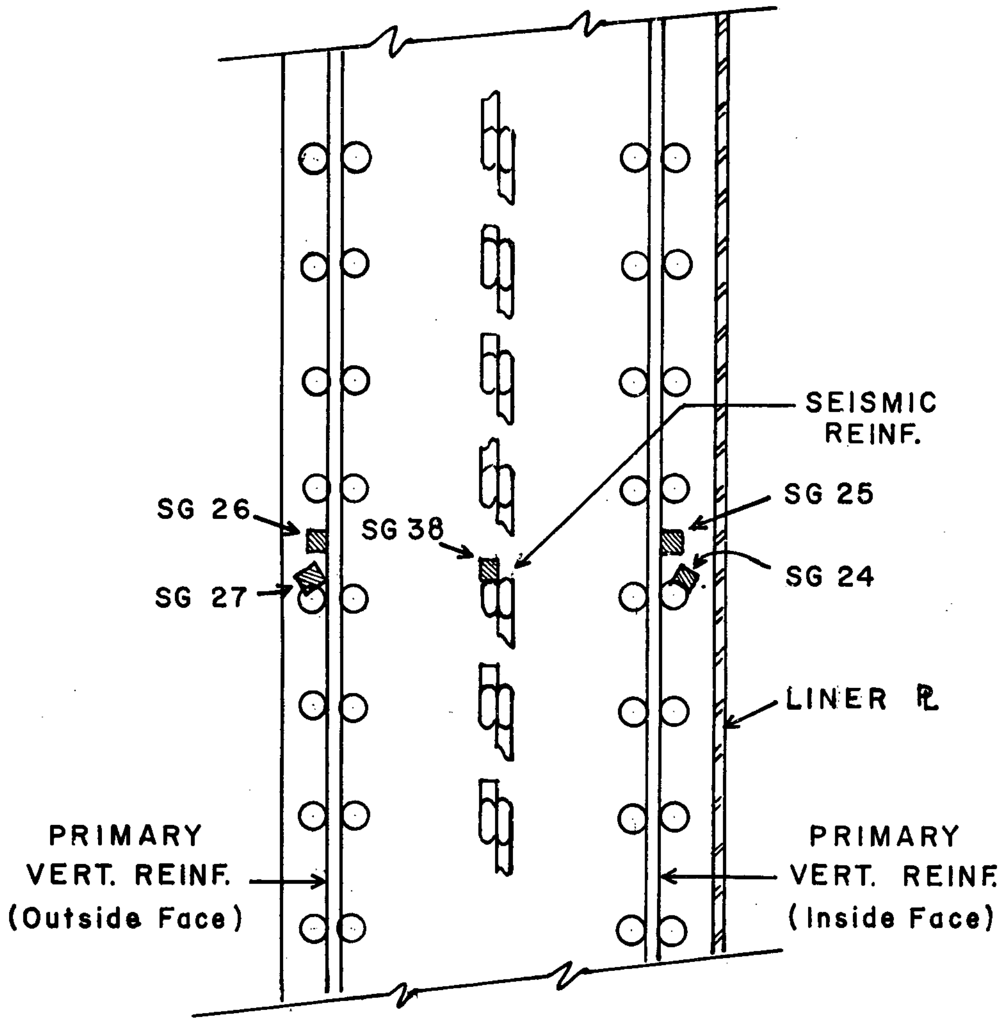
**Fig. 9 - STRAIN GAGE LOCATIONS BELOW EQUIPMENT HATCH**




SECTION C-C

(REFER TO FIGURE 13)

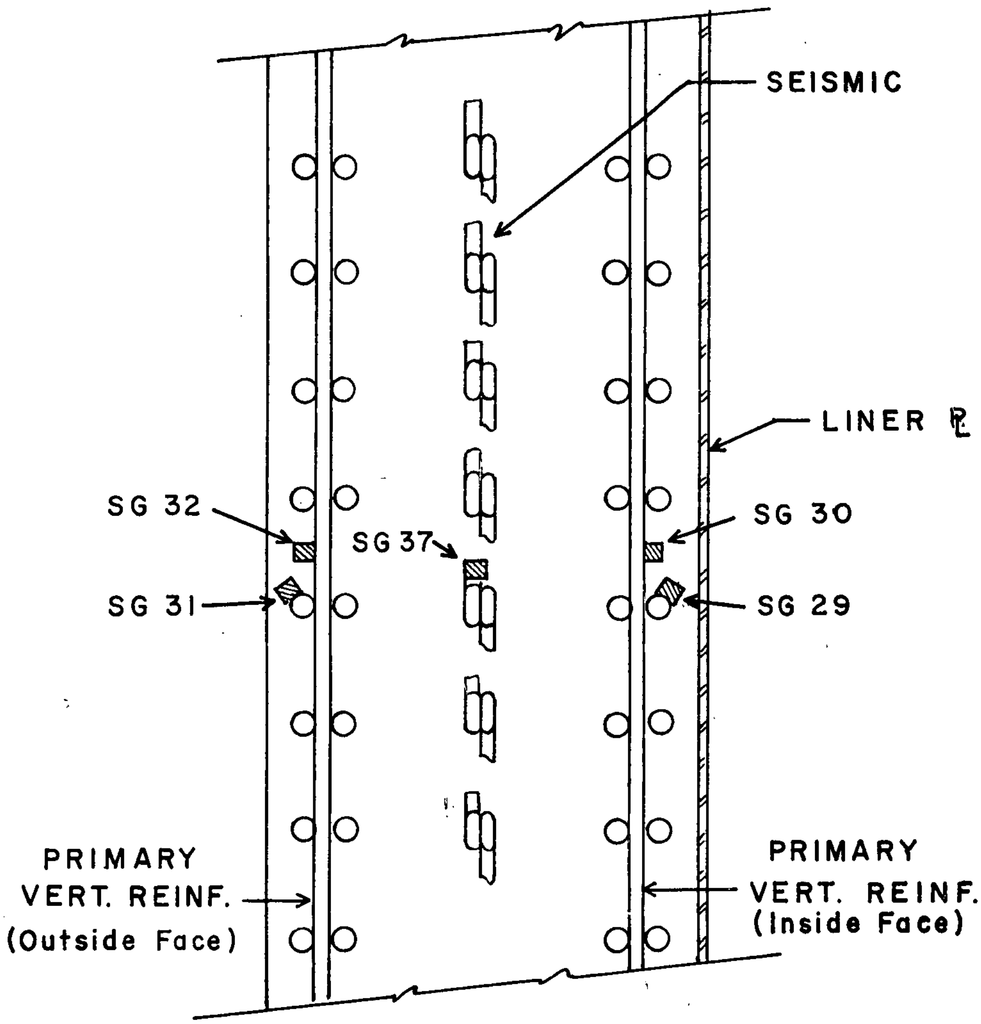
**Fig. 5 - RADIAL DISPLACEMENTS NEAR BASE, AZIMUTH 230°**




SECTION D-D

(REFER TO FIGURE 8)

Fig. 11 - STRAIN GAGE LOCATIONS IN WALL ADJACENT TO EQUIPMENT HATCH




SECTION E-E

(REFER TO FIGURE 8)

Fig. 12 - STRAIN GAGE LOCATIONS IN WALL ADJACENT TO EQUIPMENT HATCH

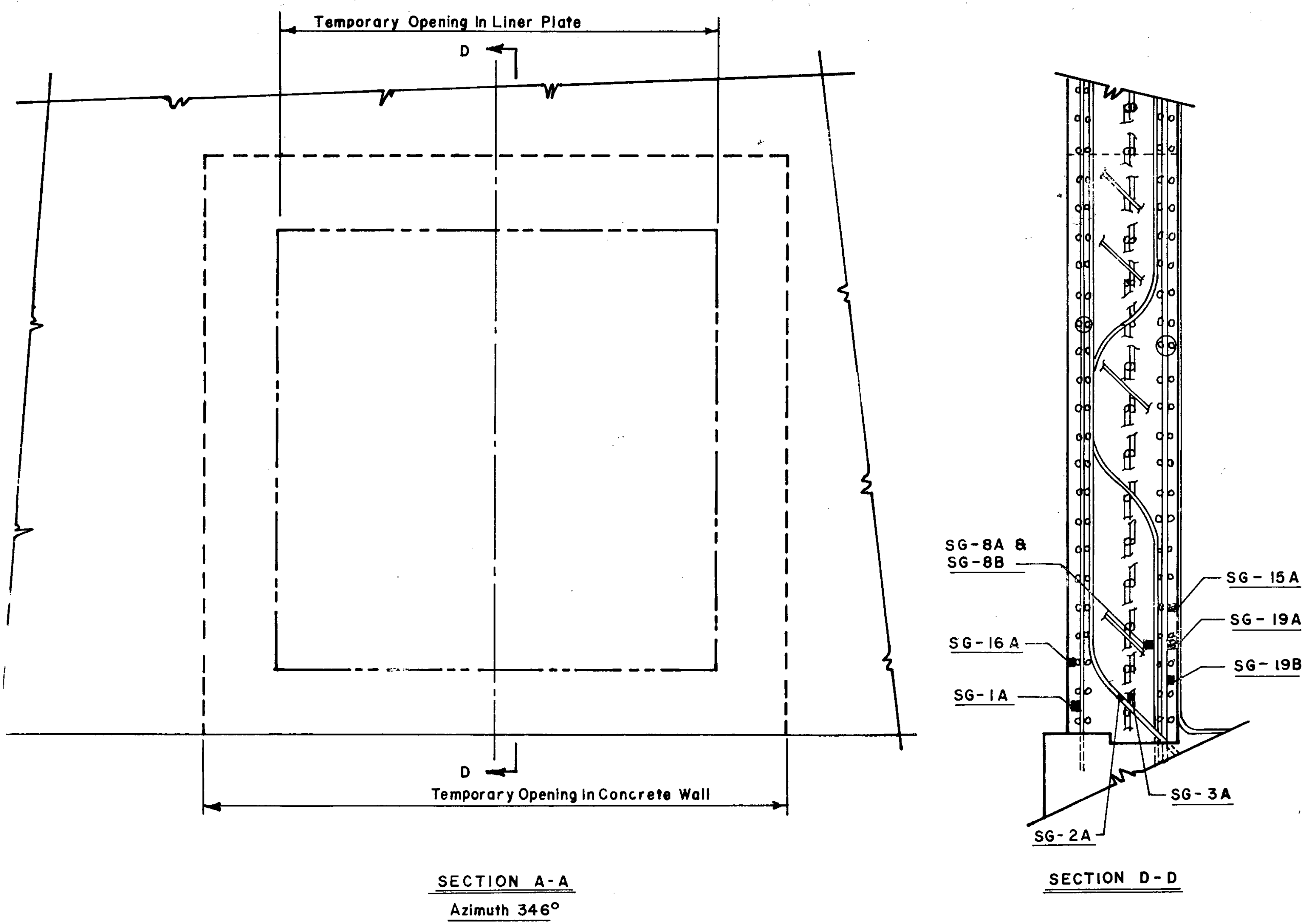



Fig. 12A - STRAIN GAGES AT TEMPORARY OPENING

TABLE 1

STRAIN GAGE SCHEDULE

| MARK NO. | HORIZONTAL LOCATION* LEFT | HORIZONTAL LOCATION* RIGHT | VERTICAL LOCATION (ELEVATION) | RESPECTIVE STRUCTURAL TYPE | REMARKS |
|---|---|---|---|---|---|
| SG-1 | 0'-0" | 0'-0" | El. 83'-4" | Primary vert. (inside face) | |
| SG-2 | 0'-0" | 0'-0" | El. 82'-9" | Hoop (inside face) | |
| SG-5 | 0'-0" | 0'-0" | El. 87'-3" | Hoop in equipment hatch boss | 2'-7 from liner plate |
| SG-7 | 0'-0" | 0'-0" | El. 92'-5" | Hoop in equipment hatch boss | |
| SG-8 | 0'-0" | 0'-0" | El. 92'-6" | Hoop in equipment hatch boss | |
| SG-9 | 0'-0" | 0'-0" | El. 90'-2" | Tie in equipment hatch boss | |
| SG-10 | 0'-0" | 0'-0" | El. 86'-5" | Hoop in equipment hatch boss | |
| SG-11 | 0'-7" | 0'-0" | El. 85'-11" | Tie in equipment hatch boss | |
| SG-12 | 0'-0" | 0'-0" | El. 82'-7" | Primary vert. (outside face) | |
| SG-13 | 0'-0" | 0'-0" | El. 82'-1" | Hoop (outside face) | |
| SG-17 | - | 15'-3" | El. 101'-6" | Hoop in equipment hatch boss | |
| SG-18 | - | 15'-4" | El. 100'-10" | Tie in equipment hatch boss | |
| SG-19 | - | 15'-2" | El. 101'-0" | Hoop in equipment hatch boss | |
| SG-20 | - | 12'-6" | El. 100'-5" | Tie in equipment hatch boss | |
| SG-21 | - | 8'-10" | El. 100'-8" | Hoop in equipment hatch boss | |
| SG-22 | - | 8'-7" | El. 101'-6" | Hoop in equipment hatch boss | |
| SG-24 | - | 21'-0" | El. 82'-9" | Hoop (inside face) | |
| SG-25 | - | 21'-0" | El. 83'-4" | Primary vert. (inside face) | |
| SG-26 | - | 22'-3" | El. 82'-7" | Primary vert. (outside face) | |
| SG-27 | - | 22'-0" | El. 82'-4" | Hoop (outside face) | |
| SG-29 | 21'-0" | - | El. 120'-3" | Hoop (inside face) | |
| SG-30 | 21'-0" | - | El. 120'-10" | Primary vert. (inside face) | |
| SG-31 | 21'-7" | - | El. 120'-9" | Hoop (outside face) | |
| SG-32 | 21'-5" | - | El. 121'-2" | Primary vert. (outside face) | |
| SG-33 | 0'-0" | 0'-0" | El. 82'-9" | Seismic | |
| SG-34 | 0'-0" | 0'-0" | El. 89'-9" | Seismic | |
| SG-35 | - | 13'-10" | El. 101'-6" | Seismic | |
| SG-36 | - | 17'-0" | El. 101'-6" | Seismic | |
| SG-37 | 21'-0" | | El. 120'-3" | Seismic | |
| SG-38 | - | 21'-0" | El. 82'-9" | Seismic | |

* For correct orientation of left and right directions see working line on Fig. 8.

TABLE 1 (Continued)

| MARK NO. | HORIZONTAL LOCATION LEFT | RIGHT | VERTICAL LOCATION (ELEVATION) | RESPECTIVE STRUCTURAL TYPE | REMARKS |
|---|---|---|---|---|---|
| SG-43 | 0'-0" | 0'-0" | El. 92'-6" | Hoop in equip. hatch boss | |
| SG-44 | 0'-0" | 0'-0" | El. 85'-4" | Hoop in equip. hatch boss | |
| SG-46 | - | 8'-7" | El. 101'-6" | Hoop in equip. hatch boss | |
| SG-47 | - | 9'-6" | El. 101'-8" | Primary vert. (center of boss) | |
| SG-48 | - | 11'-7" | El. 101'-1" | Primary vert. (center of boss) | |
| SG-49 | - | 14'-1" | El. 101'-6" | Primary vert. (center of boss) | |
| SG-50 | - | 15'-2" | El. 101'-5" | Primary vert. (center of boss) | |
| SG-51 | 0'-0" | 18'-5" | El. 101'-11" | Primary vert. (outside face) | |
| SG-52 | 0'-0" | 0'-3" | El. 92'-0" | Hoop (center of equip. hatch boss) | |
| SG-53 | 0'-0" | 0'-7" | El. 90'=5" | Hoop (center of equip. hatch boss) | |
| SG-54 | 0'-0" | 0'-8" | El. 88'-4" | Hoop (center of equip. hatch boss) | |
| SG-55 | 0'-0" | 1'-1" | El. 91'-6" | Radial shear bar | 4'-5 from liner plate |
| SG-56 | 0'-5" | 0'-0" | El. 88'-9" | Radial shear bar | 5'-6 from liner plate |
| SG-57 | - | 12'-2" | El. 100'-10" | Radial shear bar | 6'-9 from liner plate |
| SG-58 | - | 9'-10" | El. 101'-3" | Radial shear bar | 3'-0 from liner plate |
| SG-59 | - | 10'-1" | El. 101'-4" | Radial shear bar | 5'-3 from liner plate |

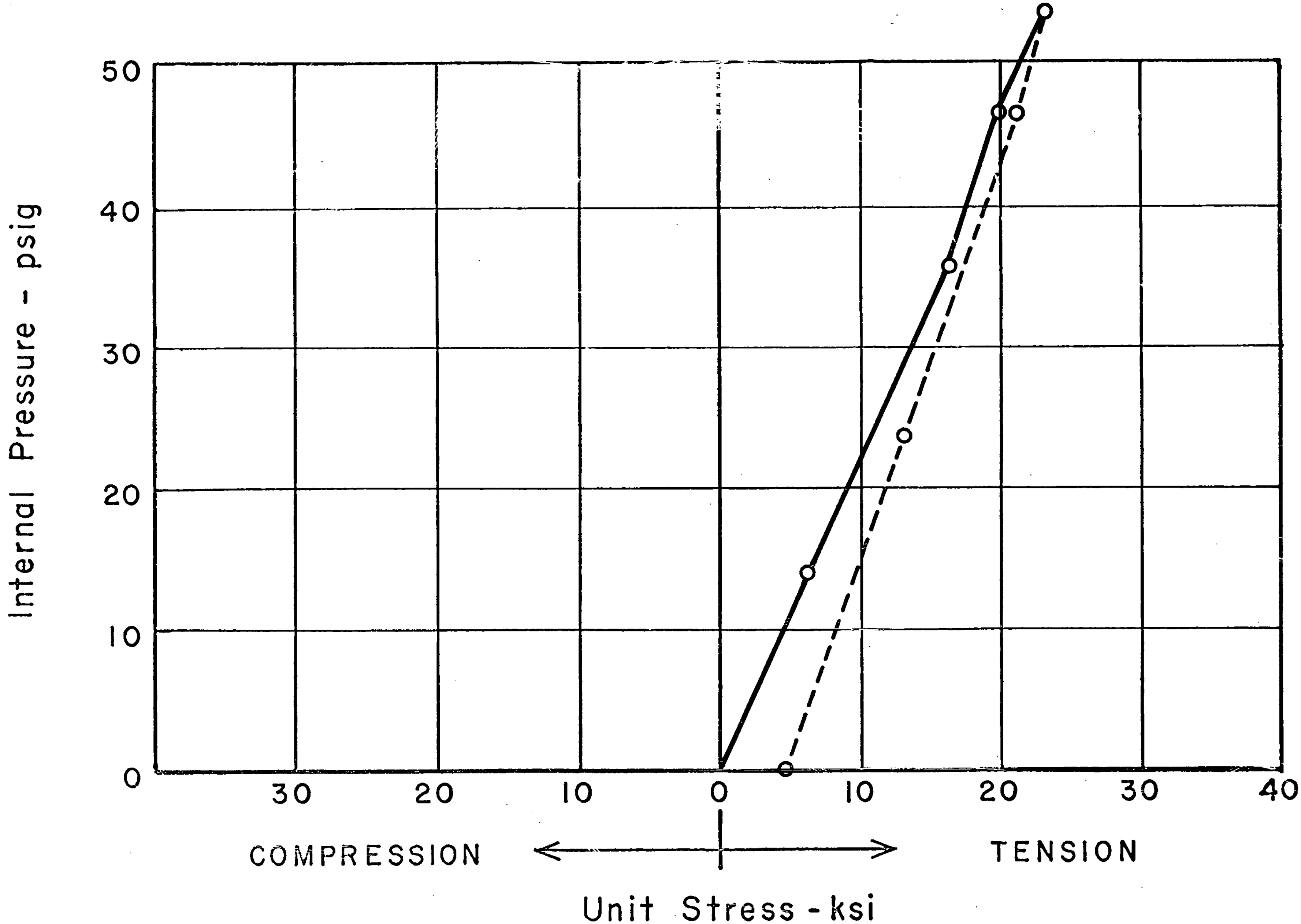
## TABLE 2

## STRAIN GAGE SCHEDULE

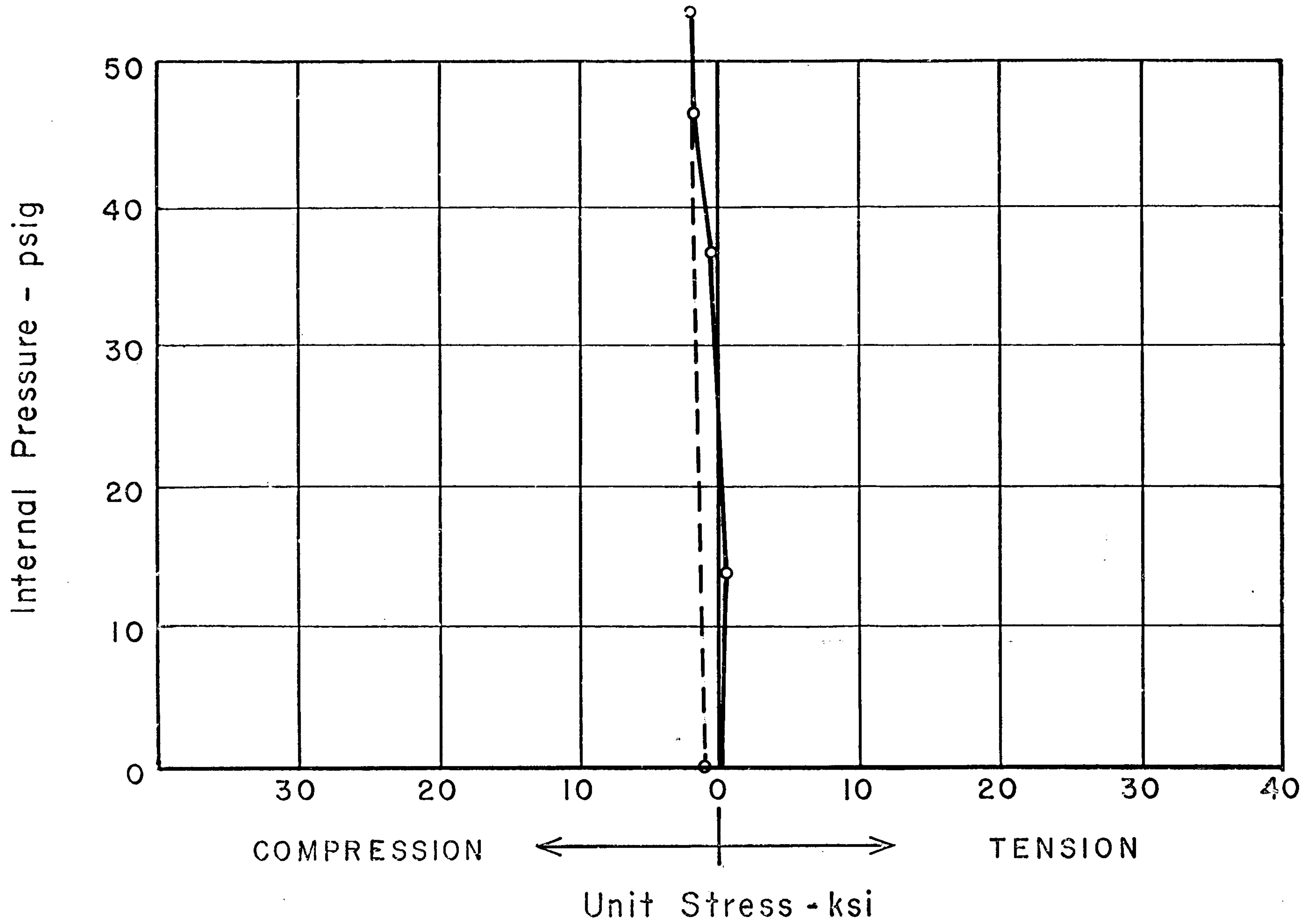
| MARK NO. | HORIZONTAL LOCATION* LEFT | HORIZONTAL LOCATION* RIGHT | VERTICAL LOCATION (ELEVATION) | RESPECTIVE STRUCTURAL TYPE | REMARKS |
|---|---|---|---|---|---|
| SG-1A | | 0'-6" | El. 44'-2 | Primary vert. (outside face) | |
| SG-2A | - | 0'-6" | El. 44'-2 | Secondary vertical | |
| SG-3A | - | 0'-6" | El. 44'-2 | Seismic | |
| SG-8A | - | 0'-6" | El. 46'-6 | Secondary vertical | |
| SG-8B | - | 0'-6" | El. 44'-2 | Secondary vertical | |
| SG-15A | - | 0'-6" | El. 48'-0 | Hoop (inside face) | |
| SG-16A | - | 0'-6" | El. 45'-11 | Hoop (outside face) | |
| SG-19A | - | 0'-6" | El. 46'-6 | Primary vert. (inside face) | |
| SG-19B | - | 0'-6" | El. 44'-2 | Primary vert. (inside face) | |

* For correct orientation of left and right directions see working line on Fig. 12A

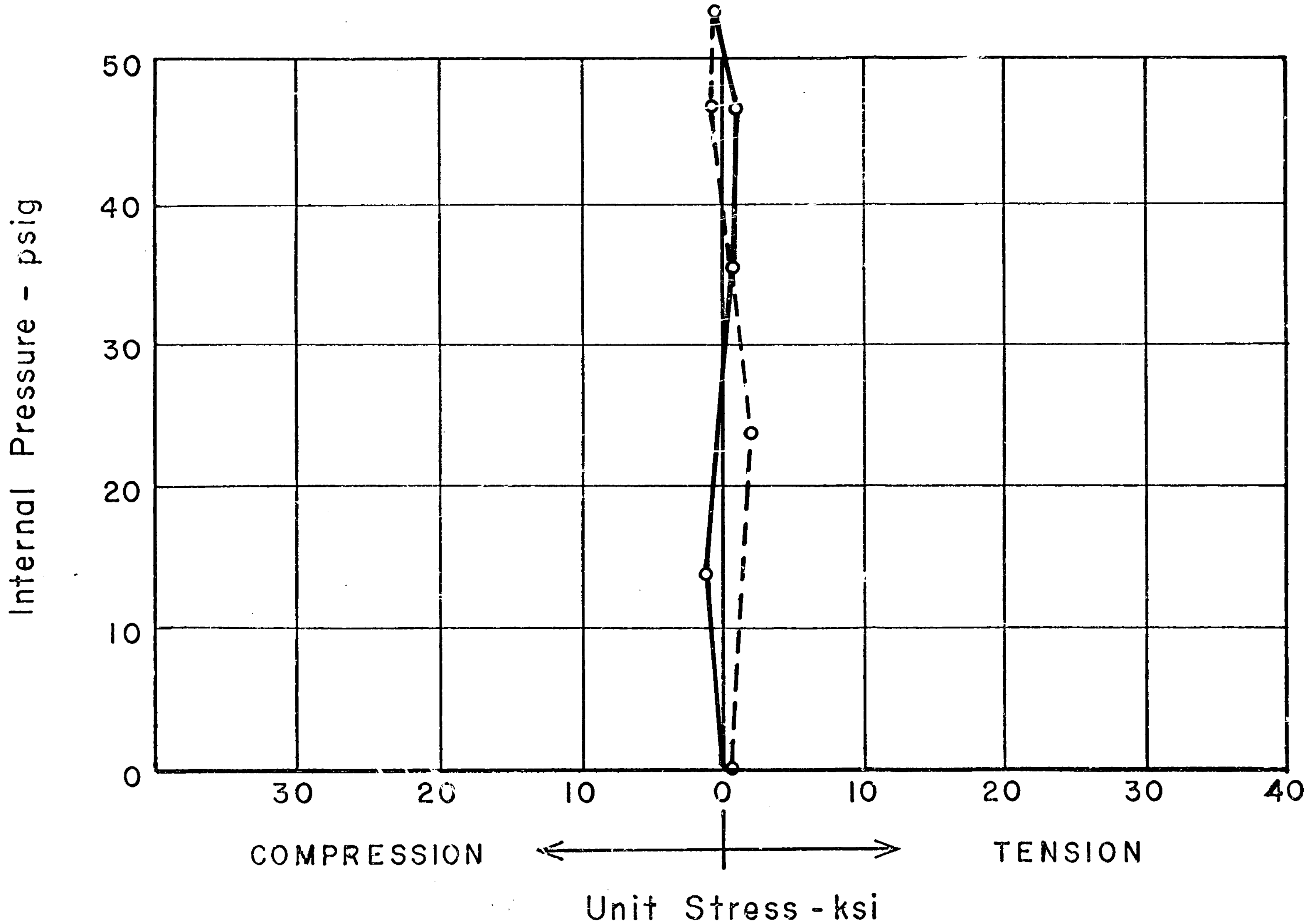
GAGE SG 2 - Equipment Hatch - Hoop (inside face)



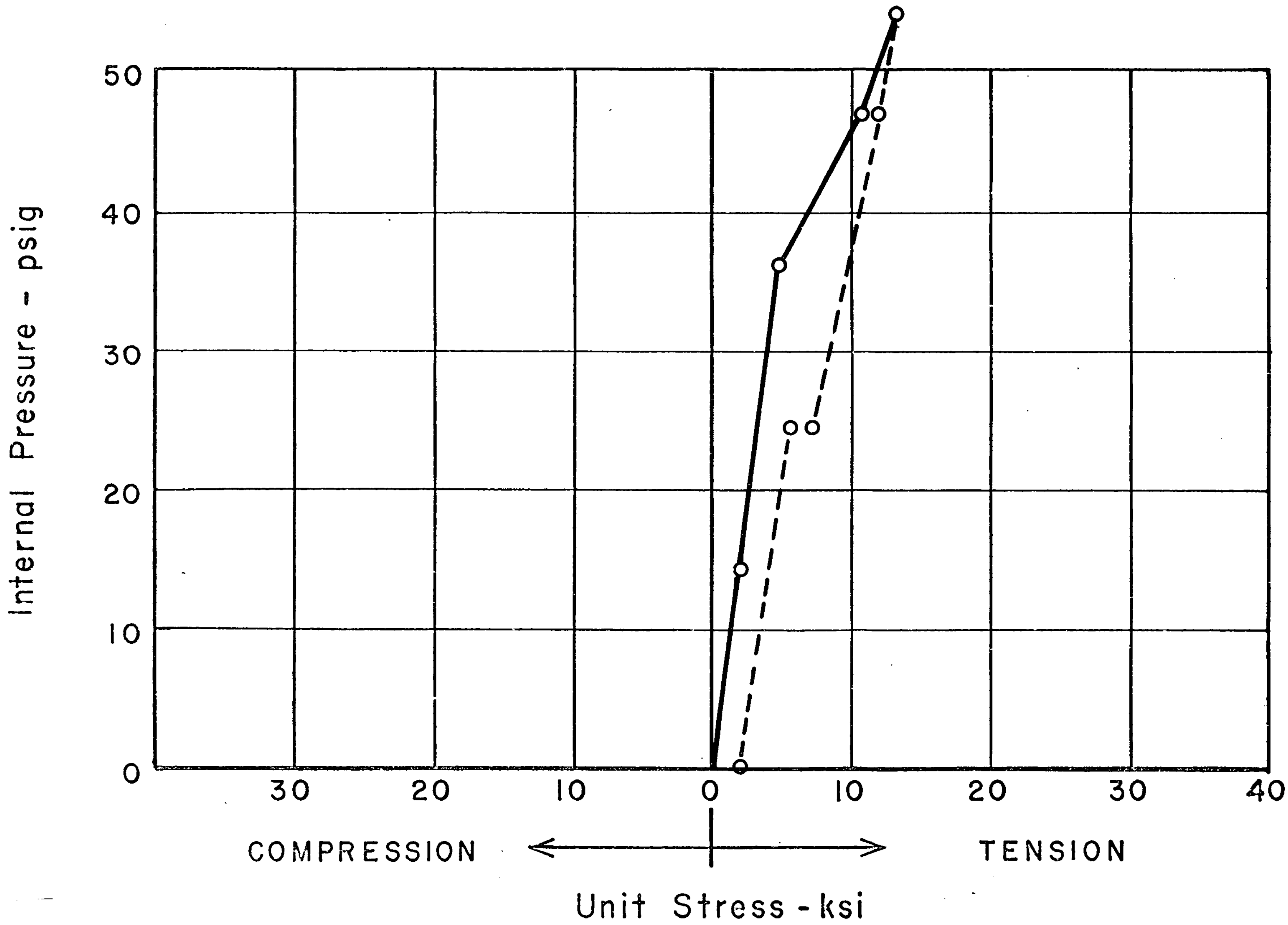
GAGE SG 5 - Equipment Hatch - Hoop in Equip. Hatch Boss



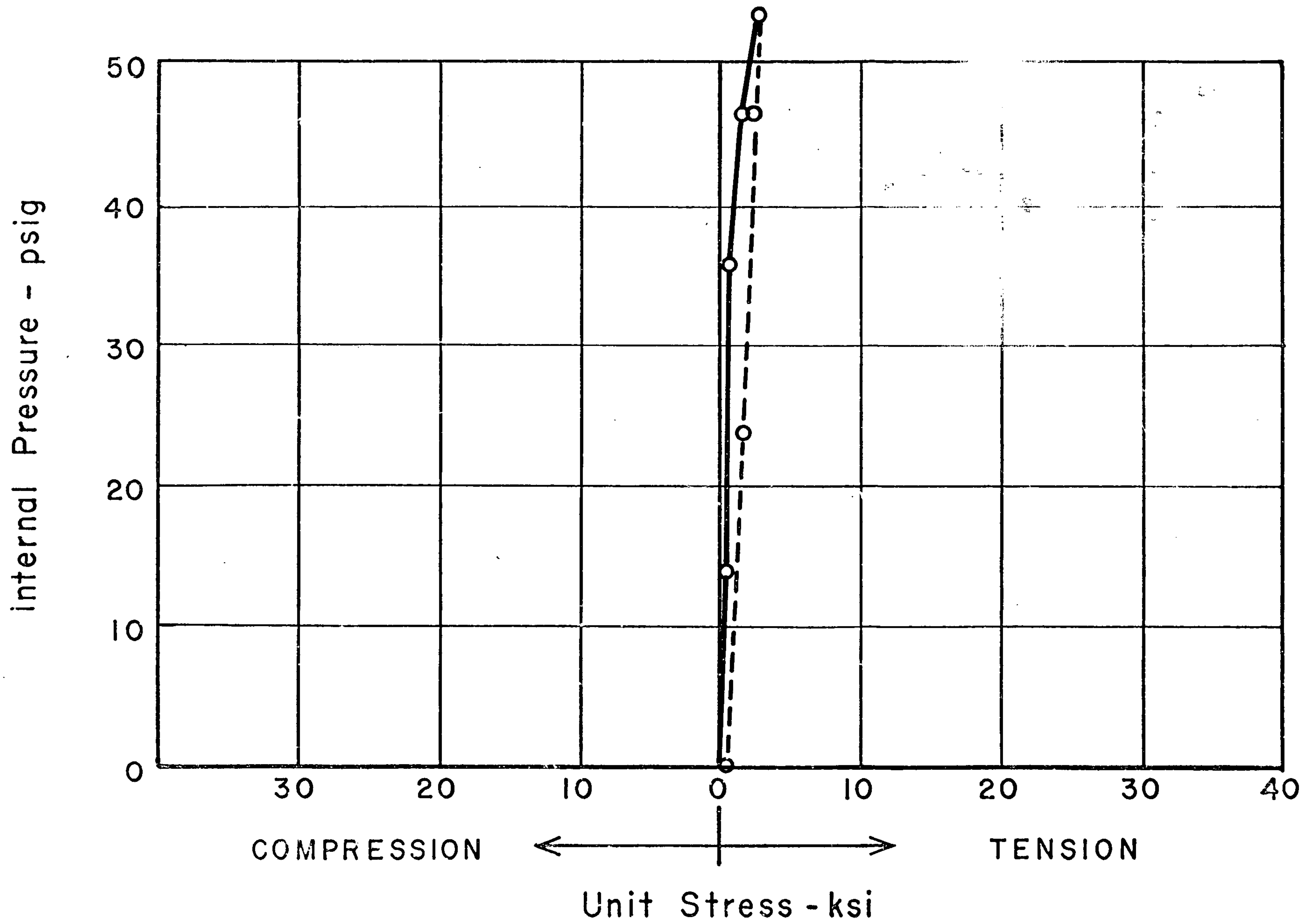
GAGE SG 5R - Equipment Hatch - Hoop in Equip. Hatch Boss



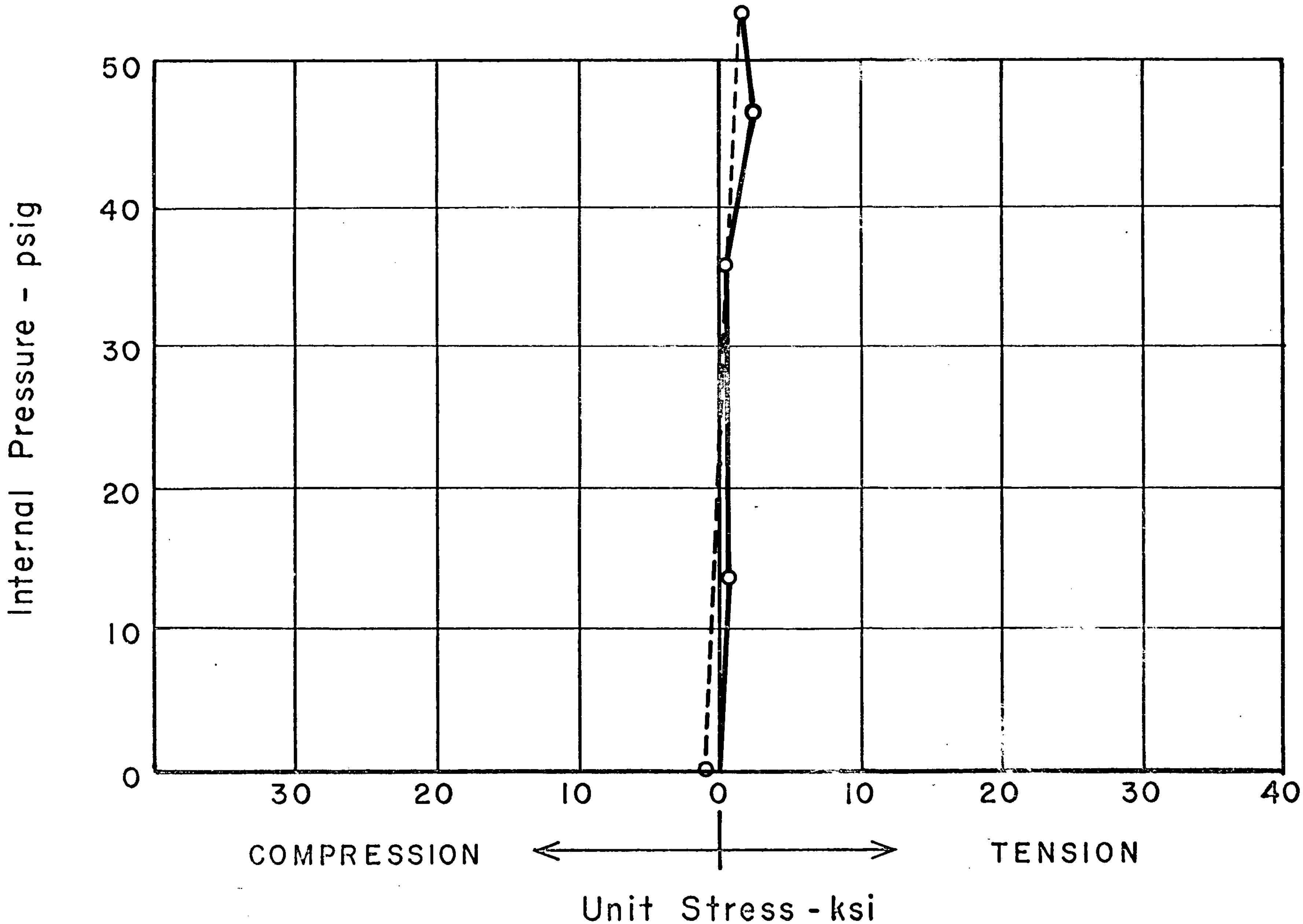
GAGE SG 7 – Equipment Hatch – Hoop in Equip. Hatch Boss



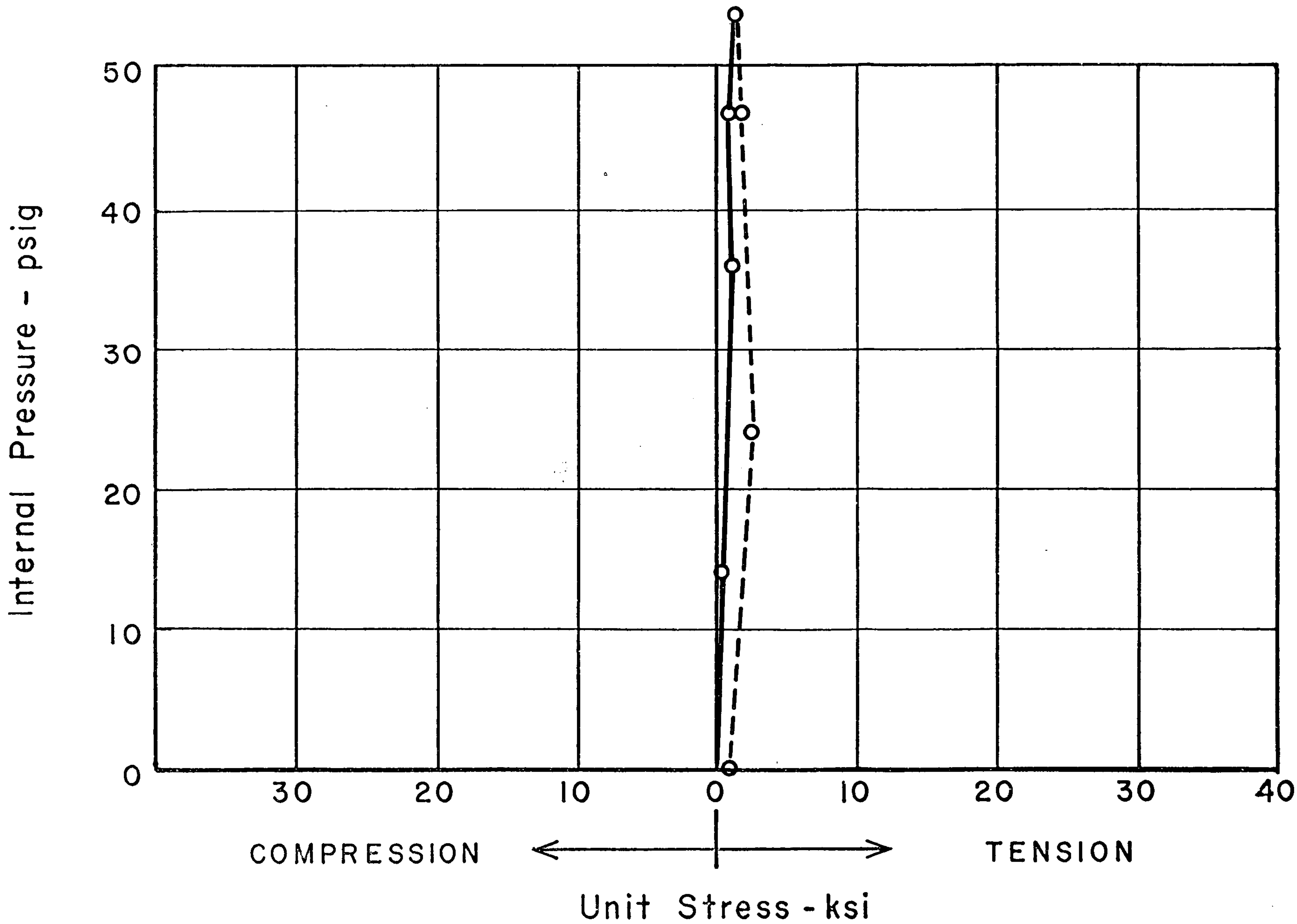
GAGE SG 8 – Equipment Hatch – Hoop in Equip. Hatch Boss



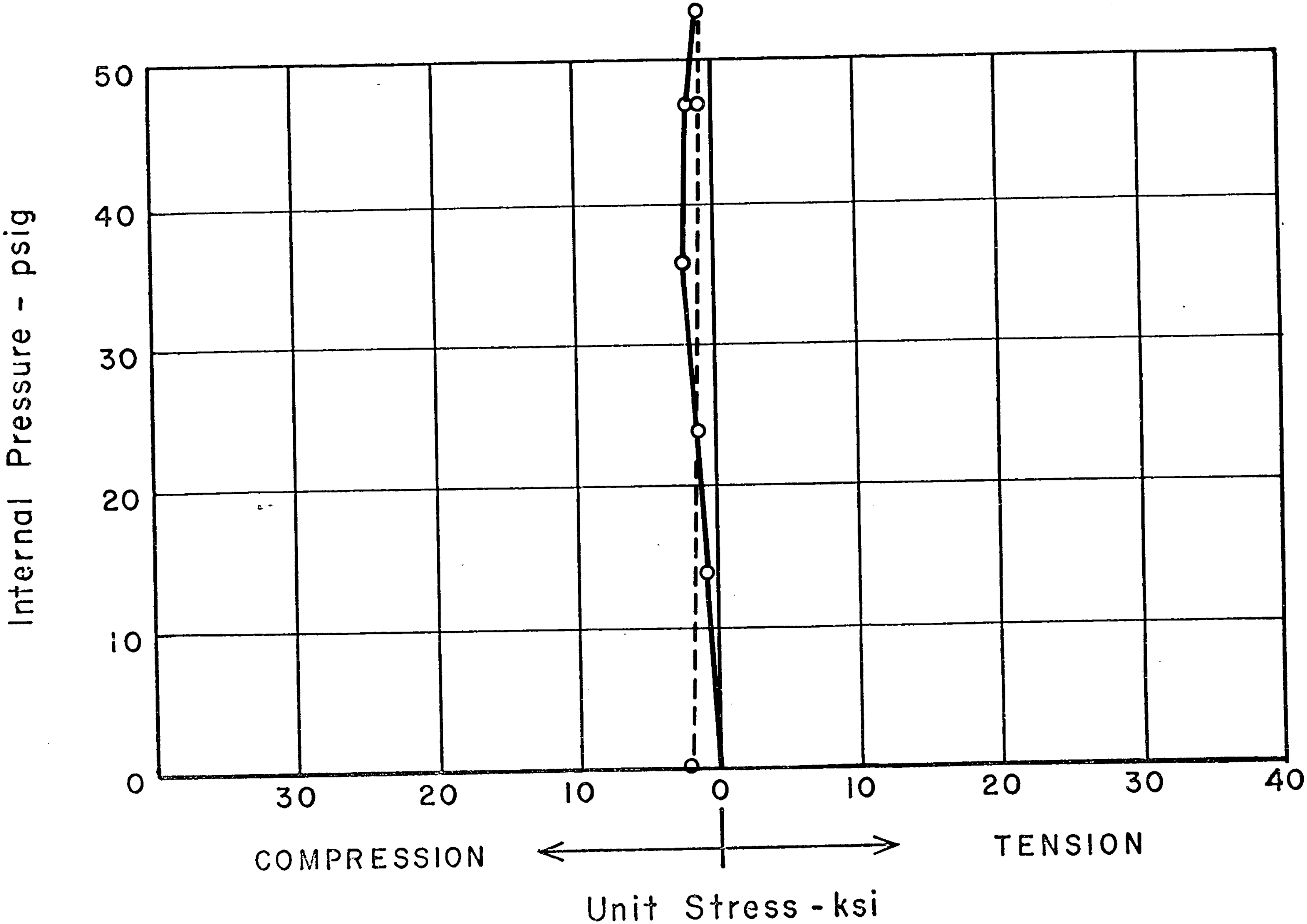
## GAGE SG 8R - Equipment Hatch - Hoop in Equip. Hatch Boss



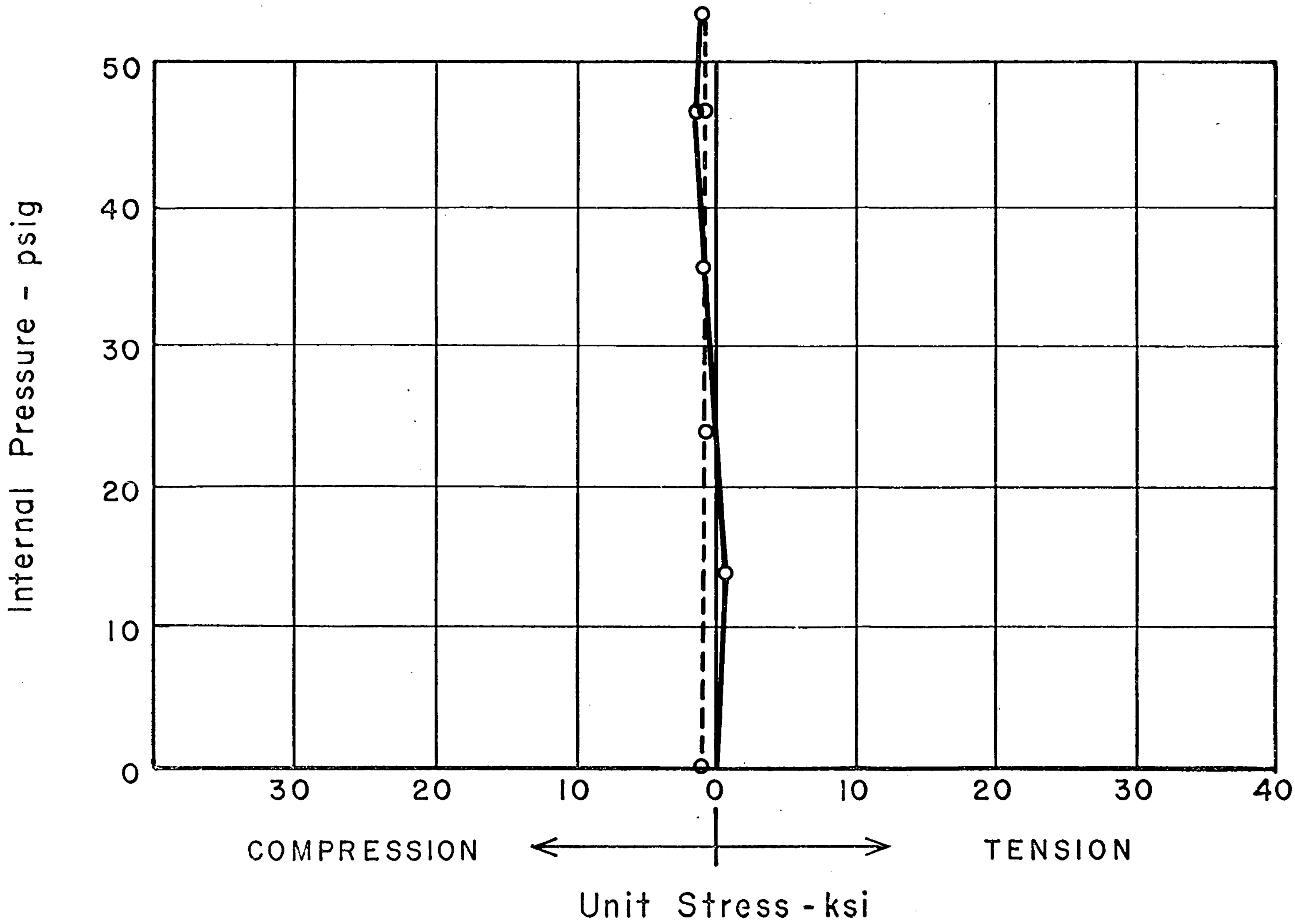
GAGE SG 9 - Equipment Hatch - Tie in Equip. Hatch Boss

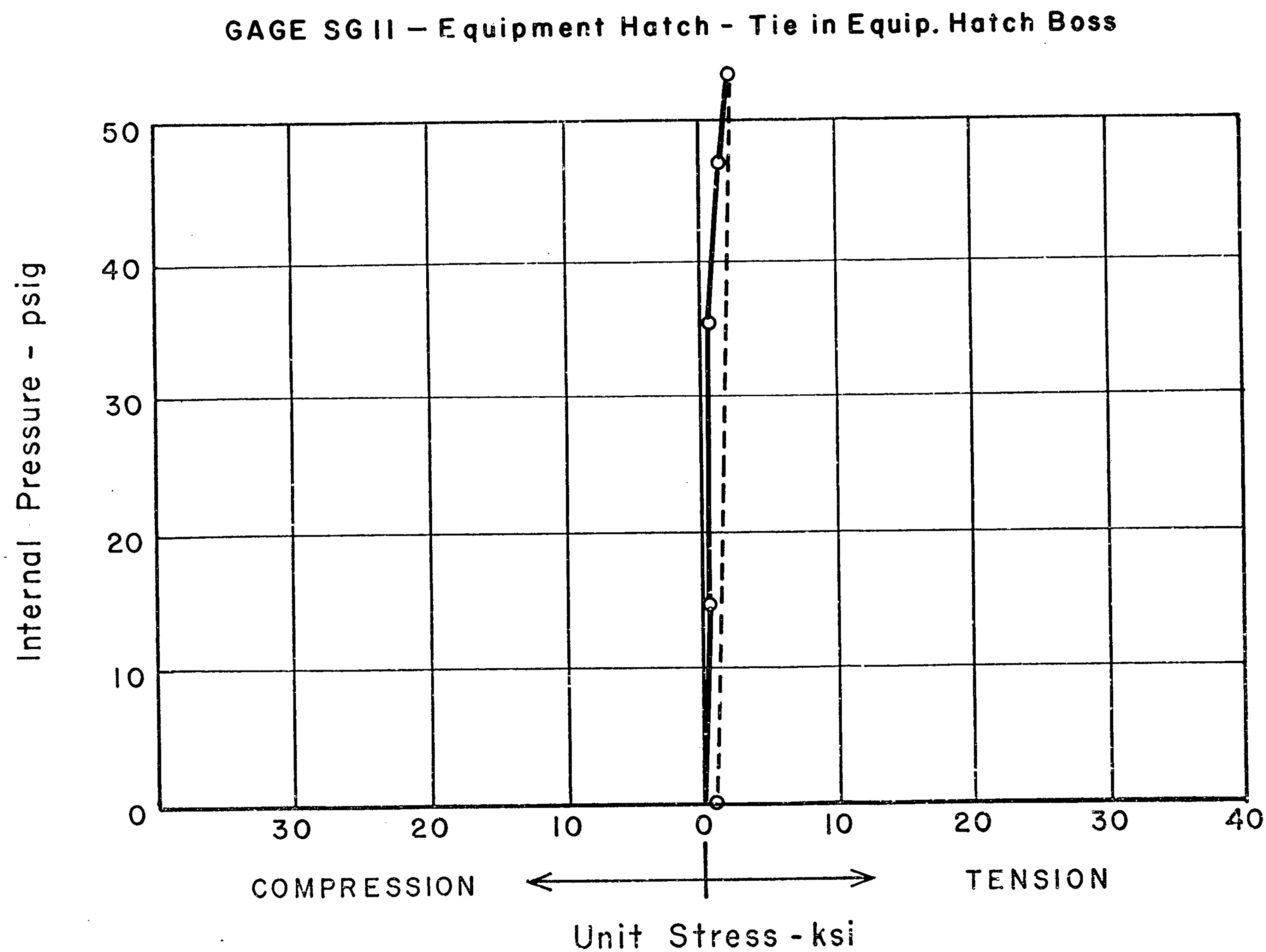


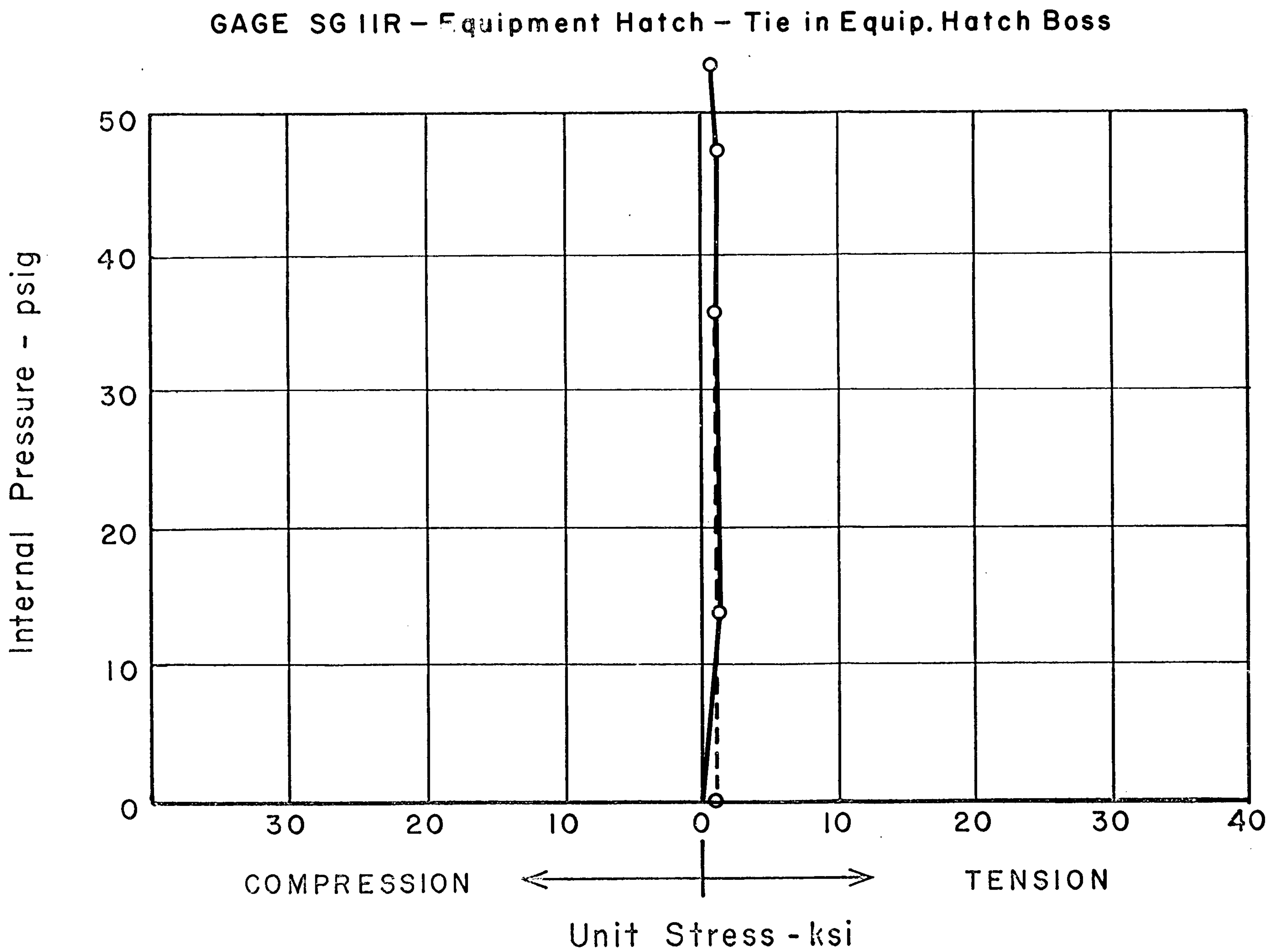
GAGE SG10 - Equipment Hatch - Hoop in Equip. Hatch Boss



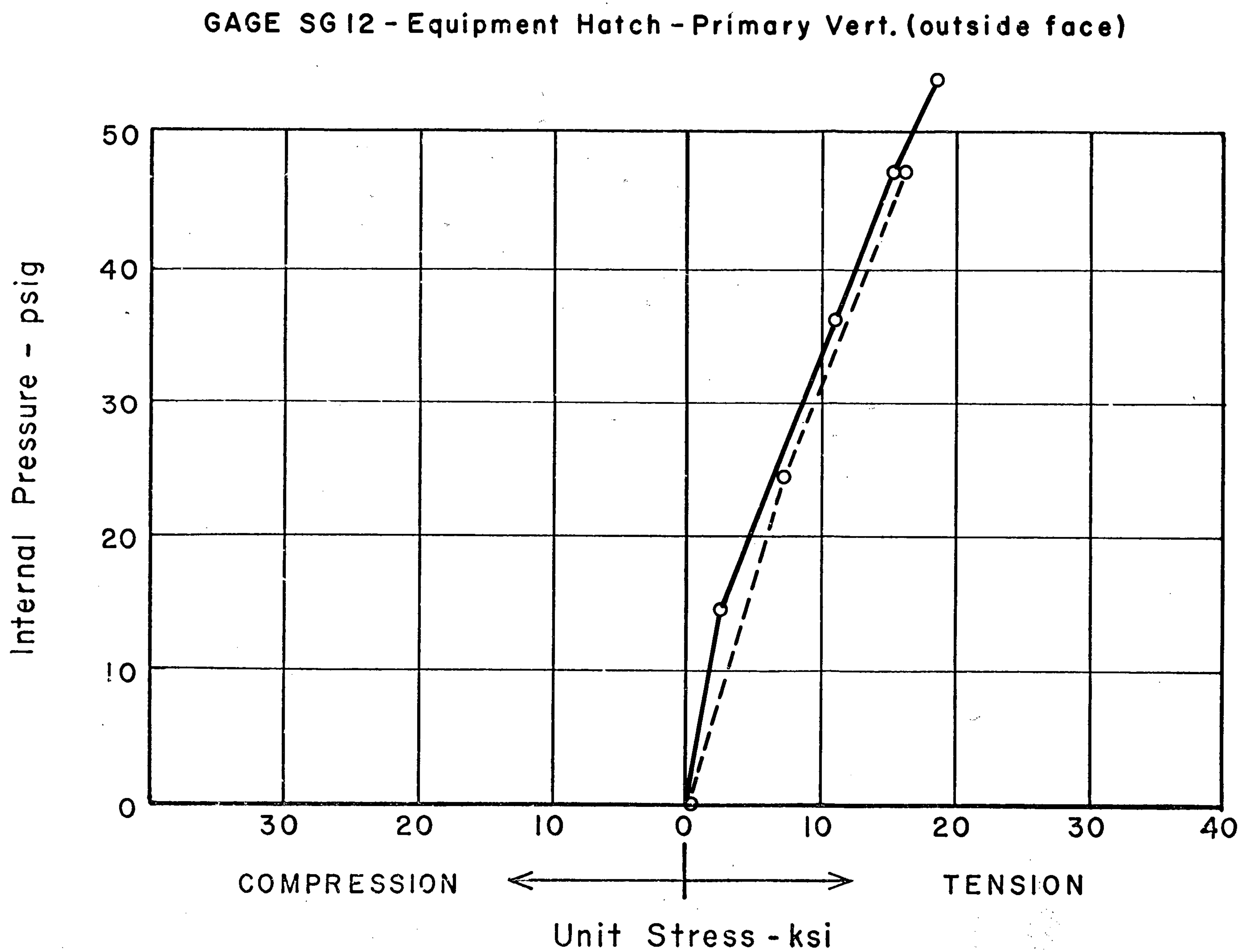
GAGE SG 10R - Equipment Hatch - Hoop in Equip. Hatch Boss



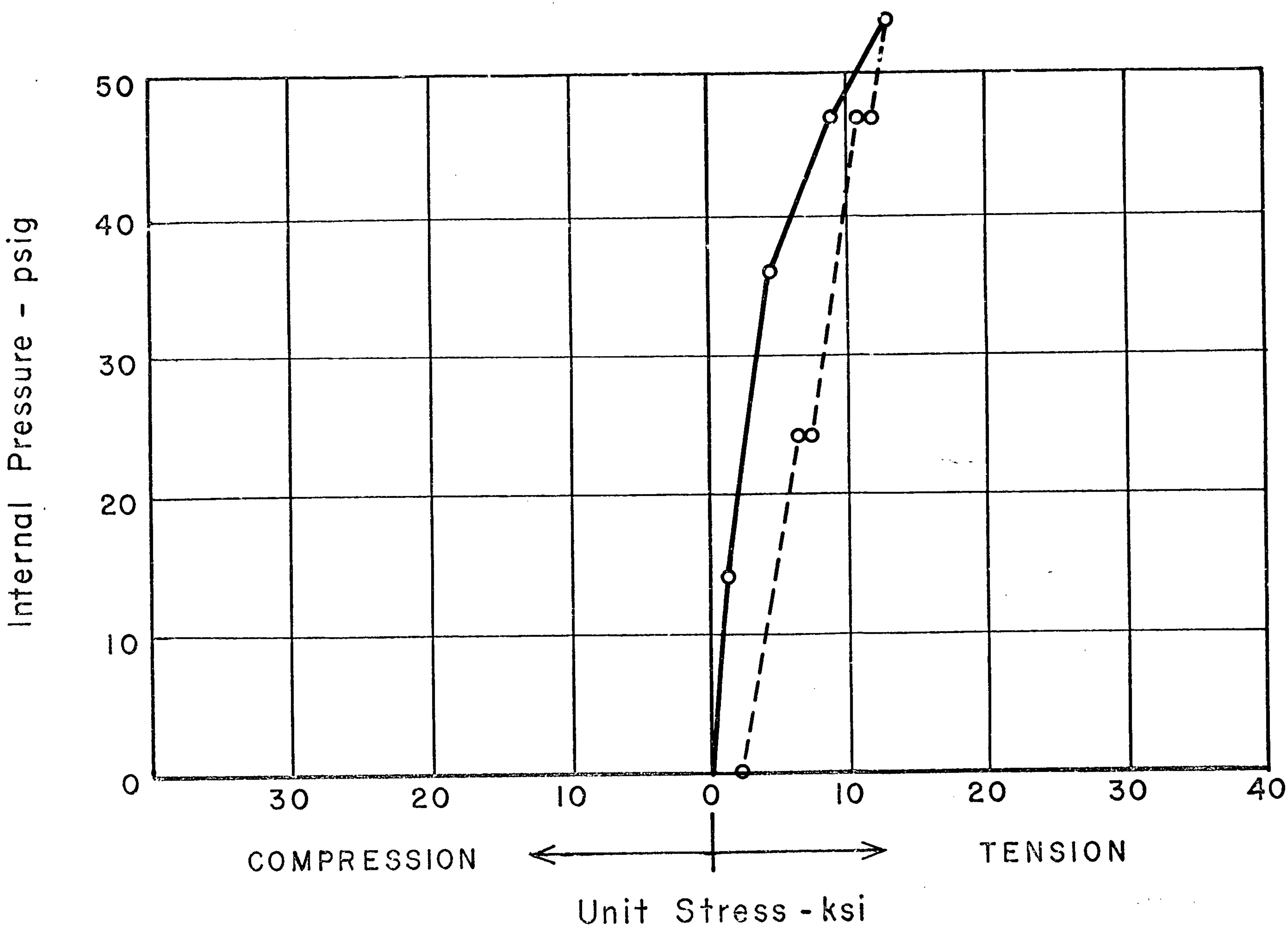

GAGE SG 11 – Equipment Hatch – Tie in Equip. Hatch Boss
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

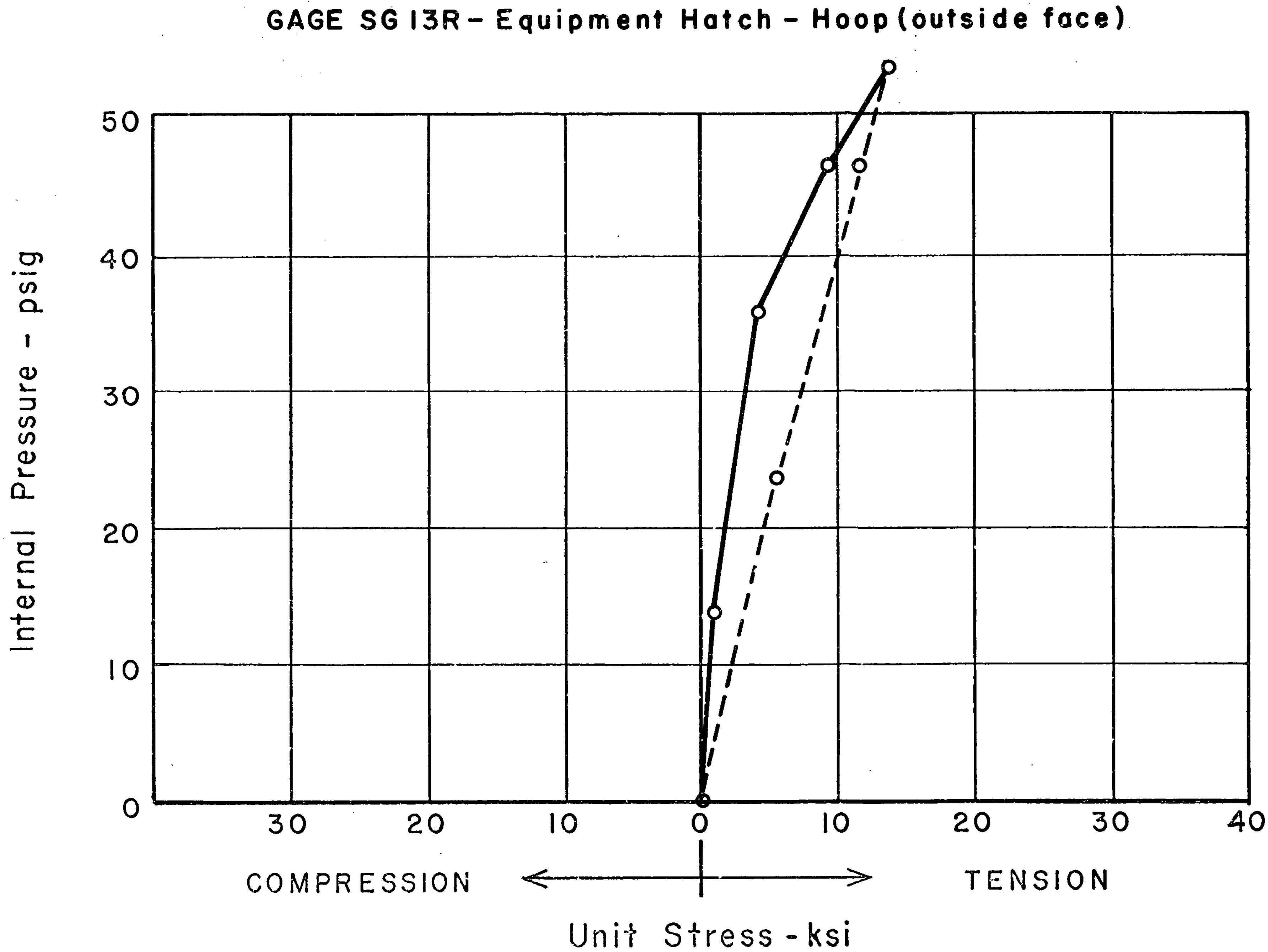


GAGE SG 11R – Equipment Hatch – Tie in Equip. Hatch Boss
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

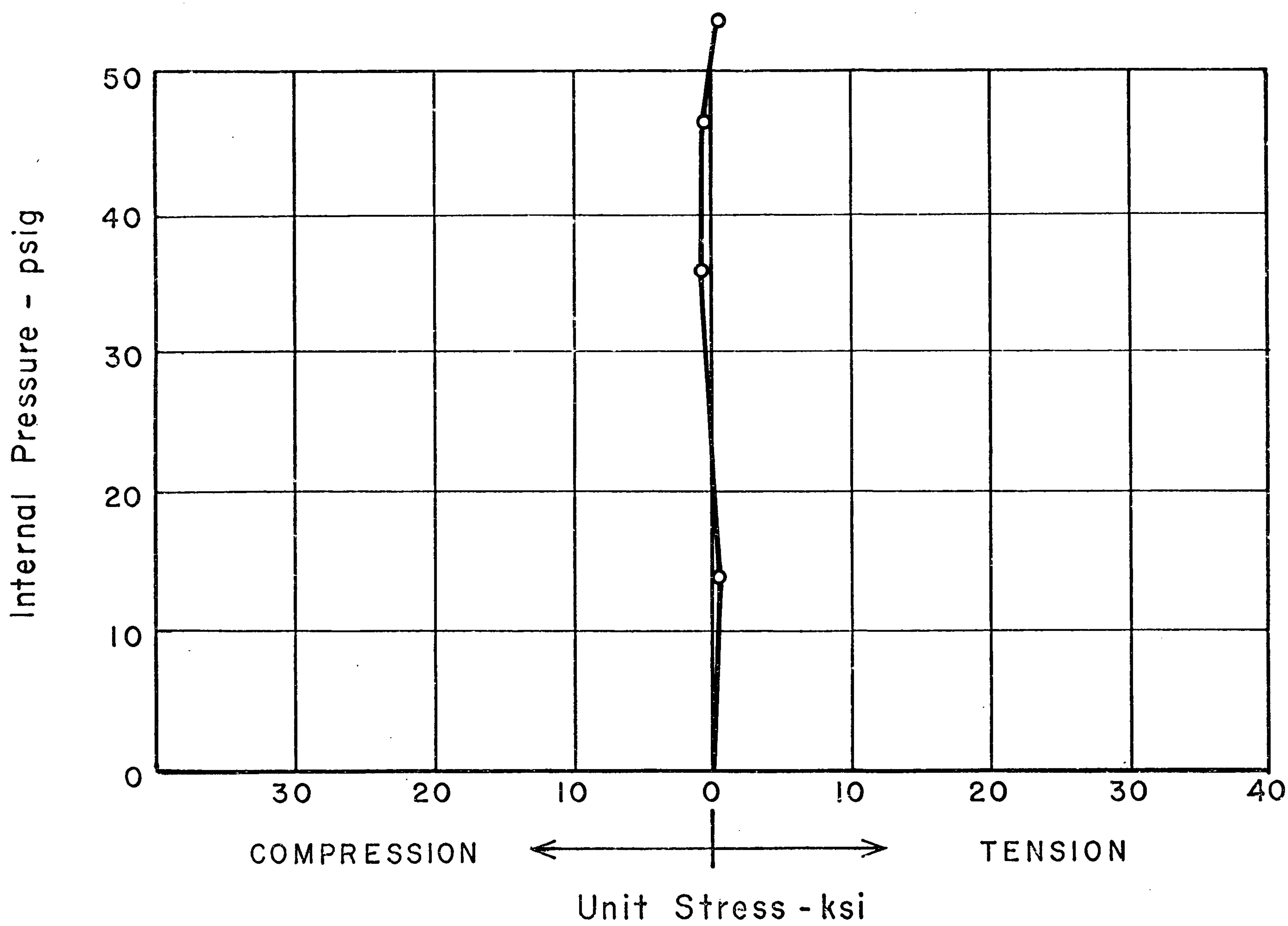

GAGE SG 12 - Equipment Hatch - Primary Vert. (outside face)
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

GAGE SG 13 - Equipment Hatch - Hoop (outside face)

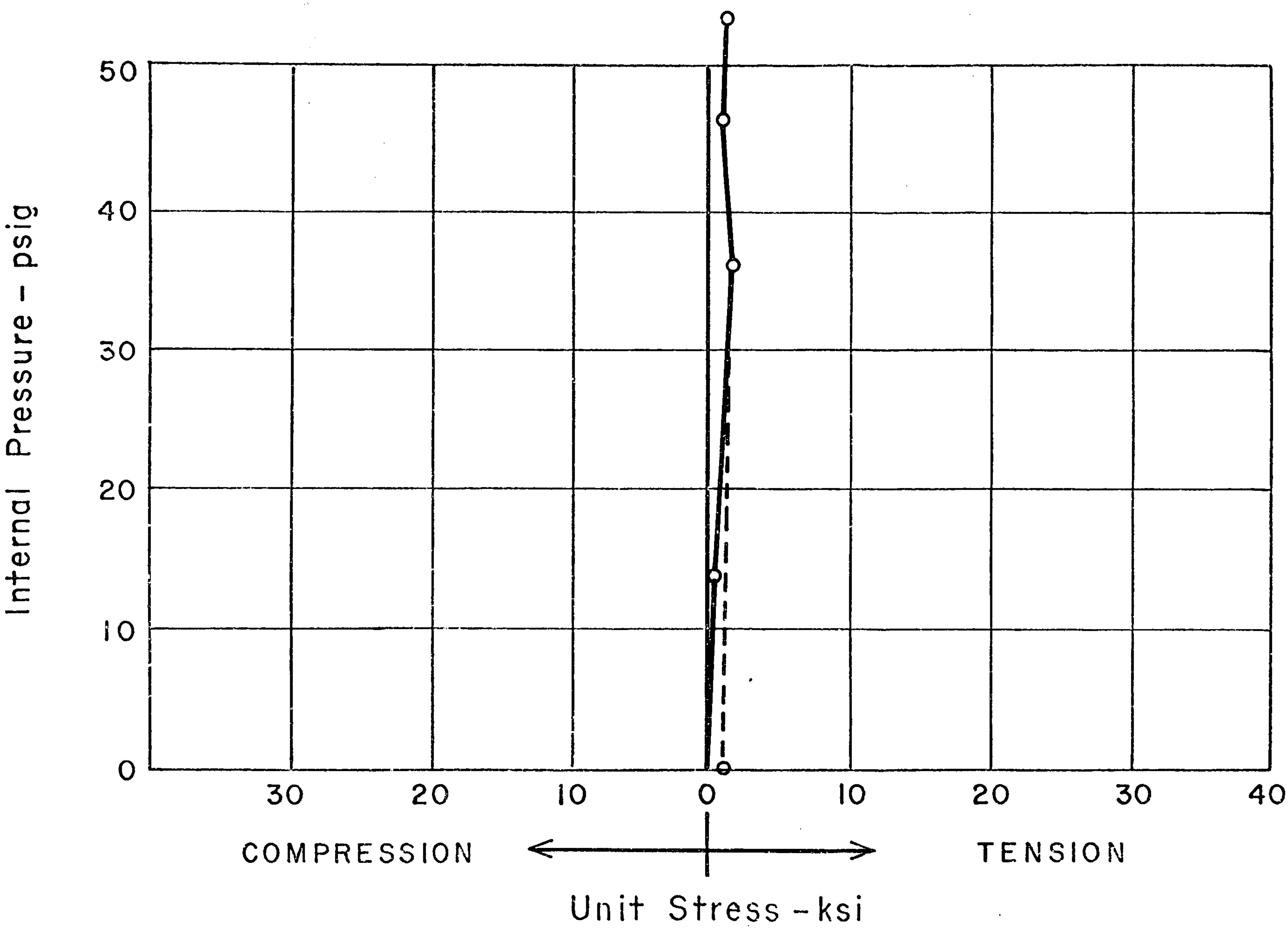


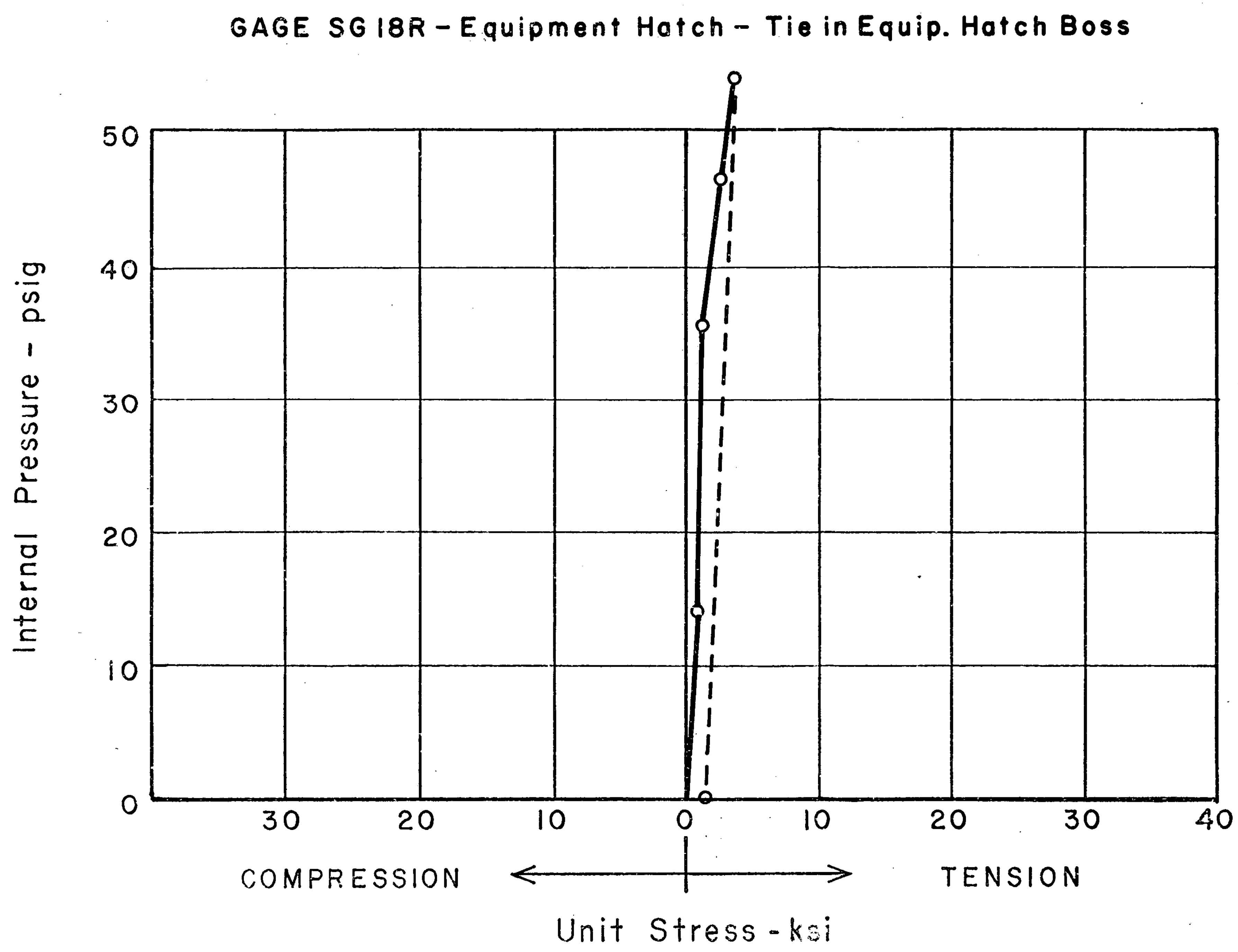

GAGE SG 13R - Equipment Hatch - Hoop (outside face)
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

GAGE SG 17 - Equipment Hatch - Hoop in Equip. Hatch Boss

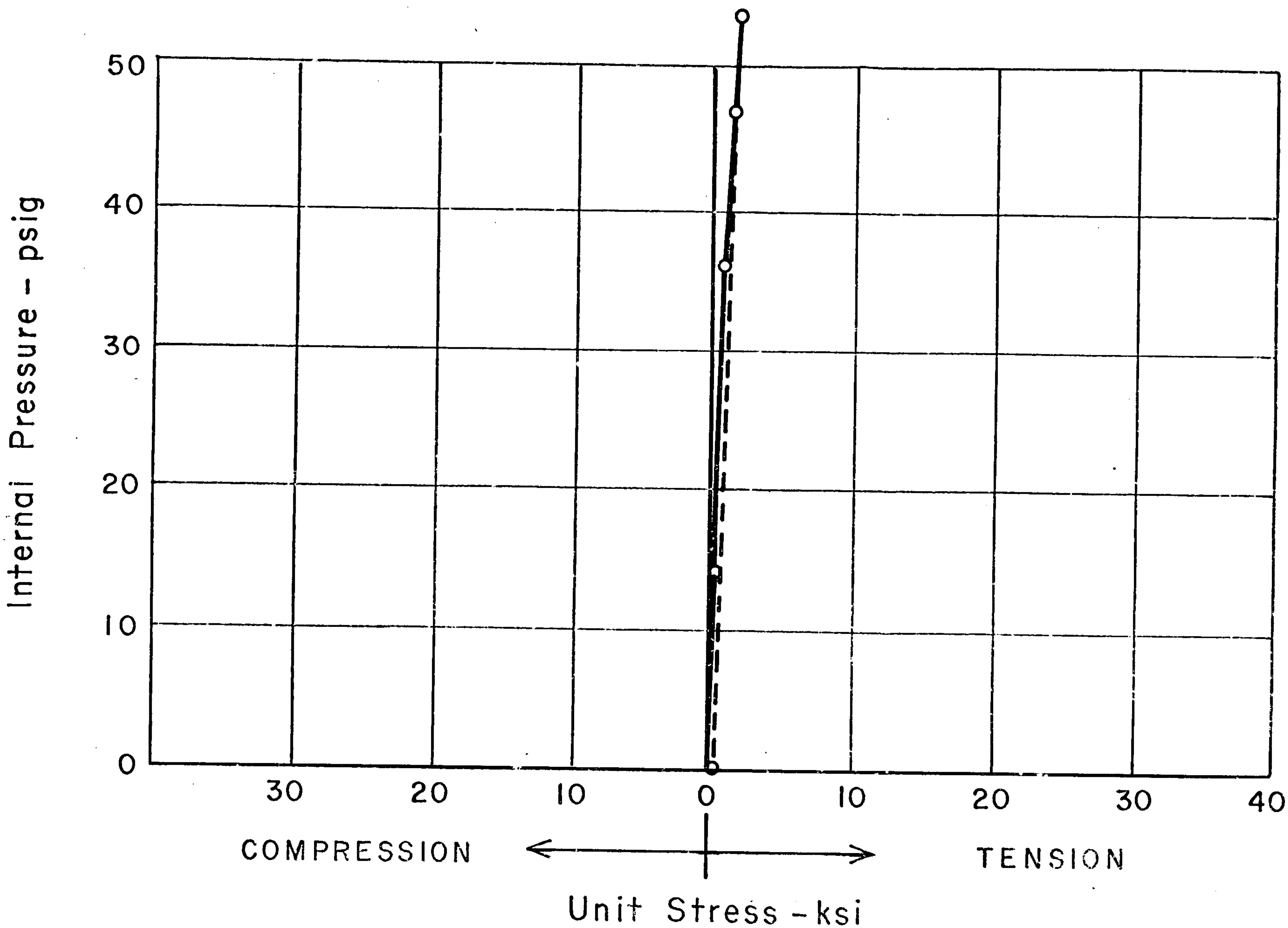


GAGE SG18 – Equipment Hatch – Tie in Equip. Hatch Boss

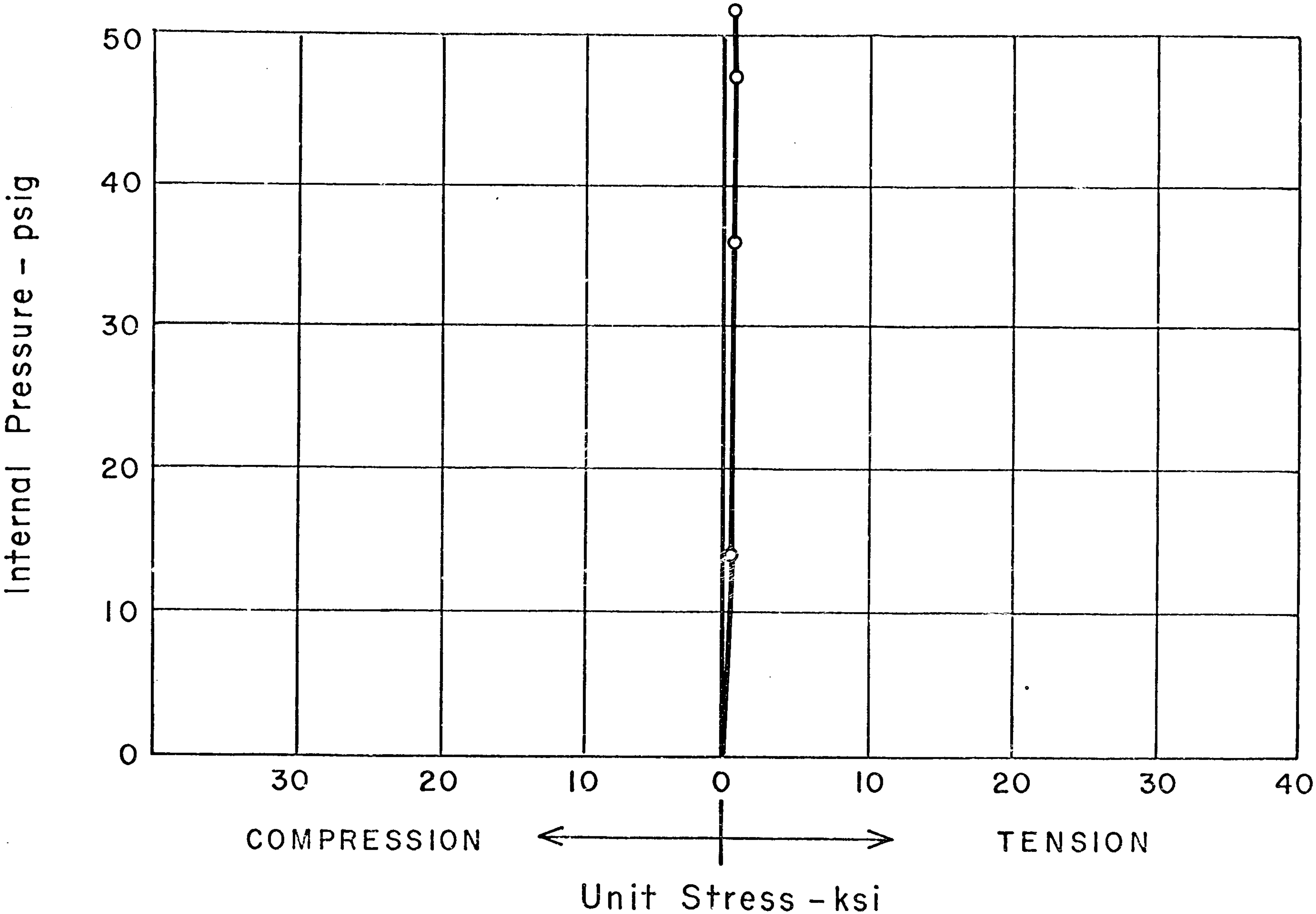



GAGE SG 18R - Equipment Hatch - Tie in Equip. Hatch Boss
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

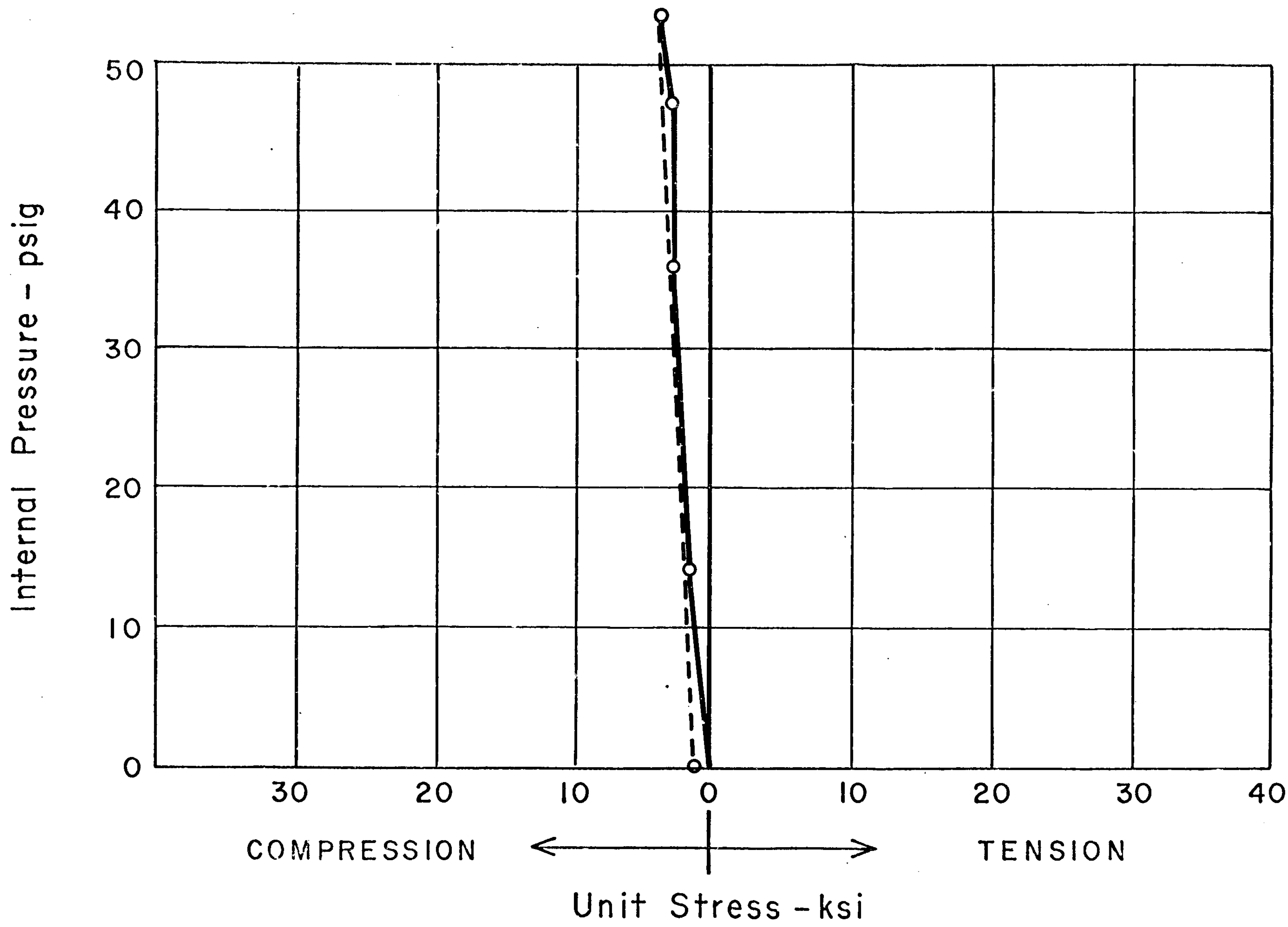
GAGE SG 19 - Equipment Hatch - Hoop in Equip. Hatch Boss

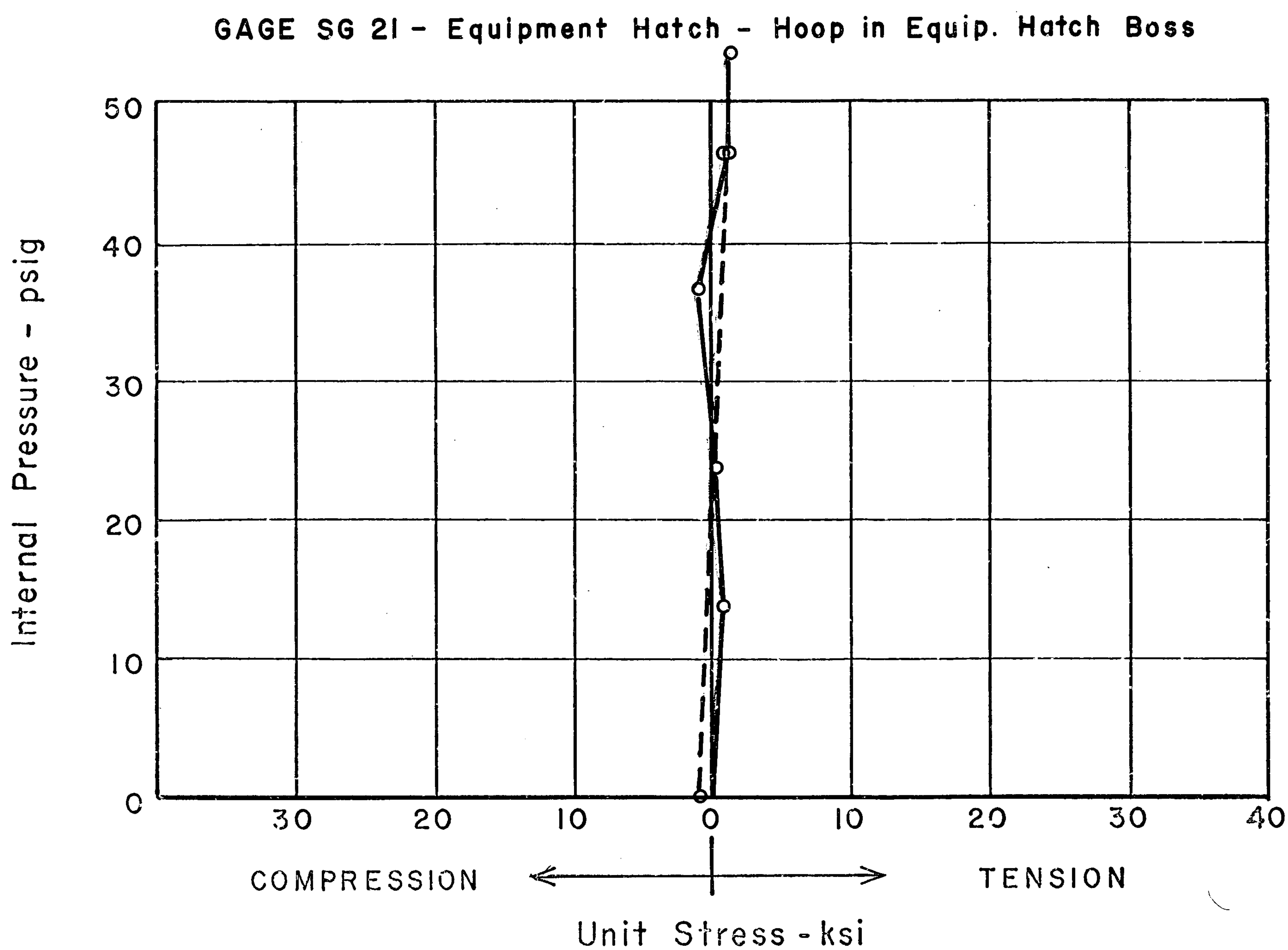


GAGE SG 20 - Equipment Hatch - Tie in Equip. Hatch Boss

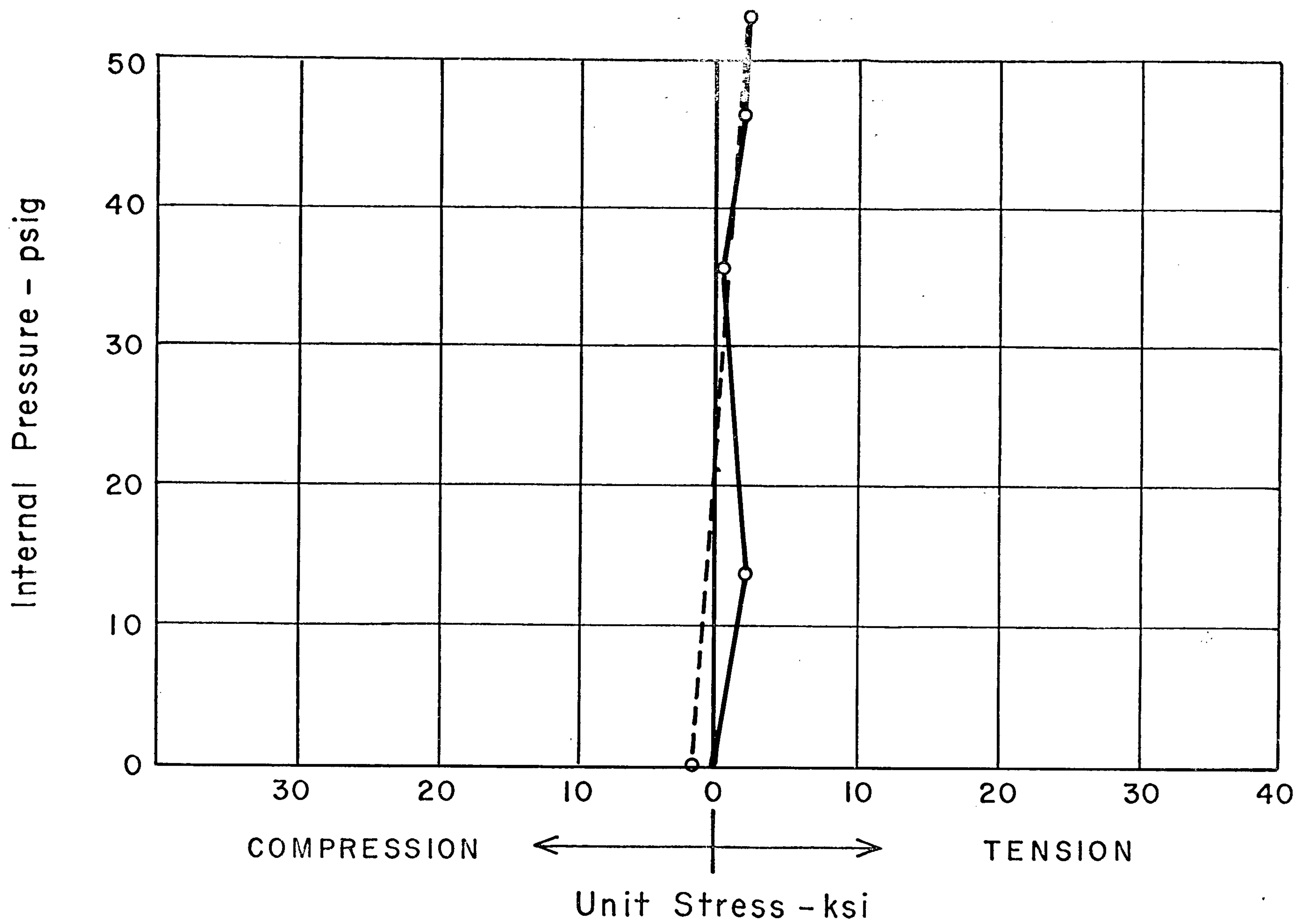


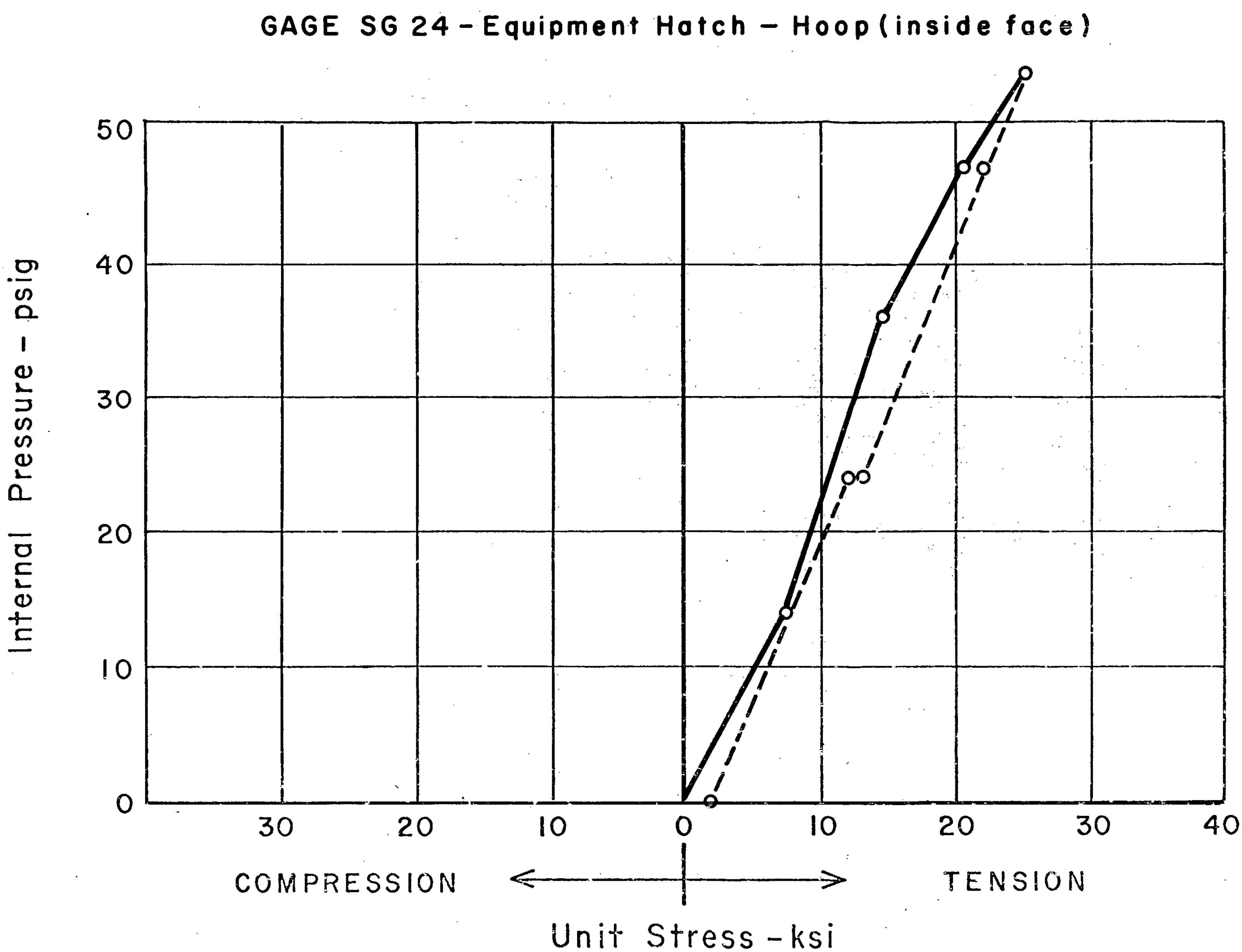
GAGE SG 20R – Equipment Hatch – Tie in Equip. Hatch Boss



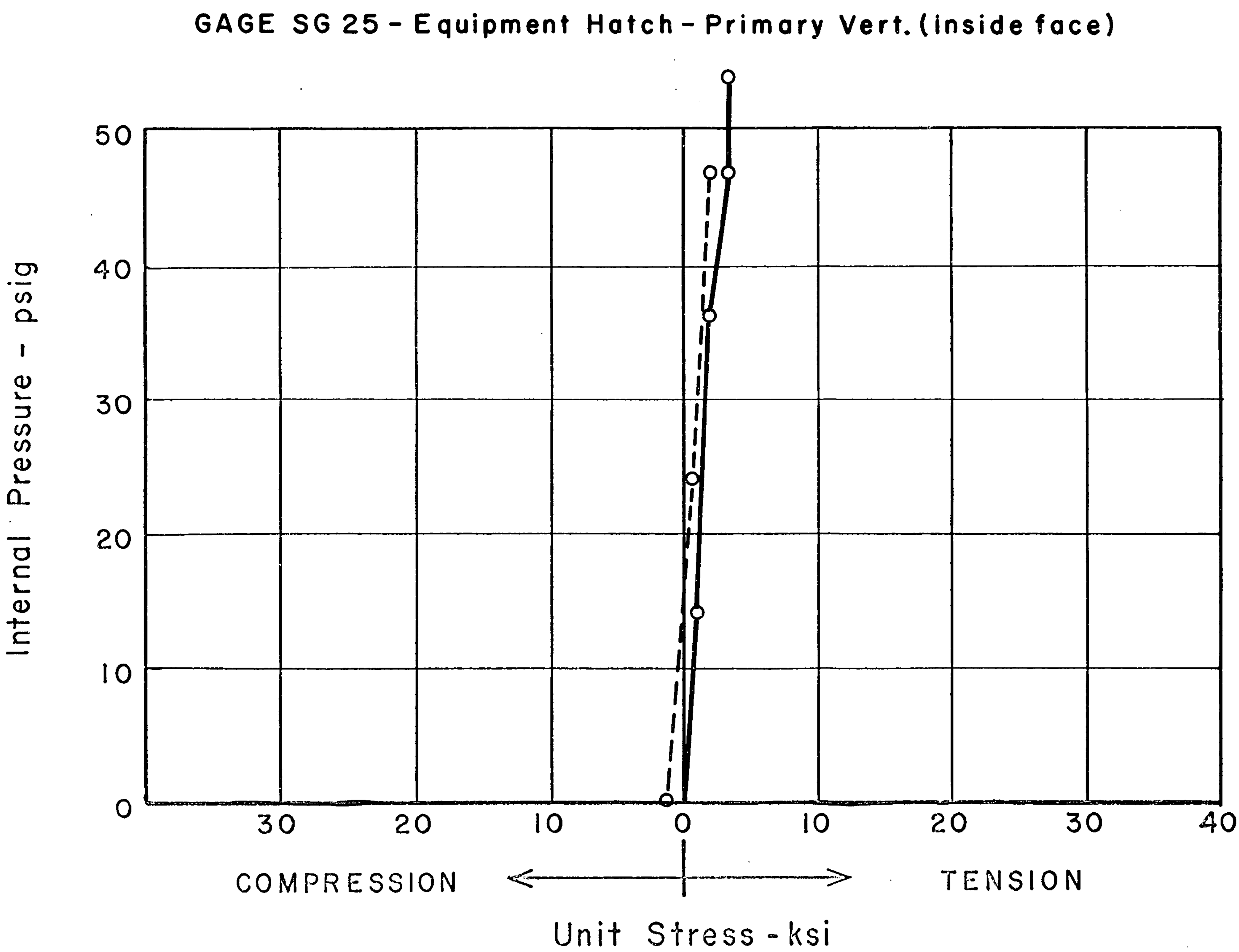

GAGE SG 21 - Equipment Hatch - Hoop in Equip. Hatch Boss
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

GAGE SG 22 - Equipment Hatch - Hoop in Equip. Hatch Boss

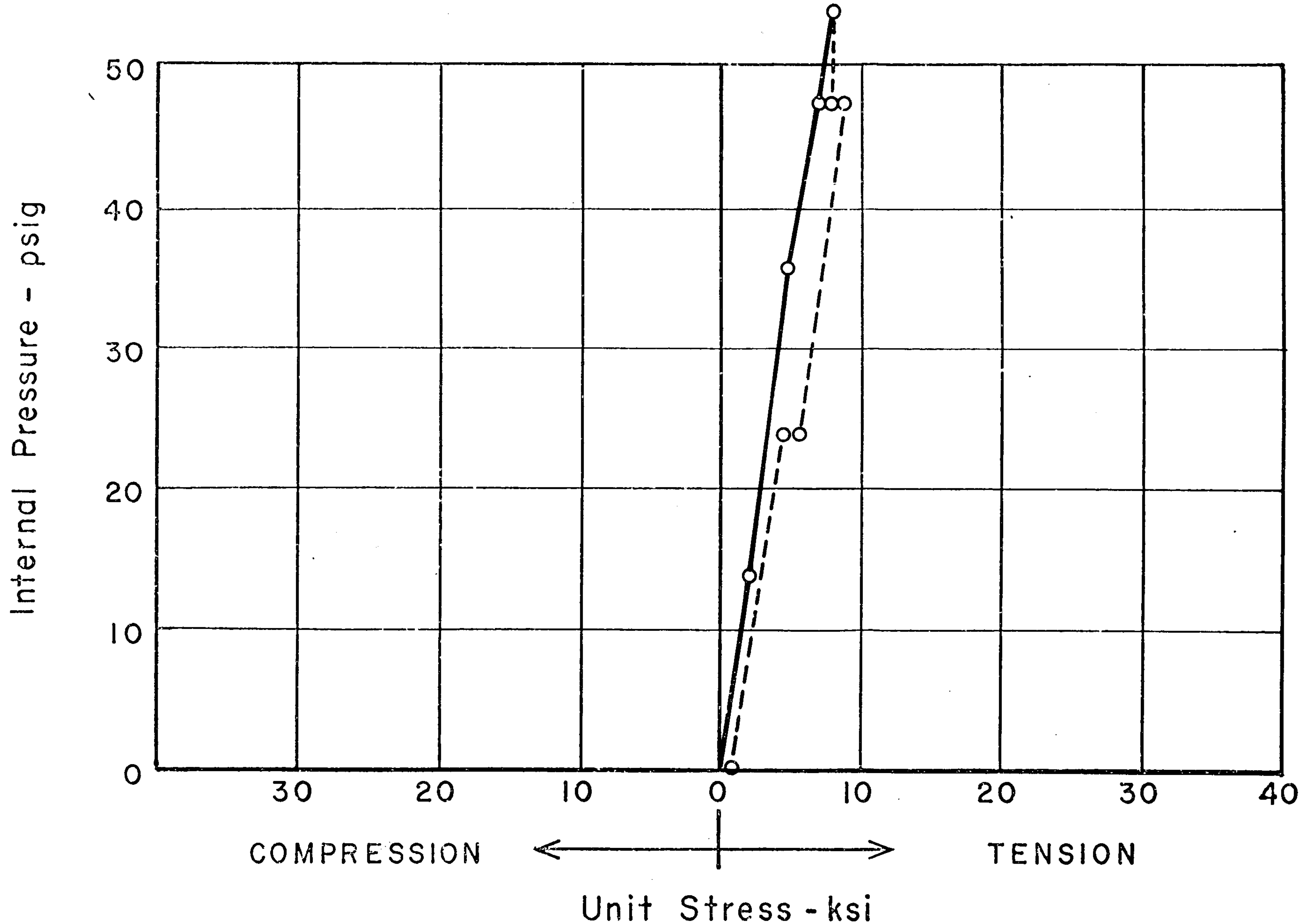




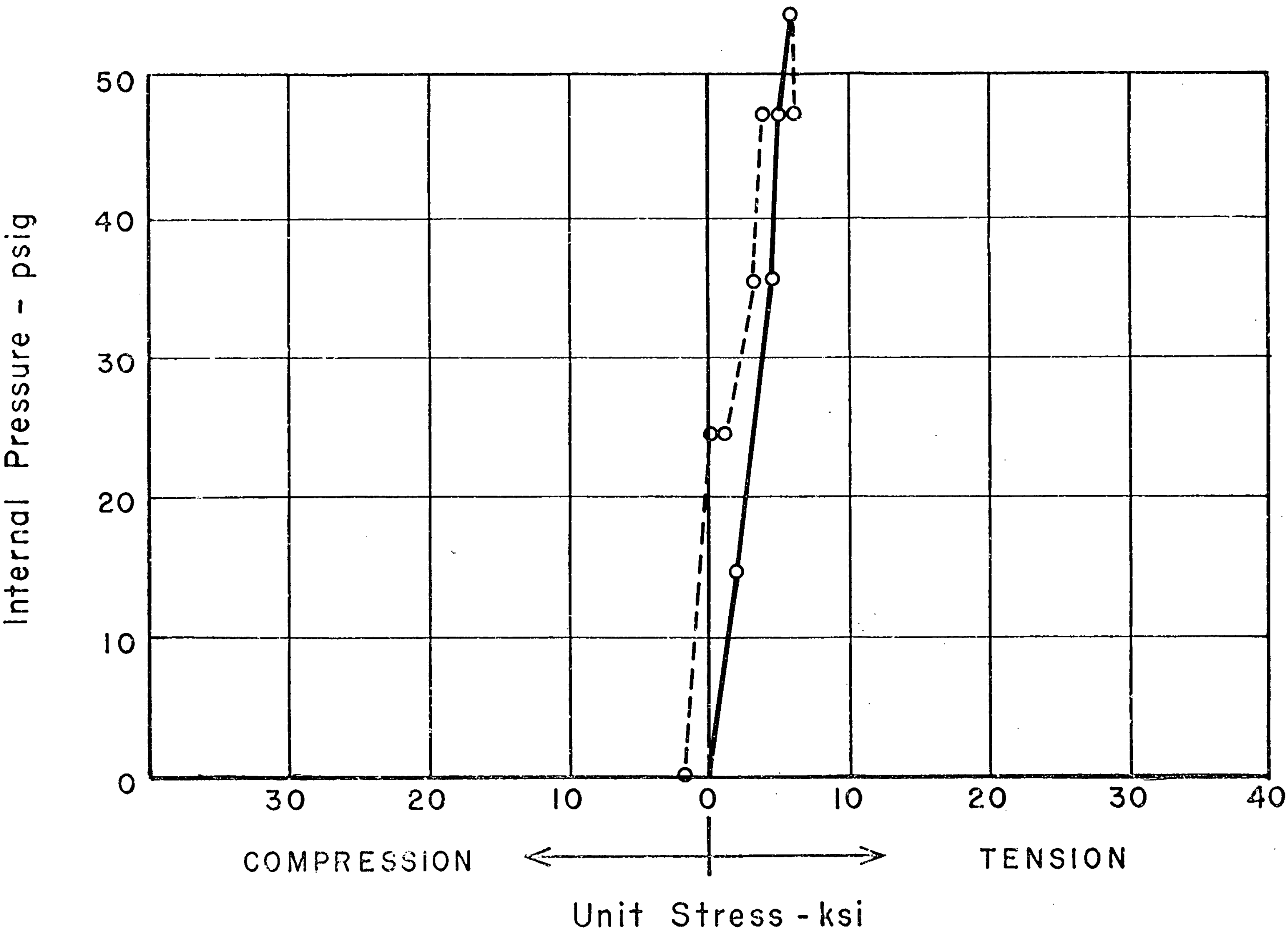
GAGE SG 24 - Equipment Hatch - Hoop (inside face)
Internal Pressure - psig
0
10
20
30
40
50
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi


GAGE SG 25 - Equipment Hatch - Primary Vert. (inside face)
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

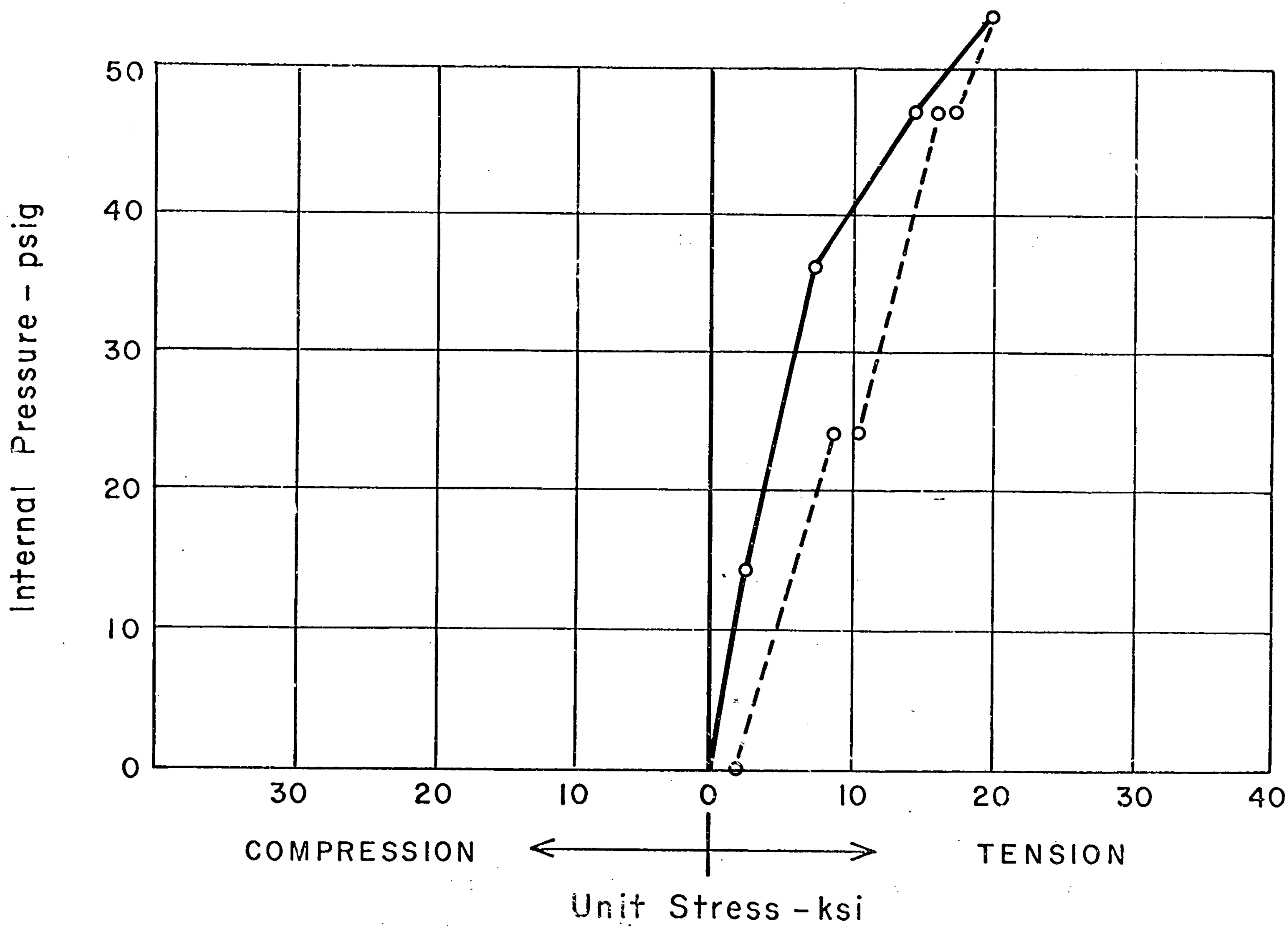
GAGE SG 26 – Equipment Hatch – Primary Vert. (outside face)

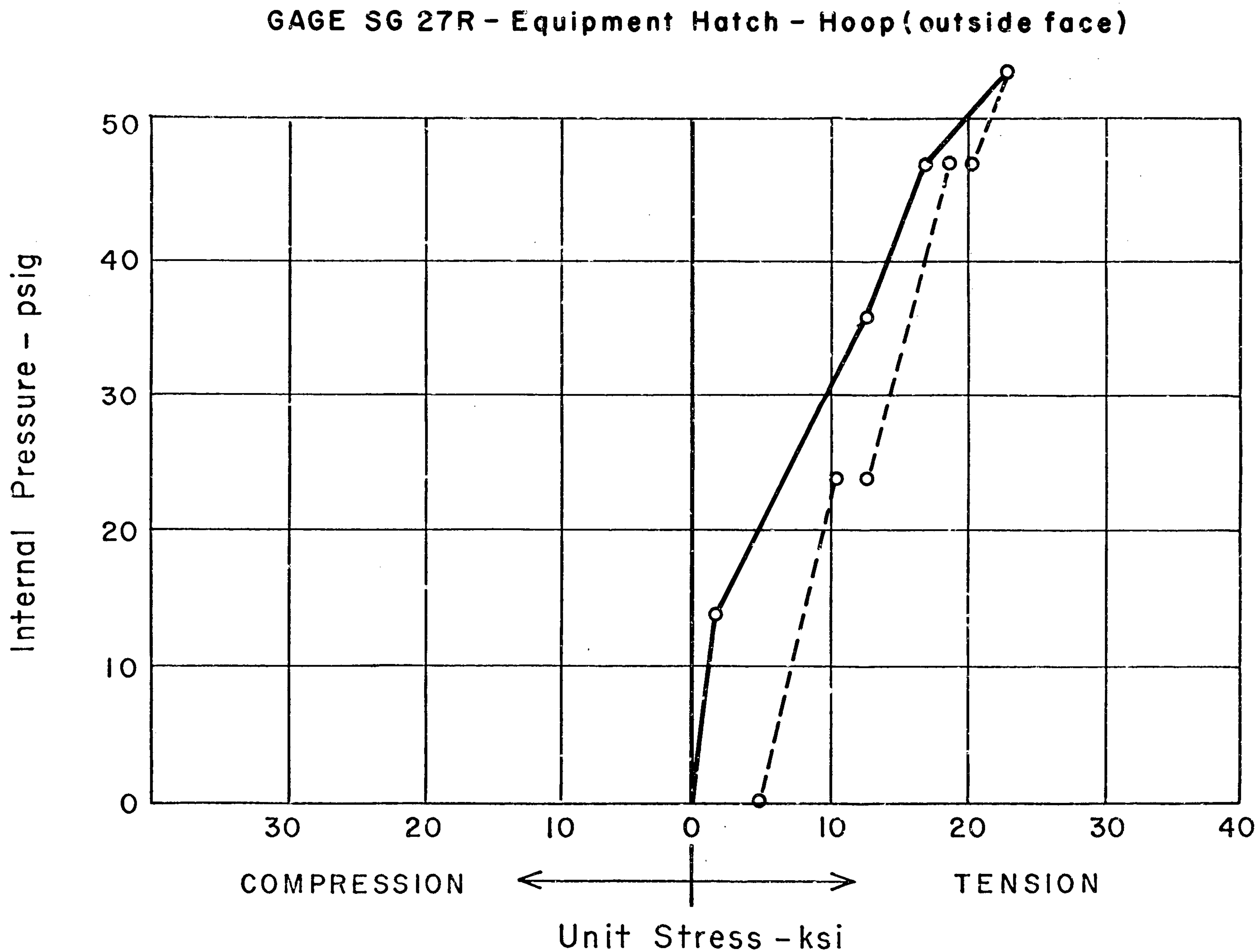


GAGE SG 26R - Equipment Hatch - Primary Vert. (outside face)

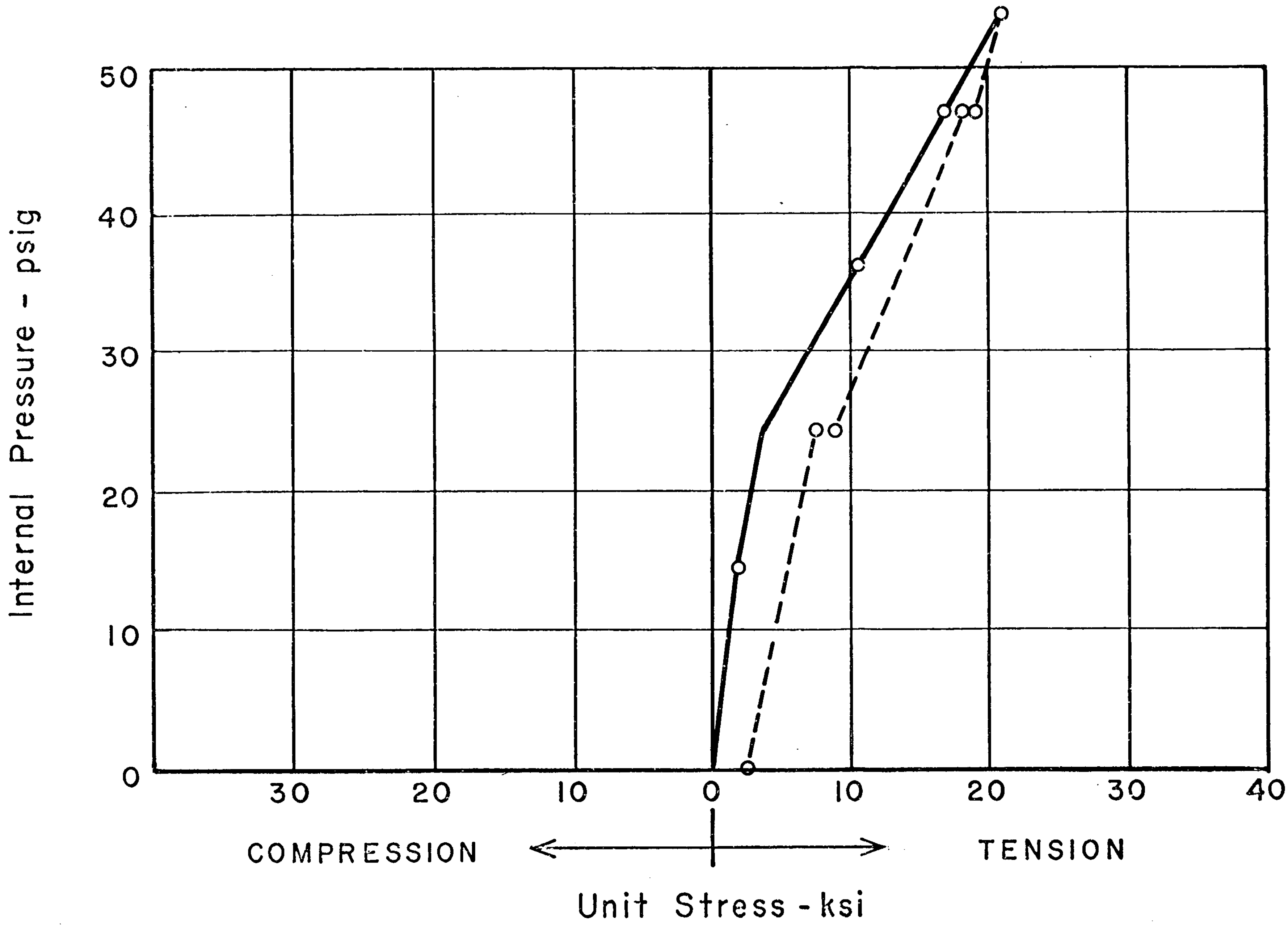


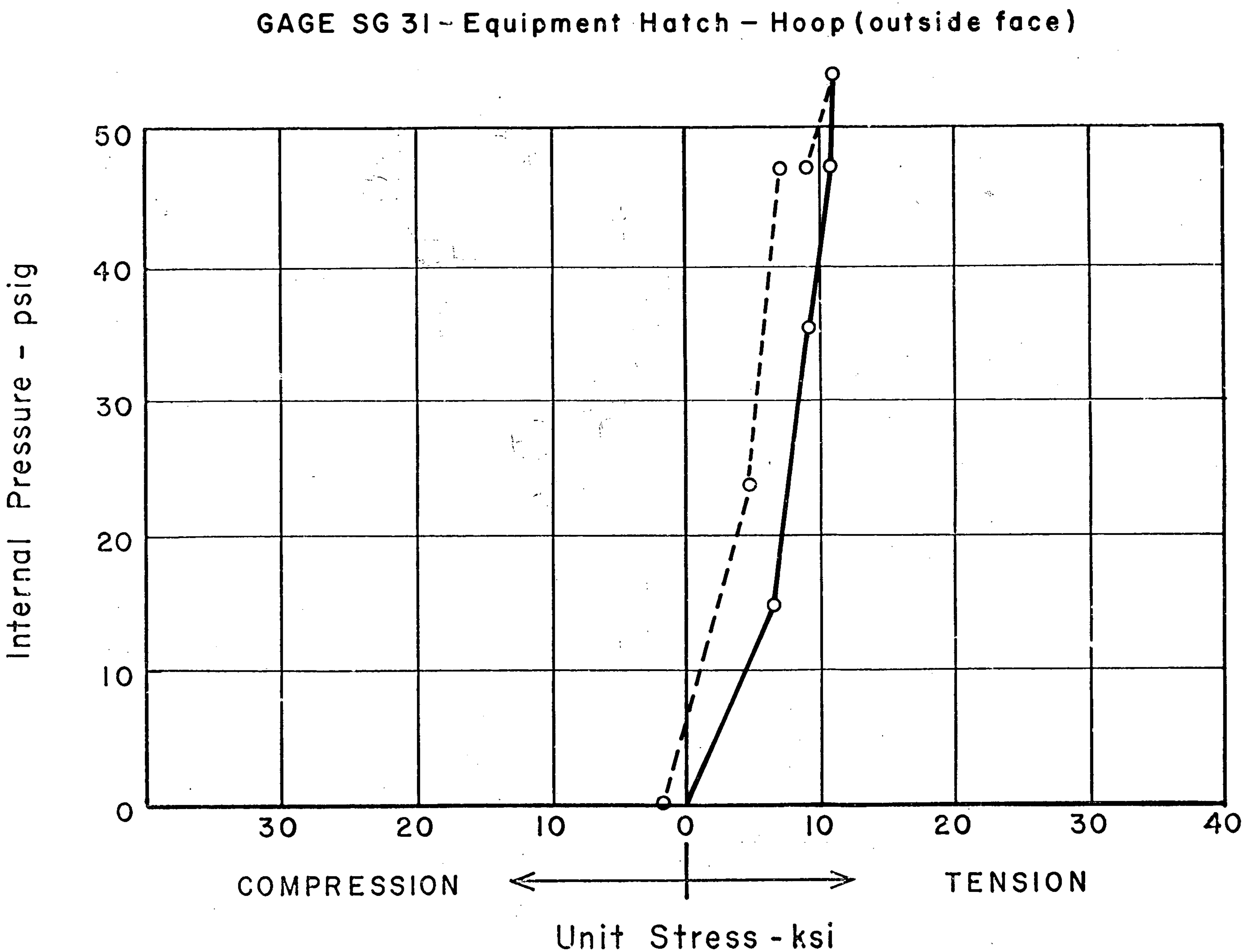
GAGE SG 27 - Equipment Hatch - Hoop (outside face)



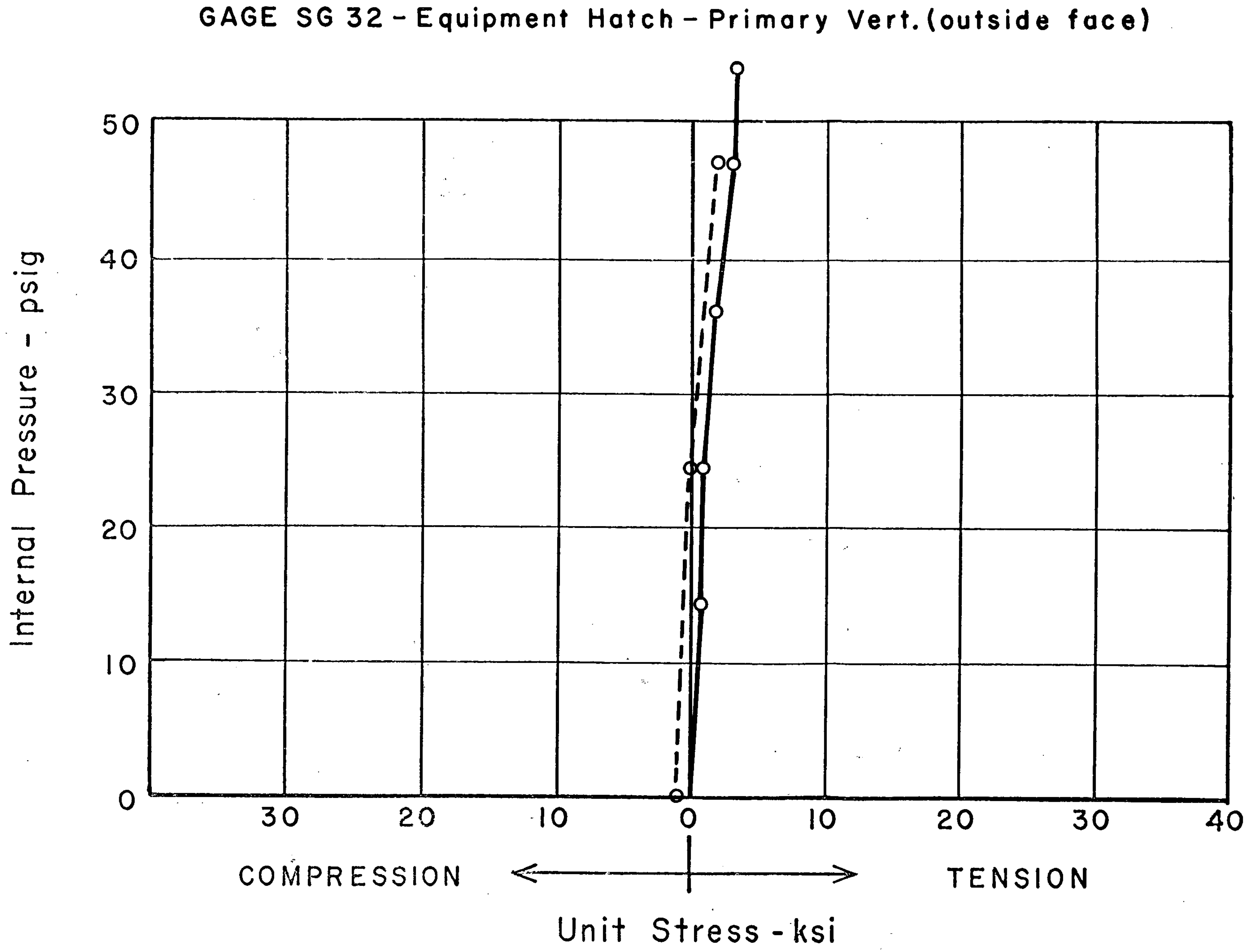

GAGE SG 27R - Equipment Hatch - Hoop (outside face)
Internal Pressure - psig
0
10
20
30
40
50
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

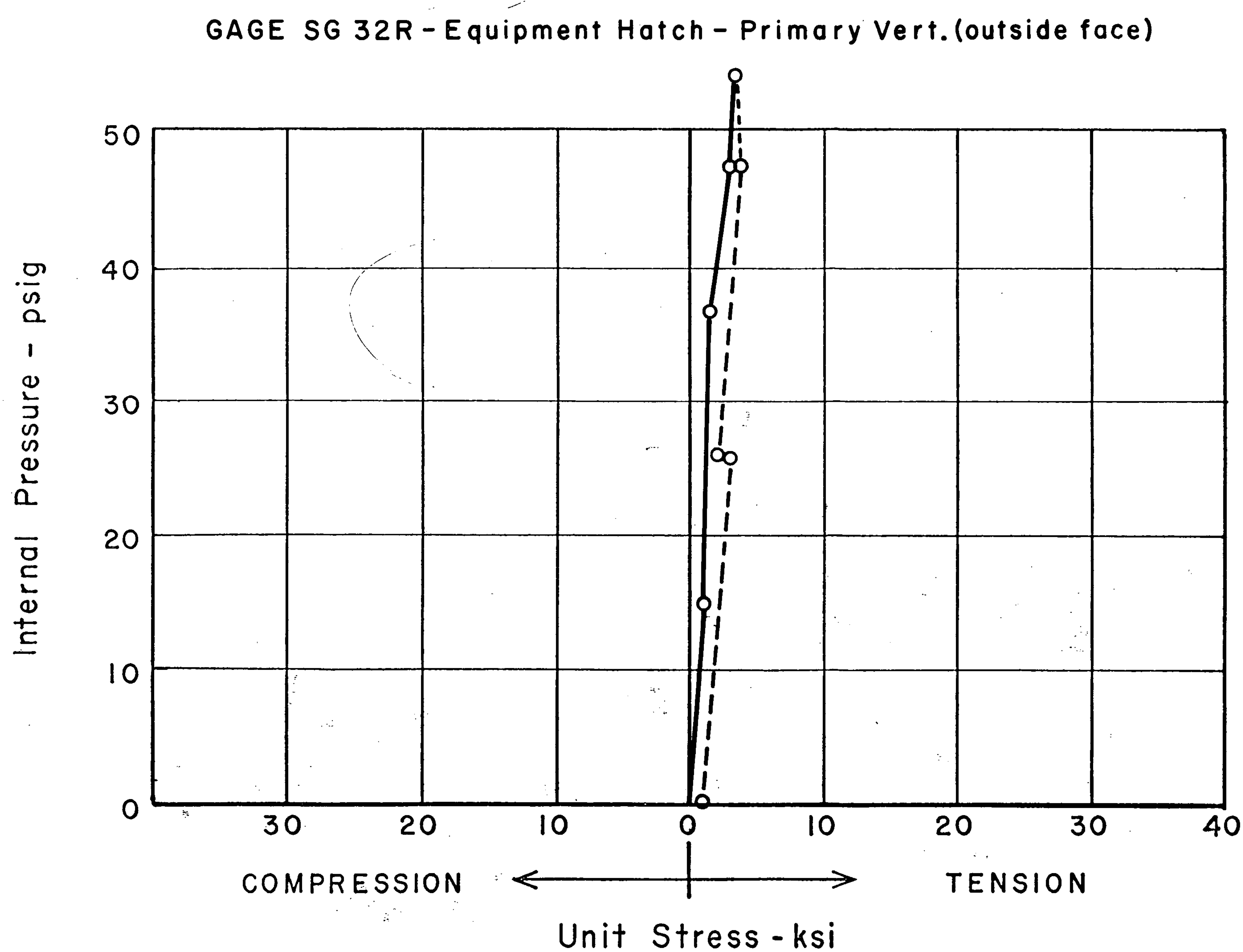
GAGE SG 30 - Equipment Hatch - Primary Vert. (inside face)





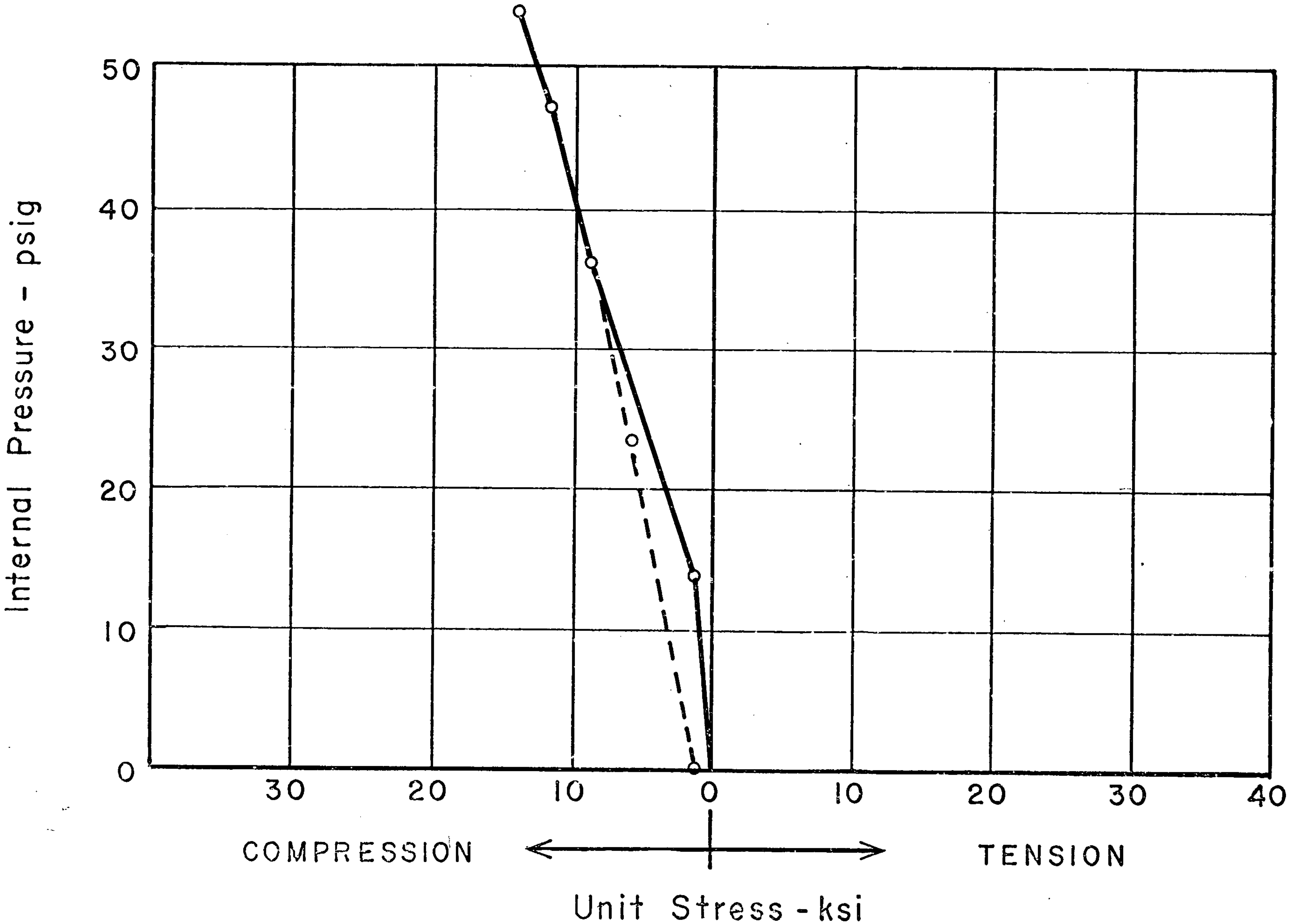
GAGE SG 31 - Equipment Hatch - Hoop (outside face)
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

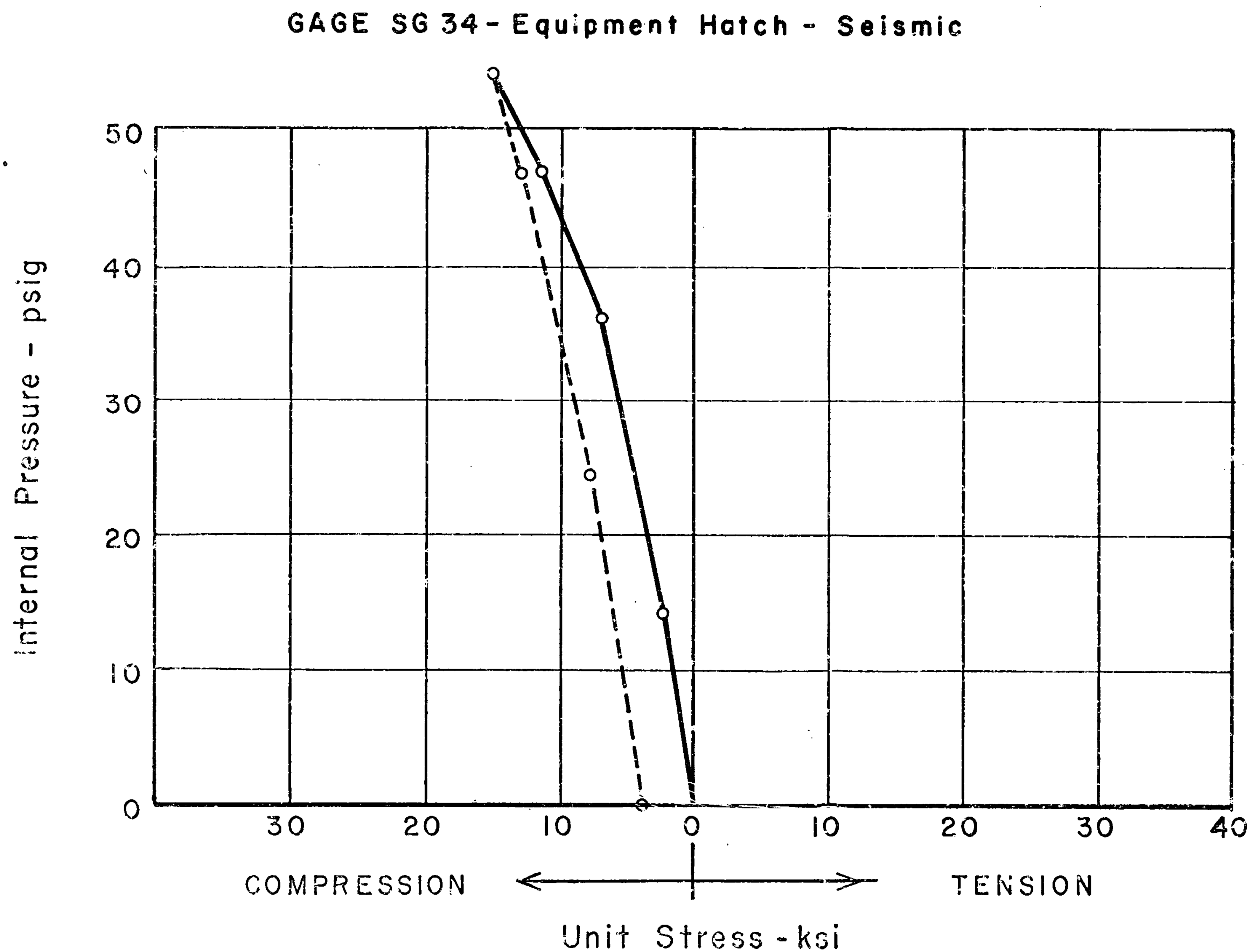

GAGE SG 32 - Equipment Hatch - Primary Vert. (outside face)
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi



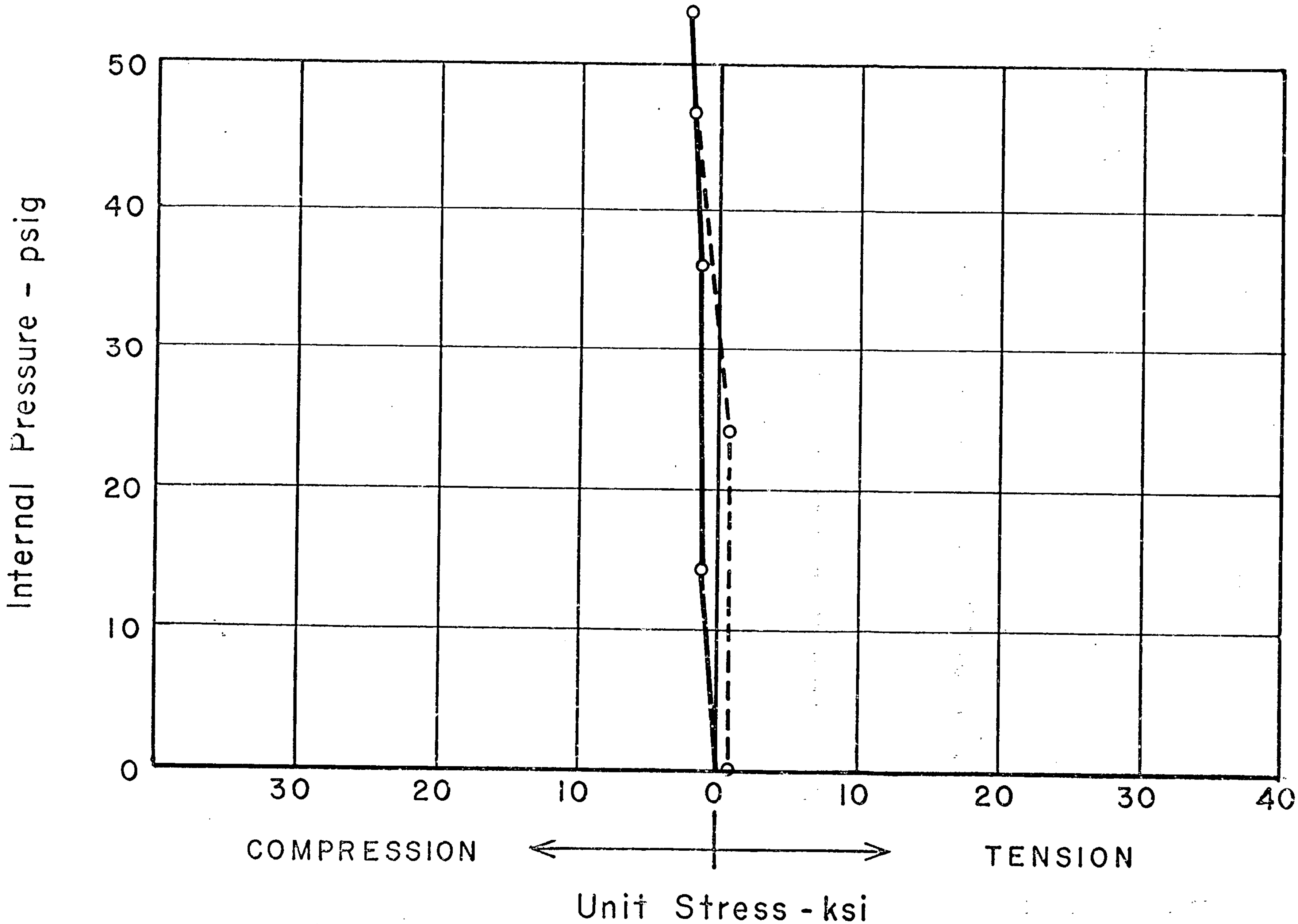
GAGE SG 32R - Equipment Hatch - Primary Vert. (outside face)
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

GAGE SG 33 - Equipment Hatch - Seismic

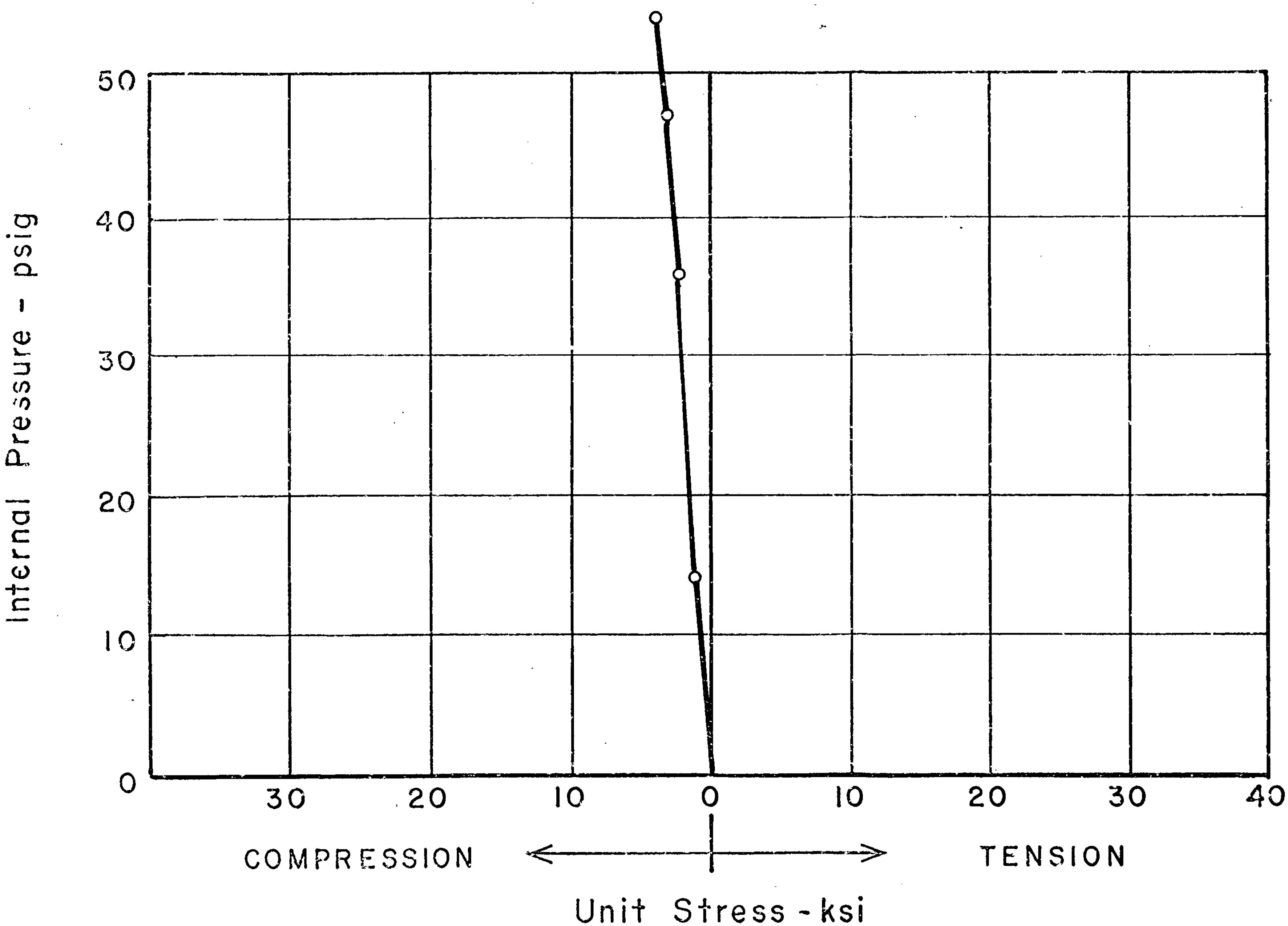


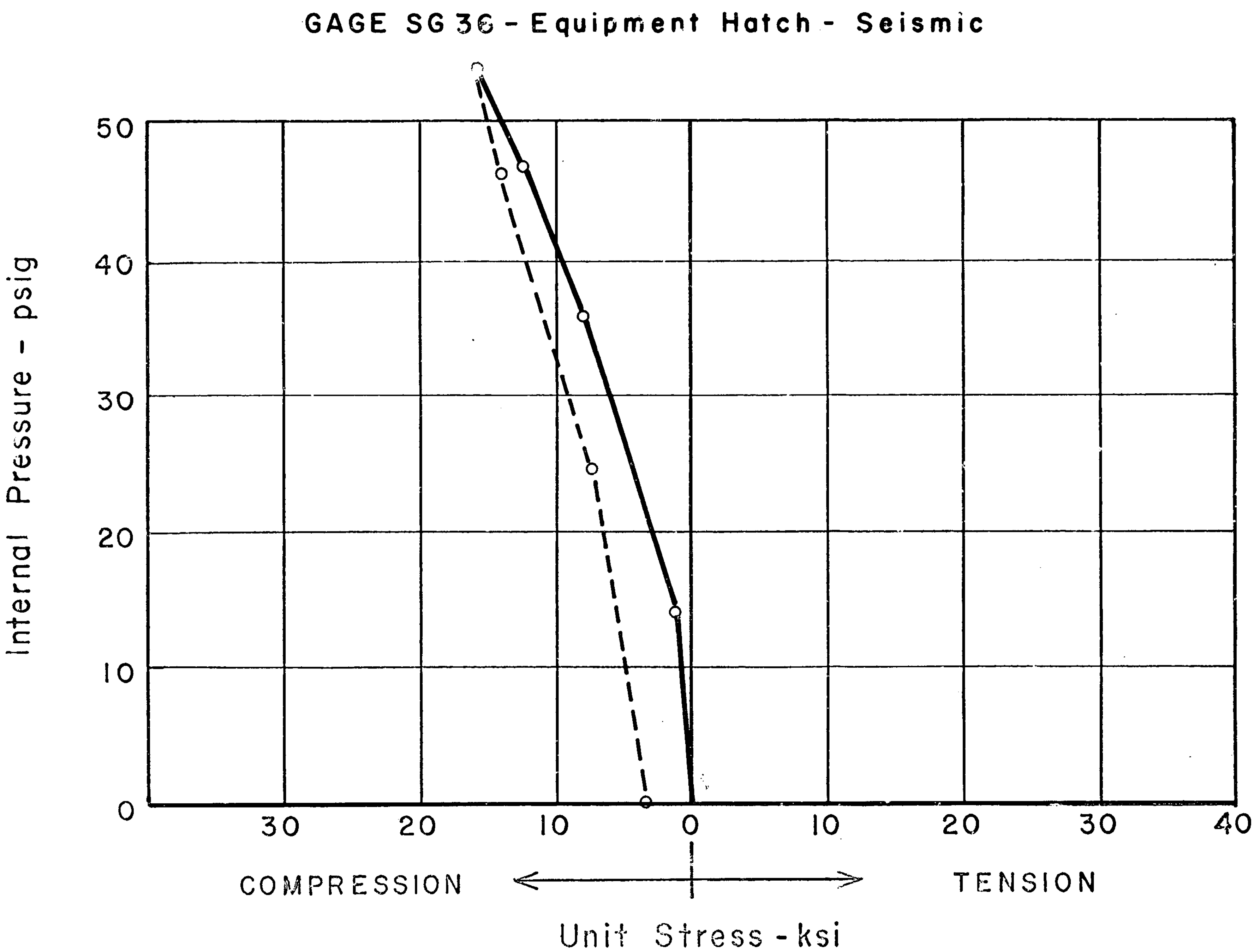

GAGE SG 34 - Equipment Hatch - Seismic
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

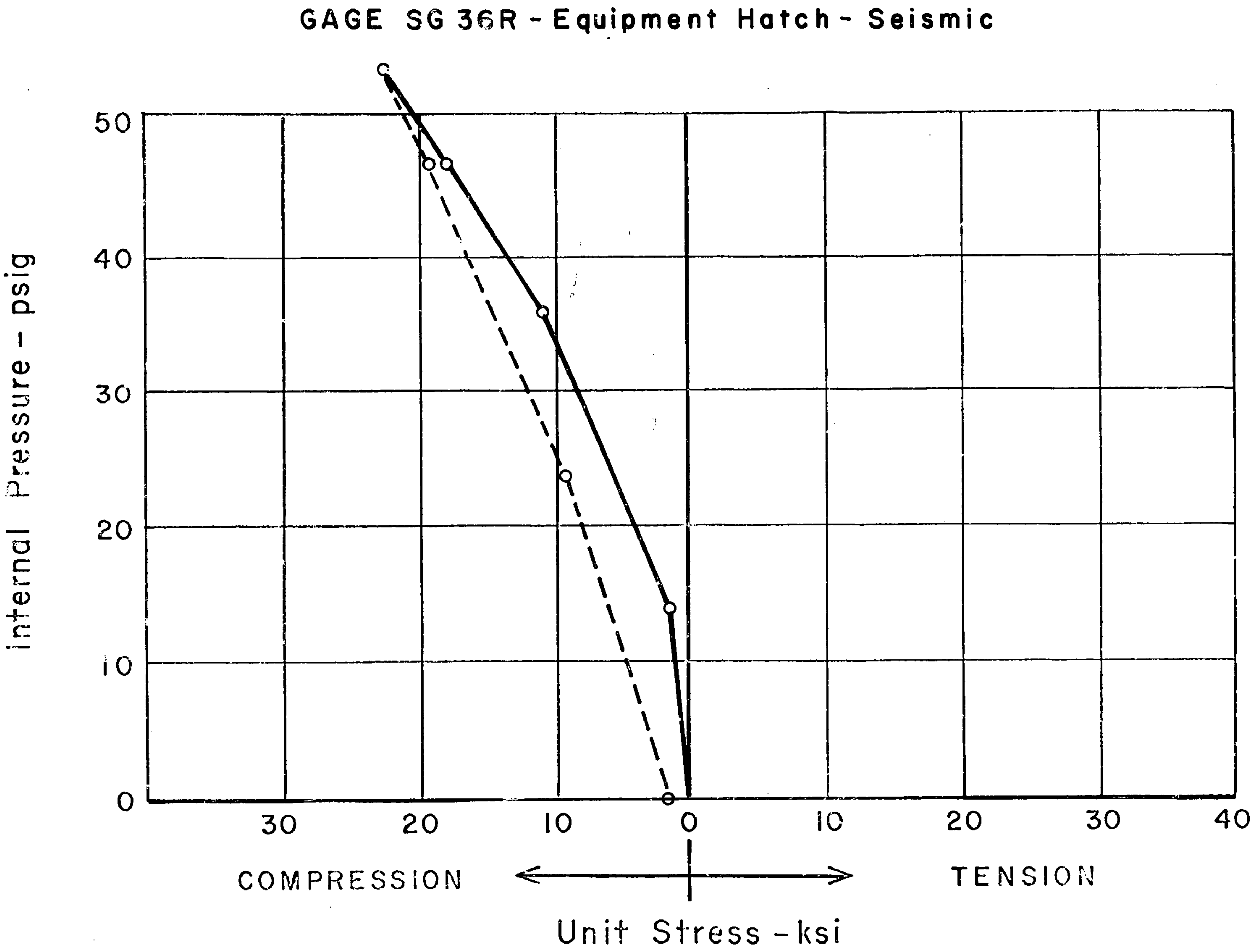
GAGE SG 35 - Equipment Hatch - Seismic



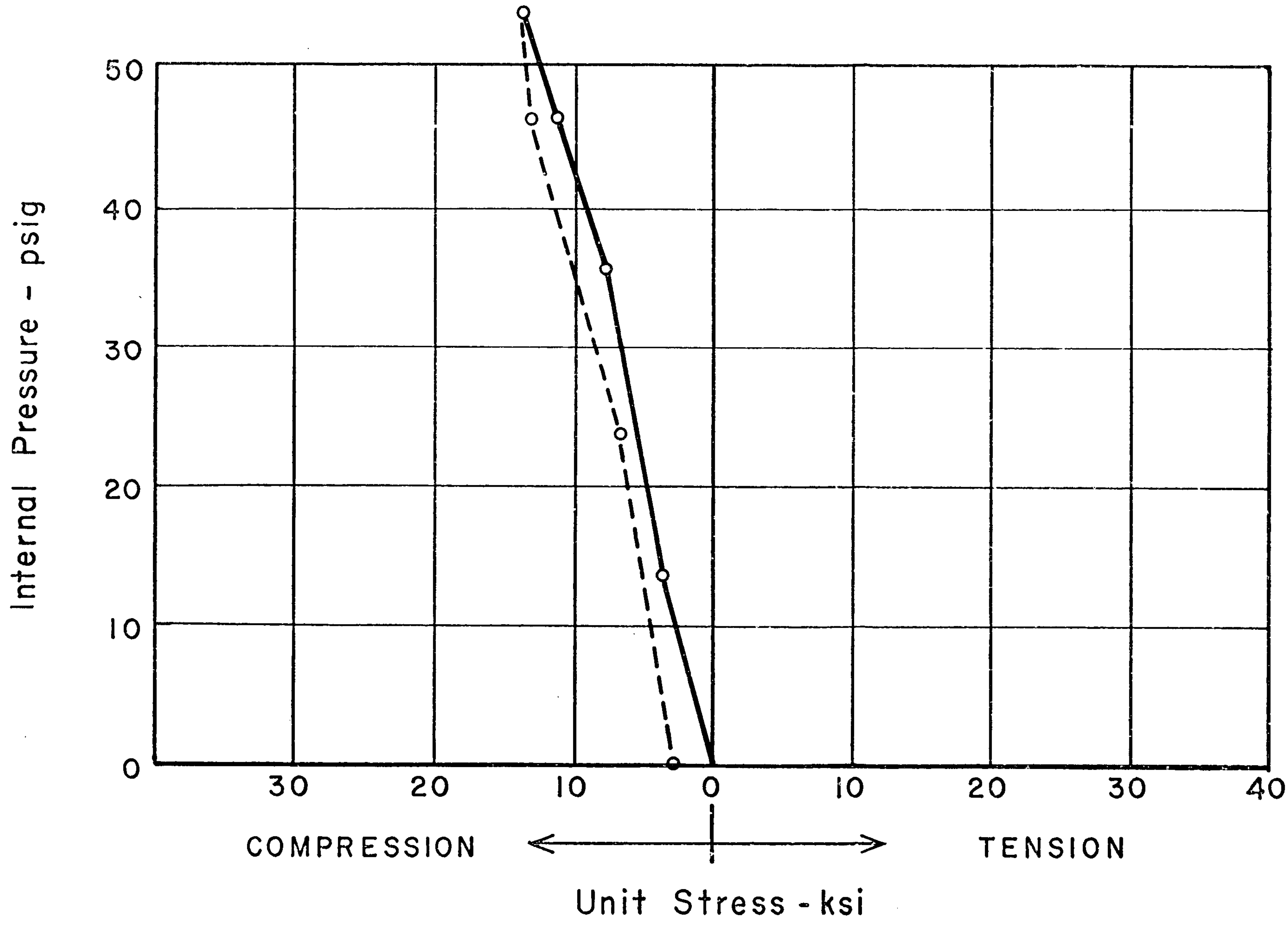
GAGE SG 35R - Equipment Hatch - Seismic



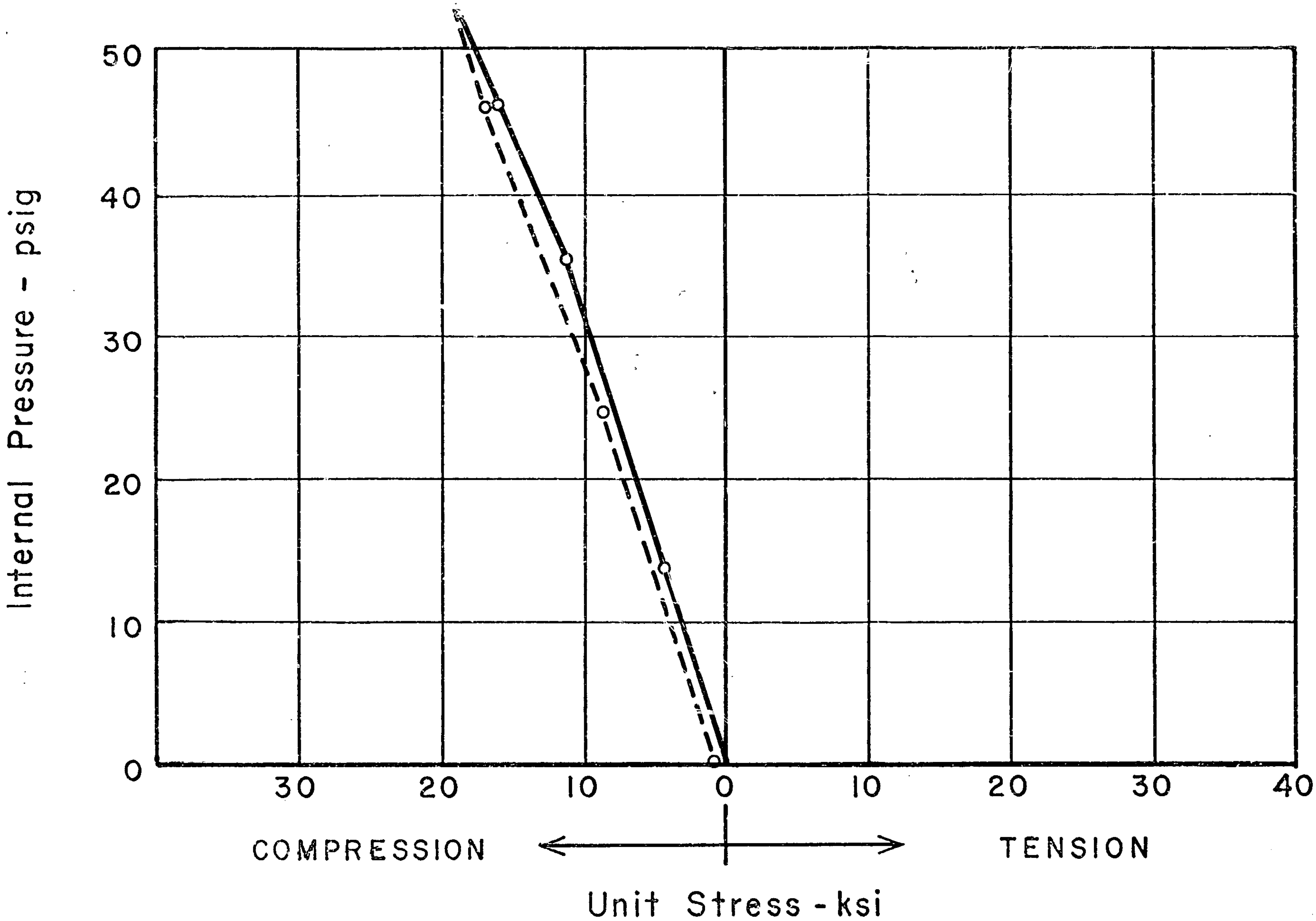

GAGE SG 36 - Equipment Hatch - Seismic
Internal Pressure - psig
0
10
20
30
40
50
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

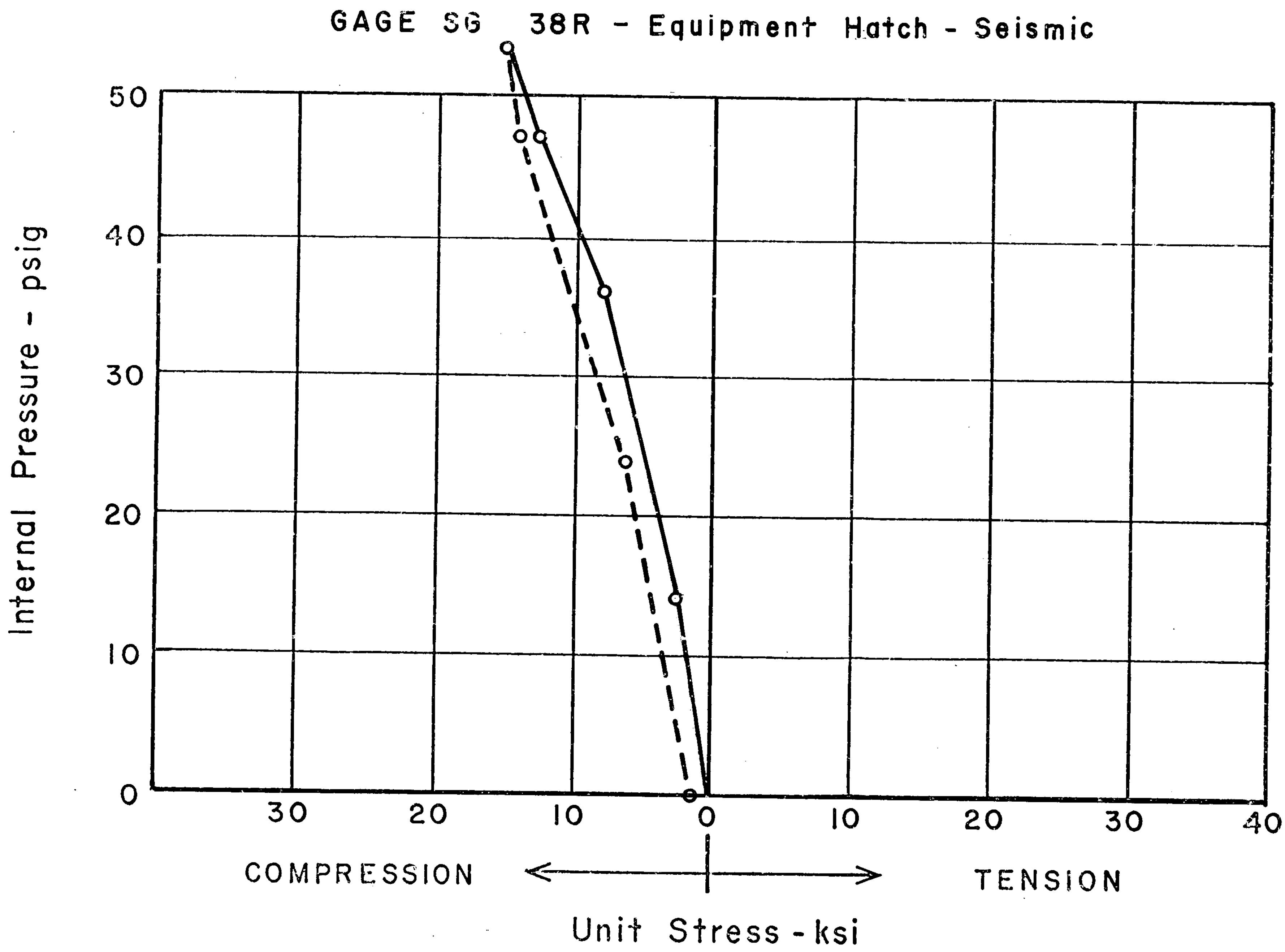

GAGE SG 36R - Equipment Hatch - Seismic
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

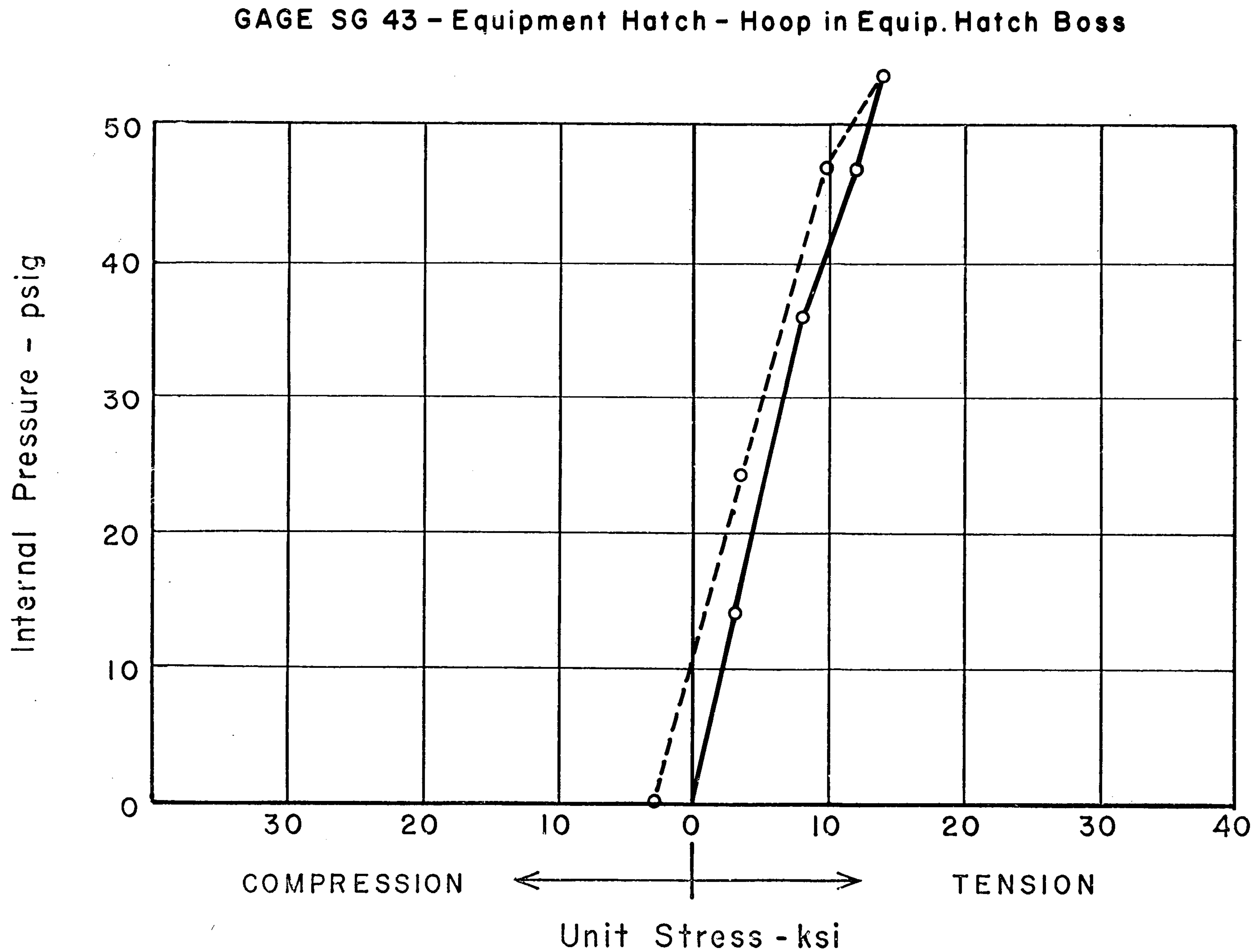
GAGE SG 37 - Equipment Hatch - Seismic



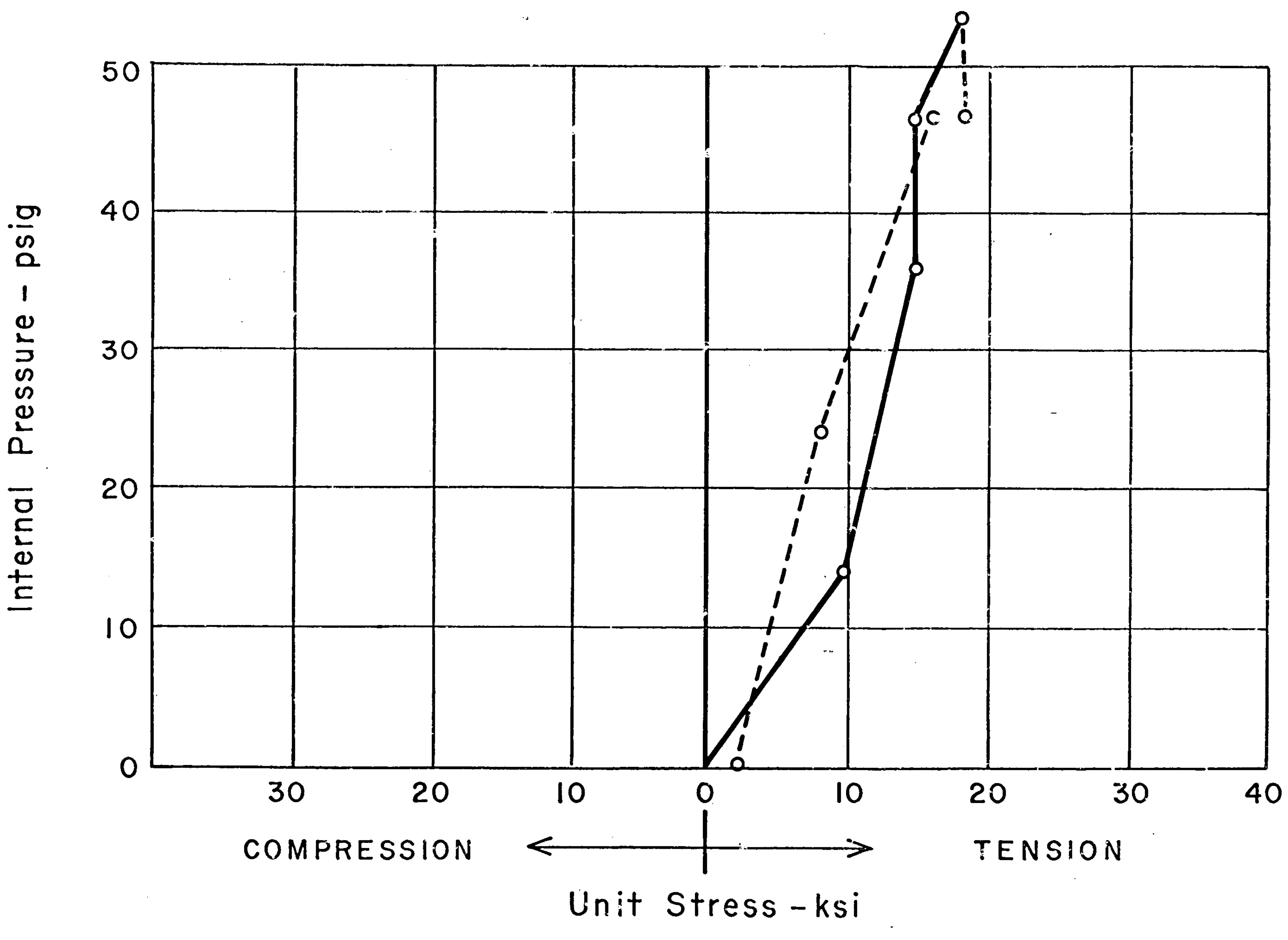
## GAGE S[illegible] 38 – Equipment Hatch – Seismic



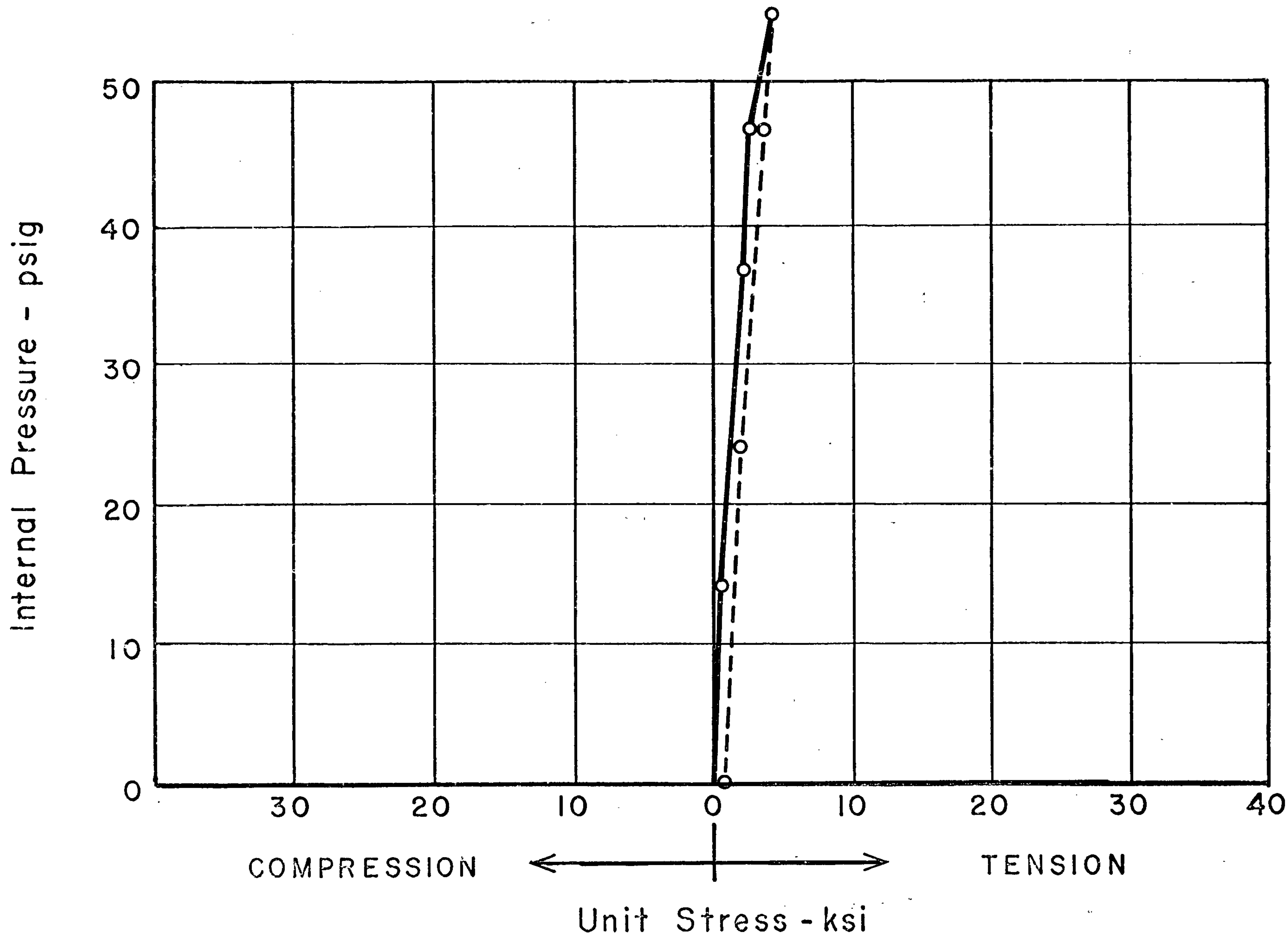

GAGE SG 38R - Equipment Hatch - Seismic
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi


GAGE SG 43 - Equipment Hatch - Hoop in Equip. Hatch Boss
Internal Pressure - psig
0
10
20
30
40
50
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

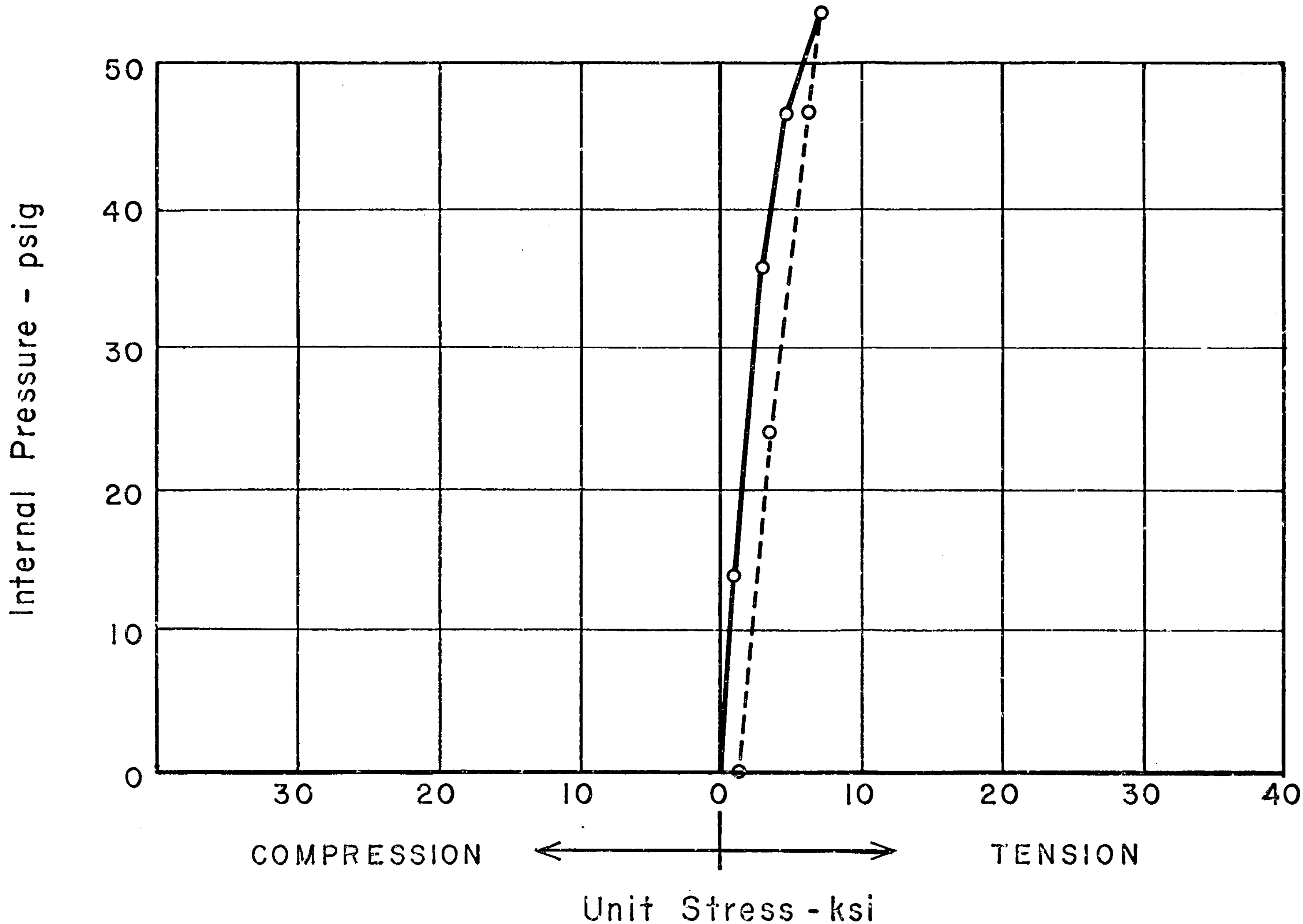
# GAGE SG 43R – Equipment Hatch – Hoop in Equip. Hatch Boss



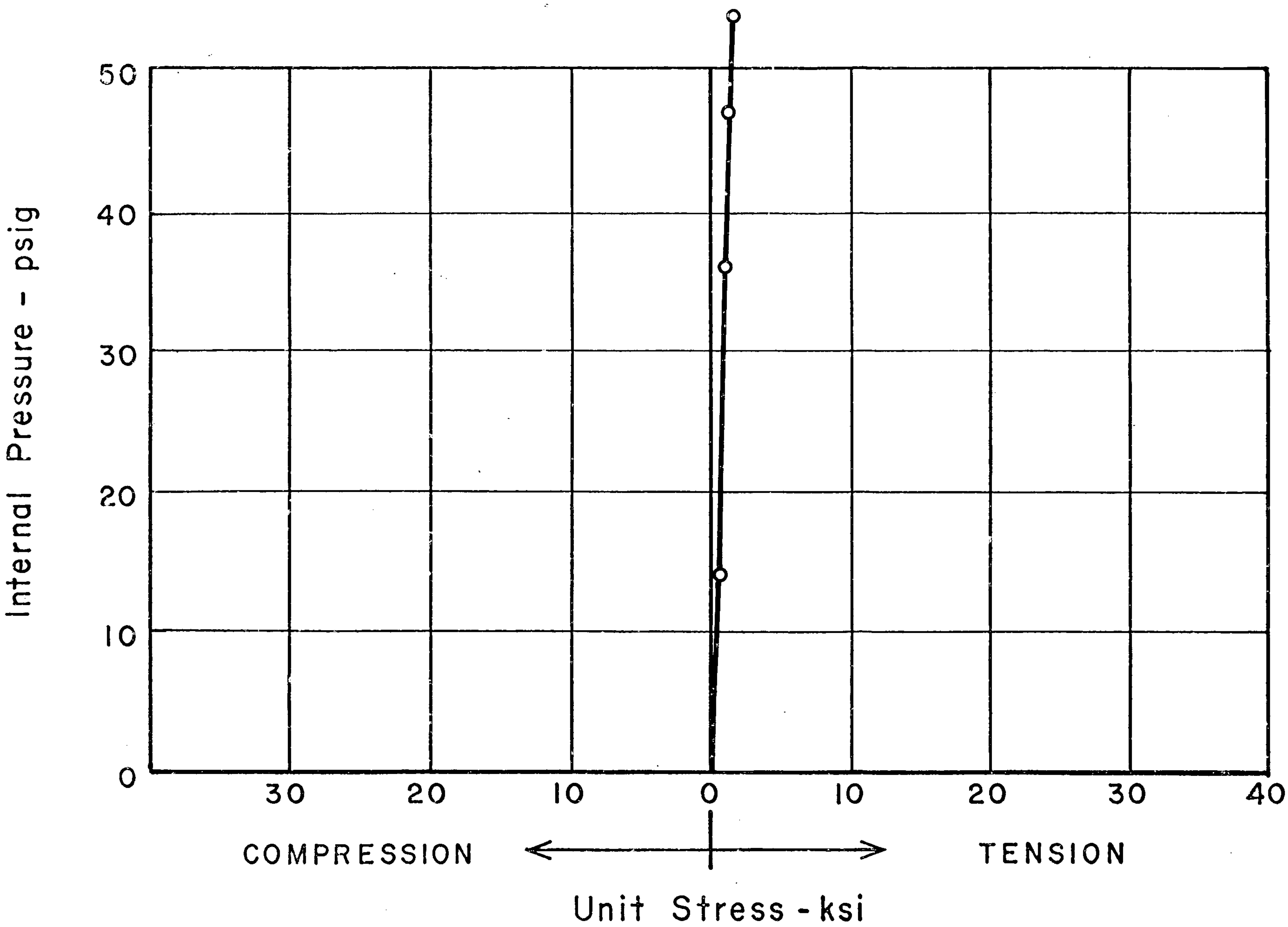
GAGE SG 44 - Equipment Hatch - Hoop in Equip. Hatch Boss



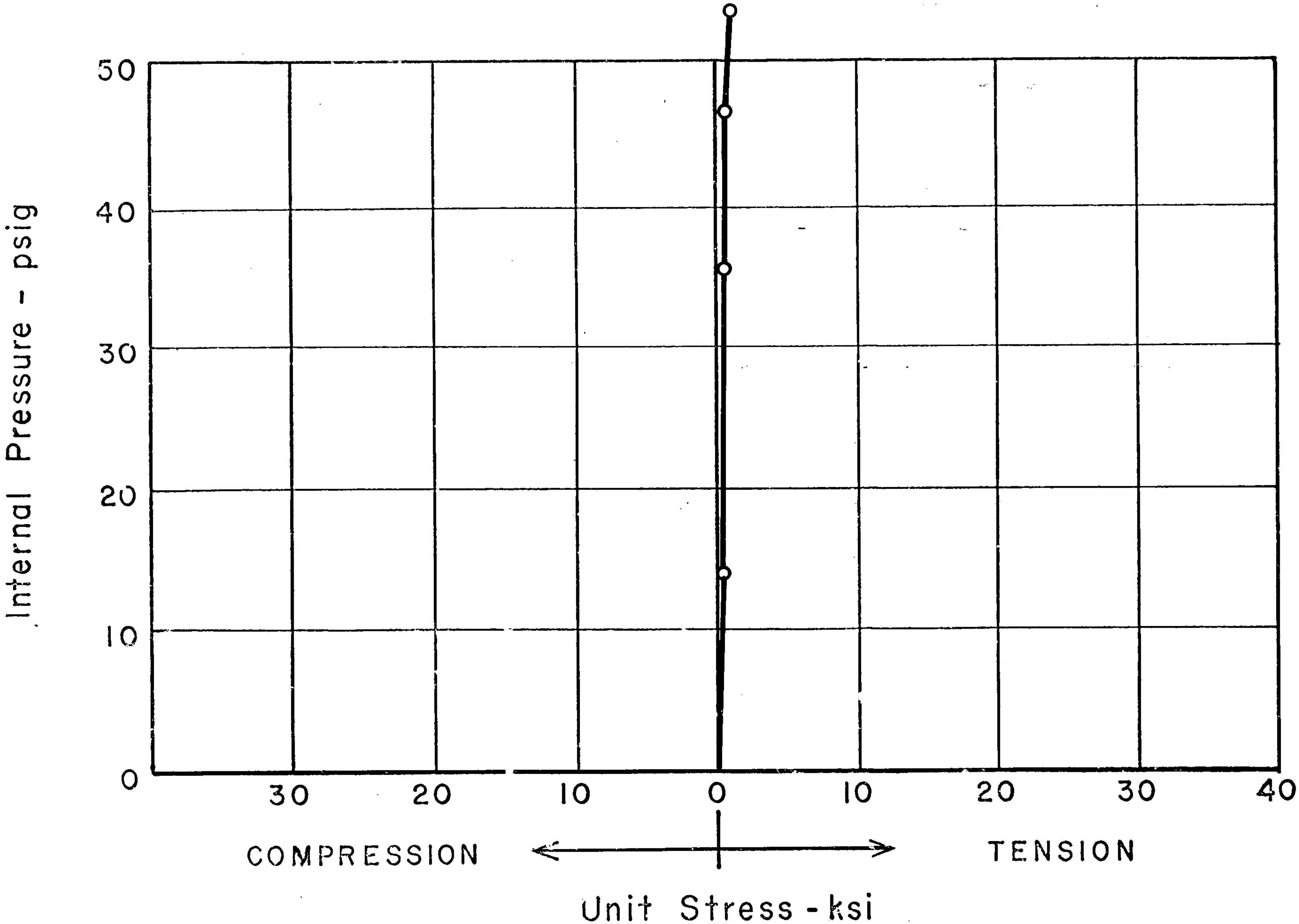
GAGE SG 44R - Equipment Hatch - Hoop in Equip. Hatch Boss



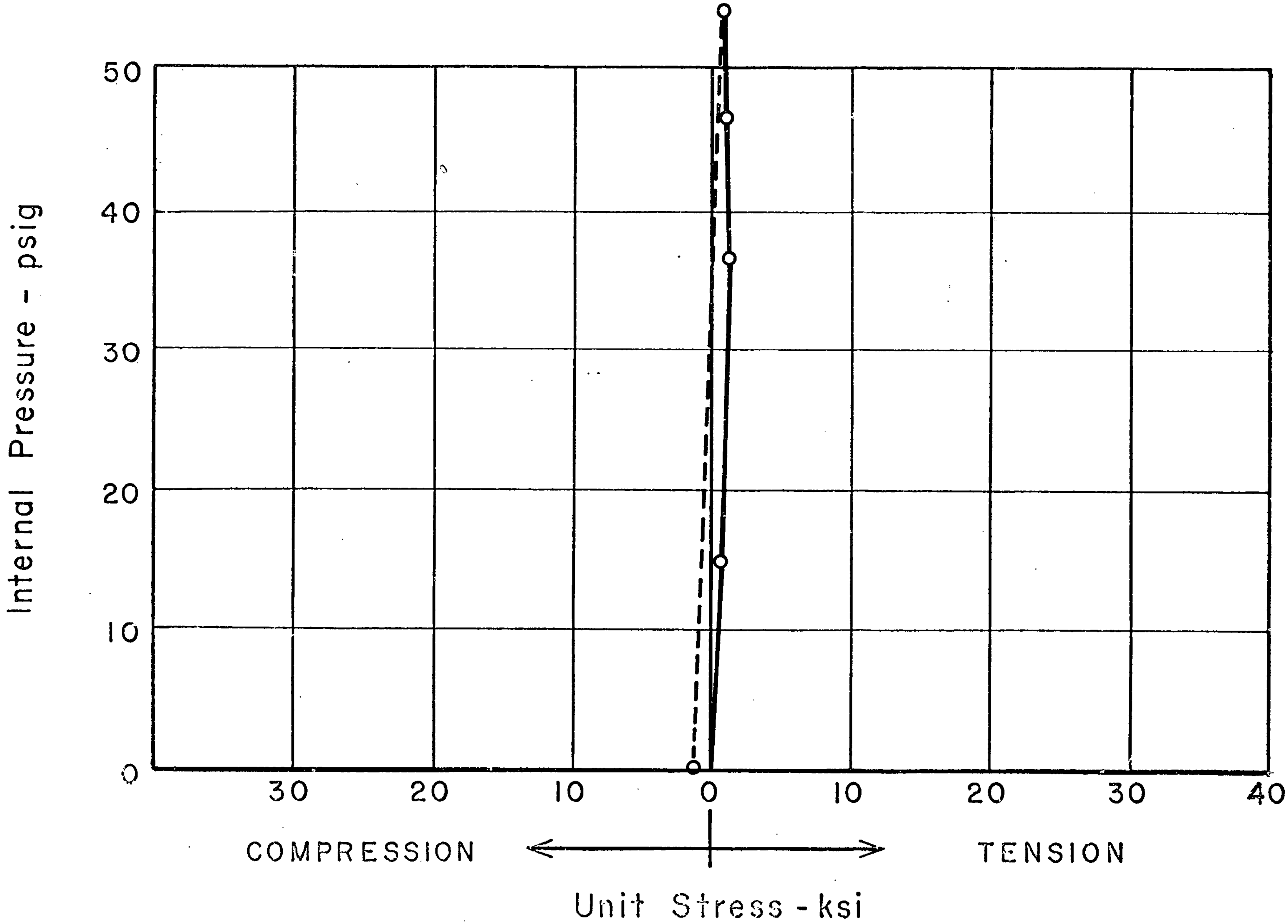
GAGE SG 46 - Equipment Hatch - Hoop in Equip. Hatch Boss

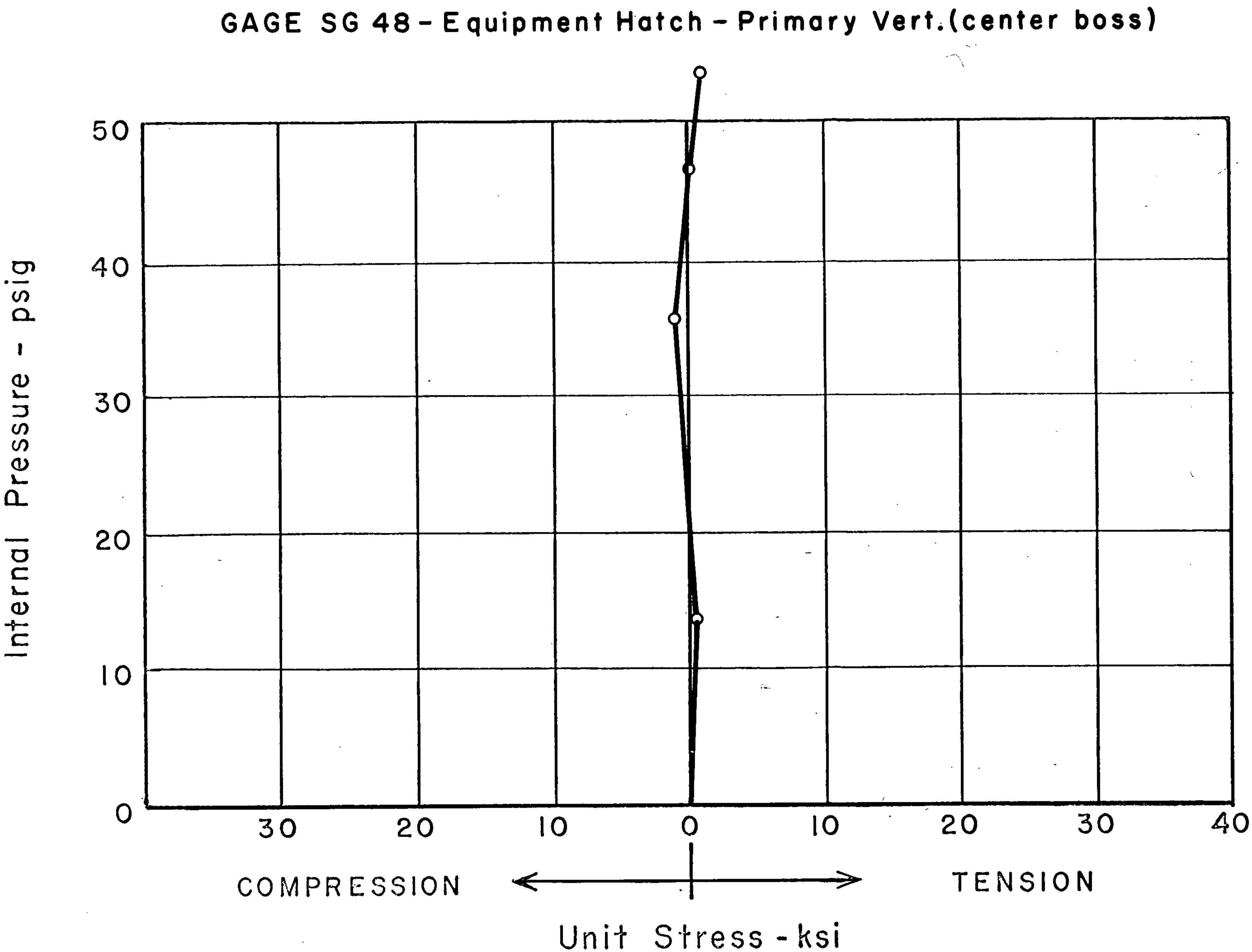


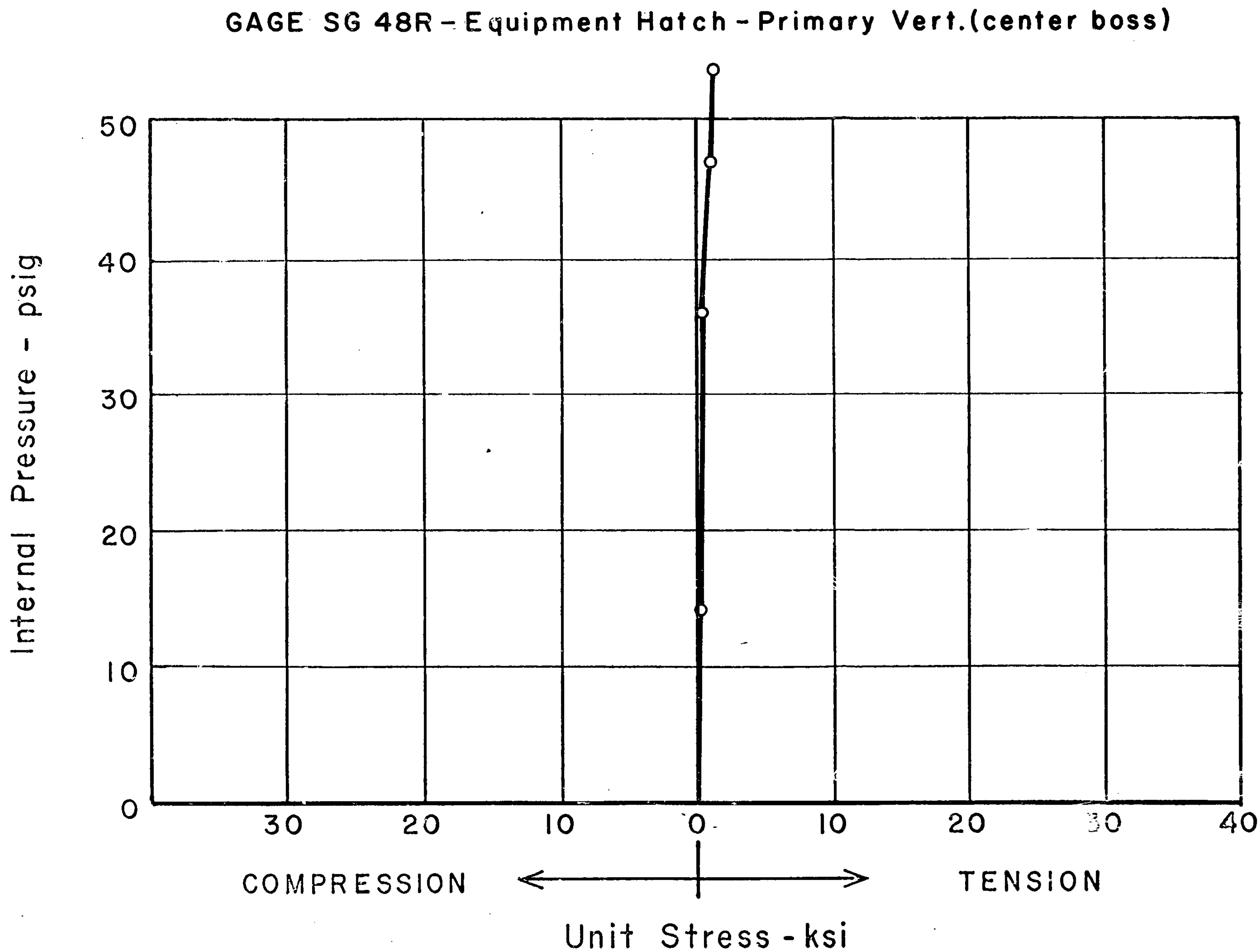
GAGE SG 47 – Equipment Hatch – Primary Vert. (center of boss)



GAGE SG 47R - Equipment Hatch - Primary Vert.(center of boss)

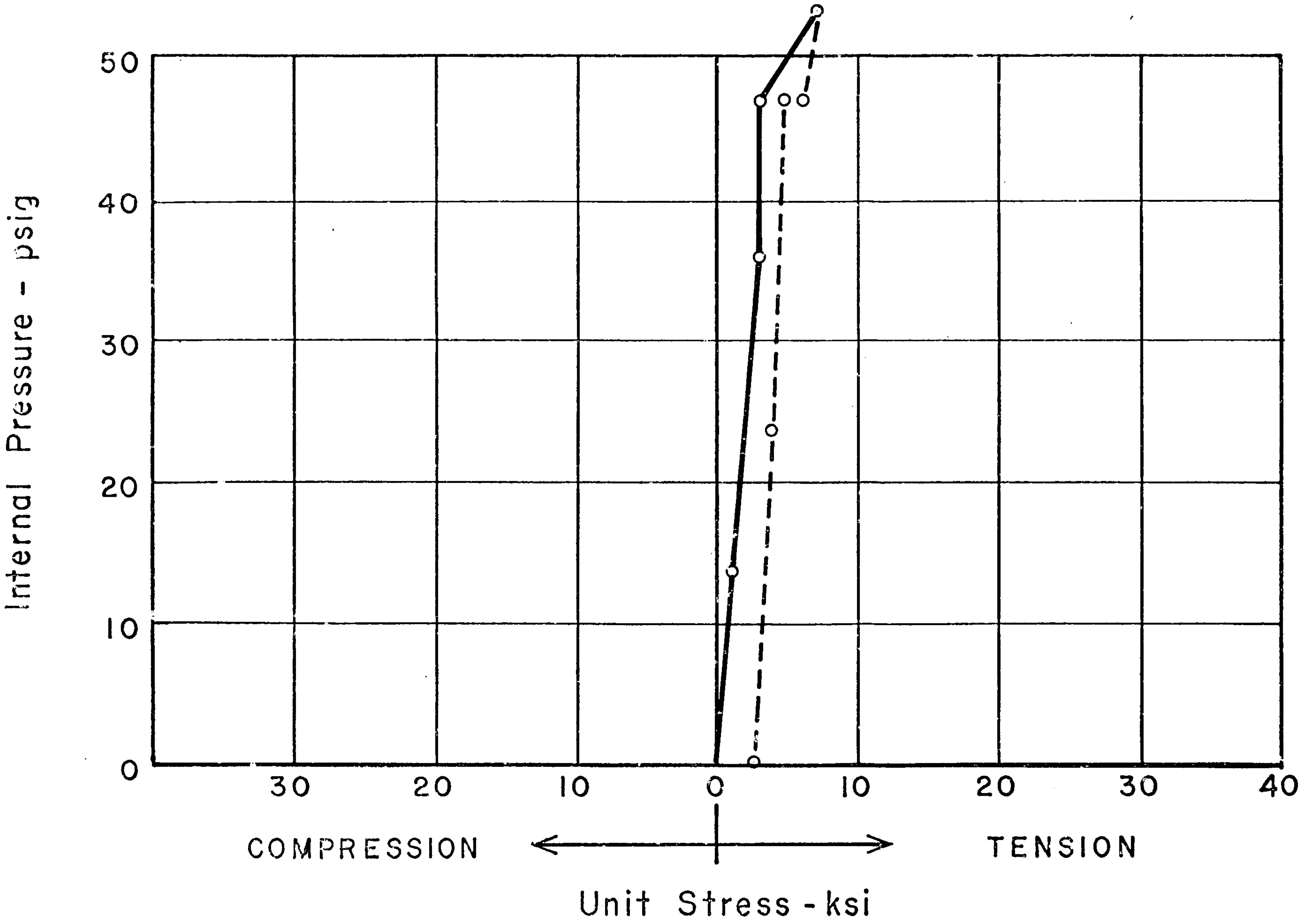



GAGE SG 48 - Equipment Hatch - Primary Vert. (center boss)
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

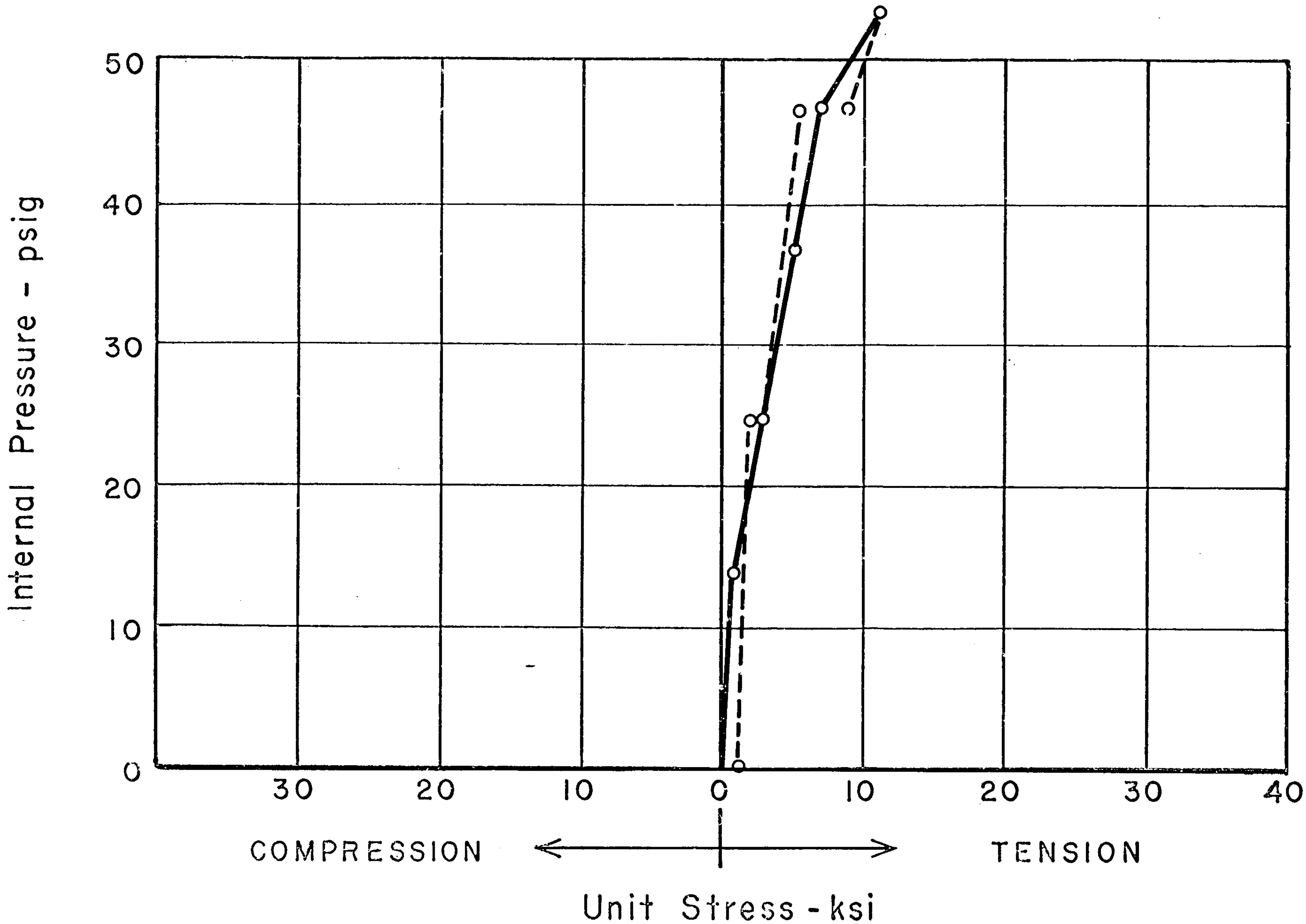


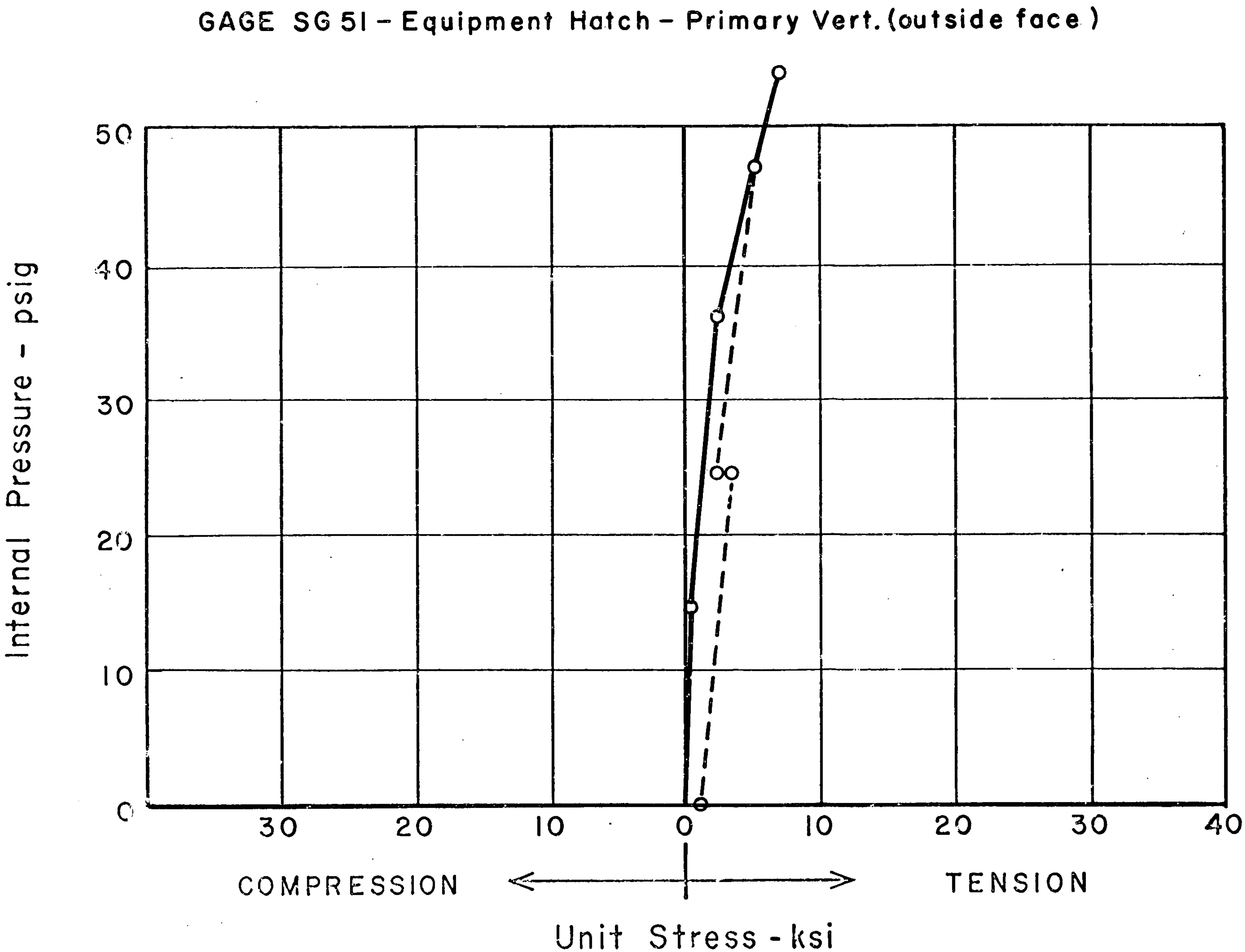
GAGE SG 48R - Equipment Hatch - Primary Vert. (center boss)
Internal Pressure - psig
0
10
20
30
40
50
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

GAGE SG 49 - Equipment Hatch - Primary Vert. (center of boss)



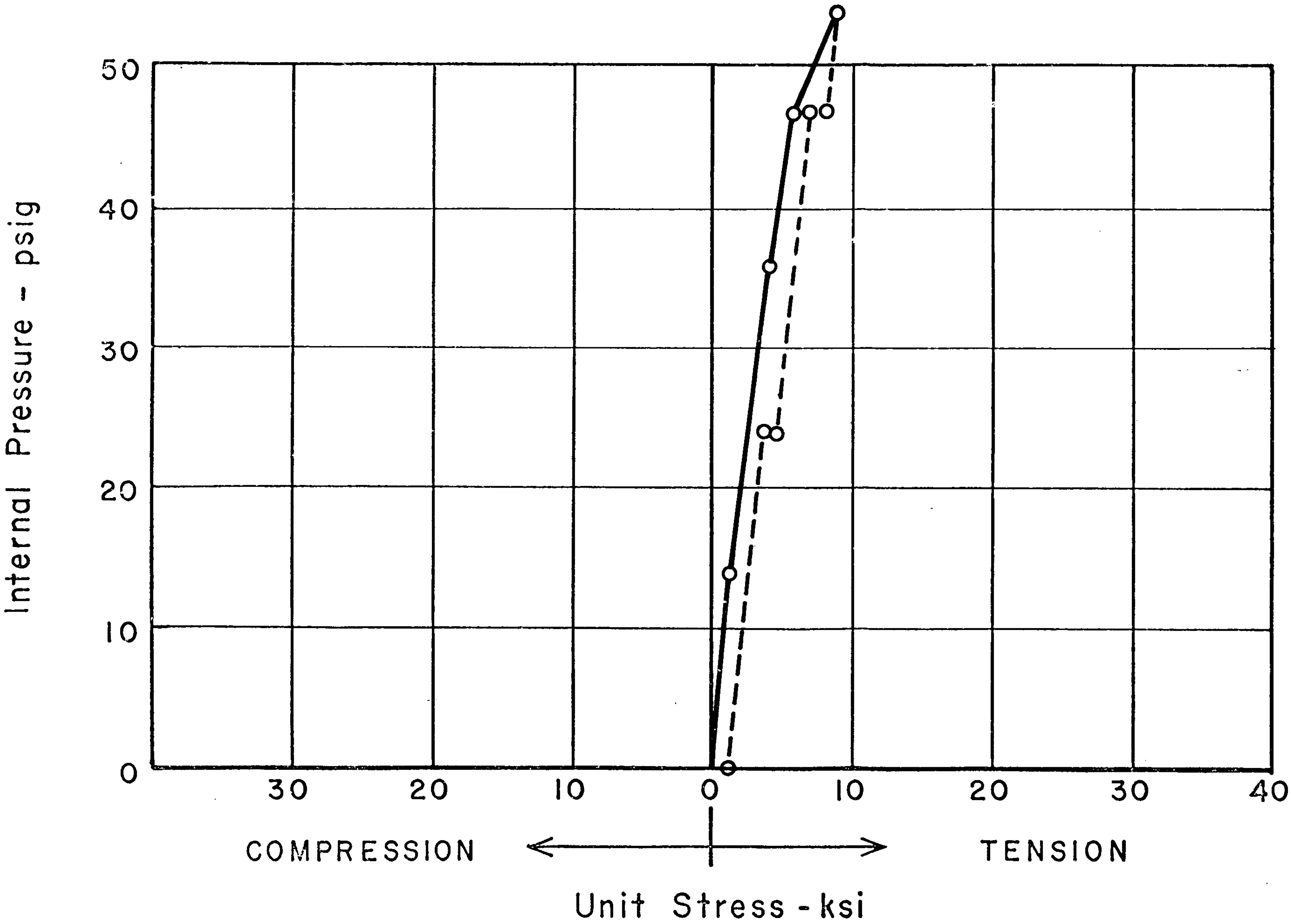
GAGE SG 50 - Equipment Hatch - Primary Vert. (center of boss)

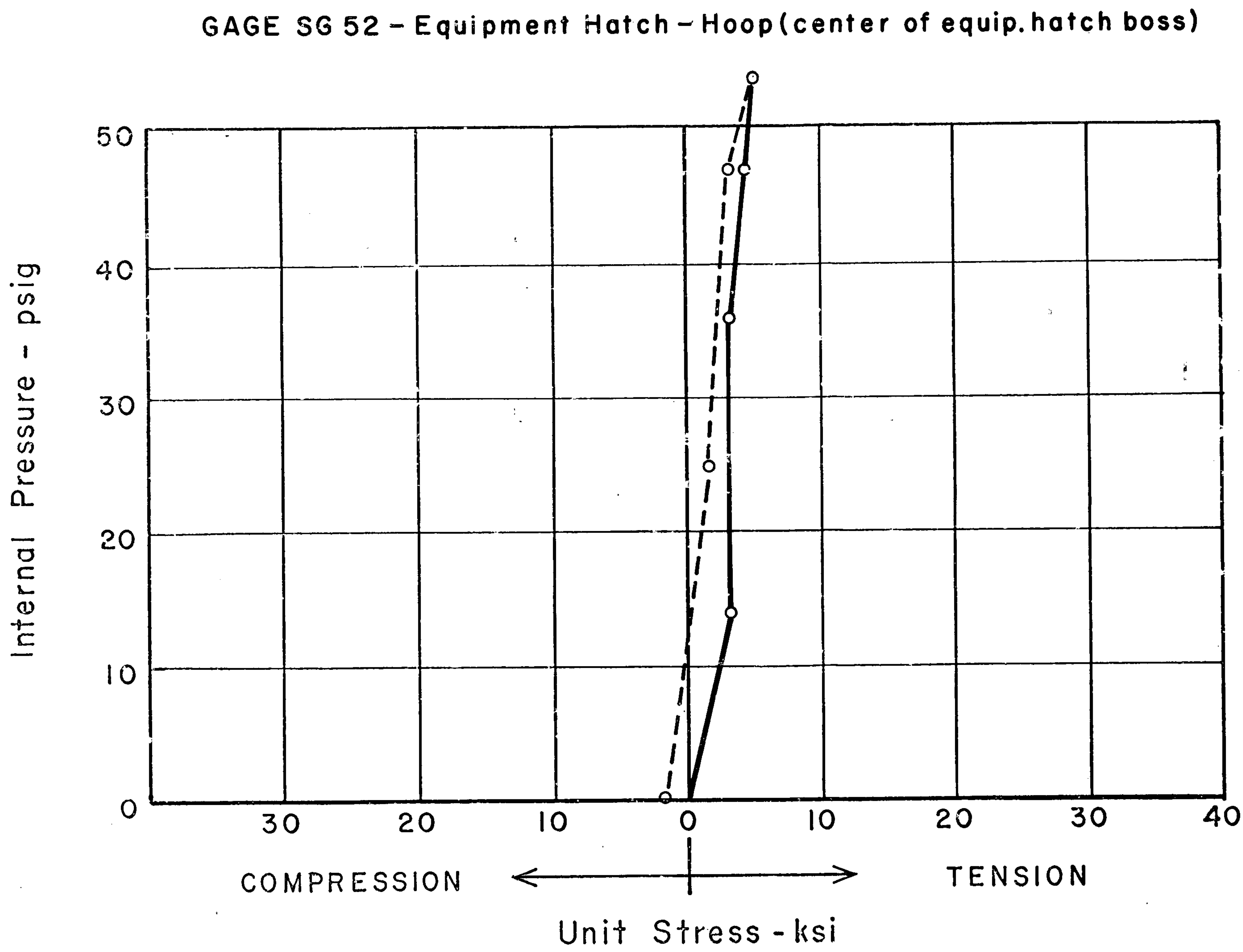




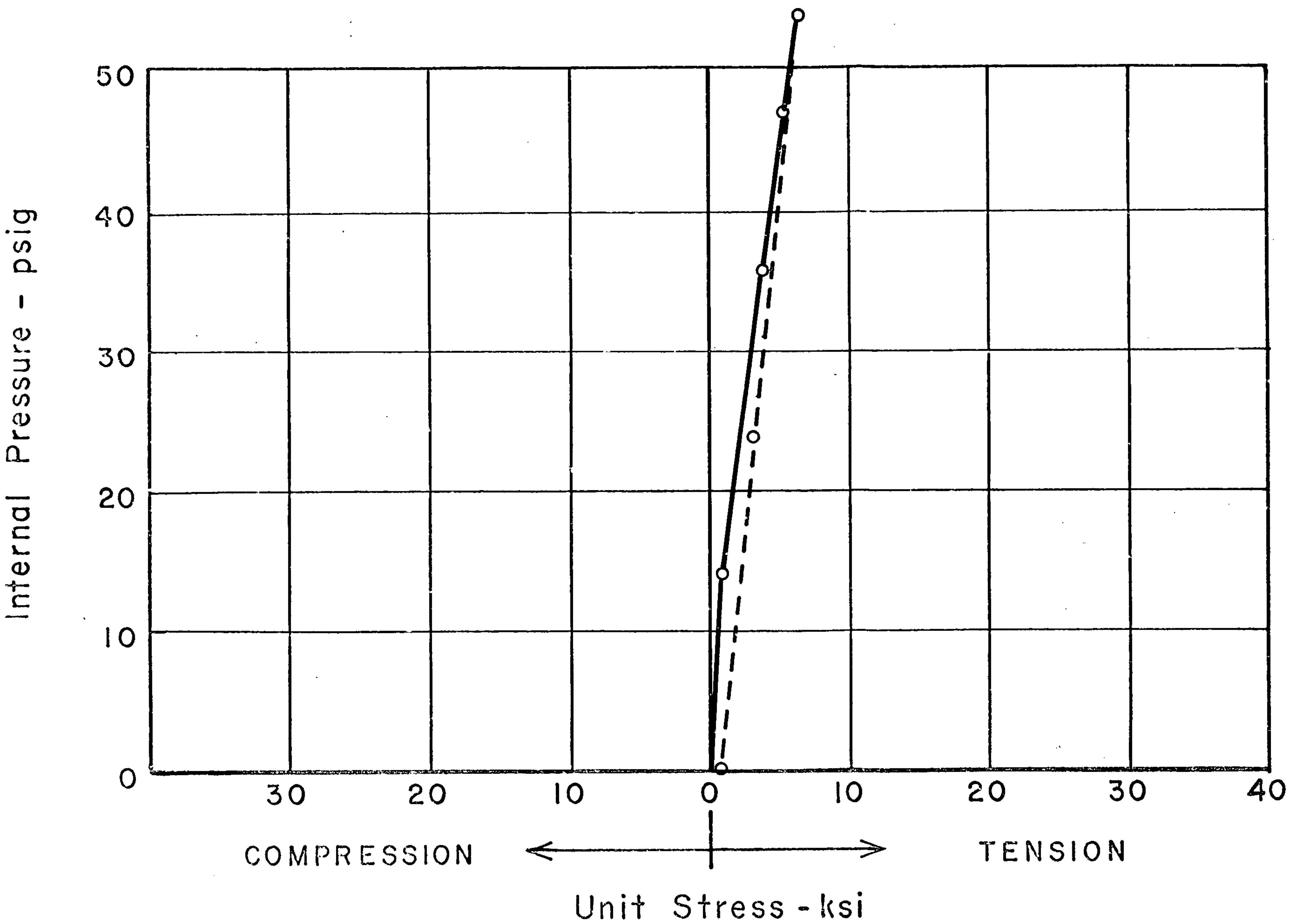
GAGE SG 51 - Equipment Hatch - Primary Vert. (outside face)
Internal Pressure - psig
0
10
20
30
40
50
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

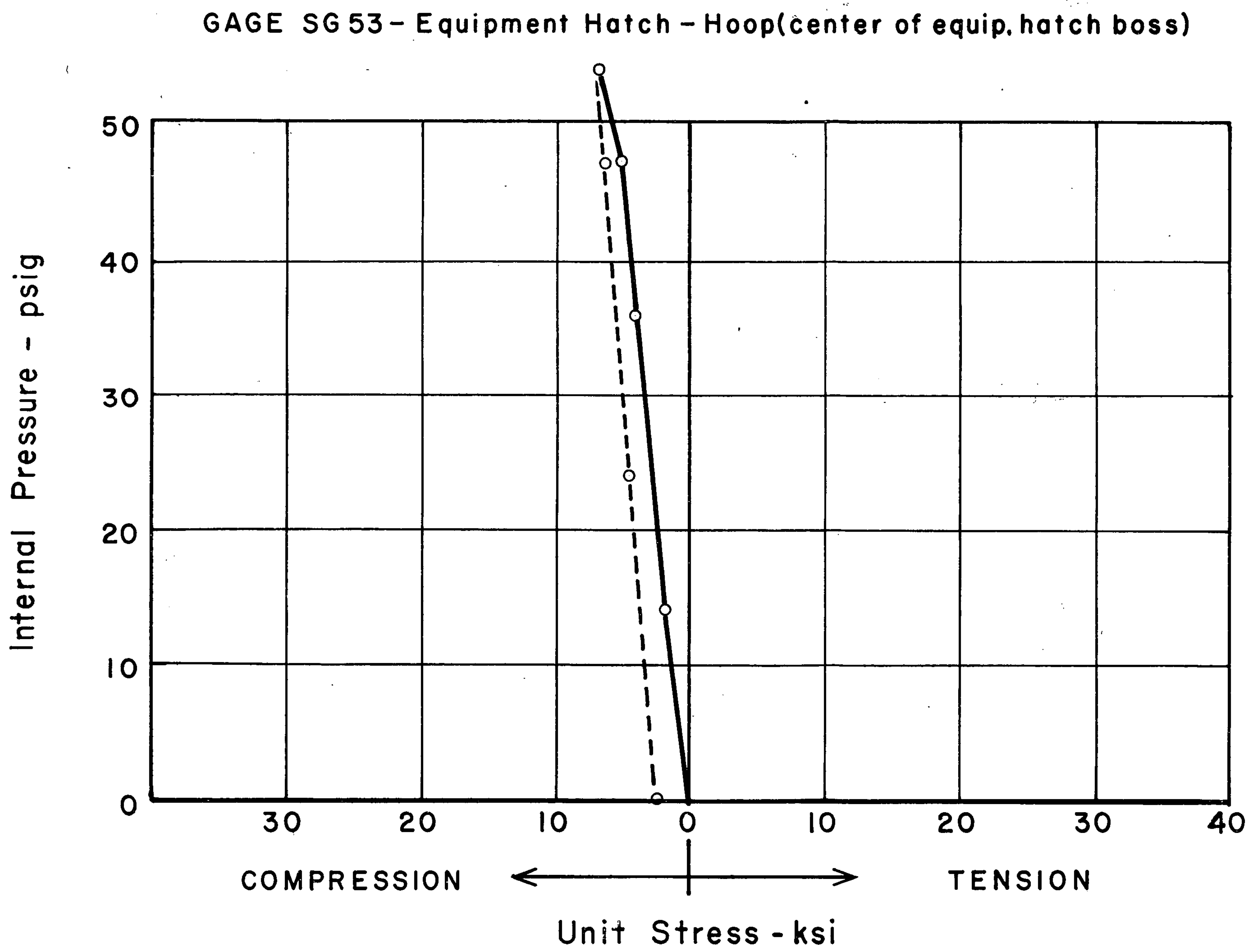
GAGE SG 51R – Equipment Hatch – Primary Vert. (outside face)



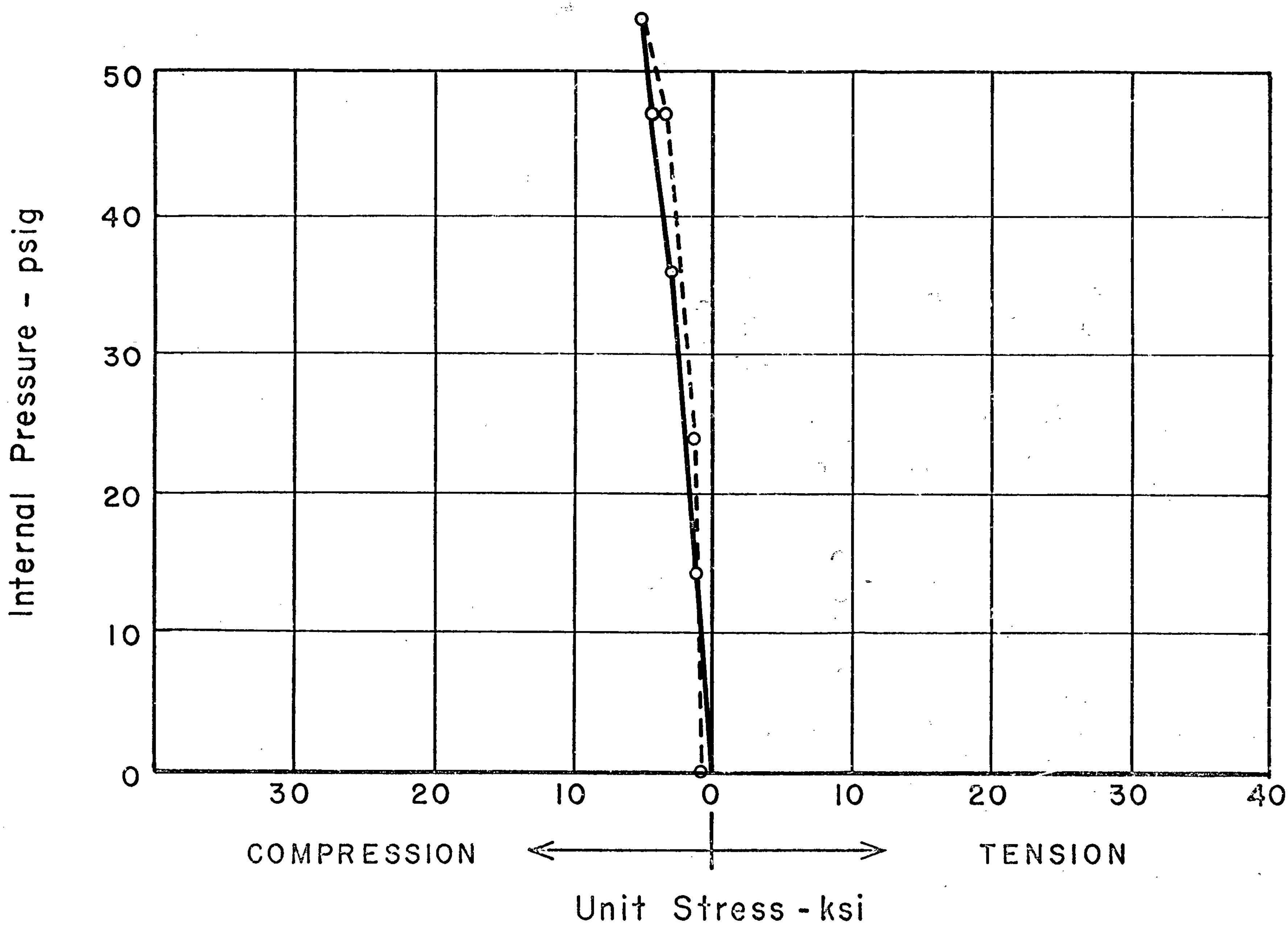

GAGE SG 52 - Equipment Hatch - Hoop (center of equip. hatch boss)
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

GAGE SG 52R – Equipment Hatch – Hoop (center of equip. hatch boss)

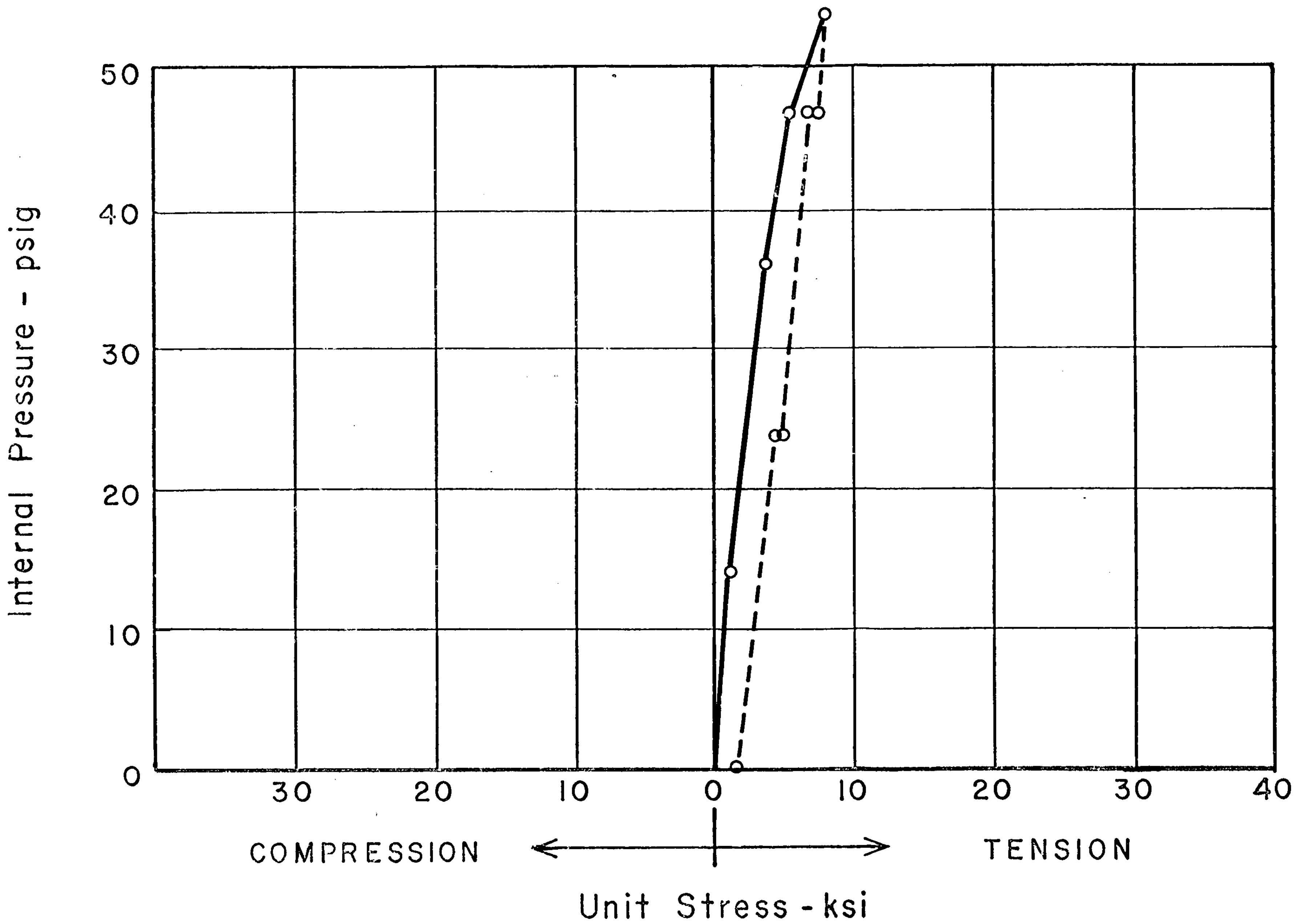


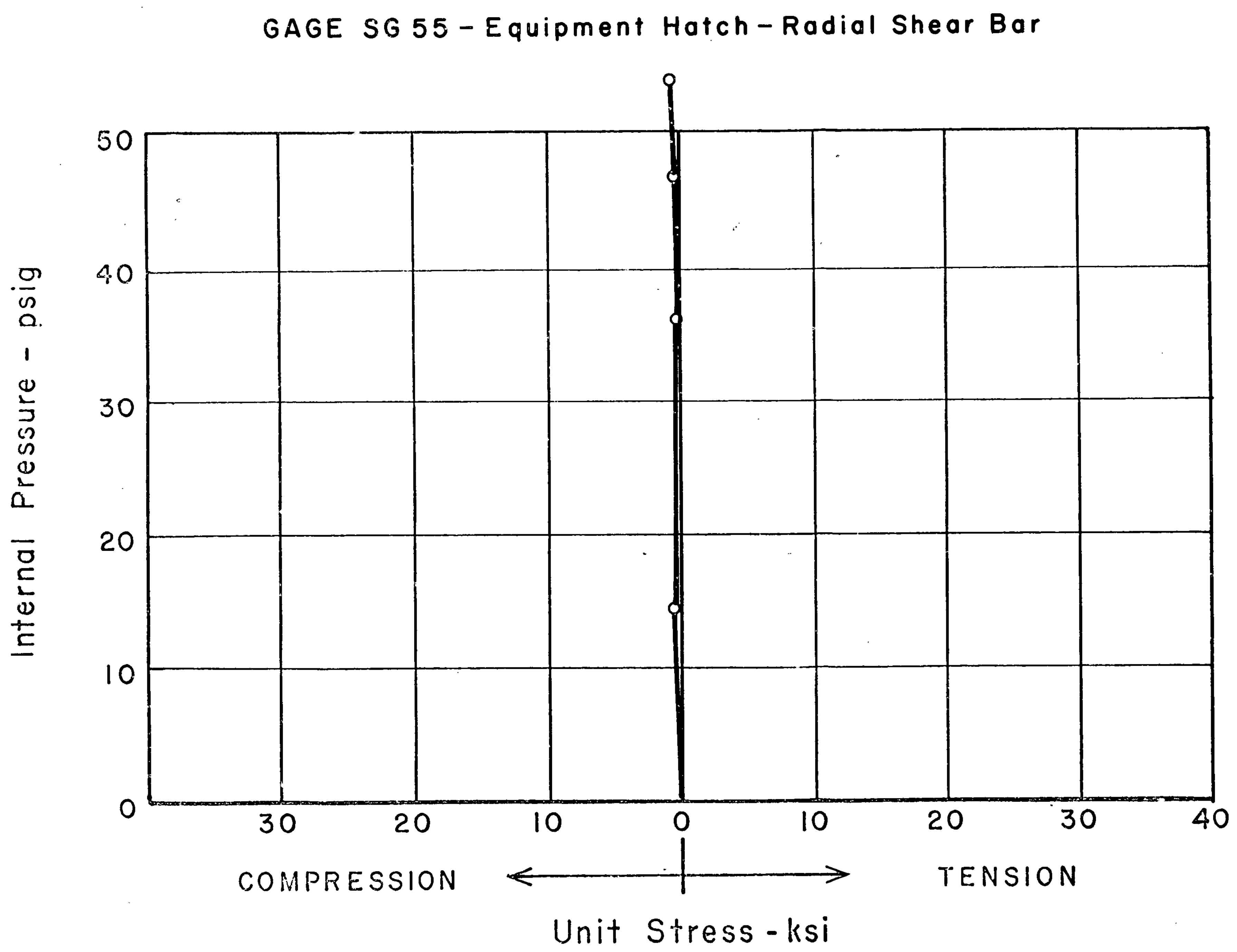

GAGE SG 53 - Equipment Hatch - Hoop(center of equip. hatch boss)
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

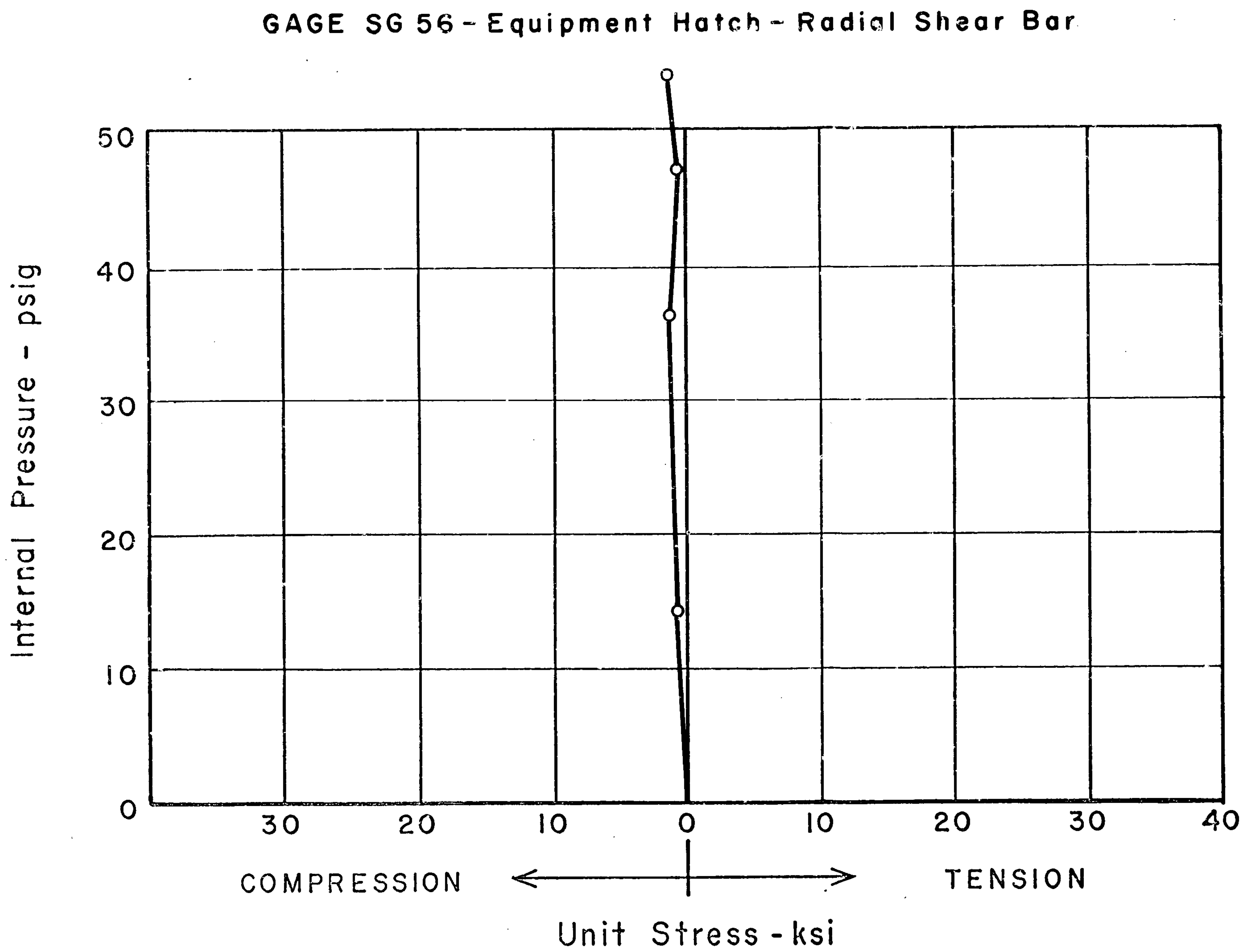
GAGE SG 53R – Equipment Hatch – Hoop (center of equip. hatch boss)

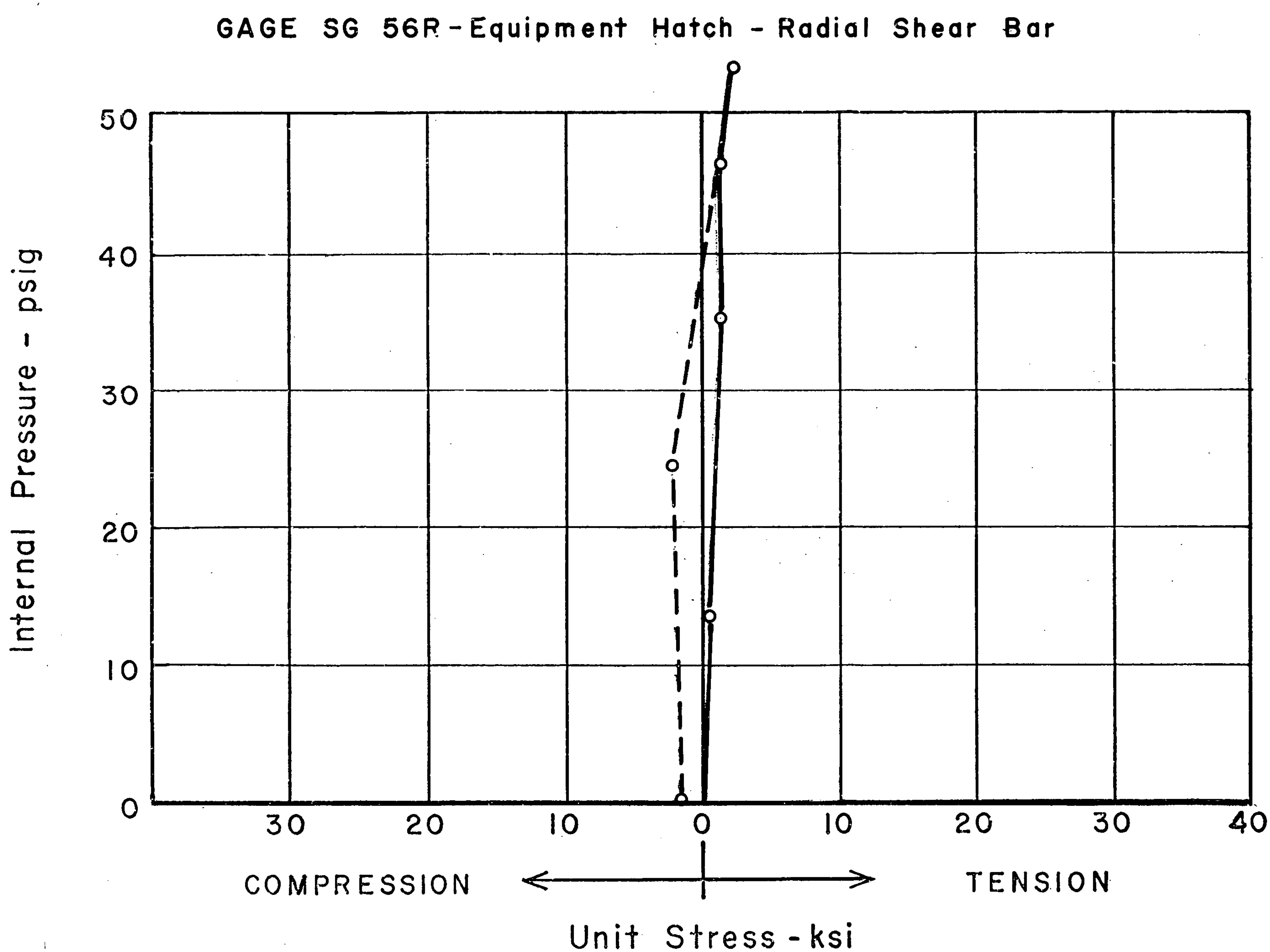


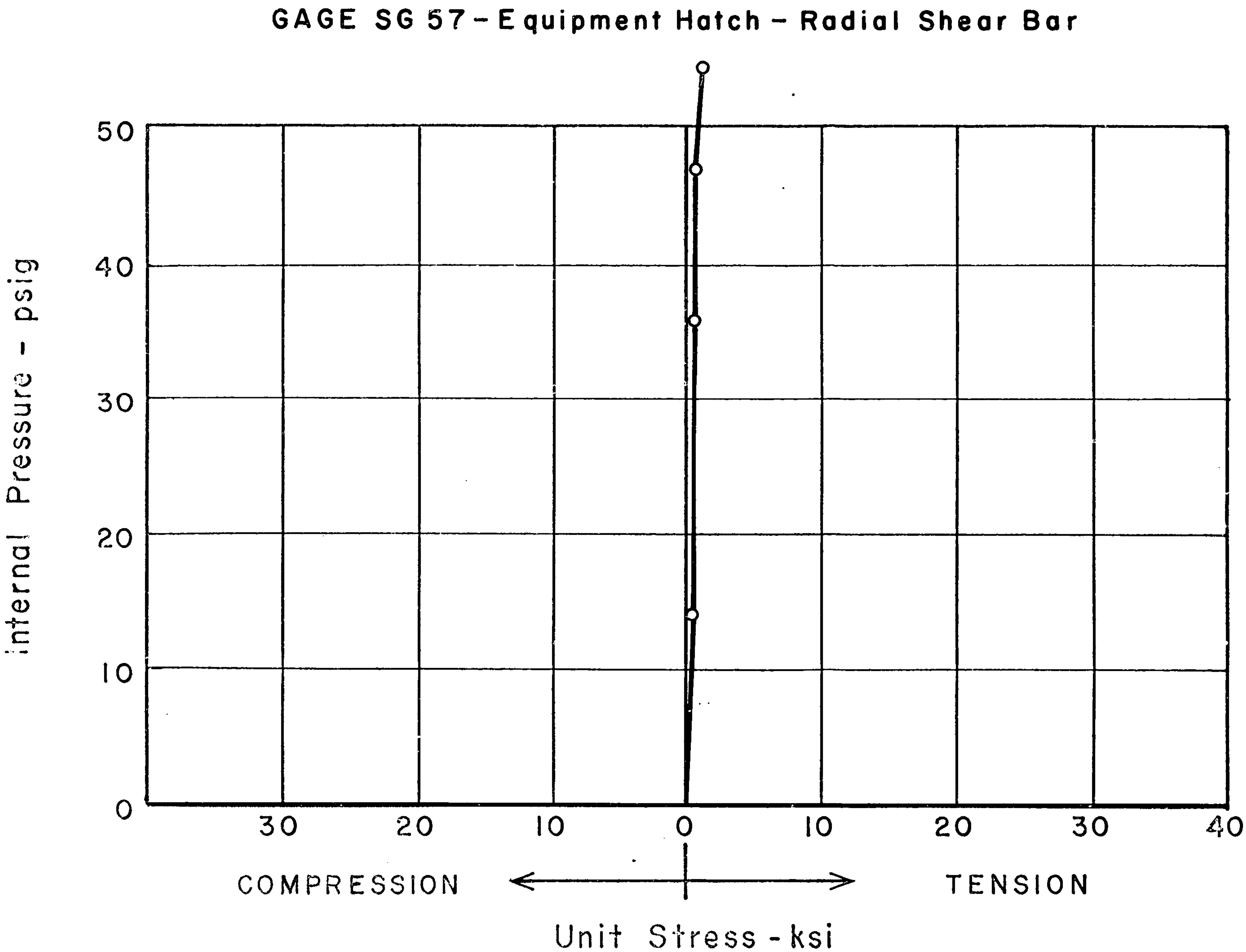
GAGE SG 54 - Equipment Hatch - Hoop (center of equip. hatch boss)




GAGE SG 55 - Equipment Hatch - Radial Shear Bar
Internal Pressure - psig
0
10
20
30
40
50
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

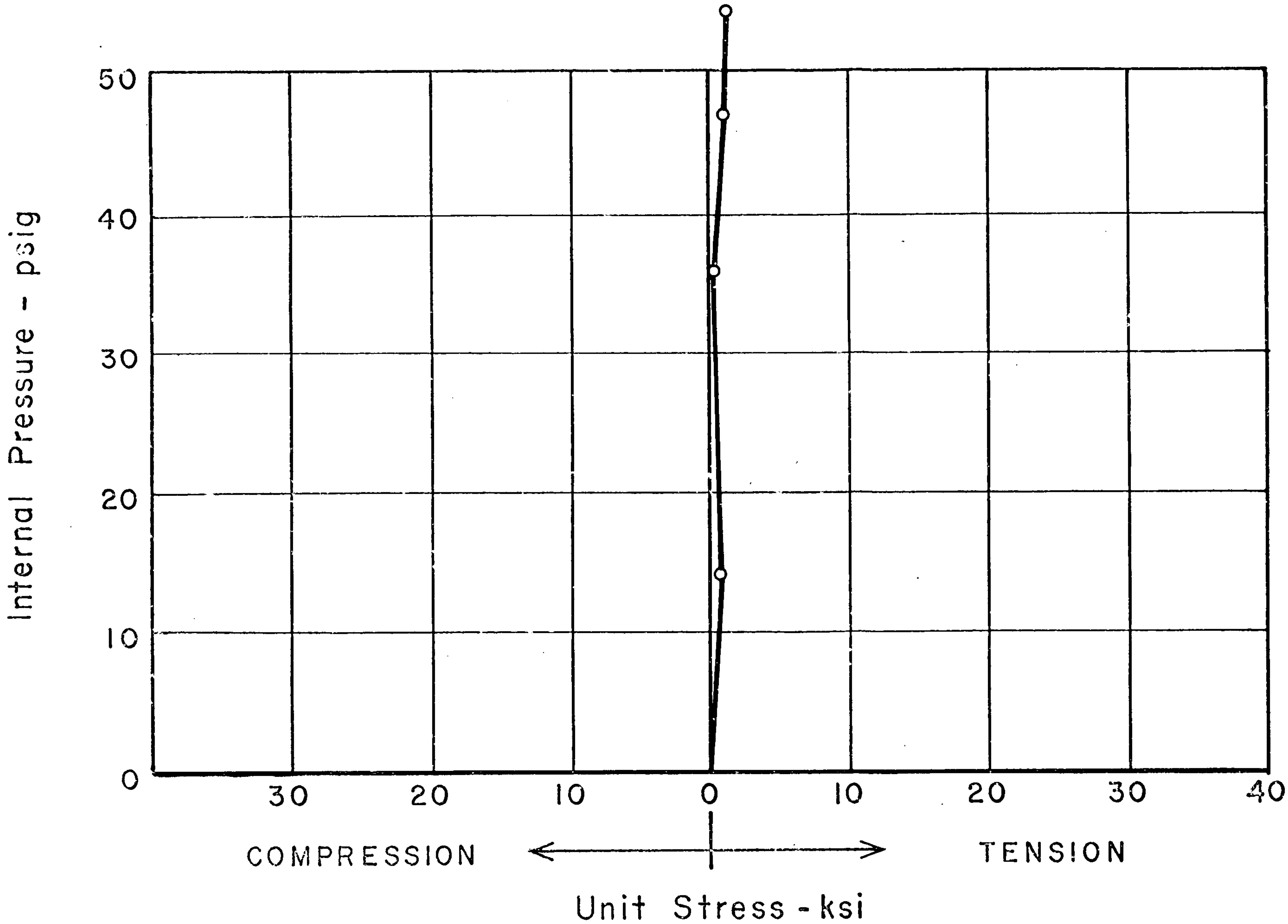

GAGE SG 56 - Equipment Hatch - Radial Shear Bar
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

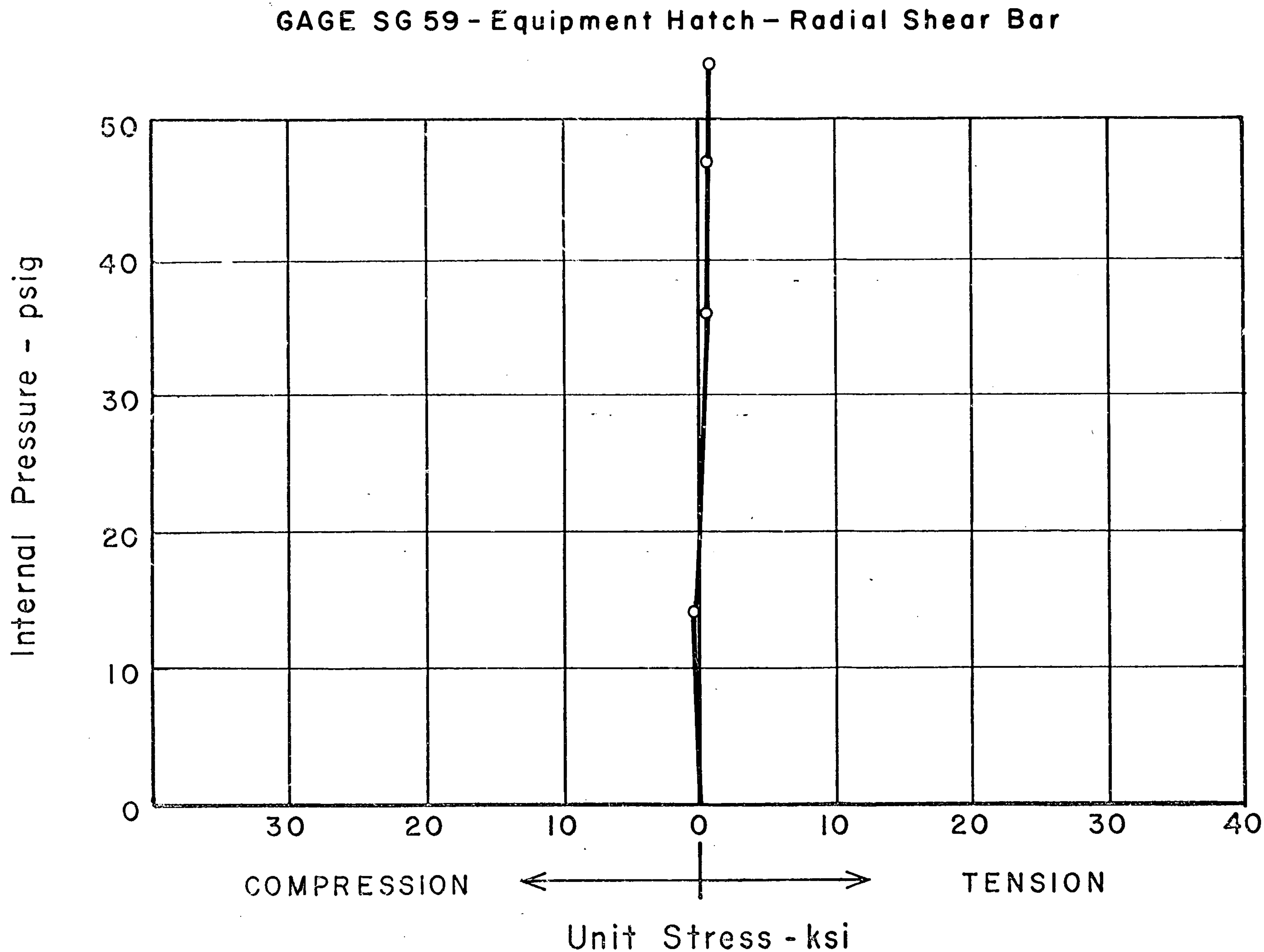

GAGE SG 56R - Equipment Hatch - Radial Shear Bar
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

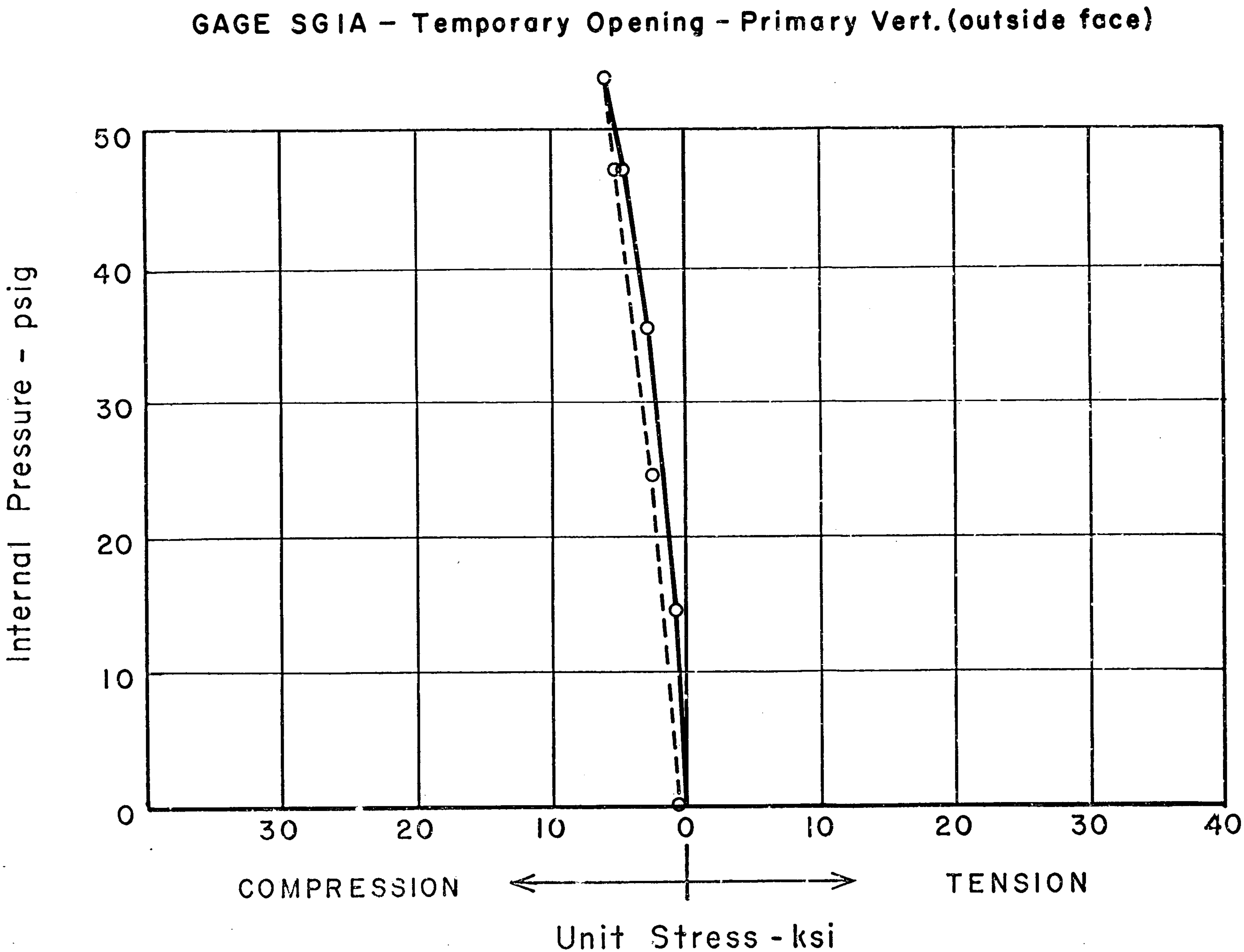


GAGE SG 57 - Equipment Hatch - Radial Shear Bar
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

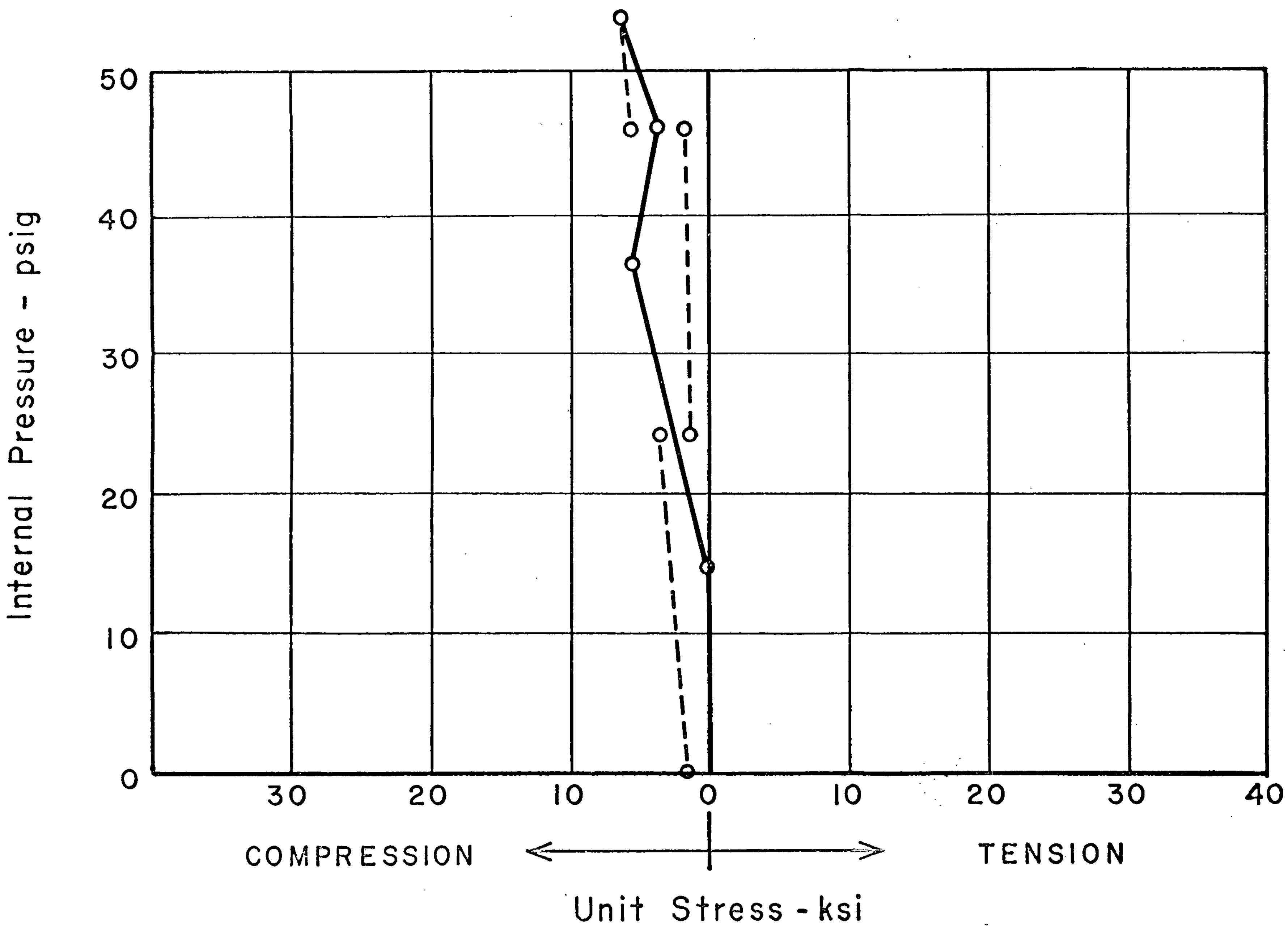
GAGE SG 58R - Equipment Hatch - Radial Shear Bar

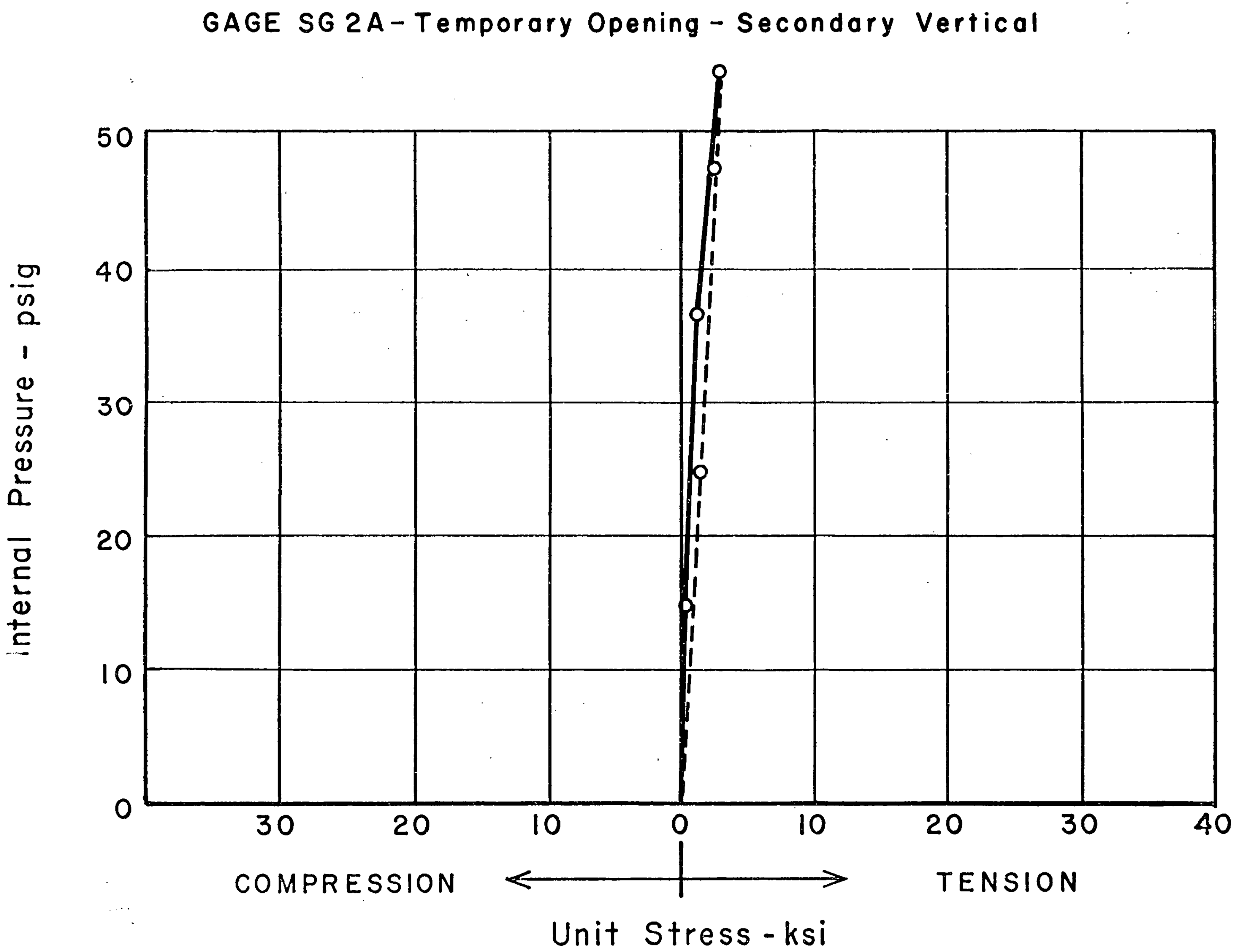



GAGE SG 59 - Equipment Hatch - Radial Shear Bar
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

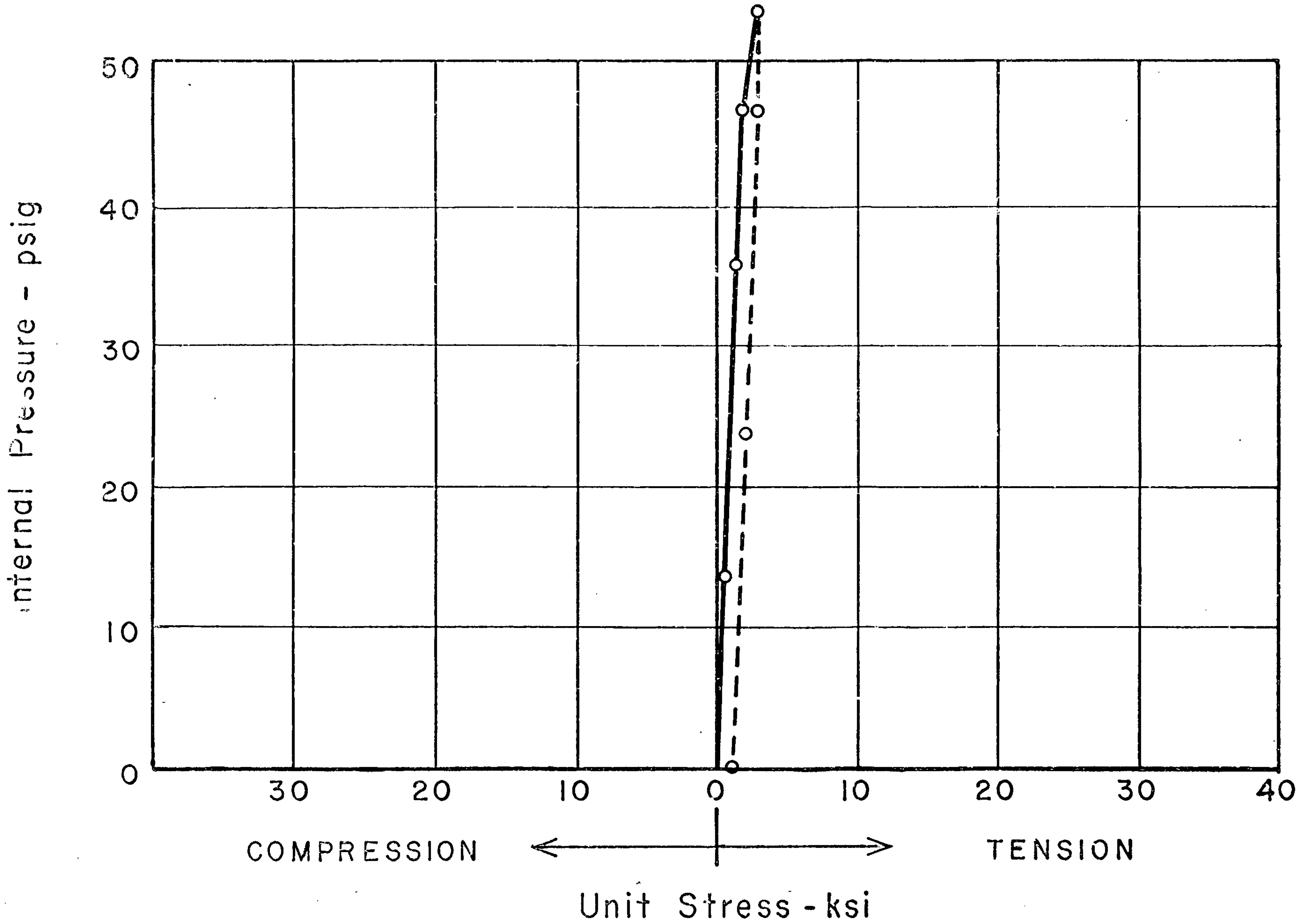

GAGE SG1A - Temporary Opening - Primary Vert. (outside face)
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

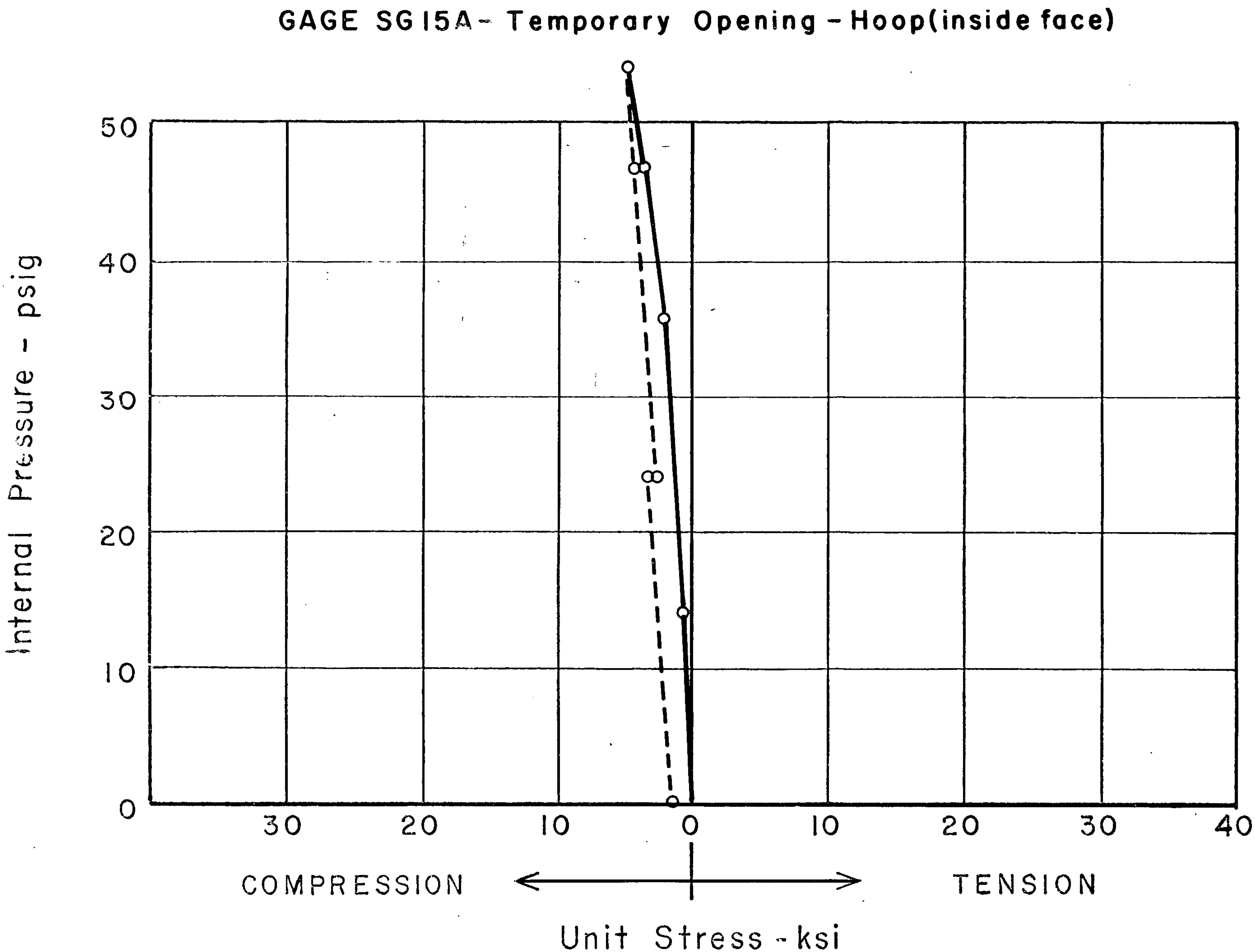
GAGE SG1AR - Temporary Opening - Primary Vert. (outside face)

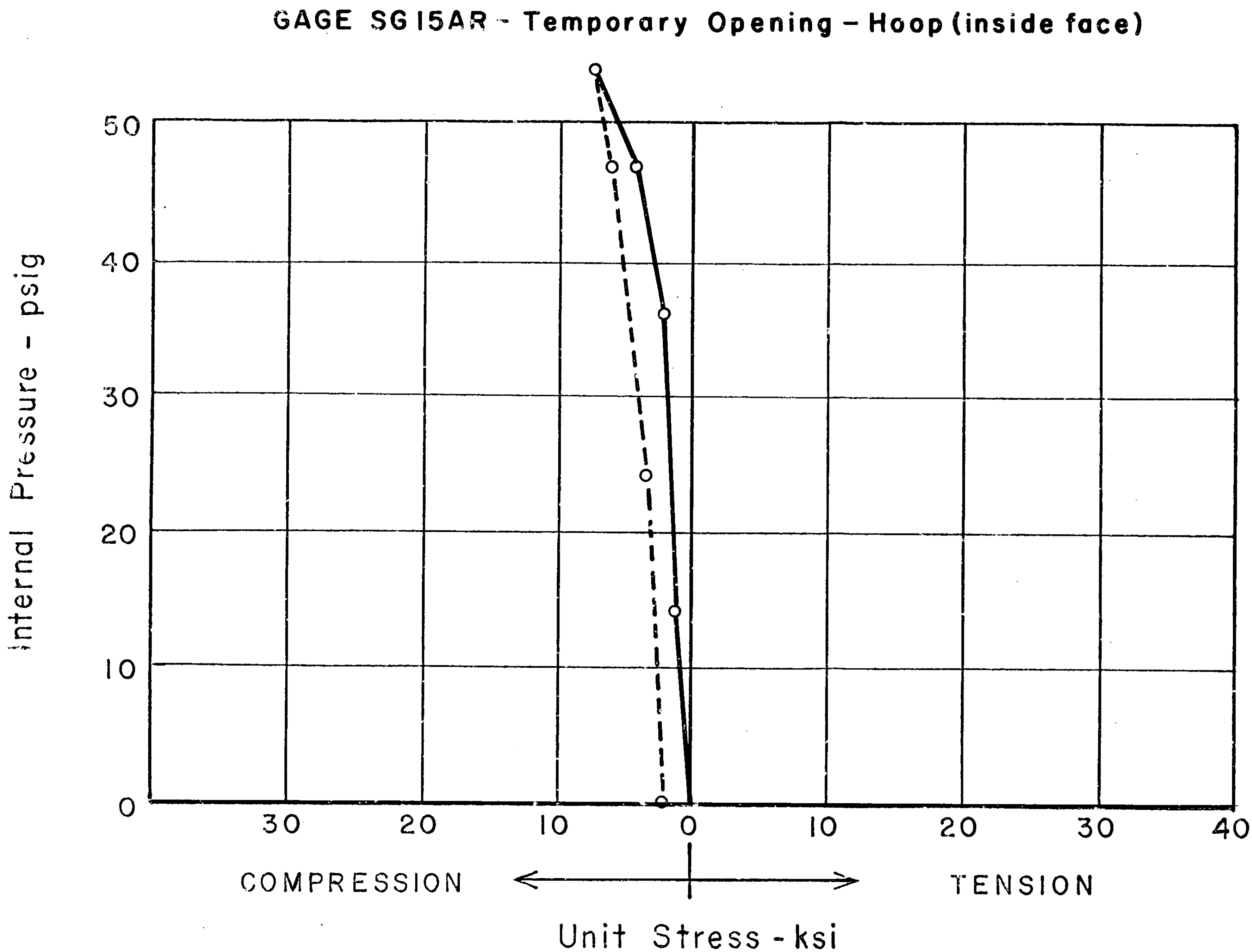


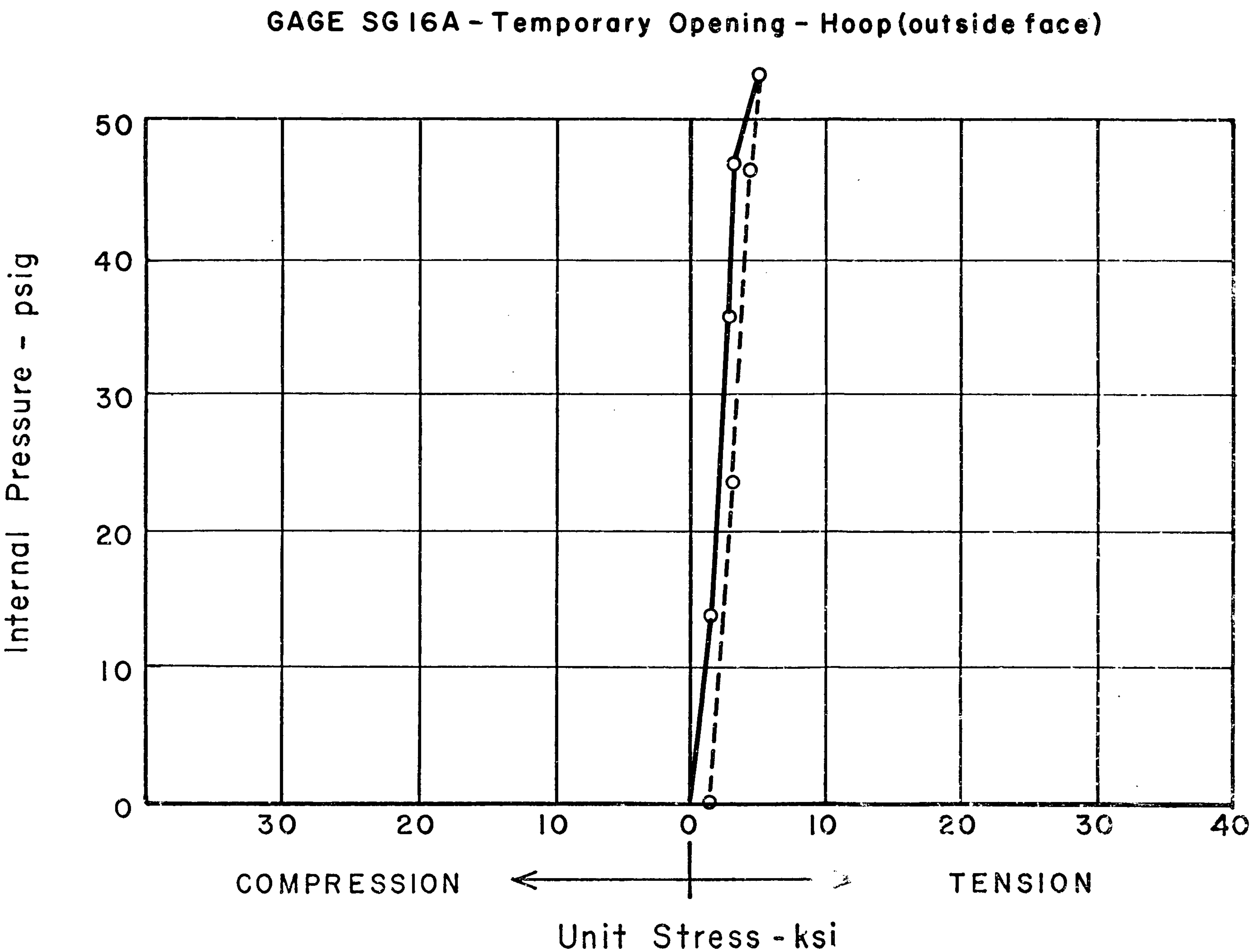

GAGE SG 2A - Temporary Opening - Secondary Vertical
Internal Pressure - psig
0
10
20
30
40
50
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

GAGE SG 3A - Temporary Opening - Seismic

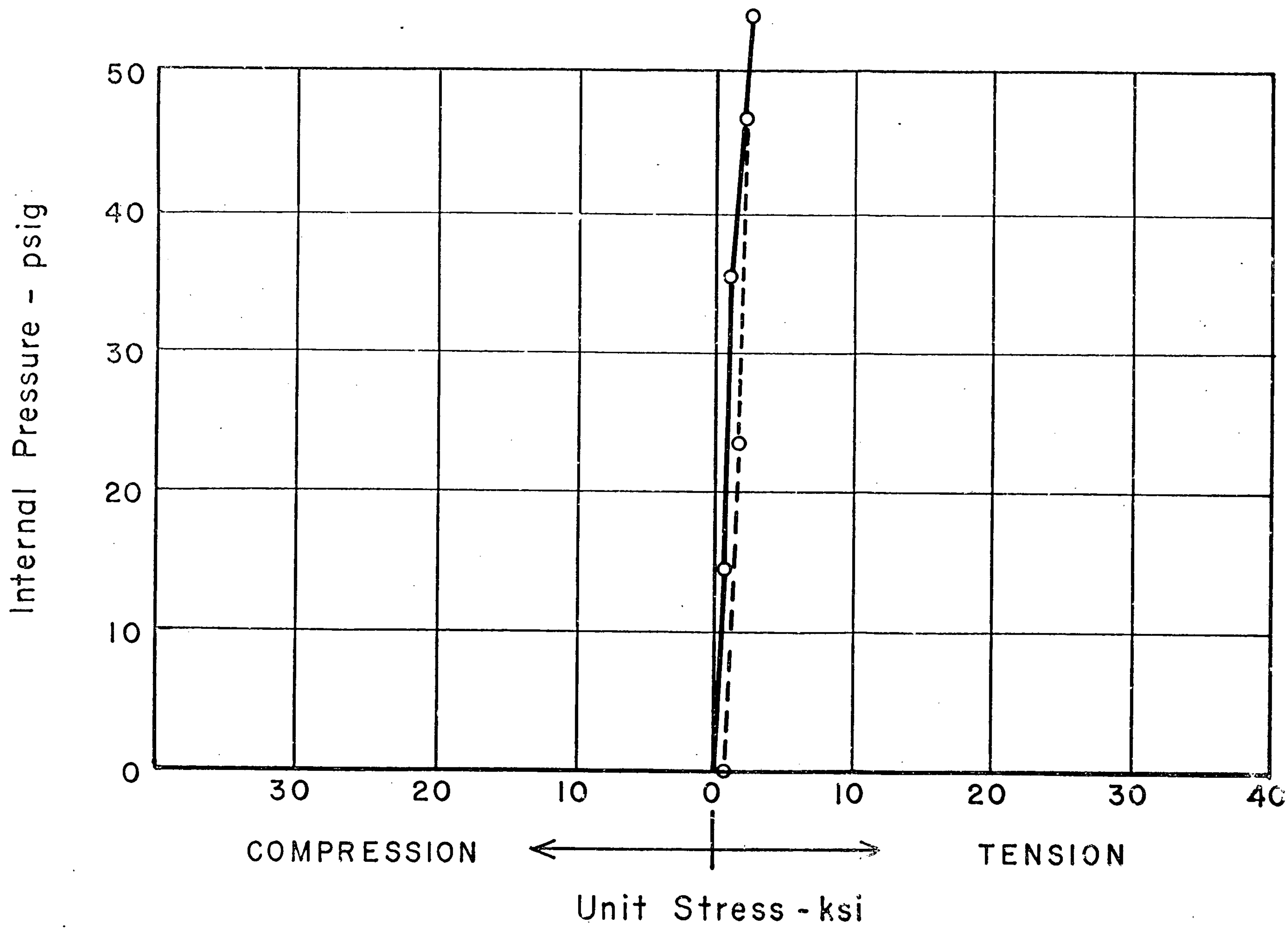



GAGE SG15A - Temporary Opening - Hoop(inside face)
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi


GAGE SG15AR - Temporary Opening - Hoop (inside face)
Internal Pressure - psig
0
10
20
30
40
50
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi


GAGE SG 16A - Temporary Opening - Hoop (outside face)
Internal Pressure - psig
50
40
30
20
10
0
30
20
10
0
10
20
30
40
COMPRESSION
TENSION
Unit Stress - ksi

GAGE SG16AR- Temporary Opening - Hoop(outside face)



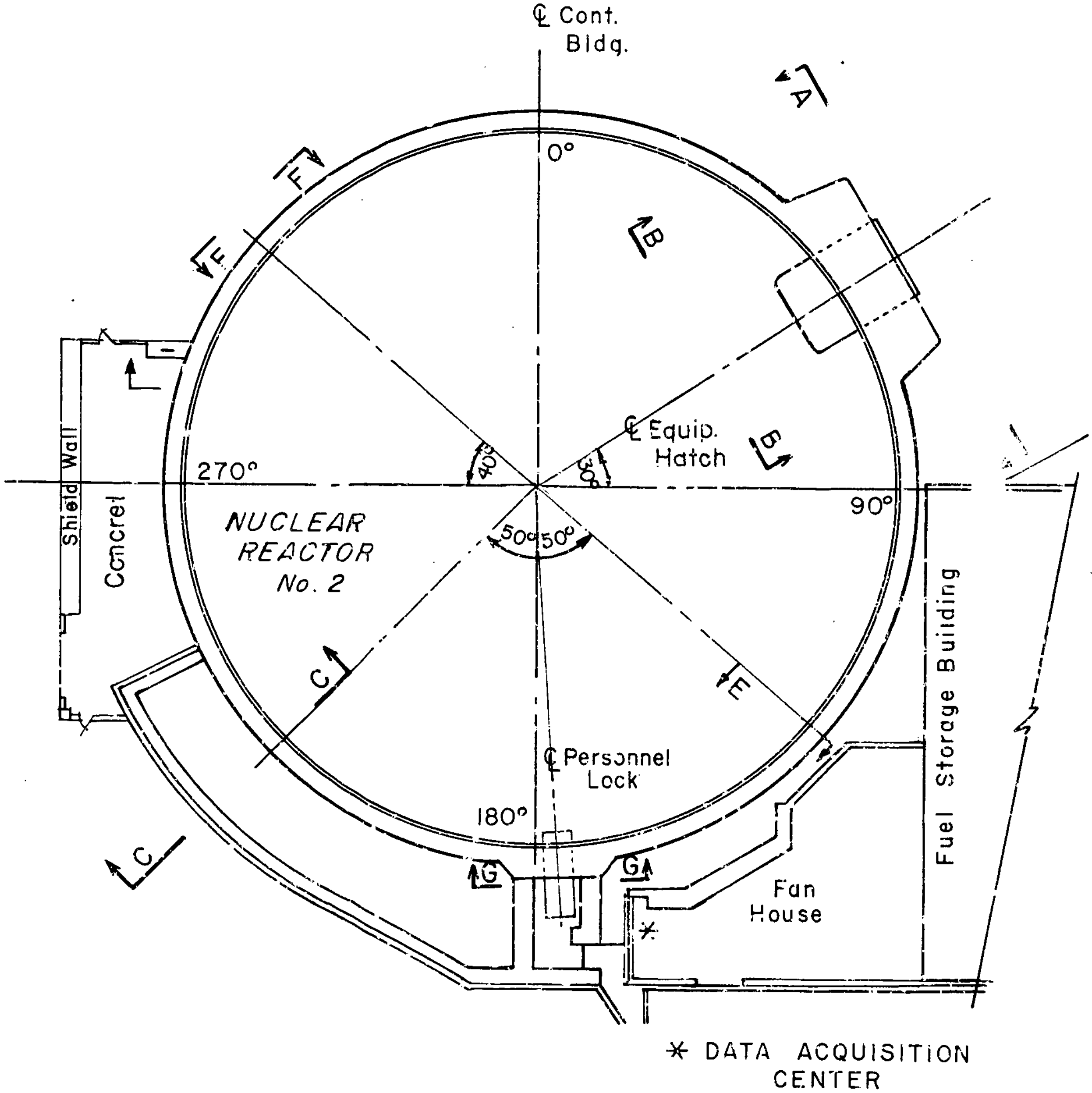
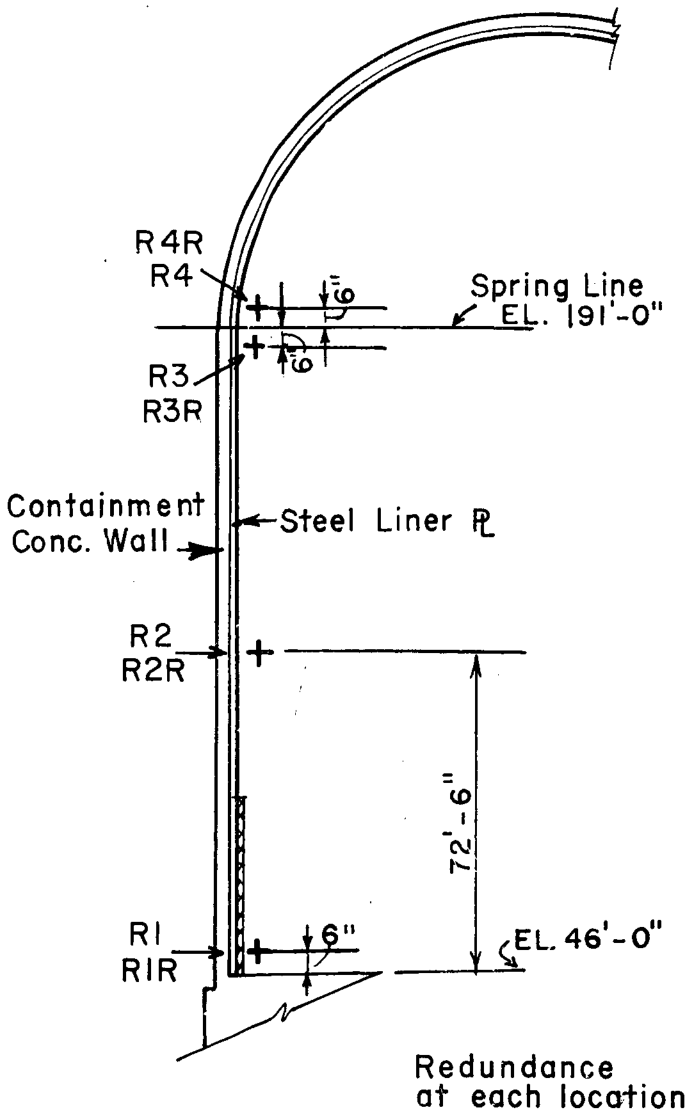


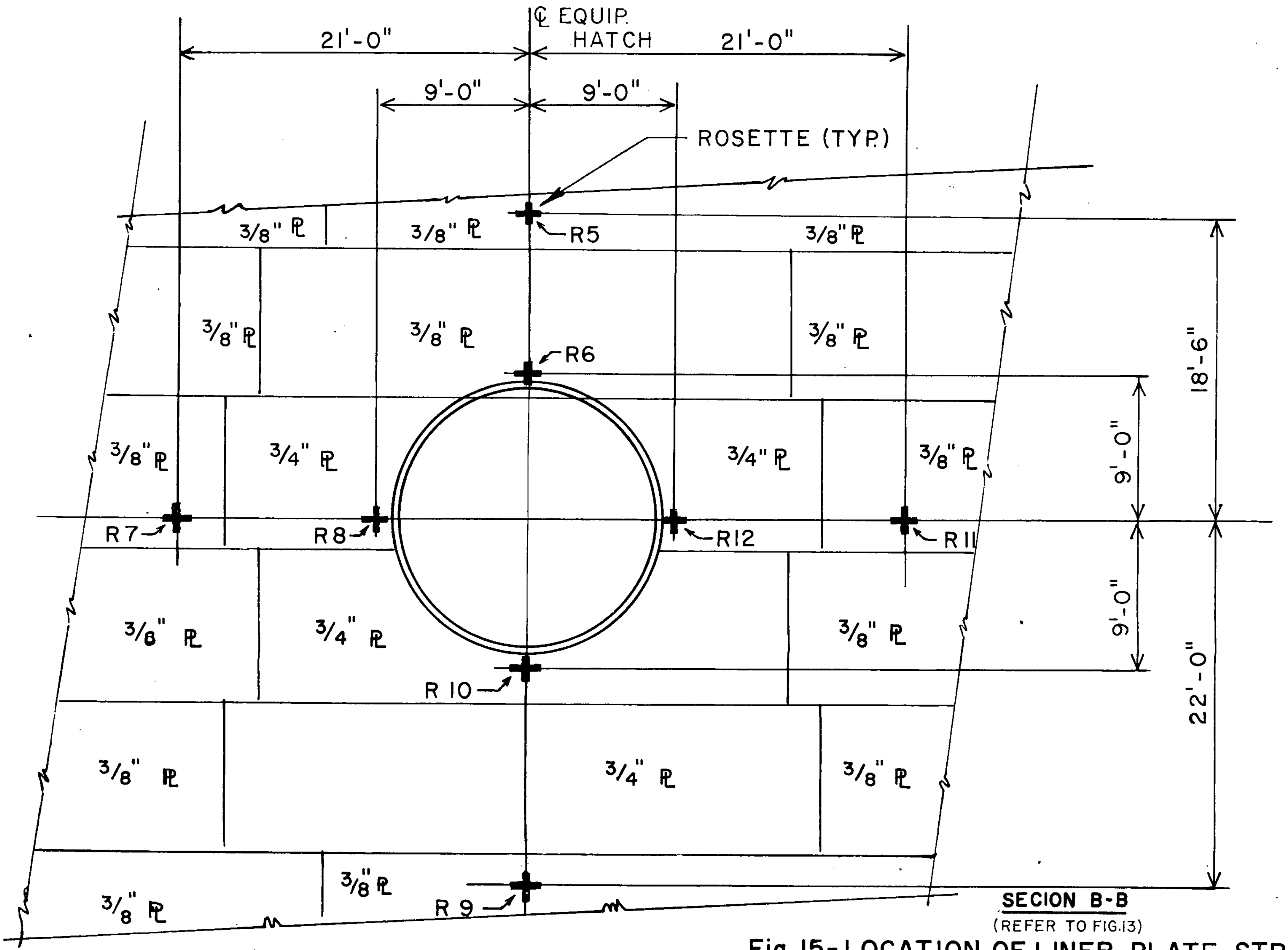

Fig. 13 - KEY PLAN, LOCATION OF LINER PLATE STRAIN GAGES




SECTION E-E

(REFER TO FIGURE 13)

**Fig. 14 - LOCATION OF LINER PLATE STRAIN GAGES AT AZIMUTH 130°**




**SECION B-B**
(REFER TO FIG.13)

**Fig. 15 - LOCATION OF LINER PLATE STRAIN GAGES NEAR EQUIPMENT HATCH**

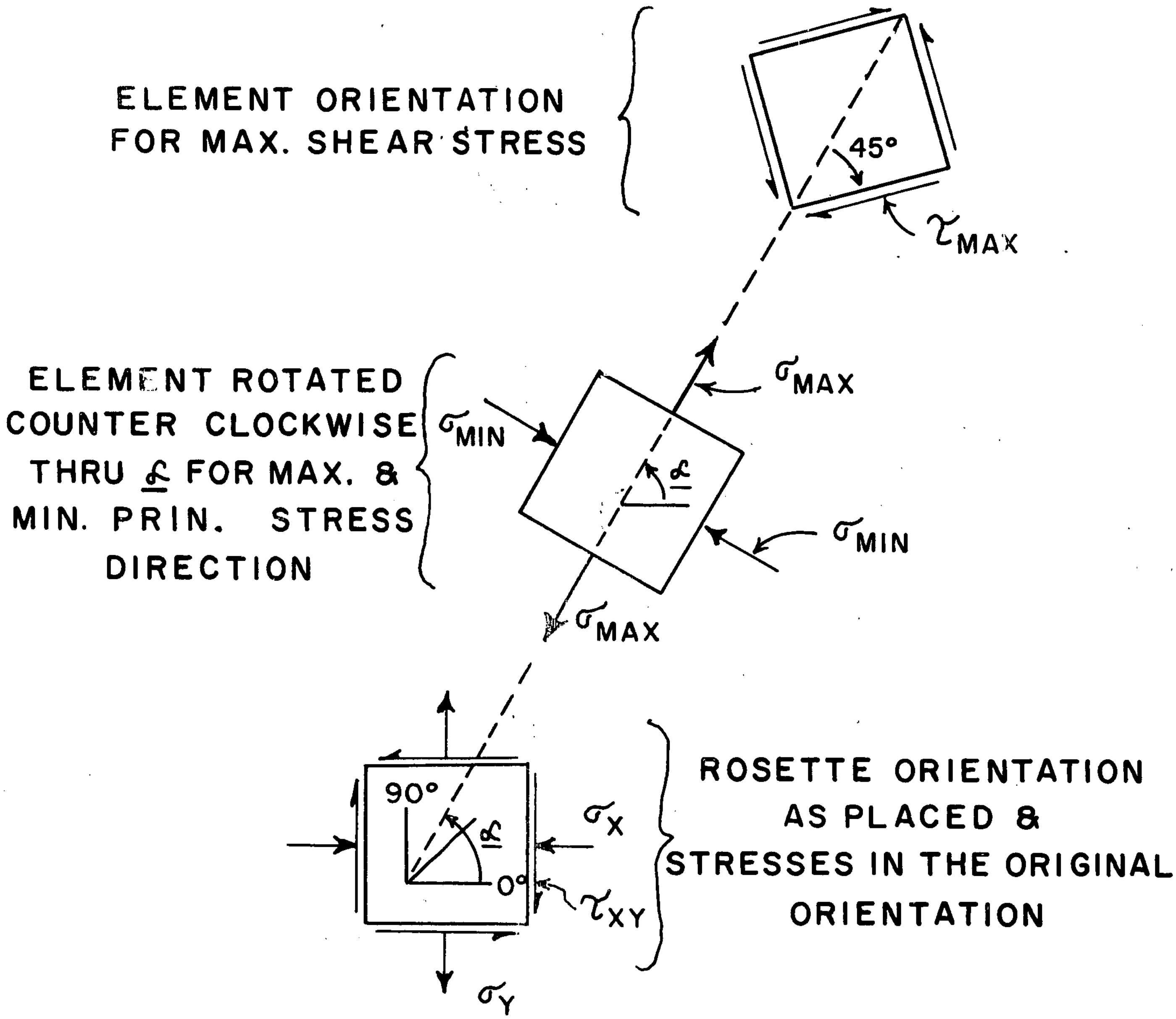



FIG. 16 - ROSETTE DATA OUTPUT KEY

TABLE 3*

PRINCIPAL AND NORMAL STRESSES IN LINER PLATE

| PRESSURE | $\tau_{max}$ | $\sigma_{max}$ | $\sigma_{min}$ | $\theta$ | $S_x$ | $S_y$ | $\tau_{xy}$ |
|---|---|---|---|---|---|---|---|
| | | | Gage Number R1 (Azimuth 130°) | | | | |
| 14 | 25,285 | 27,480 | -23,089 | 42 | 4,672 | -281 | 25,163 |
| 36 | 14,411 | 30,320 | 1,497 | 135 | 16,042 | 15,775 | -14,411 |
| 47 | 10,081 | 27,170 | 7,008 | 132 | 16,052 | 18,127 | -10,027 |
| 54 | 6,509 | 24,365 | 11,346 | 128 | 16,183 | 19,529 | -6,291 |
| 47 | 17,560 | 28,621 | -6,499 | 47 | 10,102 | 12,021 | 17,534 |
| 47 | 11,245 | 24,378 | 1,887 | 48 | 12,107 | 14,159 | 11,198 |
| 24.4 | 5,256 | 16,297 | 5,785 | 44 | 11,208 | 10,873 | 5,253 |
| 24.4 | 5,947 | 17,236 | 5,343 | 46 | 11,144 | 11,434 | 5,945 |
| 0 | 347 | 4,511 | 3,816 | 87 | 3,818 | 4,509 | 33.5 |
| | | | Gage Number R1R (Azimuth 130°) | | | | |
| 14 | 1,515 | -639 | -3,669 | 97 | -3,627 | -682 | -357 |
| 36 | 1,692 | 12,112 | 8,727 | 76 | 8,936 | 11,903 | 814 |
| 47 | 2,973 | 15,961 | 10,015 | 73 | 10,523 | 15,453 | 1,662 |
| 54 | 3,504 | 18,169 | 11,162 | 104 | 11,587 | 17,744 | -1,673 |
| 47 | 3,977 | 13,609 | 5,655 | 76 | 6,119 | 13,145 | 1,863 |
| 47 | 3,732 | 13,965 | 6,501 | 77 | 6,864 | 13,601 | 1,606 |
| 24.4 | 1,786 | 9,202 | 5,630 | 85 | 5,653 | 9,178 | 290 |
| 24.4 | 2,184 | 11,526 | 7,158 | 85 | 7,189 | 11,495 | 368 |
| 0 | 1,194 | 7,014 | 4,627 | 90 | 4,627 | 7,014 | 11 |

NOTE: Refer to Fig. 13 for gage orientation and data interpretation.

TABLE 3 (PAGE 2)

| PRESSURE | $\tau$ max | $\sigma$ max | $\sigma$ min | $\theta$ | $S_x$ | $S_y$ | $\tau$ xy |
|---|---|---|---|---|---|---|---|
| | | | Gage Number R2 (Azimuth 130°) | | | | |
| 14 | 390 | 1,012 | 231 | 165 | 956 | 287 | - 201 |
| 36 | 5,973 | 23,062 | 11,116 | 179 | 23,057 | 11,122 | - 257 |
| 47 | 7,472 | 28,166 | 13,221 | 179 | 28,155 | 13,231 | - 390 |
| 54 | 5,860 | 24,834 | 13,114 | 12 | 24,306 | 13,643 | 2,432 |
| 47 | 7,304 | 27,625 | 13,017 | 177 | 27,582 | 13,060 | - 792 |
| 47 | 7,906 | 28,020 | 12,207 | 175 | 27,888 | 12,339 | -1,439 |
| 24.2 | 5,346 | 18,064 | 7,373 | 173 | 17,916 | 7,521 | -1,249 |
| 24.2 | 4,925 | 20,212 | 10,362 | 176 | 20,173 | 10,402 | - 624 |
| 0 | 2,158 | 11,707 | 7,391 | 2 | 11,702 | 7,397 | 145 |
| | | | Gage Number R2R (Azimuth 130°) | | | | |
| 14 | 16,154 | 32,104 | - 204 | 158 | 27,550 | 4,350 | -11,243 |
| 36 | 9,725 | 10,553 | -8,896 | 57 | - 2,986 | 4,643 | 8,945 |
| 47 | 6,430 | 14,840 | 1,980 | 44 | 8,678 | 8,142 | 6,425 |
| 54 | --- | YIELD | --- | -- | --- | --- | --- |
| 47 | --- | --- | --- | -- | --- | --- | --- |
| 47 | --- | --- | --- | -- | --- | --- | --- |
| 24.2 | --- | --- | --- | -- | --- | --- | --- |
| 24.2 | --- | --- | --- | -- | --- | --- | --- |
| 0 | --- | --- | --- | -- | --- | --- | --- |

TABLE 3 (PAGE 3)

| PRESSURE | $\tau_{max}$ | $\sigma_{max}$ | $\sigma_{min}$ | $\theta$ | $S_x$ | $S_y$ | $\tau_{xy}$ |
|---|---|---|---|---|---|---|---|
| | | | Gage Number R3 (Azimuth 130°) | | | | |
| 14 | 898 | - 2,334 | - 4,129 | 77 | - 4,035 | - 2,428 | 402 |
| 36 | 2,951 | 18,570 | 12,667 | 2 | 18,563 | 12,674 | 201 |
| 47 | 4,373 | 24,114 | 15,368 | 2 | 24,102 | 15,380 | 323 |
| 54 | 3,918 | 21,960 | 14,125 | 33 | 19,682 | 16,403 | 3,558 |
| 47 | 3,823 | 20,830 | 13,183 | 3 | 20,810 | 13,203 | 390 |
| 47 | 4,466 | 22,695 | 13,763 | 1 | 22,690 | 13,767 | 201 |
| 24.2 | 2,989 | 15,956 | 9,978 | 0 | 15,956 | 9,978 | 0 |
| 24.2 | 2,454 | 16,042 | 11,135 | 0 | 16,042 | 11,135 | 0 |
| 0 | 854 | 9,471 | 7,763 | 170 | 9,420 | 7,814 | - 290 |
| | | | Gage Number R3R (Azimuth 130°) | | | | |
| 14 | 280 | 652 | 93 | 104 | 127 | 618 | - 134 |
| 36 | 3,462 | 24,839 | 17,915 | 119 | 19,593 | 23,162 | -2,967 |
| 47 | 3,549 | 21,819 | 14,721 | 7 | 21,705 | 14,835 | 892 |
| 54 | 4,091 | 26,400 | 18,219 | 6 | 26,314 | 18,305 | 837 |
| 47 | 3,574 | 21,678 | 14,531 | 1 | 21,674 | 14,535 | 178 |
| 47 | 4,009 | 21,989 | 13,971 | 3 | 21,973 | 13,987 | 357 |
| 24.2 | 2,478 | 14,699 | 9,744 | 179 | 14,698 | 9,745 | - 89 |
| 24.2 | 1,897 | 15,983 | 12,188 | 1 | 15,982 | 12,190 | 67 |
| 0 | 275 | 9,742 | 9,191 | 56 | 9,366 | 9,567 | 257 |

TABLE 3 (Page 4)

| PRESSURE | $\tau$ max | $\sigma$ max | $\sigma$ min | $\theta$ | $S_x$ | $S_y$ | $\tau_{xy}$ |
|---|---|---|---|---|---|---|---|
| Gage Number R4 (Azimuth 130°) | | | | | | | |
| 14 | 13,953 | 32,078 | 4,172 | 66 | 8,856 | 27,394 | 10,429 |
| 36 | 14,999 | 12,161 | -17,837 | 161 | 9,041 | -14,717 | - 9,157 |
| 47 | 12,531 | 18,870 | - 6,193 | 165 | 17,202 | - 4,525 | - 6,246 |
| 54 | 16,280 | 26,388 | - 6,171 | 158 | 21,753 | - 1,536 | -11,377 |
| 47 | 8,610 | 38,439 | 21,219 | 51 | 28,089 | 31,569 | 8,432 |
| 47 | 4,252 | 26,934 | 18,431 | 37 | 23,831 | 21,533 | 4,093 |
| 24.2 | 3,039 | 13,686 | 7,608 | 19 | 13,056 | 8,238 | 1,852 |
| 24.2 | 3,805 | 19,652 | 12,041 | 34 | 17,308 | 14,385 | 3,513 |
| 0 | 2,891 | 8,132 | 2,349 | 179 | 8,129 | 2,352 | - 123 |
| Gage Number R4R (Azimuth 130°) | | | | | | | |
| 14 | 421 | - 3,473 | - 4,315 | 119 | - 4,117 | - 3,671 | - 357 |
| 36 | 3,226 | 17,954 | 11,502 | 1 | 17,951 | 11,504 | 123 |
| 47 | 4,426 | 22,779 | 13,926 | 2 | 22,769 | 13,936 | 290 |
| 54 | 5,046 | 26,879 | 16,786 | 1 | 26,874 | 16,791 | 223 |
| 47 | 3,782 | 18,344 | 10,781 | 0 | 18,343 | 10,781 | 56 |
| 47 | 4,172 | 20,536 | 12,192 | 0 | 20,536 | 12,193 | 67 |
| 24.2 | 2,791 | 14,515 | 8,934 | 179 | 14,513 | 8,936 | - 112 |
| 24.2 | 2,489 | 13,902 | 8,925 | 179 | 13,901 | 8,926 | - 78 |
| 0 | 948 | 7,742 | 5,847 | 167 | 7,642 | 5,946 | - 424 |

| PRESSURE | $\tau$ max | $\sigma$ max | $\sigma$ min | $\theta$ | $S_x$ | $S_y$ | $\tau$ xy |
|---|---|---|---|---|---|---|---|
| | | | Gage Number R5 (Nr. Equipment Hatch) | | | | |
| 14 | 161 | - 253 | - 575 | 17 | - 280 | - 548 | 89 |
| 36 | 2,287 | 21,738 | 17,163 | 162 | 21,313 | 17,588 | -1,327 |
| 47 | 3,118 | 27,644 | 21,407 | 165 | 27,225 | 21,826 | -1,562 |
| 54 | 3,428 | 31,952 | 25,095 | 166 | 31,546 | 25,501 | -1,617 |
| 47 | 2,670 | 26,056 | 20,717 | 168 | 25,807 | 20,966 | -1,127 |
| 47 | 2,694 | 26,060 | 20,672 | 167 | 25,797 | 20,934 | -1,160 |
| 24.2 | 1,872 | 17,698 | 13,953 | 169 | 17,566 | 14,086 | - 692 |
| 24.2 | 1,776 | 19,259 | 15,707 | 167 | 19,067 | 15,899 | - 803 |
| 0 | 667 | 12,288 | 10,954 | 154 | 12,033 | 11,208 | - 524 |
| | | | Gage Number R6 (Nr. Equipment Hatch) | | | | |
| 14 | 2,124 | 1,771 | - 2,476 | 15 | 1,488 | - 2,193 | 1,060 |
| 36 | 4,191 | 18,836 | 10,454 | 178 | 18,828 | 10,462 | - 257 |
| 47 | 6,739 | 26,293 | 12,816 | 179 | 26,291 | 12,817 | - 156 |
| 54 | 8,361 | 31,416 | 14,694 | 1 | 31,409 | 14,701 | 346 |
| 47 | 8,822 | 26,201 | 8,557 | 5 | 26,090 | 8,668 | 1,394 |
| 47 | --- | OUT | --- | --- | --- | --- | --- |
| 24.2 | --- | --- | --- | --- | --- | --- | --- |
| 24.2 | --- | --- | --- | --- | --- | --- | --- |
| 0 | --- | --- | --- | --- | --- | --- | --- |

TABEL 3 (PAGE 6)

| PRESSURE | $\tau$ max | $\sigma$ max | $\sigma$ min | $\theta$ | $S_x$ | $S_y$ | $\tau$ xy |
|---|---|---|---|---|---|---|---|
| | | | Gage Number R7 (Nr. Equipment Hatch) | | | | |
| 14 | 11,714 | 23,645 | 217 | 114 | 4,213 | 19,650 | -8,812 |
| 36 | 15,962 | 15,858 | -16,065 | 15 | 13,671 | -13,878 | 8,064 |
| 47 | 13,732 | 22,184 | - 5,281 | 11 | 21,189 | - 4,286 | 5,131 |
| 54 | 14,666 | 25,603 | - 3,729 | 10 | 24,634 | - 2,760 | 5,242 |
| 47 | 5,109 | 22,882 | 12,664 | 161 | 21,833 | 13,713 | -3,101 |
| 47 | 6,152 | 24,028 | 11,725 | 171 | 23,732 | 12,021 | -1,885 |
| 24.2 | 5,516 | 14,009 | 2,976 | 1 | 14,003 | 2,983 | 268 |
| 24.2 | 6,086 | 12,528 | 356 | 4 | 12,454 | 430 | 948 |
| 0 | 8,663 | 3,691 | -13,634 | 20 | 1,676 | -11,619 | 5,555 |
| | | | Gage Number R8 (Nr. Equipment Hatch) | | | | |
| 14 | 609 | -1,380 | - 2,597 | 104 | - 2,524 | - 1,453 | - 290 |
| 36 | 439 | 6,674 | 5,796 | 86 | 5,800 | 6,670 | 56 |
| 47 | 721 | 6,956 | 5,514 | 107 | 5,644 | 6,826 | - 413 |
| 54 | 923 | 7,987 | 6,140 | 104 | 6,249 | 7,878 | - 435 |
| 47 | 1,152 | 4,922 | 2,618 | 114 | 2,989 | 4,551 | - 845 |
| 47 | 1,216 | 4,883 | 2,450 | 111 | 2,763 | 4,570 | - 814 |
| 24.2 | 854 | 3,381 | 1,673 | 125 | 2,237 | 2,817 | - 803 |
| 24.2 | 565 | 3,796 | 2,667 | 95 | 2,674 | 3,789 | - 89 |
| 0 | 149 | 4,230 | 3,932 | 51 | 4,047 | 4,114 | 145 |

TABLE 3 (PAGE 7)

| PRESSURE | $\tau_{max}$ | $\sigma_{max}$ | $\sigma_{min}$ | $\theta$ | $S_x$ | $S_y$ | $\tau_{xy}$ |
|---|---|---|---|---|---|---|---|
| | | | Gage Number R9 (Nr. Equipment Hatch) | | | | |
| 14 | 279 | 1,460 | 902 | 179 | 1,460 | 902 | - 11 |
| 36 | 3,997 | 16,736 | 8,742 | 178 | 16,721 | 8,757 | -346 |
| 47 | 5,083 | 20,826 | 10,659 | 177 | 20,807 | 10,679 | -446 |
| 54 | 5,383 | 24,399 | 13,633 | 177 | 24,370 | 13,662 | -558 |
| 47 | 4,380 | 20,082 | 11,321 | 177 | 20,051 | 11,351 | -513 |
| 47 | 4,385 | 20,273 | 11,503 | 176 | 20,227 | 11,549 | -636 |
| 24.2 | 2,430 | 13,098 | 8,238 | 175 | 13,066 | 8,270 | -390 |
| 24.2 | 2,355 | 14,577 | 9,866 | 177 | 14,564 | 9,879 | -245 |
| 0 | 789 | 9,530 | 7,953 | 176 | 9,522 | 7,961 | -112 |
| | | | Gage Number R10 (Nr. Equipment Hatch) | | | | |
| 14 | 11,400 | 26,045 | 3,245 | 17 | 24,159 | 5,131 | 6,280 |
| 36 | 10,395 | 8,655 | -12,135 | 120 | -7,072 | 3,591 | -8,923 |
| 47 | 7,329 | 13,481 | - 1,177 | 132 | 5,338 | 6,966 | -7,283 |
| 54 | 8,362 | 16,586 | - 139 | 134 | 7,856 | 8,592 | -8,354 |
| 47 | 10,552 | 33,048 | 11,944 | 0 | 33,047 | 11,944 | 112 |
| 47 | 6,601 | 23,048 | 9,846 | 173 | 22,872 | 10,023 | -1,517 |
| 24.2 | 4,229 | 12,846 | 4,389 | 157 | 11,539 | 5,695 | -3,056 |
| 24.2 | 5,269 | 15,399 | 4,860 | 161 | 14,245 | 6,014 | -3,290 |
| 0 | 6,765 | 6,351 | -7,179 | 126 | -2,534 | 1,705 | -6,425 |

TABLE 3 (PAGE 8)

| PRESSURE | $\tau_{max}$ | $\sigma_{max}$ | $\sigma_{min}$ | $\theta$ | $S_x$ | $S_y$ | $\tau_{xy}$ |
|---|---|---|---|---|---|---|---|
| | | | Gage Number 11 (Nr. Equipment Hatch) | | | | |
| 14 | 8,546 | 25,076 | 7,984 | 134 | 16,329 | 16,731 | - 8,544 |
| 36 | 15,404 | 5,275 | -25,534 | 45 | - 9,962 | -10,297 | 15,403 |
| 47 | 9,342 | 13,588 | - 5,095 | 38 | 6,399 | 2,094 | 9,090 |
| 54 | 12,082 | 15,293 | - 8,871 | 37 | 6,702 | - 280 | 11,567 |
| 47 | 4,556 | 25,685 | 16,572 | 173 | 25,568 | 16,689 | - 1,026 |
| 47 | 3,257 | 23,764 | 17,250 | 177 | 23,742 | 17,273 | - 379 |
| 24.2 | 1,485 | 13,354 | 10,385 | 46 | 11,814 | 11,925 | 1,483 |
| 24.2 | 6,352 | 10,827 | - 1,878 | 37 | 6,281 | 2,667 | 6,090 |
| 0 | 13,200 | - 2,232 | -28,632 | 41 | -13,525 | -17,339 | 13,061 |
| | | | Gage Number 12 (Nr. Equipment Hatch) | | | | |
| 14 | 1,172 | 4,570 | 2,225 | 169 | 4,490 | 2,304 | - 424 |
| 36 | 2,722 | -14,222 | -19,666 | 96 | -19,599 | -14,290 | - 602 |
| 47 | 2,724 | - 6,597 | -12,046 | 98 | -11,931 | - 6,711 | - 781 |
| 54 | 2,872 | - 9,516 | -15,259 | 95 | -15,220 | - 9,554 | - 468 |
| 47 | 1,440 | - 632 | - 3,511 | 110 | - 3,165 | - 978 | - 937 |
| 47 | 1,887 | 2,612 | - 1,162 | 110 | - 736 | 2,186 | - 1,193 |
| 24.2 | 1,595 | 1,409 | - 1,782 | 120 | - 1,001 | 628 | - 1,372 |
| 24.2 | 877 | -11,241 | -12,995 | 108 | -12,821 | -11,415 | - 524 |
| 0 | 1,432 | -21,416 | -24,280 | 131 | -23,060 | -22,636 | - 1,417 |

# APPENDIX B

## DISPLACEMENT DATA

TABLE 4

RADIAL DISPLACEMENTS OF WALL

NEAR ELECTRICAL TUNNEL - INCHES

AZIMUTH 230°

| DATE | 3/5/71 | 3/5/71 | 3/6/71 | 3/6/71 | 3/8/71 | 3/9/71 | 3/10/71 | 3/10/71 | 3/11/71 | 3/12/71 | 3/12/71 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TIME | 0340 | 2000 | 0622 | 1750 | 0530 | 1200 | 1345 | 2000 | 2400 | 1130 | 2015 |
| PRESS. | 14 | 36 | 47 | 54 | 47 | 47 | 47 | 24.2 | 24.2 | 24.2 | 0 |
| ELECT. TUNNEL | | | | | | | | | | | |
| 1 | No room for installation | | | | | | | | | | |
| 2 | +0.0035 | +0.0255 | +0.036 | +0.046 | +0.045 | +0.047 | +0.048 | +0.038 | +0.038 | +0.039 | +0.014 |
| 3 | +0.006 | +0.034 | +0.049 | +0.062 | +0.061 | +0.062 | +0.063 | +0.051 | +0.050 | +0.051 | +0.019 |
| 4 | +0.006 | +0.043 | +0.062 | +0.079 | +0.077 | +0.078 | +0.081 | +0.064 | +0.063 | +0.063 | +0.025 |
| 5 | +0.007 | +0.052 | +0.075 | +0.093 | +0.089 | +0.091 | +0.093 | +0.075 | +0.074 | +0.074 | +0.029 |
| 6 | +0.0065 | +0.057 | +0.085 | +0.108 | +0.105 | +0.105 | +0.107 | +0.085 | +0.085 | +0.085 | +0.032 |
| 7 | +0.0035 | +0.069 | +0.102 | +0.123 | +0.112 | +0.113 | +0.124 | +0.100 | +0.099 | +0.097 | +0.076 |
| 8 | +0.011 | +0.076 | +0.113 | +0.141 | +0.136 | +0.139 | +0.139 | +0.100 | +0.110 | +0.208 | +0.046 |
| 9 | +0.017 | +0.091 | +0.131 | +0.163 | +0.157 | +0.158 | +0.160 | +0.129 | +0.127 | +0.125 | +0.052 |
| 10 | +0.0085 | +0.094 | +0.137 | +0.174 | +0.143 | +0.145 | +0.168 | +0.133 | +0.131 | +0.015 | +0.047 |
| 11 | +0.0115 | - | - | - | - | - | - | - | - | - | - |
| 12 | +0.006 | +0.085 | +0.132 | +0.173 | +0.156 | +0.157 | +0.160 | +0.116 | +0.113 | +0.1085 | +0.014 |
| 13 | +0.020 | +0.134 | +0.192 | +0.238 | +0.219 | +0.22 | +0.228 | +0.175 | +0.179 | +0.170 | +0.062 |
| 14 | +0.023 | +0.145 | +0.205 | +0.254 | +0.235 | +0.237 | +0.241 | +0.184 | +0.181 | +0.178 | +0.068 |
| 15 | +0.024 | +0.154 | +0.219 | +0.269 | +0.249 | +0.251 | +0.255 | +0.193 | +0.190 | +0.186 | +0.069 |
| 16 | +0.023 | +0.163 | +0.231 | +0.282 | +0.260 | +0.262 | +0.262 | +0.199 | +0.197 | +0.194 | +0.057 |

*Gages generally at one-ft intervals. Gage No. 1 at Elev. 46'-6", Gage No. 16 at 61'-6"

TABLE 5

RADIAL DISPLACEMENTS OF WALL

NEAR PIPE BRIDGE - INCHES

AZIMUTH 290°

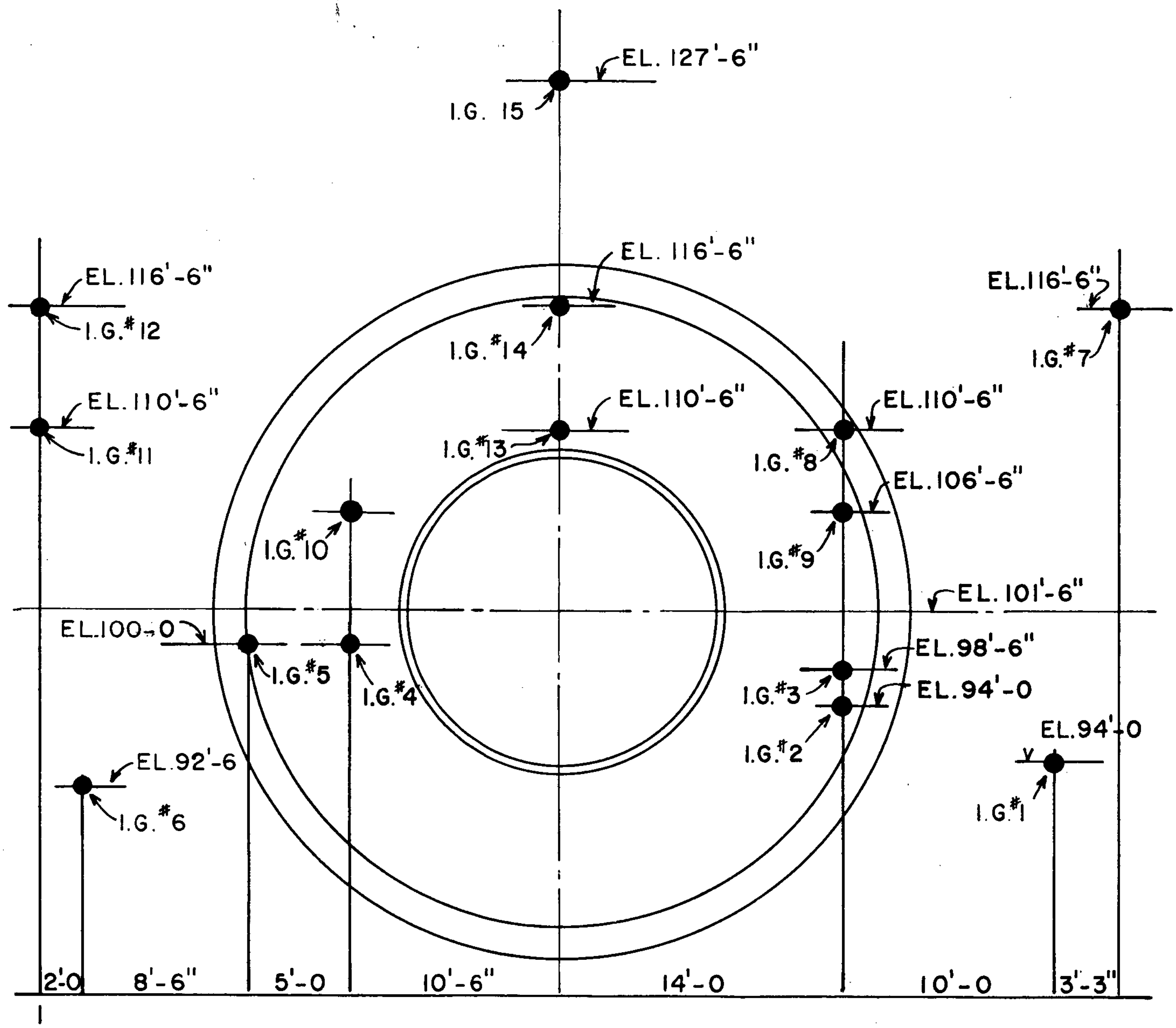
| DATE<br>TIME<br>PRESS. | 3/5/71<br>0340<br>14 | 3/5/71<br>2000<br>36 | 3/6/71<br>0622<br>47 | 3/6/71<br>1750<br>54 | 3/8/71<br>0530<br>47 | 3/9/71<br>1200<br>47 | 3/10/71<br>1345<br>47 | 3/10/71<br>2000<br>24.2 | 3/11/71<br>2400<br>24.2 | 3/12/71<br>1130<br>24.2 | 3/12/71<br>2015<br>0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PIPE BRIDGE | | | | | | | | | | | |
| 1 | -0.003 | +0.006 | +0.008 | +0.012 | +0.009 | +0.009 | +0.006 | +0.007 | +0.006 | +0.004 | +0.004 |
| 2 | +0.002 | +0.028 | +0.036 | +0.043 | +0.037 | +0.036 | +0.027 | +0.029 | +0.028 | +0.021 | +0.021 |
| 3 | -0.003 | +0.027 | +0.040 | +0.051 | +0.043 | +0.042 | +0.030 | +0.030 | +0.028 | +0.020 | +0.014 |
| 4 | -0.004 | +0.039 | +0.056 | +0.072 | +0.061 | +0.060 | +0.045 | +0.044 | +0.041 | +0.030 | +0.025 |
| 5 | -0.006 | +0.048 | +0.070 | +0.091 | +0.075 | +0.074 | +0.056 | +0.050 | +0.048 | +0.035 | +0.022 |
| 6 | -0.009 | +0.054 | +0.081 | +0.109 | +0.088 | +0.089 | +0.067 | +0.058 | +0.054 | +0.039 | +0.027 |
| 7 | -0.001 | +0.069 | +0.103 | +0.134 | +0.111 | +0.110 | +0.090 | +0.074 | +0.071 | +0.055 | +0.037 |
| 8 | -0.006 | +0.085 | +0.123 | +0.158 | +0.132 | +0.132 | +0.108 | +0.088 | +0.086 | +0.066 | +0.046 |
| 9 | -0.008 | +0.094 | +0.137 | +0.177 | +0.149 | +0.147 | +0.124 | +0.097 | +0.093 | +0.081 | +0.052 |
| 10 | -0.005 | +0.108 | +0.158 | +0.202 | +0.178 | +0.163 | +0.145 | +0.110 | +0.105 | +0.090 | +0.061 |
| 11 | +0.006 | +0.153 | +0.196 | +0.255 | +0.199 | +0.201 | +0.181 | +0.131 | +0.129 | +0.111 | +0.072 |
| 12 | +0.004 | +0.137 | +0.197 | +0.252 | +0.213 | +0.212 | +0.192 | +0.139 | +0.136 | +0.121 | +0.072 |
| 13 | -0.014 | +0.136 | +0.200 | +0.260 | +0.213 | +0.213 | +0.190 | +0.134 | +0.132 | +0.113 | +0.070 |
| 14 | +0.009 | +0.155 | +0.228 | +0.291 | +0.246 | +0.245 | +0.233 | +0.157 | +0.156 | +0.147 | +0.076 |
| 15 | +0.005 | +0.157 | +0.237 | +0.303 | +0.252 | +0.249 | +0.243 | +0.158 | +0.158 | +0.151 | +0.072 |
| 16 | +0.006 | +0.166 | +0.253 | +0.323 | +0.270 | +0.267 | +0.263 | +0.167 | +0.169 | +0.160 | +0.071 |

TABLE 6

RADIAL DISPLACEMENTS OF CYLINDER WALL - INCHES

AZIMUTH 135° AT 10' INCREMENTS

| | DATE<br>TIME<br>PRESS. | 3/5/71<br>0340<br>14 | 3/5/71<br>2000<br>36 | 3/6/71<br>0622<br>47 | 3/6/71<br>1750<br>54 | 3/8/71<br>0530<br>47 | 3/9/71<br>1200<br>47 | 3/10/71<br>1345<br>47 | 3/10/71<br>2000<br>24.2 | 3/11/71<br>2400<br>24.2 | 3/12/71<br>1130<br>24.2 | 3/12/71<br>2015<br>0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ELEV. | | | | | | | | | | | |
| P16 | 91'-0" | 0.053 | 0.447 | 0.616 | 0.721 | 0.696 | 0.708 | 0.696 | 0.370 | 0.366 | 0.369 | 0.119 |
| P17 | 101'-0" | 0.089 | 0.447 | 0.564 | 0.712 | 0.641 | 0.643 | 0.644 | 0.345 | 0.344 | 0.345 | 0.106 |
| P18 | 111'-0" | 0.133 | 0.483 | 0.635 | 0.728 | 0.668 | 0.668 | 0.669 | 0.340 | 0.340 | 0.341 | 0.093 |
| P19 | 121'-0" | - | - | - | - | - | - | - | - | - | - | - |
| P20 | 131'-0" | 0.155 | 0.475 | 0.615 | 0.740 | 0.665 | 0.665 | 0.666 | 0.315 | 0.314 | 0.314 | 0.069 |
| P21 | 141'-0" | - | - | - | - | - | - | - | - | - | - | - |
| P22 | 151'-0" | 0.126 | 0.440 | 0.568 | 0.640 | 0.600 | 0.601 | 0.601 | 0.294 | 0.292 | 0.282 | 0.070 |
| P23 | 161'-0" | 0.125 | 0.439 | 0.584 | 0.695 | 0.625 | 0.625 | 0.625 | 0.315 | 0.315 | 0.285 | 0.065 |
| P24 | 171'-0" | 0.125 | 0.421 | 0.558 | 0.680 | 0.609 | 0.610 | 0.610 | 0.327 | 0.326 | 0.327 | 0.104 |
| P25 | 181'-0" | - | - | - | - | - | - | - | - | - | - | - |
| P26 | 191'-0" | 0.107 | 0.332 | 0.430 | 0.518 | 0.465 | 0.465 | 0.465 | 0.220 | 0.220 | 0.220 | 0.061 |




**SECTION A-A**

(REFER TO FIG. 13)

**Fig. 17 – LOCATION OF EXTENSOMETERS NEAR EQUIPMENT HATCH**

TABLE 7

RADIAL DISPLACEMENTS OF WALL

NEAR EQUIPMENT HATCH - INCHES*

| DATE<br>TIME<br>PRESS. | 3/5/71<br>0340<br>14 | 3/5/71<br>2000<br>36 | 3/6/71<br>0622<br>47 | 3/6/71<br>1750<br>54 | 3/8/71<br>0530<br>47 | 3/9/71<br>1200<br>47 | 3/10/71<br>1345<br>47 | 3/10/71<br>2000<br>24.2 | 3/11/71<br>2400<br>24.2 | 3/12/71<br>1130<br>24.2 | 3/12/71<br>2015<br>0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | 0.095 | 0.127 | 0.125 | - | - | - | - | - | - | - | - |
| P2 | 0.093 | 0.368 | 0.514 | 0.628 | 0.568 | 0.574 | 0.575 | 0.318 | 0.313 | 0.311 | 0.128 |
| P3 | 0.087 | 0.360 | 0.507 | 0.620 | 0.563 | 0.568 | 0.569 | 0.318 | 0.314 | 0.313 | 0.131 |
| P4 | 0.094 | 0.383 | 0.536 | 0.622 | 0.568 | 0.557 | 0.578 | 0.318 | 0.308 | 0.308 | 0.132 |
| P5 | 0.104 | 0.437 | 0.619 | 0.716 | 0.654 | 0.663 | 0.664 | 0.370 | 0.360 | 0.359 | 0.145 |
| P6 | 0.109 | 0.452 | 0.623 | 0.738 | 0.681 | 0.683 | 0.684 | 0.381 | 0.379 | 0.381 | 0.142 |
| P7 | 0.105 | 0.421 | 0.574 | 0.688 | 0.621 | 0.629 | 0.628 | 0.333 | 0.328 | 0.327 | 0.105 |
| P8 | 0.080 | 0.355 | 0.526 | 0.613 | 0.560 | 0.565 | 0.566 | 0.321 | 0.316 | 0.314 | 0.135 |
| P9 | 0.083 | 0.099 | 0.111 | 0.129 | 0.121 | 0.124 | 0.125 | - | - | - | - |
| P10 | 0.091 | 0.347 | 0.486 | 0.588 | 0.590 | 0.591 | 0.591 | 0.491 | 0.489 | 0.490 | 0.060 |
| P11 | 0.079 | 0.450 | 0.619 | 0.711 | 0.682 | 0.690 | 0.699 | 0.388 | 0.376 | 0.377 | 0.134 |
| P12 | 0.071 | 0.451 | 0.619 | 0.706 | 0.678 | 0.689 | 0.688 | 0.387 | 0.370 | 0.370 | 0.132 |
| P13 | 0.085 | 0.363 | 0.521 | 0.559 | 0.508 | 0.521 | 0.520 | 0.297 | 0.275 | 0.273 | 0.079 |
| P14 | 0.084 | 0.355 | 0.498 | 0.555 | 0.496 | 0.511 | 0.510 | 0.280 | 0.257 | 0.255 | 0.132 |
| P15 | 0.086 | 0.398 | 0.569 | 0.639 | 0.574 | 0.590 | 0.589 | 0.347 | 0.317 | 0.316 | 0.162 |

*See Fig. 17 for location

TABLE 8

VERTICAL DISPLACEMENTS OF WALL AND DOME - INCHES

AZIMUTH 315°

| DATE<br>TIME<br>PRESS. | 3/5/71<br>0340<br>14 | 3/5/71<br>2000<br>36 | 3/6/71<br>0622<br>47 | 3/6/71<br>1750<br>54 | 3/8/71<br>0530<br>47 | 3/9/71<br>1200<br>47 | 3/10/71<br>1345<br>47 | 3/10/71<br>2000<br>24.2 | 3/11/71<br>2400<br>24.2 | 3/12/71<br>1130<br>24.2 | 3/12/71<br>2015<br>0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 46' to 95'-0" (wall) | 0.0203 | 0.0328 | 0.0438 | 0.0798 | 0.0741 | 0.0749 | 0.0755 | 0.0319 | 0.0305 | 0.0315 | 0.0003 |
| 46' to 143'-0" (wall | 0.0463 | 0.0548 | 0.0693 | 0.1052 | 0.0996 | 0.1004 | 0.1022 | 0.0589 | 0.0396 | 0.0401 | 0.0033 |
| 46' to 191'-0" (springline) | 0.1335 | 0.1593 | 0.1991 | 0.2568 | 0.2436 | 0.2445 | 0.2467 | 0.1344 | 0.1141 | 0.1156 | 0.0063 |
| 46' to 262'-0" (apex) | 0.2865 | 0.325 | 0.440 | 0.638 | 0.6016 | 0.6025 | 0.6047 | 0.3424 | 0.3221 | 0.3236 | 0.0293 |

TABLE 9

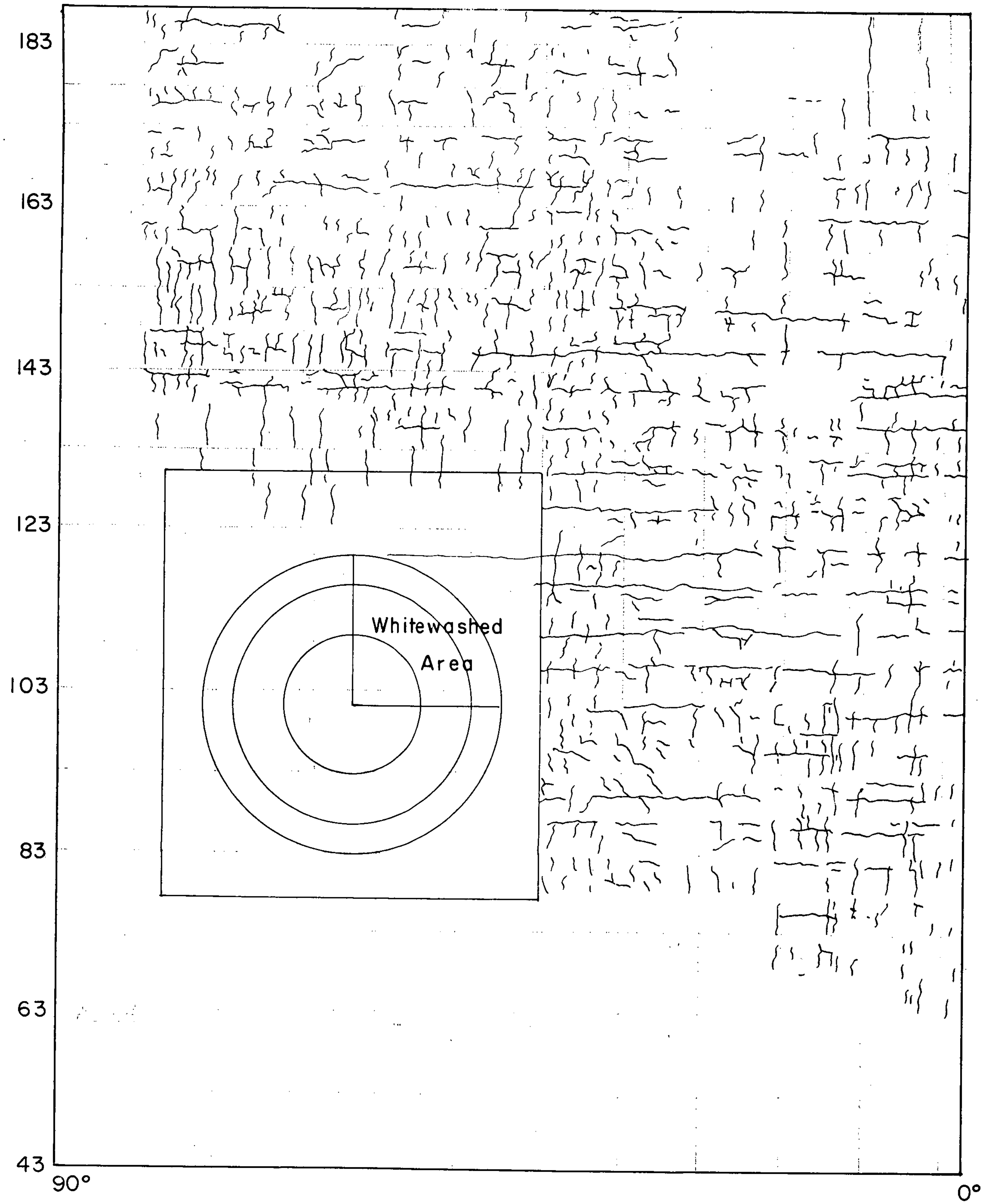
DIAMETER CHANGE OF EQUIPMENT HATCH SHELL - INCHES

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| P33* | 0 | 0.0159 | 0.0176 | 0.0227 | 0.0172 | 0.0207 | 0.0207 | 0.0116 | 0.0072 | 0.0087 | 0.0038 |
| P34 | 0 | 0.0004 | 0.0054 | 0.0067 | 0.0005 | 0.0011 | 0.0005 | 0.0036 | 0.0061 | 0.0063 | 0.0032 |

* P33 - Unreliable data due to disturbance of invar wire and sensing device during inspection

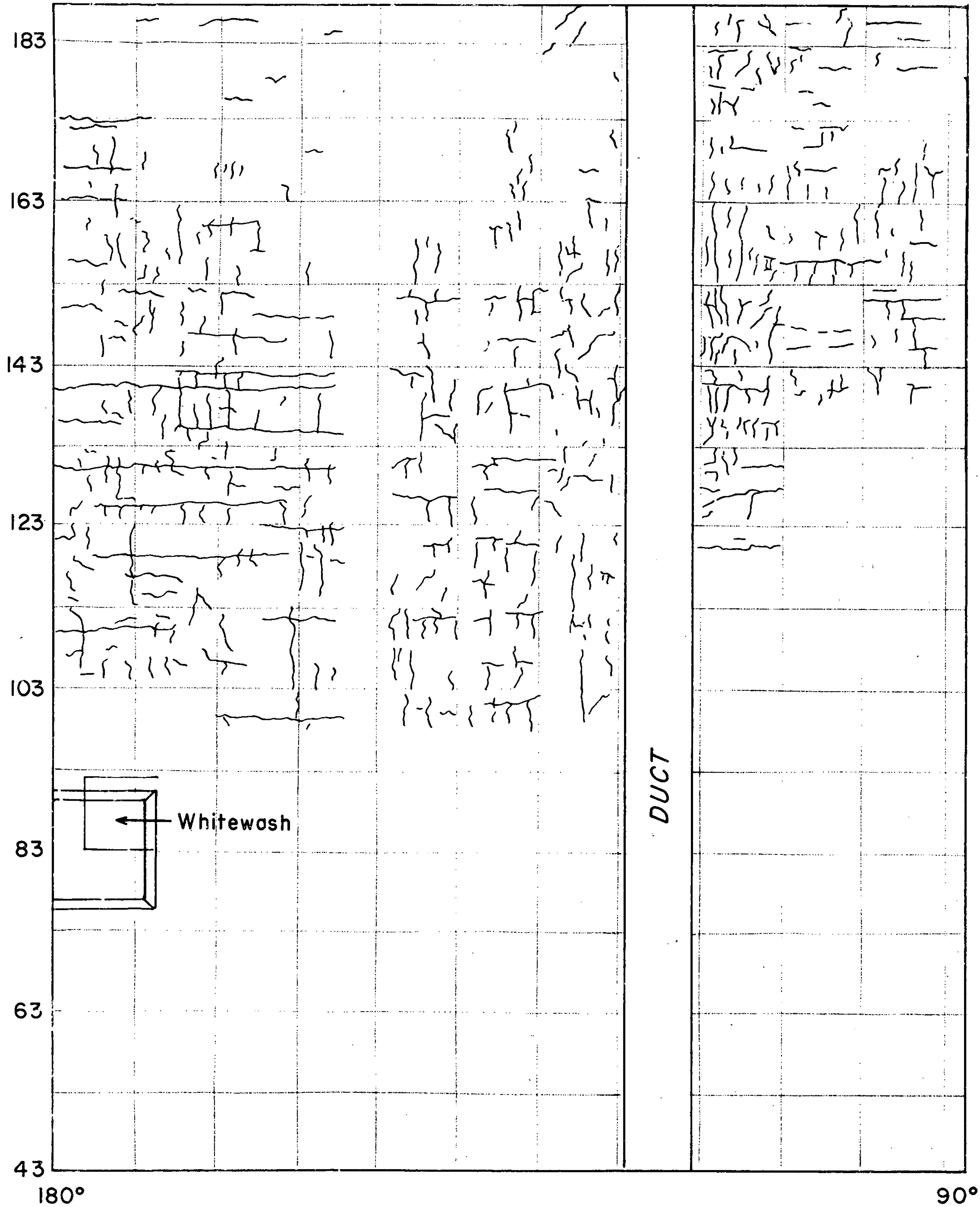
# APPENDIX C

## CRACK SURVEYS




PRE-TEST CRACK SURVEY

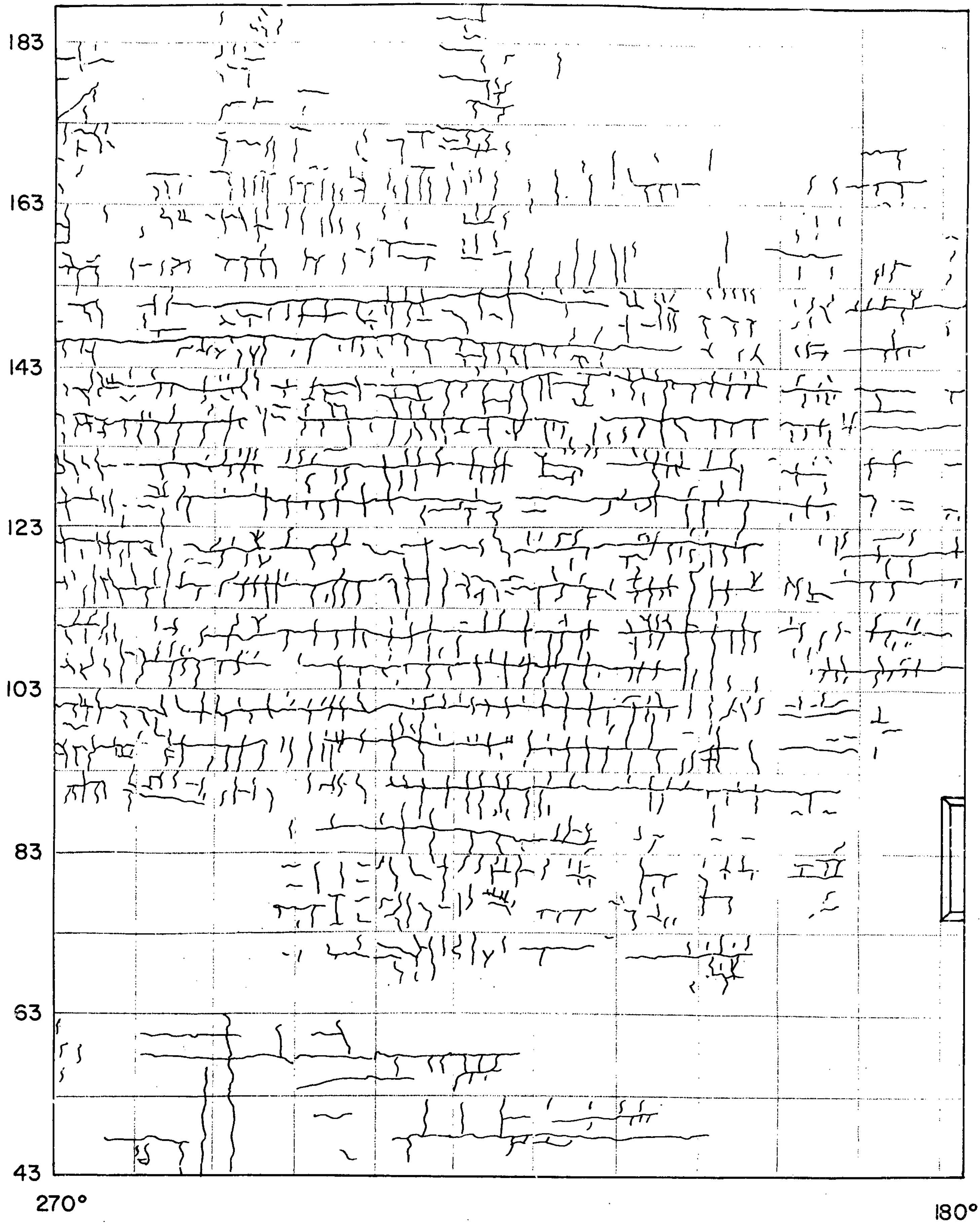
AZIMUTH 0 to 90°
ELEV. 43'-0" to 188'-0"




PRE-TEST CRACK SURVEY

AZIMUTH 90° to 180°

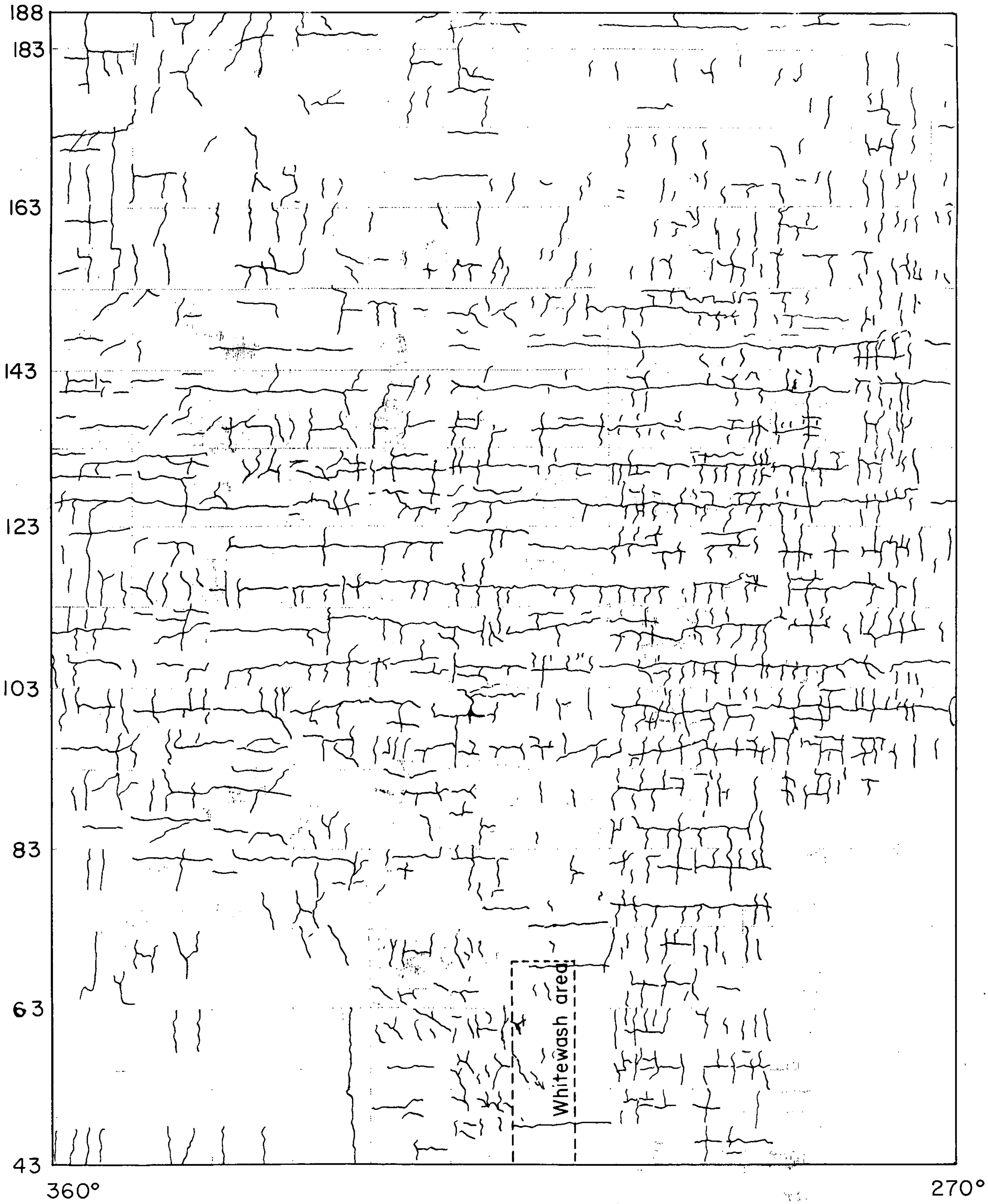
ELEV. 43'-0" to 188'-0"




PRE-TEST CRACK SURVEY

AZIMUTH 180° to 270°

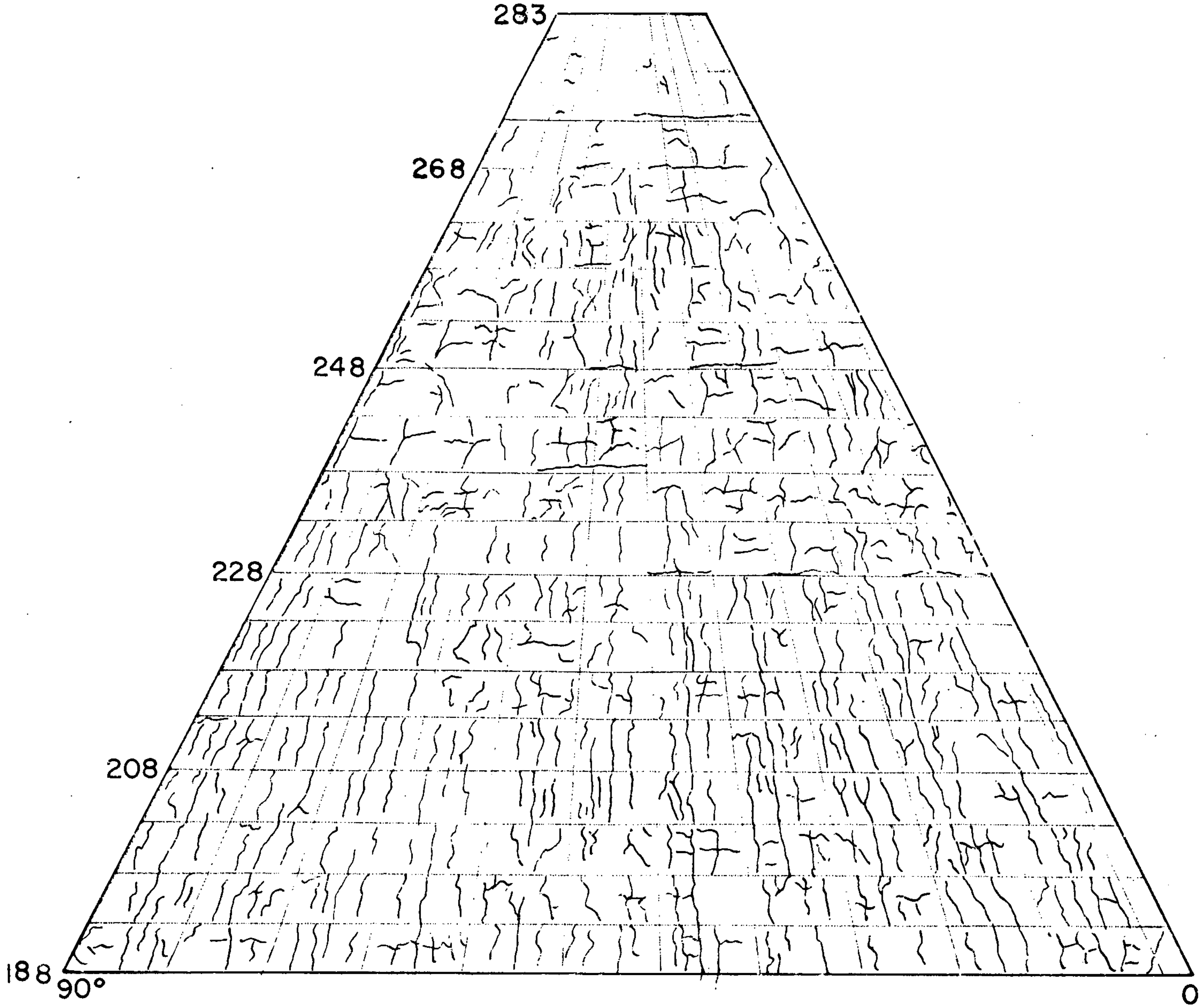
ELEV. 43'-0" to 188'-0"




PRE-TEST CRACK SURVEY

AZIMUTH 270° to 360°

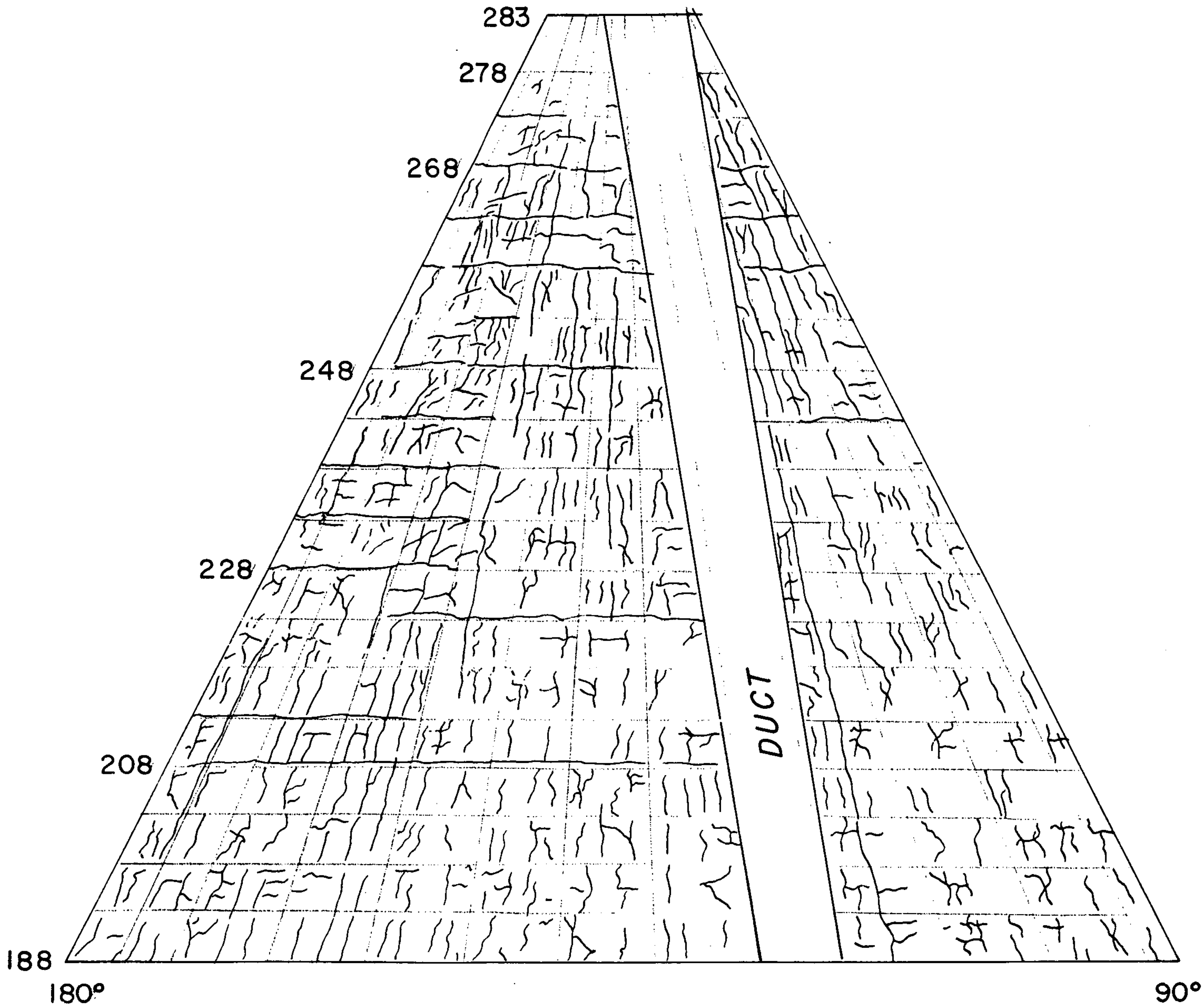
ELEV. 43'-0" to 188'-0"




PRE-TEST CRACK SURVEY

AZIMUTH 0 to 90°

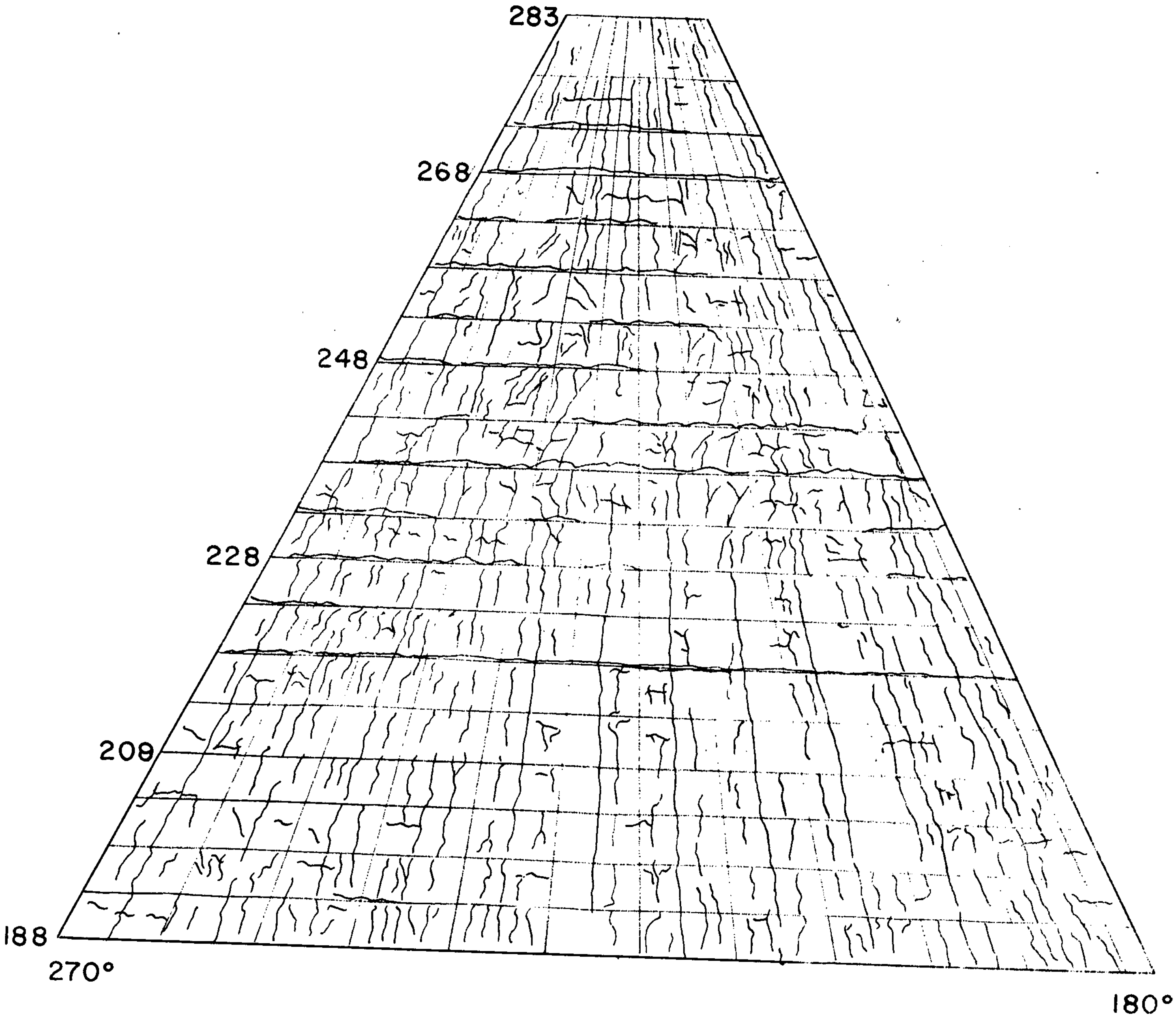
ELEV. 188'-0" TO TOP OF DOME



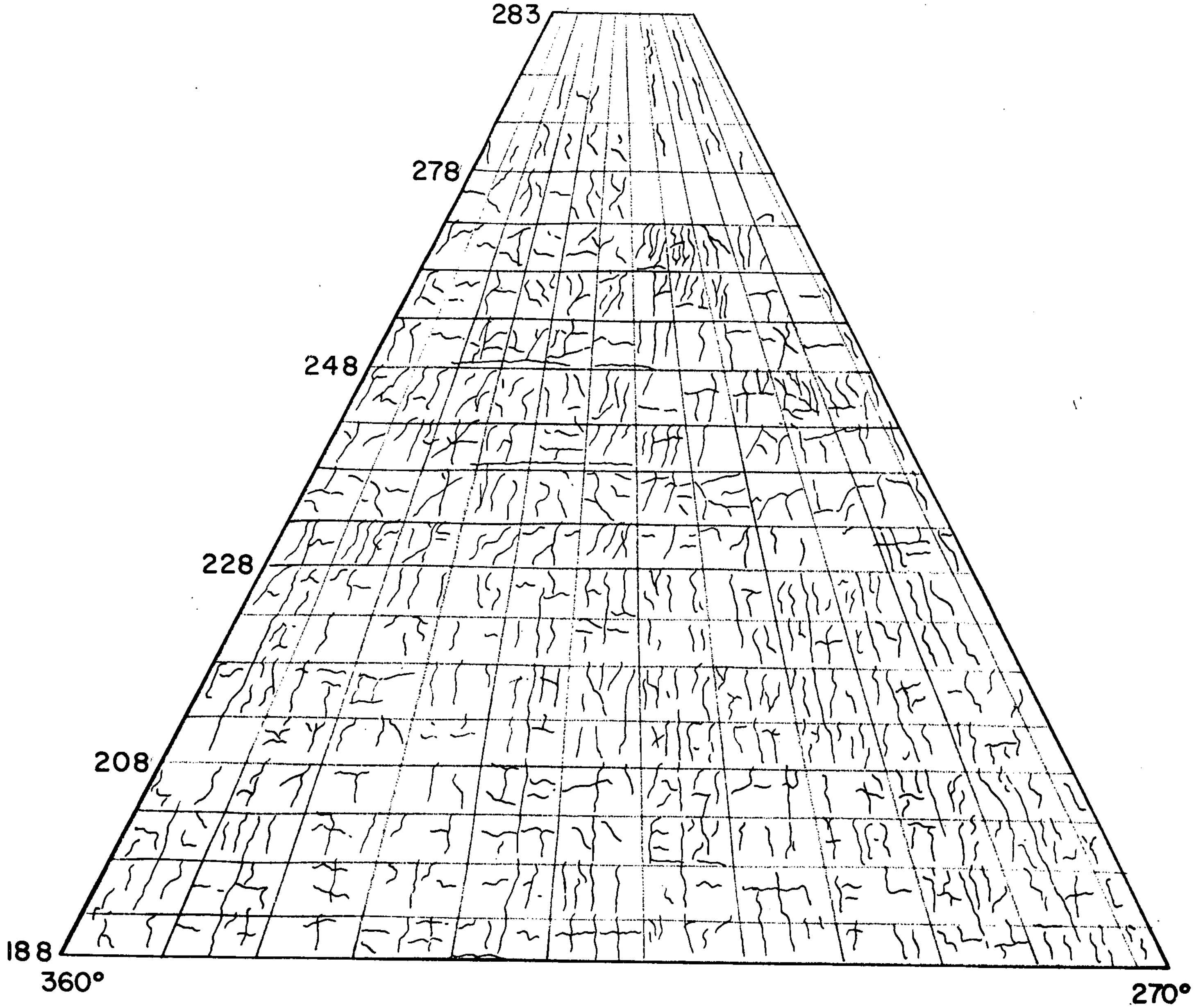

PRE-TEST CRACK SURVEY

AZIMUTH 90° to 180°

ELEV. 188'-0" TO TOP OF DOME



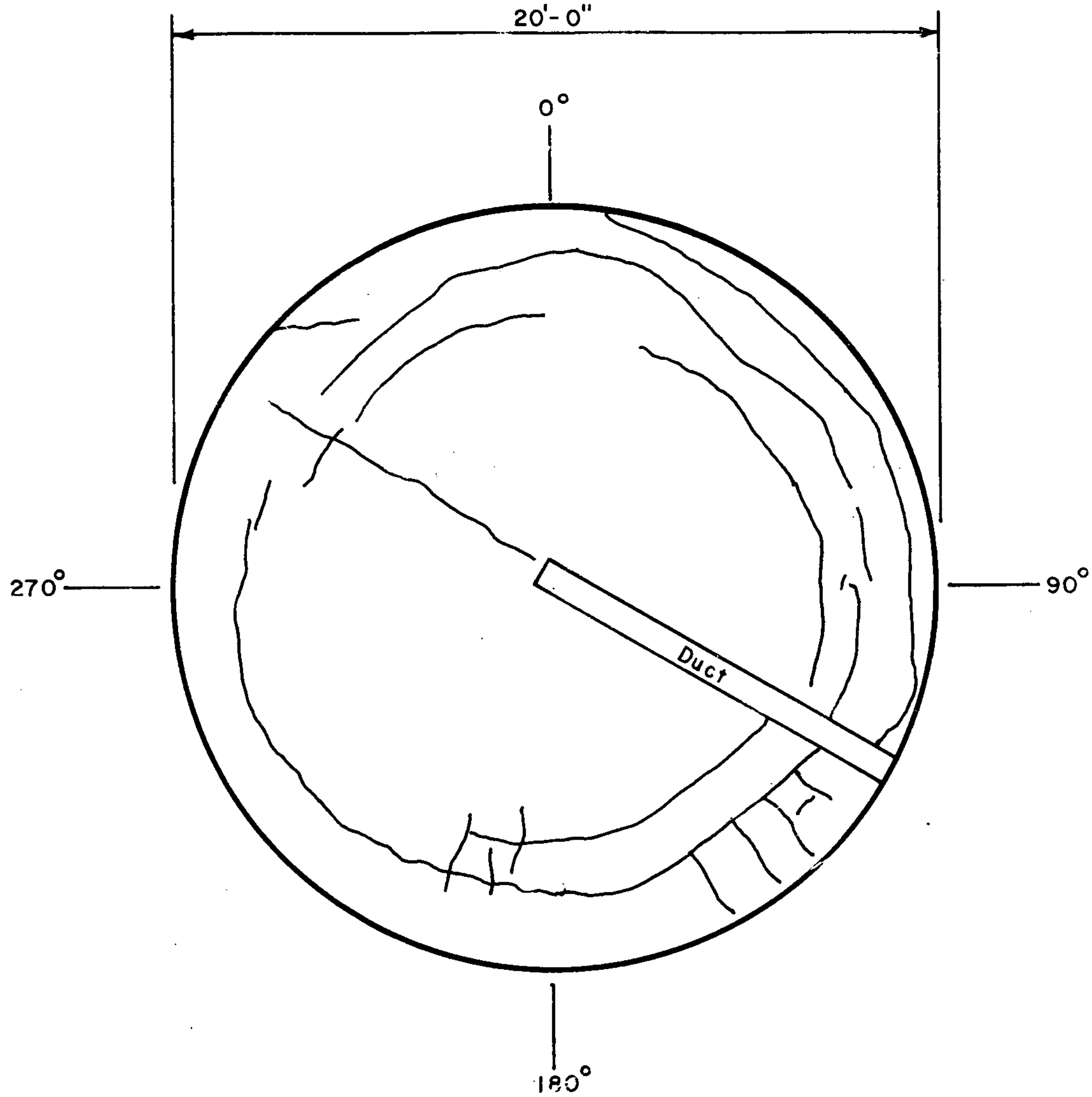

PRE-TEST CRACK SURVEY
AZIMUTH 180° to 270°
ELEV. 188'-0" TO TOP OF DOME




PRE-TEST CRACK SURVEY

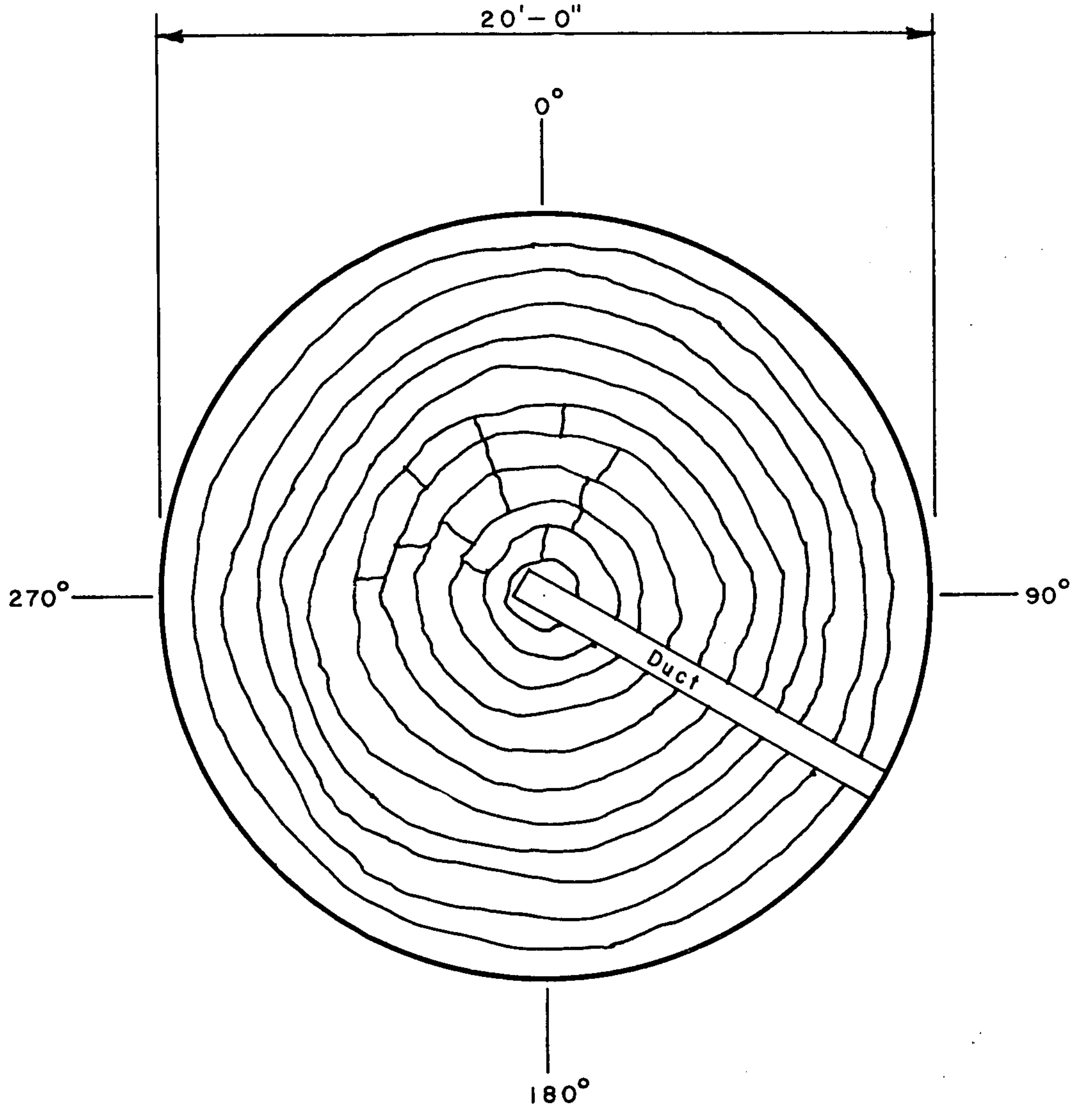
AZIMUTH 270° to 360°

ELEV. 188'-0" TO TOP OF DOME




PRE - TEST CRACK SURVEY

20' DIAMETER - TOP OF DOME

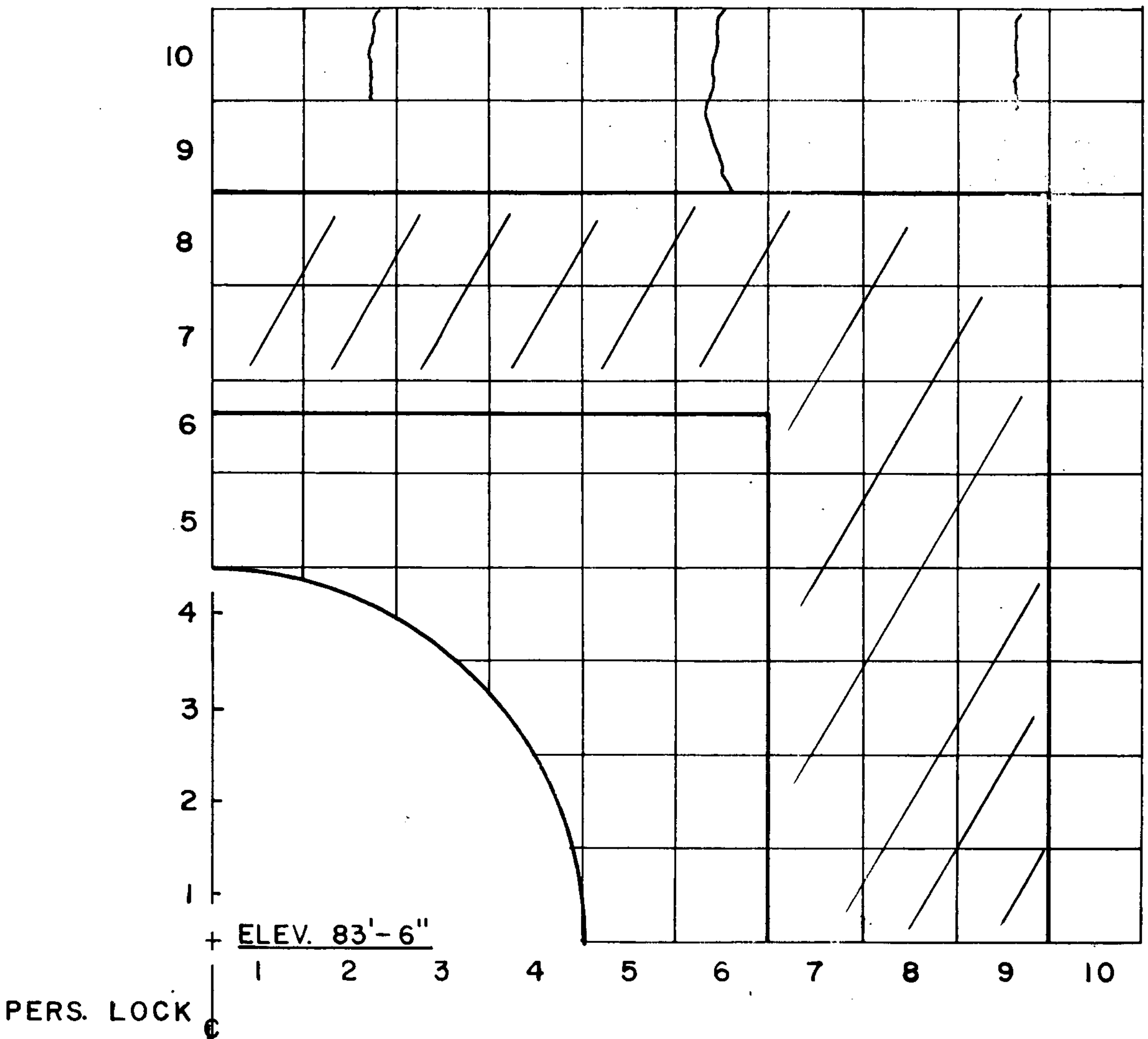



TYPICAL CIRCUMFERENTIAL CRACKING AT APPROX. 18" SPACING AND WIDTH OF 0.008".

TYPICAL VERTICAL CRACKING AT APPROX. 30" SPACING AND WIDTH OF 0.008"

## CRACK SURVEY AT 54psi PRESSURE

## 20' DIAMETER - TOP OF DOME




# INDIAN POINT GENERATING STATION

Unit No. 2

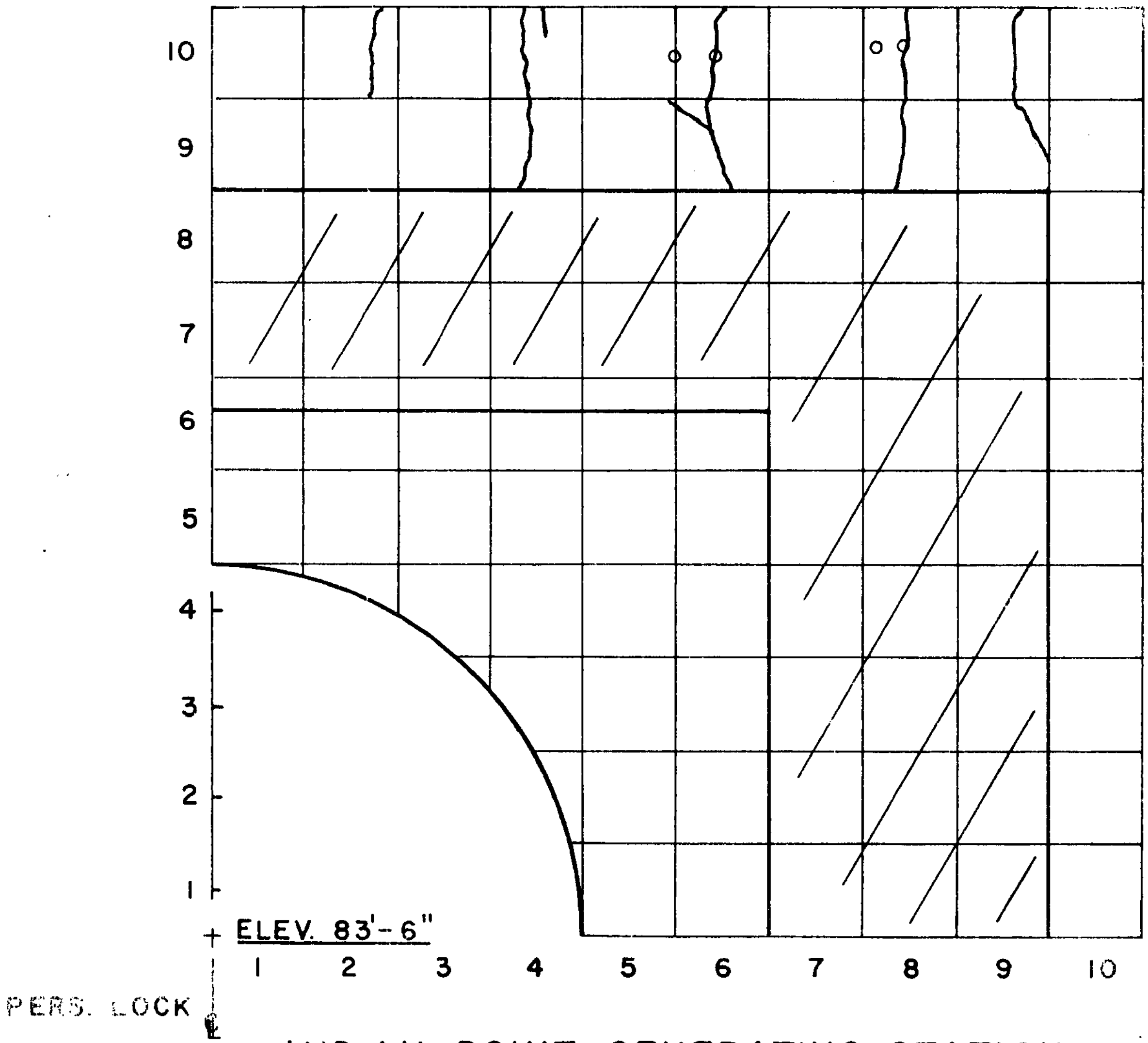
## PERSONNEL LOCK BOSS AREA

Date: 3-8-71

Time: 0700

Pressure: 14psi

Surveyed by: R. K.

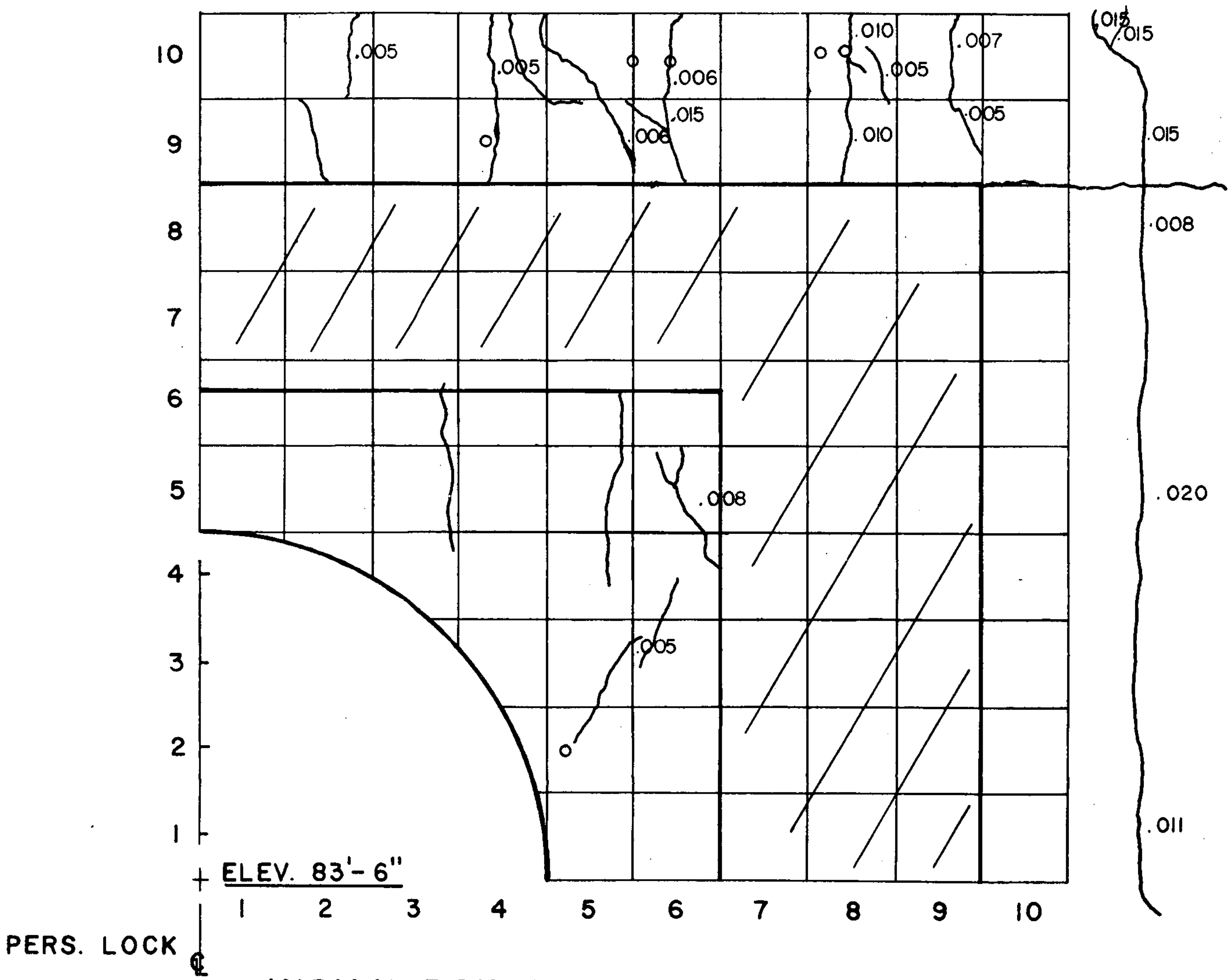



INDIAN POINT GENERATING STATION

Unit No. 2

PERSONNEL LOCK BOSS AREA

Date: 3-5-71
Time: 2200
Pressure: 36psi
Surveyed by: R. K.



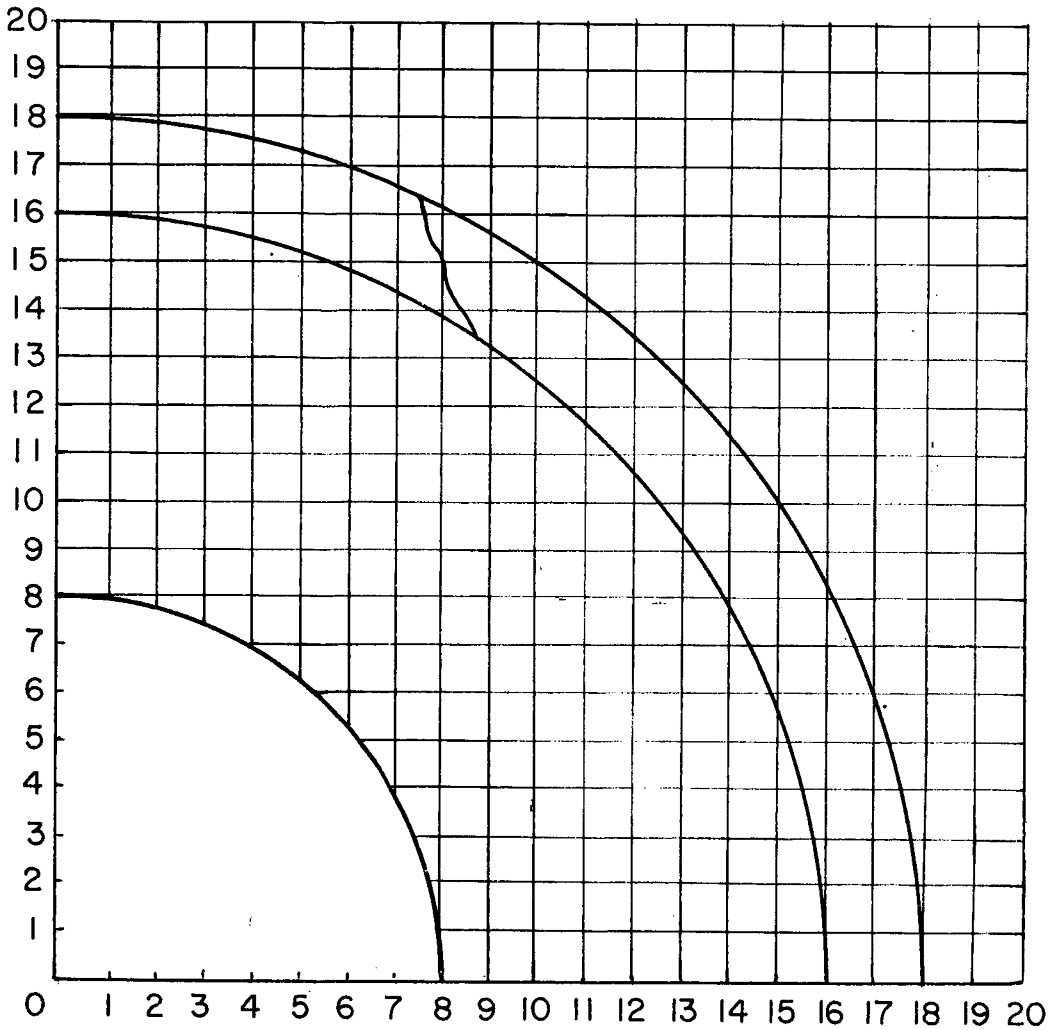

# INDIAN POINT GENERATING STATION

## Unit No. 2

## PERSONNEL LOCK BOSS AREA

Date: 3-6-71
Time: 0800
Pressure: 47 psi
Surveyed by: R. K.

NOTE: 54 psi SAME PATTERN NO NEW CRACKS OR EXTENSION OF EXISTING CRACKS



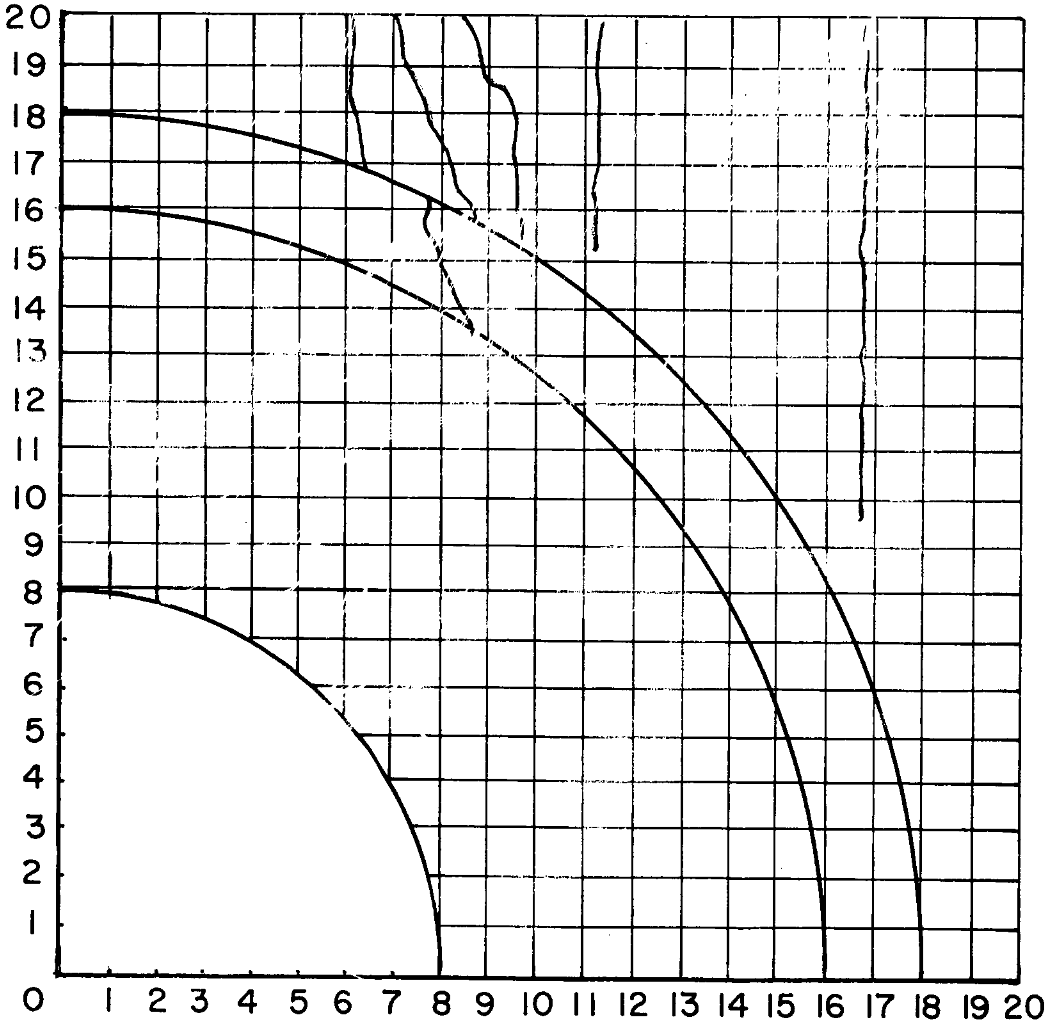

INDIAN POINT GENERATING STATION

Unit No. 2

EQUIPMENT HATCH BOSS

Job No. 9134

Date: 3-5-'71
Time: 0700
Pressure: 14 psi
Surveyed by: R. K.



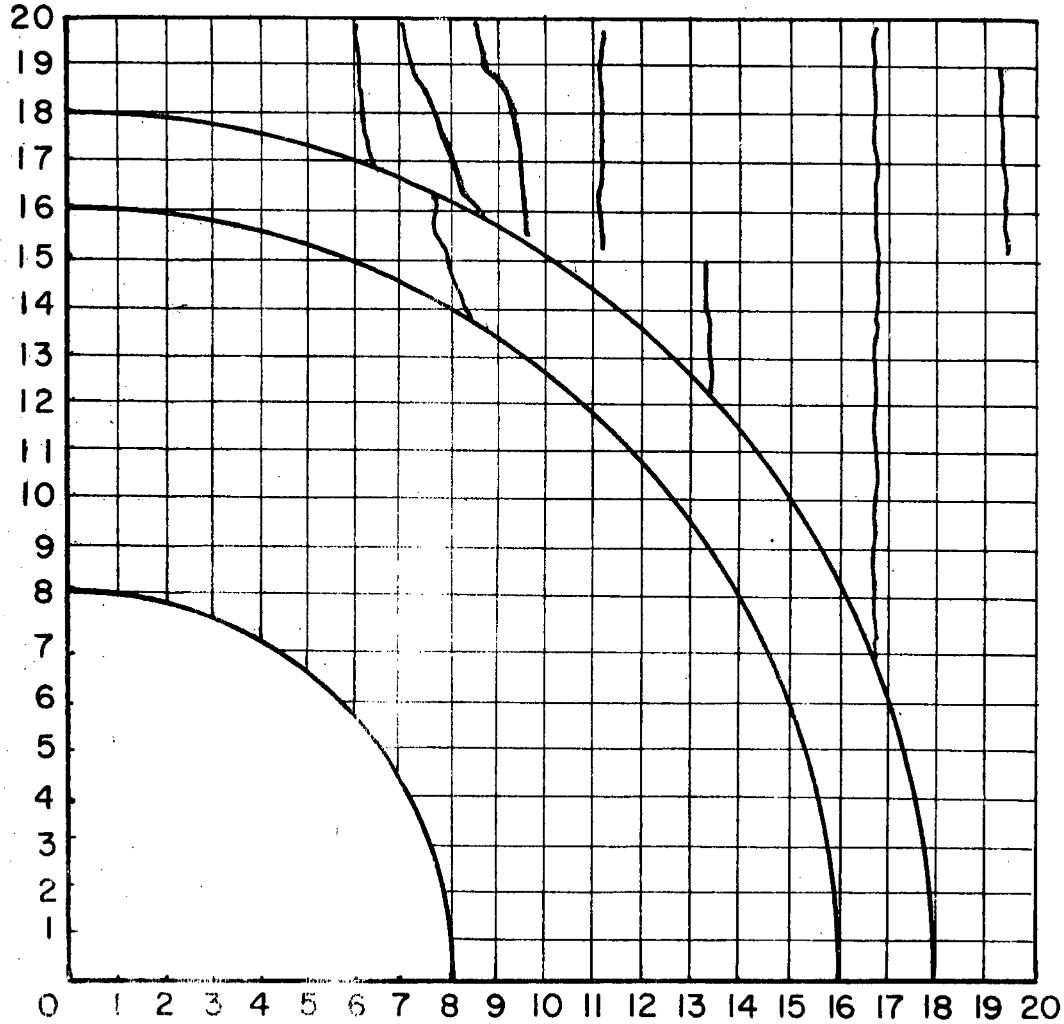

INDIAN POINT GENERATING STATION

Unit No. 2

EQUIPMENT HATCH BOSS

Job No. 9134

Date: 3-5-'71
Time: 2200
Pressure: 36 psi
Surveyed by: R.K.



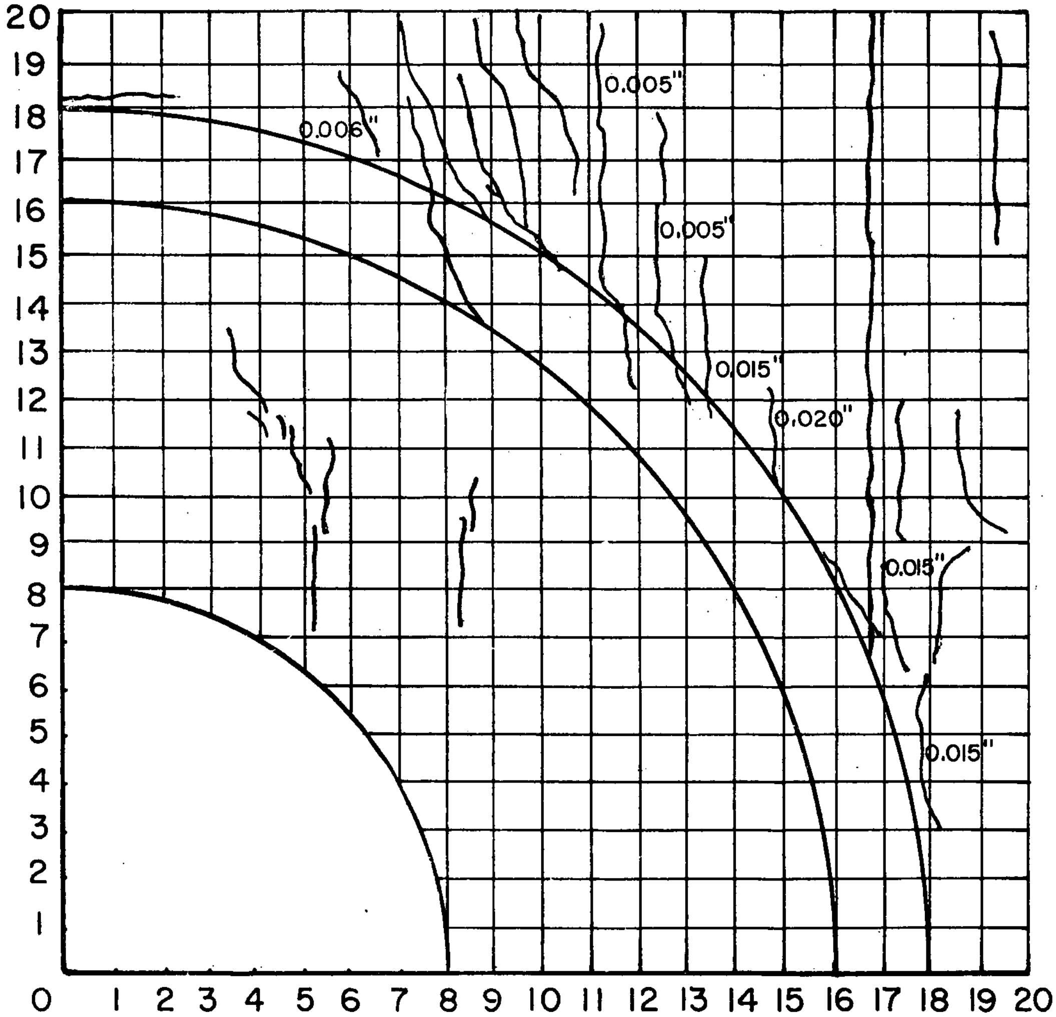

INDIAN POINT GENERATING STATION

Unit No. 2

EQUIPMENT HATCH BOSS

Job No. 9134

Date: 3-6-'71
Time: 0800
Pressure: 47 psi
Surveyed by: R.K.-V.M.




INDIAN POINT GENERATING STATION

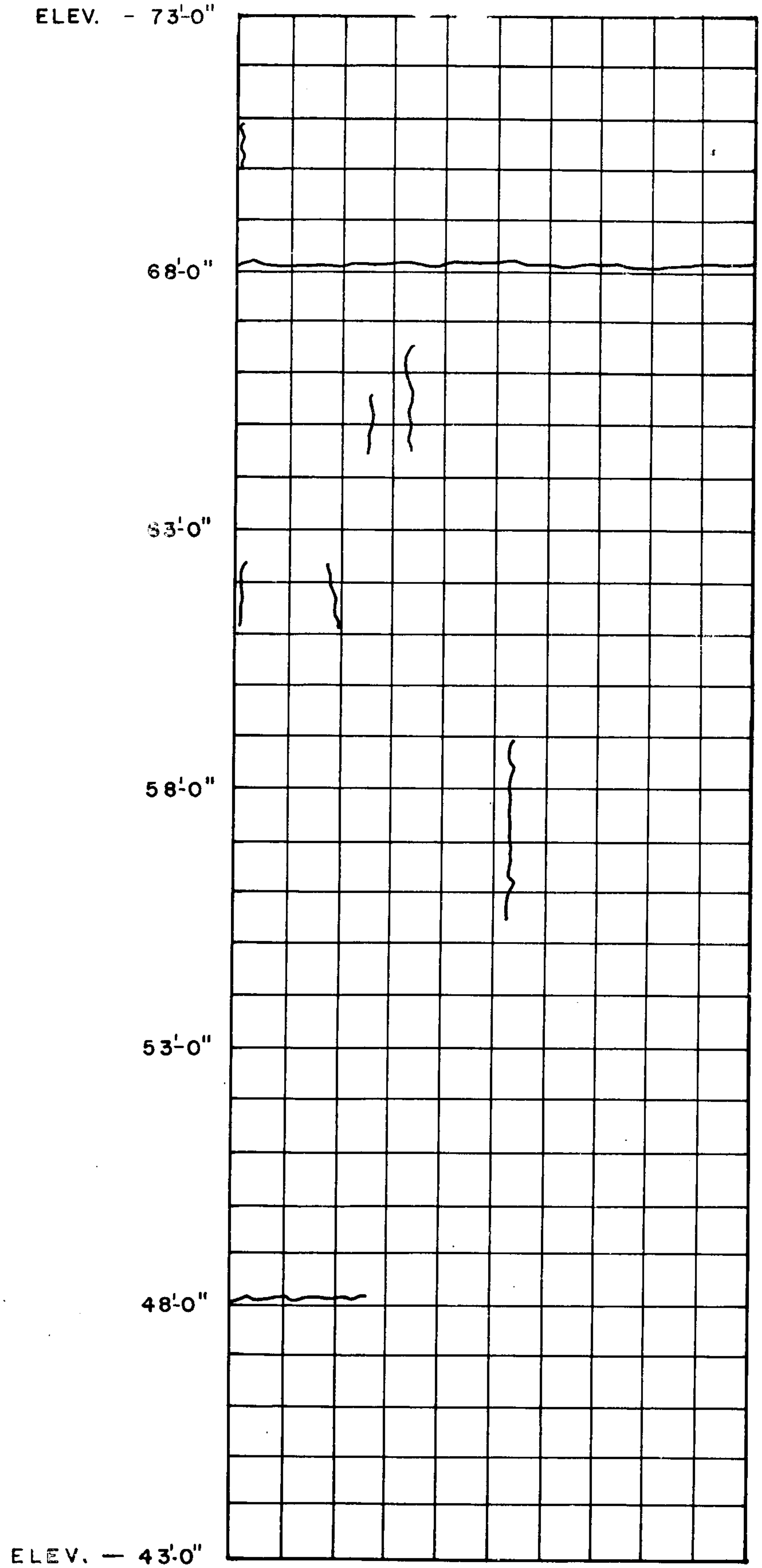
Unit No. 2

EQUIPMENT HATCH BOSS

Job No. 9134

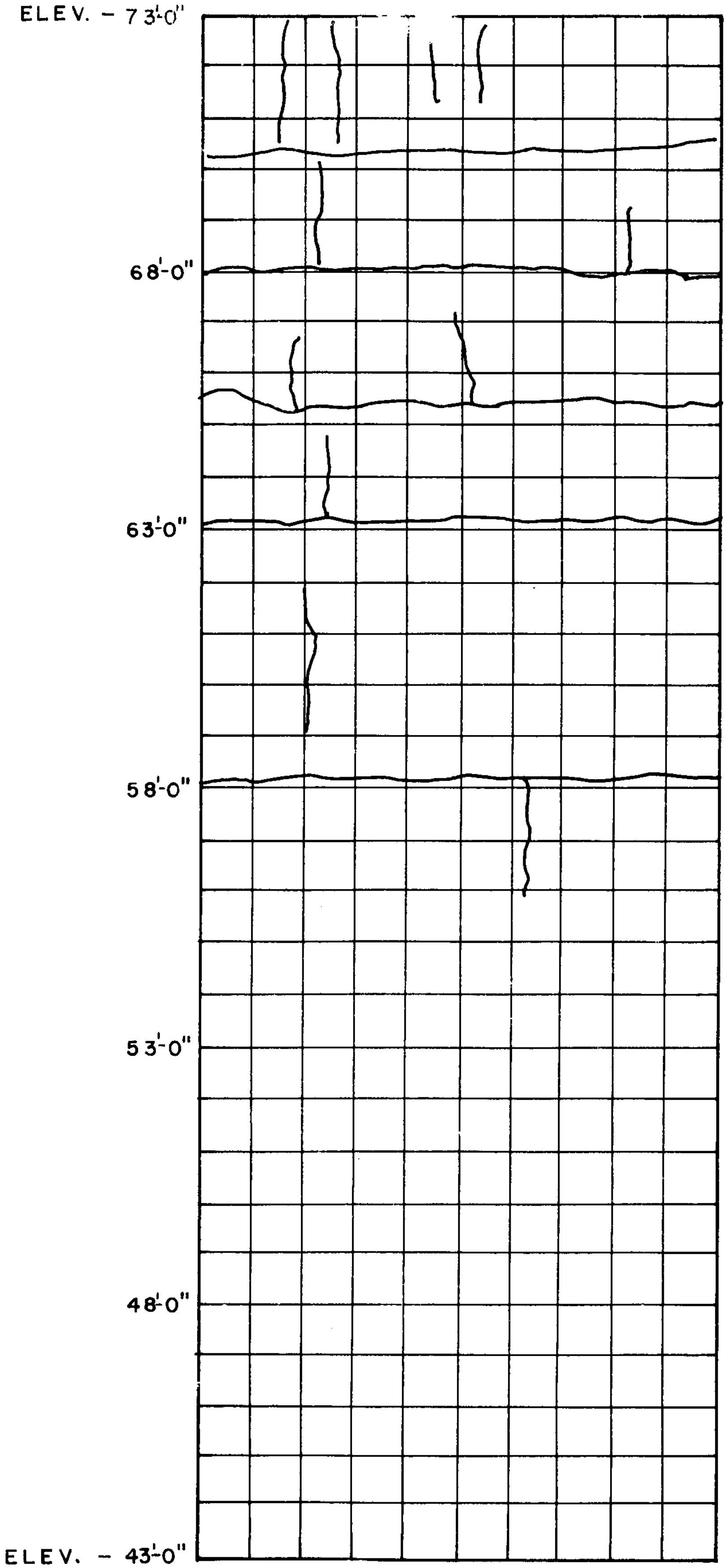
Date: 3-6-'71
Time: 1700
Pressure: 54 psi
Surveyed by: W.S.

Note: UNLESS OTHERWISE NOTED ALL CRACKS ARE LESS THAN 0.005"



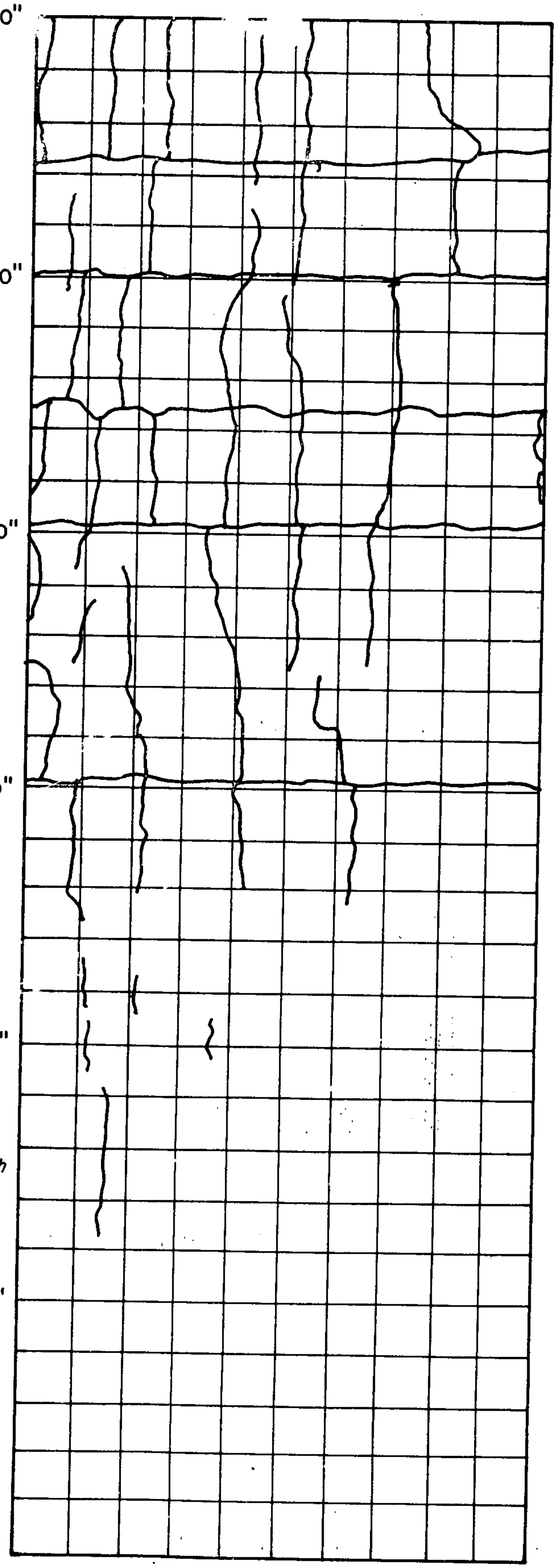

DATE: ______
TIME: ______
PRESSURE: "0" psi

INDIAN POINT GENERATING STATION
UNIT NO. 2 - CRACK SURVEY
AZIMUTH 310°




DATE: 3-5-71
TIME: 2200
PRESSURE: 36 psi

INDIAN POINT GENERATING STATION
UNIT NO. 2 - CRACK SURVEY
AZIMUTH 310°




*Note:*
*Initial Crack At Elev. 48.0' Did Not Show Thru Whitewash Under Pressure.*

NOTE: Largest Crack Measured 0.002" In Width.

DATE: 3-6-71
TIME: 1700
PRESSURE: 47 & 54 psi

INDIAN POINT GENERATING STATION
UNIT NO. 2 - CRACK SURVEY
AZIMUTH 310°

10-I

REGULATORY DOCKET FILE COPY