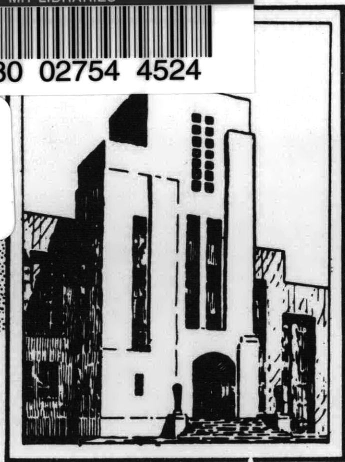

NAVY DEPARTMENT

DAVID TAYLOR MODEL BASIN

HYDROMECHANICS

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PROGRESS REPORT

EXPERIMENTAL STRESSES AND STRAINS IN A RING-STIFFENED CYLINDER OF OVAL CROSS-SECTION (MAJOR-TO-MINOR AXIS RATIO OF 1.5)

by

William P. Couch and John G. Pulos

[redacted]

STRUCTURAL MECHANICS LABORATORY

RESEARCH AND DEVELOPMENT REPORT

March 1963

Report 1726
S-F013 0302

PRNC-TMB-648 (11-56)

DEPARTMENT OF THE NAVY
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From: Commanding Officer and Director, David Taylor Model Basin
To: Chief, Bureau of Ships (442) (in duplicate)

Subj: Test results of an oval cylinder stiffened with transverse ring-frames; forwarding of progress report on

Encl: (1) DTMB Report 1726 entitled "Experimental Stresses and Strains in a Ring-Stiffened Cylinder of Oval Cross-Section (Major-to-Minor Axis Ratio of 1.5)" 2 copies

1. The measured stresses and strains obtained from hydrostatic tests of an internally stiffened cylinder with a quasi-elliptical cross-section are presented in enclosure (1).

2. Test results indicate that an equivalent-circular-cylinder solution based on the local radius of curvature concept for the major-to-minor axis ratio of 1.5 used in this test apparently will not predict the deformations and stresses of an oval cylinder stiffened by elastic rings.

E.E. Johnson

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EXPERIMENTAL STRESSES AND STRAINS IN A RING-STIFFENED CYLINDER OF OVAL CROSS-SECTION (MAJOR-TO-MINOR AXIS RATIO OF 1.5)

by

William P. Couch and John G. Pulos

March 1963

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ABSTRACT

As part of its structural research into new and untried pressure-hull configurations,[1]* the David Taylor Model Basin has been investigating the response of noncircular cylindrical shells, stiffened with transverse ring-frames, to hydrostatic pressure loading. This effort is being conducted in order to provide background information in case the Bureau of Ships has to incorporate noncircular hull configurations in submarine design. At the present time very little information exists in this problem area which could be of immediate use to naval architects.

BACKGROUND

The experimental studies being conducted at the Model Basin are closely related to the analytical efforts by the group at the Polytechnic Institute of Brooklyn. These latter studies presently constitute a major part of the overall program on transverse strength of submarine structures which is being sponsored jointly by the Office of Naval Research (Code 439) and the Bureau of Ships (Code 442) at that Institute. A number of publications have already appeared which present the findings of the Polytechnic studies. Kempner in Reference 2 summarizes the results found up through 1961. It is of some interest here to bring to light the more significant results so that structural designers can better understand and appreciate the difference in behavior between circular and noncircular cylindrical pressure hulls.

The first problem amenable to mathematical solution, and one which could provide an insight into the mechanism

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* References are listed on page 16

of deformation of noncircular cylindrical pressure hulls, was that of the simply supported oval cylinder. Romano and Kempner[3] have developed such an anlysis and their results indicate that for this case the use of the local radius of curvature of the oval cross-section in the well-known and proven formulas for circular cylinders[4] gives very good agreement in the stresses and deformations with the "exact" Fourier series solution developed in Reference 3. The results of the analysis of the simply-supported oval shell also showed that the stresses in an oval shell, even with a small eccentricity (ovality) differ significantly from those in a circular shell of equal length and weight.

The next logical step in the development of adequate theory for the realistic interaction problem in the case of an oval cylinder stiffened with ring-frames possessing finite elastic stiffness properties, was to investigate the problem of the clamped oval shell. Vafakos, Romano, and Kempner have developed such an analysis[5] and their results indicate that the stresses in an oval shell differ significantly from those in an axisymmetric circular shell of equal length and weight. Just as in the case of the simply-supported shell, these investigators found that a simple equivalent circular cylinder solution based on the local radius of curvature concept yields good results for the deformations and stresses in a clamped oval shell. The maximum stress was shown to be an axial stress due principally to bending, and occurred at those points of the clamped edges which had the least curvature.

Major effort by the Polytechnic group during the past year has been directed toward solving the noncircular elastic ring problem and coupling these results to the equations already developed for the noncircular shell. In contrast to the simple analogy of the equivalent circular cylinder using the local radius of curvature concept for the simply-supported and clamped oval shells of short length, no such simple solution can be hoped for in the case of the cylinder stiffened by elastic rings. The reason for this is that the deformation mechanism is one in which the transverse displacements are radially outward in the region of the major axis and radially inward in the region of the minor axis, with respect to the initial undeformed cross-section. The elastic-ring analysis indicates such behavior, and it is the development of extreme circumferential bending varying around the periphery which precludes the use of the equivalent cylinder with local radius of curvature concept to predict the deformations and stresses. This is contrary to the cases of the simply-supported and clamped oval shells of short length in which the transverse displacements are all radially inward around the periphery of the oval cross-section.

The analytical results found so far indicate that whereas in the stiffened circular cylinder the area of the stiffening rings plays the dominant role in the shell deformations, in the case of the stiffened oval cylinder the inertia of the ring cross-section is of paramount importance in the deformation. This is due to the fact that the axisymmetric nature of the circular cylinder problem precludes the development of tangential (v) displacements; however, in the oval cylinder problem the tangential displacements are very important and these arise as a consequence of a shear flow which develops along the oval periphery to maintain overall equilibrium of the forces. Due to symmetry considerations this "running shear" is zero at the two extremes of each of the major and minor axes of the oval (quasi-elliptic) cross-section. This brings up an important problem in regard to the location of the stiffening rings, i.e. whether they be located on the outside or on the inside surface of the non-circular shell, will determine the nature of the bending moments caused by the shear flow and the fact that the shell and frame median lines are not truly coincident. This "eccentricity" between the shell and frame median lines will determine the magnitude and sense of the circumferential bending moments and their effect on further distorting the noncircular shape. These questions are being investigated in greater detail.

The analysis for the elastically-supported oval cylinder has been completed by the Polytechnic group, and the computer programs developed for the theory are presently being "de-bugged" and made ready to carry out numerical calculations for a range of geometries which are of interest to the Bureau of Ships.

The objective of this report is to make immediately available both to the Bureau of Ships and the Polytechnic group preliminary test data already generated by the Model Basin studies. This information will aid in the evaluation of the theoretical analyses which have been developed, and assist in guiding future structural research on noncircular pressure hulls.

DESCRIPTION OF MODEL AND TEST PROCEDURES

Model EC-1 is an internally stiffened cylinder with a quasi-elliptical cross-section. Two radii were used to develop the cross-section of the model as shown in Figure 1. The shell of the model was fabricated in four strakes of HY-100 steel plating with the diametrical strakes having the same thickness and radius. The model was stiffened with transverse T-frames fabricated also from HY-100 steel plating. Heavier frames were placed at the two ends of the model to preclude premature failure near the rigid closure bulkheads.

The design and fabrication of Model EC-1 were sponsored by the Office of Naval Research (Code 439). The instrumentation, testing, and data reduction were sponsored by the Bureau of Ships (Code 442). The model was first used for vibration and noise studies and is presently being used for static strength studies. Under the latter studies, the model has been tested in two hydrostatic pressure runs to obtain elastic strain data. The maximum pressures reached for the first and second runs were 500 psi and 620 psi, respectively. The model was not tested to collapse. Strains were measured on the model by the use of electrical resistance strain gages.

Plans are presently underway to modify the model for penetration studies.

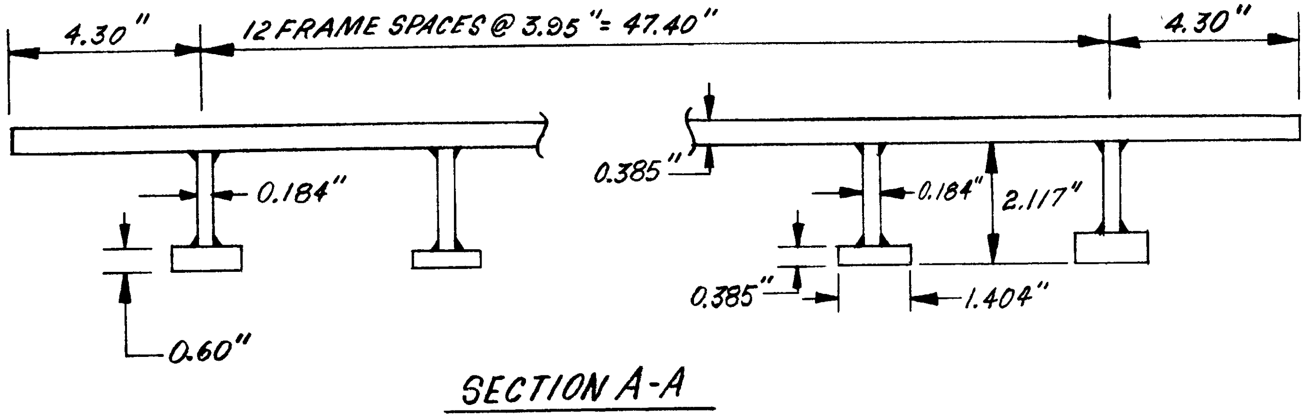
TEST RESULTS AND DISCUSSION

Strain-sensitivity factors determined for each strain gage are given in Figures 2 and 3. These factors are the slope of the linear portion of the pressure-strain curve and are measured in microinches per inch per psi of pressure. The slope was found for each of the two pressure runs, and an average value was determined for each gage.

Figures 4 to 7 give the stress distributions along the shell between adjacent frames on both the outside and inside surfaces of the model at locations corresponding to the major and minor axes of the cross-section. The experimental stresses represent average values determined from the measured strains at corresponding locations. Figures 8 and 9 give the midbay stress distributions for a quadrant of the oval shell of the model on both the outside and the inside surfaces, respectively. The stress distributions shown in Figures 8 and 9 were determined from strain gages located on the shell midway between Frames 6 and 7. Figure 10 gives the circumferential flange stress for a quadrant of Frame 7. It should be noted that the stress distributions shown in Figures 8 through 10 are plotted as a function of the angle (θ) which the local normal to the surface of the model makes with the major axis.

In Figures 4 through 10 are also plotted the stress distribution based on using the local radius of curvature and shell thickness of the oval cross-section in the analysis of

Von Sanden and Günther[6] for a ring-stiffened circular cylinder. From an inspection of these figures it is quite apparent that a simple equivalent circular cylinder solution based on the local radius of curvature concept will not yield good results for the deformations and stresses of an oval cylinder stiffened by elastic rings.



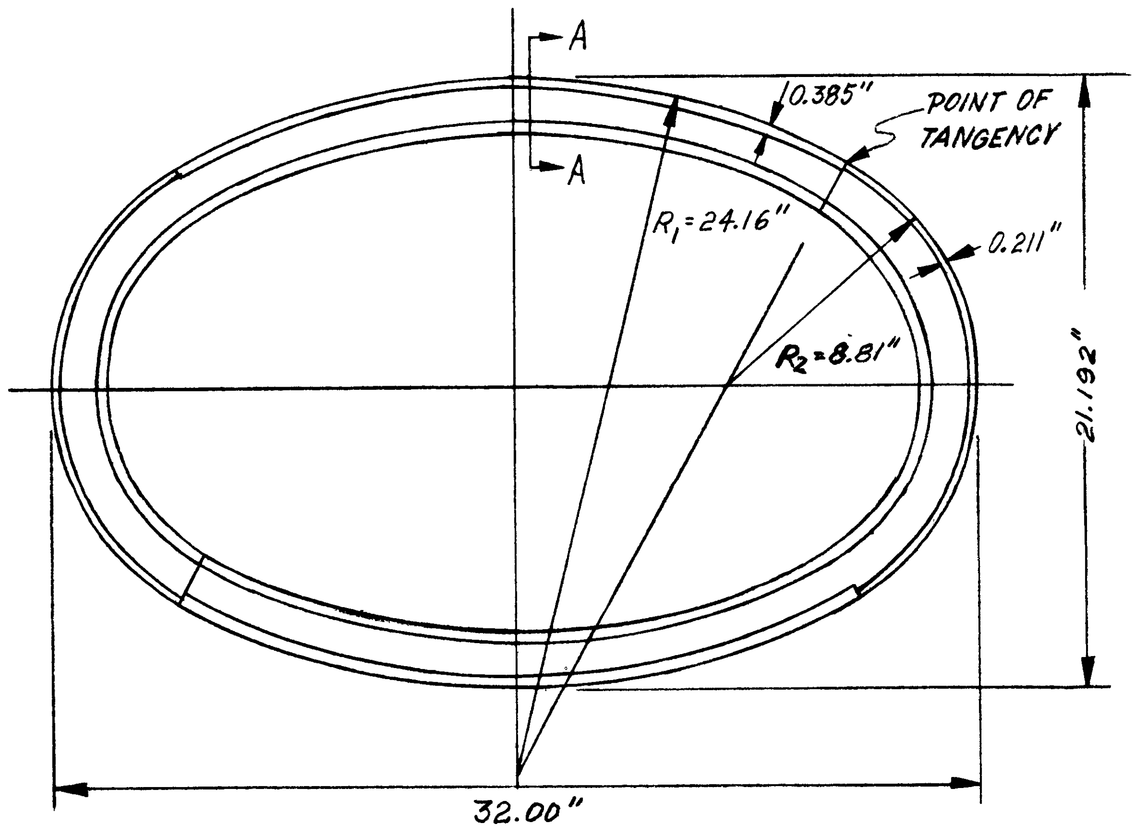


Figure 1 – Details of Model EC-1

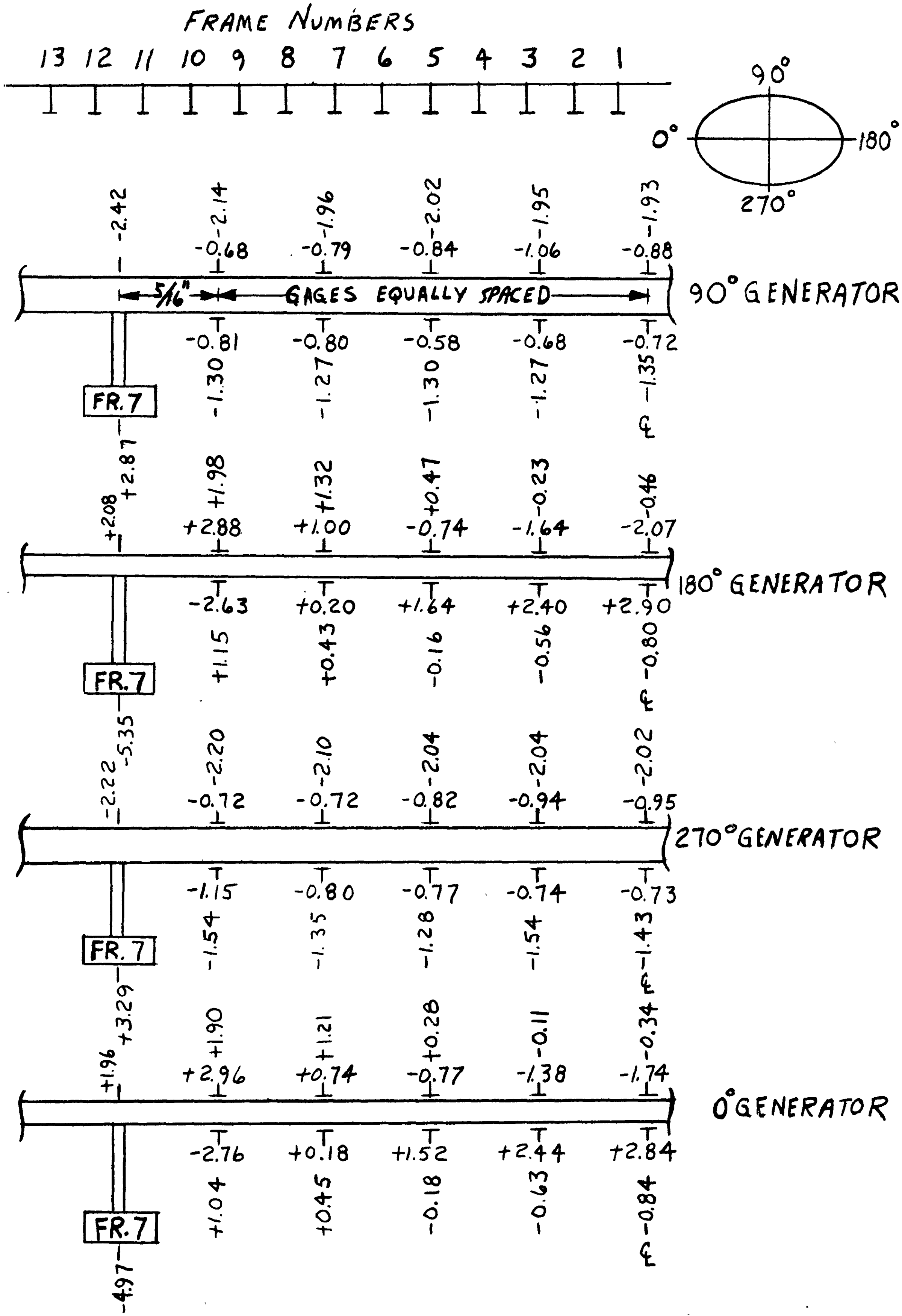


Figure 2 – Measured Strain Sensitivities for Model EC-1 (between Stations 6½ and 7)

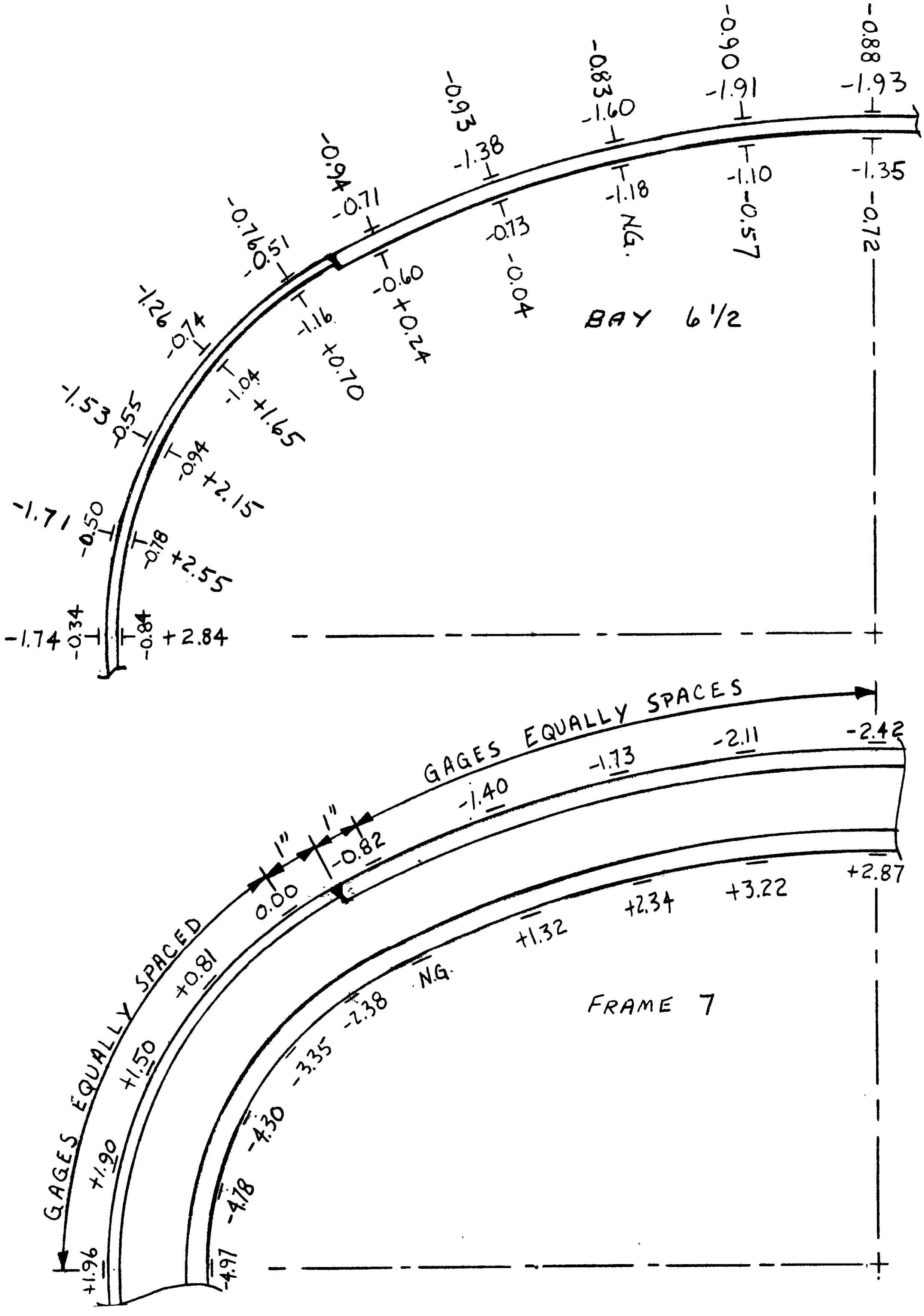


Figure 3 – Measured Strain Sensitivities for Model EC-1 (Stations 6½ and 7)

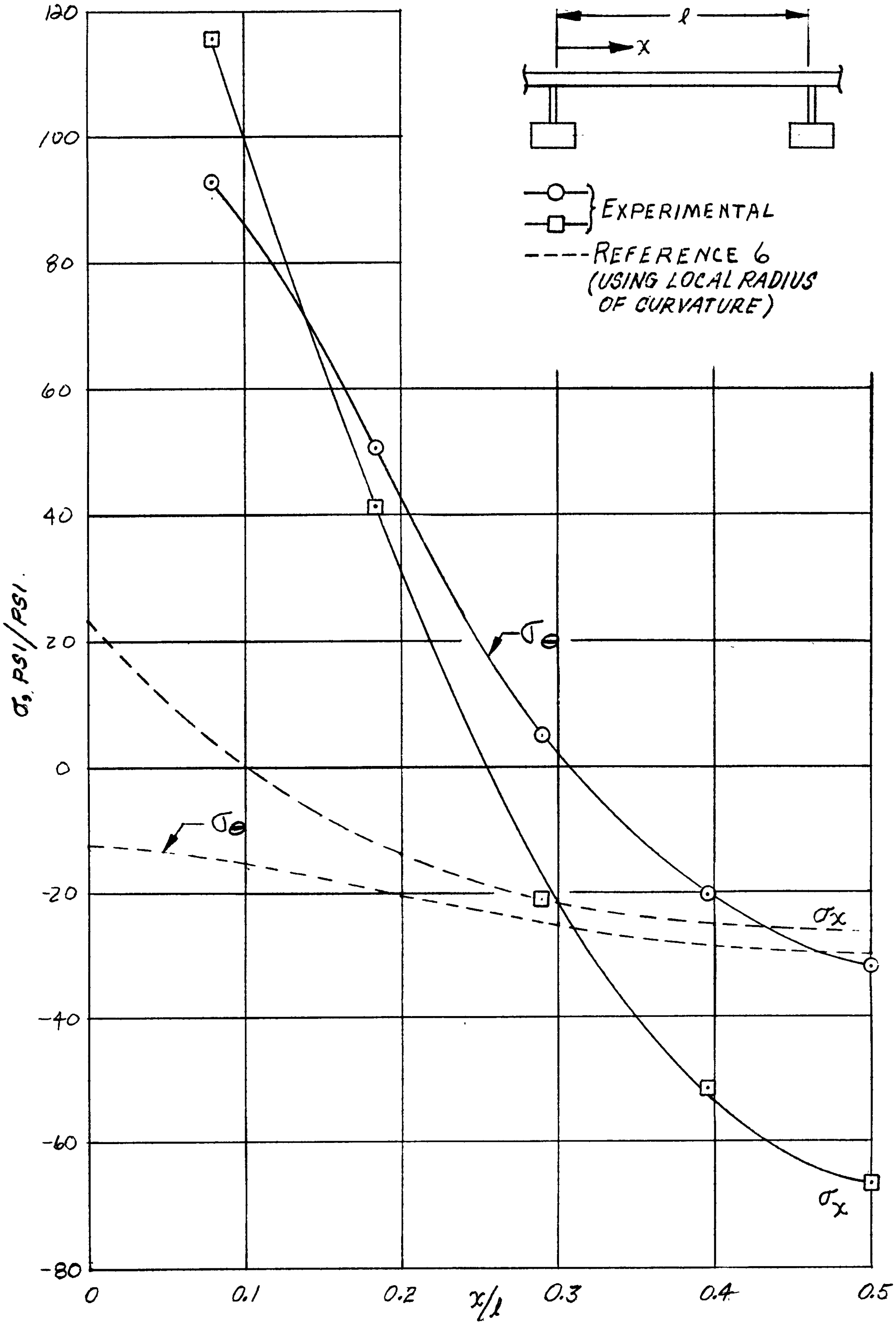


Figure 4 – Stress Distribution on Outside Surface of the Shell at the Major Axis

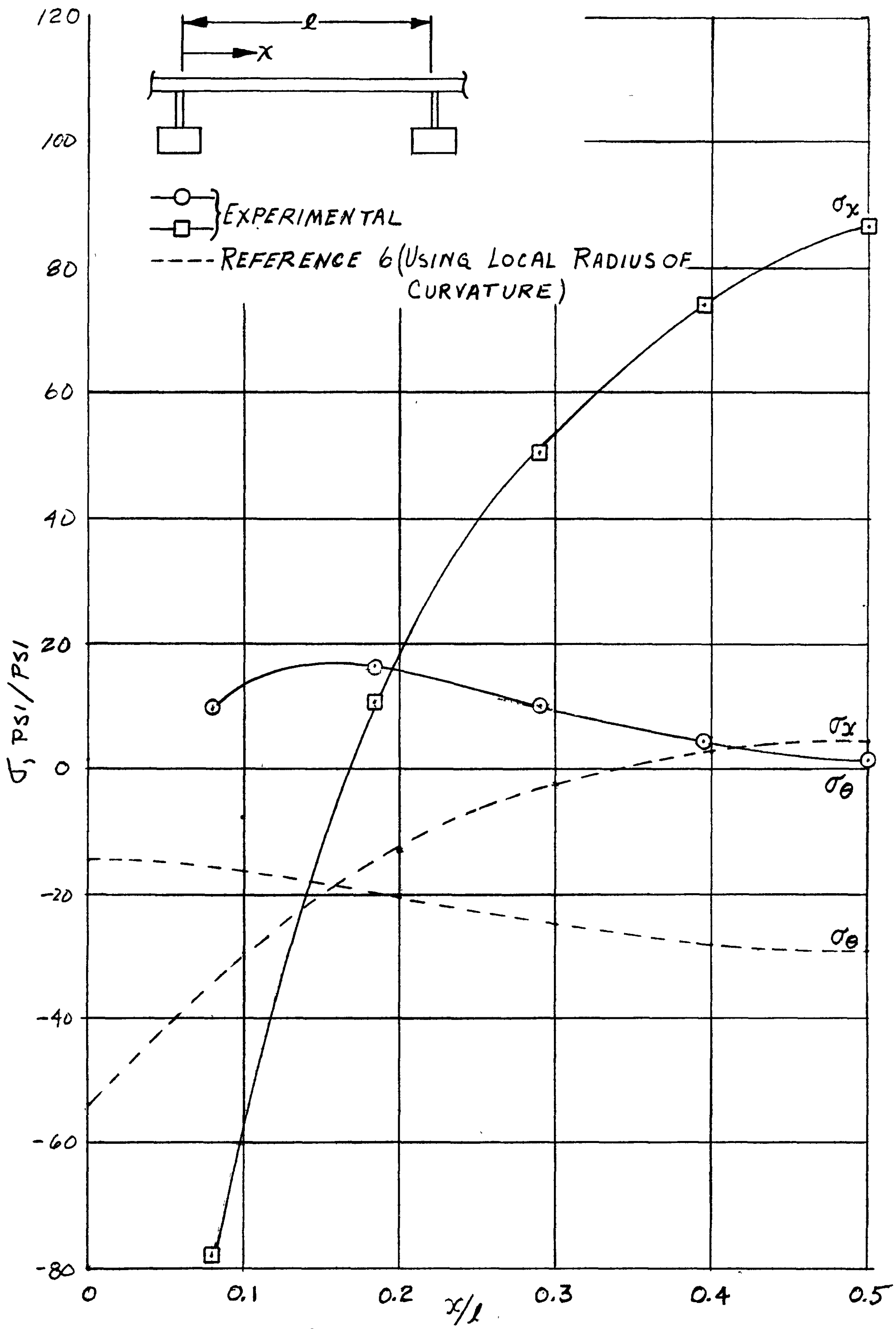


Figure 5 – Stress Distribution on Inside Surface of the Shell at the Major Axis

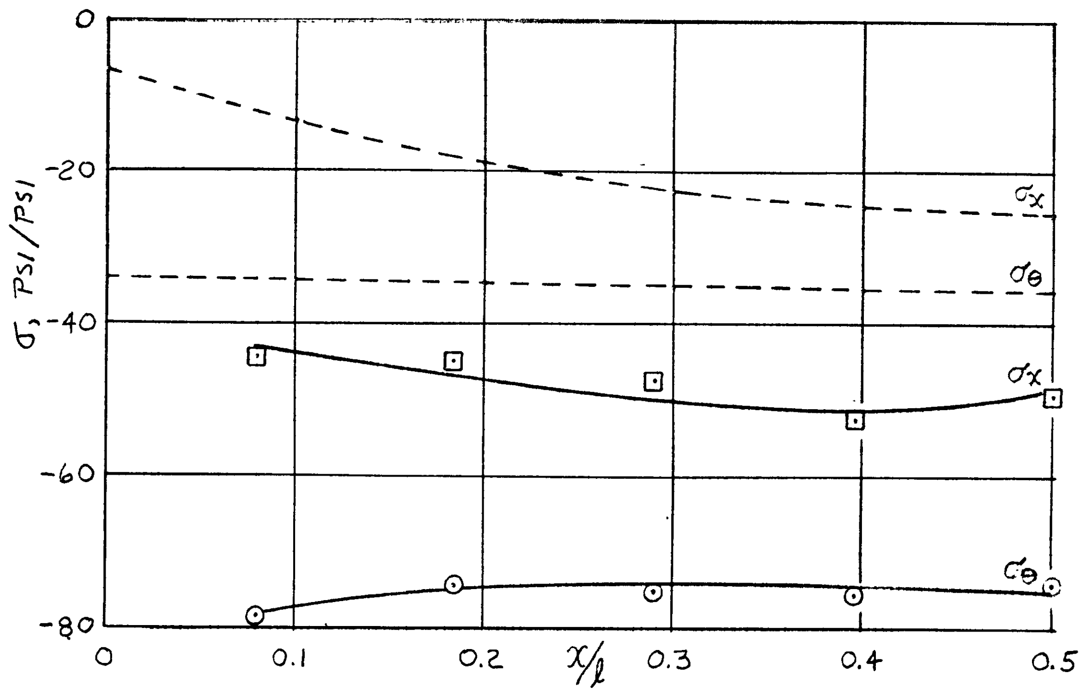


Figure 6 – Stress Distribution on Outside Surface of the Shell at the Minor Axis

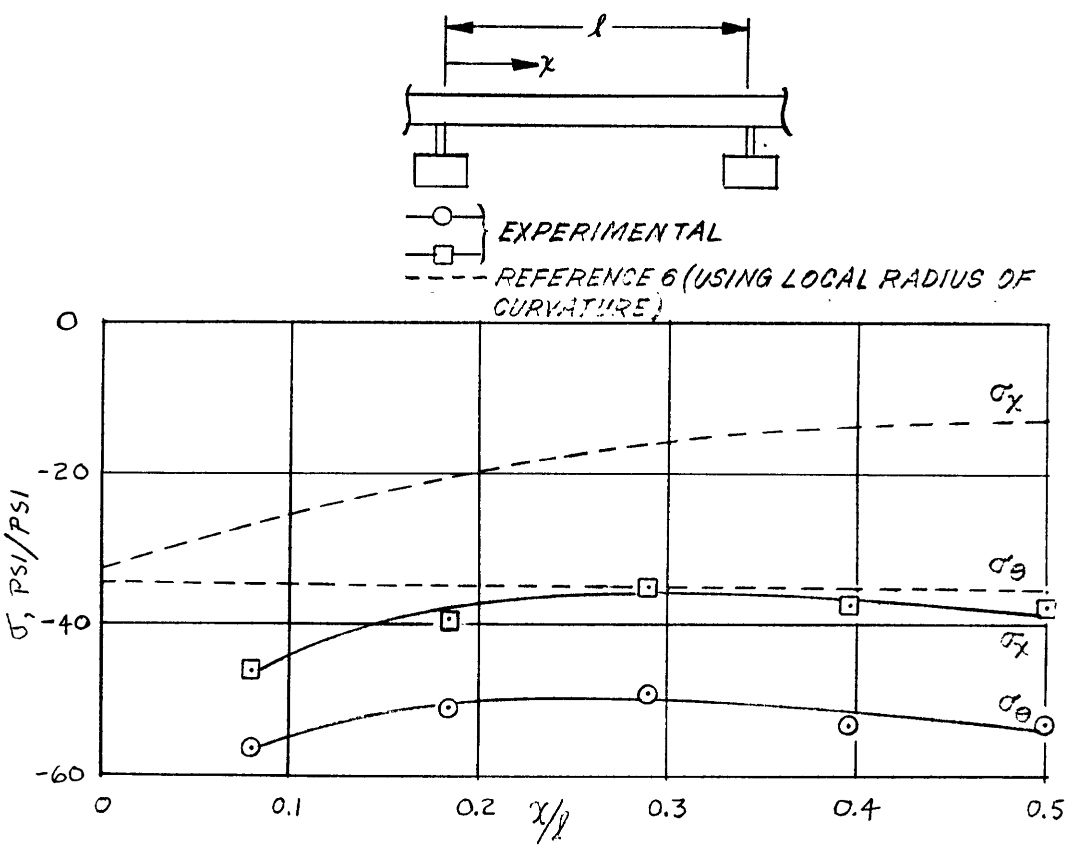


Figure 7 – Stress Distribution on Inside Surface of the Shell at the Minor Axis

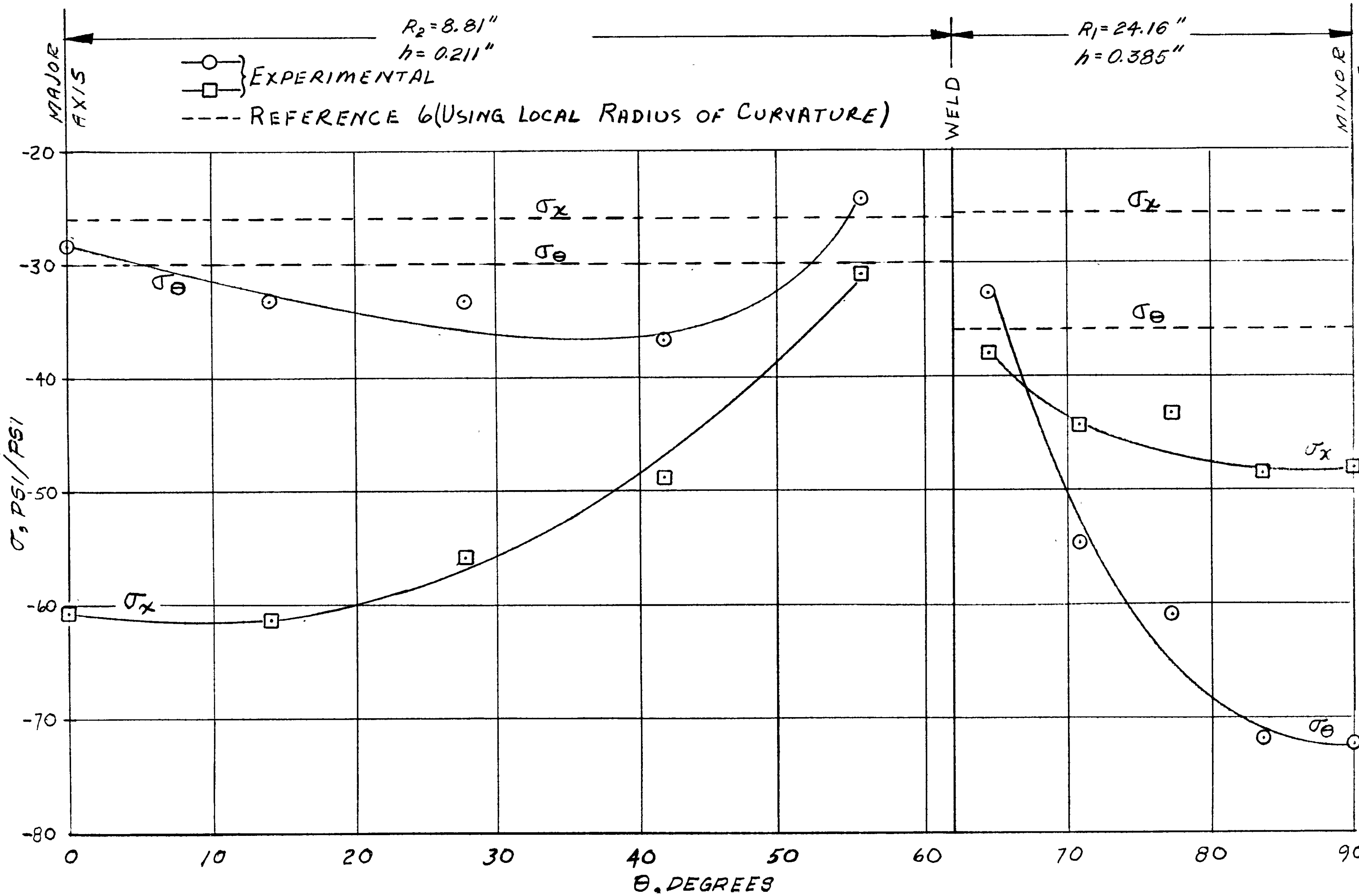


Figure 8 – Mid-Bay Stress Distribution on Outside Surface of a Quadrant of Shell

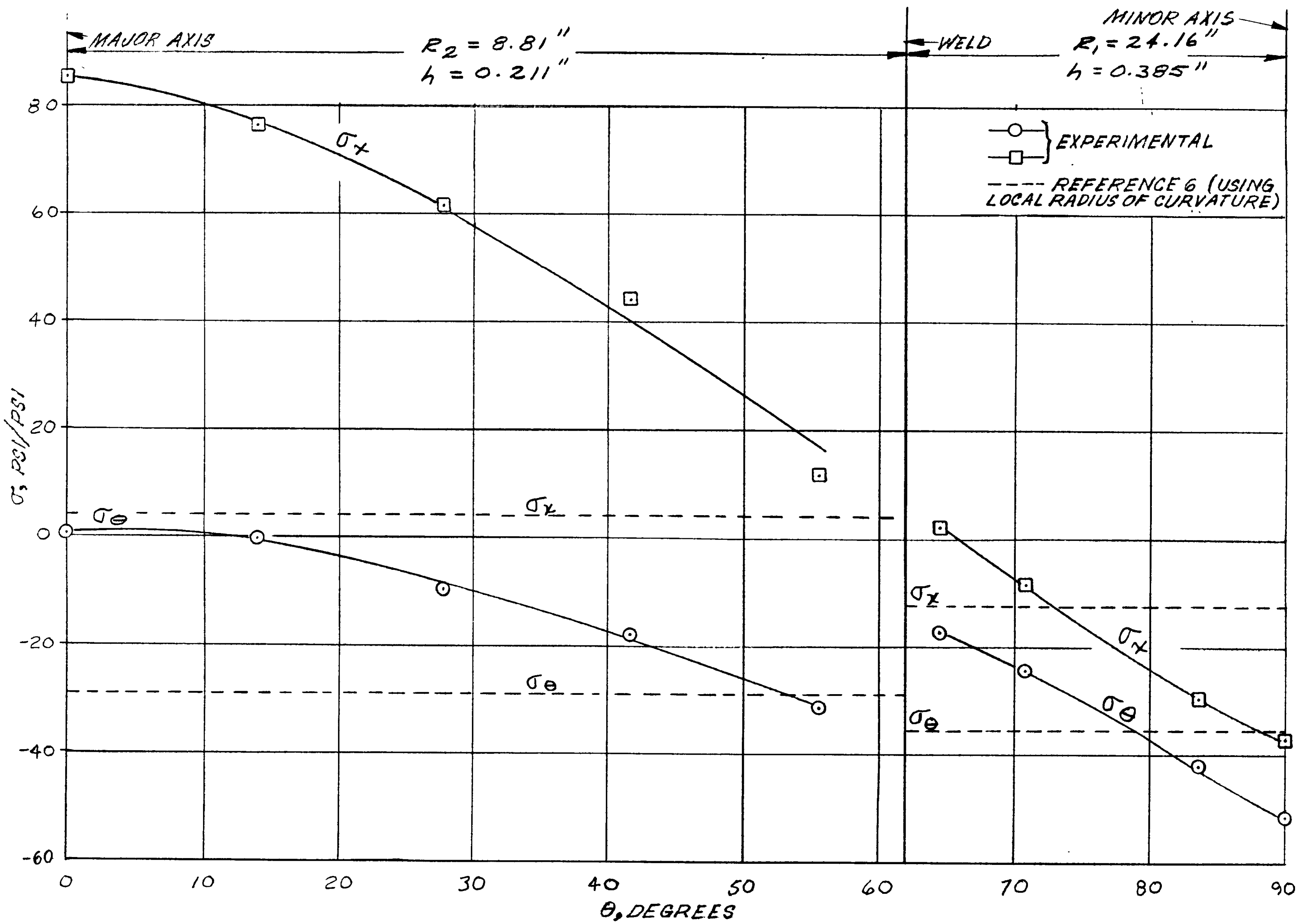


Figure 9 – Mid-Bay Stress Distribution on Inside Surface of a Quadrant of Shell

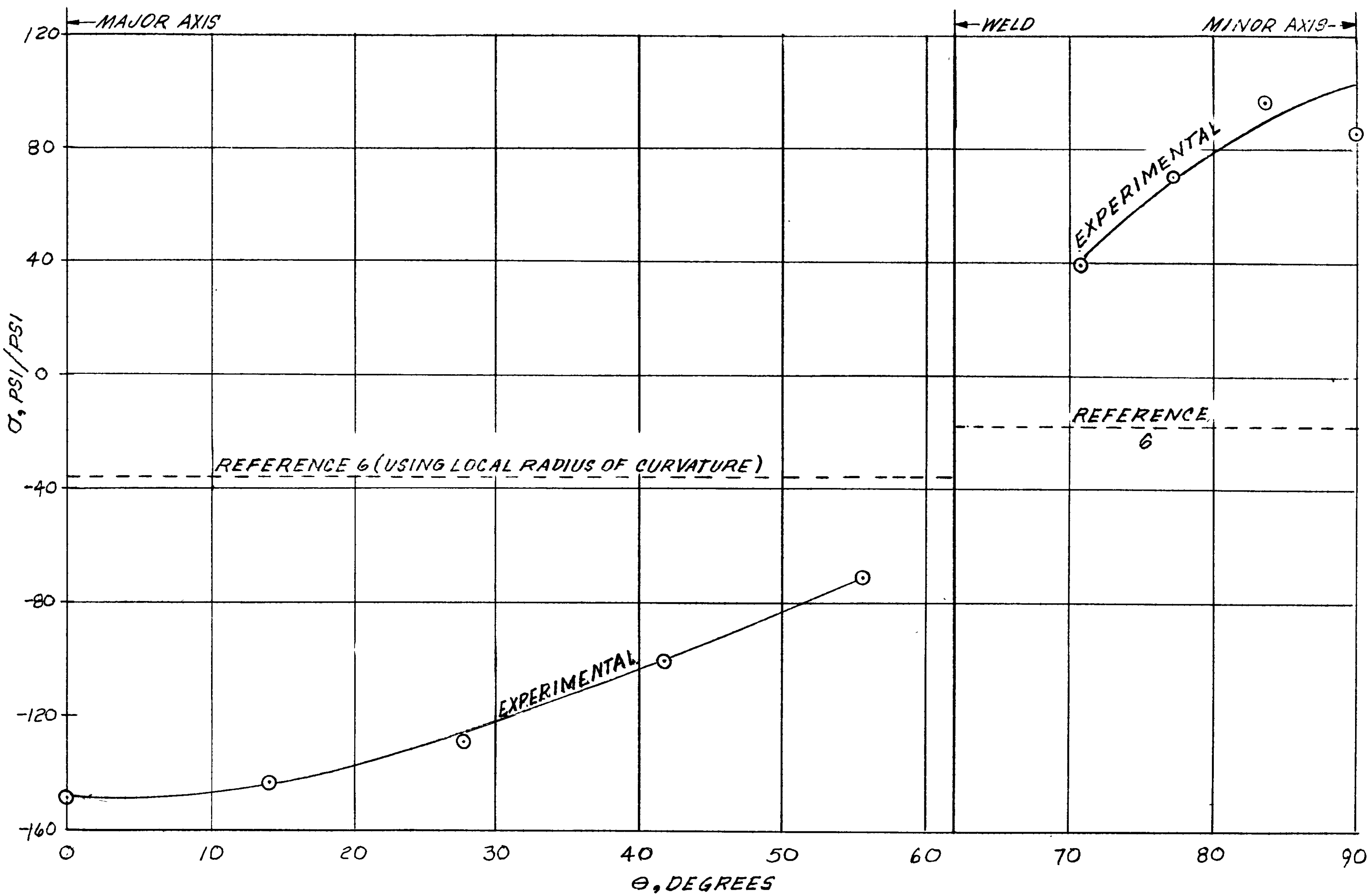


Figure 10 – Circumferential Flange Stress for a Quadrant of Frame 7

REFERENCES

1. Bureau of Ships Long Range Research and Development Plan, Volume I and II, Chapter 4 (Hulls), CONFIDENTIAL (Mar 1962.)

2. Kempner, J., "Summary of Research on Reinforced and Unreinforced Cylindrical Shells, 1952-1961," Polytechnic Institute of Brooklyn Report PIBAL 598 (Feb 1962).

3. Romano, F.J. and Kempner, J., "Stress and Displacement of a Simply Supported Non-Circular Cylindrical Shell Under Lateral Pressure," Polytechnic Institute of Brooklyn Report PIBAL 415 (Jul 1958).

4. Timoshenko, S., "Theory of Plates and Shells," McGraw-Hill Book Co.,Inc. (1940).

5. Vafakos, W.P., Romano, F.J., and Kempner, J., "Stress and Displacemnt Analysis of Clamped Non-Circular Cylindrical Shells Under Hydrostatic Pressure," Polytechnic Institute of Brooklyn Report PIBAL 594 (June 1961).

6. Von Sanden, K. and Günther, K., "The Strength of Cylindrical Shells, Stiffened by Frames and Bulkheads, Under Uniform External Pressure on All Sides," Werft and Reederei (1920); Vol. 9, pp. 189-198; Vol. 10, pp. 216-221. Also David Taylor Model Basin Translation 38 (Mar 1952).

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