STRESSES IN DECOMPRESSION CHAMBER MODEL OF COOPERATIVE WIND TUNNEL

THESIS
BY

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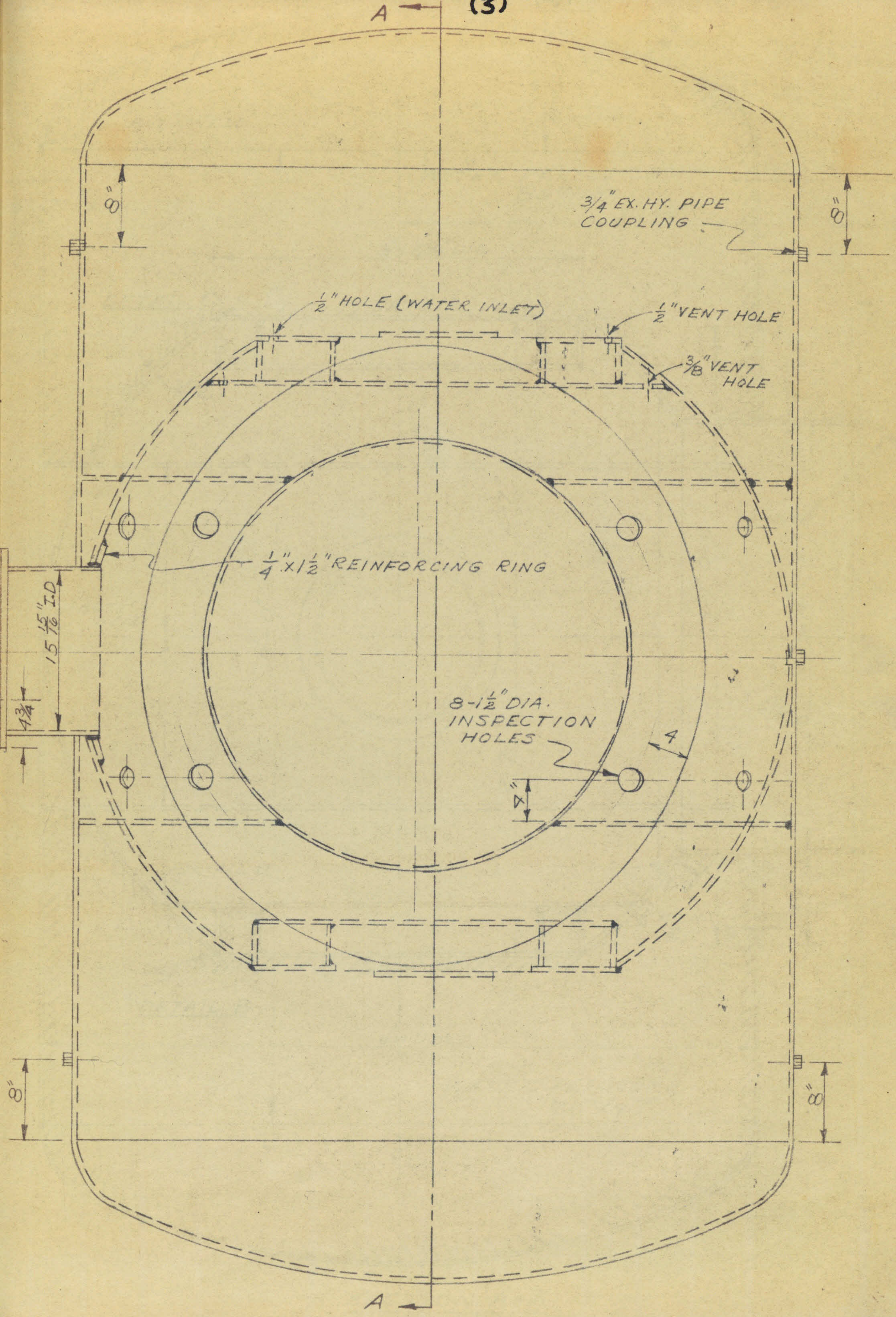
The author wishes to express his appreciation to Professor Martel and Professor Converse for their helpful suggestions in the preparation of this thesis; also to Mark Serrurier under whose direction the tests were run, and to Orhan Emre who worked with the author in obtaining the experimental data.

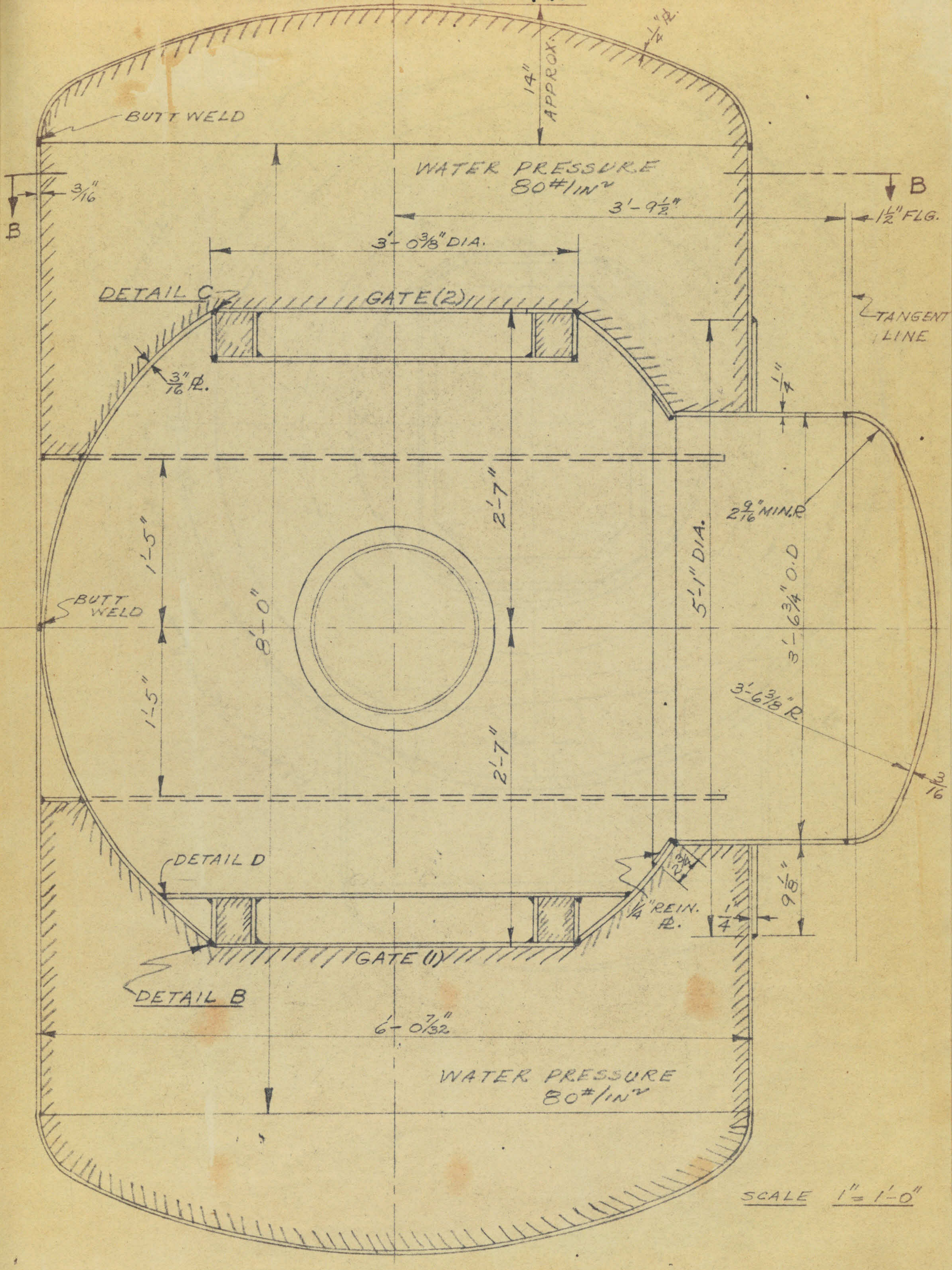
INTRODUCTION

The data for this thesis was compiled from a series of tests performed on a model of the Decompression Chamber of the Co-operative Wind Tunnel at the California Institute of Technology.

The model, constructed by the Consolidated Steel Company, is of structural steel and approximately 1/5 scale size. The ends, which in the full scale size will connect to the rest of the tunnel, were sealed off, thus allowing pressure conditions to be duplicated. The pressure on the full scale chamber will be 47 lbs/ sq. in. (air pressure). The pressure used in the tests was 80 lbs/sq. in. water pressure. The construction around Gate (1) and Gate (2) is slightly different in the model as may be seen from the drawings on page 4 . This is to allow for comparative tests. Both gates are to be the same in the full size tunnel since both will be subject to the same pressure conditions. The plate thickness in the model is not to scale but the relation is such that 53 lbs/sq. in pressure produces the same stress in the model as 47 lbs./sq.in produces in the full size chamber.

In compiling the test data all recorded readings were included except in one or two cases where the results were obviously astray due to some mechanical slip. Nearly all of such readings were not recorded at all, and in many cases gauge readings at a particular spot were repeated several times until consistent results were obtained.


A
3/4" EX. HY. PIPE COUPLING
8"
8"
1/2" HOLE (WATER INLET)
1/2" VENT HOLE
3/8" VENT HOLE
1/4" x 1 1/2" REINFORCING RING
15 15/16" I.D.
4 3/4
8-1 1/2" DIA. INSPECTION HOLES
4
4"
8"
8"
A


14" APPROX.
1/4" PL.
BUTT WELD
WATER PRESSURE
80#/IN²
3/16"
B
B
3'-9 1/2"
1 1/2" FLG.
3'-0 3/8" DIA.
DETAIL C
GATE (2)
TANGENT LINE
3/16" PL.
1/4"
2'-7"
2 9/16" MIN. R
1'-5"
BUTT WELD
8'-0"
5'-1" DIA.
3'-6 3/4" O.D
3'-6 3/8" R
1'-5"
2'-7"
3/16
DETAIL D
2 3/4
1/4" REIN. PL.
1/4
9 1/8"
GATE (1)
DETAIL B
6'-0 7/32"
WATER PRESSURE
80#/IN²
SCALE 1" = 1'-0"

SECTION A-A

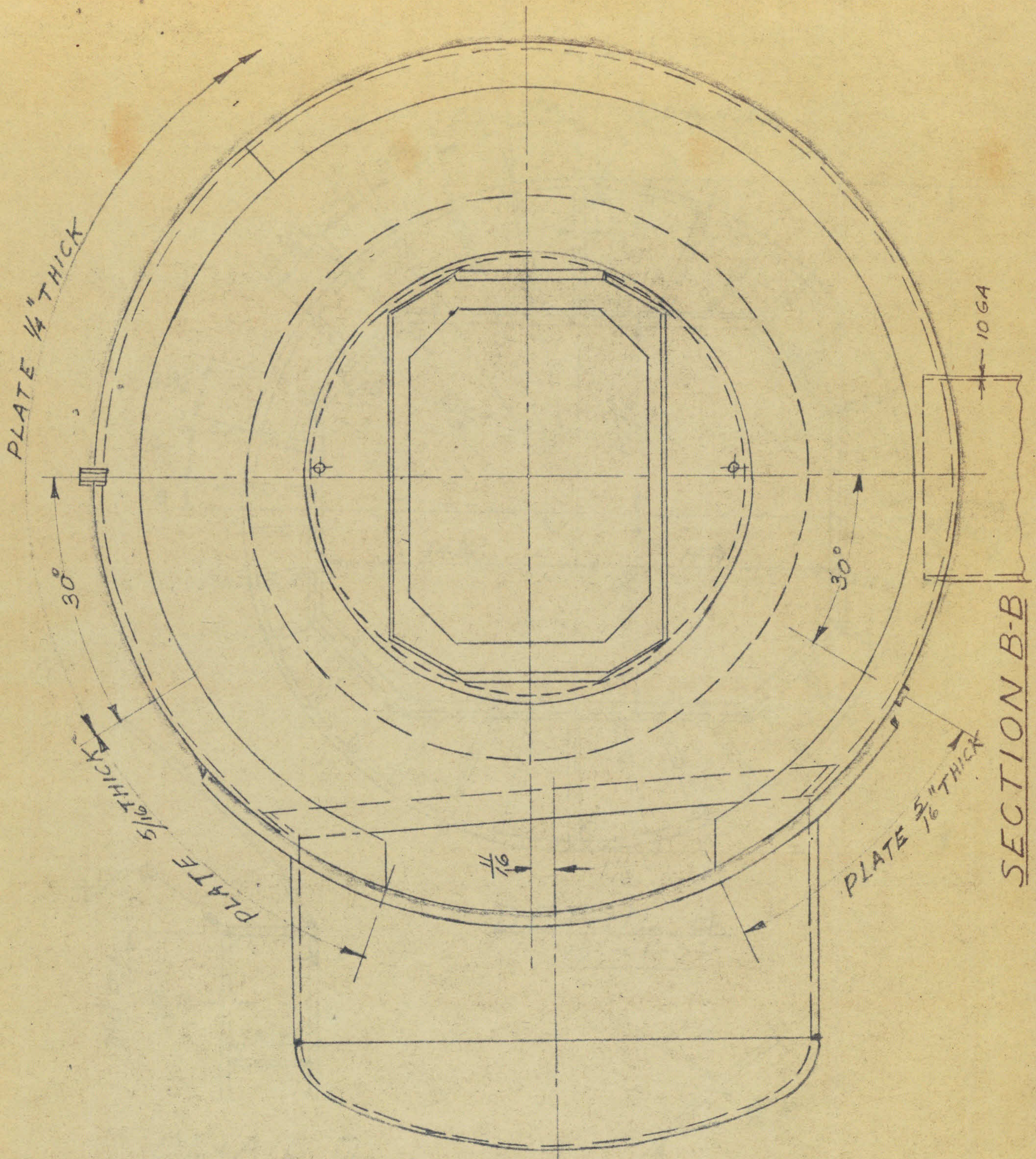
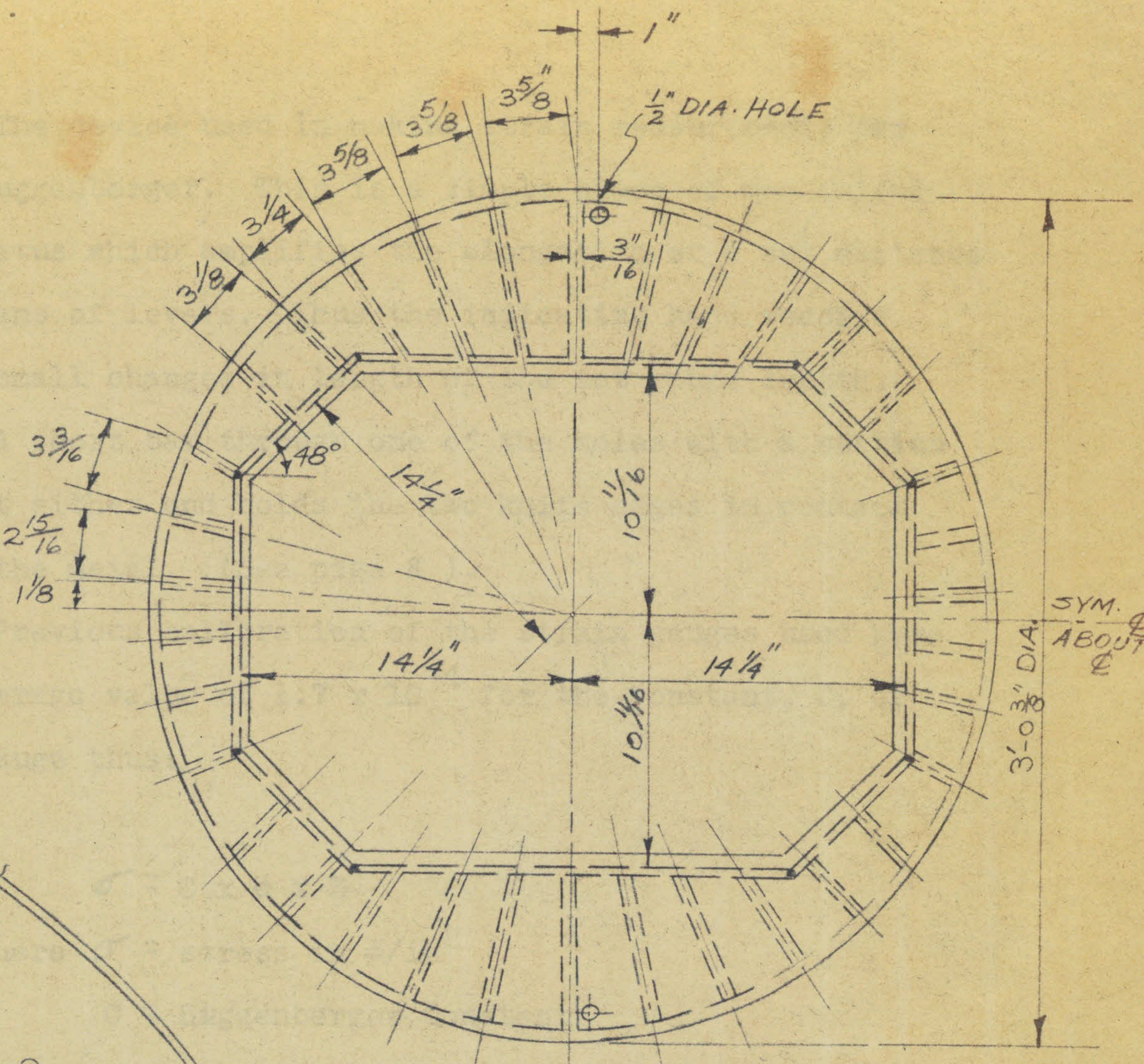
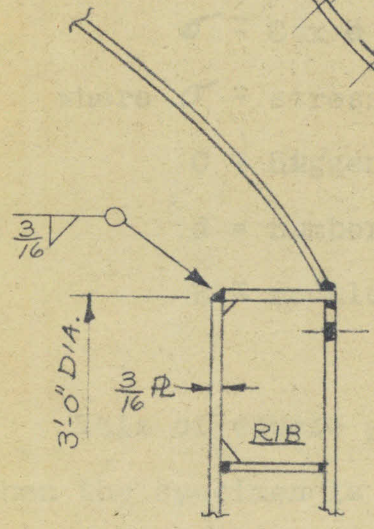


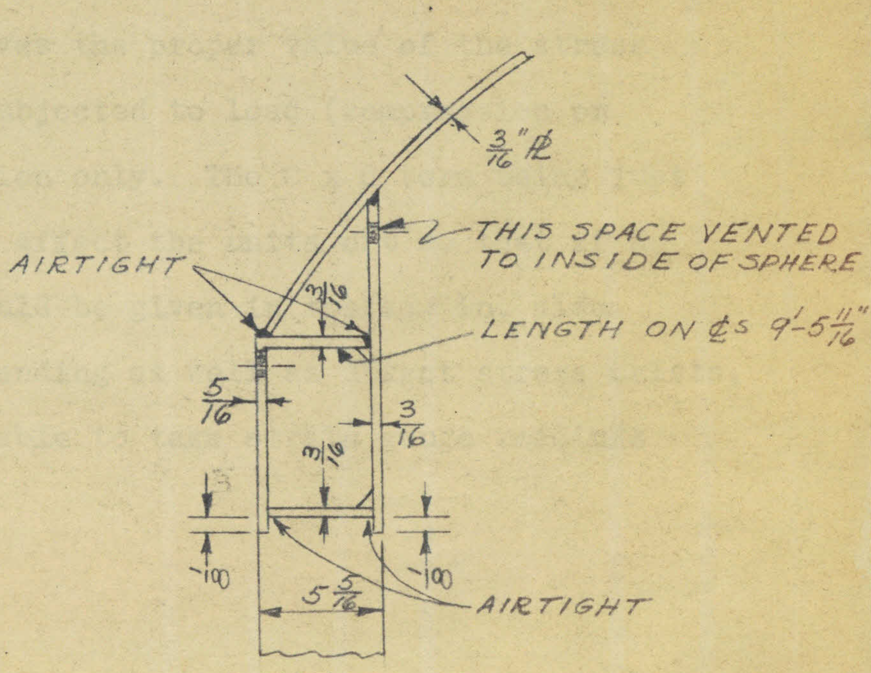
PLATE 1/4" THICK
10 GA
30°
30°
PLATE 5/16" THICK
PLATE 5/16" THICK
7/16
SECTION B-B



DETAIL B.
1½" = 1'-0"



DETAIL C



DETAIL D

The device used in making strain measurements was the Huggenberger. This is a simple piece of mechanical apparatus which amplifies the elongation of a set distance by means of levers. Thus the indicating hand records very small changes in length of the set gauge length.

A short bar through one of the holes with a suction cup at either end holds the two knife edges in contact with the metal. (See page 8).

Previous calibration of the strain gauges used gave an average value of 1.7×10^{-4} for the constant, C, of the gauge thus:

$$\sigma = C \times d \times E$$

where σ = stress in #/in^2

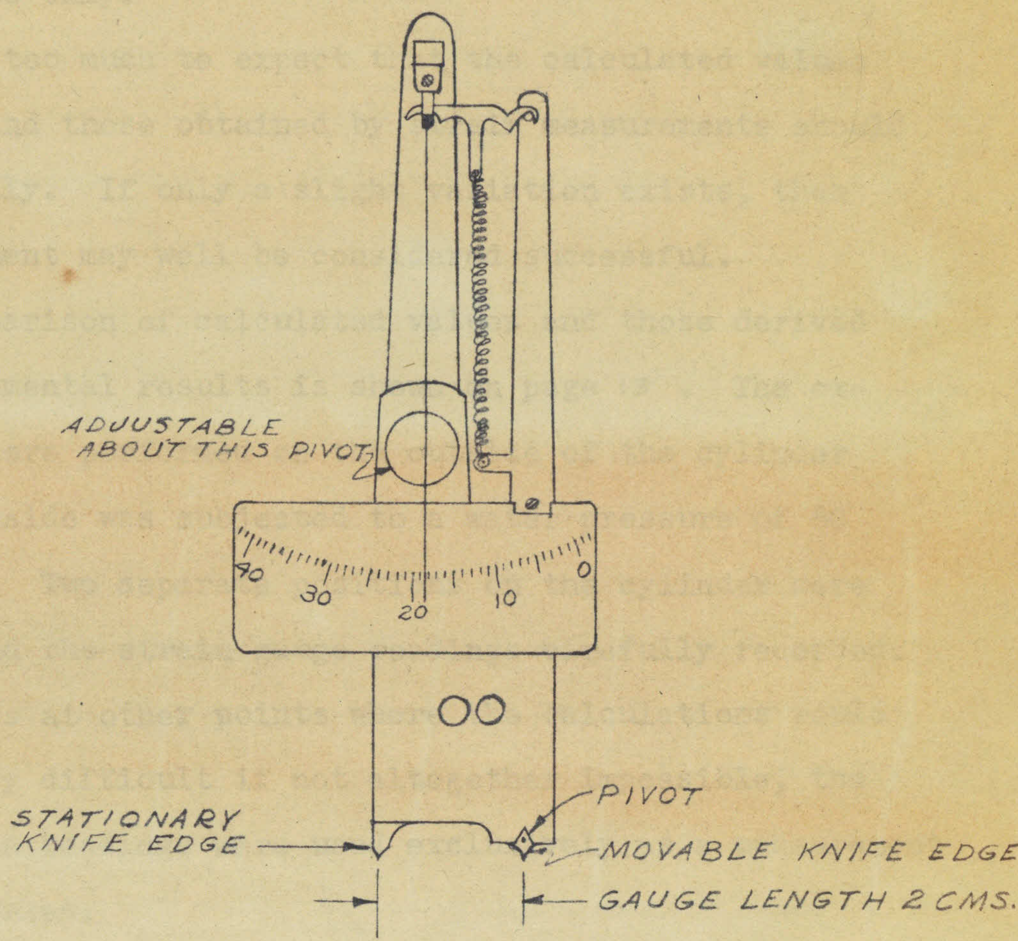
C = Huggenberger Constant

d = number of divisions moved

E = modulus of elasticity

This of course gives the proper value of the stress when the specimen is subjected to load (compression or tension) in one direction only. The C x d term being just a ratio ~~which~~ does not affect the units of σ so that if E is in lbs/sq. in. σ would be given in lbs/sq. in. also.

In plates where bending as well as direct stress exists, it would be very desirable to take strain gauge readings



HUGGENBERGER STRAIN GAUGE

on both sides of the plate simultaneously so as to get a more accurate picture of the amount of bending stress in the plate. Under the conditions of the test this was impossible since one side of the wall had water pressure on it. Hence, all the readings taken were taken on one side of the plate only.

It is too much to expect that the calculated values of stress and those obtained by strain measurements should check exactly. If only a slight variation exists, then the experiment may well be considered successful.

A comparison of calculated values and those derived from experimental results is shown on page 13 . The experiments were performed on the outside of the cylinder when the inside was subjected to a water pressure of 80 lbs/sq. in. Two separate positions on the cylinder were selected and the strain gauge readings carefully recorded. For the stresses at other points where the calculations would be extremely difficult if not altogether impossible, the strain gauge readings were used exclusively as a measurement of the stresses.

To insure gauge readings that were free from errors due to slipping of the knife edges, jarring of the surface, etc., all readings were checked both in the increasing pressure and decreasing pressure. The strain gauges were under constant observation as the pressure was brought up to the maximum and again as it was being reduced to zero.

The problem of calculating the stresses set up in steel plate cylinders and spheres under pressure is a straightforward one. The computations are simple and the results are usually very close to the actual stresses. However, when cylinders intersect, or a part of a sphere is cut to provide a gate opening, or some other irregularity has to be introduced, the computations are not so straightforward and there is always some doubt as to how close the computed stresses are to actuality. There is only one way to settle that question and that is to devise some means of measuring the stresses produced under certain controlled loading. Methods of measuring can be even more faulty than methods of computations, so that the only real satisfaction is obtained in a correlation of the two.

The shape of the model afforded an excellent opportunity to investigate conditions which are difficult to calculate and again to compare experiment and theory where the theory is definite and experimental results should be fairly accurate.

Some of the extensometer deflections were so small that no great accuracy could be expected in the readings, but such conditions indicate low stresses so that those particular points would never be critical. Since the conditions under which the tests were run permitted readings taken on one side of the plate only, bending stresses and direct stresses could not be differentiated. In such cases the theory provides the only solution.

Due to the high relative rigidity of welded joints the stress distribution in the plates close to such joints is rather difficult to evaluate and strain gauge readings in such places were sometimes very different from what might be expected.

MEASUREMENTS TAKEN ON OUTSIDE OF CYLINDER

Water pressure 80#/in.^{2}

Gauge No.	Circumferential		Stress #/in.^{2}	Longitudinal		Stress #/in.^{2}
	Initial	Final		Initial	Final	
2	18	20	12,900	19	20	9000
3	18	20	12,600	19	19.8	7900

$$\sigma = C \times d \times E$$

$$= 1.7 \times 10^{-4} \times d \times 30 \times 10^{6}$$

$$= 5100 \times d \text{ #/sq.in.}$$

$$\varepsilon_{long.} = \frac{\sigma_{long.}}{E} - \mu \frac{\sigma_{circum.}}{E}$$

$$\varepsilon_{circum.} = \frac{\sigma_{circum.}}{E} - \mu \frac{\sigma_{long.}}{E}$$

$$\sigma_{long.} = \frac{(\varepsilon_{long.} + \mu\varepsilon_{circum})}{1 - \mu^2} E$$

$$\sigma_{circum.} = \frac{(\varepsilon_{circum} + \mu\varepsilon_{long})}{1 - \mu^2} E$$

μ = Poissons ratio for structural steel = 0.3
$\varepsilon_{long.}$ = Strain in longitudinal direction.
$\sigma_{long.}$ = Stress in longitudinal direction
$\varepsilon_{Circum.}$ = Strain in circumferential direction
$\sigma_{Circum.}$ = Stress in circumferential direction

$$\frac{\sigma_{Circum}}{E} = 2 \times 1.7 \times 10^{-4}$$

$$\sigma_{long.} = \frac{30 \times 10^{6} \, (1 \times 1.7 \times 10^{-4} + 2 \times 1.7 \times 10^{-4} \times .3)}{1 - .09}$$

$$= \frac{1.7 \times 10^{-4} \times 1.6 \times 30 \times 10^{6}}{.91}$$

$$= \underline{9000 \text{ #/ in.}^2}$$

$$\sigma_{circum} = \frac{E\,\varepsilon_{circum.}}{1-\mu^2}$$

$$= \frac{30 \times 10^6 \,(2 \times 1.7 \times 10^{-4} + 1 \times 1.7 \times 10^{-4} \times .3)}{.91}$$

$$= \frac{30 \times 10^6 \times 1.7 \times 10^{-4} \times 2.3}{.91}$$

$$= 12,900\#/\text{ in.}^2$$

CALCULATED VALUES

$$\sigma_{long.} = \frac{\pi d^2 p}{4\pi d t} = \frac{pd}{4t} = \frac{80 \times 6 \times 12 \times 16}{4 \times 3} = 7700\ \#/\text{in}^2$$

$$\sigma_{circum.} = \frac{Pd}{2t} = \frac{80 \times 6 \times 12 \times 16}{2 \times 3} = 15400\#/\text{in.}^2$$

P = Water pressure $\#/\text{in.}^2$
d = Diameter of cross section
t = Thickness of plate

Direction	Calculated Stress	Measured Stress	Per Cent Diff. on Calculated
Longitudinal	7700	9000	+17 (Safe)
Circumferential	15,400	12,900	- 16 (Unsafe)
Longitudinal	7700	7900	+ 2.6 (Safe)
Circumferential	15,400	12,600	-18 (Unsafe)

STRAIN GAUGE READINGS AND STRESSES AT GATE (1)

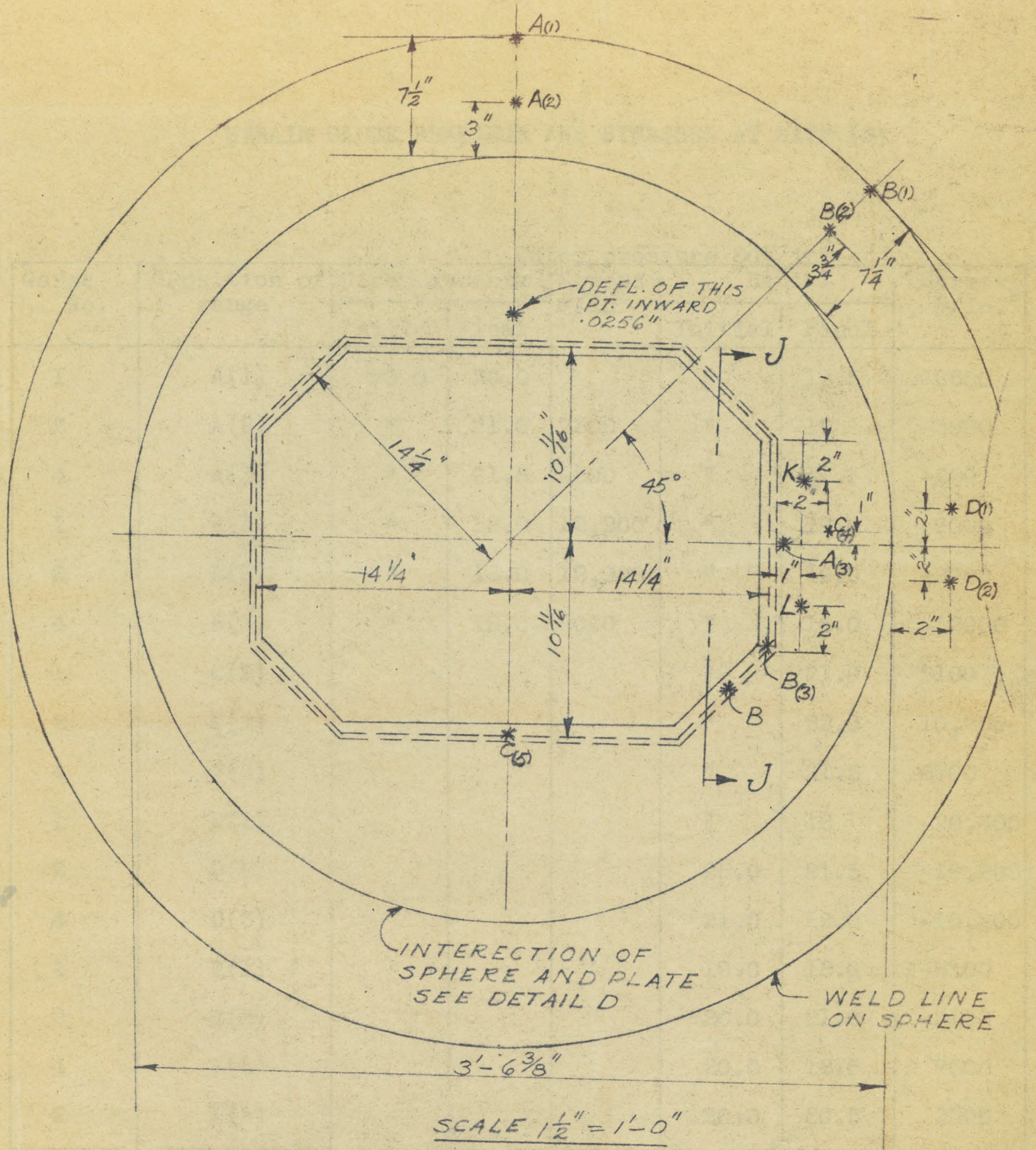
Gauge No.	#Position of Gauge	Circumferential Reading		Stress #/in^2	Radial Reading		Stress #in.^{2}
		Initial	Final		Initial	Final	
1	A(1)	20.0	18.5	7600	20.0	20.0	
2	A(2)	20.0	19.0	7300	20.0	19.0	7300
4	A(3)	20.0	20.0				
4	A(4)	22.0	21.8	1000			
2	B	16.0	15.5	2500			
3	B(1)	20.0	20.0		20.0	20.0	
4	B(2)	19.0	19.0		20.1	20.0	
5	B(3)	19.5	19.5				
5	C(4)				24.0	24.0	
1	C5)	13.0	13.0				
5	D(1)	20.0	19.5	800	19.8	21.0	5900
7	D(2)	20.0	19.0	4800	20.0	20.5	1100
2	E				24.0	20.0	20,400
2	F				20.0	17.0	15,300
2	G				16.0	14.5	7600
6	H				20	20	
7	I				20	19	5100
7	K				20	21.5	7600
7	L				18.5	20.0	7600

#See fig. on page 15 + 18.

Circumferential readings on the sphere are taken in a direction perpendicular to the radius as seen in fig. on page 15.

Radial readings on the sphere are taken in a radial direction as seen in the same fig.

Radial readings on the plane surface are vertical tangential reading horizontal



VIEW FACING GATE(1) FROM INSIDE SPHERE SHOWING POINTS AT WHICH MEASUREMENTS WERE TAKEN.

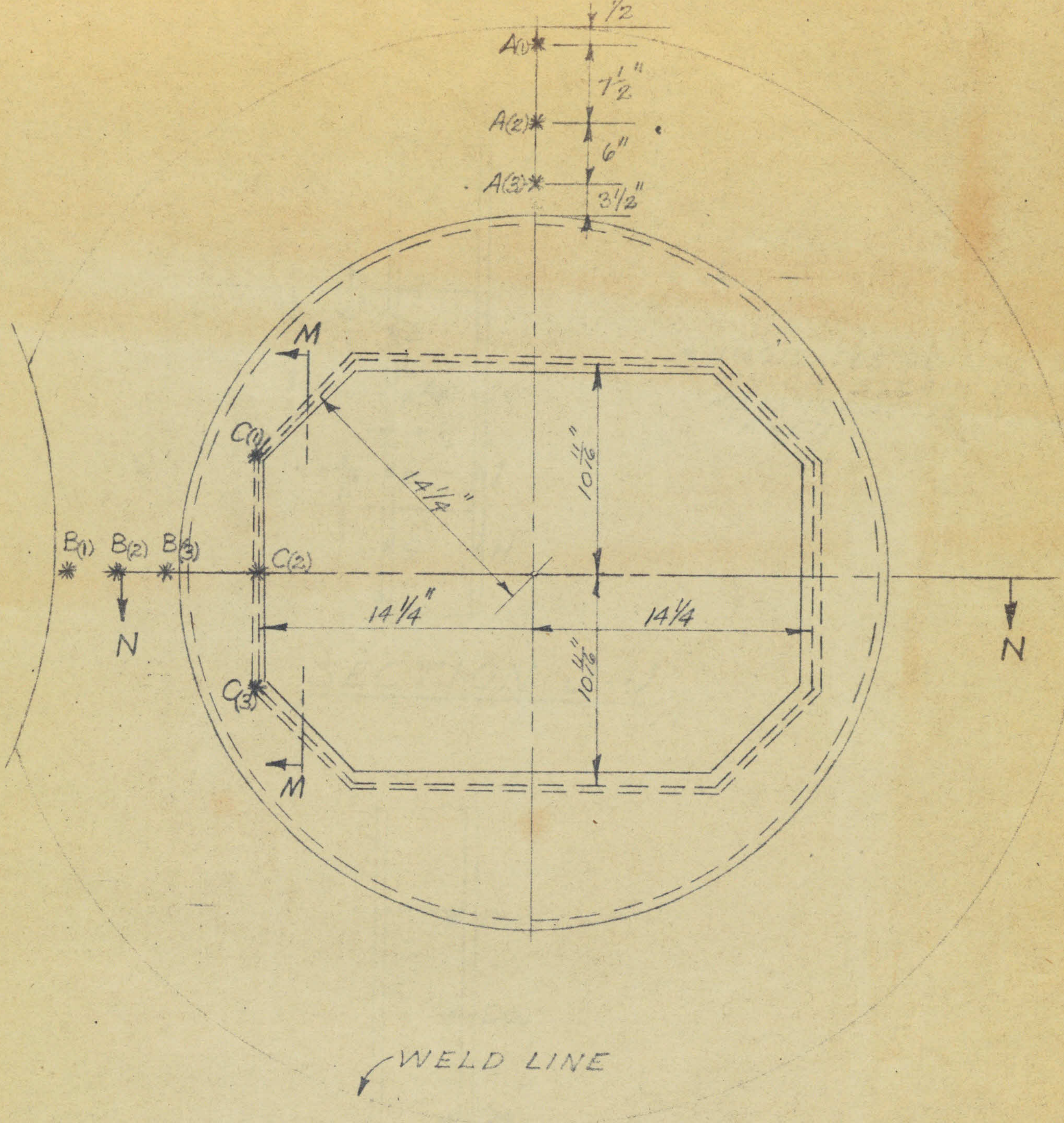
STRAIN GAUGE READINGS AND STRESSES AT GATE (2)

Water pressure 80#/in^2

Gauge No.	#Position of gauge	Circumferential		Stress #/in^2	Radial		Stress #/in.^{2}
		Initial	Final		Initial	Final	
1	A(1)	20.0	20.0		20	19.5	-2800
2	A(2)	"	21.0	7300	"	19	-3920
4	A(3)	"	21.5	9300	"	19.5	-280
1	B(1)	"	18.0	12,900	"	19.0	-9000
2	B(2)	"	18.0	12,900	"	19.0	-9000
4	B(3)	"	19.0	9000	"	18.0	-12900
1	C(1)				"	21.0	5100
2	C(2)				"	22.0	10,200
4	C(3)				"	21.2	6700
1	D(1)				"	16	-20,400
2	D(2)				25.0	21.5	-19,600
4	D(3)				21.0	19.0	-10,200
4	E(1)				19.0	18.0	-5100
2	E(2)				20.0	21.0	5100
4	F(1)				20.0	18.5	7600
2	F(2)				20.0	20.5	2500

See fig. on page 17 + 18.

Where readings in only one direction are recorded corresponding readings in a perpendicular direction are negligible.



VIEW FACING GATE (2) FROM INSIDE SPHERE SHOWING POINTS AT WHICH MEASUREMENTS WERE TAKEN.

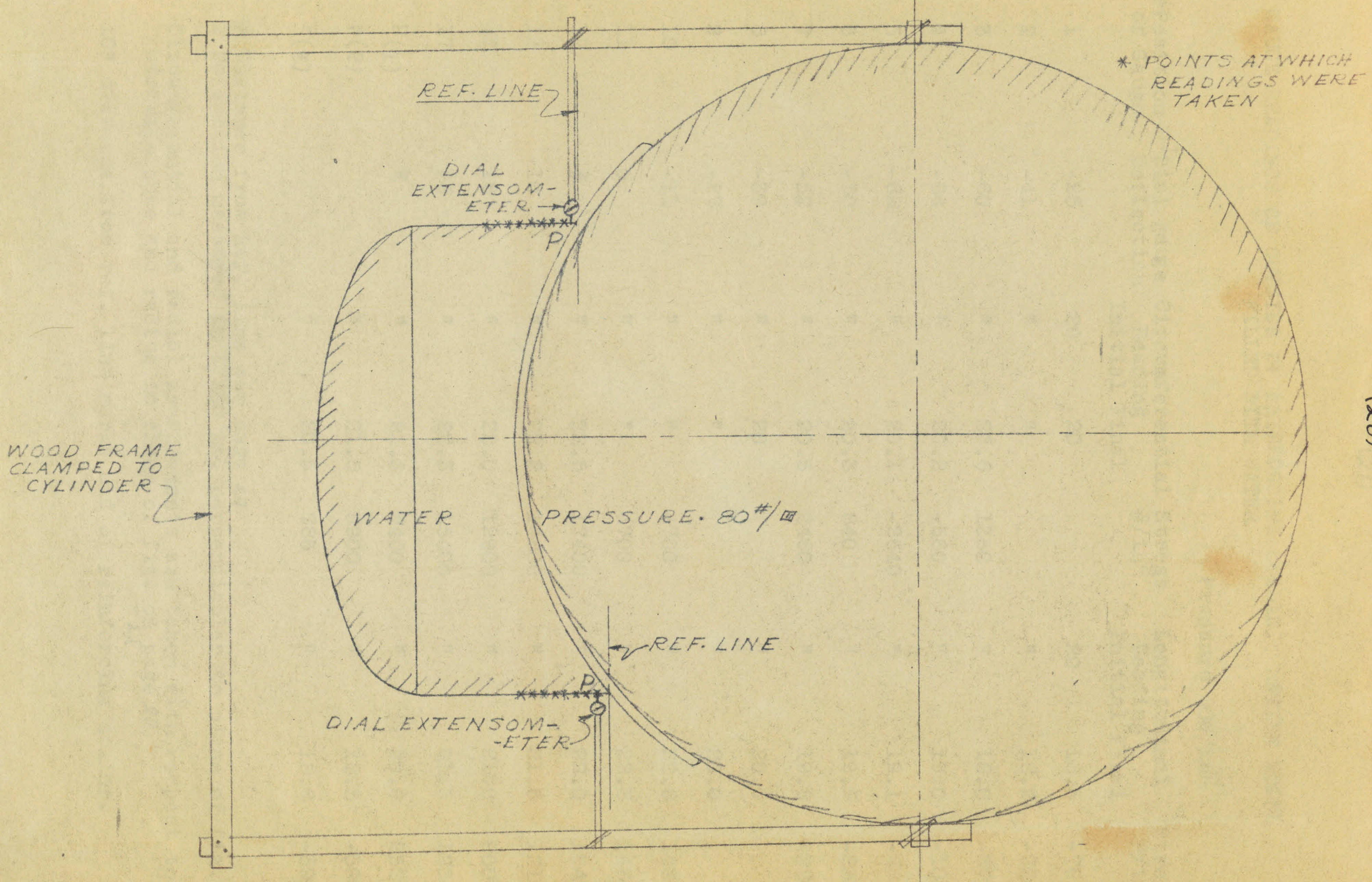
READINGS TAKEN ON TOP AND BOTTOM SURFACES OF SMALL INTERSECTING CYLINDER

#Position of Gauge	1 Dial Gauge Defl.		Circumferential Reading (Top)		Stress #/in.^{2}	Longitudinal Reading (Top)		Stress "/in.^{2}
	Top	Bottom	Initial	Final		Initial	Final	
1	120	110	20	20.25	1400			
2	225	110	"	21.0	8120	20.0	21.5	4500
3	225	105	"	22.0	12,900	"	21.0	9000
4	220	90	"	22.0	12,000	"	20.5	6200
5	205	75	"	22.0	11,600	"	20.25	4760
6	185	170	"	22.0	11,600	"	20.25	4760
7	o285	155	"	22.0	11,600	"	20.25	4760
8	180	50	"	22.0	11,600	"	20.25	4760

See fig. on page 20.
o Doubtful

1 dial gauge defl. are measured in 1/100 mm.
Above readings were taken with entire model filled with water under a pressure of 80#/sq. in.

Dial gauge readings are neglibly small, but the change in values, however, are indicative of the pressure distribution over the area covered.



VIEW LOOKING IN THE DIRECTION OF SECTION B-B

GAUGE READINGS ON OUTSIDE OF REINFORCING COLLAR. ENTIRE MODEL FILLED WITH WATER

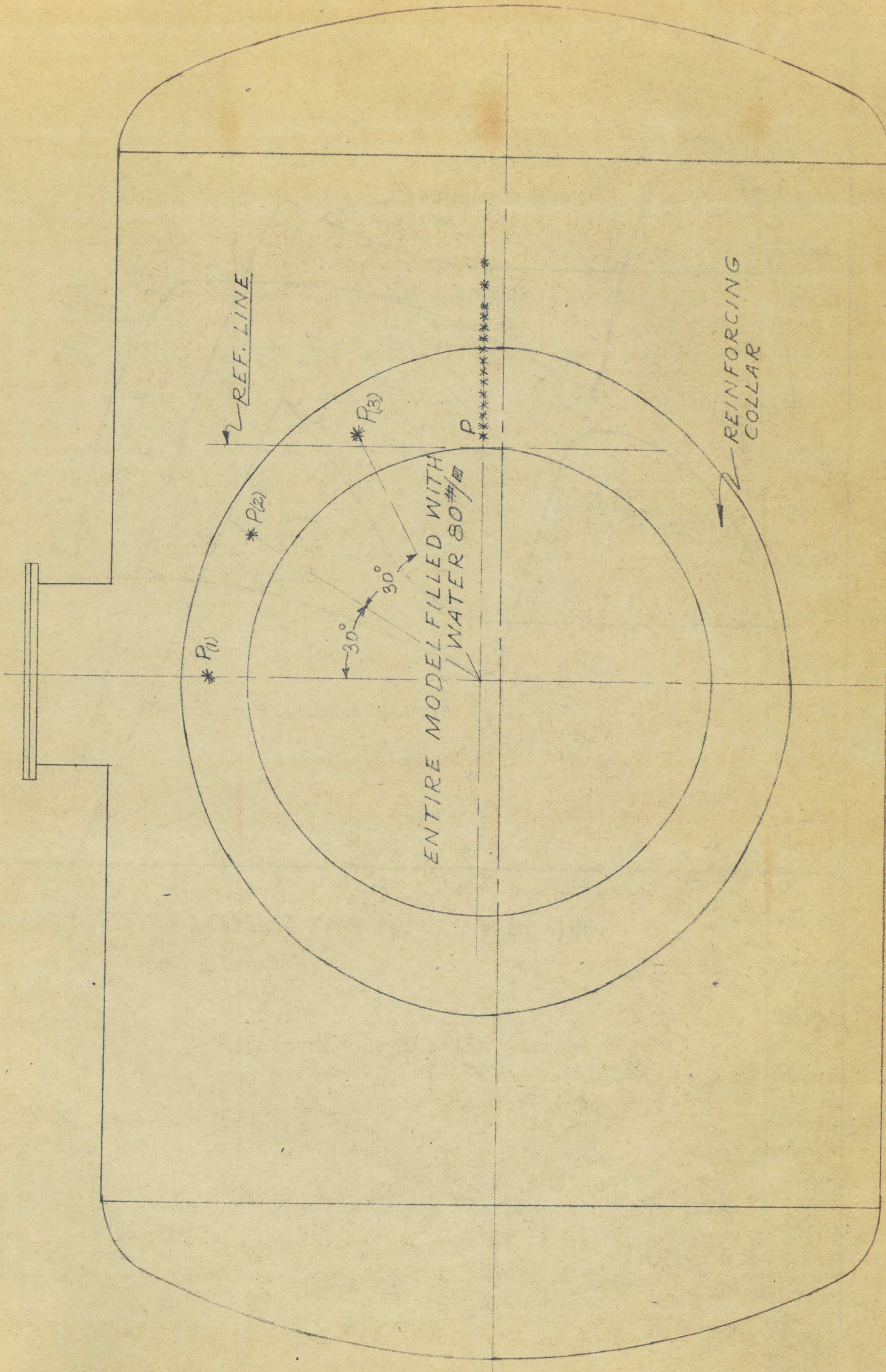
Pressure 80#/in²

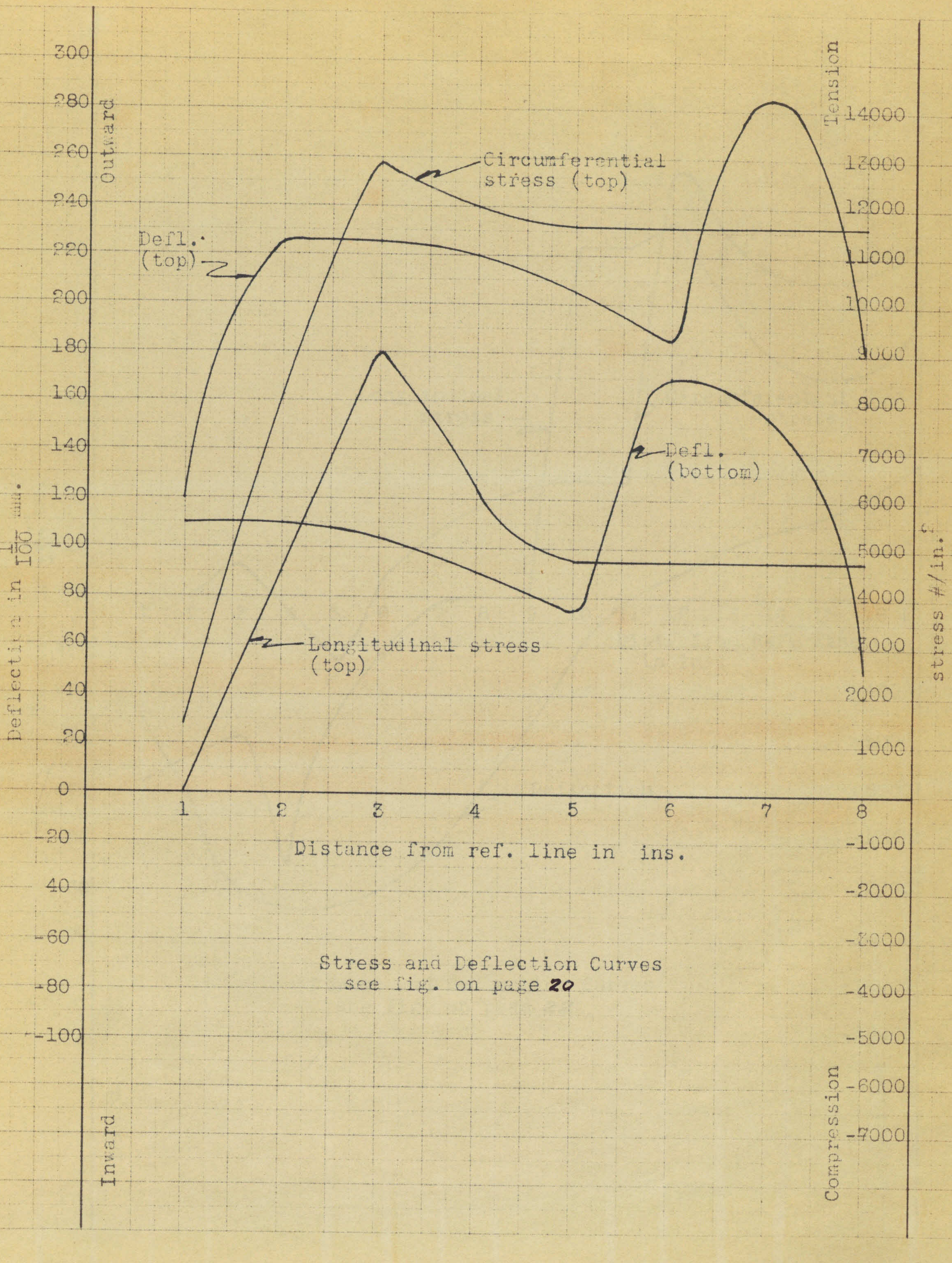
#Position of Gauge	P[1]Dial gauge Deflection	Circumferential Reading Initial	Circumferential Reading Final	Stress #/in²	Longitudinal Reading Initial	Longitudinal Reading Final	Stress #/in²
1	-25	20	20		20	18.5	-7650
2	-41	"	"		"	18.2	-9200
3	-60	"	20.6	1350	"	18.8	-5720
4	-64	"	20.2	-560	"	19.0	-10900
5	-63	"	20.1	-2640	"	19.1	-4870
6	-60	"	20.3	840	"	19.5	-2300
7	-52	"	20.5	2460	"	19.8	-280
8	-39	"	20		"	20.0	
9	-27	"	"		"	20.0	
10	-11	"	"	4700	"	22.8	14300
11	0	"	"	4700	"	22.8	14300
12	4	"	22.5	17400	"	22.0	15400
13	10	"	22.2	14800	"	21.5	12100
15	16	"	22.0	12900	"	21.0	9000
17	28	"	22.3	15400	"	21.5	12300
$P_{(1)}$	"	"	21.5	8400	"	20.0	2520
P(2)		"	21.5	5900	"	18.5	-5900
$P_{(3)}$		"	20.5	785	"	18.8	-5900

Distance from Ref. line see page 22.
1 Deflection measured in 1/100 mm. perpendicular to plane of fig. on page 22

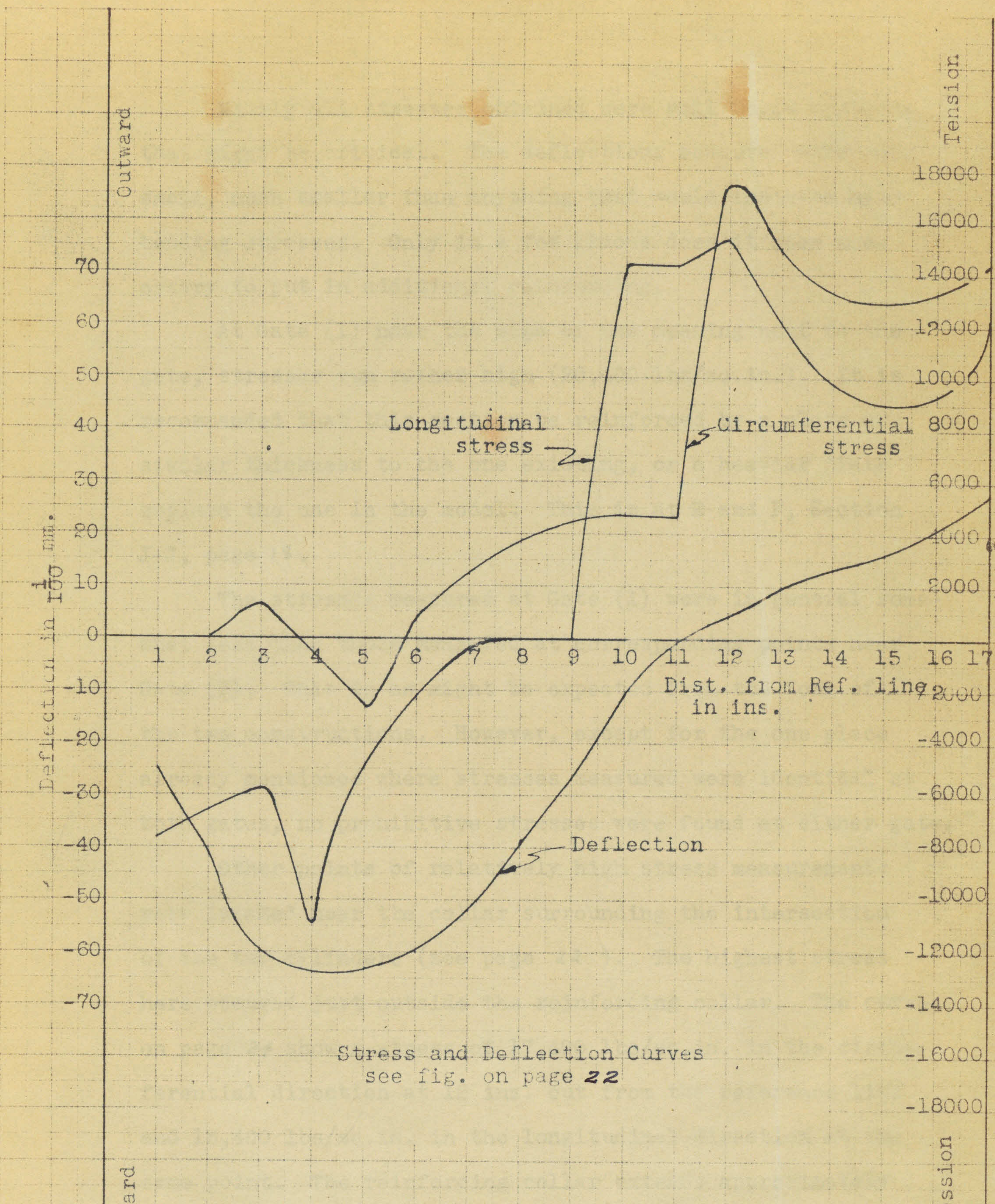
Circumferential and radial measurements are taken with respect to circumference and radius in plane of fig. on page 22.

10" distance from ref. line marks end of reinforcing collar.


REF. LINE
REINFORCING COLLAR
P
P(3)
P(2)
P(1)
30°
30°
ENTIRE MODEL FILLED WITH WATER 80#/□"



Stress and Deflection Curves
see fig. on page 20



Stress and Deflection Curves
see fig. on page 22

Nearly all stresses obtained were **well** below anything that might be critical. The deflections measured were very small, much smaller than anything that would indicate high bending stresses. Only in a few places does it seem necessary to put in additional reinforcing.

At Gate (1) near the edge of the opening next to the gate, stresses run rather high (20,400 lbs/sq.in.). It is recommended that this section be reinforced by a plate of similar thickness to the one existing, or a heavier plate replace the one in the model. This is at E and F, Section J-J, page 18.

The stresses measured at Gate (1) were in general somewhat less than those measured at corresponding points near Gate (2). This is as might be expected from the form of the two constructions. However, except for the one place already mentioned where stresses measured were identical at both gates, no prohibitive stresses were found at either gate.

Other points of relatively high stress measurements were located near the collar surrounding the intersection of the two cylinders (see page 22). The highest stress here occured just outside the reinforcing collar. The curves on page 24 show a stress of 17,400 lbs/sq.in. in the circumferential direction at 12 ins. out from the reference line and 15,400 lbs/sq.in. in the longitudinal direction at the same point. The reinforcing collar extends approximately

10 ins. out from the reference line. These stresses are not excessive, but are much higher than those measured at typical points elsewhere on the circumference (see page 21). The proximity to the weld line is obviously the reason for this increase in stress.