STRESS DISTRIBUTION IN TWO CIRCULAR CYLINDERS INTERSECTING AT RIGHT ANGLES UNDER THE INFLUENCE OF INTERNAL PRESSURE

Thesis by

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In Partial Fulfillment of the Requirements

For the Degree of

Aeronautical Engineer

California Institute of Technology

Pasadena, California

#### ACKNOWLEDGEMENT

The author is indebted to Dr. Ernest E. Sechler, Professor of Aeronautics, Galifornia Institute of Technology, chairman of the supervising committee, for his valuable guidance in the formulation of this thesis, and to Dr. Tuan G. Fung, Research Fellow in Aeronautics, and Dr. George W. Housner, Assistant Professor of Applied Mechanics, other members of the supervising committee for the helpful comments and suggestions offered. He is also grateful to Mr. William H. Bowen, Superintendent, Guggenheim Aeronautical Laboratory, Galifornia Institute of Technology for his able assistance and advice in the procurement and preparation of the test specimens and testing equipment.

Further indebtedness is acknowledged to Lieutenant Commander Vernon E. Teig, U. S. Navy who collaborated in conducting the experiments and in the preparation of all tables and graphs presented herein.

#### ABSTRACT

This investigation is an experimental study of the stress distribution in two circular cylinders intersecting at right angles and acted on by internal pressure. Two specimens of the thick-wall category were tested to rupture and a strain gage analysis was made of critical points. The specifications of the specimens tested were so chosen that this investigation would be the logical beginning of an overall study of intersecting cylinders under the influence of internal pressure.

The results of two tests are insufficient to indicate trends or establish facts as conclusive. The conclusions reached as a result of this investigation are, therefore, of such a nature as to require confirmation by subsequent continuation of this study. These conclusions are:

1. The maximum stresses present in specimens of the type tested are in the plane of intersection and tangent to the ellipse of intersection at a point approximately fifteen degrees from the crotch.

2. Additional resistance to the high stresses at the plane of intersection is necessary over that required in the wall of a straight pipe.

3. Bending associated with the stressing of this type of intersection by the application of internal pressure is of minor importance in specimens in the thick wall range.

All the tests were made in collaboration with Lieutenant Commander Vernon R. Teig, U. S. Navy in the Structures Laboratory, Guggenheim Aeronautical Laboratory, California Institute of Technology, Pasadana, California, during the school year 1948-49.

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## EXPLANATION OF SYMBOLS

E	Young's Modulus of Elasticity (assumed as 30,000,000 psi)
R	Strain Gage Reading
a and R	Internal Radius of Pipe (inches)
ď	External Radius of Pipe (inches)
k	Strain Gage Constant (-200)
P	Internal Pressure (psi)
\$	Thickness of Pipe (inches)
€a	Axial Strain (in/in)
é,	Radial Strain (in/in)
Et	Tangential Strain (in/in)
61	Principal Strain (in/in)
6 a	Axial Stress (psi)
C r	Radial Stress (psi)
Q <sup>*</sup>	Tangential Stress (psi)
σ1,2	Principal Stresses (psi)
щ	Poisson's Ratio (assumed to be 0.3)

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#### INTRODUCTION

This investigation represents the first phase of a thorough study of the stress distribution in two intersecting circular cylinders under internal pressure being undertaken by the California Institute of Technology. In this phase all specifications of the specimens were held constant except wall thickness. Two mild steel specimens were tested having an internal radius of 3.84 inches and wall thicknesses of 0.4 inches for the first specimen and 0.3 inches for the second.

An exact theoretical solution of this problem involves mixed boundary conditions and the attendant complexities, and therefore, has not been solved. Frior to the construction of the 20-inch supersonic wind tunnel at the Jet Propulsion Laboratory, California Institute of Technology, it had been assumed generally that for piping which is to be stressed tangentially up to a value allowed by the governing code. the safe procedure would be to furnish heavy ribs to take all bending stresses of the elliptical intersection. Analysis of the loading induced in the joints of that wind tunnel, however, indicated that axial stiffness of the pipe itself would materially aid in resisting the deformation of the elliptical intersection. This prompted the series of tests reported in Reference (a). The results of these tests were not conclusive, and the investigator recommended that a more thorough study be made. No other study of this problem could be found in the engineering publications and indexes available at the Galifornia Institute of Technology.

The tests reported herein were made in collaboration with Lieutenant Commander Vernon H. Teig, U. S. Navy in the Structures Laboratory, Guggenheim Aeronautical Laboratory, Galifornia Institute of Technology, Pasadena, Galifornia during the school year 1948-49.

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#### EQUIPMENT AND PROCEEDINE

The test specimens used in this investigation were made from two sections of eight-inch Mational Matra Strong Welded Steel Pipe, ASTM 53-47, having a yield point of 30,000 psi and an ultimate strength of 48,000 psi. These pipe sections were machined to the dimensions and uniformity shown in Figure 5. The axial dimension was made two and one half diameters to insure that the end effects would not interfere with the effects at the intersection. The sections were joined by welding so as to make minety degree elbows. Any excess weld metal was ground down so as to approximate an integral specimen of constant wall thickness machined out of a single billet.

The pipe ends were sealed with standard eight-inch welding caps containing a three-quarters inch threaded stud located on the centerline having a nut provided for attaching a restraint between the ends of the specimen. The restraint was not used in these tests, however. The studs were drilled and tapped to receive hydraulic fittings. Except for wall thickness, which was 0.4 inch for specimen I and 0.3 inch for number II, the specimens were identical in all respects.

A large pan was placed under the specimens to receive the oil upon rupture and to prevent the pan walls from interfering with the hydraulic fittings connected to the pipes, the specimen was cradled in blocks at points about six and sixteen inches from the ends of the specimen.

Surface strains were measured with variable resistance wire strain gages of the Baldwin-Southwark AR-7 and A-8 types. The positions of

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the active gages used in the tests are shown in Fig. 7.

Other equipment consisted of a potentiometer and Wheatstone's bridge circuit, a six-wolt battery, a Blackhawk hand-operated hydraulic pump, hydraulic pressure gage and miscellaneous plumbing and electrical wiring.

The set upsof the test equipment are shown in Figures 1 and 3.

The procedure followed in each test was identical. Within the elastic limit of the specimens, strain gage readings were recorded with the specimens alternately loaded and unloaded, thereby providing average zero readings for each set of load readings and indicating yielding in the specimens when the gage readings failed to return to their preload values. Above the yield point of the specimens, strain gage readings were recorded as before with the specimen alternately loaded and unloaded, but only the zero reading obtained after loading was used in computing strains. In this region of plasticity, however, at intervals, before proceeding to a higher load, strain gage readings were recorded at intermediate loads. Readings at zero load were not taken after these intermediate loads but only after a load was applied which exceeded the highest previous load on the specimen. In order to obtain good results in the region of high strains, internal pressure was held constant, until strain readings stopped increasing, before data was recorded.

The amount of opening of the legs was measured during and after the application of each load. The measurement was made with a tram

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bar between two punch marks made in the top of the stude located at the ends of the specimens. It was intended to report that portion of each test which was in the elastic range with the restraint applied across the legs to prevent bending. Since the amount of opening of the legs of each specimen was so small as to be unmeasurable in the elastic range, this portion of the intended investigation was abanoned.

#### RESULTS

The following results were obtained from the tests made on the two specimens described in EQUIPMENT AND PROCEDURE:

1. Stress and strain data recorded in Tables I to XVIII.

2. The loads resulting in yielding and rupture of the specimens were:

Internal Pressure (psi)

Rapture	Yield			
3350	1800	I	Specimen	e data da
2950	1200	II	Specimen	

- 3. Rupture occurred across the weld at a point about 14.7 degrees above the crotch in both specimens.
- The elliptical intersection was distorted into an egg shape with the broadest part of the egg on the crotch side of the elbow.
- 5. A visible area of cold-working was evident in the vicinity of the crotch of both specimens when high values of internal pressure were applied.

#### DISCUSSION

The data recorded during these tests were strain gage and battery voltage readings. In addition, the distance between two punch marks at the ends of the specimens (described in EQUIPMENT AND PROCEDURE) were measured. This distance did not change until immediately before rupture of the specimens.

The reduction of the strain gage readings taken within the elastic range into strains and stresses in the axial, tangential, and principal directions involved only the usual strain gage reduction equations and the classical elasticity equations for resolving stresses in a plane (see sample calculations). In the computation of stresses, a value of Young's Modulus of Elasticity equal to 30,000,000 psi and a value of Poisson's ratio of 0.3 were used.

In a uniform stress field, stresses and strains may be computed in the plasticity region from strain gage readings. This is possible because an elastic material strained beyond its elastic limit unloads and reloads along a curve parallel to the original curve of the material below the elastic limit. In a non-uniform stress field such as was present in the specimens tested, stresses can be computed only until the local yield point is reached. After any point in the specimen has yielded, all points in the specimen show strain when the applied load has been removed. For those points which have not reached their local yield point, these strains are due to residual stresses in the material set up by parts of the specimen which have taken on permanent set.

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Utilizing this fact, the value of all stresses and strains can be computed from strain gage readings until the local yield point is reached. For the tests conducted, no stresses were computed after first yield of the specimens were reached since it is considered that they do not contribute to the analysis of the problem under investigation at this stage. After local yielding, the determination of stresses are impossible using elasticity equations since it is not known what part of the zero-load strain is due to permanent set and what part is due to residual stresses. Since the theory of plasticity is in a nebulous stage, computations in this range have been left for later study.

As an assistance in analyzing the stresses and strains measured and computed in this investigation, the graphs shown in Figs. 10 through 49 were prepared.

Strain gage readings taken above the elastic limit of a specimen previously have been considered in general to be unreliable. The similarity of strain curves for the two specimens at the various positions investigated, and at positions on the same specimen but removed from the critical intersection (i.e. curves 1, 2, and 4 of Fig. 12), indicate that strain gage readings taken above the elastic limit can be trusted in a qualitative analysis. Since the mechanical and electrical properties of the strain gages are not known to a high degree of certainty in this range, however, the readings obtained are of unknown reliability in a quantitative analysis.

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Previous discussions of the intersection of circular cylinders under internal pressure have showed concern for the bending effects present. Results of this investigation do not indicate that the bending effects are of great relative importance. In tests of both specimens, no bending deformations were visible or measurable within the elastic range and were not of measurable magnitude in the plastic range until the load was increased to very nearly the rupture point. Furthermore, it is significant that the actual rupture of both specimens apparently was caused by tangential stresses despite the fact that specimen II had a tangential defect at the weld in the vicinity of the rupture point. This defect in specimen II was a small crack between the weld and the parent metal in the vicinity of the crotch. It opened visibly during the early stages of loading but eventual rupture was at right angles to this crack.

The classical equation for the tangential stress in a thickwalled cylinder under internal pressure is:

$$G_{t} = \frac{pa^{2}}{r^{2}} \frac{r^{2} + b^{2}}{b^{2} - a^{2}}$$

which in the case of a pipe having the dimensions of specimen II is:

Thus, for the second specimen

p yield = 
$$\frac{30,000}{12,3188}$$
 = 2,435 psi  
p ultimate =  $\frac{48,000}{12,3188}$  = 3,978 psi

The internal pressure causing yielding of specimen II was found experimentally to be 1200 psi, and of rupture to be 3350 psi.

In the case of specimen I:

p yield (straight tube - theoretical) = 3,288 psi
p yield (intersecting tubes - experimental) = 1,800 psi
p ultimate (straight tube - theoretical) = 5,261 psi
p ultimate (intersecting tubes - experimental) = 2,950 psi

The results of these tests, therefore, do not indicate "that welded pipe fittings can be designed with an ample safety factor against both excessive deformation and rupture, without the use of any ribbing and without increasing the thickness ratio of the fittings materially over that needed for plain pressure pipe", as was suggested in the conclusions of Reference (a,).

The deformation and point of rupture obtained with the "second specimen of 90 degree elbow made from seamless tubing, 4.5 inches 0.D. with 0.12 inch wall thickness", reported in Reference (a), shows close agreement with the results obtained in this investigation. Since other tests on the 90-degree elbow reported in Reference (a) showed apparent structural defects in the pipe from which the specimens were made, it is considered that the results obtained therefrom (which did not agree with the results obtained in this investigation) are unreliable, and lead to false conclusions if considered. Since yielding occurred at a load of approximately 54 per cent of the rupture pressure in the first specimen and at approximately 41 per cent of the rupture pressure in the second specimen, it is considered that limit design would be feasible in the construction of elbows similar to those tested where small permanent deformations could be tolerated. However, fatigue limitations to the theory of limit design must not be ignored.

The specimens used in this investigation were large and contained approximately eleven gallons of oil while tests were in progress. Large gravity effects were present, therefore, which may have had a considerable effect on stress distribution at low values of applied load. These gravity forces may cause highly undesirable bending effects when the specimen is supported by point reactions as was the case during these tests. These undesirable effects would be more in evidence in tests conducted on thinner-walled specimens, and it is recommended that for subsequent tests that a continuous support be provided.

Whereas experimental results obtained with the two specimens compared favorably in most respects, no explanation for the divergence of the axial strain curves of Figs. 29 and 30 can be offered. The divergence at these positions could be foreseen while data was being taken with the second specimen but no faulty techniques or instrumental failures were discovered. It is recommended that later phases of this investigation explore further the regions concerned.

#### CONCLUSIONS

The results of two tests are insufficient to indicate trends or establish facts as conclusive. The conclusions reached as a result of this investigation are, therefore, of such a nature as to require confirmation by subsequent continuation of this study. These conclusions are:

1. The maximum stresses present in specimens of the type tested are in the plane of the intersection and tangent to the ellipse of intersection at a point approximately fifteen degrees from the crotch. It is probable that when the legs of the specimen lie in the horizontal plane that the highest stress concentration is at an angle of approximately fifteen degrees <u>above</u> the crotch.

2. For two circular cylinders intersecting at right angles and acted on by internal pressure, the area in the vicinity of the intersection requires additional resistance to the high stresses present. For cylinders of about 8 inches internal diameter and 0.3 to 0.4 inches wall thickness, the wall thickness in the vicinity of the intersection should be increased approximately 100 per cent.

3. Bending associated with the stressing of two circular cylinders intersecting at right angles by the application of internal pressure appears to be of minor importance.

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#### RECOMMENDATIONS

It is recommended that:

1. In any further experimental work conducted on this problem, that strain gage rosettes be located near the weld 15 degrees above and below the crotch.

2. In any further experimental work conducted on this problem, that a continuous support be provided on the under side of the specimens.

3. In any further work conducted on this problem that an investigation be made of the apparently incongruous results obtained in these tests for the axial strains near the weld at the rear of the intersection.

 Further investigation be made of the bending present and of the effects of bending restraints.

# EQUATIONS AND SAMPLE CALCULATIONS A.REDUCTION OF STRAIN GAGE DATA

The test gage mounted on the specimen and a dummy gage mounted on identical, unstrained material are included in a Wheatstone Bridge



circuit. The opposite sides of the circuit are two precision resistances of magnitude Q.

Under load the potentiometer is varied so that no current flows between points A and B. We wish to determine the relation between the voltage V.

across  $\overline{\text{AB}}$  and the unit strain,  $\epsilon$ , in the test specimen.

From the circuit diagram, we determine that

 $I_1(2Q) = H$   $I_2(2R + \Delta R) = B$   $V = I_1Q - I_2R$ 

Hence

$$\mathbf{v} = \frac{\mathbf{E}}{2} - \frac{\mathbf{E}\mathbf{E}}{2\mathbf{E}\mathbf{F} \Delta \mathbf{R}} = \frac{\mathbf{E}}{4} \frac{\Delta \mathbf{E}}{\mathbf{R}} \left[ 1 + \frac{\mathbf{E}}{2\mathbf{R}} \right]^{-1} \approx \frac{\mathbf{E}}{4} \frac{\Delta \mathbf{R}}{\mathbf{R}}$$

To eliminate the ratio  $\Delta$  R/R, the following relation for resistivity of a conductor is employed.

$$R = K \frac{L}{A}$$

where K is a resistivity constant, L the length of the conductor, and A its cross-sectional area. Then

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Hence

$$\frac{\Delta \mathbf{R}}{\mathbf{R}} = \frac{\Delta \mathbf{L}}{\mathbf{L}} = \frac{\Delta \mathbf{A}}{\mathbf{A}}$$

For a cylindrical conductor

$$\frac{\Delta_{A}}{A} = 2 \frac{\Delta_{T}}{r} = -2 \sqrt{\frac{L}{L}} = -2 \sqrt{\epsilon}$$
 r is the radius of the cross section

Therefore

$$\frac{\Delta \mathbf{R}}{\mathbf{R}} = (1 + 2\mathbf{i})\mathbf{E}$$

♦ is the Poisson's ratio for the strain gage material.

Substituting directly into the equation for the voltage reading

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$$\overline{v} = \frac{\pi}{4} (1 + 2\sqrt{3}) \in$$

Hence

185

$$\epsilon = \frac{4\mathbb{Y}}{(1+2\sqrt{2})\mathbb{Z}}$$

This equation is usually employed in the form

where  $\epsilon$  is obtained in inches per inch times 10<sup>-3</sup>.

B. COMPUTATION OF STRAINS FROM STRAIN GAGE R'S (ROSETTES)



(a)  $\Delta \epsilon_1 = R_1 - \frac{1}{k} R_3$ (b)  $\Delta \epsilon_2 = 1.02 \epsilon_2 - \frac{1}{k} (R_1 + R_3)$ (c)  $\Delta \epsilon_3 = R_3 - \frac{1}{k} R_1$ 

where k = -200 for the rosettes used in these tests.

C. COMPUTATION OF AXIAL AND TANGENTIAL STRAINS

(a) 
$$G_a = \frac{E}{I - \mu^2} \left[ \epsilon_a + \mu(\epsilon_t) \right]$$
  
(b)  $G_t = \frac{E}{I - \mu^2} \left[ \epsilon_t + \mu(\epsilon_a) \right]$ 

D. CONFUTATION OF PRINCIPAL STRESSES

$$\sigma_{1,2} = \frac{E}{2(1-\mu)(1+k)} \left[ (R_1 + R_3) \pm \frac{(1-\mu)(1+k)}{(1+\mu)(1-k)} \cdot r \right]$$

where

$$Y = \left| \frac{R_1 + R_3 + 2R_2}{\sin 2\theta} \right|$$
  
tan 20 =  $-\frac{R_1 + R_3 - 2R_2}{R_1 - R_3}$ 

E. COMPUTATION OF PRINCIPAL STRAIN

$$\epsilon_1 = \frac{1}{E} (\sigma_1 - \mu \sigma_2)$$

## F. COMPUTATION OF STRAINS ABOVE ELASTIC LIMIT

Beyond the elastic limit, strains computed as above are but one component of the total strain. The other component is the strain remaining at a point with zero external load applied.

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## TABLE I

## VARIATION OF TANGENTIAL AND AXIAL STRAINS WITH VARIATION OF INTERNAL PRESSURE

Test I

Position #1

Gages 2,3

		— R —		≺	- de	>		4			4	∈ →
Press.	Axial	Tang.	Disg.	Arial	Tang.	Princ.	•	Princ.	Axial	Tang.	Axial	Tang.
500	.0430	.1133	-	.0436	.1135	-	-	-	2560	4170	.0436	.1135
750	.0645	.1416	-	.0652	.1419	-	-	-	3550	5320	.0652	.1419
1000	.0856	.1892	-	.0865	.1896	-	-	-	4725	7100	.0865	.1896
1250	.1068	.2381	-	.1080	.2386	-	-	-	5910	8930	.1080	.2386
1500	.1284	.2890	-	.1298	.2896	-	-	-	71.40	10830	.1298	.2896
1600	.1325	.3003	-	.1340	. 301.0	-	-	-	7400	11240	.1340	. 3010
1700	.1398	. 31.60	-	.1414	. 31.67	-	-	-	7800	11840	.1414	. 3167
1800	.1468	. 3335	-	.1485	. 3342	-	-	-	-	-	.1460	.7388
1900	.1546	. 3552	-	.1564	. 3560	-	-	-	-	-	.1704	.7403
2000	.1627	. 3856	-	.1646	. 3864	-	-	-	-	-	.2075	.7209
2050	.1674	. 3899	-	.1693	. 3907	-	-	-	+ 1	-	.2227	.7092
2150	.1809	.4807	-	.1833	.4816	-	-	-	-	-	.2449	.7873
750	.0616	.1480	-	.0623	.1483	-	-	-	400	-	.1239	4540
1700	.1420	. 3337		.1437	. 3344	-	-	-	-	-	.2053	.6401
2200	.1850	4263	-	.1871	.4356	-	-	-	-	-	.2581	7481
2300	.1941	4474		.1963	.4484	-	-	-	-	-	2861	.7438
2400	.1993	.4922	-	.2018	.4932	-	-		-	-	.2938	.8333
2500	.2135	.4801	-	.21.59	4812		-	-	-	- 1	.2953	.9880
2600	.0804	. 391.5	-	.0824	. 3955	-	-	-	-	-	. 3602	2.2024
2800	.2096	. 5993	-	.2126	.6003	-	-	-	-	-	.9139	4.1237
3000	.2146	.6726	-	.2161	.6937	-	-			-	1.1340	5.5106
3250	.2411	.7970	-	.2451	.7982	-	-	-	-	-	1.3111	6.8218

Pressures and stresses in lb./sq.in. Strains given in inches per inch x  $10^3$ 

## TABLE II

# Position #2

Gages 4,5,6

	*	-R-	>	4	- 16-	>			- o -		4-1	€>
Press.	Axial	Tang.	Diag.	Arial	Tang.	Princ.	0	Princ.	Axial	Tang.	Agial	Tang.
500	.0181	.1318	.0696	.01.88	.1319	.1322	2-42	4540	1889	4530	.01.88	.1319
750	.0234	.1908	.1052	.0244	.1909	.1909	0-39	6534	2690	6540	.0244	.1909
1000	.0305	.2693	.1489	.0318	.2694	.2690	0-15	91.89	3707	9177	.0318	.2694
1250	.0474	. 3300	.1780	.0480	. 3302	.3306	2-10	11382	4855	11340	.0480	. 3302
1500	.0576	.4050	.2194	.0596	.4053	.4058	1-58	13964	5973	13920	.0596	.4053
1600	.0522	.4300	.2360	.0543	.4303	.4302	0-47	14722	6045	14690	.0543	.4303
1700	.0531	.4600	.2510	.0554	.4603	.4601	0-47	15719	6380	15700	.0554	.4603
1800	.0580	.4807	.2619	.0604	.4810		-	-	-	-	.0546	.4994
1900	.0657	.4976	.2736	.0682	.4979	-	-		610	-	.0512	-5335
2000	.0644	.5211	.2866	.0670	.5214	-	-	-	-		.0448	.6029
2050	.0690	. 5319	.2935	.0717	. 5322	-		-	-	-	.0379	.6365
2150	.0608	. 5297	.2921	.0634	. 5300	-	-	-	-	-	.0191	.8161
750	.01.97	.2410	.1035	.0209	.2411	-040	-		-		0234	.5272
1700	.0528	.4400	.2409	.0550	.4403		-	-	weth	-	.0107	.7264
2200	.0693	.5643	.3106	.0721	.5646		-		-	-	.0302	.8649
2300	.0718	.4518	.2357	.0741	.4522	-		-	upper-	-	.0188	1.5388
2400	.0754	.5411	.2932	.0781	.5415	-	-		sills	-	.0171	2.1654
2500	.0878	. 5583	. 3058	.0906	. 5587	-	-				.0362	2.7001
2600	.0955	.6440	. 3646	.0987	.6445	-	-	-	-	-	0780	3.8779
2800	.1176	. 6682	.3796	.1209	.6688	-	-	**		-	2543	5.5926
3000	.1336	.8351	.4486	.1378	.8358		-	-	-	-	4013	7.8630
3250	.1358	.9513	.5011	.1406	.9520	-	-	-	-	-	4910	9.4319

Pressures and stresses in 1b./sq.in. Strains given in inches per inch x  $10^3$ 

Test I

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## TABLE III

# Position #3

Test I

Gages 7,8,9

	4	- R-	>		- se			4	- o -	~~	4	$\epsilon \rightarrow$
Press.	Axial	Tang.	Diag.	Axial	Tang.	Princ.	0	Princ.	Axial	Tang.	Axial	Tang.
500	-0.0127	0.1562	0.0623	-0.0119	0,1561	.1566	86-59	5041	1151	5025	-0.0119	0.1561
750	-0.0167	0.2350	0.0910	-0.0155	0.2349	.2362	85-54	7621	1813	7595	0155	0.2349
1000	-0.0161	0.3273	0.1320	0145	0.3272	. 3289	86-06	10684	2760	10650	0145	0.3272
1250	-0.0273	0.4080	0.1487	0253	0.4079	.4117	87-17	1.3286	3200	13200	0253	0.4079
1500	-0.0368	0.4970	0.1875	-0.0343	0.4968	.5002	85-28	16118	3775	1,6050	0343	0.4968
1600	0397	0.5420	0.2098	-0.0370	0.5418	-5446	85-57	17561	41.35	17500	0370	0.5418
1700	0487	0.5810	0,2221	-0.0458	0.5808	. 5836	86-01	18760	4235	18700	0458	0.5808
1800	0421	0.6126	0.2367	0390	.6124	-	-	-	-	-	2812	1.2756
1900	0007	0.5102	.2010	+ .0019	. 5102	-	-	-	-	-	4396	1.7756
2000	0641	0.7296	.2511	0605	.7293		-	-		-	7452	3.1196
2050	0600	0.6597	.2101	0567	.6594	-	-	-	-	-	7604	3.2577
2150	0648	0.7677	.2941	0610	.7674	-	-	-	-	-	-1.0346	5.3378
750	0176	0.2486	.1007	0164	.2484	-	-	-	eno-	-	9900	4.81.88
1700	0552	0.6031	.2356	0522	.6028	-	-	-	-	-	-1.0258	5.1732
2200	0888	0.8357	. 3172	0846	.8353	-	47875	-	w125-	-	-1.0363	5.3448
2300	0333	0.9655	. 3673	0285	.9653	-	-	-	-	-	-1.3724	8.2622
2400	0485	0,9982	. 3958	0435	. 9980	-	-	200	-	-	-1.8190	10.7686
2500	0661	1.0539	.4339	0608	1.0536	-	-	-	667	-	-2.2653	12.7903
2600	0889	1.1337	.4893	0832	1.1333	-	-	-	-	-	-2.9376	15.1911
2800	0841	NQ	. 5448	-	-	-	witte	-	400	-	-	-
3000	1180	NO	.6350		-	-	-	4104	-	-		-
3250	1311	MG	NG		-	-	-5359	-	-	-		-

Pressures and stresses in 1b./sq.in. Strains given in inches per inch x 103

## TABLE IV

Position #4

Test I

and the

# Oages 10,11,12

	-	-R-	<u> </u>	4	-2E-			4	— <b>σ</b> —		4	∊→
Press.	Axial	Tang.	Diag.	Axial	Tang.	Princ.	. 0	Princ.	Axial	Tang.	Axial	Tang.
500	.0369	.1582	.1411	.0377	.1.584	.1723	-17-51	5916	2805	5,590	.0377	.1584
750	.0565	.2183	.2070	.0576	.2186	.2443	-20-22	8369	4060	7,840	.0576	.2186
1000	.0748	. 3270	.2862	.0764	.3274	. 3533	-17-03	12148	5750	11,530	.0764	. 3274
1250	.0996	. 3977	. 3467	.1016	. 3982	.4274	-16-40	14808	7290	14,120	.1016	. 3982
1,500	.1150	.4890	4240	.1174	.4896	. 5257	-16-34	18136	8720	17,280	.1174	.4896
1600	.1502	. 5220	.4620	.1528	.5228	.5611	-17-04	19632	10190	18,710	.1528	5228
1700	0.1549	0.5520	0.4820	.1577	. 5528	. 5905	-16-28	20655	10650	19,780	.1577	.5528
1.800	.1429	.5841	.5168	.1458	.5848	-	1000	-	-	-	.1562	5833
1900	.1595	.6040	.5370	.1625	.6048	Main		-	egia		.1532	6169
2000	.1650	.61.64	. 5539	.1681	.6172	-	-	1000	-	-	1345	7743
2050	.1738	.61.33	. 5646	.1769	.6142	-	-	-		-	.1422	8531
2150	.1893	.6289	. 5878	.1924	.6298	-	-		-	-	.1570	1.3555
750	.0650	2287	.2057	.0661	.2290	-	-	-	-	-	.0302	0.9547
1700	1481	. 51.32	.4655	1507	51.39	-		- 480-	(10)		.1148	1,2396
2200	1944	.6584	. 5990	.1977	6554	-	-	-	-	-	.1725	1. 3850
2300	1821	5772	5305	.1850	5781	- 100	-	etter	-	-	-4297	2.0265
2400	.2165	.6072	-5714	.2195	.6083	with	-	-	-	-	.7248	2.7650
2500	2469	6392	.6210	2501	.6322	-	-	-		-	9061	3, 3265
2600	2667	.7040	.6368	.2702	.7053		-	-		-	1.0969	3,9296
2800	2931	.7206	6524	.2967	7221	495	-	-	-		1. 5359	5,2937
3000	3268	.7730	.6833	. 3307	.7746	-	-		-	-	2.1318	6.9961
3250	.3630	.8555	.6837	.3673	.8573	-	-	-	-	-	2.6431	8.6785

Pressures and stresses in 1b./sq.in. Strains given in inches per inch x  $10^3$ 

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## TABLE V

# Position #5

# Gages 13,14,15

		— R –	~~>	<> ∆ €>					- r-		4	6-7
		Along	Normal									•
Press.	Arial	Weld	to Weld	Arial	Tang.	Princ.	0	Prine.	Arial	Tang.	Axial	Tang.
500	0.2150	0.1288	0.2170	0.2210	0.1293	.2344	66-45	8847	8474	6420	0,2210	.1293
750	0. 3265	0.1955	0.3286	0.3356	0.1970	. 3555	67-01	13415	12816	9758	. 3356	.1970
1000	0.4380	0.2633	0.4440	.4503	0,2655	.4783	66-31	18070	17306	13158	.4503	.2655
1250	0.5324	0.3163	0.5420	.5473	. 3190	. 5834	66-16	21,996	21076	15892	.5473	. 3190
1500	0.6515	0.3854	0.6590	0.6698	. 3887	.7120	66-43	26814	25634	19350	.6698	. 3887
1600	0.7020	0.4150	0.7140	0.7216	.4185	.7694	66-19	28979	27748	20880	.7216	.4185
1700	0.7370	0.4330	0.7580	0.7576	.4343	.8128	65-32	30596	29381	21917	.7576	.4343
1800	0.7797	0.4558	0.7959	.8016	.4599	-	-		-	-	.8933	.4476
1900	0.8272	0.4849	0.8498	.8504	.4892	-	-		-000	-	1.1027	.4711
2000	0.8738	0.5068	0.8907	.8983	.5115	-		-	•	-	1,3280	.4510
2050	0.8844	0.5203	0.9001	.9092	. 5249	-	-	-	-	-	1.4455	.4866
2150	0.9243	0. 5438	0.9376	.9502	.5486	-	-	where-	-	-	1.8839	.6597
750	0. 3123	0.1795	0. 3096	. 3209	,1811		-	-	-		1.2546	.2922
1700	0.7164	0.4150	0.7269	.7364	.4187	-	-	-	-	-	1.6701	. 5298
2200	0.9250	0. 5356	0.9381	.9509	.5404	-	-	-	-	-	1,9229	.6762
2300	0.9648	0, 5649	1.0095	.9920	. 5700	-	-	-	-	-	2.9586	1.1058
2400	1.0026	0.5841	1.0292	1.0307	.5615	-	-	-	-	-	3.6251	1.3387
2500	1.0108	0.5920	1.0229	1.0391	.7058	-	-		-250	-	4.2130	1.7047
2600	1.0683	0.6175	1,0510	1.0980	. 6229	-	-	-	-	-	5.0013	1.8820
2800	1.0585	0.6775	1.0585	1.0884	. 6829	-	-	-	-	-	6.8464	2.4601
3000	1.0871	0.7703	1.0629	1,1180	.7770	-	-	-	-	1.	8.9184	2.9686
3250	1.1626	0.9040	1.0636	1,1956	.9095	-	-	-	-	- 1	10,7605	3. 5506

Pressures and stresses in 1b./sq.in. Strains given in inches per inch x  $10^3$ 

Test I

### TABLE VI

#### Position #6

### Gages 16,17,18

5 ∆€-R  $-\epsilon \rightarrow$ Arial Axial Axial Tang. Diag. Ax1a1 Tang. Princ. e Princ. Tang. Tang. Press. .2045 500 -.0101 .2050 .0429 -.0091 .2045 .2180 13-28 6970 1725 6650 -,0091 .0408 -.0112 .3054 . 3371. 16-47 10691 2650 9950 . 3054 750 -.0127 .3055 -,0112 -.0141 0.4170 0.0554 -.0120 .4169 .461.5 17-04 14655 3730 13640 -.0120 .4169 1000 1250 -.0126 0.5090 0.0717 .5089 .5627 17-03 17920 4700 16690 -.0101 . 5089 -.0101 20470 17-14 22012 .6234 1500 -.0126 .6235 .0873 -.0095 .6234 .6907 5850 -.0095 6450 22100 -.0059 17-20 23780 .6720 1600 -.0093 0.6720 0.0959 .6720 .7450 -.0059 661.0 .7099 1700 0.7100 0.0987 -.0126 .7099 .7862 17-11 25042 23270 -.0126 -.0162 0.7495 0.1074 .7494 . 6988 1800 -.0126 .0332 -,0089 --1900 0.8001 0.1144 .8001 .0883 .8339 -.0073 -.0033 -1,0209 2000 0.8535 0.1308 .0099 .8535 .2527 .0056 0.1434 .2884 .8756 2050 0.8551 .0096 .8551 .0053 -.9247 .6063 1.8557 21,50 .0260 0.9246 0.1562 .0306 -750 .0063 .2957 .0547 .0078 .2957 .5835 1,2267 ---.1281 .8018 .6050 1.7328 1700 .0253 .8017 .0293 ---.9469 .9467 .1609 .0442 . 5930 1.9099 2200 .0395 ----1.3146 3.8451 2300 1.0085 .1958 .0682 1.0088 .0632 ---.1246 1.8874 .1191 1,1058 5.2142 2400 1,1052 .2224 ----2500 .1674 1.1740 .2418 .1733 1.1748 2.2353 6.2563 --2.5718 1.2382 7.4738 2600 .2271 1,2371 .2678 .2333 ---2.9714 9.8491 .3148 1.3137 .3051 . 3214 1.3153 2800 ---. 3416 .3900 2.7935 12.0549 . 3834 1.3148 1.3167 3000 -100 -.3779 3250 . 3106 NG . 3106

Pressures and stresses in 1b./sq.in. Strains given in inches per inch x 10°

Test I

# TABLE VII

# Position #7

# Gages 19,20,21

	*	Along	Normal	<del>~ _</del>	— se -	$\rightarrow$		<del>~</del>	J	$\rightarrow$	4	€→
Press.	Axial	Weld	to Weld	Axial	Tang.	Princ.	Ð	Prine,	Arial	Tang.	Arial	Tang.
500	.0700	0385	.0868	.0716	0381	.1015	-63-06	2823	2479	-399	.0716	0381
750	.1045	0615	.1253	.1069	0608	.1451	-63-55	4090	3518	-770	.1069	0608
1000	.1340	0818	.1759	.1372	0809	.2019	-62-06	5594	4983	-931	.1372	0809
1250	.1732	1040	.2082	.1772	1029	.2488	-64-00	6779	5827	-1339	.1772	-,1029
1500	.2276	1344	.2633	.2328	1386	. 3206	-64-42	8681	7469	-1917	.2328	1386
1600	.2382	1400	.2780	.2437	1442	. 3368	-64-30	9144	7901	-1957	.2437	1442
1700	.2477	1452	.2900	.2534	1438	. 3508	-64-30	9534	8113	-1881	.2534	1438
1800	.2549	1508	. 3186	.2608	1492		-	-	-	-	. 3051	1899
1900	.2690	1542	.3344	.2753	1525	-	-	-	-	-	. 3469	2175
2000	.2753	1650	.3544	.2817	1633	-	-	-	-	-	.4062	3066
2050	.2941	1581	. 3635	. 3010	1500	-	-	-	-	-	.4235	31.59
21.50	. 3064	1632	. 3728	. 3135	1614	-	-	-	-	-	.4603	4078
750	.1011	0599	1220	.1034	0623	-	-		-	-	.2502	3087
1700	-2411	0599	2942	2471	0584	-	-	-	-	-	. 3939	3048
2200	3175	1641	- 3826	. 2249	1622	-	-	-	-	-	.4706	4109
2300	3123	1560	3890	. 3197	1520	-	-	-	-	-	.4601	5308
2400	3228	- 1614	4048	. 3304	1595	-	-	-	-	-	4598	-,6319
2500	3268	- 1598	4109	3346	1578	-	-	-	-	-	1973	-, 7219
2600	3380	1544	.4311	260	1523	-	-	-	-		-5333	- 8354
2800	3486	- 1458	4686	3572	- 1435	-	-		-		6613	-1-0814
3000	3630	- 1373	51 38	3722	- 1344	-	-	-		100	7255	-1.3275
3250	.4287	1021	.5800	.4397	0991	-	-	-	- 3	+ 62	.8197	-1.4149

Pressures and stresses in lb./sq.in. Strains given in inches per inch x  $10^3$ 

Test I

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- Salation

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## TABLE VIII

## Position #8

Gages 22&23

	4	— R—	>	۲	- 46-	>			- o		4-	E->
Press.	Arial	Tang.	Diag.	Axial	Tang.	Prine.	0	Prine.	Axial	Tang.	Axial	Tang.
500	.0058	0613	-	.0058	0613	.0058	0	-415	-415	-1965	.0058	0613
750	.0054	0875	-	.0054	0875	.0054	Ó	-686	-686	-2832	.0054	0875
11000	.0018	1263	-	.001.8	1263	.0018	0	-1190	-1190	-4148	.001.8	1263
1250	.0118	1675	800	.0118	1675	.0118	0	-1266	-1266	-5407	.0118	1675
1500	.0218	1956	-	.0218	1956	.0218	0	-1216	-1216	-6235	.0218	1956
1600	.0352	21.00	-	.0352	-,2100	.0352	0	-916	-916	-6574	.0352	2100
1700	.0419	2280	-	.0419	-,2280	.0419	0	-874	-874	-71.02	.0419	-,2280
1800	.0417	2425	-	.0417	2425	-	-	-		-	.1019	2680
1900	.0474	-2563	-	.0474	2563	-	-		-	-	.1.469	2941
2000	.0597	2696		.0597	2696	-	-		-	-	.2184	3303
2050	.0640	2696	-	.0640	- 2696	-	-	-	-	-	.2329	3382
21.50	.0720	2891	-	.0720	2891	-	-	-			. 3098	3850
750	0003	0825	-02567	0003	0825	-	-	-	-	-	.2375	1784
1700	.0283	2000	-	.0283	2000	-	-	-	-	-	.2661	2959
2200	.0646	2606	-	.0646	2606	489	-	-	-		. 3148	3556
2300	.0789	2942	-	.0789	2942	-	-	-	-	-	.4184	4651
2400	.0903	3029	-	.0903	3092	-	-	-	-		.5437	-,6020
2500	.1060	3259	-	.1060	32.59	-	-	-	-	-	.7146	8523
2600	.1161	3248	-	.1161	32.48	-	-	-	with	-	.7247	8512
2800	.1401	3318	-	.1400	3318	-	-	-	-	-	.9385	-1.2150
3000	.1855	3549		.1855	3549	-	-	-	-	-	1.1440	-1.7719
32.50	.2273	3218	-	.2273	3218		-	-	-	-	1.2880	-2.0626

Pressures and stresses in lb./sq.in. Strains given in inches per inch x  $10^3$ 

Test I

## TABLE IX

## Position #9

Test I

		- R-	>	4	- se-	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~		4	- J-		4	£>
Press.	Axial	Tang.	Diag.	Arial	Tang.	Princ.	÷	Prine.	Axial	Tang.	Axial	Tang.
500	0.0468	0.2245	-	0.0468	0.2245	0.2245	090	7860	3762	7860	-0468	.2245
750	0.0646	0.3290		0.0646	0.3290	0.3290	090	11,500	5385	11500	.0646	. 3290
1000	0.0585	0.4560		0.0585	0.4560	0.4560	090	1,5600	6440	1.5600	.0585	.4560
1250	0.1178	0.5720	. 🝝	0.1178	0.5720	0.5720	090	20000	9535	20000	.1178	. 5720
1500	0.1340	0.6980	-	0.1340	0.6980	0.6980	090	24300	11320	24300	.1340	. 6980
1600	0,1235	0.7580		0.1235	0.7580	0.7580	090	26200	11560	26200	.1235	.7580
1700	0.1310	0.8120	-	0.1310	0.8120	0.8120	090	28050	12350	28050	.1310	.8120
1800	0.1441	0.8602	-	.1441	0.8602		augu-	-	-	-	.1246	1.0058
1900	0.1366	0.9786		.1366	0.9786	-	-	-	-	-	.1843	2.01.39
2000	0.1198	1.0962	-	.1198	1.0962			-		-	.2643	3.7938
2050	0.1084	1.1037	-	.1084	1.1037		-	-	-	-	. 3632	4.1425
21.50	0.1140	1.1909	-	.1140	1.1809	-	-	-	-	-	.5995	6.6369
750	0.0346	. 3310	-	.0346	. 3310	-	-	-	-	-	. 5201	5.7870
1700	.0958	.8170	-	.0958	.8170	-	-	-	-	-	. 5813	6.2730
2200	.1198	1.0619	-	.1198	1.0619		-	-	-	-	. 5911	6.3979
2300	.0827	NG	-	.0827	-	-	-	-	etto	-	.9537	
2400	.1373	NO	-	.1373	-		-	-	-	-	1.1481	-
2500	.1609	NG	-	.1609		-	-	-	-	-	1.1530	-
2600	.1669	NO	-	.1669	-	-		-	-		1.0149	-
2800	.1644	NO	-	.1644	-	-	-	-	-	-	.4478	
3000	.1006	MO		.1006	-		-		-	-	2094	-
3250	.0175	NG		.0175	-	-	-	-	-	-	6431	-

Pressures and stresses in lb./sq.in. Strains given in inches per inch x  $10^3$ 

20

Gages 1-24

#### TABLE NO.X

## VARIATION OF TANGENTIAL AND AXIAL STRAINS WITH VARIATION OF INTERNAL PRESSURE

Test II

#### Position #1

Gages 2,3

	+	-8-			-26-		*	4	- r			€->
Press.	Axial	Tang.	Diag.	Axial	Tang.	Princ.	0	Princ.	Axial	Tang.	Axial	Tang.
400	.0600	.1385		.0670	.1388	-	-	-	3580	5239	-0670	.1388
600	.0815	.1970	-	.0825	.1974		-	-	4672	7326	.0825	.1974
800	.1142	.2680	-	.1155	.2686		-	-	6465	9996	.1155	.2686
1000	.1376	. 3298	-	.1392	.3305			-	7860	12275	.1392	. 3305
1100	.1535	. 3677	-	.1553	. 3685	-	-	-	8767	13686	.1553	.3685
1200	.1657	.4020		.1677	.4028	-	-	-	-	- 10 Mar	.1795	. 38 31
1250	.1724	.4182	-	.1745	.4191	-	-	-	-	1 m	.1905	. 3906
1300	.1848	.4316	-	.1870	.4325	4925	450	-	-	-	.2070	. 3978
500	.0705	.1632	-	.0713	.1636	-	-	les:		sab	.0913	.1289
900	.1254	. 3019	-	.1269	. 3025	-	sit			-	.1469	.2678
1400	.1940	4794		.1964	.4804	with "	-	-	409	-	.2531	. 3806
1600	.2226	. 5814	-	.2255	.5825		-in	-	-	-	.3474	.3389
600	.0869	.2171	-	.0880	.2175	-	-		-	-	.2099	0261
1200	.1718	.4421	-	.1740	.4430	-	-		-	-	.2959	.1994
1800	.1989	.6038	100	.2019	.6048		-	440	-	-	.6174	1.7911
2000	.2622	.8185	-	.2663	.8198	-	-	-	-	100	1.1349	4.1168
2200	.2623	.9078	-	.2668	.9091	-09	-		such	-	1.4475	6,6002
2400	.2727	1.0532	-	.2780	1.0546		-			-	1.7004	9.4359
2600	,2848	1.1135	-	2904	1.1149	-	-	-		-	1.8471	12.5249
2800	.2852	NO	-	-	-				- '	-		

Pressures and stresses in lb./sq.in. Strains given in inches per inch x 103

## TABLE XI

## Position #2

Gages 4.5.6

		-R-	~	4	-06-	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~		4	-0-		4	$\epsilon \rightarrow$
Press.	Axial	Tang.	Diag.	Axial	Tang.	Prine.	0	Princ.	Arial	Tang.	Axial	Tang.
400	.0112	.1296	.0739	.0118	.1297	.1296	-1-28	4401	1672	4392	.0118	.1297
600	.0172	.1824	.1164	.0181	.1825	.1841	-5-41	6234	2404	6195	.0181	.1825
800	.0228	.2475	.1564	.0240	.2476	.2497	-5-21	8450	3241	8401	.0240	.2476
1000	.0284	. 3047	.1918	.0299	. 3048	.3070	-5-11	10397	3999	10346	.0299	. 3048
1100	.0307	.3374	.2152	.0324	.3376	.3408	-5-45	11524	4408	11450	.0324	. 3376
1200	.0358	. 3708	.2357	.0377	. 3710	-	-	Kand	ADDING		.0247	. 3668
1250	.0375	. 3804	2408	.0394	. 3806	-	-	-	-	-	.0246	.3797
1300	.0375	. 3944	.2456	.0395	. 3946	-	-	-	-		.021.6	. 3968
500	.0140	.1506	.0941	.01.48	.1507	-	-	-	68	-	0031	1529
900	.0253	.2773	.1742	.0267	.2774	-	-		-		.0088	.2796
1400	.0392	.4182	.2618	.0413	.4184	-	-	-	-	-	.0087	.4508
1600	.0443	.4806	. 3925	.0467	.4808	-		-	-		01.48	. 6006
600	.0166	.1751	.1109	.0175	.1752	-	-	-	-		0440	.2950
1200	.0296	.3525	.2184	.0314	. 3526	-	-	-100	-	-	0301	.4724
1800	.0653	. 5121	. 3289	.0679	.5124	-	-	-	-	-	0584	.7023
2000	.0794	.6330	.4089	.0826	.6334		-	-		-	2413	4.3461
2200	.1129	.7303	.4958	.1166	.7309		-	-	vitam	-	5001	6.8078
2400	1365	.8720	.5836	.1409	.8727	-	-	-	-	-	6110	9.2633
2600	.1419	.9022	.61.38	.1464	.9029	-			-	-	6156	11.1987
2800	.1772	.9618	. 6995	.1820	.9627	-	-	-	-	-	5345	12.4117

Pressures and stresses in 1b./sq.in. Strains given in inches per inch x  $10^3$ 

Test II

# TABLE XII

# Position #3

# Gages 7.8.9

		-R-	<del>~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~</del>		- DE-			4	-0-	>	4	€>
Press.	Axial	Tang.	Diag.	Axial	Teng.	Prine.		Prine.	Axial	Tang.	Arial	Tang.
400	0145	.1962	.0762	0135	.1961	.1972	+86-02	6356	1491	6334	0135	.1961
600	-,0211	.2798	.1095	0197	.2797	.2811	+86-14	9058	2117	9027	0197	.2797
800	0284	.3848	.1515	0265	.3847	. 3863	+86-19	12459	2931	12420	0265	- 3847
1000	0386	.4796	.1862	0362	.4794	.4819	+86-13	15504	3548	15446	0362	.4794
1100	0446	.5384	.2080	0419	.5382	-5410	+86-12	17394	3943	17329	0419	.5382
1200	0475	.6036	.2287	- 0445	.6034	-	3 <b></b>	804	-	-	1597	.8508
1250	0545	.61.86	.2355	0514	.6183	-100	-	-	-	-	2109	1.0195
1,300	0588	.6543	.2466	0555	.6540	-	-	-	-	-	- 31 37	1.3860
500	0186	.2354	.0948	0174	.2353	40%	-	-	-	-	2756	.9673
900	0386	.4492	.1706	0364	.4490	-	-	-	-	-	2946	1,1810
1400	0652	.7153	.2831	061.6	.7150	-	-	-	-	-	-,8225	3.1558
1600	1002	.9984	. 3850	0952	.9979		-	-		-	-2.0917	8.4310
600	0303	.3196	.1352	0287	. 3194	-	645	-	4507	-	2.0252	7.7525
1200	0583	.6458	.2583	0551	.6455	-	-	**	-	-	-2.0516	8.0786
1800	1563	NO	.4931	-	-	-	-	-	-	-	-	
2000	- 1540	NG	.3516	-	-	4950	NUTUR	-	489	-	-	-
2200	1809	NO	.7002	-	1918 esta	-	-	-	-00-	-		-
2400	2214	NO	.8117	-	-		-	-	104	-	-	100
2600	1979	IIG	NO	-	-		-	103	wight	-		-
2800	0874	MG	NG		2016	-	-	1 ett)	-	AR .	-	400
		5.0	/			term to	inches		$h = 10^{3}$			

Pressures and stresses in 1b./sq.in. Strains given in inches per inch

Test II

## TABLE XIII

## Position #4

Gages 10,11,12

		-R-		4	- DE-	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~			- 5-		4	E-+
Press.	Axial	Tang.	Diag.	Axial	Tang.	Princ,	. 0	Prine.	Axial	Tang.	Axial	Tang.
400	.0366	.1817	.1698	.0375	.1819	.2038	-19-57	6873	3036	6366	.0375	.1819
600	.0567	.2586	.2441	.0580	.2589	.2907	-20-18	9844	41574	9110	.0580	.2589
800	.0729	. 3511	. 3267	.0747	. 3515	. 3925	-19-46	13273	5938	12327	.0747	. 351.5
1,000	.0924	.4308	.4087	.0946	.431.3	.4860	-20-30	16418	7385	15156	.0946	. 431.3
1100	.1023	.4780	.4473	.1047	.4785	.5354	-19-58	18124	8186	16811	.1047	.4785
1200	.1162	. 5226	.4847	.1188	.5232	-	-	-		4	,1022	. 51.48
1250	.1212	.5345	.4993	.1239	.5351		-		-		.1017	. 5217
1300	.1259	.5470	.5117	.1286	.5476	-	-	-		-	.0998	. 5286
500	.0462	.2125	.1975	.0473	.2127	- 00	-	-	-	-	.0185	.1937
900	.0864	. 3890	. 3411	.0883	.3894		-	-	-	-	.0595	. 3704
1400	.1404	. 5819	.5403	.1433	.5826	-	-	-	-	-	.0795	.5115
1.600	.1927	.6107	. 5701	.1958	.6117	-	-	-	-	-	-,0536	. 5417
600	.0649	.2404	.2171	.0661	.2407	4000	-	-	-	-	- 1833	.1707
1200	.1375	.4740	.4328	.1399	.1747	-		-		-	1095	.4047
1800	.2279	.6714	.5814	.2313	.6725	-	-	-		-	.6633	2.4305
2000	. 3182	.7103	.5727	. 321.8	.7119	-	-150	-	400	-	1.6984	4.8164
2200	.3792	.8006	. 5930	. 3832	.8025	-489	-	-	-	-	2.5154	7:0360
2400	.4330	.9358	.6742	.4377	.9380	-	-	-		-	3-5395	9.9191
2600	.4897	1.0230	.6909	.4958	1.0254			-	-10	-	4-8255	13.2397
2800	.5078	1.0089	.7735	.5128	1.0114	-	-	-	-	-	6.9492	18,8651

Pressures and stresses in lb./sq.in. Strains given in inches part 103

Test II

#### TABLE XIV

# Position #5

Gages 13,14,15

		-R-	>	4	- 36-	>		4	-σ-			$\epsilon \rightarrow$
Press.	Axial	Tang.	Diag.	Axial	Tang.	Princ.	0	Princ.	Arial	Tang.	Arial	Tang.
400	.2625	.1332	.2447	.2632	.1345	.2783+	72-02	10356	10010	7039	.2632	.1345
600	. 3728	.1923	. 3520	3738	.1942	. 3841 -	71-32	14481	14246	10099	.3738	.1942
800	.5032	.2584	.4749	.5045	.2609	.5364+	71-13	19950	19215	13594	. 5045	.2609
1000	.6292	. 3195	. 5919	. 6308	. 3226	.6625 +	71-24	24900	23989	16874	.6308	- 3226
1100	. 6909	. 3459	.6490	.6926	- 3494	.7364+	71-26	27302	26290	18371	. 6926	. 3494
1200	.7570	. 3778	.7105	.7589	. 381.6	<b>c</b> 70	-	42	800	482	.9014	3298
1250	.7700	. 3827	.7258	.7719	- 3866	-	-	5.000 C		-	.9568	. 3201
1300	.7945	. 3898	.7434	.7964	. 3938	-	-	-		-	1.0488	. 3248
500	. 3039	.1523	.2876	. 3047	.1538	-	-	482		-	.5571	.0848
900	.5576	.2826	.5277	.5590	.2854	4000	et	190	-	-	.8114	.2164
1400	.8687	.4258	.8154	.8708	.4301	4550	-000	49.9	-		1,4479	. 3315
1600	.9385	.4719	.8862	.9409	.4766	<b>100</b>	-	60	-	100	3,0029	. 5085
600	. 3329	.1861	. 3163	. 3338	.1878	100	-	-	-	-	2.3958	.2197
1200	.6525	. 3559	.6259	.6543	. 3592	-	-	-		-	2.7163	. 3911
1800	.9330	. 5298	.8630	.9356	.5345			-	-		4.7072	.8899
2000	.9076	. 5814	.8339	.9105	. 5859	-	1000	-		-	6.2507	1.0764
2200	.9146	.7028	.8174	.9181	.7074	-	-	-	-	-	8.7857	1.6676
2400	.9861	.8362	.8385	.9903	.8411	-	-	enero		400	11.6937	2.8194
2600	1.0498	.9176	.9190	1.0544	.9228		120	4503	-	-	14.6300	4.8068
2800	NG	.9635	.9618	4000-			ditta	0001	-	-		-

Pressures and stresses in lb./sq.in. Strains given in inches per inch x  $10^3$ 

114

Test II

#### TABLE XV

## Position #6

Gages 16,17,18

		- R-			- 46-			4	-0-		4	$\leftarrow \rightarrow$
Press.	Axial	Tang.	Diag.	Axial.	Tang.	Prine.	. 0	Prine.	Arial	Tang.	Axial	Tang.
400	0112	.2513	.0228	0099	2512	.2833	+18-16	8924	2160	8183	0099	.2512
600	0327	. 361.6	.0356	0309	.3614	. 3997	+16-35	12493	2555	11609	0309	. 3614
800	0234	.4904	.0492	0209	.4903	.5494	+17-50	17320	4161	15957	0209	.4903
1000	0271	.6189	.0588	0240	.6188	. 6962	+18-09	21949	5328	20164	0240	.6188
1100	0267	.6813	.0670	0233	.6812	.7663	+18-10	24192	5971.	22228	0233	.6812
1200	0239	.7516	.0764	0201	.7515	easter	sett	-	1000		.0675	.9130
1250	0236	.7700	.0807	0198	.7699	-	-	estr	-	-	.1160	-9642
1300	0156	.8065	.0871	0116	. 3064	-		-	-	-	.1944	1.0455
500	0123	. 3002	.0269	0108	. 3001	-	atib	-	-	100	.1952	.5392
900	0200	.5619	.0592	0172	.5618	100	-	-	-	401	.1888	.8009
1400	.0063	.9046	.1094	.01.08	.9046	-	-	-	sijen	-	.5171	1.5374
1600	.0998	1.1515	.1934	.1056	1.1520		-	-	-		2.1334	5.4698
600	.0223	0.3995	.0636	.0243	. 3996		-	-		-	2.0521	4.7174
1200	.0383	0.7923	.1262	.0423	.7925		-	-	-		2.0701	5.1103
1800	.1779	1.3328	.2289	.1846	1.3337	-	-		-	-	2.6365	10,6465
2000	.2632	1.4870	.2820	.2706	1.4883	100	man	-		-	2.9129	16.1530
2200	. 3718	NG	. 31.26	-		- 1004	-0158	-		-	-	-
2400	.4696	NG	. 3324	-	-	- 100	-		180	-	**	
2600	. 5635	NG	.2928	4889	atte	4005	ess	mitr	-160	-670		-
2800	.6793	NO	.1957	-	-	-	-	-	-	-	-	-

Pressures and stresses in 1b./sq.in. Strains given in inches per inch x  $10^3$ 

Test II

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AL5

## TABLE XVI

## Position #7

Gages 19,20,21

		- <u>k</u>		-	de-			4	- <u></u> - <u></u> -	->		e->
Press.	Axial	Tang.	Diag.	Axial	Tang.	Prine.	0	Princ.	Axial	Tang.	Axial	Tang.
400	0066	0336	.0425	-,0068	0336	.0435-	- 38-55	- 605	-557	-1174	0068	0336
600	0112	0475	.061.4	0114	0476	.0626 -	39-21	- 862	-847	-1681	0114	0476
800	0175	0640	.0822	0178	0641	.0836 -	39-29	-1118	-1220	-2288	0178	0641
1000	0224	0759	.1013	0228	0760	.1026-	-39-58	-1391	-1503	-2730	0228	0760
1100	0244	-,0838	.1132	0248	0839	.1147 -	39-58	-1570	-1648	-3010	0248	0839
1200	0242	0896	.1218	0246	0897			-	1000		0298	1084
1250	0269	0860	.1236	0273	0861		-	-	-	-	0318	1169
1300	0276	0930	.1269	- 0281	0931	-	-	40	-	-	0316	1277
500	0103	0359	.0109	0105	0360	-	-	-	400	estr	0140	0706
900	0203	0678	.0938	0206	0679	-	-	-	-	-	0241	1025
1400	0333	1031	.1334	0338	1033		-	-	4555	-	0387	1686
1600	0493	0998	.1394	0498	-,1000		-		-	-	0634	2847
600	0156	0389	.0509	01.58	0390	-	-	-	-	-	0294	2237
1200	0413	0802	.1015	0417	0804	-	-	-	-	-	0553	2651
1800	0743	1020	.1379	0748	1024	-	with	-	-	-	2306	4977
2000	1085	0854	.1229	1089	0859	400	-	-		****	4937	7576
2200	1139	0573	.1440	1142	0579	-10	-	-	-	-	8624	9176
2400	1261	0255	.1821	1262	0261	-			-	-	-1.0256	8471
2600	1211	.0154	.2083	-,1210	.0148	-			-	-	-1.1384	6243
2800	0847	.0710	.2546	0843	.0706	-	-	-		-	-1.5323	1973

Pressures and stresses in lb./sq.in. Strains given in inches per inch x  $10^3$ 

Test II

A16

# TABLE XVII

Position #8

Gages 22 6 23

	-	-R-		-	- &-	$\rightarrow$		4	- r		-	<>
Press.	Axial	Tang.	Diag.	Axial	Tang.	Prine.	0	Prine.	Axial	Tang.	Axial	Tang.
400	0390	0307	-	0390	0307	0307	-	-	-1.589	-1398		0307
600	0579	0432	-	0579	0432	0432		-	-2338	-1998	0579	0432
800	0730	0597		0730	0597	0597	-	-	-2997	-2690	0730	0597
1000	0934	0741	-	0934	0741	0741	-	vete	-3811	-3366	0934	0741
1100	-,1023	-,0801	-	1023	0801	0801	-	-	mli164	~3653	1023	0801
1200	-,1083	0856	-	1083	0856	-	-	-	-		1270	0846
1250	- 1145	-,0896	-	1145	0896		-	uder.		-	1355	0848
1300	-,1171	0918	-	- 1171	0918	with	-	-	1000	-	1370	~.0833
500	0443	0353	4005	0443	0353	-	-	-	with-	949	0642	0268
900	0868	0674		0868	0674	-		-	-	-	1067	0588
1400	1255	0963	4010	1255	0963	ette	·	-	-188	-	1465	0732
1600	1479	0923		1479	0923	-	aip			-	2295	0248
600	0635	0361	-	0635	0361	-	-10	-	-	-	1451	.0314
1200	1248	0754	-	1248	0754	-	-510	-	eb.	-	2064	0079
1800	1697	0787	40	1697	0787	-	-	ama	-	-	3453	.3800
2000	1945	0733	-	1945	0733	-	ete	-	wite	-	4368	0032
2200	1808	061.0	eta	1808	0610	-	-	-	-	-	-, 61.09	.0402
2400	1527	0502	-	-,1527	0502	-	-	-	-	-	7606	.1.302
2600	1447	0276	-	- 1447	0276	-	-	+	-		9359	2580
2800	1137	0113	-	1137	0113	utte:	-	-		-	-1.2371	.5097

Pressures and stresses in lb./sq.in. Strains given in inches per inch x  $10^3$ 

Test II

A17

## TABLE XVIII

## Position #9

Gages 1 & 24

		— R —			- 46-	~~>		-	- J-		-	6
Press.	Axial	Teng.	Diag.	Axial	Tang.	Prine.	0	Princ.	Axial.	Tang.	Axial	Tang
400	.0379	.2609		.0379	.2609	.2609	-	-	3831	8978	.0379	260
600	.0586	. 3790	-	.0586	.3790	. 3790	-	<b>电动</b>	5681	13076	.0586	379
800	.0790	.5128	-	.0790	.5128	. 51.28	-	400-	7675	17688	.0790	. 512
1000	1023	.6519		.1023	.6519	.651.9	-	V (1000)	9822	22505	.1023	.651
11.00	.1174	.7238	-	.1174	.7238	.7238	662m	-	11028	25024	.1174	.723
1200	.0953	.8185	-	.0953	.8185	1	-	-	eteo	-	.2061	1,196
1250	.0911	.8575	-	.0911	.8575	sight	-	-	-	-	.2821	1.442
1300	.0774	.9016	-	.0774	.9016	-	0.000	wide.	-	683	.4146	1.894
500	.0483	. 3181	Keep	.0483	. 3181	and a	- 660	autor -	-	1000	. 3855	1, 310
900	.0890	.6071		.0890	.6071	-	400	-	sip	-	. 4262	1.599
1400	.1186	1.0540	need.	.1186	1.0540	woode		-	-	-	.81.26	4.139
1600	.1198	NG	-	.1198		-	mille	- augh	-	dilb	1.3072	-
600	.0375	NQ	and it	.0375		1045	-		-	-	1.2249	-
1200	.0563	NG	-	.0563			-	-	-	-	1.2437	-
1800	.1484	NO	most	.1484	-	-	-		-rah	1000	1.4052	-
2000	.0664	NG	-	.0664	1945	-	-			-	.7650	2565
2200	.0468	NG	-	.0468			4965	eath	enger	•	0689	<b>(11)</b>
2400	0429	NG	and.	0429	544		estito	-		-	7222	674
2600	0440	NG	-left:	0440	1.000		4105	-	units	-	7927	
2800	- 0856	NG	-	0856	-	-	-		-	-	-1.0672	•

Pressures and stresses in 1b./sq.in. Strains given in inches per inch x  $10^3$ 

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Test II

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i i TABLE NO. XIX Relation of load to p.  $\frac{R}{t}$ Test I:  $\frac{R}{t} = \frac{3.84}{.4}$  9.6 Test II:  $\frac{R}{t} = \frac{3.84}{.3}$  12.8

Test I

Test II

P	p.s	р	P.t
500	4800	400	5120
750	7200	600	7680
1000	9600	800	10240
1250	12000	1000	12800
1500	14400	1100	14080
1600	15360	1200	15360
1700	16320	1250	1.6000
1800	17280	1300	16640
1900	18240	1400	17920
2000	19200	1600	20480
2050	19680	1800	23040
21.50	20640	2000	25600
2200	21120	2200	281.60
2300	22080	2400	30720
2400	23040	2600	33280
2500	24000	2800	35840
2600	24960		
2800	26880		
3000	28800		
3250	31200		

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Fig. 1 First specimen and test setup.

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Fig. 2 Closeup view of first specimen showing rupture.

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Fig. 3 Second specimen and test setup.

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Fig. 4 Closeup view of second specimen showing rupture.







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# FIG. 7

<u>LOCATION</u> OF STRAIN GAGES TESTS I AND II

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FIG.9

ORIENTATION OF STRAIN GAGES, TEST I

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