EVALUATION OF TENSION SPLICE DESIGNS USED IN ROOF TRUSSES

by

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ABSTRACT

EVALUATION OF TENSION SPLICE DESIGNS USED IN ROOF TRUSSES

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Tension splices used in conventional roof trusses were analyzed and tested to verify the existing analysis and existing designs. Based upon the analytical results, test specimens were strain gaged at calculated critical locations and tested to failure. Points of critical stress and modes of failure were determined. The adequacy of the analytical procedures and present designs were compared to the test results and recommendations were made for modifications. Based upon the recommended modifications, newly designed specimens were tested to failure.

ACKNOWLEDGEMENTS

The author would like to extend his warmest thanks to everyone who helped in the completion of this thesis. Special thanks goes out to Dr. Jack D. Bakos, my advisor, who helped me immensely in this work; to Mr. Ramesh Patel who aided me as my partner in the laboratory work necessary to complete this thesis; also to the Manufacturing Division of the Republic Steel Corporation for their donation of the test specimens.

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LIST OF SYMBOLS

SYMBOL	DEFINITION	UNITS OR REFERENCE
P	Applied axial force	kips
P_2	Bolt force	kips
w	Uniform force ordinate developed at plate contact area	kips/in.
ℓ	Length of plate contact area	in.
P_1	Resultant force of the contact area reaction	kips
E	Modulus of elasticity	kips/in.^{2}
G	Shear modulus of elasticity	kips/in.^{2}
I	Moment of inertia	in.^{4}
A	Cross sectional area	in.^{2}
L	Length of the bolt	in.
δ	Deformation	in.
$\bar{y}$	Distance to the centroid	in.
f	Stress	kips/in.^{2}
M	Moment	kips-in.
c	Distance to the neutral axis	in.

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CHAPTER I

INTRODUCTION

The objective of this thesis is to study the reliability of tension splice connections used in the bottom chords of a long span trusses, i.e., spans over 40'; the 40' limitation primary because this is the longest span that can be trucked. This type of connection has been designed primary for ease in shop fabrication in the jig and for ease in field erection.

The major problem is that the force in the chords does not act at the center of gravity of the splice plate. Hence, the splice plate is subjected to considerable bending. The problem is to determine the amount of bending & reduce it if possible.

The following steps have been used in this project:

1. Analysis and calculations.
2. Test for adequacy and check computations in currently used splice plates.
3. Recommendations for modification.
4. Retest of modified samples.

Because the step between theory and actual results is made difficult by the theoretical assumptions used in the equations, the results will never reach perfection; these results can, however, under proper fabrication techniques, be brought within a resonable limit of error.

CHAPTER II

ANALYTICAL PROCEDURE

Two bolts connection:

The basis for the calculation of forces acting on the plate of the connection shown in Figure 2.1 is based on the fundamental equilibrium equations:

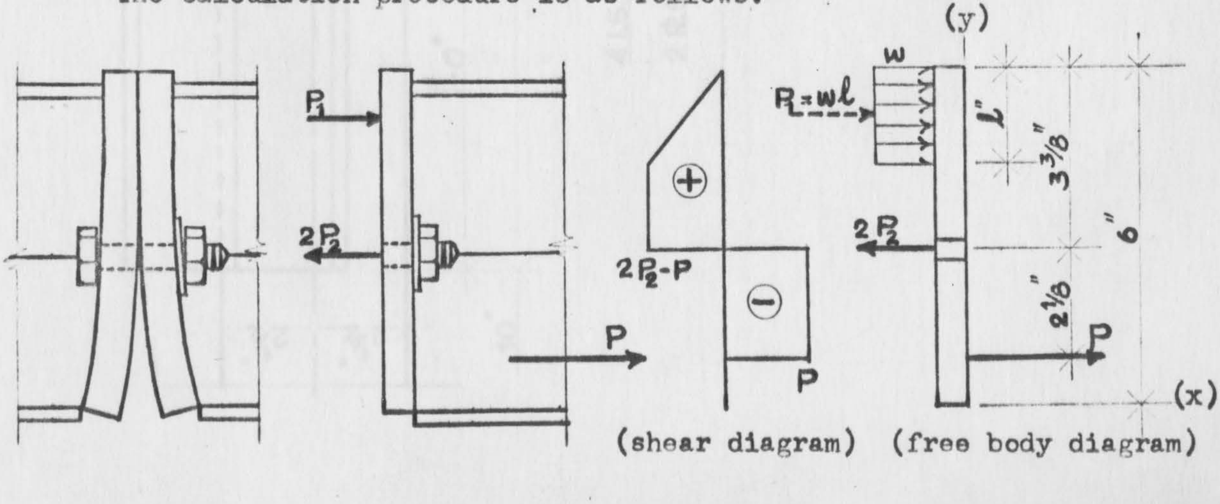
$$\sum F = 0$$
$$\sum M = 0$$

Compatibility of deflection yields another equation used to solve for the unknown forces. This equation exists due to the fact that the deflection of the plate at the bolt position is equal to the deformation of the bolt. Note that all forces are calculated in terms of axial force in the angles.

Also included in the theory are the following assumptions:

1. The weight of the members can be neglected.
2. The surfaces of the splice plates are smooth.
3. The contact force required to maintain equilibrium in the plate is assumed to be uniform. In other words, the opposite plate creates a uniform reaction over the contact area, see figure below.

The calculation procedure is as follows:



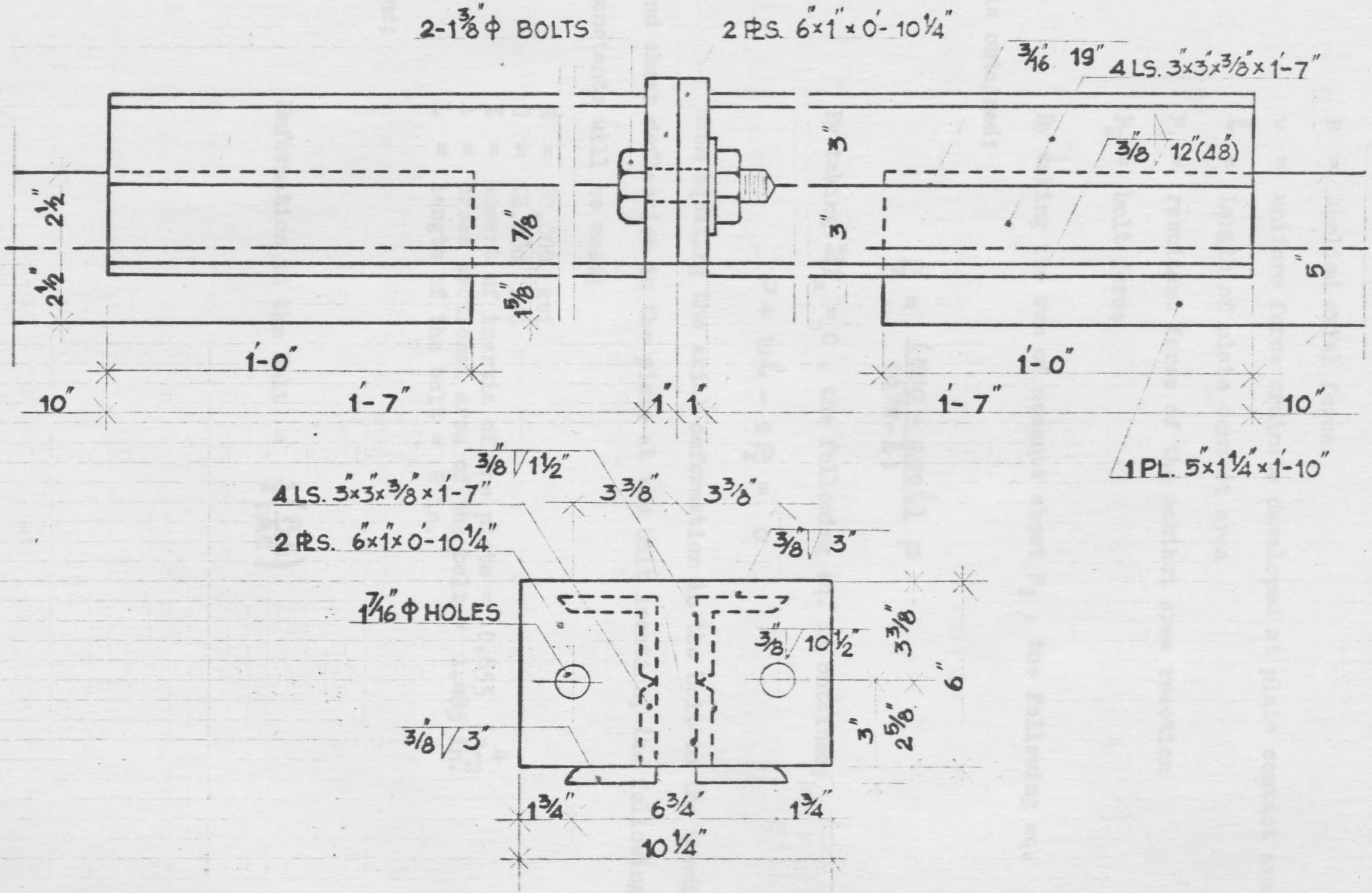


FIG. 2.1 DETAILS OF TWO BOLTS SPECIMEN

in which

P = applied axial force

w = uniform force ordinate developed at plate contact area

ℓ = length of plate contact area

P_1 = resultant force of the contact area reaction

P_2 = bolt force

By taking the sum of moments about P_1 , the following eq. is obtained;

$$P_2 = \frac{(5.50 - 0.50\ell)}{(6.75-\ell)} P \qquad (1)$$

By taking $\Sigma F_x = 0$, the following eq. is obtained;

$$P + w\ell - 2P_2 = 0 \qquad (2)$$

When equating the axial deformation in the bolt to the bending and shear deflection in the plate at the bolt location, the following constants will be used;

E = 30,000 ksi
G = 12,000 ksi
I = moment of inertia of the plate = 0.855 in.^{4}
A = cross sectional area of the bolt = 1.485 in.^{2}
L = length of the bolt = 2 in.

and;

$$\text{Deformation in the bolt} = \frac{1}{2}\left(\frac{P_2 L}{AE}\right)$$

To find the deflection in the plate, Castigliano's second theorem [4]* is applied as follows;

$$\delta_{BENDING} = \frac{1}{EI}\left\{\int_0^{3\frac{3}{8}-l}\left[P(2\tfrac{1}{8}+x) - 2P_2x\right](-x)\,dx + \int_0^{l}\left(\frac{4.25}{11.0l-l^2}\right)\left(\frac{2.125}{11.0l-l^2}\right)(2P_2)\frac{x^4}{2}\,dx\right\}$$

$$= \frac{1}{EI}\left[-1.063P(3.375-l)^2 - \left(\frac{P-2P_2}{3}\right)(3.375-l)^3 + \frac{1.806\,P_2 l^3}{(11.0-l)^2}\right]$$

$$\delta_{SHEAR} = \frac{1}{AG}\left\{\int_0^{3\frac{3}{8}-l}(2P_2-P)\,dx + \int_0^{l}\left(\frac{4.25}{11.0l-l^2}\right)^2(2P_2)x^2\,dx\right\}$$

$$= \frac{1}{AG}\left[(2P_2-P)(3.375-l) + \frac{12.05\,P_2 l}{(11.0-l)^2}\right]$$

Now, δ in the bolt = δ due to bending + δ due to shear

Thus,

$$P_2 = \left[\frac{103.4 - 69.4l + 15.4l^2 - 1.1l^3}{121.7 - 89.0l + 23.4l^2 - 2.3l^3 + \dfrac{60.3l + 6.3l^3}{(11.0-l)^2}}\right]P \qquad (3)$$

Equating Eq.(1) = Eq.(3), the following is obtained;

$$\frac{103.4 - 69.4l + 15.4l^2 - 1.1l^3}{121.7 - 89.0l + 23.4l^2 - 2.3l^3 + \dfrac{60.3l + 6.3l^3}{(11.0-l)^2}} - \frac{5.50 - 0.50l}{6.75 - l} = 0$$

By trial and error method,

$$l = 1.34 \text{ in.}$$

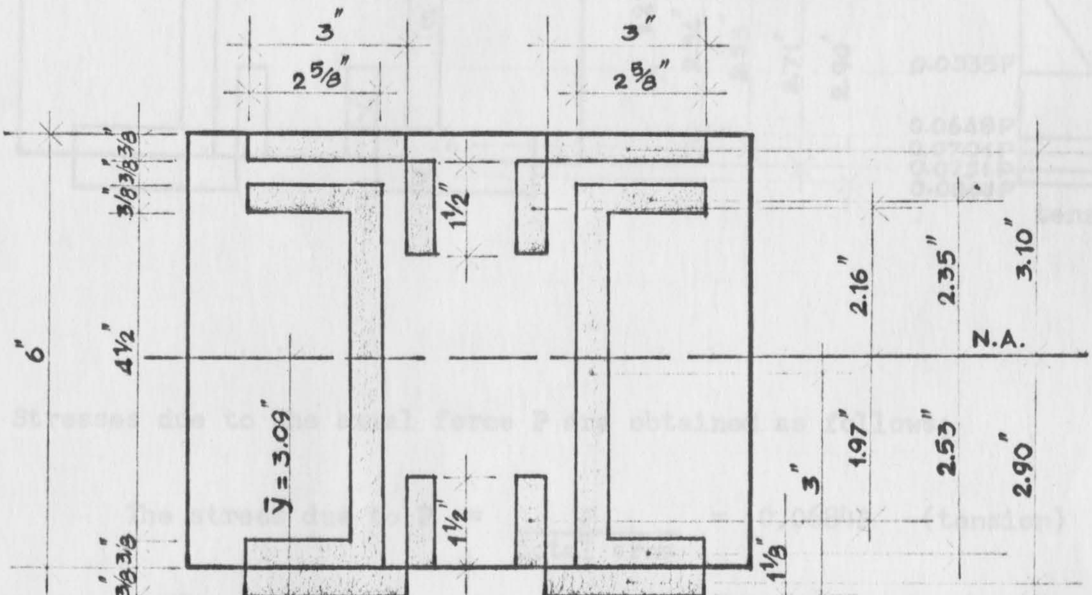
Substituting the value of l in Eq.(1) and Eq.(2), the values of P_2 and w are obtained;

$$P_2 = 0.893P \text{ kips}$$
$$w = 0.586P \text{ kips/in.}$$

The next step is to find the forces acting in the welds. If these forces are known, the complete free body diagram as well as the moment diagram of the plate can be drawn.

Using the Figure shown below, the first step is to find the centroid and moment of inertia of the weld group. Using techniques outlined in any steel design text [1]* or [2]*, the following is obtained:

1. centroid $\bar{y}$ = 3.09 in.
2. moment of inertia (I) = 79.916 $in.^4$

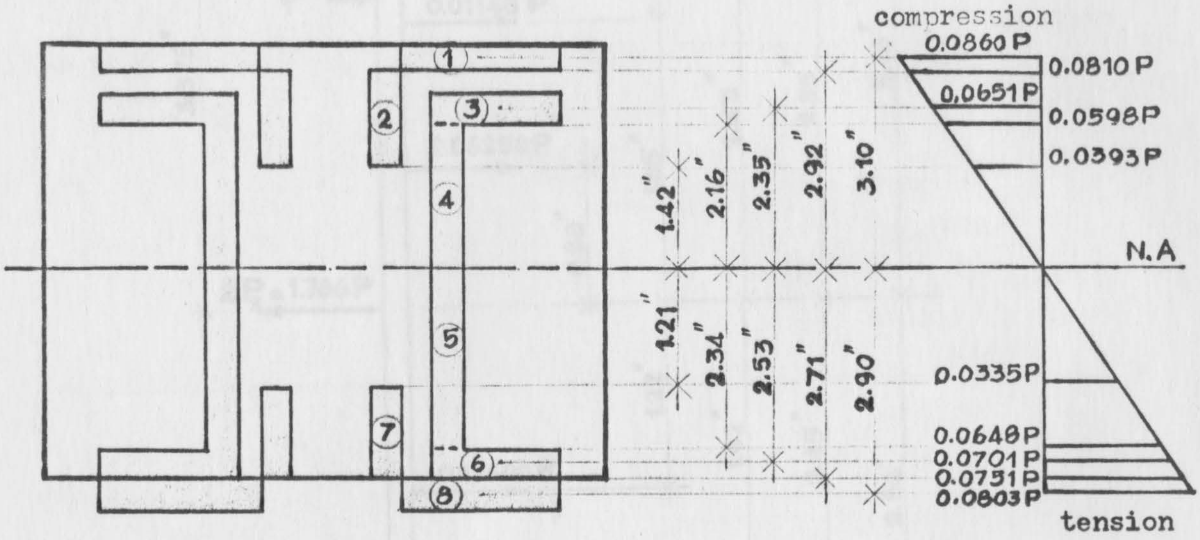


Since the force does not act at the centroid of the weld group, there will be a couple of moment equal to P(3.09 - 7/8) or 2.215P acting. Thus, the stresses in the welds can be determined as;

$$f = \frac{P}{A} \pm \frac{Mc}{I}$$

* Numbers in brackets indicate reference cited.

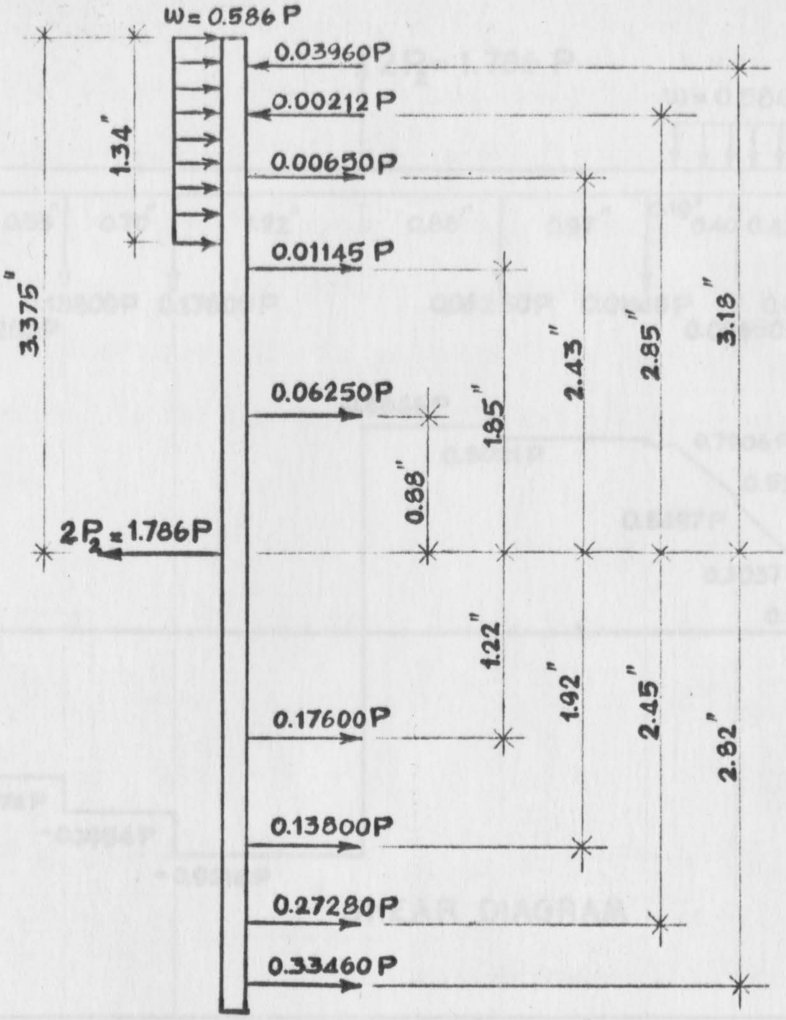
Stresses from the flexure portion of this interaction formula are shown on the Figure below;



Stresses due to the axial force P are obtained as follows;

$$\text{The stress due to P} = \frac{P}{\text{total area}} = 0.0684P \quad \text{(tension)}$$

Combining the stress due to the axial force and due to flexure according to the above expressed interaction formula, the combined effect shown on the following free body diagram is obtained along with the forces obtained previously. Thus, a complete free body diagram is obtained.



Checking;

Summation of forces = 1.82772P - 1.77655P
= 0.05117P (error = 2.8 %)

Summation of moments at ($2P_2$) = 2.2250P - 2.2170P
= 0.0080P (error = 0.3 %)

The complete shear and moment diagrams are shown in Figure 2.2

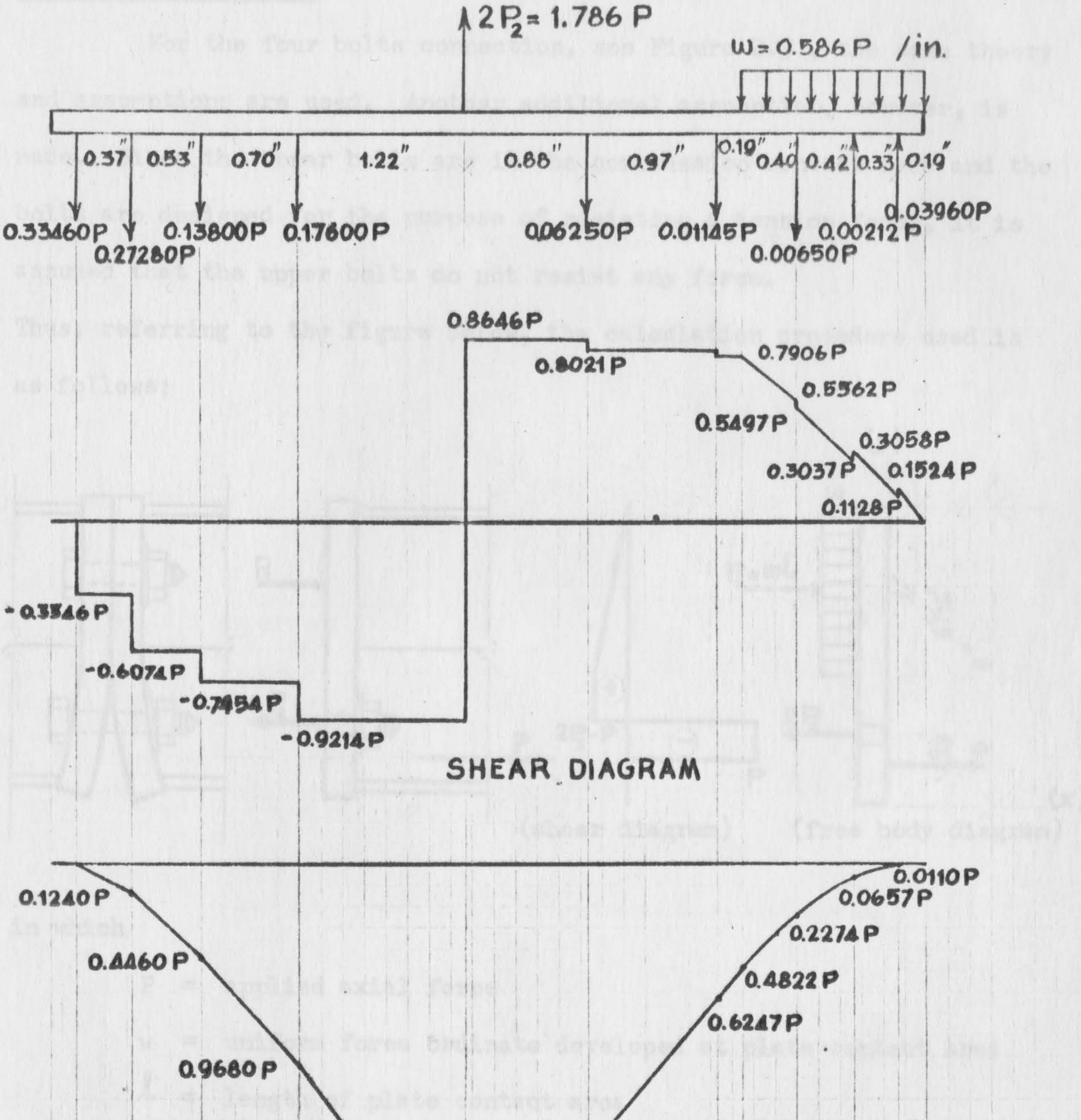
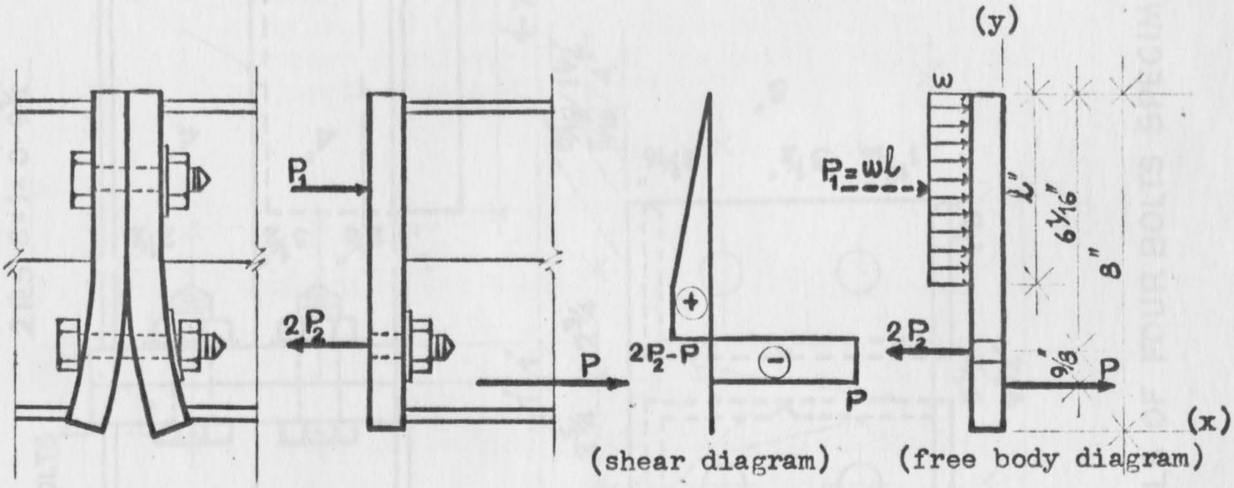


FIG. 2.2 SHEAR AND MOMENT DIAGRAMS OF TWO BOLTS SPECIMEN

Four bolts connection:

For the four bolts connection, see Figure 2.3 , the same theory and assumptions are used. Another additional assumption, however, is made. Since the upper bolts are in the compression contact area and the bolts are designed for the purpose of resisting a tension force, it is assumed that the upper bolts do not resist any force.

Thus, referring to the figure below, the calculation procedure used is as follows;



(shear diagram) (free body diagram)

in which

P = applied axial force

w = uniform force ordinate developed at plate contact area

l = length of plate contact area

P_1 = resultant force of the contact area reaction

P_2 = bolt force

By taking the sum of moments about P_1 , the following eq. is obtained;

$$P_2 = \frac{(7.18 - 0.50\,l)}{(12.12 - l)}\,P \qquad (1)$$

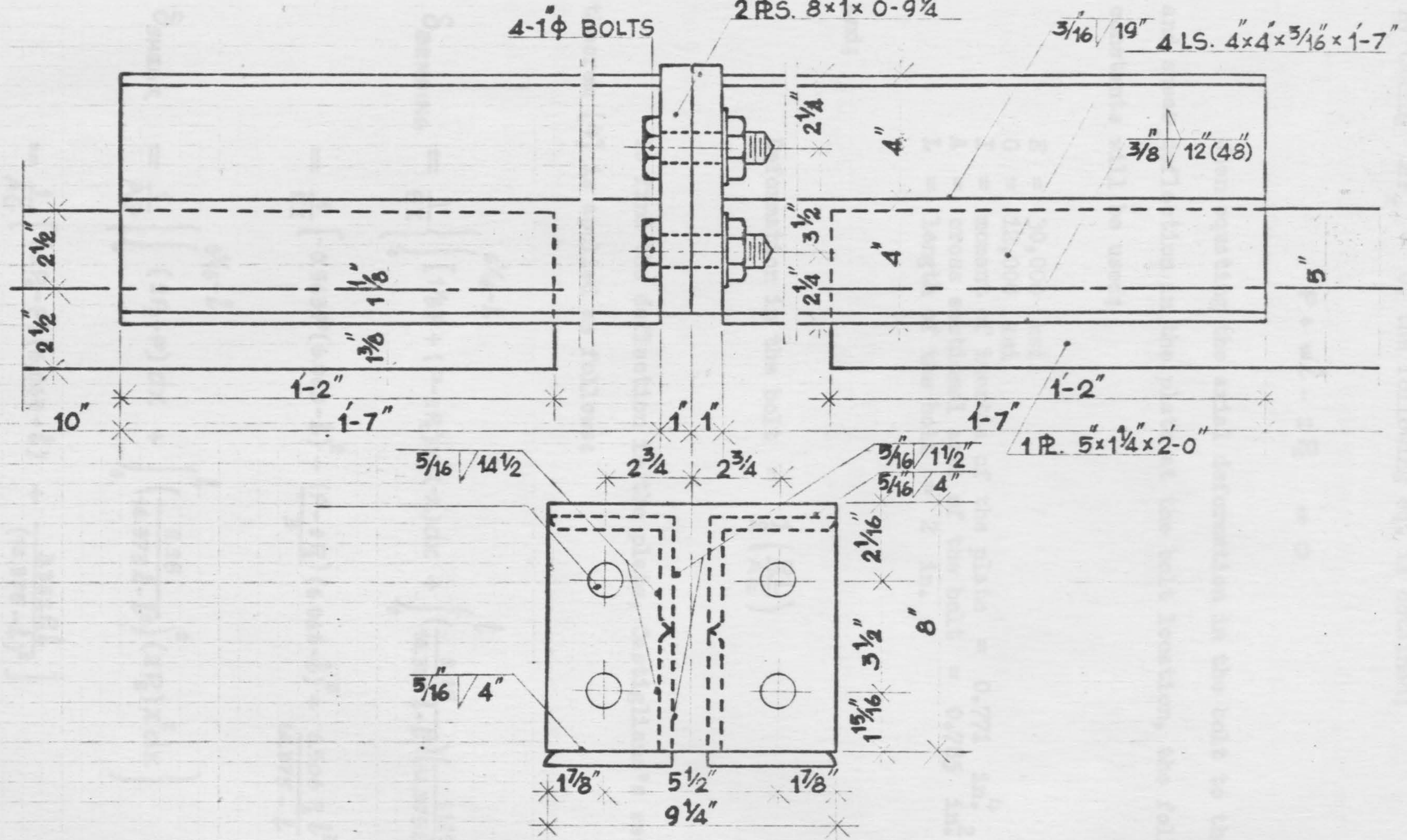


FIG. 2.3 DETAILS OF FOUR BOLTS SPECIMEN

By taking $\Sigma F_x = 0$, the following eq. is obtained;

$$P + w\ell - 2P_2 = 0 \qquad (2)$$

When equating the axial deformation in the bolt to the bending and shear deflection in the plate at the bolt location, the following constants will be used;

E = 30,000 ksi
G = 12,000 ksi
I = moment of inertia of the plate = 0.771 $in.^4$
A = cross sectional area of the bolt = 0.785 $in.^2$
L = length of the bolt = 2 in.

and;

Deformation in the bolt = $\frac{1}{2}\left(\frac{P_2 L}{AE}\right)$

To find the deflection in the plate, Castigliano's second theorem [4] is applied as follows;

$$\delta_{BENDING} = \frac{1}{EI}\left\{\int_0^{6\frac{1}{16}-\ell}\left[1\tfrac{1}{8}P+(P-2P_2)x\right](-x)\,dx + \int_0^{\ell}\left(\frac{2.25}{14.375\ell-\ell^2}\right)\left(\frac{1.125}{14.375\ell-\ell^2}\right)(P_2x^2)x^2\,dx\right\}$$

$$= \frac{1}{EI}\left[-0.563P(6.063-\ell)^2 - \frac{(P-2P_2)}{3}(6.063-\ell)^3 + \frac{0.506\,P_2\ell^3}{14.375-\ell}\right]$$

$$\delta_{SHEAR} = \frac{1}{AG}\left\{\int_0^{6\frac{1}{16}-\ell}(2P_2-P)\,dx + \int_0^{\ell}\left(\frac{2.25}{14.375\ell-\ell^2}\right)^2(2P_2)x^2\,dx\right\}$$

$$= \frac{1}{AG}\left[(2P_2-P)(6.063-\ell) + \frac{3.382P_2\ell}{(14.375-\ell)^2}\right]$$

Now,

$$\delta \text{ in the bolt} = \delta \text{ due to bending} + \delta \text{ due to shear}$$

Thus,

$$P_2 = \left[\frac{222.32 - 93.40\ell + 13.45\ell^2 - 0.67\ell^3}{359.65 - 159.00\ell + 24.60\ell^2 - 13.50\ell^3 + \dfrac{16.91\ell + 1.03\ell^3}{(14.375 - \ell)^2}} \right] P \qquad (3)$$

Equating Eq.(1) = Eq.(3), the following is obtained;

$$\frac{222.32 - 93.40\ell + 13.45\ell^2 - 0.67\ell^3}{359.65 - 159.00\ell + 24.60\ell^2 - 13.50\ell^3 + \dfrac{16.91\ell + 1.03\ell^3}{(14.375 - \ell)^2}} - \frac{7.18 - 0.50\ell}{12.12 - \ell} = 0$$

By trial and error method,

$$\ell = 4.47 \text{ in.}$$

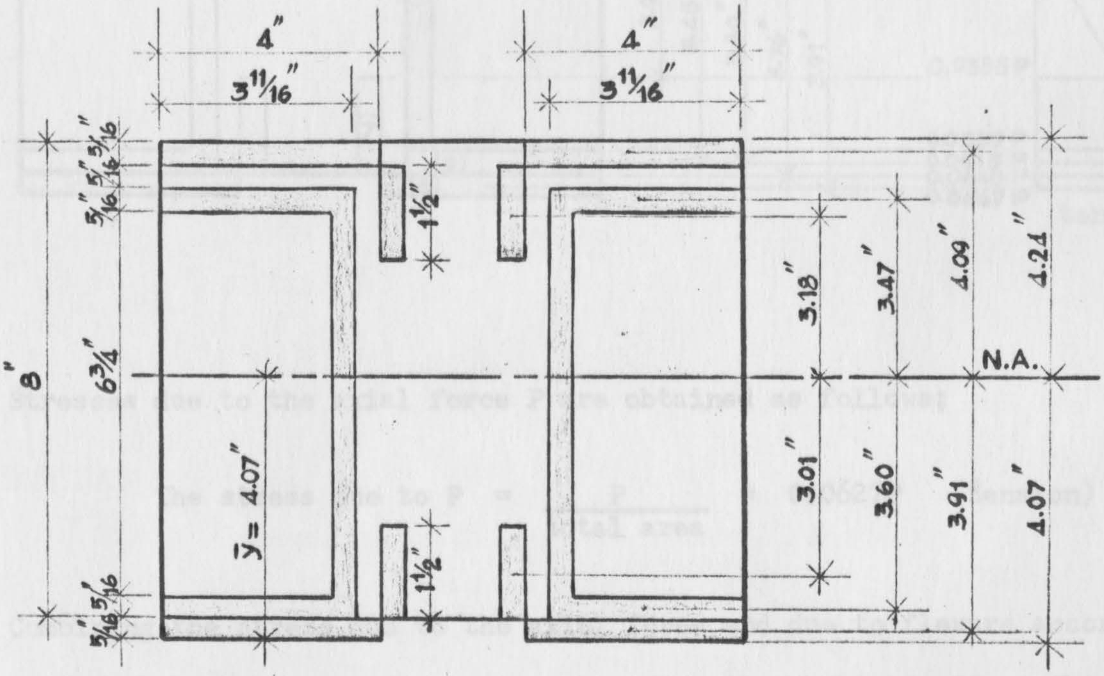
Substituting the value of ℓ in Eq.(1) and Eq.(2), the values of P_2 and w are obtained;

$$P_2 = 0.646P \text{ kips}$$
$$w = 0.0653P \text{ kips/in.}$$

The next step is to find the forces acting in the welds. If these forces are known, the complete free body diagram as well as the moment diagram of the plate can be drawn.

Using the Figure shown below, the first step is to find the centroid and moment of inertia of the weld group. Using techniques outlined in any steel design text, the following is obtained:

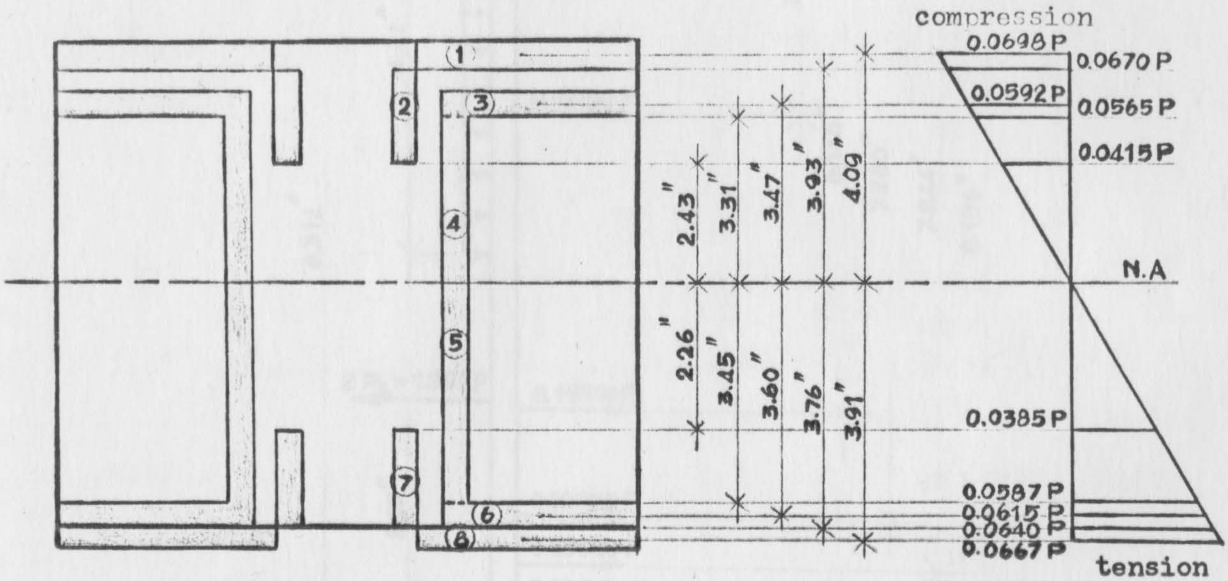
1. centroid $\overline{y}$ = 4.07 in.
2. moment of inertia (I) = 172.83 $in.^4$



Since the force does not act at the centroid of the weld group, there will be a couple of moment equal to P(4.07 - 1.125) or 2.945P acting. Thus, the stresses in the welds can be determined as;

$$f = \frac{P}{A} \pm \frac{Mc}{I}$$

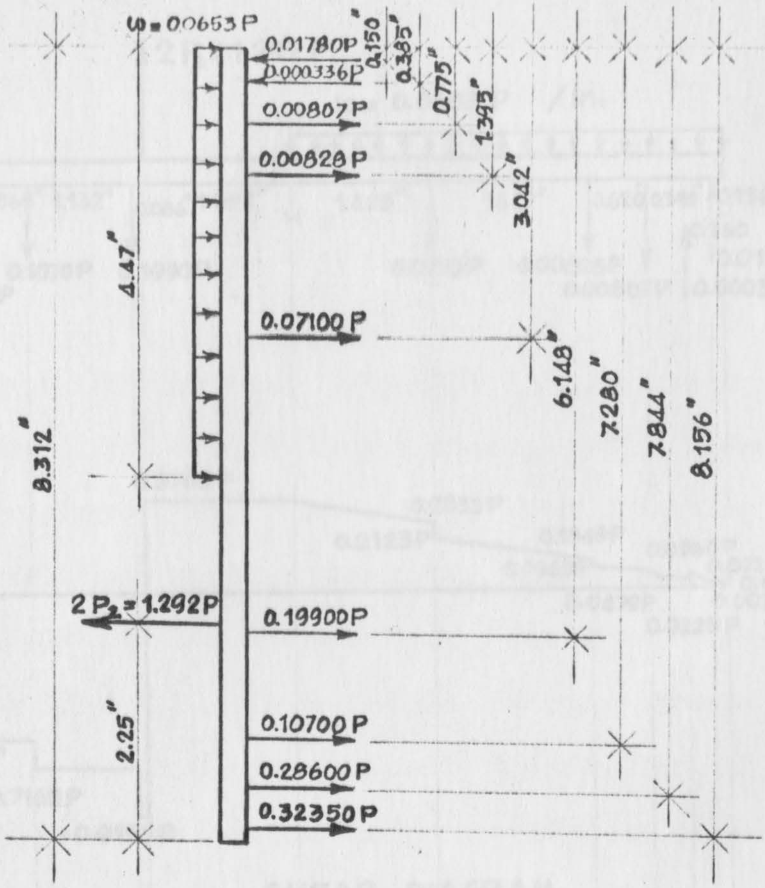
Stresses from the flexure portion of this interaction formula are shown on the Figure below;



Stresses due to the axial force P are obtained as follows;

$$\text{The stress due to P} = \frac{P}{\text{total area}} = 0.0627P \quad \text{(tension)}$$

Combining the stress due to the axial force and due to flexure according to the above expressed interaction formula, the combined effect shown on the following free body diagram is obtained along the forces obtained previously. Thus, a complete free body diagram is obtained.



<u>Checking;</u>

Summation of forces	=	1.31013P - 1.29485P	
	=	0.01528P	(error = 1.2 %)
Summation of moments at top	=	7.852799P - 7.765800P	
	=	0.086999P	(error = 1.1 %)

The complete shear and moment diagrams are shown in Figure 2.4

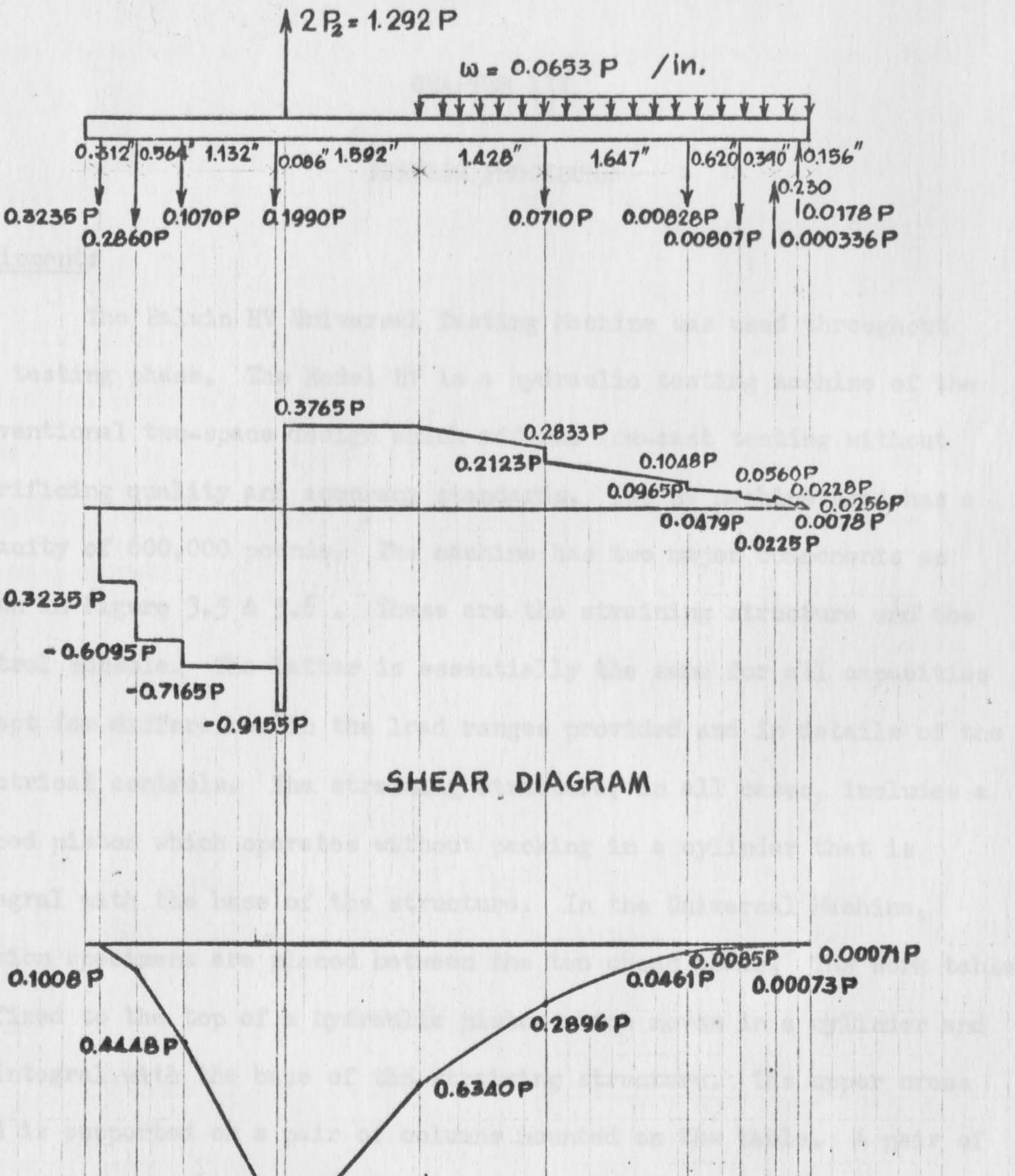


FIG. 2.4 SHEAR AND MOMENT DIAGRAMS OF FOUR BOLTS SPECIMEN

CHAPTER III

TESTING PROCEDURE

Equipment:

The Balwin HV Universal Testing Machine was used throughout the testing phase. The Model HV is a hydraulic testing machine of the conventional two-space design which affords low-cast testing without sacrificing quality and accuracy standards. The HV machine used has a capacity of 600,000 pounds. The machine has two major components as shown in Figure 3.5 & 3.6 . These are the straining structure and the control console. The latter is essentially the same for all capacities except for differences in the load ranges provided and in details of the electrical controls. The straining structure, in all cases, includes a lapped piston which operates without packing in a cylinder that is integral with the base of the structure. In the Universal Machine, tension specimens are placed between the two cross heads. The work table is fixed to the top of a hydraulic piston which moves in a cylinder and is integral with the base of the straining structure. The upper cross head is supported on a pair of columns mounted on the table. A pair of columns fixed to the base of the straining structure supports the lower crosshead which is vertically adjustable. Each crosshead contains a tapered grip jaw pocket located on the vertical axis of the load-apply cylinder and piston. Upper movement of the hydraulic piston applies load to a tension specimen supported between the crossheads. Pressure to move the piston in the cylinder is produced by a motor-driven hydraulic pump whose output passes through suitable control valves.

For the strain measurements, the BSG-6 Switch Balance and BAM-1 Bridge Amplifier were selected. The strain gages selected were SR-4, type A-8 with a gage factor of 1.83 ± 2 %. These are shown in Figure 3.3

Up to six channels of the strain gages can be individually connected in to the inputs of the BSG-6 so that any individual channel can be prebalanced and switched in to single channel instrumentation.

The strain gages were placed at various locations of the splice plates including the points of maximum moments from the analysis as shown in Figure 3.1 . The design end result was to obtain a stress distribution along the length of the plate. Also, bending was assumed to be one-dimensional.

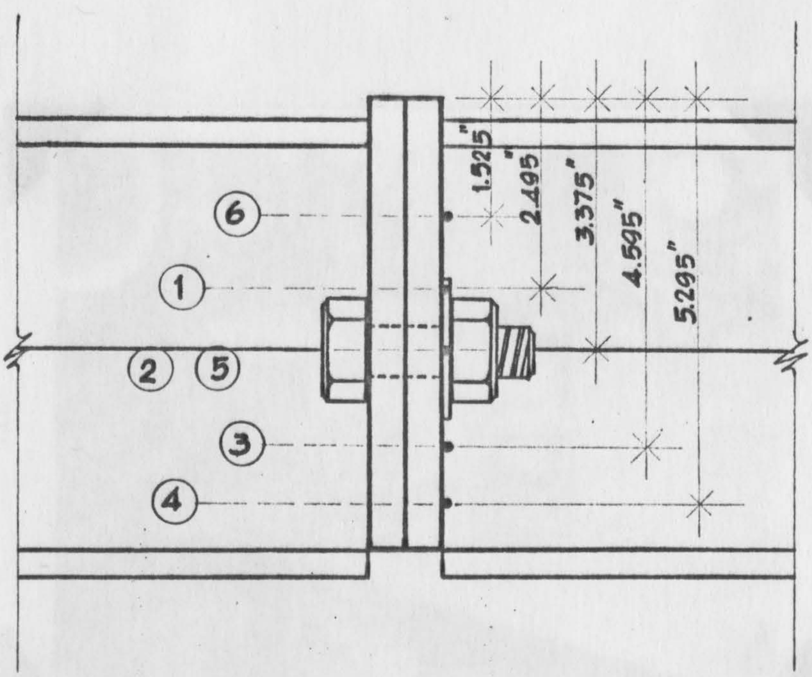


Figure 3.1 Gage locations of the two bolts specimen

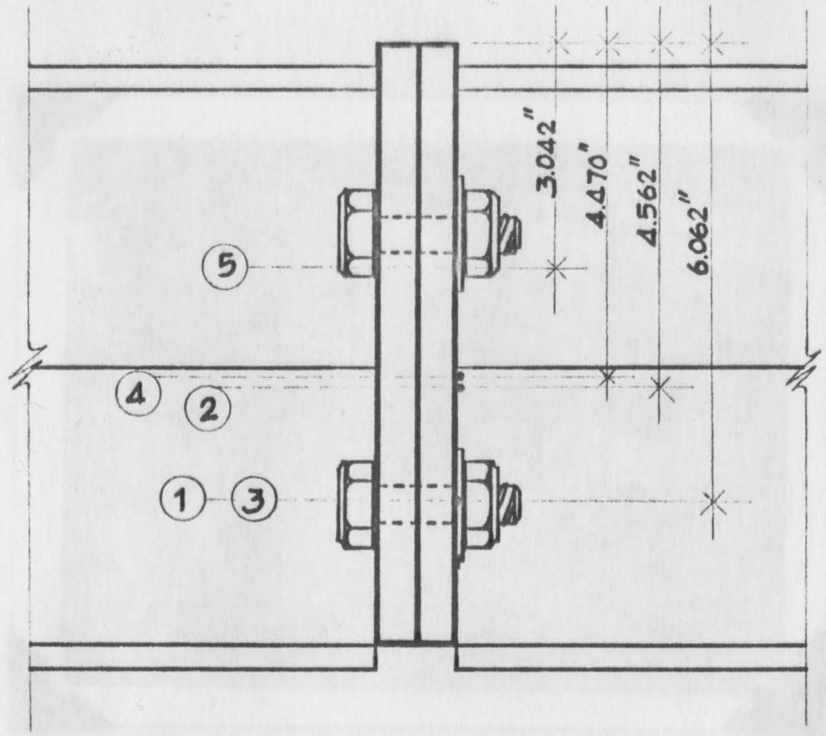


Figure 3.2 Gage locations of the four bolts specimen

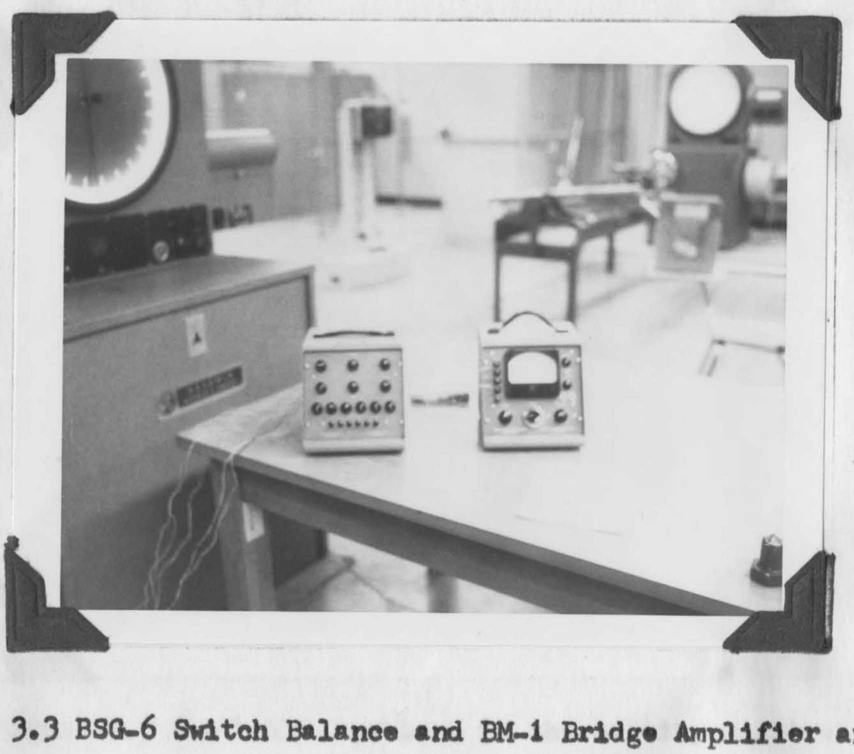


Figure 3.3 BSG-6 Switch Balance and BM-1 Bridge Amplifier and Meter

Figure 3.4 Strain gages on the four bolts specimen

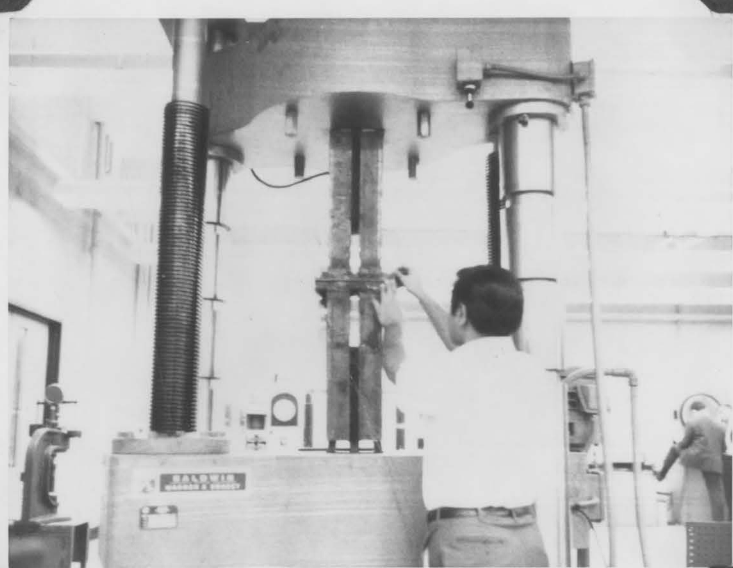


Figure 3.5 Two bolts specimen in the testing machine

Figure 3.6 Four bolts specimen in the testing machine

Test Procedure:

Using the standard bonding techniques, the strain gages were bonded on the prepared surfaces of the splice plates at the positions shown in Figures 3.1 and 3.2. From these positions, it was hoped that the stress distribution along the plate could be obtained. The specimens were clamped between the two crossheads of the testing machine by tapered, grip jaw pockets. The load was increased gradually in increments of 5,000 pounds.

The strains were recorded at every load increment of 5,000 lbs. and load-strain curves were plotted to determine the stress level at each gage position. The load was increased until failure occured. Note was made of the progressive failure as indicated by popping mill scale, increased deformation, etc. Figures 4.1 and 4.2 show the test specimens after failure.

CHAPTER IV

TEST RESULTS

Referring to the graphs and data (Fig. 4.3, 4.4, 4.5, 4.7, 4.8 and Tables 4.1, 4.2, 4.3, 4.4) the maximum loads causing bolt failures were 275,000 pounds for the two bolts specimen and 230,000 pounds for the four bolts specimen. The average yield stresses of splice plates are 79.75 ksi and 54.23 ksi for the two bolts and four bolts specimens respectively as determined from the load-strain curves.

The yield zone locations were determined by the mill scale scalings on the surfaces of the steel and by the strain readings. The bolt failures did not occur simultaneously because of imperfections in the specimens. In the experiment, the contact area caused by the reaction of the adjacent plate followed what had been initially assumed. But, in the two bolts specimen, the two splice plates began to move apart after reaching the yield point. This resulted from the large deformation in the bolts. Similarly, the bending in the splice plate of the four bolts specimen followed the contact area assumption. The splice plates in the two bolts specimen, however, started to bend in the other direction after the two contact areas were apart and the load was beyond the yield point in the bolts. This can be explained due to the fact that there was considerable yielding occuring across the cross section of the splice plate and hence, there was a redistribution of stress. There were no failures in the welds or chord members. In addition, the contact areas in both specimens were not uniform because the contact surfaces of the plates were not perfectly smooth. These failures were shown in

Figure 4.1 & 4.2.

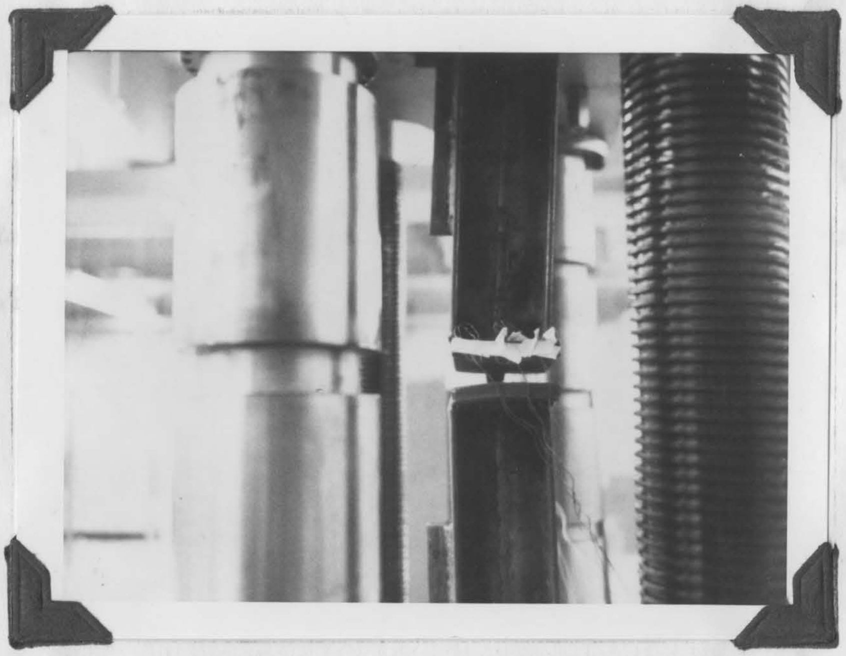


Figure 4.1 Two bolts specimen after failure

Figure 4.2 Four bolts specimen after failure

The graphs depicting load and deformation in this test correlate with Hooke's law. The stress is calculated from the equation $\sigma = E\epsilon$ up to the proportional limit. (In this case where the load ceased being proportion to the strain.)

The stress distributions of the splice plates were then drawn to show stresses at different sections of the plates, as shown in Figures 4.6 and 4.9.

TABLE 4.1

SUMMARY OF TEST RESULTS ON TWO BOLTS SPECIMEN

Load (lbs)	Strain reading x 50 micro in./in.					
	gage 1	gage 2	gage 3	gage 4	gage 5	gage 6
5,000	1.0	5.5	6.1	-	1.0	-
10,000	1.0	6.5	6.1	-	2.5	-
15,000	2.1	8.1	8.5	-	4.5	-
20,000	3.0	11.0	11.0	0.5	6.5	0.5
25,000	4.6	14.0	13.0	1.0	9.5	1.0
30,000	5.5	16.5	15.0	1.0	11.5	1.1
35,000	6.5	18.5	16.8	1.1	13.1	1.7
40,000	7.5	20.5	18.5	1.5	16.0	2.1
45,000	8.5	24.0	20.0	1.6	17.0	2.5
50,000	9.5	25.0	21.5	2.0	19.0	3.0
55,000	10.0	27.0	22.5	2.0	21.0	3.2
60,000	11.0	29.0	24.3	2.0	23.0	3.8
65,000	12.0	31.5	26.0	2.1	25.0	4.1
70,000	12.5	33.0	27.2	2.3	26.5	4.9
75,000	13.0	36.0	28.9	2.5	28.0	5.1
80,000	13.9	38.0	30.0	2.9	30.0	5.5
85,000	14.2	40.0	31.5	3.0	32.0	6.0
90,000	15.0	42.0	33.0	3.0	33.5	6.5
95,000	15.2	44.3	34.1	3.0	35.5	7.0
100,000	16.0	47.0	36.0	3.0	37.3	7.1
105,000	16.3	49.0	37.0	3.0	39.0	7.9
110,000	17.0	51.0	38.5	3.1	41.0	8.0
115,000	17.1	53.0	40.0	3.2	43.9	8.9
120,000	17.5	55.0	41.5	3.2	46.0	9.0
125,000	17.9	57.0	43.0	3.2	48.0	9.5
130,000	18.0	59.0	45.0	3.2	50.3	10.0
135,000	18.2	61.2	46.5	3.3	52.5	10.3
140,000	19.0	64.0	48.2	3.6	55.0	11.0
145,000	19.0	66.0	50.0	3.8	58.0	11.2
150,000	19.3	68.5	52.2	3.9	60.9	12.0
155,000	19.9	71.0	54.5	4.0	64.0	12.2
160,000	20.0	74.0	56.5	4.0	67.0	13.0
165,000	20.3	77.0	59.4	4.0	70.5	13.5
170,000	21.0	80.0	62.0	4.0	74.1	14.2
175,000	21.5	83.5	64.9	4.2	78.2	15.0
180,000	22.0	87.5	67.8	4.3	82.5	16.0
185,000	22.9	92.5	71.5	4.3	87.2	16.8
190,000	23.5	98.0	75.5	4.9	93.0	17.5
195,000	24.5	106.0	80.5	5.0	100.0	18.9
200,000	25.5	111.0	85.5	5.0	108.0	20.0
205,000	27.0	119.0	90.5	5.0		21.5
225,000	28.0	174.0	109.5	6.0		28.5
250,000	40.0		164.5	8.0		38.0
275,000	Remarks: bolt failure					

TABLE 4.2

SUMMARY OF TEST RESULTS ON TWO BOLTS SPECIMEN

Load (lbs)	Stress = $\epsilon \times 50 \times 10^{-6} \times 29{,}005 = 1.45\epsilon$ (ksi)					
	gage 1	gage 2	gage 3	gage 4	gage 5	gage 6
5,000	1.45	7.98	8.85	-	1.45	-
10,000	1.45	8.70	8.85	-	3.63	-
15,000	3.05	11.75	12.33	-	6.53	-
20,000	4.35	15.95	15.95	0.73	9.43	0.73
25,000	6.67	20.30	18.85	1.45	13.70	1.45
30,000	7.98	23.93	21.75	1.45	16.68	1.60
35,000	9.43	26.83	24.36	1.60	19.00	2.47
40,000	10.88	29.73	26.83	2.18	23.32	3.05
45,000	12.33	34.80	29.00	2.32	24.65	3.63
50,000	13.78	36.25	31.18	2.90	27.55	4.35
55,000	14.50	39.15	32.63	2.90	30.45	4.64
60,000	15.95	42.05	35.24	2.90	33.35	5.51
65,000	17.40	45.68	37.70	3.05	36.25	5.95
70,000	18.13	48.58	39.44	3.34	38.43	7.11
75,000	18.85	52.20	41.91	3.63	40.60	7.40
80,000	20.16	55.10	43.50	4.21	43.50	7.98
85,000	20.59	58.00	45.68	4.35	46.40	8.70
90,000	21.75	60.90	47.85	4.35	48.58	9.43
95,000	22.04	64.24	49.45	4.35	51.48	10.15
100,000	23.20	68.15	52.20	4.35	54.09	10.30
105,000	23.64	71.05	53.65	4.35	56.55	11.46
110,000	24.65	73.95	55.83	4.50	59.45	11.60
115,000	24.80	76.85	58.00	4.64	63.66	12.91
120,000	25.38	79.75	60.18	4.64	66.70	13.05
125,000	25.96		62.35	4.64	69.60	13.78
130,000	26.10		65.25	4.64	72.94	14.50
135,000	26.39		67.43	4.79	76.13	14.94
140,000	27.55		69.89	5.22	79.75	15.95
145,000	27.55		72.50	5.51		16.24
150,000	27.99		75.69	5.66		17.40
155,000	28.86			5.80		17.69
160,000	29.00			5.80		18.85
165,000	29.44			5.80		19.58
170,000	30.45			5.80		20.59
175,000	31.18			6.09		21.75
180,000	31.90			6.24		23.20
185,000	33.21			6.24		24.36
190,000	34.08			7.11		25.38
195,000	35.53			7.25		27.41
200,000	36.98			7.25		29.00
205,000	39.15			7.25		31.18
225,000	40.60			8.70		41.33
250,000	58.00			11.60		55.10
275,000						

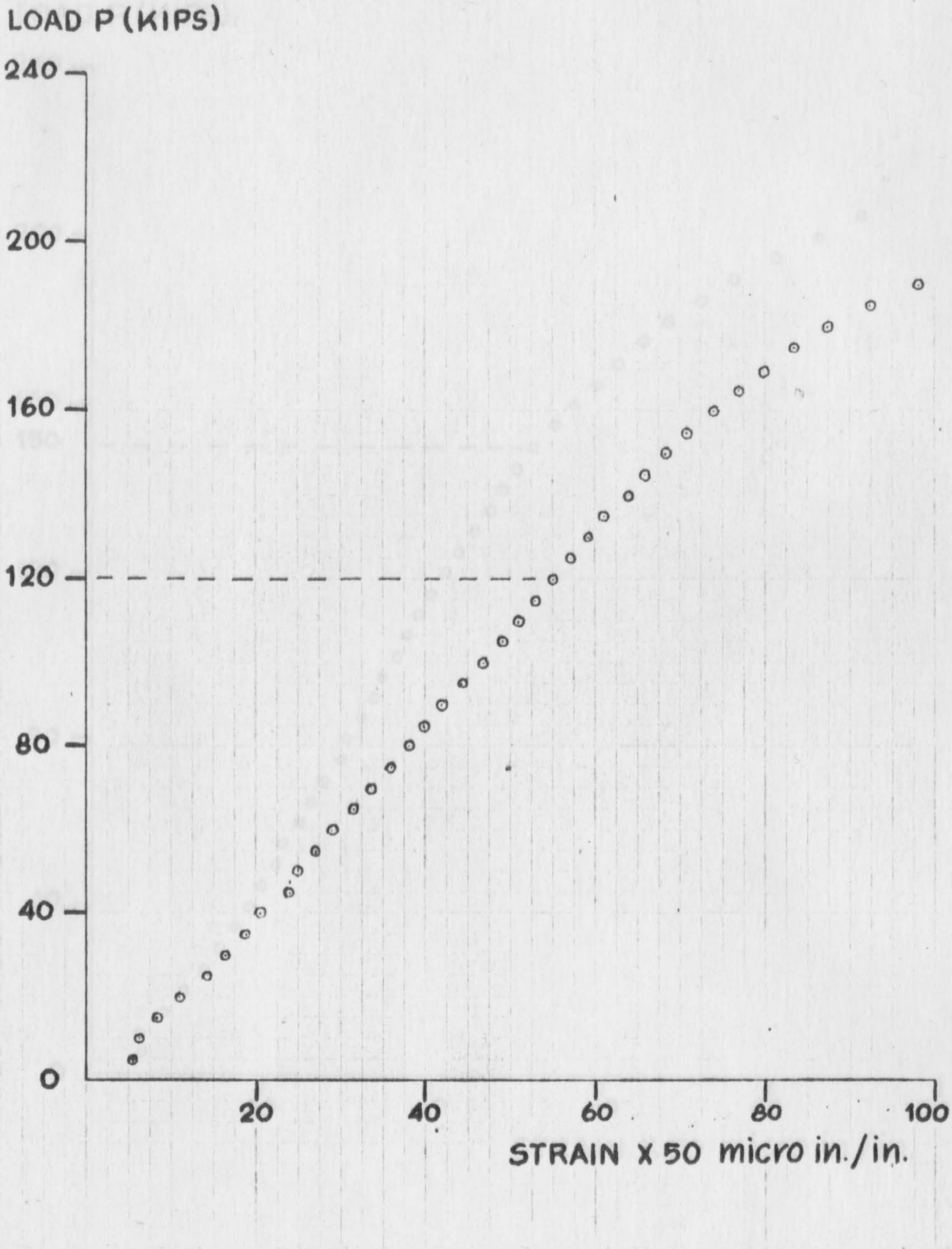


FIG.4.3 LOAD-STRAIN CURVE OF TWO BOLTS SPECIMEN, GAGE LOCATION (2)

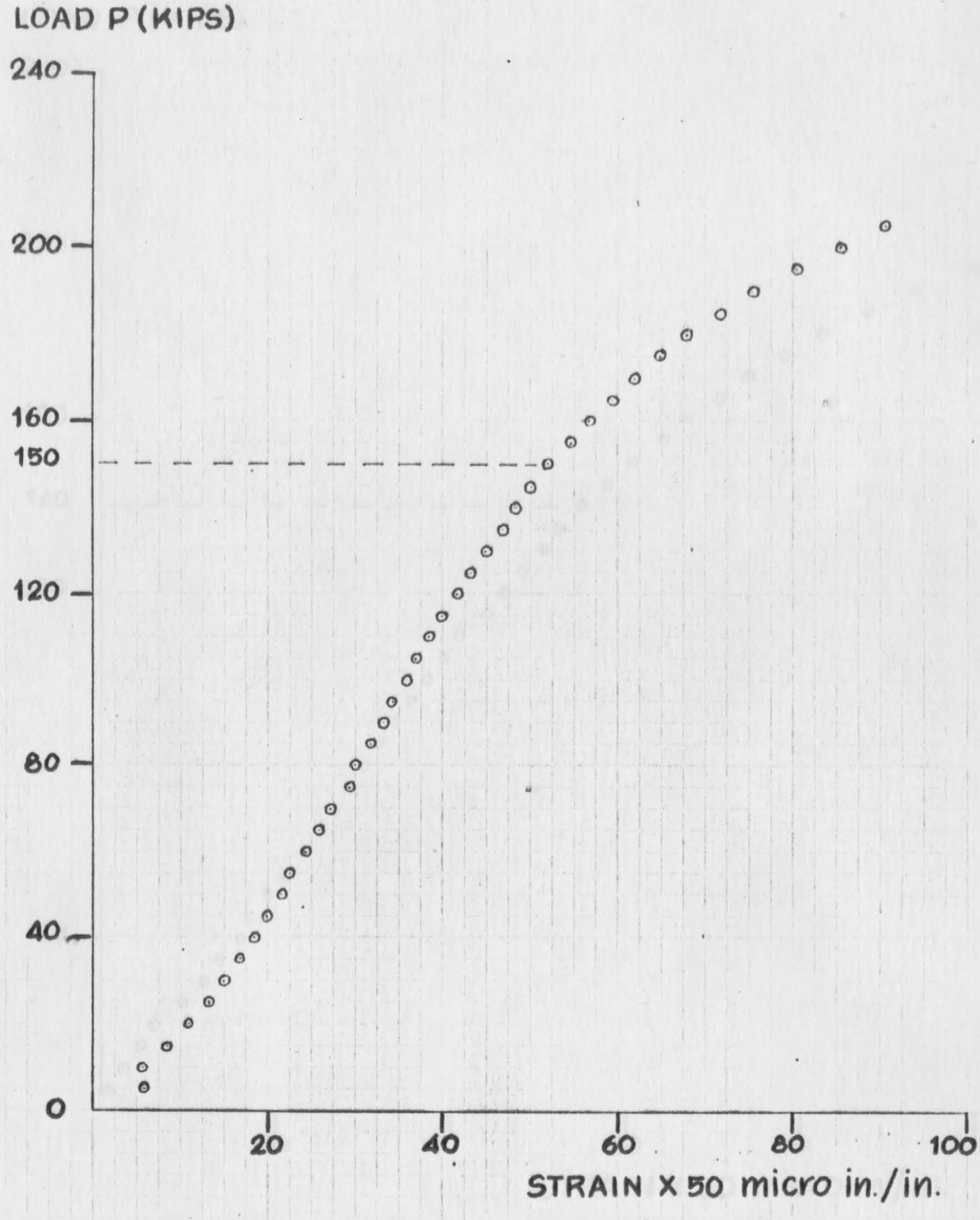


FIG. 4.4 LOAD-STRAIN CURVE OF TWO BOLTS SPECIMEN, GAGE LOCATION (3)

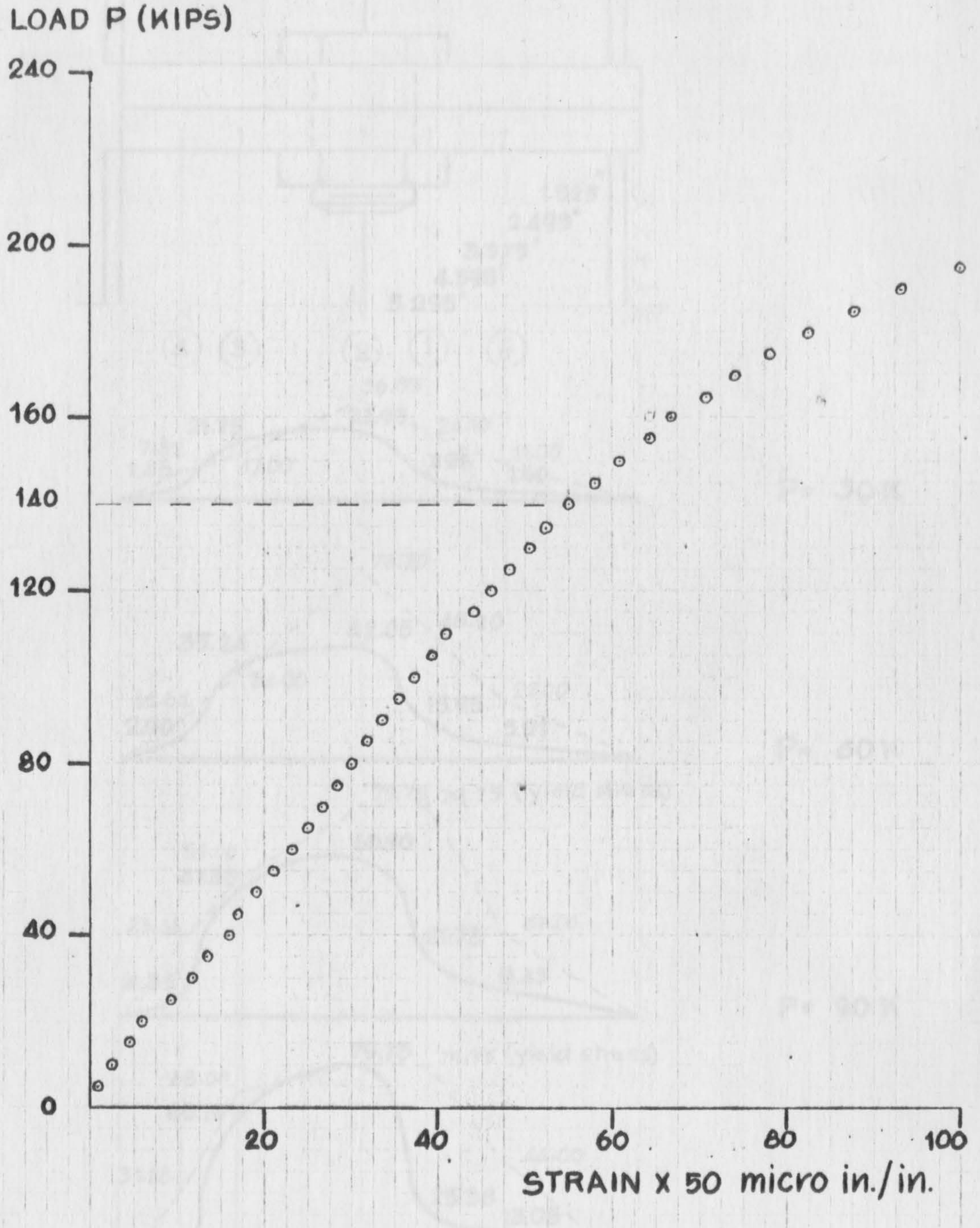


FIG. 4.5 LOAD-STRAIN CURVE OF TWO BOLTS SPECIMEN, GAGE LOCATION (5)

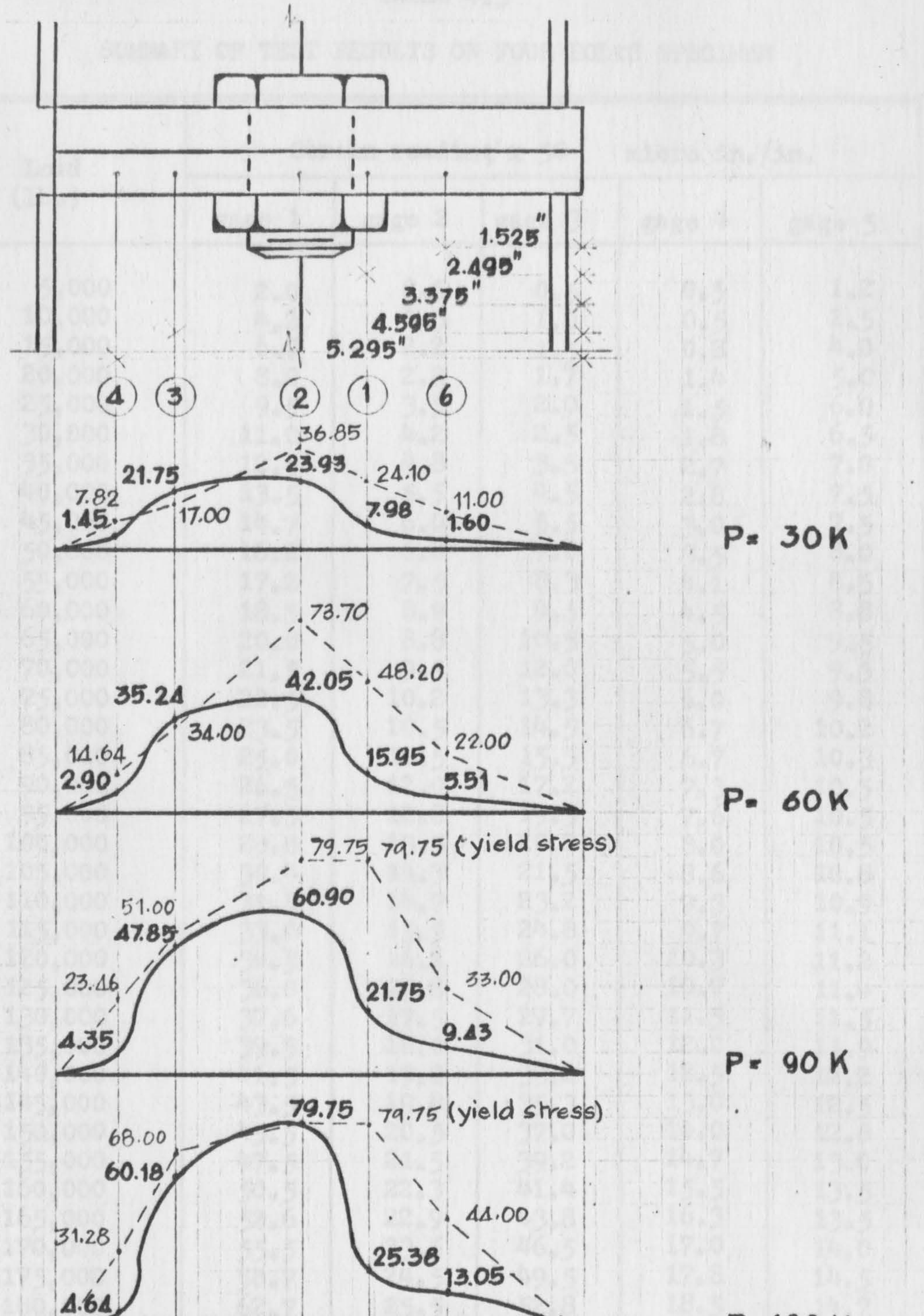


FIG. 4.6 STRESS DISTRIBUTION OF THE 2-BOLTS PLATE IN KSI

TABLE 4.3

SUMMARY OF TEST RESULTS ON FOUR BOLTS SPECIMEN

Load (lbs)	Strain reading x 50 micro in./in.				
	gage 1	gage 2	gage 3	gage 4	gage 5
5,000	2.0	0.5	0.5	0.5	1.2
10,000	4.2	1.5	1.0	0.5	2.5
15,000	6.7	2.2	1.5	0.8	4.0
20,000	8.0	2.8	1.7	1.4	5.0
25,000	9.5	3.5	2.0	1.5	6.0
30,000	11.0	4.2	2.5	1.8	6.5
35,000	12.5	4.8	3.5	2.7	7.0
40,000	13.5	5.5	4.5	2.8	7.5
45,000	14.7	6.0	5.5	3.0	7.5
50,000	16.2	6.8	7.0	3.5	8.0
55,000	17.2	7.5	8.3	4.1	8.5
60,000	18.5	8.0	9.5	4.5	8.8
65,000	20.0	8.8	10.5	5.0	9.5
70,000	21.5	9.5	12.0	5.5	9.5
75,000	22.5	10.2	13.3	6.0	9.8
80,000	23.5	10.5	14.5	6.7	10.2
85,000	25.0	11.5	15.5	6.7	10.3
90,000	26.5	12.0	17.2	7.3	10.5
95,000	27.5	12.8	19.5	7.6	10.5
100,000	28.8	13.5	20.2	8.0	10.5
105,000	30.4	14.3	21.5	8.6	10.8
110,000	31.5	14.7	23.2	9.3	10.9
115,000	33.0	15.5	24.8	9.7	11.1
120,000	34.5	16.2	26.0	10.3	11.2
125,000	36.0	16.8	28.0	10.7	11.4
130,000	37.6	17.5	29.7	11.5	11.5
135,000	39.5	18.0	31.0	12.0	11.9
140,000	41.5	19.0	33.2	12.5	12.2
145,000	43.5	19.8	35.3	13.0	12.5
150,000	45.5	20.5	37.0	14.0	12.8
155,000	47.5	21.5	39.2	14.7	13.0
160,000	50.5	22.3	41.4	15.5	13.5
165,000	52.6	22.9	43.8	16.3	13.5
170,000	55.5	23.5	46.5	17.0	14.0
175,000	58.7	24.5	49.5	17.8	14.5
180,000	62.7	25.5	52.8	18.5	14.7
185,000	66.7	26.0	56.0	19.5	14.9
190,000	71.0	26.8	60.1	20.2	15.0
195,000	75.8	27.7	65.8	21.0	15.5
200,000	80.5	28.5	71.8	21.8	16.0
205,000	85.8	29.5	79.6	22.7	16.5
210,000	91.0	30.2	86.8	23.5	16.7
215,000	95.7	31.0	95.6	24.5	17.5
220,000	100.0	31.7	104.8	25.5	18.0
225,000	103.5	32.5	112.3	26.3	19.3
230,000		Remarks: bolt failure			

TABLE 4.4

SUMMARY OF TEST RESULTS ON FOUR BOLTS SPECIMEN

Load (lbs)	Stress = $\epsilon \times 50 \times 10^{-6} \times 29{,}005 = 1.45\epsilon$ (ksi)				
	gage 1	gage 2	gage 3	gage 4	gage 5
5,000	2.90	0.73	0.73	0.73	1.74
10,000	6.09	2.18	1.45	0.73	3.63
15,000	9.72	3.19	2.18	1.16	5.80
20,000	11.60	4.06	2.47	2.03	7.25
25,000	13.78	5.08	2.90	2.18	8.70
30,000	15.95	6.09	3.63	2.61	9.43
35,000	18.13	6.96	5.08	3.92	10.15
40,000	19.58	7.98	6.53	4.06	10.88
45,000	21.32	8.70	7.98	4.35	10.88
50,000	23.49	9.86	10.15	5.08	11.60
55,000	24.94	10.88	12.04	5.95	12.33
60,000	26.83	11.60	13.78	6.53	12.76
65,000	29.00	12.76	15.23	7.25	13.78
70,000	31.18	13.78	17.40	7.98	13.78
75,000	32.63	14.79	19.29	8.70	14.21
80,000	34.08	15.33	21.03	9.72	14.79
85,000	36.25	16.68	22.48	9.72	14.94
90,000	38.43	17.40	24.94	10.59	15.23
95,000	39.88	18.56	28.28	11.02	15.23
100,000	41.76	19.58	29.29	11.60	15.23
105,000	44.08	20.74	31.18	12.47	15.66
110,000	45.68	21.32	33.64	13.49	15.81
115,000	47.85	22.48	35.96	14.07	16.10
120,000	50.03	23.49	37.70	14.94	16.24
125,000	52.20	24.36	40.60	15.52	16.53
130,000	54.52	25.38	43.07	16.68	16.68
135,000	57.28	26.10	44.95	17.40	17.29
140,000		27.55	48.14	18.13	17.69
145,000		28.71	51.19	18.85	18.13
150,000		29.73		20.30	18.56
155,000		31.18		21.32	18.85
160,000		32.34		22.48	19.58
165,000		33.21		23.64	19.58
170,000		34.08		24.65	20.30
175,000		35.53		25.81	21.03
180,000		36.98		26.83	21.32
185,000		37.70		28.28	21.61
190,000		38.86		29.29	22.19
195,000		40.17		30.45	22.48
200,000		41.33		31.61	23.20
205,000		42.78		32.92	23.93
210,000		43.79		34.08	24.22
215,000		44.95		35.53	25.38
220,000		45.97		36.98	26.12
225,000		47.13		38.14	27.99
230,000					

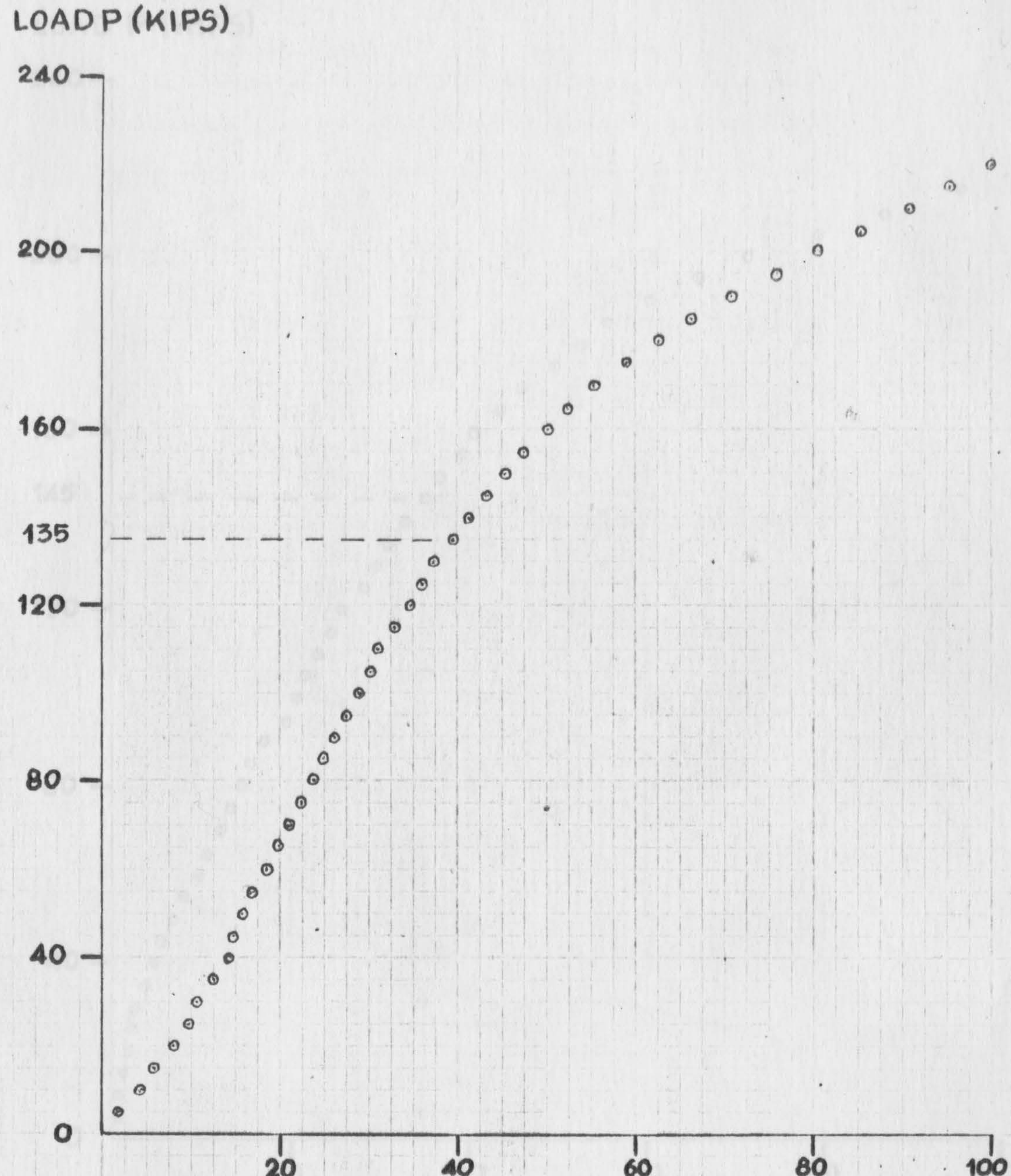


FIG. 4.7 LOAD-STRAIN CURVE OF FOUR BOLTS SPECIMEN, GAGE LOCATION (1)

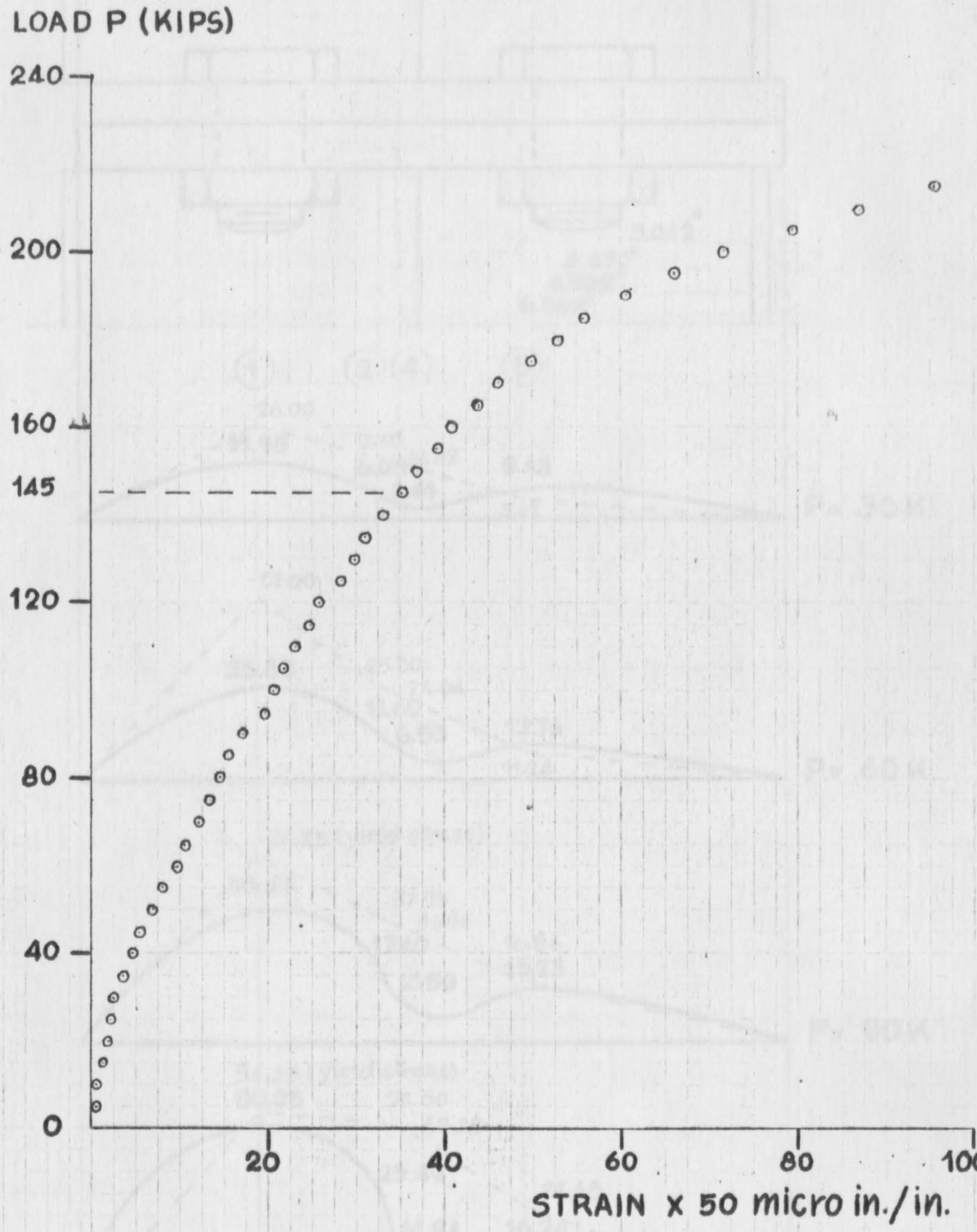


FIG. 4.8 LOAD-STRAIN CURVE OF FOUR BOLTS SPECIMEN, GAGE LOCATION (3)

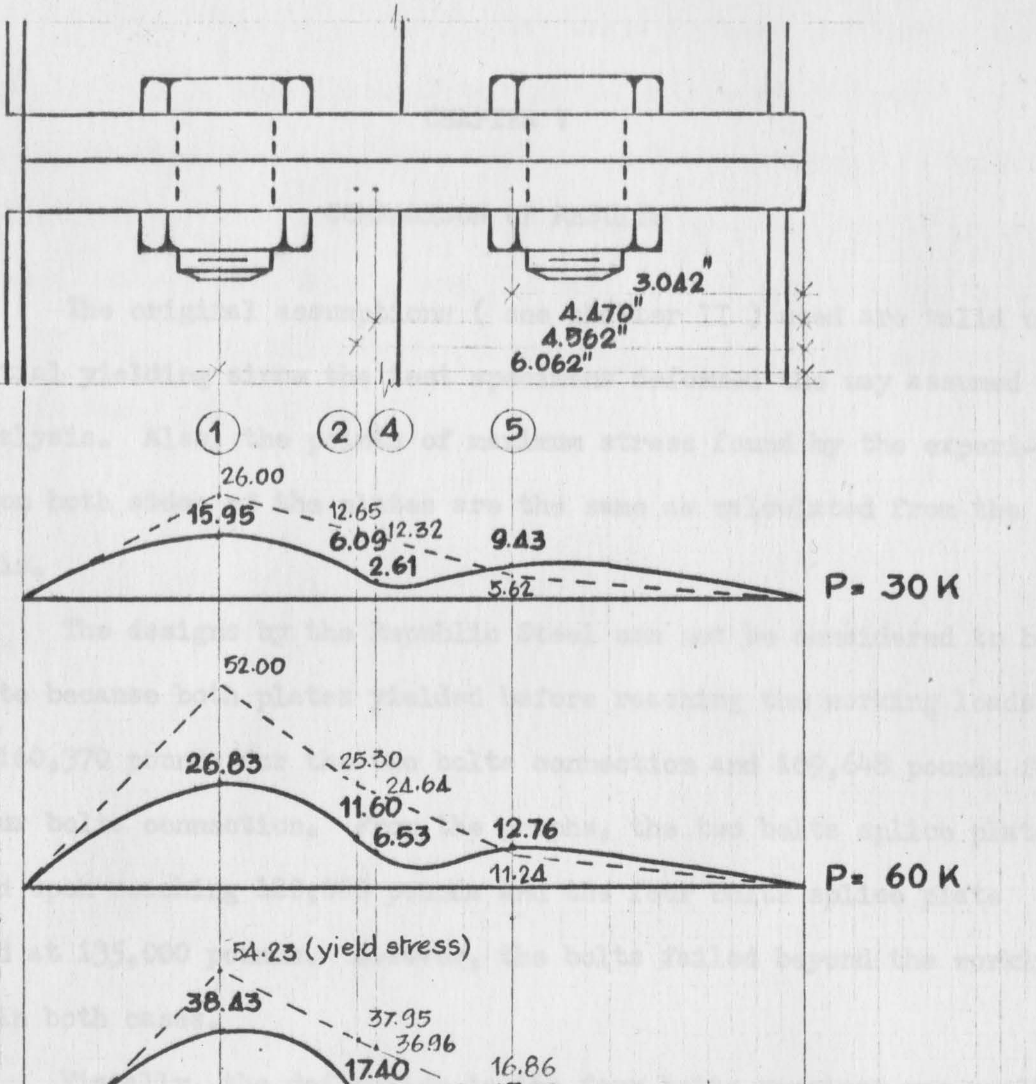


FIG.4.9 STRESS DISTRIBUTION OF THE 4-BOLTS PLATE IN KSI

CHAPTER V

COMPARISON OF RESULTS

The original assumptions (see chapter II) used are valid up to initial yielding since the test specimens deformed the way assumed in the analysis. Also, the points of maximum stress found by the experiments on both sides of the plates are the same as calculated from the analysis.

The designs by the Republic Steel can not be considered to be adequate because both plates yielded before reaching the working loads, i.e., 160,370 pounds for the two bolts connection and 169,648 pounds for the four bolts connection. From the graphs, the two bolts splice plate yielded upon reaching 120,000 pounds and the four bolts splice plate yielded at 135,000 pounds. However, the bolts failed beyond the working loads in both cases.

Visually, the deflection in the four bolts specimen was small enough that no recommendation for improvement. The deflection seemed to be too great in the two bolts specimen. To meet the objective of this thesis, therefore, improved design ideas are recommended as shown in chapter VI.

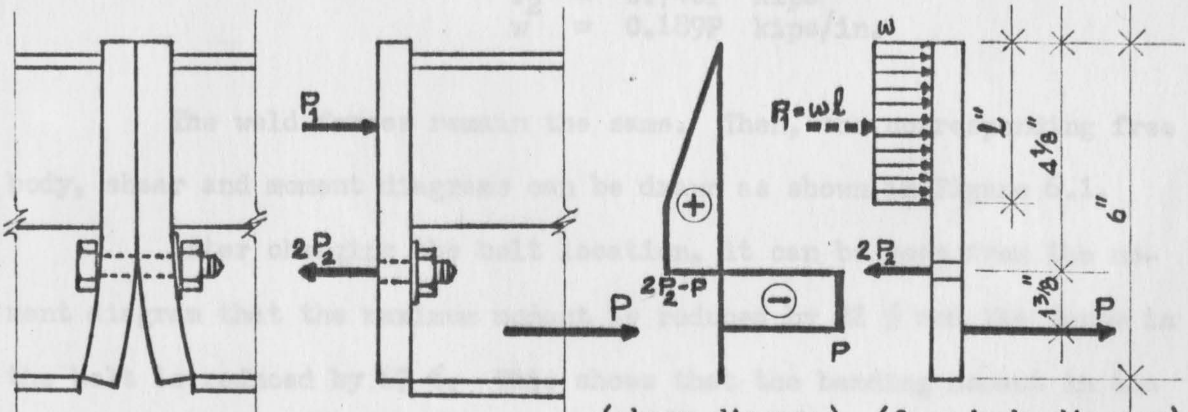
From Figure 4.6 & Figure 4.9, it can be seen that the actual stress and the calculated stress for the same loads at various points differ by a considerable amount. This can be explained as follows; first, the contribution of the chord angles and the splice angles to the stiffness of the splice plates was ignored in the analysis because of the difficulty encountered when trying to determine exactly how much stiffness is really added. This is a conservative neglect, i.e., the actual stress would definitely be less than the calculated stress which ignors the angle contribution to the stiffness of the plates. Secondly, a uniformly distributed contact area was not realized between the splice plates as assumed. Thus, in testing, less flexural stress was realized by the plates. Lastly, residual stresses from the welding and drilling were ignored in the calculations.

CHAPTER VI

RECOMMENDATIONS & CONCLUSIONS

Because of the excessive stresses and displacements, particularly in the two bolts connection, some recommendations as to improving must be made. A change in the bolt positions for the two bolts splice plate is recommended. This will reduce the maximum moment in the plate as well as decrease the deflections.

In order to change the bolt position by moving 3/4" towards the applied load P (see the Figure below), the following procedure is obtained;



(shear diagram) (free body diagram)

By taking the sum of moments about P_1 , the follwing eq. is obtained;

$$P_2 = \frac{(5.50 - 0.50\ell)}{(8.25 - \ell)} P$$

By taking $\Sigma F_x = 0$, the following eq. is obtained;

$$P + w\ell - 2P_2 = 0$$

As before, by equating the axial deformation in the bolt to the bending and shear deflection in the plate at the bolt location, the following constants will be used;

E = 30,000 ksi
G = 12,000 ksi
I = moment of inertia of the plate = 0.855 $in.^4$
A = cross sectional area of the bolt = 1.485 $in.^2$
L = length of the bolt = 2 in.

and;

$$\text{Deformation in the bolt} = \frac{1}{2}\left(\frac{P_2 L}{AE}\right)$$

Using $\frac{1}{2}\left(\frac{P_2 L}{AE}\right) = \delta_{BENDING} + \delta_{SHEAR}$, and proceeding as before the following results are obtained;

ℓ = 2.53 in.
P_2 = 0.740P kips
w = 0.189P kips/in.

The weld forces remain the same. Then, the corresponding free body, shear and moment diagrams can be drawn as shown in Figure 6.1.

After changing the bolt location, it can be seen from the moment diagram that the maximum moment is reduced by 32 % and the force in the bolt is reduced by 17 %. This shows that the bending moment in the plate depends on the bolt position. The sizes of the bolts for the new two bolts specimen will remain unchanged and the deflection in the bolts and splice plates anticipated in both flexure and axial stresses will be reduced. Furthermore, a bolt size change is recommended for the four bolts connection. Larger bolts should be utilized for those bolts carrying the high tension loads and those top bolts, assumed only to carry any existing shear force, can remain unchanged. Recall that the tension carrying bolts failed during testing.

The analysis presented here is only one approach to the problem and by now means is intended to be the only approach to the problem. The analysis assumed one-dimensional bending, i.e., beam action to be predominated. It is recommended that perhaps plate theory be extended to this problem as another method of analysis. Since there was a wide gap between the actual and calculated stresses, it is hoped that the application of plate theory could lessen the gap.

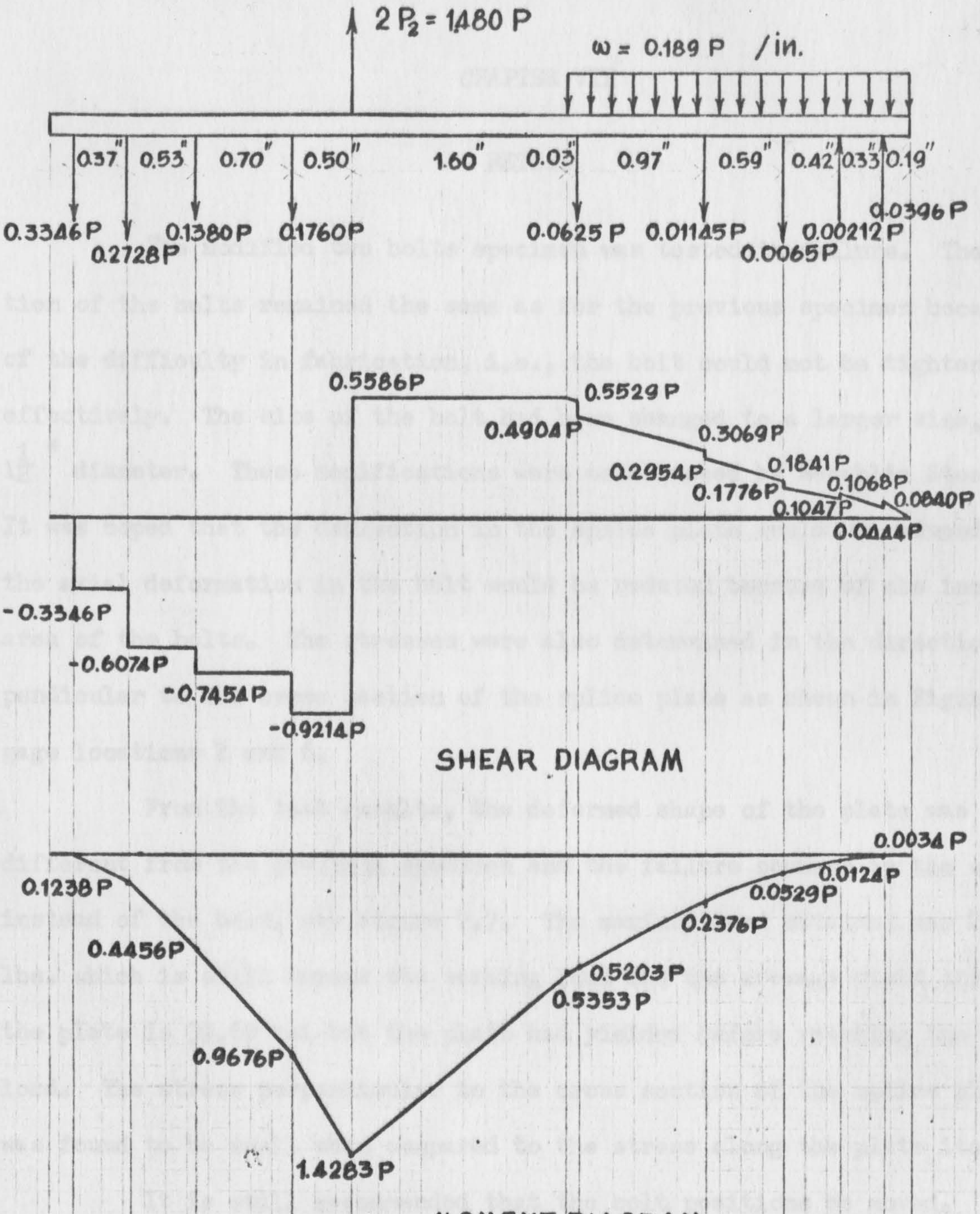


FIG. 6.1 SHEAR AND MOMENT DIAGRAMS OF MODIFIED TWO BOLTS SPECIMEN

CHAPTER VII

RETEST

The modified two bolts specimen was tested to failure. The position of the bolts remained the same as for the previous specimen because of the difficulty in fabrication, i.e., the bolt could not be tightened effectively. The size of the bolt had been changed to a larger size, i.e., $1\frac{1}{2}''$ diameter. These modifications were established by Republic Steel. It was hoped that the deflection in the splice plate would be reduced since the axial deformation in the bolt would be reduced because of the increased area of the bolts. The stresses were also determined in the direction perpendicular to the cross section of the splice plate as shown in Figure 7.1, gage locations 2 and 6.

From the test results, the deformed shape of the plate was quite different from the previous specimen and the failure occured in the weld instead of the bolt, see Figure 7.7. The maximum load obtained was 247,000 lbs. which is still beyond the working load and the average yield stress of the plate is 39.69 ksi but the plate had yielded before reaching the working load. The stress perpendicular to the cross section of the splice plate was found to be small when compared to the stress along the plate itself.

It is still recommended that the bolt positions be moved. It is felt that shifting the bolt position as previously mentioned, while maintaining the initial diameter will result in a more effective modification than increasing the bolt diameters. Additional specimens will be fabricated in this way but unfortunately the results will not be included in this study.

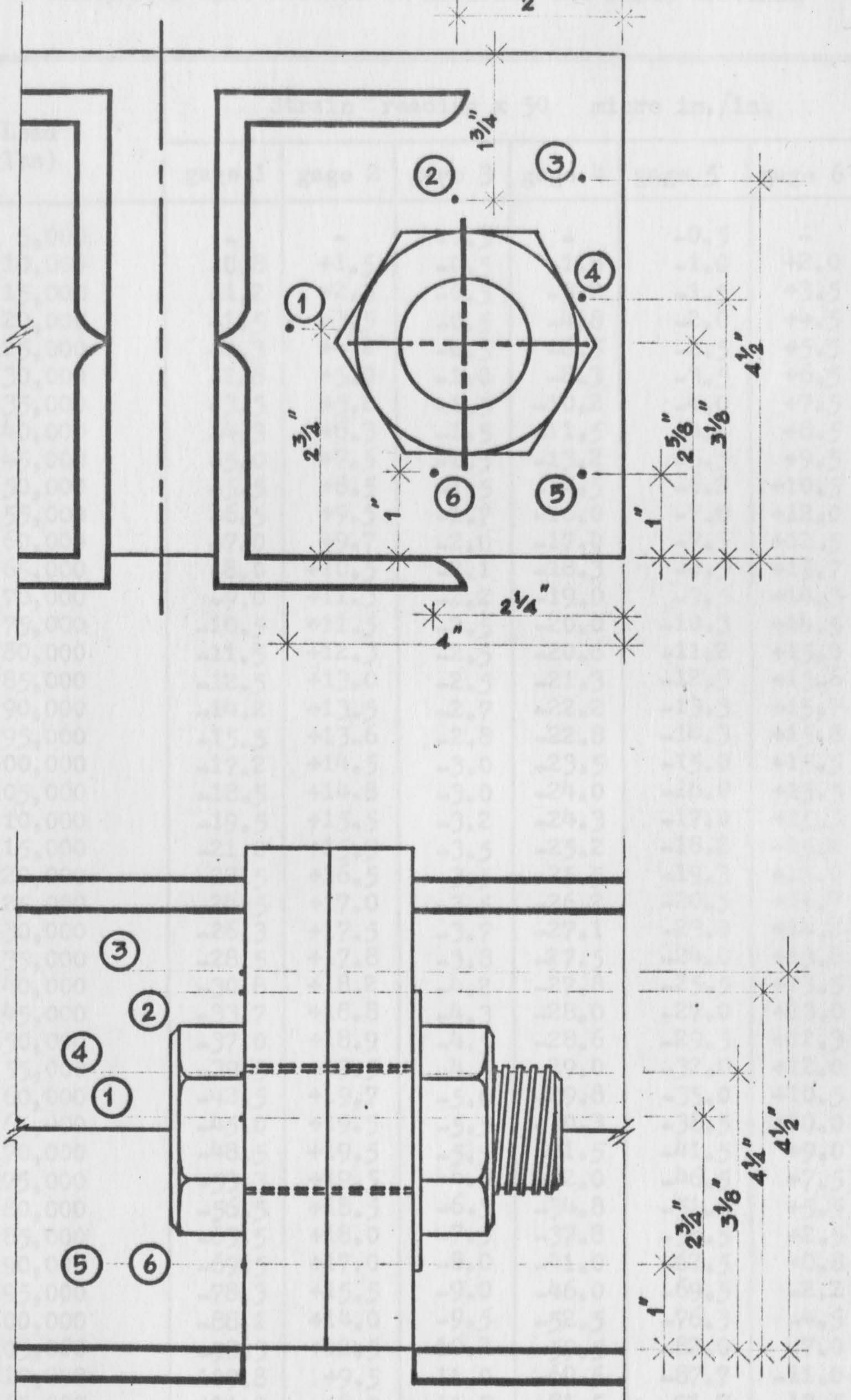


Figure 7.1 Gage locations of modified two bolts specimen

TABLE 7.1

SUMMARY OF TEST RESULTS ON MODIFIED TWO BOLTS SPECIMEN

Load (lbs)	Strain reading x 50 micro in./in.					
	gage 1	gage 2	gage 3	gage 4	gage 5	gage 6
5,000	-	-	-0.5	-	-0.5	-
10,000	-0.8	+1.5	-0.5	-1.8	-1.0	+2.0
15,000	-1.2	+2.5	-0.5	-3.2	-1.5	+3.5
20,000	-1.5	+3.5	-0.5	-4.8	-2.0	+4.5
25,000	-2.3	+4.2	-0.5	-6.5	-2.5	+5.5
30,000	-2.8	+5.0	-1.0	-8.3	-3.5	+6.5
35,000	-3.5	+5.8	-1.5	-10.2	-4.0	+7.5
40,000	-4.3	+6.3	-1.5	-11.5	-4.5	+8.5
45,000	-5.0	+7.5	-1.5	-13.2	-5.5	+9.5
50,000	-5.5	+8.5	-1.5	-14.5	-6.2	+10.5
55,000	-6.5	+9.5	-1.7	-16.0	-7.0	+12.0
60,000	-7.0	+9.7	-2.0	-17.0	-7.5	+12.5
65,000	-8.0	+10.5	-2.1	-18.3	-8.5	+13.7
70,000	-9.0	+11.3	-2.2	-19.0	-9.5	+14.3
75,000	-10.5	+11.5	-2.5	-20.0	-10.3	+14.5
80,000	-11.5	+12.3	-2.5	-20.6	-11.2	+15.0
85,000	-12.5	+13.0	-2.5	-21.3	-12.3	+15.6
90,000	-14.2	+13.5	-2.7	-22.2	-13.3	+15.7
95,000	-15.5	+13.6	-2.8	-22.8	-14.3	+15.8
100,000	-17.2	+14.5	-3.0	-23.5	-15.0	+15.5
105,000	-18.5	+14.8	-3.0	-24.0	-16.0	+15.5
110,000	-19.5	+15.5	-3.2	-24.3	-17.0	+15.5
115,000	-21.0	+15.9	-3.5	-25.2	-18.2	+15.2
120,000	-22.5	+16.5	-3.5	-25.5	-19.3	+15.0
125,000	-24.5	+17.0	-3.5	-26.2	-20.5	+14.7
130,000	-26.3	+17.5	-3.7	-27.1	-23.0	+14.2
135,000	-28.5	+17.8	-3.8	-27.5	-24.0	+13.8
140,000	-30.8	+18.2	-4.2	-27.8	-25.5	+13.5
145,000	-33.7	+18.8	-4.3	-28.0	-27.0	+13.0
150,000	-37.0	+18.9	-4.5	-28.6	-29.5	+12.3
155,000	-39.5	+19.5	-4.5	-29.0	-32.0	+12.0
160,000	-42.5	+19.7	-5.0	-29.8	-35.0	+10.5
165,000	-45.0	+19.5	-5.5	-30.3	-38.5	+10.0
170,000	-48.5	+19.5	-5.5	-31.5	-41.5	+9.0
175,000	-53.3	+19.5	-6.5	-32.0	-46.5	+7.5
180,000	-56.5	+18.5	-6.5	-34.8	-51.5	+5.5
185,000	-63.5	+18.0	-7.5	-37.8	-56.5	+2.5
190,000	-69.5	+17.0	-8.0	-41.0	-62.5	+0.8
195,000	-78.3	+15.5	-9.0	-46.0	-69.5	-2.2
200,000	-88.1	+14.0	-9.5	-52.5	-76.3	-4.5
205,000	-98.3	+12.5	-10.2	-59.5	-82.0	-7.0
210,000	-109.8	+9.5	-11.0	-69.5	-87.7	-11.0
215,000	-121.8	+8.0	-11.7	-81.5	-91.7	-13.5
220,000	-132.8	+6.5	-12.3	-89.8	-96.5	-15.5
230,000	-153.3	+0.0	-12.5	-83.0	-119.0	-22.7
247,000		Remarks: weld failure				

TABLE 7.2

SUMMARY OF TEST RESULTS ON MODIFIED TWO BOLTS SPECIMEN

Load (lbs)	Stress = $\epsilon \times 50 \times 10^{-6} \times 29{,}005 = 1.45\epsilon$ (ksi)					
	gage 1	gage 2	gage 3	gage 4	gage 5	gage 6
5,000	-	-	-0.73	-	-0.73	-
10,000	-1.16	+2.18	-0.73	-2.61	-1.45	+4.20
15,000	-1.74	+3.63	-0.73	-4.64	-2.18	+5.08
20,000	-2.18	+5.08	-0.73	-6.96	-2.90	+6.53
25,000	-3.34	+6.09	-0.73	-9.43	-3.63	+7.98
30,000	-4.06	+7.25	-1.45	-12.04	-5.08	+9.43
35,000	-5.08	+8.41	-2.18	-14.79	-5.80	+10.88
40,000	-6.24	+9.14	-2.18	-16.68	-6.53	+12.33
45,000	-7.25	+10.88	-2.18	-19.14	-7.98	+13.78
50,000	-7.98	+12.33	-2.18	-21.03	-8.99	+15.23
55,000	-9.43	+13.78	-2.47	-23.20	-10.15	+17.40
60,000	-10.15	+14.07	-2.90	-24.65	-10.88	+18.13
65,000	-11.60	+15.23	-3.05	-26.54	-12.33	+19.87
70,000	-13.05	+16.39	-3.19	-27.55	-13.78	+20.74
75,000	-15.23	+16.68	-3.63	-29.00	-14.94	+21.03
80,000	-16.68	+17.84	-3.63	-29.87	-16.24	+21.75
85,000	-18.13	+18.85	-3.63	-30.89	-17.84	+22.62
90,000	-20.59	+19.58	-3.92	-32.19	-19.29	+22.77
95,000	-22.48	+19.72	-4.06	-33.06	-20.74	+22.91
100,000	-24.94	+21.03	-4.35	-34.08	-21.75	+22.48
105,000	-26.83	+21.46	-4.35	-34.80	-23.20	+22.48
110,000	-28.28	+22.48	-4.64	-35.24	-24.65	+22.48
115,000	-30.45	+23.06	-5.08	-36.54	-26.39	+22.04
120,000	-32.63	+23.93	-5.08	-36.98	-27.99	+21.75
125,000	-35.53	+24.65	-5.08	-37.99	-29.73	+21.32
130,000	-38.14	+25.38	-5.37	-39.30	-33.35	+20.59
135,000		+25.81	-5.51	-39.88	-34.80	+20.01
140,000		+26.39	-6.09	-40.31		+19.58
145,000		+27.26	-6.24	-40.60		+18.85
150,000		+27.41	-6.53	-41.47		+17.84
155,000		+28.28	-6.53	-42.05		+17.40
160,000		+28.57	-7.25	-43.21		+15.23
165,000		+28.28	-7.98	-43.94		+14.50
170,000		+28.28	-7.98			+13.05
175,000		+28.28	-9.43			+10.88
180,000		+26.83	-9.43			+7.98
185,000		+26.10	-10.88			+3.63
190,000		+24.65	-11.60			+1.66
195,000		+22.48	-13.05			-3.19
200,000		+20.30	-13.78			-6.53
205,000		+18.13	-14.79			-10.15
210,000		+13.78	-15.95			-15.95
215,000		+11.60	-16.97			-19.58
220,000		+9.43	-17.84			-22.48
230,000		+0.00	-18.13			-32.92
247,000						

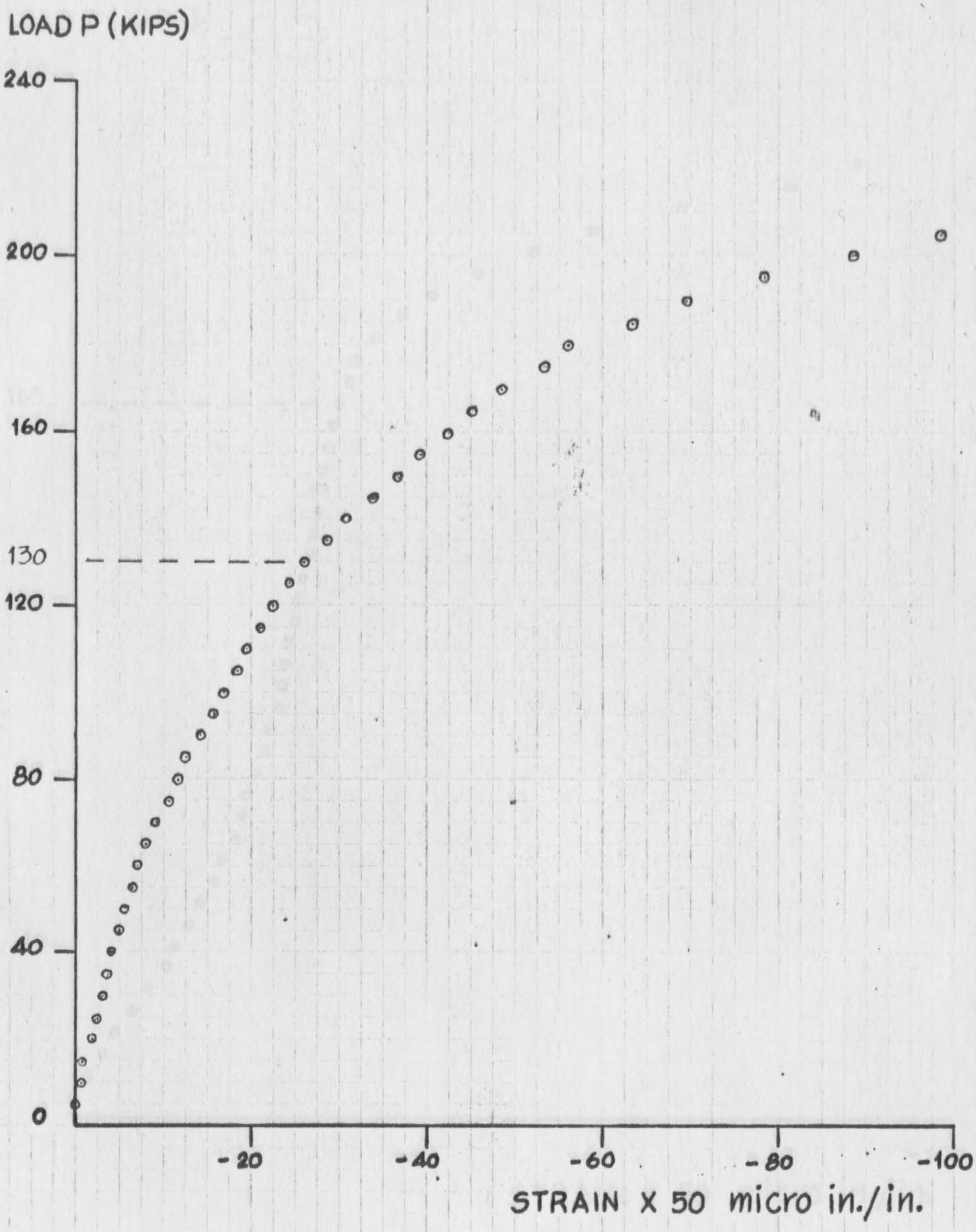


FIG. 7.2 LOAD-STRAIN CURVE OF MODIFIED TWO BOLTS SPECIMEN, GAGE LOCATION (1)

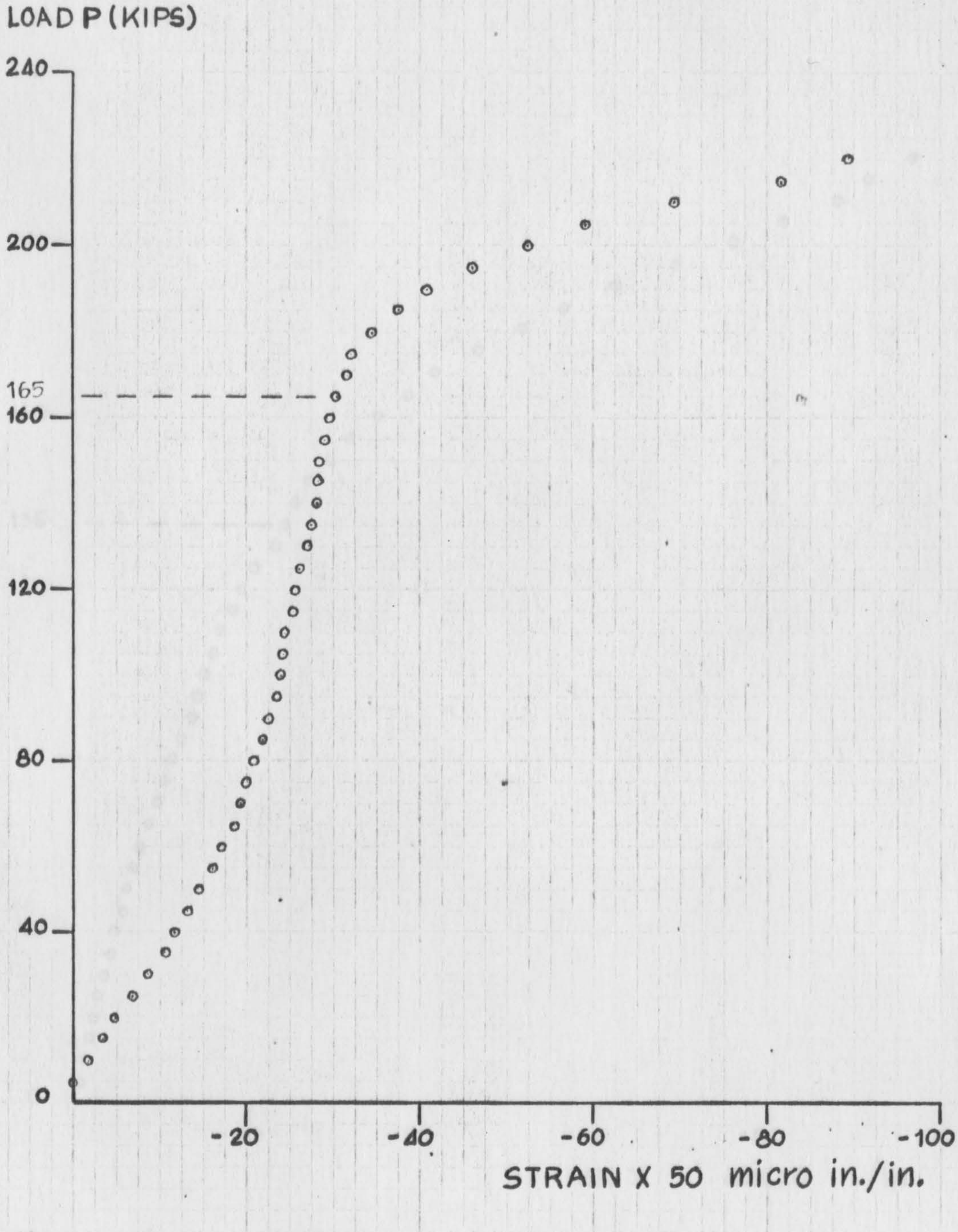


FIG. 7.3 LOAD-STRAIN CURVE OF MODIFIED TWO BOLTS SPECIMEN, GAGE LOCATION (4)

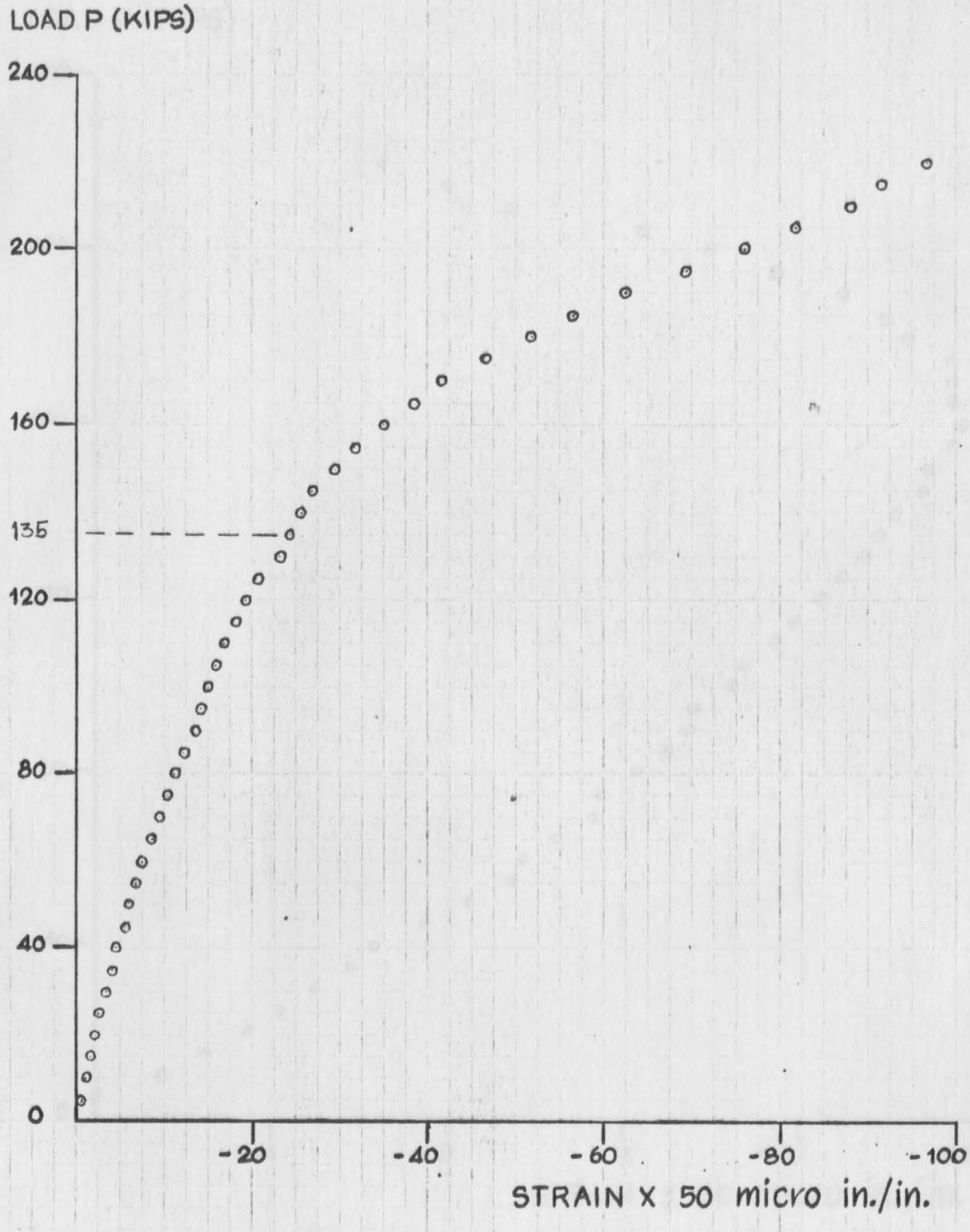


FIG. 7.4 LOAD-STRAIN CURVE OF MODIFIED TWO BOLTS SPECIMEN, GAGE LOCATION (5)

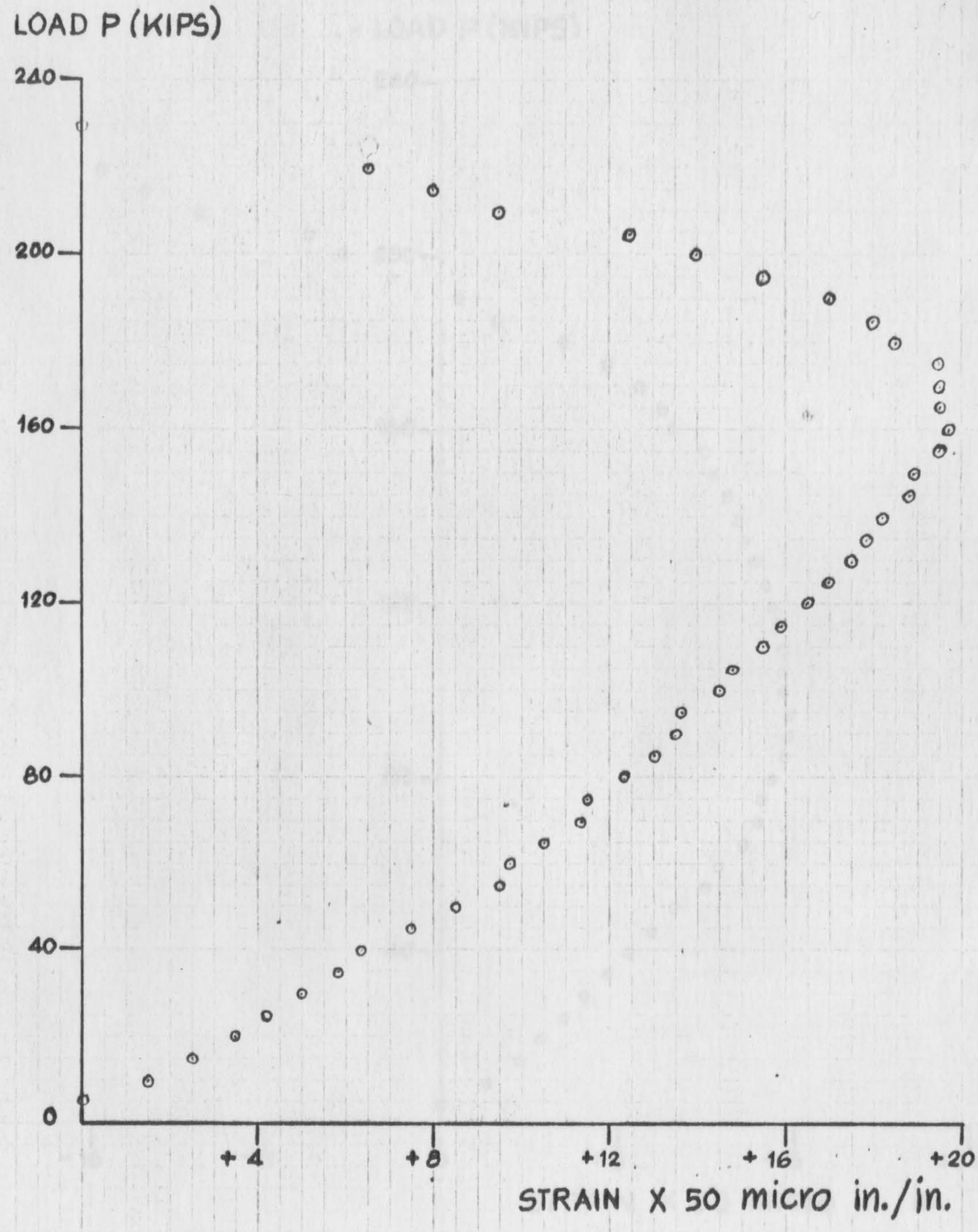


FIG. 7.5 LOAD-STRAIN CURVE OF MODIFIED TWO BOLTS SPECIMEN, GAGE LOCATION (2)

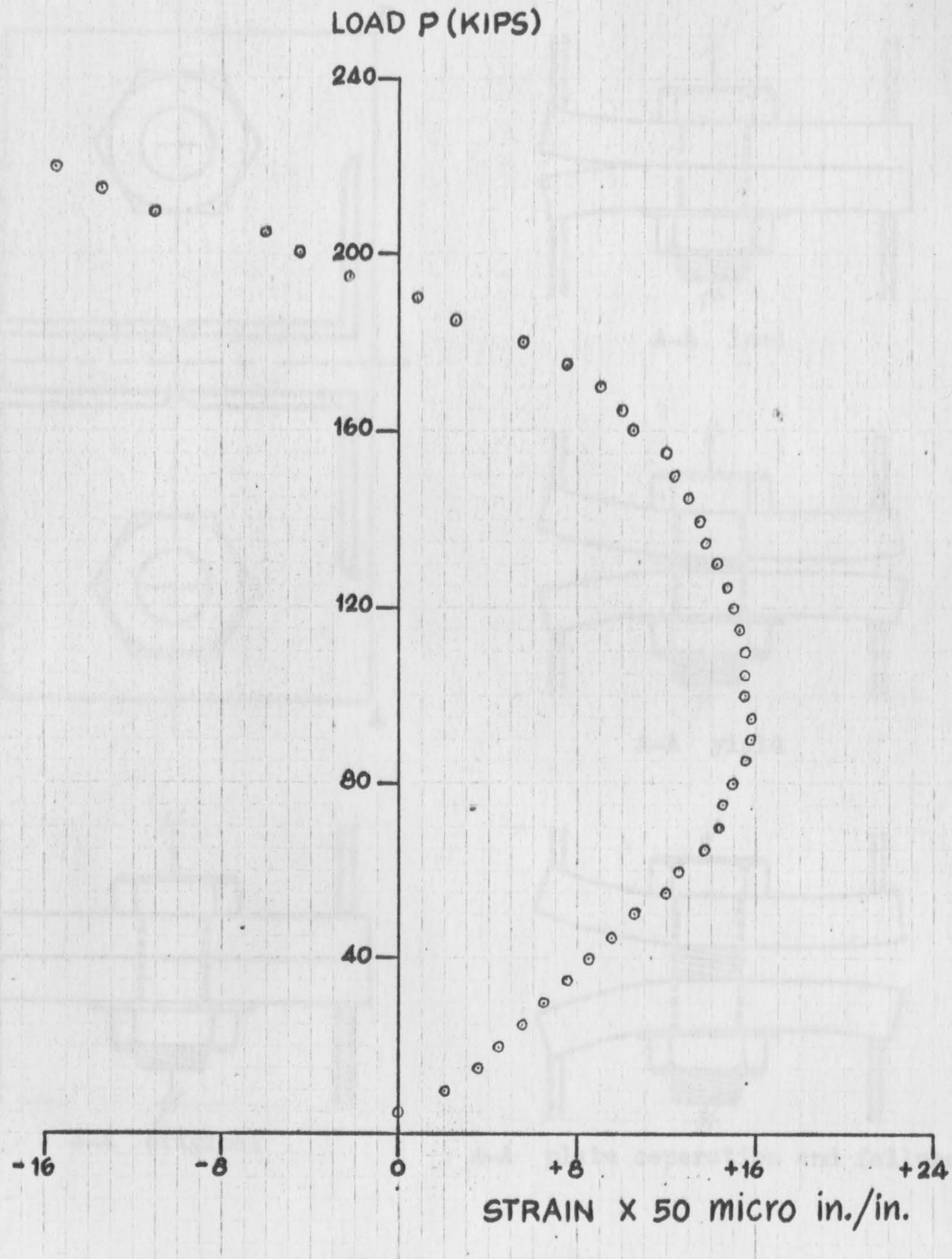


FIG. 7.6 LOAD-STRAIN CURVE OF MODIFIED TWO BOLTS SPECIMEN, GAGE LOCATION (6)

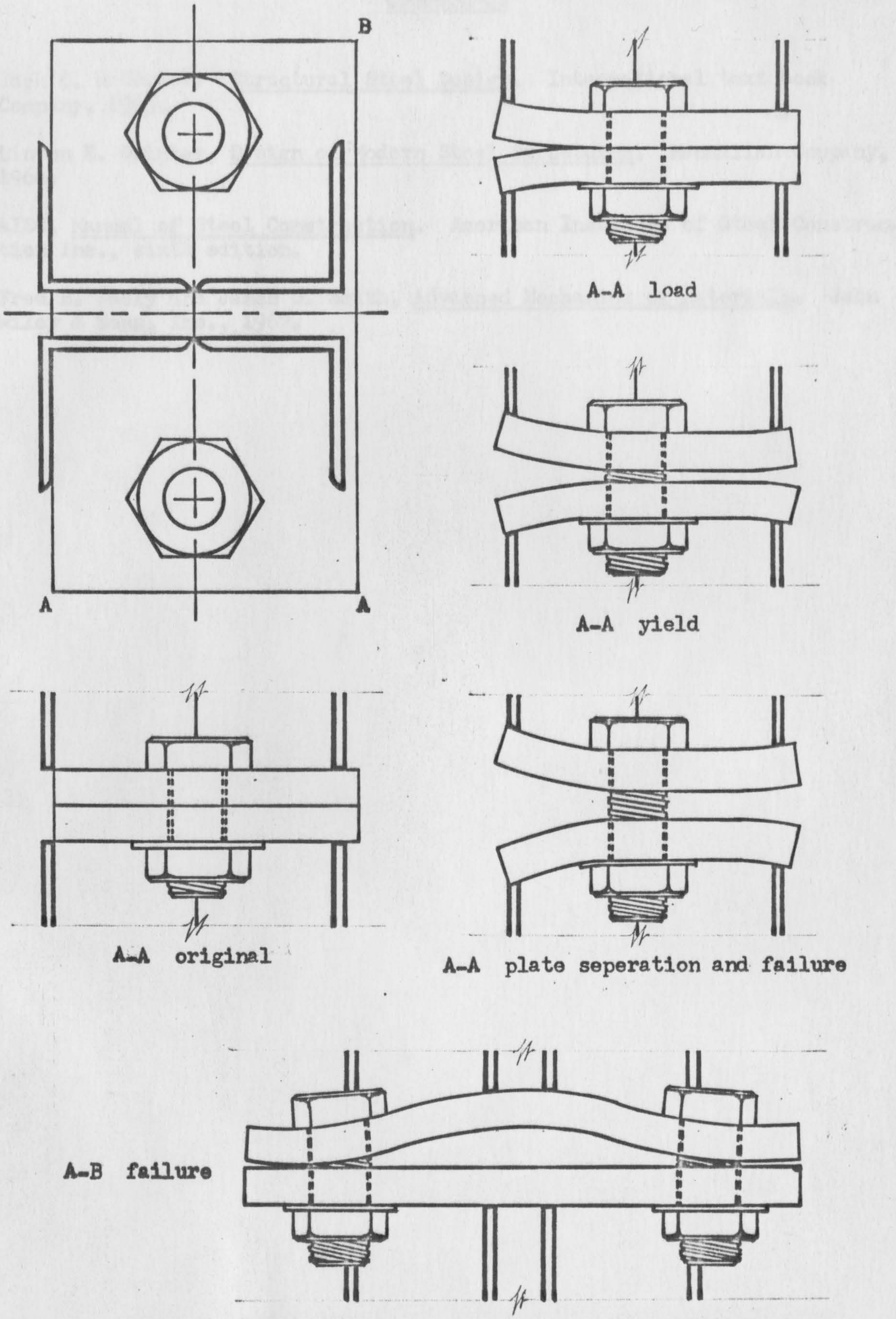


Figure 7.7 Failure of modified two bolts specimen

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