"AN EXPERIMENTAL INVESTIGATION OF STRESS RELATIONS AMONG THE RIVETS OF A WEB SPLICE".

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- 1935 -

Submitted in Partial Fulfillment of the Requirements

for the Degree
of

Bachelor of Science

from the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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487 Commonwealth Avenue

Boston, Massachusetts

May 15, 1935

Sewell
Professor ~~Allyne L. Merrill~~
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge, Massachusetts

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In accordance with the requirements for the Degree of Bachelor of Science in Architectural Engineering, I herewith submit the accompanying thesis for your approval.

Respectfully yours

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ACHNOWLEDGMENTS

The assistance of Professor William H. Lawrence, Professor Ralph G. Adams and Mr. Robert W. Vose is gratefully acknowledged.

INTRODUCTION

Purpose

The object of the investigation was to determine the stress relations among the rivets of a web splice of the type shown on page 11a, in order to check the method of design now in use.

Scope

Inasmuch as the funds available were limited and the cost of the specimen large, it was possible to test only one splice. However, it is believed that the results obtained are representative.

Method

A splice was designed on the basis that each rivet group in any one plate resisted a moment due to the deflection of the plate. The center plates were made so thick that if the above theory was true, some of the rivets in one of their groups would be stressed twice as much as any rivet in the outer plates. Thus, if this theory was true rather than the one that the stress in the rivets varied directly as the distance of the rivets from the center of gravity of the web section, it would be evident by any reasonable method of measuring rivet stresses.

SUMMARY

Problem

The problem resolved itself into two principal parts; one, to design the desired splice, and two, to determine the stresses in the rivets.

Solution

The design of the splice is given in Appendix A, Page 14.

It was decided that only a qualitative indication of the relative stresses among the rivets was necessary. An attempt was made to do this by boring holes longitudinally through the rivets, and measuring the deflection of the rivets under stress by passing the largest drill rod possible through the hole. As the hole decreased in size through shear, only a smaller drill rod would be accepted. The strain should give an indication of the stress, especially below the plastic limit.

Conclusions

The following conclusions were reached.

1. The stresses in the rivets of a web splice are extremely variable and incapable of close computation.

2. The stresses in the rivets of a web splice vary approximately as their distance from the center of gravity of the web section.

3. The method outlined of measuring the relative stresses

in rivets is satisfactory when only a qualitative indication is necessary.

BODY OF THESIS

Method of Measurement.

As a preliminary, the splice shown on page11a was designed, the work given in Appendix A, page 14 .

The first problem to arise was in what manner could the relative stresses in the rivets be measured. One method thought of was to mark the rivets, mark spots on the web, and take the changes in the relative positions under loadings. Not only would this have been a very tedious process, but the distortion in the web would probably have made the readings worthless as an indication of the distortion in the rivets.

Finally, just when it seemed as if the thesis would have to be given up, Mr. Vose had the idea of boring holes longitudinally through the rivets, and measuring the distortion of these holes and therefore of the rivets by the use of graduated sizes of drill rods. This sounded like a good idea, but several phases had to be investigated in order to prove its worth. Possibly the distortion of the rivets would be so small before the flow point was reached, that it would be impossible to determine. The diameters of the drill rods varies usually between .002 and .003 of an inch. Furthermore, drill holes through thick pieces of metal do not always turn out straight.

Since the distortion of a rivet under stress was not known, it was felt that the only way to determine if the gradation of the drill rods was fine enough, was by experiment.

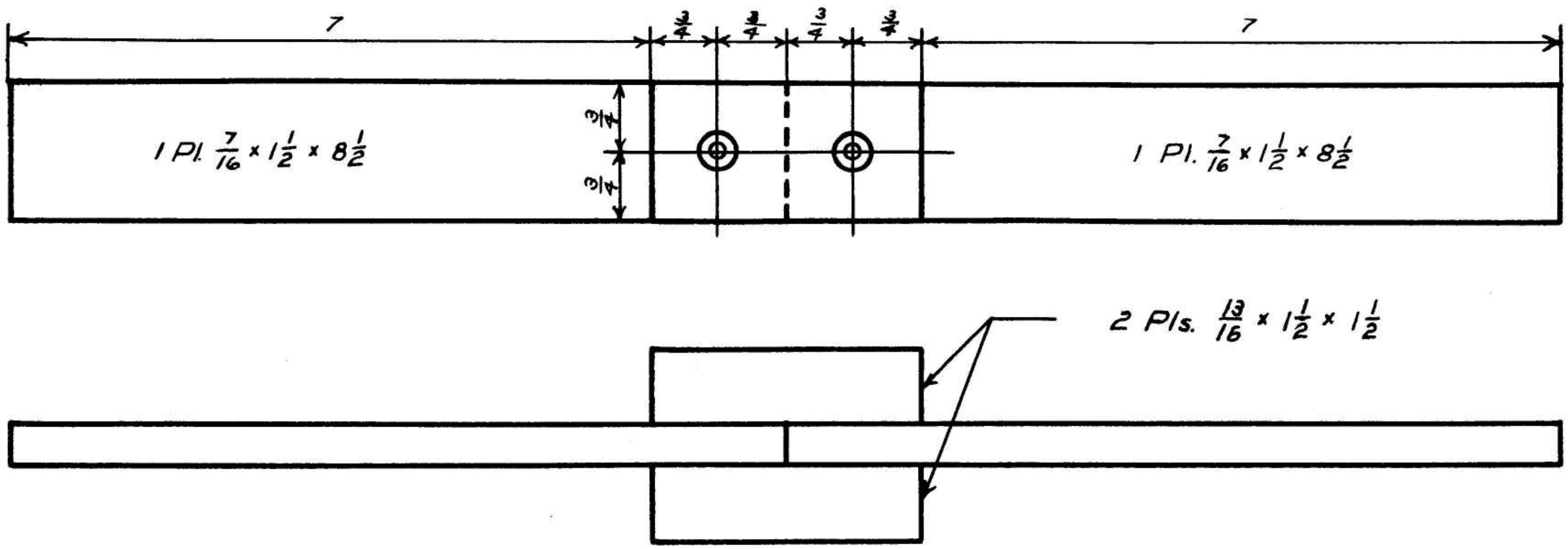
There was some question as to the manner in which the rivets would distort. They might shear, or they might bend sharply. In either case, a large enough distortion would probably be indicated by the drill rod.

As purchased, drill rods are of mild, untempered steel. These rods are not flexible enough to become adapted to a sharp bend. On the other hand, it seemed likely that any slight curve in the hole caused through drilling would not prevent the rod from passing through the hole. The size of the drill hole was a serious consideration. A large hole would be easy to drill and would be straight, but it would materially weaken the rivet in shear. Also if the rivet wall was too thin, the hole might be distorted by compression on the rivet rather than by shear.

A trial piece was designed as shown on page 9-a, in order that the measuring method be tested before building the large and expensive specimen. One was made with 5/64" drill holes, one with 3/32" drill holes, and one with 7/64" drill holes. These were tested in pure tension. The plates were purposely made the same thickness as the center plates and web of the large splice so that the conditions would be as nearly the same as possible. The drill rods were rounded off for about 1/8" on the ends.

The data on the tests is presented on page 9-b. These tests show that stress is indicated at about one-third the ultimate strength of the rivet. Until considerable yield has taken place, the rivets of each group show a good similarity in their distortion readings. This is a good and convenient

TYPICAL TRIAL PIECE



Scale: 1/2" = 1"
Rivet holes drilled and reamed to 3/8"

Dia. of ROD PASSING
d = drag felt on rod
t = tight fit
vt = very tight fit

DATA ON TRIAL SPECIMENS

LOAD-#	3 SPECIMENS					
	5/64" DRILL HOLE		3/32" DRILL HOLE		7/64" DRILL HOLE	
	RIVET-1	RIVET-2	RIVET-1	RIVET-2	RIVET-1	RIVET-2
0	.0790	.0790	.0950	.0950	.1110	.1110
500	.0790	.0790	.0950	.0950	.1110	.1110
1000	.0790	.0790	.0950	.0950	.1110	.1110
1500	.0790	.0790	.0950	.0950	.1110	.1110
2000	.0790	.0790	.0950	.0950d	.1110	.1110
2500	.0790	.0790	.0950	.0950d	.1110	.1110
3000	.0790	.0790d	.0950	.0950t	.1110 d	.1110
3500	.0790 d	.0790 d	.0950d	.0950t	.1110t	.1110d
4000	.0790 d	.0790 d	.0950t	.0950vt	.1110vt	.1110d
4500	.0790t	.0770d	.0950vt	.0950vt	.1110vt	.1110d
5000	.0750vt	.0750 d	.0950vt	.0950vt	.1060t	.1110d
5500	.0720vt	.0720t	.0920	.0920	.1030t	.1110d
6000	.0690t	.0690d	.0920d	.0920d	.0990t	.1110t
6500	.0630t	.0660t	.0920vt	.0920vt	.0920t	.1080d
7000	.0595t	.0630t	.0875	.0875	.0850t	.1060vt
7500	.0550t	.0595vt	.0875vt	.0875vt	.0770t	.1010d
8000	.0500vt	.0500vt	.0810t	.0810	.0630t	.0950t
8500	.0420vt	.0420vt	.0770t	.0750vt	.0500vt	.0875vt
9000	holes	closed	.0690vt	.0630vt	broke 8500#+	
9500			.0550vt	.0390vt		
				broke 9500#+		

method of making qualitative measurements of the stresses in rivets. Most of the failure in the rivets was due to pure shear.

The 3/32" drill hole was selected as the best for the 3/8" rivet. The 5/64" drill hole was a little too difficult to drill. The 7/64" drill hole did not give as good results as the others, and was evidently too large for the rivet.

Splice Investigation

In designing the splice, it was kept as small as possible. The number of rivets could not be too small, or the splice would not be representative.

In order to save money and time only part of the rivets were drilled. Those drilled are indicated and numbered in the figure on page 11-a. The action of the splice probably was not affected much by the drill holes. They are relatively small and are symmetrically placed.

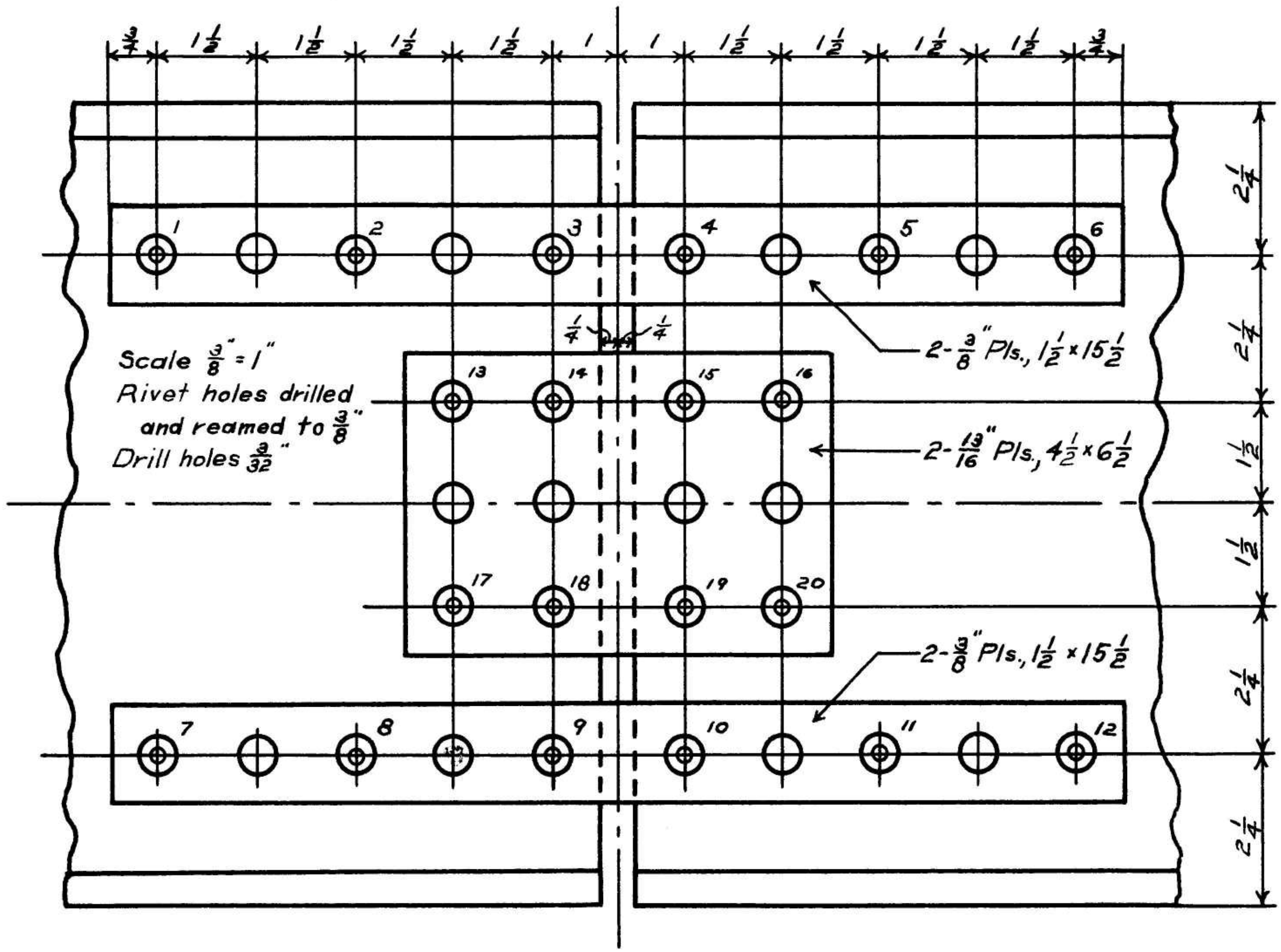
Rivets 13 - 20 were chosen because they would be the highest stressed ones in the center plate. Rivets 1 - 12 were chosen as representative of those in the outer plates. 3/32" holes were drilled. In all drill holes it was necessary to burr out the ends. A small rat-tail file was used for this purpose. A little "3 in 1" oil placed on the rods was helpful.

The loading was as shown on page 11-b. Point supports were used and applied through 9" plates under the beam. The forces were transmitted to the beam through one small round rod and one small square rod, which amounted to points.

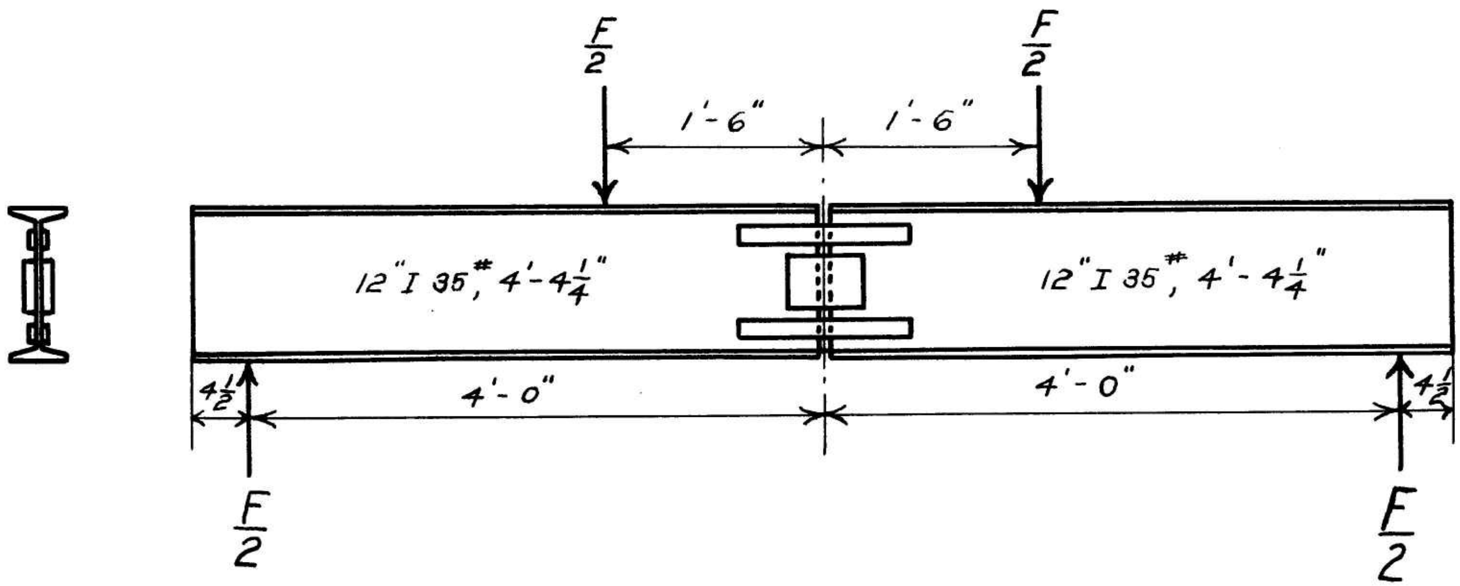
A 400,000 point Rheile testing machine was used because it was convenient to work with and because it was not necessary to have a high degree of accuracy in the loading. The rivets probably remained deformed even after some of the load was removed, so once a loading was reached, it was used.

At 28,800#, the distortion had become so large that it was obviously useless to take any further measurements. The splice sustained a maximum load of about 32,000#. Failure

DETAIL OF SPLICE



TEST SPECIMEN SHOWING LOADING



Scale: 3/4" = 1'

occurred in the rivets. Some could be heard to snap.

The web was designed on the basis of plate deflection so that rivets 13 - 20 would be stressed twice as much as rivets 1 - 12. The data for the experiment is presented on pages 12a-12c. It is very difficult to determine whether a certain feel of the rod represents a drag, a tight fit, or a very tight fit. In taking a great number of measurements, one's psychology is very likely an appreciable factor. In order that the "feel" with its accompanying designation might not be lost, the whole experiment was carried out in one stretch.

In some cases the rod dragged, became a tight fit, and then a loose fit again. This was evidently an anomaly disconnected with the stress in the rivet. It was probably caused by a little sliver of steel remaining in the hole.

The data definitely proves that the method by which the splice was designed is wrong. Not only did rivets 13 - 20 fail to be stressed twice as much as rivets 1 - 12, they actually were stressed less. An average of the loads at which the first indication of distortion appeared in rivets 13 - 20 was about 15,000 pounds. The same average for rivets 1 - 12 was about 10,000 pounds. On the second indication the average for rivets 13 - 20 was about 19,500 pounds, for rivets 1 - 12 about 14,000 pounds. As the load was increased the difference between the distortions of the two groups became less.

It is difficult to make any general conclusions from the preceding. As long as the elastic limit is not greatly exceeded, the data indicates a stress in rivets 13 - 20 of about 2/3 that

DIA. of ROD PASSING
d = drag felt on rod
t = tight fit
vt = very tight fit

DATA ON TEST SPLICE

LOAD-#	RIVET NUMBER						
	1	2	3	4	5	6	7
0	.095	.095	.095	.095	.095	.095	.095
3000	.095	.095	.095	.095	.095	.095d	.095
4350	.095	.095	.095	.095	.095	.095d	.095
5000	.095	.095	.095	.095	.095	.095d	.095
6200	.095d	.095	.095	.095	.095	.095d	.095
7100	.095t	.095	.095	.095	.095	.095d	.095
8000	.095vt	.095	.095	.095	.095	.095d	.095
9100	.092	.095d	.095	.095d	.095	.095d	.095
10000	.092	.095d	.095d	.095	.095	.095d	.095
11000	.092	.095t	.095t	.095t	.095	.095t	.095d
12000	.092	.095t	.095vt	.095vt	.095	.095d	.095d
13000	.092d	.095vt	.095vt	.093vt	.095	.095d	.095t
15225	.088	.092d	.095vt	.092	.095	.095d	.095vt
16875	.088	.092t	.092	.092	.096d	.095d	.092
18300	.088vt	.088	.092vt	.092d	.092	.095t	.092
19325	.085t	.088d	.088	.088	.088	.095vt	.092
20800	.081t	.088vt	.088vt	.088d	.088	.092	.092vt
22150	.079t	.085vt	.085vt	.085d	.088	.092vt	.088
23550	.075t	.081vt	.081vt	.085vt	.088vt	.088	.088
24975	.069t	.077vt	.072vt	.077t	.081	.085vt	.085d
28800	.045	.050	.042	.050	.069	.069	.075

DATA ON TEST SPLICE

LOAD-#	RIVET NUMBER						
	8	9	10	11	12	13	14
0	.095	.095	.095	.095+	.095	.095	.095
3 000	.095	.095	.095	.095+	.095	.095	.095
4 350	.095	.095	.095	.095+	.095	.095	.095
5 000	.095	.095	.095	.095+	.095	.095	.095
6 200	.095	.095	.095	.095+	.095	.095	.095
7 100	.095	.095	.095	.095vt	.095	.095	.095
8 000	.095	.095d	.095	.095vt	.095	.095	.095
9 100	.095	.095+	.095	.095vt	.095d	.095	.095
10 000	.095	.095+	.095	.095vt	.095d	.095d	.095
11 000	.095	.095+	.095	.095vt	.095d	.095d	.095d
12 000	.095d	.095vt	.095	.095vt	.095d	.095d	.095
13 000	.095d	.095vt	.095d	.095vt	.095+	.095d	.095d
15 225	.095d	.092d	.095vt	.095vt	.095vt	.095d	.095d
16 875	.095d	.092+	.095vt	.095vt	.095vt	.095d	.095+
18 300	.095+	.092vt	.092+	.095vt	.095vt	.095d	.095vt
19 325	.095vt	.092vt	.092+	.095vt	.092d	.095+	.092
20 800	.095vt	.092vt	.092vt	.095vt	.092+	.092d	.088
22 150	.092vt	.088+	.088d	.092+	.092vt	.092vt	.088d
23 550	.092vt	.088vt	.088vt	.092vt	.088d	.088+	.085+
24 975	.088d	.081vt	.081+	.088+	.088+	.085vt	.079
28 800	.079	.063	.063	.081	.079	.066	.060

DATA ON TEST SPLICE

LOAD-#	RIVET NUMBER						
	15	16	17	18	19	20	
0	.095	.095	.095	.095d	.095	.095	
3000	.095d	.095	.095d	.095d	.095	.095	
4350	.095d	.095	.095d	.095d	.095	.095	
5000	.095d	.095	.095d	.095d	.095	.095	
6200	.095	.095	.095d	.095d	.095	.095	
7100	.095	.095	.095	.095t	.095	.095	
8000	.095	.095	.095	.095d	.095	.095	
9100	.095	.095	.095	.095d	.095	.095	
10000	.095	.095d	.095	.095t	.095	.095d	
11 000	.095	.095d	.095	.095t	.095	.095d	
12 000	.095	.095d	.095	.095d	.095	.095d	
13000	.095	.095d	.095	.095	.095	.095d	
15225	.095	.095d	.095d	.095d	.095d	.095d	
16 875	.095d	.095d	.095	.095d	.095	.095	
18 300	.095t	.095t	.095	.095vt	.095d	.095	
19 325	.095vt	.095t	.095vt	.092	.095d	.095	
20 800	.092d	.092	.092t	.088	.095vt	.095vt	
22 150	.088	.092vt	.088d	.088d	.092vt	.092d	
23 550	.088vt	.088d	.085t	.085d	.088d	.088d	
24 975	.081	.085t	.079d	.079d	.081	.081	
28 800	.069	.072	.060	.063	.066	.066	

in rivets 1 - 12. Upon the straight line theory, the stress would be less than 1/2. This may be caused partly by the exceptional stiffness of the center plates, but conditions in the splice are so varying that it would hardly seem justifiable to say that the straight-line theory does not hold approximately true. In fact, the strongest and most general conclusion reached is that the stress distribution among the rivets of a web splice is very erratic and does not lend itself to exact computation.

At the end of the experiment the outer plates appeared to be strained whereas the center plates did not. A possible reason for the decrease in the difference between the stresses in the two sets of rivets with increased loads is that as the outer plates became more distorted, the center plates took a larger share of the load, thus increasing the stress in their rivets.

After the test, which progressed without any difficulties, the specimen was left in the testing materials laboratory. The splice is of no further value.

APPENDIX A

The design of the splice is based upon the following working stresses:

shearing value	= 12,000 #/sq.in.
bearing value	= 24,000 #/sq.in.
double shear value of 3/8" rivet	= 2,654#

Moment of resistance of a rivet group in center plates,

of rivets 13,14,17,18 $= 4 \times 2{,}654 \times 1.677 = 17{,}780$

of center rivets $= 2 \times 2{,}654 \times \frac{.75}{1.677} \times .75 = 1{,}780$

Total = 19,560 in.lb.

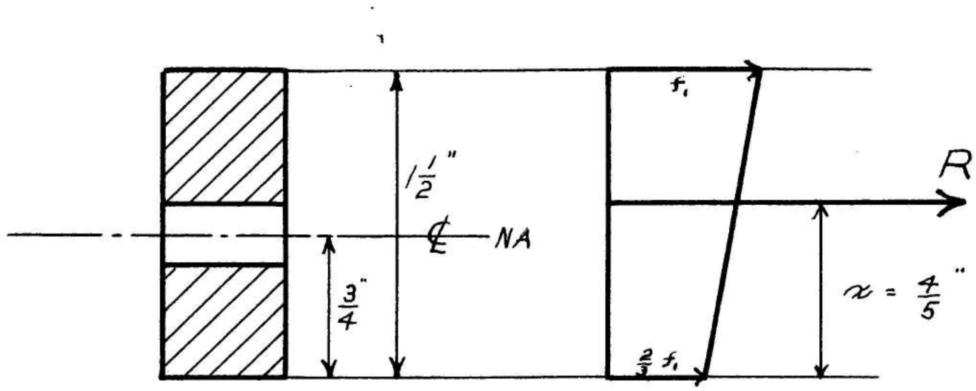
Design the rest of the splice on the basis that the resisting moment of the group in the center plates is 39,120 in.lb. This provides a factor of safety of 2, which should surely prove the theory if it is true.

f_1 = stress at outer edge of outer plates

f_2 = stress at inner edge of outer plates

f_3 = stress at outer edge of inner plates

$$f_2 = f_1 \times \frac{3}{4\frac{1}{2}} = \frac{6}{9} f_1 = \frac{2}{3} f_1$$



Net Cross Section of Outer Plate

Resultant of Stress on Gross Section of Outer Plate

$$Rx = (\frac{6}{9} f_1 \times \frac{3}{2}) \frac{3}{4} + (\frac{f_1 3}{9} \times \frac{1}{2} \times \frac{3}{2}) \frac{2}{3} \times \frac{3}{2} = x (\frac{3}{2} \times \frac{6}{9} f_1 + \frac{3}{9} f_1 \times \frac{1}{2} \times \frac{3}{2})$$

$$x = \frac{\frac{6}{12} + \frac{3}{18}}{\frac{6}{9} + \frac{3}{18}} = \frac{(3 + 1) \times 6}{6 \times 5} = \frac{4}{5}" = .800 \text{ in.}$$

for outer plates, assuming 1 inch width

$$\frac{P}{A} = \frac{R}{1\frac{1}{8}} = \frac{f_1(\frac{18}{18} + \frac{9}{36})}{1\frac{1}{8}} = \frac{10}{9} f_1$$

moment of R about NA

$$= .050 \times \frac{10}{9} f_1 = .0556 f_1 \text{ in. lbs.}$$

fiber stress due to moment

$$= \frac{My}{I} = \frac{.0556 f_1 \times \frac{3}{4}}{\left[\frac{1.5^3}{12} - \frac{(\frac{3}{8})^3}{12}\right]} = .1489 f_1 \text{ lb. per sq.in.}$$

f_4 = stress at outer edge of outer plate at net section.

$f_4 = 1.111\ f_1 + .149\ f_1 = 1.260\ f_1$

$\therefore$ when f_4 = 18,000 lb./sq.in., f_1 = 14,300 #/sq.in.

$f_3 = \frac{1}{2} f_1$ = 7,150 lb./sq.in.

when combined thickness of center plates = 1 in.

$$M = \frac{f\ I}{y} = \frac{7,150 \times 9 \times 4}{12 \times 2^3 \times 9} = 24,100 \text{ in.lb.}$$

twice moment of resistance of rivets = 39,120 in.lbs.

combined thickness of center plates must be

$$= \frac{39,120}{24,100} = 1.621 \text{ in.}$$

use 2 - $\frac{13}{16}$ in. plates, + = 1.624 ins.

R necessary to develop full moment of resistance of rivets in outside plate

$$\frac{P}{A} \text{ for each rivet } = \frac{R}{3}$$

M = force due to moment of R which is out of line with the rivets

$$R \times \frac{1}{20} = M \times 3, \quad M = \frac{3}{20} R$$

$$F = \sqrt{M^2 + (\frac{P}{A})^2} = 2,654 \text{ (allowable double shear)}$$

$$R \sqrt{\frac{9.00}{400} + \frac{1}{9}} = 2,654, \qquad R = 7,260 \text{ lbs.}$$

For 1 in. thickness of plate

$$R = \frac{6}{9} f_1 \times 1\frac{1}{2} + \frac{3}{9} f_1 \times \frac{1}{2} \times 1\frac{1}{2} = \frac{5}{4} f_1 = \frac{5}{4} \times \frac{f_4}{1.260}$$

when R = 7,260, f_4 = 7,310 lb./sq.in.

combined thickness of plates should then be

$\frac{7,310}{18,000}$ = .406 in. (too thin)

try five rivets

$$\frac{P}{A} = \frac{R}{5}, \quad R \times \frac{1}{20} = M \times 6 + \frac{M}{2} \times 3 = \frac{15}{2} M, \quad M = \frac{R}{150}$$

$$F = R\sqrt{\frac{1}{25} + .0000445}, \quad R = \frac{2,654}{.200} = 13,270 \text{ lbs.}$$

$$f_4 = \frac{13,270 \times 1.26}{1.25} = 13,380 \text{ lb./sq.in.}$$

combined thickness = $\frac{13,380}{18,000}$ = .742

use 2 - $\frac{3}{8}$ in. plates = .750 in.

thickness of I beam necessary to prevent crushing

= .295" , using factor of safety of $1\frac{1}{2}$ = .442"

$\frac{7''}{16}$ = .437

Moment that beam section must resist

(roughly)

$f_1 = 14,300$, $f_2 = 9,540$, $f_3 = 7,150$

moment of center plates = 39,120 in.lb.

moment of outer plates

$$\frac{23,840}{2} \times \frac{3}{2} \times \frac{3}{4} \times 7.60 = 102,000 \text{ in.lb.}$$

total moment = 141,000 , say 150,000 in.lb.

Use American Standard I Beam

12" x 5", B9 x 35 lb., $+ = \frac{7}{16}$ in.

maximum moment = 57,000 ft.lbs.

maximum shear = 62,000 lbs.

It will be noticed that the splice is designed for zero shear. This is because, under the system of loading used, there is no shear at the splice section.