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INVESTIGATION OF THE STRENGTH OF RIVETED JOINTS IN COPPER SHEETS

A REPORT OF AN INVESTIGATION
CONDUCTED BY
THE ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS
IN COOPERATION WITH
THE COPPER AND BRASS RESEARCH ASSOCIATION

BY
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AND
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ABSTRACT

A riveted joint connecting copper sheets might fail in any one of the following ways: (1) By tearing out of rivets to the edge of the sheet; (2) by shearing the rivets; (3) by the bearing pressure of the rivets against the edge of the holes in the sheet; (4) by tension failure of the sheet between the rivets.

A joint of balanced design is one that is equally liable to all types of failure.

A casual study of the problem might lead to the conclusion that the ideal joint is one equally liable to all methods of failure, that is, a joint of balanced design. Actually, excess strength against tearing out of rivets to the edge of the sheet, by shearing the rivets, and by excess bearing of the rivets against the edge of the holes in the sheets, can be obtained at small cost. In contrast with this, additional strength of the sheet between rivets can be obtained only at a relatively large cost. For this reason, it is desirable to have the strength against the first three methods of failure somewhat greater than the strength of the sheet in tension. If this is true, then the strength of the sheet is the strength of the joint; and the strength of the joint depends upon the rivet pattern.

The tests described in this bulletin were planned to determine the strength of riveted joints against failure by each of the four methods described. In addition, several series of tests were made to determine the effect of the rivet pattern upon the strength of the sheets. Some of the specimens were lap joints, others were double-strap butt joints. Some of the lap joints had a single row of rivets, others had two rows and still others, three rows of rivets. Likewise, some of the butt joints had a single row of rivets, others had two rows and still others had three rows of rivets on each side of the joint. The sheet thickness for the various joints varied from 0.060 in. to 0.375 in., and the rivet diameter varied from ⅛ in. to ½ in. All rivets were driven cold. Small rivets were driven with a hand hammer, large rivets were driven with a pneumatic riveting hammer. Tests were also made to determine the relation between the load and the slip of the rivets and between the load and the separation of the sheets at the edge of the joint. The physical properties of the sheets of all thicknesses were determined by tension tests of coupon specimens. Tests were also made to determine the shearing strength of undriven rivets of all diameters. A total of 220 riveted joints was tested.

The following findings are of particular interest:

The ratio of the shearing strength of the rivets of a riveted joint to the shearing strength of similar undriven rivets varied from approximately 1.00 for ½-in. rivets to a value of the order of 1.25 for $\frac{3}{16}$-in. rivets.

The ratio of the tensile strength of the sheets of a riveted joint to the coupon strength of the same sheets varied from 0.88 to slightly more than 1.00 and was approximately the same for lap joints as it was for butt joints.

The efficiency by test of lap joints had values ranging from 0.56 for the least efficient joints with a single row of rivets to 0.85 for the most efficient joints with a triple row of rivets with alternate rivets omitted from the outer row.

The efficiency by tests of double-strap butt joints had values ranging from 0.55 for the least efficient joints with a single row of rivets on each side of the joint to 0.87 for the most efficient joints with a triple row of rivets on each side of the joint, the rivet spacing being four times as great for the outer as for the inner row of rivets.

The results of the tests are summarized in considerable detail in Section 27, page 78.

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INVESTIGATION OF THE STRENGTH OF RIVETED JOINTS IN COPPER SHEETS

I. Introduction

1. *Object and Scope of Investigation.*—A riveted joint connecting copper sheets might fail in any one of the following ways, depending upon the relative strength of the respective parts:

(1) By tearing out of rivets to the edge of the sheet

(2) By shearing the rivets

(3) By tension failure of the sheet between the rivets

(4) By the bearing pressure of the rivets against the edge of the sheet, upsetting or tearing the sheet.

For a riveted joint to be of balanced design, it should be equally safe against failure by each of the four methods of failure described in the previous paragraph; and in order to design such a joint it is therefore necessary to know the magnitude of the load required to produce each of the four types of failure. In order to get this information it was necessary to test joints designed to fail by each of the methods described.

It is relatively inexpensive to increase the strength of a riveted joint against failure by tearing out of rivets to the edge of the sheet, by rivet shear or by rivet bearing. In the first case the strength can be increased by increasing the edge distance of the rivets, in the second and third cases by increasing either the number or the size of the rivets. But, for a joint of a given rivet pattern, the strength of the sheet in tension on a section through the outer row of rivets can be increased only by increasing the thickness of the sheet. This is expensive if the sheet is long, as it often is, and should be avoided. The alternative is to select a rivet pattern that results in the greatest tensile strength of the sheet. The procedure, then, in getting information which would be useful in the design of riveted joints connecting copper sheets, would seem to consist of two parts: first, determine the unit strength that can be developed against failure by tearing out the rivets to the edge of the sheets, by rivet shear, and by rivet bearing; second, determine the rivet pattern that will give the greatest efficiency against failure by sheet tension. The tests described in this bulletin have been planned to attain these two objectives.

The specimens include lap joints and double-strap butt joints with single, double, and triple rows of rivets. The joints of the various series were designed to fail in a specified manner in each instance, some by rivet shear, others by rivet bearing, by the rivets tearing out to the edge of sheets, or by sheet tension. The variables studied include rivet pattern, rivet diameter, sheet thickness, and edge distance of the rivets. The rivet diameters, in inches, were ⅛, $\frac{3}{16}$, ¼, $\frac{5}{16}$, ⅜, and ½; the sheet thicknesses, in inches, were 0.060, 0.090, 0.113, 0.185, 0.245, and 0.375.

The physical properties of the sheets were determined from standard tension tests of coupons cut from the various sheets, and the shearing strength of the rivets was determined from shear tests of undriven rivets taken from the same lot as the rivets used in making the joints that were tested.

This investigation was limited to static tests. The fatigue strength of similar joints might well be made the object of another investigation. The load which a joint can withstand without leaking is being investigated.

2. *Acknowledgments.*—The tests described in this bulletin are a part of an investigation resulting from a cooperative agreement entered into by the Engineering Experiment Station of the University of Illinois, of which DEAN M. L. ENGER is the Director, and the Copper and Brass Research Association, of which T. E. VELTFORT is the Manager. The tests were made in the Arthur Newell Talbot Laboratory of the University of Illinois by AHMET MUNCI OZELSEL, Special Research Associate in Civil Engineering, working under the direction of WILBUR M. WILSON, Research Professor of Structural Engineering. The direct expenses of the investigation were paid from funds provided by the Copper and Brass Research Association.

II. DESCRIPTION OF TESTS

3. *Description of Apparatus.*—The tests were made in three Riéhle testing machines with capacities of 50 000 lb., 100 000 lb., and 300 000 lb., respectively. Each machine was equipped with special pin-connected pulling heads of the type shown in Fig. 1. The pin insured centric loading, and the wide rigid clevis distributed the load across the width of the sheet, that is, along the length of the joint.

The slip between two sheets of a joint was measured with the instrument shown in Fig. 2. It consists of a taper pin that fits into a taper hole in the plates, and an Ames dial that indicates the distance the taper pin projects from the plate. The method of using the instrument is as follows: The taper pin is inserted, and a zero reading is taken to determine the projection of the pin before the joint is loaded.

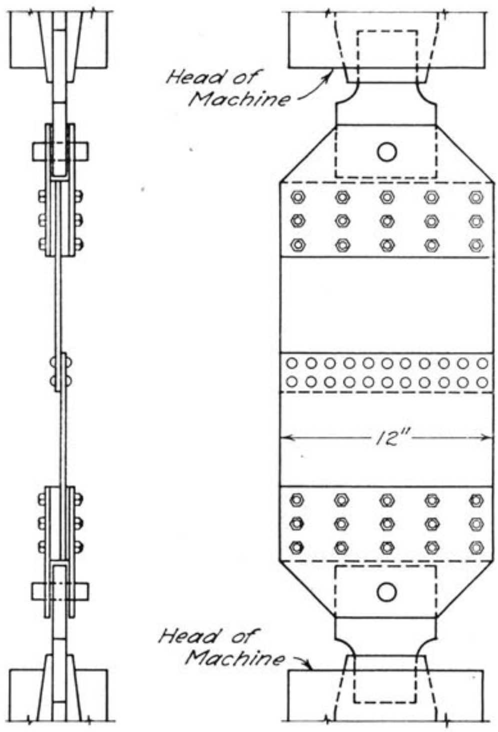


FIG. 1. SPECIMEN ATTACHED TO PULLING HEADS

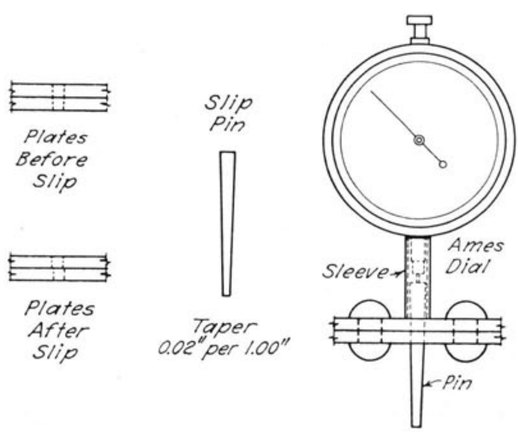


FIG. 2. GAGE FOR MEASURING SLIP

The pin is again inserted and its projection measured after an increment of load has been applied. If no slip has occurred the pin will project the same amount as originally, but if one sheet has slipped relative to the other, the pin will project farther than before. The change in projection and the taper of the pin determine the slip that has occurred. The pin used had a diameter of about ¼ in. and a taper (change in diameter) of approximately 0.02 in. per in.

A slightly different method was used in measuring the slip between two adjacent sheets of double-strap butt joints. The hole in one sheet, the sheet for which the slip was not being determined, was drilled larger than the pin, as shown in Fig. 3. Thus the projection of the pin measured the slip of the sheet not containing the large hole.

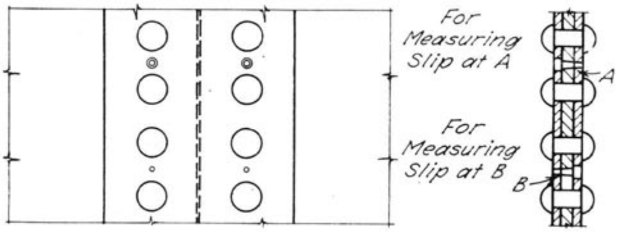


Fig. 3. Arrangement of Holes for Measuring Slip; Double-Strap Butt Joint

In the tests of lap-joint specimens with a single row of rivets, the separation of the sheets at the edges was measured with a thickness gage, as shown in Fig. 4. The opening at the edge of the sheet was read at the zero load and at subsequent loads. The differences represented the separation of the sheets due to the addition of the loads.

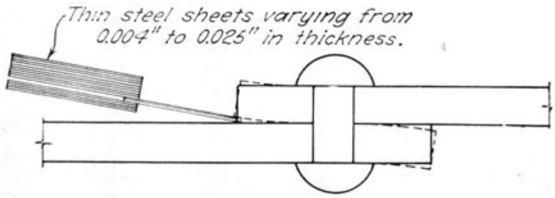


Fig. 4. Thickness Gage for Measuring the Separation of Sheets

4. *Types of Failure of Riveted Joints.*—As stated in Section 1, the objects of the tests of riveted joints connecting copper sheets were:

FIG. 5. FAILURE BY TEARING OUT OF RIVETS TO THE EDGE OF OUTSIDE SHEET, SPECIMEN CF-9A

first, to determine the unit strength that can be developed against failure (1) by tearing out of rivets to the edge of the sheets, (2) by rivet shear, and (3) by rivet bearing; second, to determine the rivet pattern that will give the greatest efficiency against failure by sheet tension. These methods of failure are described in more detail in the following paragraphs.

Failure by Tearing Out of Rivets to the Edge of the Sheet

Failure by tearing out of rivets to the edge of the sheet is shown by Figs. 5 and 6. Figure 5 shows specimen CF-9A after failure by tearing out of rivets to the edge of the outside sheet, and Fig. 6 shows specimen CB-31 after failure by tearing out of rivets to the edge of the inside sheet. This type of failure may be considered to be due to the longitudinal shear on the sheet resulting from the tendency of the rivets to force out the rectangular portion of the sheet between the rivet and the edge of the sheet, as shown in Figs. 5 and 6. This shear is not uniform, being greater near the rivet than it is near the edge of the sheet, but, for convenience in making computations, it will be considered to be uniform. The average unit sheet shear has been taken as being equal to $\frac{P}{4et}$ for the outside sheets and $\frac{P}{2et_1}$ for the inside sheet. In these expressions, P is the load per rivet, e is the distance from the center of the rivet to the edge of the sheet, t is the thickness of the outside sheet, and t_1 is the thickness of the inside sheet.

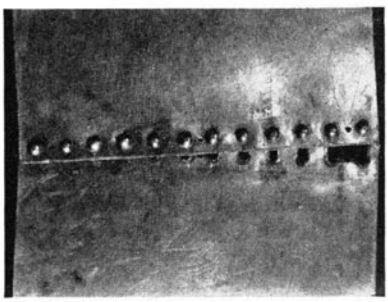


FIG. 6. FAILURE BY TEARING OUT OF RIVETS TO THE EDGE OF INSIDE SHEET, SPECIMEN CB-31

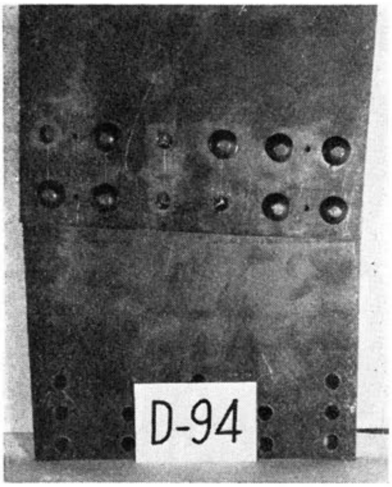


Fig. 7. Failure by Rivet Shear; Lap Joint with Double Row of Rivets, Rivets in Single Shear, Specimen D-94

Fig. 8. Failure by Rivet Shear; Double-Strap Butt Joint with Single Row of Rivets on Each Side of Joint, Rivets in Double Shear, Specimen DED-91

Failure by Rivet Shear

Specimens that failed by rivet shear are shown in Figs. 7 and 8. Figure 7 shows the failure of specimen D-94, a lap joint with rivets in single shear. Figure 8 shows the failure of specimen DED-91, a double-strap butt joint with rivets in double shear.

Failure by Bearing of Rivets on Edge of Sheet

Failure by excessive bearing of rivets on the edge of the sheet is shown by Fig. 9. The effect of excessive rivet bearing is to upset the sheet at the edge of the rivet hole and, if the bearing is further increased, eventually to tear the sheet. It is sometimes difficult to distinguish between failure by rivet bearing and tearing out of rivets to the edge of the sheet. The latter type of failure occurs with a small edge distance and the former occurs with a large edge distance.

Tension Failure of Sheet Between Rivets

Figures 10, 11, 12, and 13 show the failure of joints by sheet tension on a section through the rivet holes. The specimens of Figs. 10

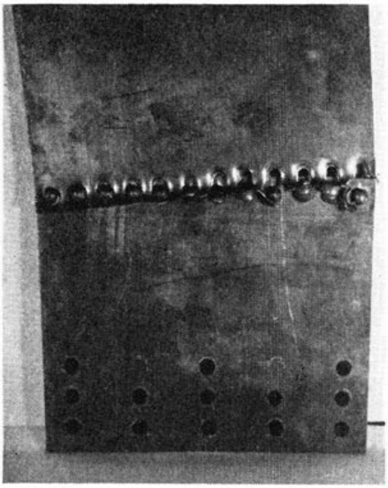


FIG. 9. FAILURE BY RIVET BEARING, SPECIMEN BE-5C

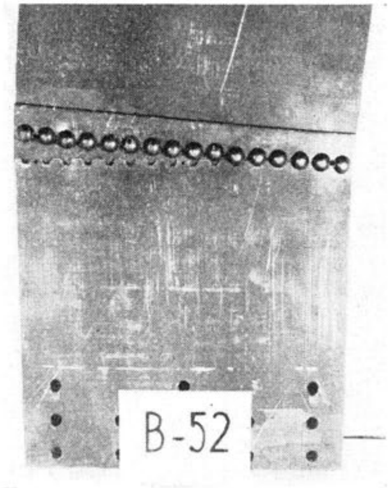


FIG. 10. FAILURE BY SHEET TENSION; LAP JOINT WITH SINGLE ROW OF RIVETS, SPECIMEN B-52

FIG. 11. FAILURE BY SHEET TENSION; LAP JOINT WITH TRIPLE ROW OF RIVETS, SPECIMEN E-99

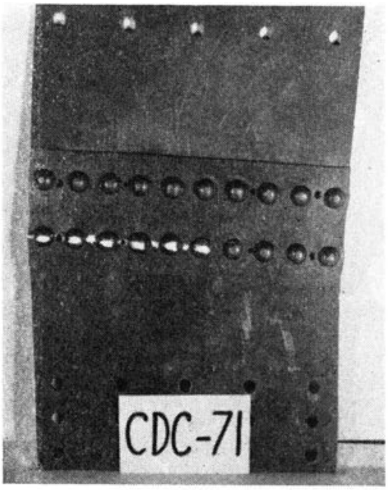


FIG. 12. FAILURE BY SHEET TENSION; DOUBLE-STRAP BUTT JOINT WITH SINGLE ROW OF RIVETS ON EACH SIDE OF JOINT, SPECIMEN CDC-71

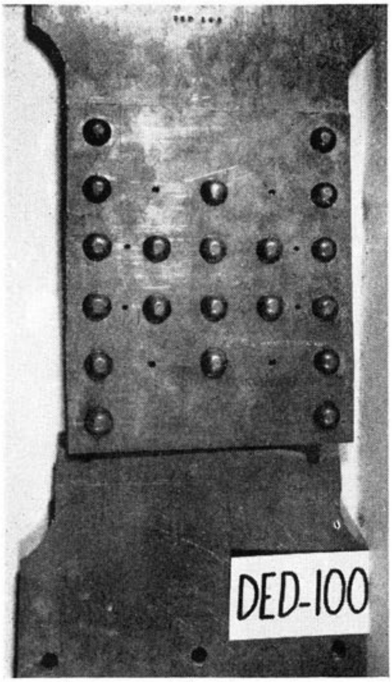


FIG. 13. FAILURE BY SHEET TENSION; DOUBLE-STRAP BUTT JOINT WITH TRIPLE ROW OF RIVETS ON EACH SIDE OF JOINT, SPECIMEN DED-100

and 11 are lap joints and those of Figs. 12 and 13 are double-strap butt joints. On the assumption that the unit strength of the net section of the sheet of a riveted joint equals the unit strength of a coupon specimen cut from the same sheet, the strength of the joint would be the product of the coupon strength of the sheet and the net section through the rivet holes. Under these conditions the efficiency of the joint would be the ratio of the net to the gross section. This is designated as the *computed efficiency* of the joint. The product of the coupon strength and the net section is designated as the *computed strength* as distinguished from the strength of the joint developed in the test, which is designated as the *strength by test*. The quotient obtained by dividing the strength by test by the product of the gross section and the coupon strength, is designated as the *efficiency by test*.

There are three geometrical factors that may affect the relation between the net and the gross area of the section of the sheet through the outer row of rivet holes for a joint of balanced design: (1) the ratio of rivet diameter to sheet thickness; (2) the number of rows of rivets; (3) the relative spacing of the rivets in the outer and the inner rows. The influences of these factors are discussed in the following paragraphs.

If the rivet spacing is represented by x and the hole diameter by h, then the ratio of the net to the gross section of a joint of the type shown in Fig. 10 is $\frac{x - h}{x}$. This fraction is the computed efficiency of the joint if failure is by sheet tension. For a balanced design, the shearing strength of a rivet equals the tensile strength of the sheet between two adjacent rivets. The shearing strength of a rivet increases with the square of the diameter. Therefore, considering only rivet shear and sheet tension, the net width between rivet holes for a joint of balanced design increases with the square of the rivet diameter, and, for a sheet of given thickness, a joint with large rivets will be more efficient than a similar joint with small rivets. But, as the distance between rivets increases, the rivet bearing increases, and the distance between rivets should not be increased beyond the point where the rivet bearing becomes the controlling factor in limiting the strength of the joint.

As previously stated, the number of rows of rivets affects the efficiency of a joint of balanced design. The joint shown in Fig. 10 is a lap joint with a single row of rivets; the one shown in the sketch of Table 12, page 38, is a lap joint with a double row of rivets. Both were designed to fail by sheet tension on a section through the rivet holes. The rivet spacing for balanced design for rivet shear and sheet tension is determined by the expression $\left(\frac{x-h}{x}\right)tT = \frac{\pi d^2}{4}S$ for the one-row joint, and by the expression $\left(\frac{x-h}{x}\right)tT = \frac{2\pi d^2}{4}S$ for the two-row joint. In these expressions t = sheet thickness, d = rivet diameter, S = unit shearing strength of the rivets, x = distance center to center of rivets, and T = unit tensile strength of the sheets. That is, the tension in the portion of the sheet between adjacent rivets is resisted by one rivet in the case of the one-row joint, and by two rivets for the two-row joint. The value of x, and also the value of $\frac{x-h}{x}$, is therefore greater for a two-row joint than it is for a one-row joint.

The efficiency of the joint is also influenced by the relative spacing of the rivets in the outer and in the inner row. The specimen shown in Fig. 11 is a lap joint with a triple row of rivets, and the rivet spacing is twice as great for the outer as for the inner row. The tension in the portion of the sheet between adjacent rivets in the outside row is resisted by four rivets, and the rivet spacing for balanced design between rivet shear and sheet tension is determined by the expression $\left(\frac{2x-h}{2x}\right)tT = \frac{4\pi d^2}{4}S$. The computed efficiency of this joint is $\frac{2x-h}{2x}$, a value which, for a balanced design, is greater than the efficiency of the one-row or the two-row joints previously described.

All of the foregoing discussion is based upon the assumption that the unit tensile strength of the portion of the sheet between two adjacent rivet holes in the outer row equals the unit strength of the same sheet as determined by tests of coupons, and is not affected by the rivet pattern. Tests of riveted joints* connecting steel plates indicate that the unit strength of the portion of a plate between adjacent rivets may range, approximately, from 85 to 120 per cent of the coupon strength of the same plate, depending upon the rivet pattern. Tests were therefore made to determine whether or not the unit strength of the copper sheets connected by riveted joints is likewise affected by the rivet pattern. This portion of the investigation covered a large variety of rivet patterns, including both lap joints and double-strap butt joints, and covered a range of rivet size from 1/8 in. to 1/2 in., and a range of sheet thickness from 0.060 in. to 0.245 in. The tests of lap joints are reported in Sections 15 to 18, and tests of double-strap butt joints are reported in Sections 19 to 23.

5. *Schedule of Tests.*—The specimens were divided into five series according to type of joint, rivet pattern, and type of failure desired. The various series were as follows:

Series I. Specimens to fail by tearing out of rivets to the edge of sheet; single row of rivets; rivets in double shear.

(1) Failure by the rivets tearing out to the edge of the outside sheets

(2) Failure by the rivets tearing out to the edge of the inside sheet.

Series II. Specimens to fail by rivet shear; lap joint; rivets in single shear.

(1) Single row of rivets

(2) Double row of rivets (chain pattern).

Series III. Specimens to fail by rivet shear; double-strap butt joint; rivets in double shear.

(1) Single row of rivets

(2) Double row of rivets (chain pattern).

Series IV. Specimens to fail by tension failure of sheet between rivets; lap joints; rivets in single shear.

(1) Single row of rivets

(2) Double row of rivets (chain pattern)

(3) Double row of rivets (stagger pattern)

(4) Triple row of rivets; alternate rivets omitted from outer rows.

* Transactions, A.S.C.E., Vol. 105, p. 1264. Discussion by W. M. Wilson.

Series V. Specimens to fail by tension failure of sheet between rivets; double-strap butt joints; rivets in double shear.

(1) Single row of rivets
(2) Double row of rivets (chain pattern)
(3) Double row of rivets (stagger pattern)
(4) Double row of rivets; spacing twice as great for outer as for inner row.
(5) Triple row of rivets; spacing four times as great for outer as for inner row of rivets.

The specimens were designed to fail in accordance with the schedule outlined. Small rivets were used with thin sheets and large rivets with thick sheets. Tests, in general, were made in duplicate. For 72 specimens the holes were drilled larger than the rivets, the oversize being $\frac{1}{64}$ in. for $\frac{1}{8}$-, $\frac{3}{16}$-, $\frac{1}{4}$-, and $\frac{5}{16}$-in. rivets, and $\frac{1}{32}$ in. for $\frac{3}{8}$- and $\frac{1}{2}$-in. rivets. For the remaining 148 specimens the rivet holes were drilled to the same size as the rivets. The $\frac{1}{8}$-, $\frac{3}{16}$-, and $\frac{1}{4}$-in. rivets were hand driven, and the $\frac{5}{16}$-, $\frac{3}{8}$-, and $\frac{1}{2}$-in. rivets were driven with an air hammer.

III. Physical Properties of Material

6. *Tensile Properties of Sheets.*—The stress-strain relation for the copper sheets was determined from coupon specimens having the dimensions shown in Fig. 14a. Coupons were cut parallel with and perpendicular to the direction of rolling. Typical stress-strain diagrams for No. 11 gage and No. 13 gage sheets are given on Fig. 15. The modulus of elasticity had values of the order of 14 000 000 and 20 000 000 lb. per sq. in., respectively, when the sheets were stressed parallel with and perpendicular to the direction of rolling for both the No. 11 and the No. 13 gage sheets.

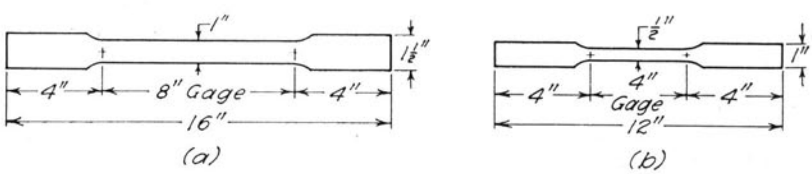


Fig. 14. Coupons for Standard Tension Tests

The tensile strength of the sheets as determined by tests of coupons of the dimensions shown in Fig. 14b is given in Table 1.

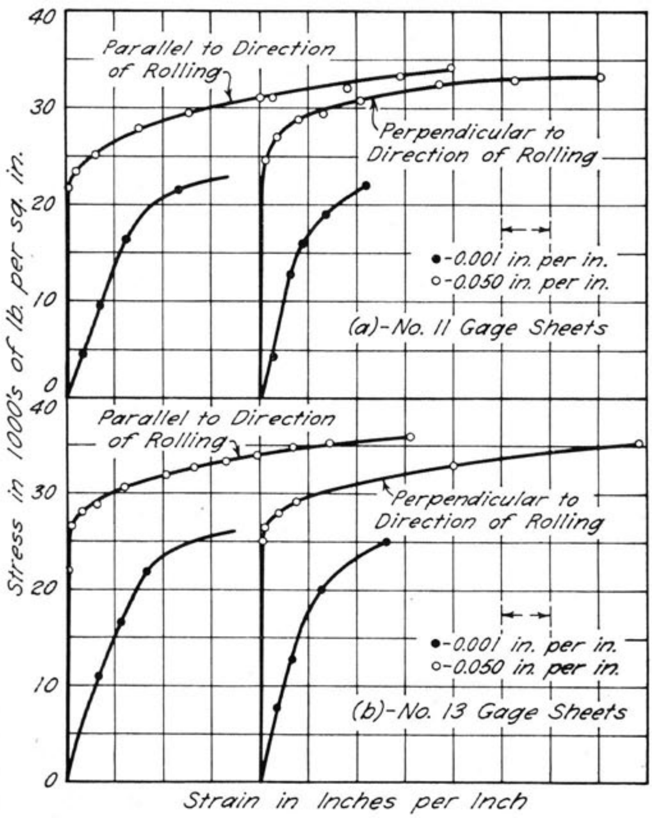


FIG. 15. STRESS-STRAIN DIAGRAMS FOR COPPER SHEETS

Some specimens were taken parallel with and others perpendicular to the direction of rolling, as indicated.

The data in Table 1 indicate that there was no significant and consistent difference in the strength of coupons taken parallel with and perpendicular to the direction of rolling. There was a very definite correlation between the tensile strength and the hardness as given by the Rockwell hardness number. Sheets with a hardness corresponding to a Rockwell number on the B Scale of 50 had a tensile strength of the order of 50 000 lb. per sq. in., whereas sheets with a hardness number of 20 to 30 had a tensile strength of the order of 35 000 lb. per sq. in. The elongation was much greater for the soft sheets than for the hard sheets. The elongation was not appreciably affected by the position of the specimen with respect to the direction of rolling for the

TABLE 1
PHYSICAL PROPERTIES OF COPPER SHEETS

Shipment No.	Average Thickness in.	Stress with Respect to Direction of Rolling	Average of Values From Two Tests			
			Ultimate Strength lb. per sq. in.	Reduction of Area per cent	Elongation in 4 in. per cent	Rockwell Hardness B scale
1	0.060 16 gage	Parallel	48 200	25.8	7.1	45
2			51 300	73.0	5.0	53
1		Perpendicular	51 500	27.4	5.6	45
2			53 700	73.2	2.8	53
1	0.090 13 gage	Parallel	35 800	51.2	36.3*	29
2			47 100	69.2	6.9	53
3			49 900	63.9	6.3	49
1		Perpendicular	35 300	51.5	36.6*	29
2			50 600	69.3	3.6	53
3			52 800	72.4	3.4	49
1	0.113 11 gage	Parallel	34 000	51.3	39.2*	30
2			47 900	65.8	8.8	52
3			47 300	65.0	6.7	44
1		Perpendicular	33 100	43.7	35.4*	30
2			49 900	66.2	3.9	52
3			51 000	65.4	3.8	44
1	0.185 6 gage	Parallel	36 400	38.0	37.1	26
2			48 900	48.8	5.6	51
1		Perpendicular	35 700	49.4	37.6	26
2			50 200	36.5	3.2	51
1	0.245 3 gage	Parallel	34 400	39.1	43.0	19
2			35 400	46.3	42.5	20
1		Perpendicular	33 600	45.8	45.7	19
2			35 300	44.6	42.5	20
1	0.375 00 gage	Parallel	36 200	36.8	32.2	23
2			35 400	44.2	28.7	18
1		Perpendicular	35 800	49.5	32.3	23
2			34 100	53.2	32.0	18

* Per cent elongation in 8 inches.

soft sheets but, for the hard sheets, the elongation was somewhat greater parallel with the direction of rolling than it was perpendicular to the direction of rolling.

Table 1 gives the coupon strength of the sheets used in the fabrication of all riveted specimens that were tested. Either two or three shipments were received of each sheet thickness. Coupons from each shipment were tested separately, as indicated in the table.

7. *Shearing Strength of Undriven Rivets.*—Preliminary to tests of the riveted joints, tests were made to determine the shearing strength of undriven rivets from the same batch as the rivets used in the joints to be tested. The rivets, like the sheets, were received in various ship-

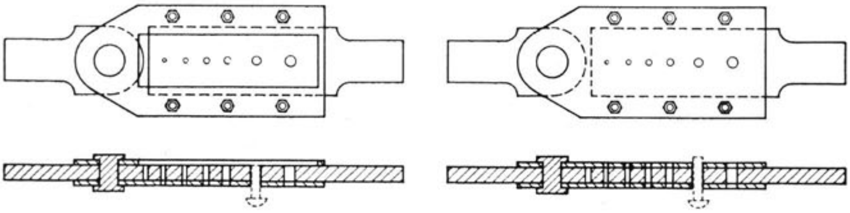


FIG. 16. APPARATUS FOR SHEAR TESTS OF UNDRIVEN RIVETS

ments, and the shearing strength of rivets in each shipment was determined separately. The apparatus used in testing the undriven rivets is shown in Fig. 16. Tests were made in both single and double shear, and four or more tests were made on a single rivet. The results of the tests are given in Table 2, each value being the average of four tests.

It is of interest to note that the unit strength in shear was considerably greater for 1/8-in. rivets than it was for 3/16-, 1/4-, 5/16-, 3/8-, and 1/2-in. rivets. The shear strength was approximately the same for all of the latter sizes.

Table 2 contains the shearing strength of undriven rivets from all shipments and all sizes that were used in the fabrication of the riveted joints that have been tested.

TABLE 2
SHEARING STRENGTH OF UNDRIVEN COPPER RIVETS
Each value is the average of four tests.

Ship-ment No.	Shear	Rivet Diameter					
		1/8 in.	3/16 in.	1/4 in.	5/16 in.	3/8 in.	1/2 in.
		Unit Shearing Strength, lb. per sq. in.					
1	Single	32 900	25 900	25 800	29 300	25 600	22 900
	Double	......	28 100	......	......	......	23 200
2	Single	......	26 800	27 600	28 000	26 800	24 600
	Double	......	26 500	26 400	26 200	28 000	24 200
3	Single	......	......	26 400	25 700	24 000	......
	Double	......	......	26 400	28 700	26 000	......
4	Single	......	......	24 400	24 000	......	......

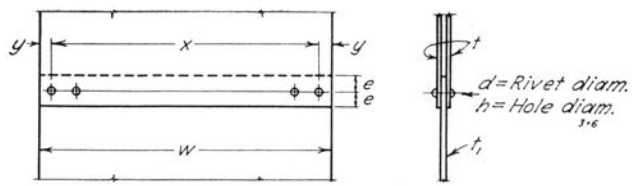
IV. Riveted Joints Designed to Fail by Tearing Out of Rivets to Edge of Sheet; Series I

8. *Series I-1; Specimens Designed to Fail by Tearing Out of Rivets to Edge of Outside Sheet.*—This series of tests was planned to determine the proper edge distance of the rivets to be used in the design of the butt straps of double-strap riveted butt joints. The specimens were designed to fail by tearing out of rivets to the edge of the outside sheet. The details of the specimens are given in Table 3, and the character of the failure is shown in Fig. 5, page 15. The variables studied were sheet thickness, rivet diameter, and edge distance of the rivets. All tests were made in duplicate, and the coupon strength of the sheets was known from the control tests reported in Table 1.

Failure of a riveted joint by tearing out of the rivets to the edge of the outside sheet may be considered as being due to the longitudinal shear on the sheet resulting from the tendency to force out the rectangular portion of the sheet between the rivet and the edge of the sheet, as shown in Fig. 5. This shear is not uniform, being greater near the rivet than it is near the edge of the sheet, but, for convenience in making computations, it will be considered to be uniform. There is also a tendency for the sheet to tear due to the high bearing pressure of the rivet upon the edge of the hole. As the load increases, this bear-

Table 3

Details of Specimens; Series I-1; Joints Designed to Fail by Tearing Out of Rivets to Edge of Outside Sheet



Specimen No.	t in.	t_1 in.	X in.	y in.	W in.	h in.	d in.	e in.
AD-3A and AD-3B	0.060	0.185	15@ 3/4 = 11 1/4	3/8	12	1/4	1/4	3/8
AD-3C and AD-3D	0.060	0.185	15@ 3/4 = 11 1/4	3/8	12	1/4	1/4	1/2
AD-5A and AD-5B	0.060	0.185	11@1 = 11	1/2	12	5/16	5/16	15/32
AD-5C and AD-5D	0.060	0.185	11@1 = 11	1/2	12	5/16	5/16	5/8
BE-5A and BE-5B	0.090	0.245	11@1 = 11	1/2	12	5/16	5/16	15/32
BE-5C and BE-5D	0.090	0.245	11@1 = 11	1/2	12	5/16	5/16	5/8
BE-7A and BE-7B	0.090	0.245	7@1 1/2 = 10 1/2	3/4	12	3/8	3/8	9/16
BE-7C and BE-7D	0.090	0.245	7@1 1/2 = 10 1/2	3/4	12	3/8	3/8	3/4
CF-7A and CF-7B	0.113	0.375	7@1 1/2 = 10 1/2	3/4	12	3/8	3/8	9/16
CF-7C and CF-7D	0.113	0.375	7@1 1/2 = 10 1/2	3/4	12	3/8	3/8	3/4
CF-9A and CF-9B	0.113	0.375	5@2 = 10	1	12	1/2	1/2	3/4
CF-9C and CF-9D	0.113	0.375	5@2 = 10	1	12	1/2	1/2	1

ing pressure first upsets and finally tears the sheet. Failure by sheet shear is most likely to occur if the edge distance is small, and failure by upsetting and tearing the sheet is most likely to occur if the rivet bearing pressure is high and the edge distance is large. As stated previously, the unit sheet shear has been taken equal to the load per rivet divided by $4et$, in which e is the distance from the center of the rivet to the edge of sheet, and t is the thickness of the outside sheet. The unit rivet bearing for the outside sheet has been taken equal to the load per rivet divided by $2td$, in which d is the diameter of the rivet.

The results of tests are reported in detail in Table 4. All specimens of a group were geometrically identical except for the edge distance of the rivets. The specimens of groups I and II had the same sheet thickness but different rivet diameters. The same statement is true of the specimens of groups III and IV and is also true of the specimens of groups V and VI. The specimens of groups II and III had the same rivet diameter but different sheet thicknesses. The same statement is true of the specimens of groups IV and V.

The specimens did not all fail by tearing out of rivets to the edge of the outside sheet. The specimens of the second part of group V failed by rivet shear; specimens of the second part of groups III, IV, and VI failed by both rivet shear and rivet bearing; specimens of the first part of group V failed by both rivet shear and tearing out of rivets to the edge of the sheet; the specimens of the second part of group I failed by sheet tension, rivet shear and by tearing out of the rivets to the edge of the outside sheet. All other specimens failed by tearing out of the rivets to the edge of the outside sheet, as planned. This type of failure is illustrated by Fig. 5. The failure of specimen AD-3C, which failed by sheet tension, rivet shear, and by tearing out of rivets to the edge of the outside sheet, is shown in Fig. 17.

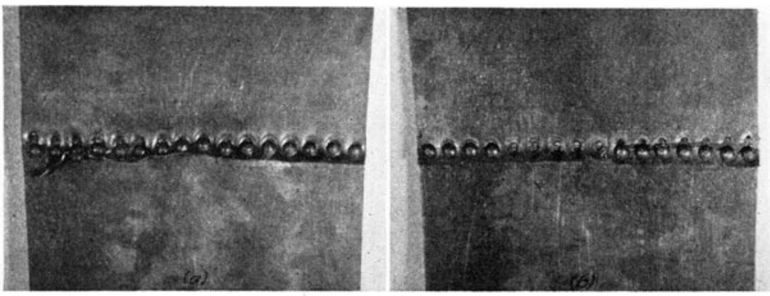


Fig. 17. Failure by Sheet Tension, by Rivet Shear, and by Tearing Out of Rivet to the Edge of Outside Sheet, Specimen AD-3C

TABLE 4

RELATION BETWEEN EDGE DISTANCE OF RIVETS AND ULTIMATE STRENGTH OF JOINTS; SPECIMENS DESIGNED TO FAIL BY TEARING OUT OF RIVETS TO EDGE OF OUTSIDE SHEET; SERIES I-1

Group No.	Specimen No.	Edge Distance of Rivets		Ultimate Load lb.	Unit Stress at Ultimate Load lb. per sq. in.			Method of Failure*
		in.	d		Sheet Tension	Sheet Shear	Rivet Bearing	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Rivet Dia., ¼ in.; Sheet Thickness, 0.060 in.; Coupon Strength of Sheet, 53 100 lb. per sq. in.								
I	AD-3A	⅜	1½	42 200	44 000	29 300	87 800	1
	AD-3B	⅜	1½	42 900	44 800	29 800	89 200	1
	Average	..	...	42 550	44 400	29 550	88 500	...
	AD-3C	½	2	49 000	51 000	25 500	102 000	2
	AD-3D	½	2	44 200	46 000	23 000	92 000	2
	Average	..	...	46 600	48 500	24 250	97 000	...
Rivet Dia., 5/16 in.; Sheet Thickness, 0.060 in.; Coupon Strength of Sheet, 53 700 lb. per sq. in.								
II	AD-5A	15/32	1½	41 100	40 600	30 400	91 400	1
	AD-5B	15/32	1½	43 500	43 000	32 200	96 800	1
	Average	..	...	42 300	41 800	31 300	94 100	...
	AD-5C	⅝	2	42 300	41 800	23 500	94 000	1
	AD-5D	⅝	2	47 000	46 400	26 100	103 500	1
	Average	..	...	44 650	44 100	24 800	98 750	...
Rivet Dia., 5/16 in.; Sheet Thickness, 0.090 in.; Coupon Strength of Sheet, 52 800 lb. per sq. in.								
III	BE-5A	15/32	1½	53 300	35 900	26 300	79 000	1
	BE-5B	15/32	1½	52 000	35 000	25 700	77 100	1
	Average	..	...	52 650	35 450	26 000	78 050	...
	BE-5C	⅝	2	56 300	37 900	20 800	83 400	3
	BE-5D	⅝	2	54 800	36 900	20 300	81 400	3
	Average	..	...	55 550	37 400	20 550	82 400	...
Rivet Dia., ⅜ in.; Sheet Thickness, 0.090 in.; Coupon Strength of Sheet, 49 900 lb. per sq. in.								
IV	BE-7A	9/16	1½	45 900	28 300	28 300	85 000	1
	BE-7B	9/16	1½	46 000	28 400	28 400	85 200	1
	Average	..	...	45 950	28 350	28 350	85 100	...
	BE-7C	¾	2	50 900	31 400	23 600	94 300	3
	BE-7D	¾	2	50 000	30 900	23 200	92 600	3
	Average	..	...	50 450	31 150	23 400	93 450	...
Rivet Dia., ⅜ in.; Sheet Thickness, 0.113 in.; Coupon Strength of Sheet, 47 300 lb. per sq. in.								
V	CF-7A	9/16	1½	53 200	26 100	26 200	78 500	4
	CF-7B	9/16	1½	52 600	25 800	25 900	77 700	4
	Average	..	...	52 900	25 950	26 050	78 100	...
	CF-7C	¾	2	54 800	26 900	20 200	80 000	5
	CF-7D	¾	2	53 400	26 200	19 700	78 700	5
	Average	..	...	54 100	26 550	19 950	79 350	...
Rivet Dia., ½ in.; Sheet Thickness, 0.113 in.; Coupon Strength of Sheet, 47 300 lb. per sq. in.								
VI	CF-9A	¾	1½	59 300	29 200	29 200	87 500	1
	CF-9B	¾	1½	56 500	27 800	27 800	83 300	1
	Average	..	...	57 900	28 500	28 500	85 400	...
	CF-9C	1	2	61 700	30 300	22 800	91 000	3
	CF-9D	1	2	63 700	31 300	23 500	94 000	3
	Average	..	...	62 700	30 800	23 150	92 500	...

*Method of failure.
1. Failed by tearing out of rivet to edge of outside sheet.
2. Failed by sheet tension, rivet shear and tearing out of rivet to edge of outside sheet.
3. Failed by rivet shear and rivet bearing.
4. Failed by rivet shear and tearing out of rivet to edge of outside sheet.
5. Failed by rivet shear.

The specimens in the two parts of each group of Table 4 differed in the magnitude of the edge distance of the rivets. Specimens in the first part of each group had an edge distance equal to 1½ times the rivet diameter and specimens in the second part of each group had an edge distance equal to 2 times the rivet diameter. A comparison of the average values of the ultimate load for the two parts of each group, given in column 5 of Table 4, reveals the fact that, in general, increasing the edge distance from $1\frac{1}{2}d$ to $2d$ increased the ultimate load-carrying capacity of the joint from 5 to 10 per cent. The specimens of groups III, IV, and VI which had an edge distance of $2d$, all failed by shearing the rivets, so that increasing the edge distance above $2d$ would not have increased the load-carrying capacity of these joints.

The data in Table 4 have been arranged in Table 5 in such a manner as to show, separately, the effects of the rivet diameter and the thickness of the outside sheet upon the sheet shear that the joint developed. The values of the sheet shear and rivet bearing, given in columns 6 and 7 of Table 5, have been adjusted to a common sheet coupon strength of 50 000 lb. per sq. in. so as to make the results of

TABLE 5
STRENGTH OF JOINTS DESIGNED TO FAIL BY TEARING OUT OF RIVETS TO EDGE OF OUTSIDE SHEET; SERIES I-1; SUMMARY OF RESULTS
Each value is the average of two tests.

Group No.	Specimen No.	Rivet Diameter in.	Sheet Thickness in.	Sheet Shear at Failure lb. per sq. in.	Sheet Shear at Failure Adjusted to 50 000 lb. per sq. in. Coupon Strength lb. per sq. in.	Rivet Bearing at Failure Adjusted to 50 000 lb. per sq. in. Coupon Strength lb. per sq. in.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Specimens with a Rivet Edge Distance of $1\frac{1}{2}d$						
I	AD-3A, AD-3B	¼	0.060	29 550	27 820*	83 330
II	AD-5A, AD-5B	5/16	0.060	31 300	29 140*	87 610
III	BE-5A, BE-5B	5/16	0.090	26 000	24 620*	73 910
IV	BE-7A, BE-7B	⅜	0.090	28 350	28 400*	85 300
V	CF-7A, CF-7B	⅜	0.113	26 050	27 540*	82 560
VI	CF-9A, CF-9B	½	0.113	28 500	30 130*	90 280
Specimens with a Rivet Edge Distance of $2d$						
I	AD-3C, AD-3D	¼	0.060	24 250	22 830*	91 340
II	AD-5C, AD-5D	5/16	0.060	24 800	23 090*	91 950
III	BE-5C, BE-5D	5/16	0.090	20 550	19 460	78 030†
IV	BE-7C, BE-7D	⅜	0.090	23 400	23 450	93 630†
V	CF-7C, CF-7D	⅜	0.113	19 950	21 100	83 880‡
VI	CF-9C, CF-9D	½	0.113	23 150	24 470	97 800†

* Failed by rivets tearing out to edge of outside sheet, others did not.
† Failed by rivet shear and rivet bearing.
‡ Failed by rivet shear.

the various tests directly comparable. The edge distance was $1\frac{1}{2}d$ for the tests reported in the upper part of the table, and $2d$ for the tests reported in the lower part of the table. For each pair of groups, I and II, III and IV, V and VI, the sheet thicknesses were the same for both groups but the rivet diameter was less for the first than for the second group. For the two groups of a pair with the same sheet thickness, the group with the larger rivet diameter consistently developed the greater sheet shear. However, the difference was not great.

For each pair of groups, II and III, and IV and V, the rivet diameter was the same for both groups but the sheet thickness was greater for the second group than for the first group. The data in Table 5 indicate that, in each instance, the unit shear at failure was less for the thick sheet than it was for the thin sheet.

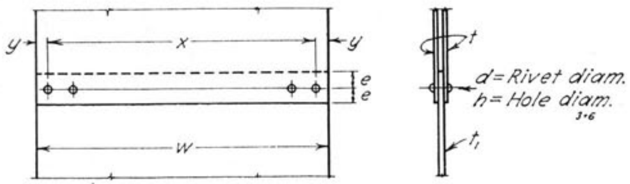
Although both the sheet thickness and the rivet diameter affected somewhat the unit shear at the ultimate load for a given edge distance expressed in terms of d, the total range in unit sheet shear at failure was not great, the range being from 26 000 to 31 300 lb. per sq. in. for an edge distance of $1\frac{1}{2}d$, and from 19 950 to 24 800 lb. per sq. in. for specimens with an edge distance of $2d$. It should also be noted that, for specimens with a rivet edge distance of $2d$, those with a sheet shear at the ultimate load of 19 950 and 20 550 lb. per sq. in. did not fail by sheet shear. Of the specimens with an edge distance of $2d$, only those of groups I and II failed by tearing out the rivets to the edge of the outside sheet. This indicates that the strength of the joints could not have been increased appreciably by increasing the rivet edge distance of the outside sheets beyond $2d$.

The results of the tests described in this section appear to justify the following statement:

For double-strap riveted butt joints designed to fail by tearing out of rivets to the edge of the outside sheet (butt straps), the sheet shear at failure varied from 26 000 to 31 300 lb. per sq. in. This was for joints with a rivet edge distance of $1\frac{1}{2}d$ and with sheets having a coupon strength in tension of approximately 50 000 lb. per sq. in. The joints had a range of sheet thickness of from 0.060 in. to 0.113 in. and a range of rivet diameter of from ¼ in. to ½ in. The total capacity of joints (as distinguished from the unit shear) that failed by tearing out of rivets to the edge of the outside sheet was from 5 to 10 per cent greater for joints with an edge distance of $2d$ than it was for joints with an edge distance of $1\frac{1}{2}d$. For the combinations of rivet diameter and sheet thickness tested, increasing the edge distance above $2d$ would not have increased the strength of the joint by a significant amount

TABLE 6

DETAILS OF SPECIMENS; SERIES I-2; JOINTS DESIGNED TO FAIL BY TEARING OUT OF RIVETS TO EDGE OF INSIDE SHEET



Specimen No.	t in.	t_1 in.	X in.	y in.	W in.	h in.	d in.	e in.
AA-11 and AA-12	0.060	0.060	25 @ 7/16 = 11	1/2	12	9/64	1/8	1/4
AA-21 and AA-22	0.060	0.060	12 @ 7/8 = 10 1/2	3/4	12	13/64	3/16	3/8
AA-23 and AA-24	0.060	0.060	12 @ 7/8 = 10 1/2	3/4	12	13/64	3/16	9/16
AB-21 and AB-22	0.060	0.090	16 @ 11/16 = 11	1/2	12	13/64	3/16	3/8
AA-31 and AA-32	0.060	0.060	7 @ 1 1/2 = 10 1/2	3/4	12	17/64	1/4	3/4
AB-31 and AB-32	0.060	0.090	9 @ 1 1/4 = 11 1/4	3/8	12	17/64	1/4	1/2
CB-31 and CB-32	0.090	0.113	11 @ 1 = 11	1/2	12	17/64	1/4	1/2
CB-33 and CB-34	0.090	0.113	11 @ 1 = 11	1/2	12	17/64	1/4	3/4
AB-51 and AB-52	0.060	0.090	6 @ 1 3/4 = 10 1/2	3/4	12	21/64	5/16	5/8
AB-53 and AB-54	0.060	0.090	6 @ 1 3/4 = 10 1/2	3/4	12	21/64	5/16	15/16
CB-51 and CB-52	0.090	0.113	8 @ 1 3/8 = 11	1/2	12	21/64	5/16	5/8
CB-53 and CB-54	0.090	0.113	8 @ 1 3/8 = 11	1/2	12	21/64	5/16	15/16
AB-71 and AB-72	0.060	0.090	4 @ 2 1/2 = 10	1	12	13/32	3/8	3/4
CB-71 and CB-72	0.090	0.113	5 @ 2 = 10	1	12	13/32	3/8	3/4
CB-73 and CB-74	0.090	0.113	5 @ 2 = 10	1	12	13/32	3/8	1 1/8
CD-91 and CD-92	0.113	0.185	5 @ 2 = 10	1	12	17/32	1/2	1
ED-91 and ED-92	0.185	0.245	6 @ 1 3/4 = 10 1/2	3/4	12	17/32	1/2	1

because of the liability to failure by rivet bearing. The unit sheet shear given in the foregoing is the total load per rivet divided by $4et$, in which t is the thickness of the outside sheets, and e is the distance from the center of the rivets to the edge of the outside sheet.

9. *Series I-2; Specimens Designed to Fail by Tearing Out of Rivets to Edge of Inside Sheet.*—The tests of this series were planned to determine the proper edge distance of the rivets for copper sheets connected by double-strap riveted butt joints.

The details of the specimens are given in Table 6, and the character of the failure is shown by Fig. 6, page 15. The variables studied are sheet thickness, rivet diameter, and edge distance of rivets. All tests were made in duplicate, and all specimens failed by tearing out the rivets to the edge of the inside sheet, as planned.

The method of failure of a riveted joint by tearing out of rivets to the edge of an outside sheet and the method of computing the unit stresses involved were described in Section 8. These apply to joints designed to fail by tearing out of rivets to the edge of the inside sheet except that, for the latter, the sheet shear equals the load per rivet divided by $2et_1$, in which e is the distance from the center of the rivet to the edge of the inside sheet, and t_1 is the thickness of the inside sheet.

The coupon strength of the sheets is given in Table 1, and the results of the tests are given in Tables 7, 8, and 9.

The tests reported in Table 7 were planned to determine the effect of the sheet thickness upon the unit strength of a joint designed to fail by the rivets tearing out to the edge of the inside sheet. A comparison was made between joints with the same rivet diameter and the same edge distance but with different sheet thicknesses, the edge distance being $2d$ for all specimens.

The results of the tests, given in detail in Table 7, are summarized in Table 8, each value being the average for two identical specimens. The columns of Table 8, beginning at the left and reading to the right, give the group number, specimen number, rivet diameter, sheet thickness, sheet shear at failure, and the rivet bearing at failure, the latter two being adjusted to a coupon strength of sheet of 50 000 lb. per sq. in. The group numbers in Table 8 correspond to the group numbers in Table 7, and the specimens for pairs of groups II and III, IV and V, etc., have the same rivet diameter but different sheet thickness, the second group of each pair always having the thicker sheet.

It is of interest to note that, for each rivet diameter, the specimen with the thinner sheet had the greater unit sheet shear at failure. However, the difference was not great, the range in the unit sheet shear at failure, adjusted to 50 000-lb.-per-sq.-in. coupon strength, being from a minimum of 20 500 lb. per sq. in. to a maximum of 27 700 lb. per sq. in. The rivet bearing at failure, adjusted to a coupon strength of 50 000 lb. per sq. in., and given in column 7, had a minimum value of 81 600 lb. per sq. in. and a maximum value of 112 600 lb. per sq. in. It should be noted, however, that failure was by sheet shear in each instance and not by rivet bearing.

The tests reported in Table 9 were planned to determine the influence of the edge distance upon the strength of riveted joints designed to fail by tearing out of rivets to the edge of the inside sheet. The tests are arranged in groups from XII to XVI. All specimens of a group had the same sheet thickness and rivet diameter, but, for each group, the edge distance of the rivets was $2d$ for the first pair and $3d$ for the second pair of specimens. The coupon strength of the sheets for the various groups is also given in the table.

TABLE 7

STRENGTH OF JOINTS DESIGNED TO FAIL BY TEARING OUT OF RIVETS TO EDGE OF INSIDE SHEET; SERIES I-2

All specimens failed by tearing out of rivets to the edge of the inside sheet.

Group No.	Specimen No.	Edge Distance of Rivets		Ultimate Load	Unit Stress at Ultimate Load lb. per sq. in.		
		in.	d	lb.	Sheet Tension	Sheet Shear	Rivet Bearing
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rivet Dia., 1/8 in.; Sheet Thickness, 0.060 in.; Coupon Strength of Sheet, 51 500 lb. per sq. in.							
I	AA-11	1/4	2	19 700	38 900	24 800	99 400
	AA-12	1/4	2	19 400	38 400	24 500	98 200
	Average	..	...	19 550	38 650	24 650	98 800
Rivet Dia., 3/16 in.; Sheet Thickness, 0.060 in.; Coupon Strength of Sheet, 51 500 lb. per sq. in.							
II	AA-21	3/8	2	15 900	27 900	26 700	106 500
	AA-22	3/8	2	14 900	26 300	25 100	100 000
	Average	..	...	15 400	27 100	25 900	103 250
Rivet Dia., 3/16 in.; Sheet Thickness, 0.090 in.; Coupon Strength of Sheet, 50 600 lb. per sq. in.							
III	AB-21	3/8	2	26 200	34 400	22 600	90 100
	AB-22	3/8	2	26 700	34 900	23 200	92 800
	Average	..	...	26 450	34 650	22 900	91 450
Rivet Dia., 1/4 in.; Sheet Thickness, 0.090 in.; Coupon Strength of Sheet, 50 600 lb. per sq. in.							
IV	AB-31	1/2	2	22 600	27 000	25 000	100 000
	AB-32	1/2	2	24 000	28 900	26 700	106 700
	Average	..	...	23 300	27 950	25 850	103 350
Rivet Dia., 1/4 in.; Sheet Thickness, 0.113 in.; Coupon Strength of Sheet, 49 900 lb. per sq. in.							
V	CB-31	1/2	2	30 300	30 600	22 300	89 500
	CB-32	1/2	2	29 000	29 300	21 400	85 600
	Average	..	...	29 650	29 950	21 850	87 550
Rivet Dia., 5/16 in.; Sheet Thickness, 0.090 in.; Coupon Strength of Sheet, 50 600 lb. per sq. in.							
VI	AB-51	5/8	2	20 800	24 200	26 600	106 000
	AB-52	5/8	2	20 800	24 200	26 600	106 000
	Average	..	...	20 800	24 200	26 600	106 000
Rivet Dia., 5/16 in.; Sheet Thickness, 0.113 in.; Coupon Strength of Sheet, 47 900 lb. per sq. in.							
VII	CB-51	5/8	2	24 900	24 600	19 600	78 200
	CB-52	5/8	2	24 900	24 600	19 600	78 200
	Average	..	...	24 900	24 600	19 600	78 200
Rivet Dia., 3/8 in.; Sheet Thickness, 0.090 in.; Coupon Strength of Sheet, 50 600 lb. per sq. in.							
VIII	AB-71	3/4	2	19 100	20 300	28 400	113 000
	AB-72	3/4	2	18 500	21 000	27 500	109 800
	Average	..	...	18 800	20 650	27 950	111 400

TABLE 7 (CONCLUDED)

STRENGTH OF JOINTS DESIGNED TO FAIL BY TEARING OUT OF RIVETS TO EDGE OF INSIDE SHEET; SERIES I-2

All specimens failed by tearing out of rivets to the edge of the inside sheet.

Group No.	Specimen No.	Edge Distance of Rivets		Ultimate Load	Unit Stress at Ultimate Load lb. per sq. in.		
		in.	*d*	lb.	Sheet Tension	Sheet Shear	Rivet Bearing
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rivet Dia., ⅜ in.; Sheet Thickness, 0.113 in.; Coupon Strength of Sheet, 47 900 lb. per sq. in.							
IX	CB-71	¾	2	21 300	19 800	20 800	83 200
	CB-72	¾	2	21 000	19 200	20 200	80 600
	Average	..	...	21 150	19 500	20 500	81 900
Rivet Dia., ½ in.; Sheet Thickness, 0.185 in.; Coupon Strength of Sheet, 36 400 lb. per sq. in.							
X	CD-91	1	2	44 800	28 100	20 200	80 600
	CD-92	1	2	44 300	27 800	20 100	79 800
	Average	..	...	44 550	27 950	20 150	80 200
Rivet Dia., ½ in.; Sheet Thickness, 0.245 in.; Coupon Strength of Sheet, 34 400 lb. per sq. in.							
XI	ED-91	1	2	63 900	33 000	18 700	74 400
	ED-92	1	2	63 900	33 000	18 700	74 400
	Average	..	...	63 900	33 000	18 700	74 400

TABLE 8

STRENGTH OF JOINTS DESIGNED TO FAIL BY TEARING OUT OF RIVETS TO EDGE OF INSIDE SHEET; SERIES I-2; SUMMARY OF RESULTS

Each value is the average from two tests.
Edge distance was 2*d* for all specimens.
All specimens failed by tearing out of rivets to the edge of the inside sheet.

Group No.	Specimen No.	Rivet Diameter in.	Sheet Thickness in.	Sheet Shear at Failure lb. per sq. in.	Sheet Shear at Failure Adjusted to 50 000 lb. per sq. in. Coupon Strength lb. per sq. in.	Rivet Bearing at Failure Adjusted to 50 000 lb. per sq. in. Coupon Strength lb. per sq. in.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
I	AA-11, AA-12	⅛	0.060	24 650	23 930	95 900
II	AA-21, AA-22	3⁄16	0.060	25 900	25 140	100 200
III	AB-21, AB-22	3⁄16	0.090	22 900	22 600	90 400
IV	AB-31, AB-32	¼	0.090	25 875	25 600	102 100
V	CB-31, CB-32	¼	0.113	21 850	21 900	87 600
VI	AB-51, AB-52	5⁄16	0.090	26 600	26 300	104 700
VII	CB-51, CB-52	5⁄16	0.113	19 600	20 500	81 600
VIII	AB-71, AB-72	⅜	0.090	27 950	27 600	112 600
IX	CB-71, CB-72	⅜	0.113	20 500	21 400	85 400
X	CD-91, CD-92	½	0.185	20 150	27 700	110 200
XI	ED-91, ED-92	½	0.245	18 700	27 200	108 100

TABLE 9

RELATION BETWEEN EDGE DISTANCE OF RIVETS AND ULTIMATE STRENGTH OF JOINTS; SPECIMENS DESIGNED TO FAIL BY TEARING OUT OF RIVETS TO EDGE OF INSIDE SHEET; SERIES I-2

All specimens failed by tearing out of rivets to the edge of the inside sheet.

Group No.	Specimen No.	Edge Distance of Rivets		Ultimate Load	Unit Stress at Ultimate Load lb. per sq. in.		
		in.	*d*	lb.	Sheet Tension	Sheet Shear	Rivet Bearing
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rivet Dia., 3/16 in.; Sheet Thickness, 0.060 in.; Coupon Strength of Sheet, 51 500 lb. per sq. in.							
XII	AA-21	3/8	2	15 900	27 900	26 700	106 500
	AA-22	3/8	2	14 900	26 300	25 100	100 000
	Average	..	...	15 400	27 100	25 900	103 250
	AA-23	9/16	3	20 300	35 800	23 100	136 000
	AA-24	9/16	3	19 800	34 700	22 800	132 000
	Average	..	...	20 050	35 250	22 950	134 000
Rivet Dia., 1/4 in.; Sheet Thickness, 0.113 in.; Coupon Strength of Sheet, 49 900 lb. per sq. in.							
XIII	CB-31	1/2	2	30 300	30 600	22 300	89 500
	CB-32	1/2	2	29 000	29 300	21 400	85 600
	Average	..	...	29 650	29 950	21 850	87 550
	CB-33	3/4	3	32 800	33 200	16 100	96 600
	CB-34	3/4	3	32 600	33 000	16 000	96 000
	Average	..	...	32 700	33 100	16 050	96 300
Rivet Dia., 5/16 in.; Sheet Thickness, 0.090 in.; Coupon Strength of Sheet, 50 600 lb. per sq. in. for AB-51 and AB-52, 47 100 lb. per sq. in. for AB-53 and AB-54							
XIV	AB-51	5/8	2	20 800	24 200	26 600	106 000
	AB-52	5/8	2	20 800	24 200	26 600	106 000
	Average	..	...	20 800	24 200	26 600	106 000
	AB-53	15/16	3	22 000	25 600	18 900	112 300
	AB-54	15/16	3	22 700	26 300	20 600	115 500
	Average	..	...	22 350	25 950	19 750	113 900
Rivet Dia., 5/16 in.; Sheet Thickness, 0.113 in.; Coupon Strength of Sheet, 47 900 lb. per sq. in. for CB-51 and CB-52, 49 900 lb. per sq. in. for CB-53 and CB-54							
XV	CB-51	5/8	2	24 900	24 600	19 600	78 200
	CB-52	5/8	2	24 900	24 600	19 600	78 200
	Average	..	...	24 900	24 600	19 600	78 200
	CB-53	15/16	3	30 100	30 100	15 700	95 800
	CB-54	15/16	3	31 100	30 200	15 800	96 500
	Average	..	...	30 600	30 150	15 750	96 150
Rivet Dia., 3/8 in.; Sheet Thickness, 0.113 in.; Coupon Strength of Sheet, 47 900 lb. per sq. in. for CB-71 and CB-72, 49 900 lb. per sq. in. for CB-73 and CB-74							
XVI	CB-71	3/4	2	21 300	19 800	20 800	83 200
	CB-72	3/4	2	21 000	19 200	20 200	80 600
	Average	..	...	21 150	19 500	20 500	81 900
	CB-73	1 1/8	3	30 200	28 000	19 900	117 900
	CB-74	1 1/8	3	30 000	27 700	19 500	116 800
	Average	..	...	30 100	27 850	19 700	117 350

A study of the results given in Table 9 reveals that increasing the edge distance of the rivets from $2d$ to $3d$ increased the strength of the joint in every instance. The increase, adjusted for the difference in coupon strength, varied from 10 per cent for group XIII to 30 per cent for group XII and 37 per cent for group XVI.

The question might be asked, if increasing the edge distance of the rivets of a joint from $2d$ to $3d$ increases the strength of the joint, why would it not be good design-practice to use an edge distance even greater than $3d$, since increasing the edge distance adds so little to the cost of the joint? The data in column 8 of Table 9 show that, for an edge distance of $3d$, the unit rivet bearing at the ultimate load had values ranging from 96 150 lb. per sq. in. to 134 000 lb. per sq. in., values higher than good design-practice would permit and, for that reason, the greater strength that might otherwise result from a greater edge distance would not be utilized in design-practice.

The tests reported in Table 5 of Section 8 indicate that, for joints designed to fail by tearing out of rivets to the edge of the *outside* sheet, increasing the edge distance from $1\frac{1}{2}d$ to $2d$ increased the strength of the joint very little, 5 to 10 per cent. The tests reported in Table 9 of this section indicate that, for joints designed to fail by tearing out of rivets to the edge of the *inside* sheet, increasing the edge distance from $2d$ to $3d$ increased the strength of the joint from 10 to 37 per cent. The apparent discrepancy is attributed to the fact that the rivet *bearing* pressure at failure is much less for the *outside* sheets than it is for the *inside* sheets. Failure of outside sheets occurred at rivet bearing values as low as 78 030 lb. per sq. in. (group III, lower part of Table 5), whereas the inside sheet with the same sheet thickness and rivet diameter (group XIV, Table 9) withstood a rivet bearing of 113 900 lb. per sq. in. This greater rivet bearing value for the inside sheet is attributed to the clamping action of the rivet.

The tests described in this section appear to justify the following statements:

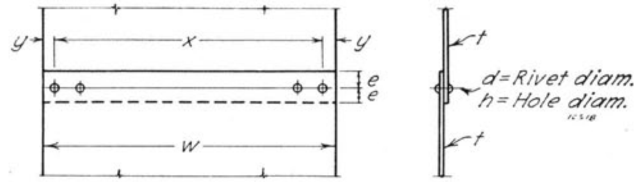
For the double-strap riveted butt joints designed to fail by tearing out of rivets to the edge of the inside sheet, the sheet shear at failure for joints with a rivet edge distance of $2d$, adjusted to a coupon strength in tension of the sheets of 50 000 lb. per sq. in., varied from 20 500 to 27 700 lb. per sq. in. This was for joints with a range of sheet thickness of from 0.060 in. to 0.245 in. and a range of rivet diameter of from ⅛ in. to ½ in. The total load carried by the joint was from 10 to 37 per cent greater for joints with an edge distance of 3*d* than it was for joints with an edge distance of 2*d*. The bearing pressure at failure for the rivets with an edge distance of 2*d* varied from 78 200 to 106 000 lb. per sq. in. The bearing pressure at failure for the rivets with an edge distance of 3*d* varied from 96 150 to 134 000 lb. per sq. in. Failure, however, was by tearing out of rivets to the edge of the sheet for all specimens.

V. Riveted Joints Designed to Fail by Rivet Shear

10. *Series II-1; Specimens Designed to Fail by Rivet Shear; Lap Joint, Single Row of Rivets.*—The specimens of this series, designed to fail by rivet shear, were lap joints with a single row of rivets. The details of the specimens are shown in Table 10.

Table 10

Details of Specimens; Series II-1; Lap Joints with Single Row of Rivets Designed to Fail by Rivet Shear



Specimen No.	t in.	X in.	y in.	W in.	h in.	d in.	e in.
A-21 and A-22	0.060	15@ ¾=11¼	⅜	12	13/64	3/16	½
B-31 and B-32	0.090	11@1 =11	½	12	17/64	¼	⅝
B-33	0.090	8@1¼=10	¾	11½	¼	¼	1
C-31	0.113	15@ ¾=11¼	⅜	12	¼	¼	½
C-32	0.113	11@1 =11	½	12	¼	¼	⅝
C-51 and C-52	0.113	8@1¼=10	⅝	11¼	21/64	5/16	¾
C-71 and C-72	0.113	7@1½=10½	¾	12	13/32	⅜	1
D-91 and D-92	0.185	5@2 =10	1	12	½	½	1

The results of the tests are given in Table 11. All specimens failed by rivet shear except B-31, B-32, C-71, and C-72, which failed by rivet bearing. The ultimate load is given in column 6, and the rivet shear corresponding to the ultimate load is given in column 9. The shearing strength of undriven rivets from the same lot as the rivets used in the joint, reported in Table 2, is given in column 11. The ratio of the

TABLE 11

STRENGTH OF LAP JOINTS WITH SINGLE ROW OF RIVETS; SPECIMENS DESIGNED TO FAIL BY RIVET SHEAR

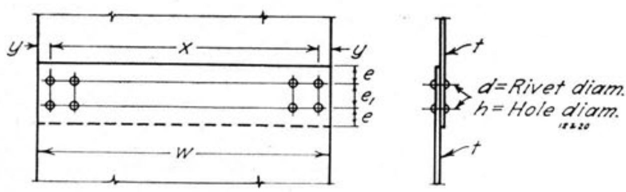
Specimen No.	Rivet Diameter	Sheet Thickness	Rivet Spacing Center to Center		Ultimate Load	Unit Stress at Ultimate Load lb. per sq. in.			Type of Failure	Single Undriven Rivet Shear lb. per sq. in.	Ratio (9)/(11)
	in.	in.	in.	dia.	lb.	Sheet Tension	Rivet* Bearing	Rivet* Shear			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
A-21[1]	3/16	0.060	3/4	4	16 900	31 500	93 700	38 300	Rivet Shear	25 900	1.48
A-22[1]	3/16	0.060	3/4	4	15 700	29 400	87 300	35 700	Rivet Shear	25 900	1.38
B-31[1]	1/4	0.090	1	4	20 100	26 600	78 000	34 200	Rivet Bearing	27 600	1.24[3]
B-32[1]	1/4	0.090	1	4	21 200	28 000	81 900	35 900	Rivet Bearing	27 600	1.30[3]
B-33	1/4	0.090	1 1/4	5	16 900	21 200	87 400	38 300	Rivet Shear	25 800	1.48
C-31	1/4	0.113	3/4	3	29 100	30 800	62 700	37 100	Rivet Shear	25 800	1.44
C-32	1/4	0.113	1	4	21 800	20 900	62 600	37 000	Rivet Shear	25 800	1.43
C-51[1]	5/16	0.113	1 1/4	4	25 200	24 900	79 400	36 500	Rivet Shear	28 000	1.30
C-52[1]	5/16	0.113	1 1/4	4	24 400	24 100	76 700	35 300	Rivet Shear	28 000	1.26
C-71[2]	3/8	0.113	1 1/2	4	27 200	27 500	80 200	30 800	Rivet Bearing	26 800	1.15[3]
C-72[2]	3/8	0.113	1 1/2	4	25 600	25 800	75 500	29 000	Rivet Bearing	26 800	1.08[3]
D-91	1/2	0.185	2	4	35 500	21 700	64 000	30 100	Rivet Shear	24 600	1.22
D-92	1/2	0.185	2	4	32 700	20 000	58 800	27 700	Rivet Shear	24 600	1.13

* Based on nominal rivet diameter.
[1] Dia. 1/64 in. greater for drilled hole than for rivet.
[2] Dia. 1/32 in. greater for drilled hole than for rivet.
[3] Failure was by rivet bearing.

shearing strength of the rivets in the riveted joints to the shearing strength of undriven rivets is given in column 12. It is of interest to note that the shearing strength of the rivets was greater for the rivets of the riveted joints than it was for the undriven rivets, the ratio of the former to the latter varying from 1.48 for the 3⁄16-in. rivets to 1.13 for ½-in. rivets. The shearing strength of the rivets of the various joints varied from 27 700 to 38 300 lb. per sq. in.

11. *Series II-2; Specimens Designed to Fail by Rivet Shear; Lap Joint, Double Row of Rivets.*—The specimens of this series, designed to fail by rivet shear, were lap joints with a double row of rivets. The details of the specimens are shown in Table 12. Figure 7, page 16, shows specimen D-94 after failure.

TABLE 12
DETAILS OF SPECIMENS; SERIES II-2; LAP JOINTS WITH DOUBLE ROW OF RIVETS DESIGNED TO FAIL BY RIVET SHEAR



Specimen No.	t in.	X in.	y in.	W in.	h in.	d in.	e in.	e_1 in.
B-21 and B-22	0.090	15 @ ¾ = 11¼	⅜	12	13⁄64	3⁄16	½	¾
D-51 and D-52	0.185	8 @ 1¼ = 10	⅝	11¼	5⁄16	5⁄16	¾	1¼
D-53 and D-54	0.185	12 @ 15⁄16 = 11¼	⅜	12	5⁄16	5⁄16	¾	1
D-71 and D-72	0.185	9 @ 1⅛ = 10⅛	9⁄16	11¼	⅜	⅜	¾	1⅛
D-93 and D-94	0.185	5 @ 2 = 10	1	12	½	½	1	2

The results of the tests are given in Table 13. All specimens failed by rivet shear as planned. The ultimate load is given in column 6 and the rivet shear corresponding to the ultimate load, based upon the rivet diameter, is given in column 9. The shearing strength of undriven rivets from the same lot as the rivets used in the joint, reported in Table 2, is given in column 10. The ratio of the shearing strength of the rivets in the riveted joints to the shearing strength of the corresponding undriven rivets is given in column 11. For all specimens except D-71, the shearing strength was greater for the rivets of the riveted joints than it was for the undriven rivets. For the ⅜-in. rivets

TABLE 13

STRENGTH OF LAP JOINTS WITH DOUBLE ROW OF RIVETS; SPECIMENS DESIGNED TO FAIL BY RIVET SHEAR

All specimens failed by rivet shear. Holes had same diameter as the rivets for all specimens.

Specimen No.	Rivet Diameter	Sheet Thickness	Rivet Spacing Center to Center		Ultimate Load	Unit Stress at Ultimate Load lb. per sq. in.			Single Undriven Rivet Shear	Ratio (9)/(10)
	in.	in.	in.	dia.	lb.	Sheet Tension	Rivet Bearing*	Rivet Shear*	lb. per sq. in.	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
B-21	3/16	0.090	3/4	4	37 600	47 900	69 500	42 600	25 900	1.64
B-22	3/16	0.090	3/4	4	37 300	47 600	69 000	42 300	25 900	1.63
Average	..	.....	...	..	37 450	47 750	69 250	42 450	25 900	1.64
D-51	5/16	0.185	1 1/4	4	47 800	33 800	46 000	34 600	28 000	1.23
D-52	5/16	0.185	1 1/4	4	45 800	32 400	44 100	33 200	28 000	1.19
Average	..	.....	...	..	46 800	33 100	45 050	33 900	28 000	1.21
D-53	5/16	0.185	15/16	3	57 500	39 400	38 300	28 800	24 000	1.20
D-54	5/16	0.185	15/16	3	58 000	39 800	38 600	29 100	24 000	1.21
Average	..	.....	...	..	57 750	39 600	38 450	28 950	24 000	1.21
D-71	3/8	0.185	1 1/8	3 1/2	55 000	39 900	39 600	24 900	26 000	0.96
D-72	3/8	0.185	1 1/8	3 1/2	57 700	41 900	41 600	26 100	26 000	1.01
Average	..	.....	...	..	56 350	40 900	40 600	25 500	26 000	0.99
D-93	1/2	0.185	2	4	60 000	36 300	54 000	25 500	24 600	1.04
D-94	1/2	0.185	2	4	60 200	36 600	54 400	25 600	24 600	1.04
Average	..	.....	...	..	60 100	36 450	54 200	25 550	24 600	1.04

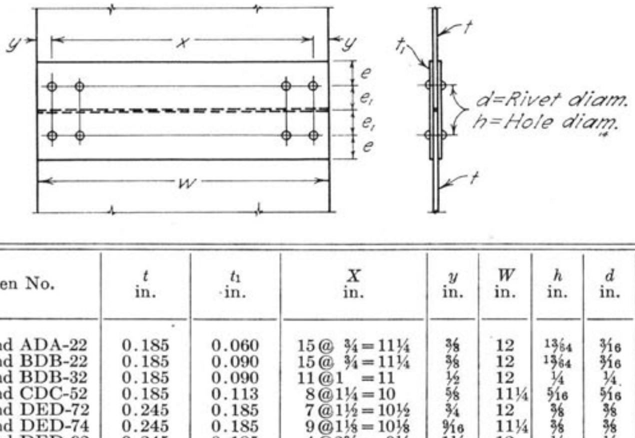
* Based upon rivet diameter.

of D-71, the strength of the rivets of the riveted joints was 0.96 of the strength of the undriven rivets. The ratio of the rivet shear of the riveted joints to the rivet shear of the undriven rivets varied from 1.64 for 3/16-in. rivets to 0.96 for 3/8-in. rivets. The shearing strength of the rivets of the various joints varied from 24 900 lb. per sq. in. to 42 600 lb. per sq. in.

12. *Series III-1; Specimens Designed to Fail by Rivet Shear; Double-Strap Butt Joint, Single Row of Rivets.*—The specimens of this series, designed to fail by rivet shear, were double-strap butt joints with a single row of rivets on each side of the joint. The details of the specimens are shown in Table 14, and the character of the failure is shown by Fig. 8, page 16.

TABLE 14

DETAILS OF SPECIMENS; SERIES III-1; DOUBLE-STRAP BUTT JOINTS WITH SINGLE ROW OF RIVETS DESIGNED TO FAIL BY RIVET SHEAR



Specimen No.	t in.	t_1 in.	X in.	y in.	W in.	h in.	d in.	e in.	e_1 in.
ADA-21 and ADA-22	0.185	0.060	15@ 3/4=11 1/4	3/8	12	13/64	3/16	1/2	3/4
BDB-21 and BDB-22	0.185	0.090	15@ 3/4=11 1/4	3/8	12	13/64	3/16	1/2	1
BDB-31 and BDB-32	0.185	0.090	11@1 =11	1/2	12	1/4	1/4	1/2	1
CDC-51 and CDC-52	0.185	0.113	8@1 1/4=10	5/8	11 1/4	5/16	5/16	5/8	1
DED-71 and DED-72	0.245	0.185	7@1 1/2=10 1/2	3/4	12	3/8	3/8	1	1
DED-73 and DED-74	0.245	0.185	9@1 1/8=10 1/8	9/16	11 1/4	3/8	3/8	1	1
DED-91 and DED-92	0.245	0.185	4@2 3/8= 9 1/2	1 1/2	12	1/2	1/2	1	1 1/2

The results of the tests are given in Table 15. All specimens failed by rivet shear, as planned. For all specimens, the shearing strength was greater for the rivets of the riveted joints than it was for the undriven rivets; the ratio of the former to the latter varied from 1.03 to 1.31. The shearing strength in double shear of the rivets of the various joints varied from 26 200 lb. per sq. in. for 3/8-in. rivets to 34 700 lb. per sq. in. for 3/16-in. rivets.

TABLE 15

STRENGTH OF DOUBLE-STRAP BUTT JOINTS WITH SINGLE ROW OF RIVETS; SPECIMENS DESIGNED TO FAIL BY RIVET SHEAR

All specimens failed by rivet shear.

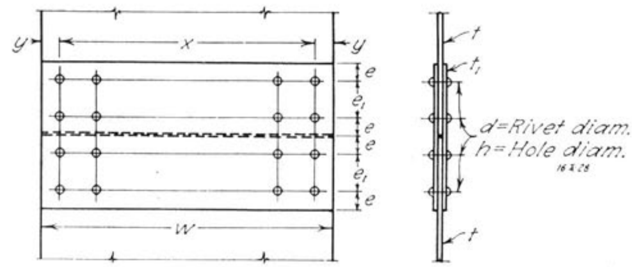
Specimen No.	Rivet Diameter	Inside Sheet Thickness	Rivet Spacing Center to Center		Ultimate Load	Unit Stress at Ultimate Load lb. per sq. in.			Single Undriven Rivet Shear	Ratio (9)/(10)
	in.	in.	in.	dia.	lb.	Sheet Tension	Rivet* Bearing	Rivet* Shear	lb. per sq. in.	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
ADA-21	3/16	0.185	3/4	4	29 800	19 000	53 400	33 600	26 500	1.27
ADA-22	3/16	0.185	3/4	4	28 400	18 200	51 000	32 200	26 500	1.21
Average	...	.....	...	...	29 100	18 600	52 200	32 900	26 500	1.24
BDB-21	3/16	0.185	3/4	4	29 600	19 300	53 300	33 500	26 500	1.26
BDB-22	3/16	0.185	3/4	4	30 600	19 900	55 000	34 700	26 500	1.31
Average	...	.....	...	...	30 100	19 600	54 150	34 100	26 500	1.29
BDB-31	1/4	0.185	1	4	38 600	23 700	69 500	33 800	26 400	1.28
BDB-32	1/4	0.185	1	4	35 400	21 700	63 500	31 000	26 400	1.17
Average	...	.....	...	...	37 000	22 700	66 500	32 400	26 400	1.23
CDC-51	5/16	0.185	1 1/4	4	42 100	27 600	81 000	30 500	28 700	1.06
CDC-52	5/16	0.185	1 1/4	4	41 100	27 100	79 300	29 700	28 700	1.03
Average	...	.....	...	...	41 600	27 350	80 150	30 100	28 700	1.05
DED-71	3/8	0.245	1 1/2	4	54 000	25 200	73 500	30 500	26 000	1.17
DED-72	3/8	0.245	1 1/2	4	55 100	25 800	75 300	31 200	26 000	1.20
Average	...	.....	...	...	54 550	25 500	74 400	30 850	26 000	1.19
DED-73	3/8	0.245	1 1/8	3	59 400	32 800	64 700	26 900	24 000	1.12
DED-74	3/8	0.245	1 1/8	3	58 000	32 100	63 100	26 200	24 000	1.09
Average	...	.....	...	...	58 700	32 450	63 900	26 550	24 000	1.11
DED-91	1/2	0.245	2 3/8	4 3/4	54 800	24 500	89 000	28 000	24 200	1.16
DED-92	1/2	0.245	2 3/8	4 3/4	55 400	24 700	90 500	28 200	24 200	1.17
Average	...	.....	...	...	55 100	24 600	89 750	28 100	24 200	1.17

* Based on rivet diameter.

13. *Series III-2; Specimens Designed to Fail by Rivet Shear; Double-Strap Butt Joint, Double Row of Rivets, Chain Pattern.*— The specimens of this series, designed to fail by rivet shear, were double-strap butt joints with a double row of rivets on each side of the joint. The details of the joints are shown in Table 16, and the character of the failure is shown by Fig. 18.

The results of the tests are given in Table 17. All specimens failed by rivet shear, as planned. For all specimens except DED-94 the shearing strength was greater for the rivets of the riveted joint than

TABLE 16
DETAILS OF SPECIMENS; SERIES III-2; DOUBLE-STRAP BUTT JOINTS WITH DOUBLE ROW OF RIVETS DESIGNED TO FAIL BY RIVET SHEAR



Specimen No.	t in.	t_1 in.	X in.	y in.	W in.	h in.	d in.	e in.	e_1 in.
CDC-21 and CDC-22	0.185	0.113	15@ ¾=11¼	⅜	12	13/64	3/16	½	¾
DED-31 and DED-32	0.245	0.185	9@1¼=11¼	⅜	12	¼	¼	½	1
DFD-51 and DFD-52	0.375	0.185	8@1¼=10	⅝	11¼	5/16	5/16	¾	1¼
CDC-71 and CDC-72	0.185	0.113	6@1⅝= 9¾	¾	11¼	⅜	⅜	¾	1½
DFD-71 and DFD-72	0.375	0.185	7@1½=10½	¾	12	⅜	⅜	¾	1½
DED-93 and DED-94	0.245	0.185	3@3 = 9	1½	12	½	½	1	2
DFD-91 and DFD-92	0.375	0.185	4@2½=10	1	12	½	½	1	2

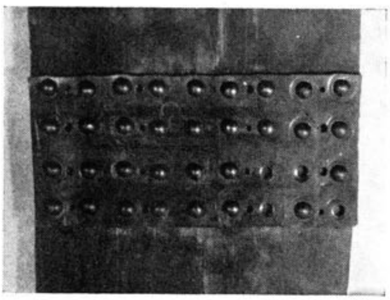


FIG. 18 (LEFT). FAILURE BY RIVET SHEAR; DOUBLE-STRAP BUTT JOINT WITH DOUBLE ROW OF RIVETS, SPECIMEN DFD-52

TABLE 17

STRENGTH OF DOUBLE-STRAP BUTT JOINTS WITH DOUBLE ROW OF RIVETS; SPECIMENS DESIGNED TO FAIL BY RIVET SHEAR

All specimens failed by rivet shear.

Specimen No.	Rivet Diameter	Inside Sheet Thickness	Rivet Spacing Center to Center		Ultimate Load	Unit Stress at Ultimate Load lb. per sq. in.			Single Undriven Rivet Shear	Ratio (9)/(10)
	in.	in.	in.	dia.	lb.	Sheet Tension	Rivet Bearing*	Rivet Shear*	lb. per sq. in.	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
CDC-21	3/16	0.185	3/4	4	55 700	35 000	50 000	31 500	26 500	1.19
CDC-22	3/16	0.185	3/4	4	56 800	35 700	51 000	32 200	26 500	1.22
Average	...	.....	...	...	56 250	35 350	50 500	31 850	26 500	1.21
DED-31	1/4	0.245	1 1/4	5	64 000	28 000	52 200	32 500	26 500	1.22
DED-32	1/4	0.245	1 1/4	5	64 600	28 200	52 700	32 900	26 500	1.24
Average	...	.....	...	...	64 300	28 100	52 450	32 700	26 500	1.23
DFD-51	5/16	0.375	1 1/4	4	85 000	28 200	80 500	30 800	26 400	1.17
DFD-52	5/16	0.375	1 1/4	4	83 000	27 500	78 500	30 000	26 400	1.14
Average	...	.....	...	...	84 000	27 850	79 500	30 400	26 400	1.13
CDC-71	3/8	0.185	1 5/8	4 1/3	51 500	48 600	79 400	24 900	24 000	1.04
CDC-72	3/8	0.185	1 5/8	4 1/3	54 000	47 500	77 400	24 300	24 000	1.01
Average	...	.....	...	...	52 750	48 050	78 400	24 600	24 000	1.03
DFD-71	3/8	0.375	1 1/2	4	97 200	28 800	43 200	27 500	26 000	1.06
DFD-72	3/8	0.375	1 1/2	4	99 500	29 500	44 200	28 100	26 000	1.08
Average	...	.....	...	...	98 350	29 150	43 700	27 800	26 000	1.07
DED-93	1/2	0.245	3	6	77 200	32 000	78 900	24 600	24 200	1.02
DED-94	1/2	0.245	3	6	74 100	30 800	75 500	23 600	24 200	0.98
Average	...	.....	...	...	75 650	31 400	77 200	24 100	24 200	1.00
DFD-91	1/2	0.375	2 1/2	5	99 300	28 900	53 000	25 300	24 200	1.05
DFD-92	1/2	0.375	2 1/2	5	99 100	28 900	52 800	25 200	24 200	1.04
Average	...	.....	...	...	99 200	28 900	52 900	25 250	24 200	1.05

* Based on rivet diameter.

it was for the undriven rivets. For the ½-in. rivets of specimen DED-94, the strength of the rivets of the riveted joint was 0.98 of the strength of the undriven rivets. The ratio of the rivet shear of the riveted joint to the rivet shear of undriven rivets varied from 0.98 for ½-in. rivets to 1.24 for ¼-in. rivets. The shearing strength of the rivets for the various joints in this series varied from 23 600 lb. per sq. in. for ½-in. rivets to 32 900 lb. per sq. in. for ¼-in. rivets. These values are somewhat lower than the corresponding values for double-strap butt joints with a single row of rivets, reported in Section 12.

The results of the tests of riveted joints designed to fail by rivet shear, described in Sections 10 to 13, inclusive, appear to justify the following statements:

The ratio of the shearing strength of the rivets of a riveted joint to the shearing strength of undriven rivets varied from approximately 1.00 for ½-in. rivets to a value of the order of 1.25 for 3/16-in. rivets. The shearing strength of undriven rivets varied for different lots of rivets. For the rivets used in these tests, the strength of undriven rivets in single shear varied from 25 900 lb. per sq. in. for 3/16-in. rivets to 22 900 lb. per sq. in. for ½-in. rivets; the corresponding strength of undriven rivets in double shear varied from 26 500 lb. per sq. in. for 3/16-in. rivets to 24 200 lb. per sq. in. for ½-in. rivets.

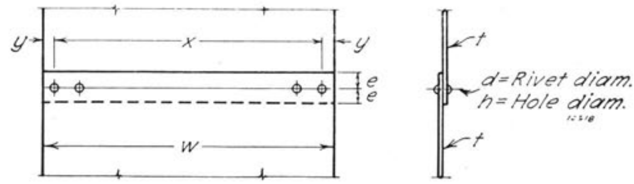
VI. Lap Joints Designed for Tension Failure of Sheet

14. *Influence of Rivet Pattern upon Efficiency of Joints Designed for Tension Failure of Sheets.*—Economy of design in sheet work depends upon the efficiency of the joints, and the efficiency of a joint depends upon the rivet pattern. For these reasons, an extensive study was made to determine the efficiency of joints designed to fail by sheet tension in which a large number of rivet patterns were used. This subject is discussed in considerable detail in Section 4; the schedule of tests is given in Section 5 and the results of the tests are given in Sections 15 to 23.

15. *Series IV-1; Specimens Designed to Fail by Sheet Tension; Lap Joint, Single Row of Rivets.*—The specimens of this series, designed to fail by sheet tension, were lap joints with a single row of rivets. The details of the specimens are shown in Table 18, and the character of the failure is shown by Fig. 10, page 17.

TABLE 18

DETAILS OF SPECIMENS; SERIES IV-1; LAP JOINTS WITH SINGLE ROW OF RIVETS DESIGNED TO FAIL BY SHEET TENSION



Specimen No.	t in.	X in.	y in.	W in.	h in.	d in.	e in.
A-11 and A-12	0.060	31 @ 3/8 = 11 5/8	3/16	12	9/64	1/8	3/8
A-31 and A-32	0.060	18 @ 5/8 = 11 1/4	3/8	12	1/4	1/4	3/4
B-34	0.090	15 @ 3/4 = 11 1/4	3/8	12	1/4	1/4	1/2
C-33	0.113	15 @ 3/4 = 11 1/4	3/8	12	1/4	1/4	1/2
B-51 and B-52	0.090	15 @ 3/4 = 11 1/4	3/8	12	5/16	5/16	1

The results of the tests are given in Table 19. All specimens failed by sheet tension, as planned. The ultimate load is given in column 6, and the various unit stresses corresponding to the ultimate load are given in columns 7, 8, and 9. The coupon strength of the sheet, reported in Table 1, is given in column 10. The ratio of the unit strength of the sheets developed in the joints to the coupon strength of the same sheets is given in column 11. This ratio is also the ratio of the efficiency by test to the computed efficiency* for the joint. This ratio, the average of two tests in each instance, varied from 0.897 for a sheet thickness of 0.060 in. and a rivet spacing of 3 diameters, to 0.989 for a sheet thickness of 0.090 in. and a rivet spacing of 2.4 diameters.

The efficiency of the joints determined by the tests is given in column 12. This efficiency is the ratio of the ultimate strength of the joint to the product of the gross area and the coupon strength of the sheet. This efficiency had average values for the various rivet patterns ranging from 55.7 to 63.5 per cent.

16. *Series IV-2; Specimens Designed to Fail by Sheet Tension; Lap Joint, Double Row of Rivets, Chain Pattern.*—The specimens of this series, designed to fail by sheet tension, were lap joints with a double row of rivets with a chain pattern. The details of the specimens are shown in Table 20, and the character of the failure is shown by Fig. 19.

*For definition of computed efficiency, see Section 4.

TABLE 19

STRENGTH OF LAP JOINTS WITH SINGLE ROW OF RIVETS; SPECIMENS DESIGNED TO FAIL BY SHEET TENSION

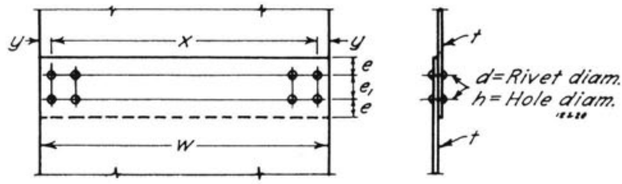
All specimens failed by sheet tension.

Specimen No.	Rivet Diameter in.	Sheet Thickness in.	Rivet Spacing Center to Center in.	Rivet Spacing Center to Center dia.	Ultimate Load lb.	Unit Stress at Ultimate Load lb. per sq. in. Rivet Shear*	Rivet Bearing*	Sheet Tension†	Coupon Strength of Sheet lb. per sq. in.	Ratio (9)/(10)	Joint‡ Efficiency by Test per cent
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
A-11	1/8	0.060	3/8	3	21 300	34 000	87 200	46 800	51 500	0.909	57.5
A-12	1/8	0.060	3/8	3	20 800	32 600	85 000	45 600	51 500	0.885	56.2
Average	..	.....	..	..	21 050	33 300	86 100	46 200	51 500	0.897	56.9
A-31	1/4	0.060	5/8	2.5	20 900	22 400	82 000	48 100	51 300	0.938	56.5
A-32	1/4	0.060	5/8	2.5	20 300	21 700	79 300	46 600	51 300	0.908	54.9
Average	..	.....	..	..	20 600	22 050	80 650	47 350	51 300	0.923	55.7
B-34	1/4	0.090	3/4	3	23 700	30 200	69 000	33 700	35 300	0.955	62.3
C-33	1/4	0.113	3/4	3	28 500	36 300	61 300	30 200	33 100	0.912	63.5
B-51	5/16	0.090	3/4	2.4	30 100	24 500	67 000	48 000	49 900	0.962	55.8
B-52	5/16	0.090	3/4	2.4	31 800	25 900	70 600	50 700	49 900	1.015	60.0
Average	..	.....	..	..	30 950	25 200	68 200	49 350	49 900	0.989	57.9

* Based on rivet diameter.
† Based on diameter of hole.
‡ The joint efficiency by test is the ratio of the ultimate load to the product of the gross section and the coupon strength of the sheet.

TABLE 20

DETAILS OF SPECIMENS; SERIES IV-2; LAP JOINTS WITH DOUBLE ROW OF RIVETS, CHAIN PATTERN; SPECIMENS DESIGNED TO FAIL BY SHEET TENSION



Specimen No.	t in.	X in.	y in.	W in.	h in.	d in.	e in.	e_1 in.
A-13 and A-14	0.060	23 @ 1/2 = 11 1/2	1/4	12	9/64	1/8	1/4	1/2
B-23 and B-24	0.090	23 @ 1/2 = 11 1/2	1/4	12	3/16	3/16	1/2	3/4
B-35 and B-36	0.090	15 @ 3/4 = 11 1/4	3/8	12	1/4	1/4	1/2	3/4
C-34 and C-35	0.113	15 @ 3/4 = 11 1/4	3/8	12	1/4	1/4	1/2	3/4
C-36 and C-37	0.113	14 @ 13/16 = 11 3/8	5/16	12	17/64	1/4	5/8	1
D-75 and D-76	0.185	7 @ 1 1/2 = 10 1/2	3/4	12	3/8	3/8	1	1 1/2
E-93 and E-94	0.245	7 @ 1 1/2 = 10 1/2	3/4	12	1/2	1/2	1	1 1/2
E-95 and E-96	0.245	5 @ 2 = 10	1	12	1/2	1/2	1	2

The results of the tests are given in Table 21. All specimens failed by sheet tension, as planned. The ratio of the unit strength of the sheets developed by the riveted joints to the coupon strength of the same sheets is given in column 11. This ratio, the average for two tests in each instance, varied from 0.955 for 3/16-in. rivets and 0.090-in. sheets to 1.204 for 1/4-in. rivets and 0.113-in. sheets. This ratio was greater for the joints with two rows of rivets than it was for the lap joints with one row of rivets, reported in Table 19. There was no apparent correlation between this ratio and either the rivet diameter or the sheet thickness.

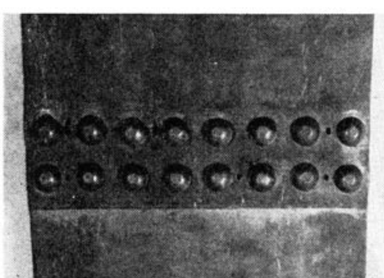


FIG. 19. FAILURE BY SHEET TENSION; LAP JOINT WITH DOUBLE ROW OF RIVETS, CHAIN PATTERN, SPECIMEN E-93

The efficiency of the joints by tests, given in column 12 of Table 21, the average of two tests in each instance, had values ranging from 59.4 to 80.0 per cent. These values of the efficiency are significantly greater than the corresponding values reported in Table 19 for lap joints with a single row of rivets.

TABLE 21

STRENGTH OF LAP JOINTS WITH DOUBLE ROW OF RIVETS, CHAIN PATTERN; SPECIMENS DESIGNED TO FAIL BY SHEET TENSION

All specimens failed by sheet tension.

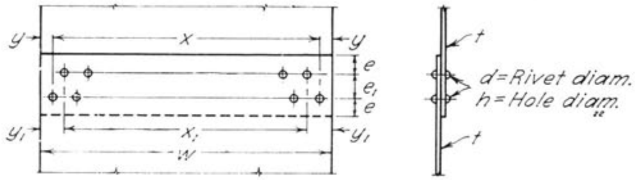
Specimen No.	Rivet Diameter in.	Sheet Thickness in.	Rivet Spacing Center to Center in.	Rivet Spacing Center to Center dia.	Ultimate Load lb.	Unit Stress at Ultimate Load lb. per sq. in. Rivet Shear*	Unit Stress at Ultimate Load lb. per sq. in. Rivet Bearing*	Unit Stress at Ultimate Load lb. per sq. in. Sheet Tension†	Coupon Strength of Sheet lb. per sq. in.	Ratio (9)/(10)	Joint‡ Efficiency by Test per cent
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
A-13	1/8	0.060	1/2	4	25 600	43 400	71 000	49 800	51 500	0.968	69.0
A-14	1/8	0.060	1/2	4	25 200	42 700	69 900	49 000	51 500	0.952	67.8
Average	..	.....	..	..	25 400	43 050	70 450	49 400	51 500	0.960	68.4
B-23	3/16	0.090	1/2	2.7	33 000	24 900	82 500	49 200	52 800	0.931	57.9
B-24	3/16	0.090	1/2	2.7	34 700	26 200	85 600	51 700	52 800	0.979	60.8
Average	..	.....	..	..	33 850	25 550	84 050	50 450	52 800	0.955	59.4
B-35	1/4	0.090	3/4	3	26 700	17 000	38 900	39 600	35 800	1.107	69.1
B-36	1/4	0.090	3/4	3	26 600	16 900	38 700	39 400	35 800	1.100	69.0
Average	..	.....	..	..	26 650	16 950	38 800	39 500	35 800	1.104	69.1
C-34	1/4	0.113	3/4	3	44 600	28 400	49 300	49 600	51 000	0.971	64.4
C-35	1/4	0.113	3/4	3	43 200	27 500	47 800	48 100	51 000	0.943	62.4
Average	..	.....	..	..	43 900	27 950	48 550	48 850	51 000	0.957	63.4
C-36	1/4	0.113	13/16	3.25	36 400	24 700	42 800	40 200	34 000	1.180	78.0
C-37	1/4	0.113	13/16	3.25	37 800	25 600	44 400	41 700	34 000	1.227	82.0
Average	..	.....	..	..	37 100	25 150	43 600	40 950	34 000	1.204	80.0
D-75	3/8	0.185	1 1/2	4	59 200	33 500	53 300	35 800	36 400	0.984	73.2
D-76	3/8	0.185	1 1/2	4	58 900	33 000	53 000	35 300	36 400	0.970	72.8
Average	..	.....	..	..	59 050	33 250	53 150	35 550	36 400	0.977	73.0
E-93	1/2	0.245	1 1/2	3	70 500	22 400	34 900	36 600	35 400	1.033	67.7
E-94	1/2	0.245	1 1/2	3	69 200	22 200	36 000	36 000	35 400	1.017	66.3
Average	..	.....	..	..	69 850	22 300	35 450	36 300	35 400	1.025	67.0
E-95	1/2	0.245	2	4	74 700	31 600	51 000	34 500	34 400	1.003	73.8
E-96	1/2	0.245	2	4	74 300	31 500	50 500	34 200	34 400	0.994	73.4
Average	..	.....	..	..	74 500	31 550	50 750	34 350	34 400	0.999	73.6

* Based on rivet diameter.
† Based on diameter of hole.
‡ The joint efficiency by test is the ratio of the ultimate load to the product of the gross section and the coupon strength of the sheet.

17. *Series IV-3; Specimens Designed to Fail by Sheet Tension; Lap Joint, Double Row of Rivets, Stagger Pattern.*—The specimens of this series, designed to fail by sheet tension, were lap joints with a double row of rivets with a stagger pattern. The details of the specimens are shown in Table 22, and the character of the failure is shown by Fig. 20.

TABLE 22

DETAILS OF SPECIMENS; SERIES IV-3; LAP JOINTS WITH DOUBLE ROW OF RIVETS, STAGGER PATTERN; SPECIMENS DESIGNED TO FAIL BY SHEET TENSION



Specimen No.	t in.	X in.	X_1 in.	y in.	y_1 in.	W in.	h in.	d in.	e in.	e_1 in.
A-33 and A-34	0.060	15@ ¾=11¼	14@ ¾=10½	⅜	¾	12	¼	¼	½	¾
B-53 and B-54	0.090	15@ ¾=11¼	14@ ¾=10½	⅜	¾	12	5/16	5/16	½	¾
C-53 and C-54	0.113	12@15/16=11¼	11@15/16=10 5/16	⅜	27/32	12	5/16	5/16	½	1
C-73 and C-74	0.113	7@ 1½=10½	6@ 1½= 9	¾	1½	12	⅜	⅜	1	1½
D-77 and D-78	0.185	11@ 1 =11	10@ 1 =10	½	1	12	⅜	⅜	¾	1
E-97 and E-98	0.245	7@ 1½=10½	6@ 1½= 9	¾	1½	12	½	½	1	1½

The results of the tests are given in Table 23. All specimens failed by sheet tension, as planned. The ratio of the unit strength of the sheets developed by the riveted joints to the coupon strength of the same sheets is given in column 11. This ratio, the average of two tests in each instance, varied from 0.95 for 5/16-in. rivets and 0.090-in. sheets to 1.076 for 5/16-in. rivets and 0.113-in. sheets. The values of this ratio were not significantly different for these joints with rivets in a stagger pattern than they were for the similar joints of Section 16 with rivets in a chain pattern. There was no consistent relation between the values of this ratio and either the rivet diameter or the sheet thickness.

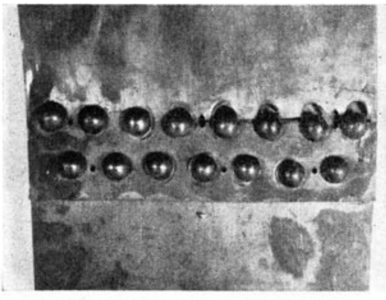


FIG. 20. FAILURE BY SHEET TENSION; LAP JOINT WITH DOUBLE ROW OF RIVETS, STAGGER PATTERN, SPECIMEN E-97

TABLE 23

STRENGTH OF LAP JOINTS WITH DOUBLE ROW OF RIVETS, STAGGER PATTERN; SPECIMENS DESIGNED TO FAIL BY SHEET TENSION

All specimens failed by sheet tension. Holes had same diameter as the rivets for all specimens.

Specimen No.	Rivet Diameter	Sheet Thickness	Rivet Spacing Center to Center		Ultimate Load	Unit Stress at Ultimate Load lb. per sq. in.			Coupon Strength of Sheet	Ratio (9)/(10)	Joint† Efficiency by Test
	in.	in.	in.	dia.	lb.	Rivet Shear*	Rivet Bearing*	Sheet Tension	lb. per sq. in.		per cent
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
A-33	¼	0.060	¾	3	23 500	15 500	50 600	49 200	51 300	0.958	63.6
A-34	¼	0.060	¾	3	24 800	16 300	53 300	51 900	51 300	1.012	67.6
Average	..	.....	..	..	24 150	15 900	51 950	50 550	51 300	0.985	65.6
B-53	5/16	0.090	¾	2.4	28 500	12 000	32 700	45 500	49 900	0.911	52.8
B-54	5/16	0.090	¾	2.4	30 900	13 000	35 500	49 300	49 900	0.989	57.4
Average	..	.....	..	..	29 700	12 500	34 100	47 400	49 900	0.950	55.1
C-53	5/16	0.113	15/16	3	45 800	23 800	51 800	51 200	47 300	1.081	71.5
C-54	5/16	0.113	15/16	3	45 300	23 600	51 300	50 700	47 300	1.071	70.7
Average	..	.....	..	..	45 550	23 700	51 550	50 950	47 300	1.076	71.1
C-73	⅜	0.113	1½	4	48 500	29 200	76 200	48 000	47 300	1.013	75.5
C-74	⅜	0.113	1½	4	47 100	28 400	74 100	46 600	47 300	0.987	73.3
Average	..	.....	..	..	47 800	28 800	75 150	47 300	47 300	1.000	74.4
D-77	⅜	0.185	1	2.7	68 600	27 100	43 100	49 900	48 900	1.019	63.1
D-78	⅜	0.185	1	2.7	68 000	26 800	42 600	49 300	48 900	1.007	62.5
Average	..	.....	..	..	68 300	26 950	42 850	49 600	48 900	1.013	62.8
E-97	½	0.245	1½	3	70 500	23 300	37 300	35 800	35 300	1.013	67.5
E-98	½	0.245	1½	3	69 200	24 100	38 400	36 900	35 300	1.045	66.3
Average	..	.....	..	..	69 850	23 700	37 850	36 350	35 300	1.034	66.9

* Based on rivet diameter.

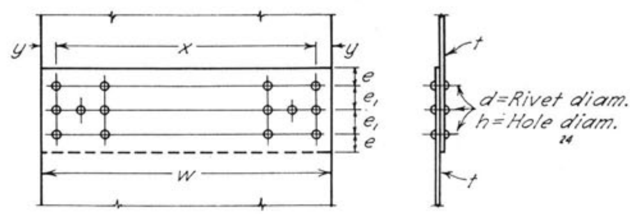
† The joint efficiency by test is the ratio of the ultimate load to the product of the gross section and the coupon strength of the sheet.

The efficiency of the joints by tests, given in column 12 of Table 23, the average of two tests in each instance, had values ranging from 55.1 to 74.4 per cent. These values of the efficiency do not differ greatly from the corresponding values reported in Section 16 for lap joints with a double row of rivets in a chain pattern.

18. *Series IV-4; Specimens Designed to Fail by Sheet Tension; Lap Joint, Triple Row of Rivets, Alternate Rivets Omitted from Both Outer Rows.*—The specimens of this series, designed to fail by sheet tension, were lap joints with a triple row of rivets with every other rivet omitted from both outer rows. The details of the specimens are shown in Table 24, and the character of the failure is shown by Fig. 21.

TABLE 24

DETAILS OF SPECIMENS; SERIES IV-4; LAP JOINTS WITH TRIPLE ROW OF RIVETS, ALTERNATE RIVETS OMITTED FROM BOTH OUTER ROWS; SPECIMENS DESIGNED TO FAIL BY SHEET TENSION



Specimen No.	t in.	X in.	y in.	W in.	h in.	d in.	e in.	e_1 in.
A-35 and A-36	0.060	14@ ¾ = 10½	⅜	11¼	¼	¼	½	¾
C-55 and C-56	0.113	10@1 = 10	⅝	11¼	5/16	5/16	¾	1
E-99 and E-100	0.245	6@1½ = 9	¾	10½	½	½	1	1½

The results of the tests are given in Table 25. All specimens failed by sheet tension, as planned. The ratio of the unit strength of the sheet developed by the riveted joints to the coupon strength of the same sheets is given in column 11. This ratio, the average of two tests in each instance, varied from 0.977 to 0.994. This ratio varied through a narrow range and the minimum value was greater than the minimum value for single-row and double-row joints of Sections 15, 16, and 17.

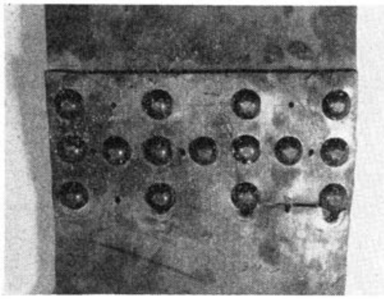


FIG. 21 (LEFT). FAILURE BY SHEET TENSION; LAP JOINT WITH TRIPLE ROW OF RIVETS, ALTERNATE RIVETS OMITTED FROM OUTER ROWS, SPECIMEN E-99

The efficiency of the joints by tests, given in column 12 of Table 25, the average of two tests in each instance, had values ranging from 78.0 to 84.9 per cent. These values are significantly greater than the corresponding values for the efficiency of lap joints with a single row and with a double row of rivets.

VII. DOUBLE-STRAP BUTT JOINTS DESIGNED FOR FAILURE BY SHEET TENSION

19. *Series V-1; Double-Strap Butt Joints Designed to Fail by Sheet Tension; Single Row of Rivets.*—The specimens of this series, designed to fail by sheet tension, were double-strap butt joints with a single row of rivets. The details of the specimens are given in Table 26, and the appearance of a specimen after failure is shown by Fig. 22. The fracture, being in the inside sheet, is not shown by this photograph. Its location is indicated by the white marks on the rivet heads.

The results of the tests are given in Table 27. All specimens failed by sheet tension, as planned. The ratio of the unit strength of the sheets developed by the riveted joints to the coupon strength of the same sheets is given in column 11. This ratio, the average of two tests in each instance, varied from 0.878 for $\frac{5}{16}$-in. rivets and 0.090-in. sheets to 1.087 for $\frac{5}{16}$-in. rivets and 0.113-in. sheets. There was no consistent relation between the values of this ratio and either the rivet diameter or the sheet thickness.

The efficiency of the joints by tests, given in column 12 of Table 27, the average of two tests in each instance, had values ranging from 54.9 to 64.8 per cent. These values are comparable with 55.7 and 63.5 per

TABLE 25

STRENGTH OF LAP JOINTS WITH TRIPLE ROW OF RIVETS, ALTERNATE RIVETS OMITTED FROM BOTH OUTER ROWS; SPECIMENS DESIGNED TO FAIL BY SHEET TENSION

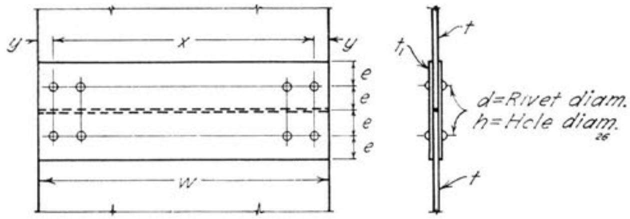
All specimens failed by sheet tension. Holes had same diameter as the rivets for all specimens.

Specimen No.	Rivet Diameter	Sheet Thickness	Rivet Spacing Center to Center		Ultimate Load	Unit Stress at Ultimate Load lb. per sq. in.			Coupon Strength of Sheet	Ratio (9)/(10)	Joint† Efficiency by Test
	in.	in.	in.	dia.	lb.	Rivet Shear*	Rivet Bearing*	Sheet Tension	lb. per sq. in.		per cent
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
A-35	¼	0.060	¾	3	28 900	19 000	62 200	50 100	51 300	0.976	84.5
A-36	¼	0.060	¾	3	29 200	19 200	62 500	50 600	51 300	0.986	85.3
Average	..	.....	..	..	29 050	19 100	62 350	50 350	51 300	0.981	84.9
C-55	5/16	0.113	1	3.2	49 400	27 900	63 500	46 800	47 300	0.990	82.2
C-56	5/16	0.113	1	3.2	50 700	28 200	64 000	47 200	47 300	0.998	84.4
Average	..	.....	..	..	50 050	28 050	63 750	47 000	47 300	0.994	83.3
E-99	½	0.245	1½	3	69 900	23 700	38 100	34 000	35 400	0.960	76.7
E-100	½	0.245	1½	3	72 300	24 600	39 500	35 200	35 400	0.994	79.3
Average	..	.....	..	..	71 100	24 150	38 800	34 600	35 400	0.977	78.0

* Based on rivet diameter.
† The joint efficiency by test is the ratio of the ultimate load to the product of the gross section and the coupon strength of the sheet.

TABLE 26

DETAILS OF SPECIMENS; SERIES V-1; DOUBLE-STRAP BUTT JOINTS DESIGNED TO FAIL BY SHEET TENSION; SINGLE ROW OF RIVETS



Specimen No.	t in.	t_1 in.	X in.	y in.	W in.	h in.	d in.	e in.
AAA-31 and AAA-32	0.060	0.060	15@ 3/4=11 1/4	3/8	12	17/64	1/4	1/2
ABA-31 and ABA-32	0.090	0.060	15@ 3/4=11 1/4	3/8	12	17/64	1/4	1/2
ACA-31 and ACA-32	0.113	0.060	15@ 3/4=11 1/4	3/8	12	17/64	1/4	1/2
AAA-51 and AAA-52	0.060	0.060	12@15/16=11 1/4	3/8	12	21/64	5/16	3/4
ABA-51 and ABA-52	0.090	0.060	12@15/16=11 1/4	3/8	12	21/64	5/16	3/4
ACA-51 and ACA-52	0.113	0.060	12@15/16=11 1/4	3/8	12	21/64	5/16	3/4
CDC-53 and CDC-54	0.185	0.113	12@15/16=11 1/4	3/8	12	5/16	5/16	7/8
CDC-71 and CDC-72	0.185	0.113	9@ 1 1/8=10 1/8	9/16	11 1/4	3/8	3/8	1

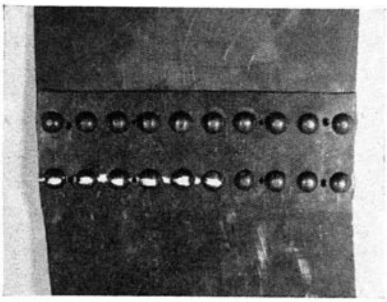


FIG. 22. FAILURE BY SHEET TENSION; DOUBLE-STRAP BUTT JOINT WITH SINGLE ROW OF RIVETS ON EACH SIDE OF JOINT, SPECIMEN CDC-71

cent for lap joints with the same type of rivet pattern, given in Table **19**. There is no significant difference in efficiency between these butt joints and the corresponding lap joints.

20. *Series V-2; Double-Strap Butt Joints Designed to Fail by Sheet Tension; Double Row of Rivets, Chain Pattern.*—The specimens of this series, designed to fail by sheet tension, were double-strap butt joints with a double row of rivets with a chain pattern. The details of the specimens are given in Table **28**, and the location of the failure is shown by Fig. **23**.

The results of the tests are given in Table **29**. All specimens failed by sheet tension, as planned. The ratio of the unit strength of the sheet developed by the riveted joints to the coupon strength of the same

TABLE 27

STRENGTH OF DOUBLE-STRAP BUTT JOINTS DESIGNED TO FAIL BY SHEET TENSION; SINGLE ROW OF RIVETS

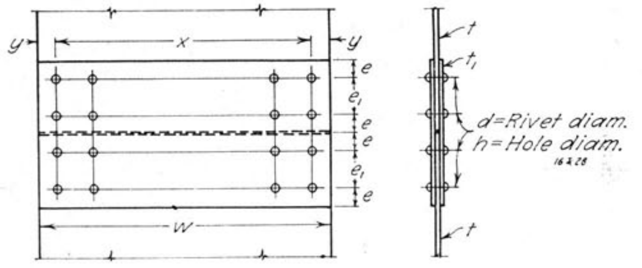
All specimens failed by sheet tension.

Specimen No.	Rivet Diameter in.	Thickness Inside Sheet in.	Rivet Spacing Center to Center in.	Rivet Spacing Center to Center dia.	Ultimate Load lb.	Unit Stress at Ultimate Load lb. per sq. in. Sheet* Tension	Unit Stress at Ultimate Load lb. per sq. in. Rivet† Bearing	Unit Stress at Ultimate Load lb. per sq. in. Rivet† Shear	Coupon Strength of Sheet lb. per sq. in.	Ratio (7)/(10)	Joint‡ Efficiency by Test per cent
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
AAA-31	¼	0.060	¾	3	23 000	49 600	95 800	14 700	51 500	0.963	62.0
AAA-32	¼	0.060	¾	3	21 900	47 300	91 300	14 000	51 500	0.920	59.0
Average	..	.....	..	..	22 450	48 450	93 550	14 350	51 500	0.942	60.5
ABA-31	¼	0.090	¾	3	30 200	43 500	84 000	19 300	47 100	0.924	59.4
ABA-32	¼	0.090	¾	3	30 900	44 500	86 000	19 700	47 100	0.946	60.8
Average	..	.....	..	..	30 550	44 000	85 000	19 500	47 100	0.935	60.1
ACA-31	¼	0.113	¾	3	29 900	34 500	66 200	19 100	34 000	1.015	65.0
ACA-32	¼	0.113	¾	3	29 600	34 100	65 500	18 900	34 000	1.003	64.6
Average	..	.....	..	..	29 750	34 300	65 850	19 000	34 000	1.009	64.8
AAA-51	5/16	0.060	15/16	3	22 300	47 600	90 000	11 200	51 500	0.924	60.2
AAA-52	5/16	0.060	15/16	3	21 800	46 500	87 900	10 900	51 500	0.904	59.0
Average	..	.....	..	..	22 050	47 050	88 950	11 050	51 500	0.914	59.6
ABA-51	5/16	0.090	15/16	3	29 600	43 400	81 100	14 900	50 600	0.858	54.2
ABA-52	5/16	0.090	15/16	3	30 300	45 300	84 600	15 500	50 600	0.898	55.6
Average	..	.....	..	..	29 950	44 350	82 850	15 200	50 600	0.878	54.9
ACA-51	5/16	0.113	15/16	3	28 700	37 000	68 700	14 400	34 000	1.090	62.4
ACA-52	5/16	0.113	15/16	3	28 400	36 500	67 900	14 300	34 000	1.074	61.8
Average	..	.....	..	..	28 550	36 750	68 300	14 350	34 000	1.087	62.1
CDC-53	5/16	0.185	15/16	3	49 100	33 900	65 300	24 600	36 400	0.932	60.7
CDC-54	5/16	0.185	15/16	3	50 000	34 600	66 700	26 100	36 400	0.950	61.7
Average	..	.....	..	..	49 550	34 250	66 000	25 350	36 400	0.941	61.2
CDC-71	⅜	0.185	1⅛	3	45 300	33 200	65 400	20 500	35 700	0.930	61.0
CDC-72	⅜	0.185	1⅛	3	45 000	32 900	64 800	20 400	35 700	0.922	60.6
Average	..	.....	..	..	45 150	33 050	65 100	20 450	35 700	0.926	60.8

* Based on diameter of hole.
† Based on rivet diameter.
‡ The joint efficiency by test is the ratio of the ultimate load to the product of the gross section and the coupon strength of the sheet.

TABLE 28

DETAILS OF SPECIMENS; SERIES V-2; DOUBLE-STRAP BUTT JOINTS DESIGNED TO FAIL BY SHEET TENSION; DOUBLE ROW OF RIVETS, CHAIN PATTERN



Specimen No.	t in.	t_1 in.	X in.	y in.	W in.	h in.	d in.	e in.	e_1 in.
BCB-21 and BCB-22	0.113	0.090	15@ 3/4=11 1/4	3/8	12	13/64	3/16	1/2	3/4
BCB-31 and BCB-32	0.113	0.090	12@15/16=11 1/4	3/8	12	1/4	1/4	1/2	3/4
CDC-55 and CDC-56	0.185	0.113	9@ 1 1/8=10 1/8	15/16	12	5/16	5/16	3/4	1 1/4
DED-51 and DED-52	0.245	0.185	8@ 1 1/4=10	5/8	11 1/4	5/16	5/16	3/4	1 1/4
CEC-71 and CEC-72	0.245	0.113	8@ 1 1/8= 9	9/16	10 1/8	13/32	3/8	1	1 1/2
DED-75 and DED-76	0.245	0.185	7@ 1 1/2=10 1/2	3/4	12	3/8	3/8	3/4	1 1/2
DED-77 and DED-78	0.245	0.185	5@ 1 7/8= 9 3/8	1	11 3/8	3/8	3/8	3/4	1 1/2
DFD-93 and DFD-94	0.375	0.185	5@ 2 =10	1	12	1/2	1/2	1	2

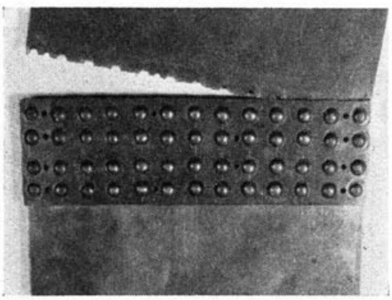


FIG. 23. FAILURE BY SHEET TENSION; DOUBLE-STRAP BUTT JOINT WITH DOUBLE ROW OF RIVETS, CHAIN PATTERN, SPECIMEN BCB-32

sheets is given in column 11. This ratio, the average of two tests in each instance, varied from 0.896 for 3/8-in. rivets and 0.245-in. sheets to 1.082 for specimens with the same rivet diameter and sheet thickness. The rivet spacing was 5 diameters for the former and 3 diameters for the latter.

The efficiency of the joints by tests, given in column 12, the average of two tests in each instance, had values ranging from 69.0 to 77.2 per cent. These values are comparable to 59.4 and 80.0 per cent for lap joints with the same rivet pattern, reported in Section 16, and to 54.9 to 64.8 per cent for the double-strap butt joints with a single row of rivets reported in Section 19.

TABLE 29

STRENGTH OF DOUBLE-STRAP BUTT JOINTS DESIGNED TO FAIL BY SHEET TENSION; DOUBLE ROW OF RIVETS, CHAIN PATTERN

All specimens failed by sheet tension.

Specimen No.	Rivet Diameter in.	Thickness Inside Sheet in.	Rivet Spacing Center to Center in.	Rivet Spacing Center to Center dia.	Ultimate Load lb.	Unit Stress at Ultimate Load lb. per sq. in. Sheet* Tension	Unit Stress at Ultimate Load lb. per sq. in. Rivet† Bearing	Unit Stress at Ultimate Load lb. per sq. in. Rivet† Shear	Coupon Strength of Sheet lb. per sq. in.	Ratio (7)/(10)	Joint‡ Efficiency by Test per cent
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
BCB-21	3/16	0.113	3/4	4	34 400	35 000	50 500	19 500	34 000	1.030	74.5
BCB-22	3/16	0.113	3/4	4	36 900	37 700	54 200	20 900	34 000	1.110	78.5
Average	..	.....	..	..	35 650	36 350	52 350	20 200	34 000	1.070	76.5
BCB-31	1/4	0.113	15/16	3 3/4	49 000	49 800	66 500	20 400	47 300	1.053	76.3
BCB-32	1/4	0.113	15/16	3 3/4	50 000	50 800	67 900	20 800	47 300	1.073	77.9
Average	..	.....	..	..	49 500	50 300	67 200	20 600	47 300	1.063	77.1
CDC-55	5/16	0.185	1 1/8	3 5/8	84 000	48 000	91 000	34 200	50 200	0.956	75.3
CDC-56	5/16	0.185	1 1/8	3 5/8	84 400	48 200	91 300	34 400	50 200	0.962	76.7
Average	..	.....	..	..	84 200	48 100	91 150	34 300	50 200	0.959	76.0
DED-51	5/16	0.245	1 1/4	4	75 200	37 100	54 700	27 200	35 300	1.051	77.3
DED-52	5/16	0.245	1 1/4	4	75 000	37 100	54 600	27 200	35 300	1.051	77.0
Average	..	.....	..	..	75 100	37 100	54 650	27 200	35 300	1.051	77.2
CEC-71	3/8	0.245	1 1/8	3	59 400	37 500	36 500	14 900	34 400	1.091	69.7
CEC-72	3/8	0.245	1 1/8	3	58 300	36 900	36 000	14 700	34 400	1.073	68.3
Average	..	.....	..	..	58 850	37 200	36 250	14 800	34 400	1.082	69.0
DED-75	3/8	0.245	1 1/2	4	80 500	37 000	54 700	22 800	35 400	1.045	77.3
DED-76	3/8	0.245	1 1/2	4	75 800	35 200	51 500	21 400	35 400	0.995	72.7
Average	..	.....	..	..	78 150	36 100	53 100	22 100	35 400	1.020	75.0
DED-77	3/8	0.245	1 7/8	5	69 400	31 500	62 900	26 200	35 300	0.893	70.6
DED-78	3/8	0.245	1 7/8	5	68 800	31 700	62 400	25 900	35 300	0.899	70.0
Average	..	.....	..	..	69 100	31 600	62 650	26 050	35 300	0.896	70.3
DFD-93	1/2	0.375	2	4	114 400	34 500	50 900	24 200	35 400	0.974	71.8
DFD-94	1/2	0.375	2	4	116 500	35 300	51 800	24 600	35 400	0.998	73.2
Average	..	.....	..	..	115 450	34 900	51 350	24 400	35 400	0.986	72.5

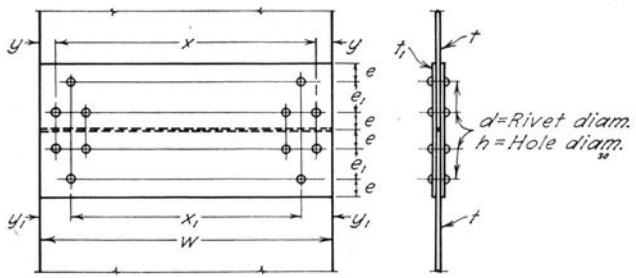
* Based on diameter of hole.
† Based on rivet diameter.
‡ Joint efficiency by test is the ratio of the ultimate load to the product of the gross section and the coupon strength of the sheet.

It is of interest to note that specimens CEC-71 and CEC-72, with a rivet spacing of $3d$, and DED-77 and DED-78, with a rivet spacing of $5d$, had very nearly the same efficiency by test. The greater ratio of net to gross section for the DED specimens was offset by the smaller ratio of unit strength of the sheet developed by the joint to the coupon strength of the same sheet.

21. *Series V-3; Double-Strap Butt Joints Designed to Fail by Sheet Tension; Double Row of Rivets, Stagger Pattern.*—The specimens of this series, designed to fail by sheet tension, were double-strap butt joints with a double row of rivets with a stagger pattern. The details

TABLE 30

DETAILS OF SPECIMENS; SERIES V-3; DOUBLE-STRAP BUTT JOINTS DESIGNED TO FAIL BY SHEET TENSION; DOUBLE ROW OF RIVETS, STAGGER PATTERN

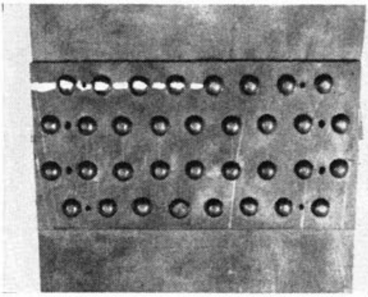


Specimen No.	t in.	t_1 in.	X in.	X_1 in.	y in.	y_1 in.	W in.	h in.	d in.	e in.	e_1 in.
BCB-23 and BCB-24	0.113	0.090	15@ 3/4=11 1/4	14@ 3/4=10 1/2	3/8	3/4	12	3/16	3/16	1/2	3/4
BCB-25 and BCB-26	0.113	0.090	12@15/16=11 1/4	11@15/16=10 5/16	3/8	27/32	12	3/16	3/16	1/2	3/4
BCB-33 and BCB-34	0.113	0.090	7@ 1 1/2=10 1/2	6@ 1 1/2=9	3/4	1 1/2	12	1/4	1/4	1/2	1
CDC-31 and CDC-32	0.185	0.113	14@ 3/4=10 1/2	13@ 3/4= 9 3/4	3/4	1 1/8	12	1/4	1/4	1/2	1
CDC-57 and CDC-58	0.185	0.113	9@ 1 1/8=10 1/8	8@ 1 1/8= 9	15/16	1 1/2	12	5/16	5/16	3/4	1 1/4
DED-53 and DED-54	0.245	0.185	8@ 1 1/4=10	7@ 1 1/4= 8 3/4	5/8	1 1/4	11 1/4	5/16	5/16	3/4	1 1/4
DFD-53 and DFD-54	0.375	0.185	12@15/16=11 1/4	11@15/16=10 5/16	3/8	27/32	12	5/16	5/16	3/4	1 1/4
DED-79 and DED-80	0.245	0.185	7@ 1 1/2=10 1/2	6@ 1 1/2= 9	3/4	1 1/2	12	3/8	3/8	1	1 1/2

of the specimens are given in Table 30, and the location of the failure is shown by Fig. 24. The location of the fracture in the inside sheet is indicated by the white marks on the rivet heads.

The results of the tests are given in Table 31. All specimens failed by sheet tension except that, for specimens CDC-57, CDC-58, DED-53,

FIG. 24 (RIGHT). FAILURE BY SHEET TENSION; DOUBLE-STRAP BUTT JOINT WITH DOUBLE ROW OF RIVETS, STAGGER PATTERN, SPECIMEN DED-54



and DED-54, initial failure was by rivet shear with impending failure by sheet tension. These are considered to have failed by sheet tension, since the maximum strength in sheet tension had been realized before failure occurred by rivet shear. The ratio of the unit strength of the sheets developed by riveted joints to the coupon strength of the same sheets is given in column 11. This ratio, the average of two tests in each instance, varied from 0.960 for $\frac{5}{16}$-in. rivets and 0.185-in. sheets to 0.997 for $\frac{1}{4}$-in. rivets and 0.185-in. sheets. This variation, which was quite small, did not bear any consistent relation to either the rivet diameter or the sheet thickness.

The efficiency of the joints by tests, given in column 12, the average of two tests in each instance, had values ranging from 66.7 to 77.8 per cent. These values are comparable with 55.1 to 74.4 per cent for lap joints with a double row of rivets with stagger pattern, with 69.0 to 77.2 per cent for double-strap butt joints with a double row of rivets with chain pattern, and with 54.9 to 64.8 per cent for double-strap butt joints with a single row of rivets. These figures indicate that: (1) For double-strap butt joints with a double row of rivets, those with a chain pattern and those with a stagger pattern had very nearly the same efficiency. (2) For joints with a double row of rivets with stagger pattern, the double-strap butt joints were somewhat more efficient than the lap joints. (3) For double-strap butt joints, those with a double row of rivets were significantly more efficient than those with a single row of rivets.

22. *Series V-4; Double-Strap Butt Joints Designed to Fail by Sheet Tension; Double Row of Rivets, Spacing Twice as Great for Outer as for Inner Row.*—The specimens of this series, designed to fail by sheet tension, were double-strap butt joints with a double row of

TABLE 31

STRENGTH OF DOUBLE-STRAP BUTT JOINTS DESIGNED TO FAIL BY SHEET TENSION; DOUBLE ROW OF RIVETS, STAGGER PATTERN

All specimens failed by sheet tension except as noted. Holes had same diameter as rivets for all specimens.

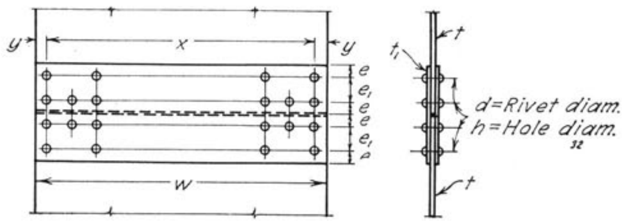
Specimen No.	Rivet Diameter in.	Thickness Inside Sheet in.	Rivet Spacing Center to Center in.	Rivet Spacing Center to Center dia.	Ultimate Load lb.	Unit Stress at Ultimate Load lb. per sq. in. Sheet Tension	Unit Stress at Ultimate Load lb. per sq. in. Rivet* Bearing	Unit Stress at Ultimate Load lb. per sq. in. Rivet* Shear	Coupon Strength of Sheet lb. per sq. in.	Ratio (7)/(10)	Joint† Efficiency by Test per cent
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
BCB-23	3/16	0.113	3/4	4	34 200	33 700	51 600	19 900	34 000	0.991	74.2
BCB-24	3/16	0.113	3/4	4	34 700	33 800	51 800	20 000	34 000	0.991	75.4
Average	..	.....	..	..	34 450	33 750	51 700	19 950	34 000	0.991	74.8
BCB-25	3/16	0.113	15/16	5	34 400	32 200	64 700	24 900	34 000	0.947	74.6
BCB-26	3/16	0.113	15/16	5	36 200	33 900	68 200	26 200	34 000	0.999	78.6
Average	..	.....	..	..	35 300	33 050	66 450	25 550	34 000	0.973	76.6
BCB-33	1/4	0.113	1 1/2	6	36 000	32 300	85 000	24 400	33 100	0.976	78.0
BCB-34	1/4	0.113	1 1/2	6	35 800	32 200	84 600	24 300	33 100	0.974	77.6
Average	..	.....	..	..	35 900	32 250	84 800	24 350	33 100	0.975	77.8
CDC-31	1/4	0.185	3/4	3	76 300	48 800	56 900	26 800	48 900	0.998	70.2
CDC-32	1/4	0.185	3/4	3	76 000	48 600	56 700	26 600	48 900	0.996	70.0
Average	..	.....	..	..	76 150	48 700	56 800	26 700	48 900	0.997	70.1
CDC-57	5/16	0.185	1 1/8	3 5/8	79 300	46 900‡	72 400	27 200	48 900	0.960	73.0
CDC-58	5/16	0.185	1 1/8	3 5/8	79 400	46 900‡	72 400	27 200	48 900	0.960	73.2
Average	..	.....	..	..	79 350	46 900	72 400	27 200	48 900	0.960	73.1
DED-53	5/16	0.245	1 1/4	4	72 400	34 200‡	55 600	27 700	35 300	0.970	74.5
DED-54	5/16	0.245	1 1/4	4	72 200	34 200‡	55 600	27 700	35 300	0.970	74.3
Average	..	.....	..	..	72 300	34 200	55 600	27 700	35 300	0.970	74.4
DFD-53	5/16	0.375	15/16	3	105 900	35 000	36 200	27 600	35 400	0.990	66.5
DFD-54	5/16	0.375	15/16	3	106 600	35 200	36 500	27 800	35 400	0.994	66.9
Average	..	.....	..	..	106 250	35 100	36 350	27 700	35 400	0.992	66.7
DED-79	3/8	0.245	1 1/2	4	77 600	34 300	56 200	23 400	35 300	0.972	74.7
DED-80	3/8	0.245	1 1/2	4	78 300	34 500	56 800	23 600	35 300	0.978	75.3
Average	..	.....	..	..	77 950	34 400	56 500	23 500	35 300	0.975	75.0

* Based on rivet diameter.
† The joint efficiency by test is the ratio of the ultimate load to the product of the gross section and the coupon strength of the sheet.
‡ Failed by rivet shear with simultaneous sheet failure indications.

rivets. Alternate rivets were omitted from the outer row in order to increase the ratio of the net to the gross section of the sheet. The details of the specimens are given in Table 32, and the location of the fracture, which was in the inside sheet, is indicated on the photograph of Fig. 25 by the white dotted line.

TABLE 32

DETAILS OF SPECIMENS; SERIES V-4; DOUBLE-STRAP BUTT JOINTS DESIGNED TO FAIL BY SHEET TENSION; DOUBLE ROW OF RIVETS, SPACING TWICE AS GREAT FOR OUTER AS FOR INNER ROW OF RIVETS



Specimen No.	t in.	t_1 in.	X in.	y in.	W in.	h in.	d in.	e in.	e_1 in.
ABA-33 and ABA-34	0.090	0.060	14@ 3/4 = 10 1/2	3/8	11 1/4	1/4	1/4	1/2	3/4
BCB-51 and BCB-52	0.113	0.090	10@1 = 10	1/2	11	5/16	5/16	1/2	1
DED-97 and DED-98	0.245	0.185	4@2 = 8	1	10	1/2	1/2	1 1/2	2
DFD-99 and DFD-100	0.375	0.185	6@1 1/2 = 9	3/4	10 1/2	1/2	1/2	1	1 1/2

The results of the tests are given in Table 33. All specimens except DFD-99 and DFD-100 failed by a tension failure of the inside sheet on the outer row of rivets, as planned. The inside sheet of DFD-99 failed along the inner row of rivets and one outside sheet of DFD-100 failed along the inner row of rivets. The ratio of the unit strength of the sheet as developed by the riveted joints to the coupon strength of

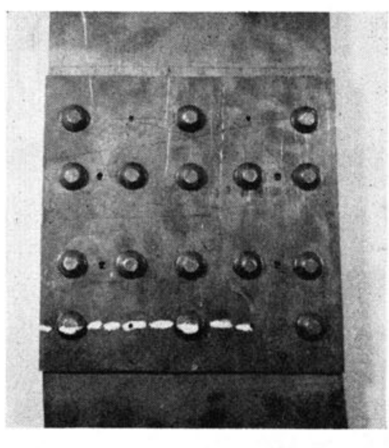


FIG. 25 (RIGHT). FAILURE BY SHEET TENSION; DOUBLE-STRAP BUTT JOINT WITH DOUBLE ROW OF RIVETS, ALTERNATE RIVETS OMITTED FROM OUTER ROWS, SPECIMEN DED-97

TABLE 33

STRENGTH OF DOUBLE-STRAP BUTT JOINTS DESIGNED TO FAIL BY SHEET TENSION; DOUBLE ROW OF RIVETS, SPACING TWICE AS GREAT FOR OUTER AS FOR INNER ROW

All specimens failed by sheet tension except as noted. Holes had same diameter as the rivets for all specimens.

Specimen No.	Rivet Diameter in.	Thickness Inside Sheet in.	Rivet Spacing Center to Center in.	Rivet Spacing Center to Center dia.	Ultimate Load lb.	Unit Stress at Ultimate Load lb. per sq. in. Rivet* Shear	Rivet* Bearing	Sheet Tension	Coupon Strength of Sheet lb. per sq. in.	Ratio (9)/(10)	Joint† Efficiency by Test per cent
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
ABA-33	¼	0.090	¾	3	39 200	17 300	75 500	47 200	49 900	0.955	77.6
ABA-34	¼	0.090	¾	3	39 600	17 400	78 000	47 400	49 900	0.951	78.0
Average	..	.....	..	..	39 400	17 350	76 750	47 300	49 900	0.953	77.8
BCB-51	5/16	0.113	1	3.2	50 800	19 500	84 700	49 400	51 000	0.969	80.1
BCB-52	5/16	0.113	1	3.2	52 600	20 200	87 600	51 100	51 000	1.001	82.9
Average	..	.....	..	..	51 700	19 850	86 150	50 250	51 000	0.985	81.5
DED-97	½	0.245	2	4	70 900	22 600	72 500	34 600	35 400	0.978	81.8
DED-98	½	0.245	2	4	72 800	23 200	74 300	35 500	35 400	1.002	84.0
Average	..	.....	..	..	71 850	22 900	73 400	35 050	35 400	0.990	82.9
DFD-99	½	0.375	1½	3	99 400[1]	23 000	48 200	37 800	35 400	1.065	71.2[1]
DFD-100	½	0.375	1½	3	95 800[2]	22 600	47 700	37 400	35 500	1.053	68.8[2]
Average	..	.....	..	..	97 600	22 800	47 950	37 600	35 450	1.059	70.0

* Based on rivet diameter.
† The joint efficiency by test is the ratio of the ultimate load to the product of the gross section and the coupon strength of the sheet.
[1] Inside sheet failed along inside row of rivets.
[2] Outside sheet failed along inside row of rivets.

the same sheets is given in column 11. This ratio, the average of two tests in each instance, varied from 0.953 to 0.990. This does not include the last two specimens which did not fail in the manner contemplated.

The efficiency of the joints by tests, given in column 12, the average of two tests in each instance, had values ranging from 77.8 to 82.9 per cent. These values are comparable with 66.7 to 77.8 per cent for double-strap butt joints with a double row of rivets, stagger pattern.

The increase in efficiency obtained by omitting every other rivet from the outer row is due to the increase in the ratio of the net section through the outer row to the gross section of the inside sheet. If, however, the number of rivets in the outer row is too small, thus allowing most of the load to be carried to the inner row of rivets, the inner sheet may fail along the inner row of rivets. This type of failure occurred for specimen DFD-99.

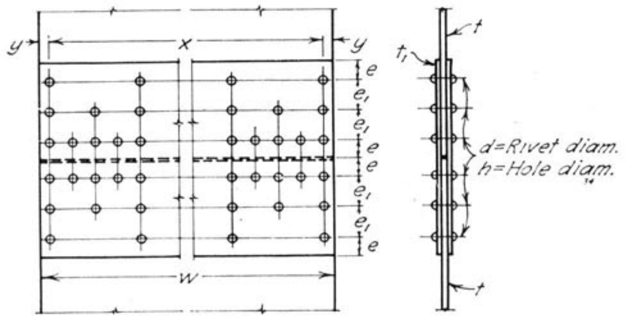
Likewise, unless the butt straps have a combined thickness considerably greater than the thickness of the inside sheet, failure may be in the butt straps through the inner row of rivets where the number of holes out of a section carrying the full load is much greater than it is for the outside row of rivets. Specimen DFD-100 failed through the inner row of rivets of the butt straps. The weakness of specimens DFD-99 along the inner row of rivets in the inner sheet and of DFD-100 along the inner row of rivets in the butt straps, weaknesses that can be eliminated by proper design, resulted in relatively low efficiencies. The strength of the butt straps could have been increased at small cost by using a thicker strap, but failure of the inner sheet along the inner row of rivets indicates that not enough rivets were provided in the outer row to protect the section of the inside sheet through the inner rows of rivets. The ratio of the net to the gross area for the section of the inner sheet through the outside row of rivets for specimens DFD-99 and DFD-100, was 0.81. Nevertheless, the efficiency of the joint as determined by the test was only 70.0 per cent. In contrast with this, the efficiency by test was nearly equal to the ratio of the net to the gross section and had values of 77.8, 81.5, and 82.9 per cent, respectively, for the first three pairs of specimens reported in Table 33, all of which failed in the inside sheet and along the outer row of rivets, as planned.

23. *Series V-5; Double-Strap Butt Joints Designed to Fail by Sheet Tension; Triple Row of Rivets, Spacing Four Times as Great for Outer as for Inner Row.*—The specimens of this series, designed

to fail by sheet tension, were double-strap butt joints with a triple row of rivets. The spacing was twice as great for the middle row and four times as great for the outer row as it was for the inner row of rivets. This rivet pattern gave a large ratio of net to gross area for the section through the outer row of rivets where failure was expected to occur. The details of the specimen are given in Table 34, and the character of the failure is shown by Fig. 26.

TABLE 34

DETAILS OF SPECIMENS; SERIES V-5; DOUBLE-STRAP BUTT JOINTS DESIGNED TO FAIL BY SHEET TENSION; TRIPLE ROW OF RIVETS, SPACING FOUR TIMES AS GREAT FOR OUTER AS FOR INNER ROW OF RIVETS



Specimen No.	t in.	t_1 in.	X in.	y in.	W in.	h in.	d in.	e in.	e_1 in.
ACA-21 and ACA-22	0.113	0.060	20@ 9/16 = 11¼	⅜	12	3/16	3/16	½	¾
ABA-34 and ABA-35	0.090	0.060	12@ ¾ = 9	⅜	9¾	¼	¼	½	¾
CDC-33 and CDC-34	0.185	0.113	12@ ¾ = 9	⅜	9¾	¼	¼	½	1
DED-55 and DED-56	0.245	0.185	12@15/16 = 11¼	⅜	12	5/16	5/16	¾	1¼
DED-85 and DED-86	0.245	0.185	8@ 1¼ = 10	¾	11½	⅜	⅜	1	1½
DED-99 and DED-100	0.245	0.185	4@ 2 = 8	1	10	½	½	1	2

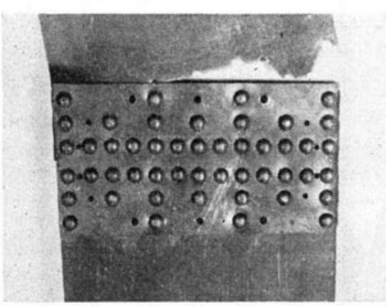


FIG. 26 (LEFT). FAILURE BY SHEET TENSION ON A ZIGZAG SECTION, SPECIMEN ABA-34

Table 35

Strength of Double-Strap Butt Joints Designed to Fail by Sheet Tension; Triple Row of Rivets, Spacing Four Times as Great for Outer as for Inner Row

All specimens failed by sheet tension except as noted. Holes had same diameter as the rivets for all specimens.

Specimen No.	Rivet Diameter in.	Thickness Inside Sheet in.	Rivet Spacing Center to Center in.	Rivet Spacing Center to Center dia.	Ultimate Load lb.	Unit Stress at Ultimate Load lb. per sq. in. Sheet Tension	Unit Stress at Ultimate Load lb. per sq. in. Rivet* Bearing	Unit Stress at Ultimate Load lb. per sq. in. Rivet* Shear	Coupon Strength of Sheet lb. per sq. in.	Ratio (7)/(10)	Joint† Efficiency by Test per cent
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
ACA-21	3/16	0.113	9/16	3	48 600[1]	48 300	60 100	23 200	51 300	0.941	79.6
ACA-22	3/16	0.113	9/16	3	50 400[1]	50 200	62 500	24 000	51 300	0.981	82.4
Average	..	.....	..	..	49 500	49 250	61 300	23 600	51 300	0.961	81.0
ABA-34	1/4	0.090	3/4	3	37 000[2]	51 500	68 500	15 700	52 800	0.975	79.8
ABA-35	1/4	0.090	3/4	3	36 700[2]	51 100	68 000	15 600	52 800	0.967	79.0
Average	..	.....	..	..	36 850	51 300	68 250	15 650	52 800	0.971	79.4
CDC-33	1/4	0.185	3/4	3	69 500[1]	47 700	62 600	18 900	50 200	0.950	76.8
CDC-34	1/4	0.185	3/4	3	74 600[1]	51 000	67 200	20 300	50 200	1.015	82.4
Average	..	.....	..	..	72 050	49 350	64 900	19 600	50 200	0.983	79.6
DED-55	5/16	0.245	15/16	3	80 300[2]	33 000	44 900	22 300	35 300	0.935	77.3
DED-56	5/16	0.245	15/16	3	82 200[2]	33 600	45 500	22 500	35 300	0.953	78.1
Average	..	.....	..	..	81 250	33 300	45 200	22 400	35 300	0.944	77.7
DED-85	3/8	0.245	1 1/4	3.3	77 400[2]	31 200	49 600	20 600	34 400	0.906	80.0
DED-86	3/8	0.245	1 1/4	3.3	76 100[2]	30 600	48 700	20 300	34 400	0.890	78.6
Average	..	.....	..	..	76 750	30 900	49 150	20 450	34 400	0.898	79.3
DED-99	1/2	0.245	2	4	76 000[2]	35 000	62 300	19 400	35 400	0.988	87.5
DED-100	1/2	0.245	2	4	75 700[2]	34 800	62 000	19 300	35 400	0.983	87.3
Average	..	.....	..	..	75 850	34 900	62 150	19 350	35 400	0.986	87.4

* Based on rivet diameter.
† Joint efficiency by test, is the ratio of the ultimate load to the product of the gross section and the coupon strength of the sheet.
[1] Butt-strap failed through inside row of rivet holes.
[2] Inside sheet failed through outside row of rivet holes as planned.

The results of the tests are given in Table 35. All specimens failed by a tension failure of the inner sheet through the outer row of rivets, except as noted in the table. The ratio of the unit strength of the sheet developed by the joints to the coupon strength of the same sheets is given in column 11. This ratio for specimens that failed by sheet tension on the inside sheet and along the outside row of holes, the average of two tests in each instance, varied from 0.898 for 3/8-in. rivets and 0.245-in. sheets to 0.986 for 1/2-in. rivets and 0.245-in. sheets.

The efficiency of the joints by tests given in column 12, the average of two tests in each instance, had values ranging from 77.7 to 87.4 per cent. These values are comparable with 77.8 to 82.9 per cent for the double-strap butt joints with rivet spacing twice as great for the outer as for the inner row.

24. *Discussion of Results; Tests to Determine Sheet Tension Developed by Joints with Various Rivet Patterns.*—The tests of riveted joints described in Sections 14 to 23 were planned to determine the effect of the rivet pattern upon the tensile strength of the sheets. The results of the tests are discussed in the following paragraphs.

The most important factors to be considered in studying the effect of the rivet pattern upon the efficiency of joints designed to fail by sheet tension are (1) the computed efficiency of the joint, and (2) the ratio of the joint strength to the coupon strength of the sheet. This ratio also equals the ratio of the efficiency of the joint by test to its computed efficiency. In these statements, the efficiency of the joint by test is its measured strength divided by the product of the gross area and the coupon strength of the sheet; and the computed efficiency is the ratio of the net to the gross section of the sheet.

Lap Joints

The results of the tests of lap joints are given in Table 36, the four types of rivet patterns being listed separately. The rivet diameter and sheet thickness are given in columns 2 and 3; and the rivet bearing and rivet shear at the ultimate load are given in columns 4 and 5. The ratio of the strength of the sheet developed in the joint to the coupon strength of the same sheet is given in column 6, the computed efficiency of the joint is given in column 7 and the efficiency by test is given in column 8. The average and minimum values of the ratio of joint strength to coupon strength of the sheets for the four rivet patterns are given in Table 37. The data in this table, together with the

TABLE 36

EFFECT OF RIVET PATTERN UPON TENSILE STRENGTH DEVELOPED BY SHEETS OF RIVETED JOINTS; LAP JOINTS

(More complete information relative to these joints is given in Tables 18, 20, 22, and 24)

Description of Joints	Rivet Diameter in.	Sheet Thickness in.	Rivet Bearing at Ultimate Load lb. per sq. in.	Shear on Rivet at Ultimate Load lb. per sq. in.	Ratio of Joint Strength to Coupon Strength of Sheet*	Efficiency of Joint per cent	
						Computed	By Test
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Single Row of Rivets (See Fig. 10 and Table 18)	1/8	0.060	86 100	33 300	0.897	63.5	56.9
	1/4	0.060	80 650	22 050	0.923	60.3	55.7
	1/4	0.090	69 000	30 200	0.955	65.3	62.3
	1/4	0.113	61 300	36 300	0.912	69.6	63.5
	5/16	0.090	68 200	25 200	0.989	58.6	57.9
Double Row of Rivets Chain Pattern (See Fig. 19 and Table 20)	1/8	0.060	70 450	43 050	0.960	71.3	68.4
	3/16	0.090	84 050	25 550	0.955	62.2	59.4
	1/4	0.090	38 800	16 950	1.104	62.5	69.1
	1/4	0.113	68 550	27 950	0.957	66.2	63.4
	1/4	0.113	43 600	25 150	1.204	66.4	80.0
	3/8	0.185	53 150	33 250	0.977	75.3	73.0
	1/2	0.245	35 450	22 300	1.025	65.4	67.0
	1/2	0.245	50 750	31 550	0.999	73.7	73.6
Double Row of Rivets Stagger Pattern (See Fig. 20 and Table 22)	1/4	0.060	51 950	15 900	0.985	66.5	65.6
	5/16	0.090	34 100	12 500	0.950	58.0	55.1
	5/16	0.113	51 550	23 700	1.073	66.2	71.1
	3/8	0.113	75 150	28 800	1.000	74.4	74.4
	3/8	0.185	42 850	26 950	1.013	62.0	62.8
	1/2	0.245	27 850	23 700	1.034	64.7	66.9
Triple Row of Rivets Alternate rivets omitted from outer rows (See Fig. 21 and Table 24)	1/4	0.060	62 350	19 100	0.981	86.5	84.9
	5/16	0.113	63 750	28 050	0.994	83.8	83.3
	1/2	0.245	38 800	24 150	0.977	79.8	78.0

* This is also the ratio of the efficiency by test to the computed efficiency of the joint.

computed efficiencies of the joints with various rivet patterns, given in column 7 of Table 36, appear to justify the following statements:

(1) The computed efficiency and the ratio of the efficiency by test to the computed efficiency of the lap joints both increased with the rivet pattern in the following order: single row, double row and triple row of rivets, alternate rivets being omitted from the outer rows of the latter. Moreover, of the lap joints with a double row of rivets and with a given rivet diameter and spacing, those with a chain pattern and those with a stagger pattern had approximately the same efficiency.

(2) The ratio of the actual to the computed efficiency of the joints was of the order of 0.90 to 0.95 for lap joints with a single row of rivets, and of the order of 0.95 to 1.00 for lap joints with a double row of rivets, and also for lap joints with a triple row of rivets with alternate rivets omitted from the outer rows.

(3) The efficiency by test had values ranging from 0.56 for the least efficient of the lap joints with a single row of rivets to 0.85 for

TABLE 37
RELATION BETWEEN RIVET PATTERN AND RATIO OF JOINT STRENGTH TO COUPON STRENGTH OF SHEET; LAP JOINTS; SUMMARY OF RESULTS

Rivet Pattern	Ratio of Joint Strength to Coupon Strength of Sheets	
	Minimum Value	Average Value
Single row of rivets	0.90	0.94
Double row of rivets, chain pattern	0.96	1.02
Double row of rivets, stagger pattern	0.95	1.01
Triple row of rivets, spacing four times as great for outer as for inner row	0.98	0.98

the most efficient of the lap joints with a triple row of rivets with alternate rivets omitted from the outer rows.

Double-Strap Butt Joints

The results of the tests of double-strap butt joints are given in Table 38, the five types of rivet patterns being listed separately. The rivet diameter and sheet thickness are given in columns 2 and 3; and the rivet shear and rivet bearing at the ultimate load are given in columns 4 and 5. The ratio of the strength of the sheet developed in the joint to the coupon strength of the same sheet is given in column 6; the computed efficiency of the joints is given in column 7, and the efficiency by test is given in column 8. The average and minimum values of the ratio of joint strength to coupon strength of the sheets for the five rivet patterns are given in Table 39. The data in this table, together with the computed efficiencies of the joints with various rivet patterns, given in column 7 of Table 38, appear to justify the following statements:

(1) The ratio of the efficiency by test to the computed efficiency was least for joints with a single row of rivets and for joints with a triple row of rivets with spacing four times as great for the outer as for the inner row. The ratio had approximately the same value for all of the double-row types of joints, and its value was approximately 5 per cent greater for the double-row types than it was for the single-row and triple-row types.

(2) The computed value of the efficiency for joints of balanced design increased with the rivet pattern in the following order: single row, double row, double row with alternate rivets in outer row omitted,

TABLE 38

EFFECT OF RIVET PATTERN UPON TENSILE STRENGTH DEVELOPED BY SHEETS OF RIVETED JOINTS; DOUBLE-STRAP BUTT JOINTS

(More complete information relative to these joints is given in Tables 26, 28, 30, 32, and 34)

Description of Joints	Rivet Diameter in.	Thickness Inside Sheet in.	Rivet Bearing at Ultimate Load lb. per sq. in.	Shear on Rivet at Ultimate Load lb. per sq. in.	Ratio of Joint Strength to Coupon Strength of Sheet	Efficiency of Joint per cent Computed	Efficiency of Joint per cent By Test
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Single Row of Rivets (See Fig. 22 and Table 26)	1/4	0.060	93 550	14 350	0.942	64.2	60.5
	1/4	0.090	85 000	19 500	0.935	64.2	60.1
	1/4	0.113	65 850	19 000	1.009	64.3	64.8
	5/16	0.060	88 950	11 050	0.914	65.2	59.6
	5/16	0.090	82 850	15 200	0.878	62.6	54.9
	5/16	0.113	68 300	14 350	1.087	57.2	62.1
	5/16	0.185	66 000	25 350	0.941	65.0	61.2
	3/8	0.185	65 100	20 450	0.926	65.8	60.8
Double Row of Rivets Chain Pattern (See Fig. 23 and Table 28)	3/16	0.113	52 350	20 200	1.070	71.5	76.5
	1/4	0.113	67 200	20 600	1.063	72.5	77.1
	5/16	0.185	91 150	34 300	0.959	79.2	76.0
	5/16	0.245	54 650	27 200	1.051	73.5	77.2
	3/8	0.245	36 250	14 800	1.082	63.7	69.0
	3/8	0.245	53 100	22 100	1.020	73.5	75.0
	3/8	0.245	62 650	26 050	0.896	78.5	70.3
	1/2	0.375	51 350	24 400	0.986	73.5	72.5
Double Row of Rivets Stagger Pattern (See Fig. 24 and Table 30)	3/16	0.113	51 700	19 950	0.991	75.5	74.8
	3/16	0.113	66 450	25 550	0.973	78.7	76.6
	1/4	0.113	84 800	24 350	0.975	79.7	77.8
	1/4	0.185	56 800	26 700	0.997	70.4	70.1
	5/16	0.185	72 400	27 200	0.960	76.2	73.1
	5/16	0.245	55 600	27 700	0.970	76.7	74.4
	5/16	0.375	36 350	27 700	0.992	67.2	66.7
	3/8	0.245	56 500	23 500	0.975	76.9	75.0
Double Row of Rivets Alternate rivets omitted from outside row (See Fig. 25 and Table 32)	1/4	0.090	76 750	17 350	0.953	81.7	77.8
	5/16	0.113	86 150	19 850	0.985	82.7	81.5
	1/2	0.245	73 400	22 900	0.990	83.8	82.9
	1/2	0.375	67 950	22 800	1.059	66.2	70.0
Triple Row of Rivets Spacing four times as great for outer as for inner row (See Fig. 26 and Table 34)	3/16	0.113	61 300	23 600	0.961	84.3	81.0
	1/4	0.090	68 250	15 650	0.971	81.7	79.4
	1/4	0.185	64 900	19 600	0.983	81.0	79.6
	5/16	0.245	45 200	22 400	0.944	82.3	77.7
	3/8	0.245	49 150	20 450	0.898	88.4	79.3
	1/2	0.245	62 150	19 350	0.986	88.7	87.4

and triple row with spacing four times as great for the outer as for the inner row.

(3) The efficiency by test had values ranging from 0.55 for the least efficient of the double-strap butt joints with a single row of rivets to 0.87 for the most efficient double-strap butt joints with a triple row of rivets and with spacing four times as great for the outer as for the inner row.

(4) The computed efficiency of a joint with a given sheet thickness and type of rivet pattern can be increased by increasing the rivet spacing and the rivet diameter until a "balanced design" is obtained that is equally liable to fail by rivet shear, tearing out of rivet to the

TABLE 39

RELATION BETWEEN RIVET PATTERN AND RATIO OF JOINT STRENGTH TO COUPON STRENGTH OF SHEET; DOUBLE-STRAP BUTT JOINT; SUMMARY OF RESULTS

Rivet Pattern	Ratio of Joint Strength to Coupon Strength of Sheets	
	Minimum Value	Average Value
Single row of rivets	0.88	0.95
Double row of rivets, chain pattern	0.90	1.02
Double row of rivets, stagger pattern	0.96	0.98
Double row of rivets, alternate rivets omitted from outer row	0.95	1.00
Triple row of rivets, spacing four times as great for outer as for inner row	0.90	0.96

edge of sheet, rivet bearing, and sheet tension. However, the cost is so much less for increasing the strength of a joint in rivet shear, rivet bearing, and tearing out of rivet to the edge of sheet, than it is for increasing the strength of the sheet in tension, that some excess strength in rivet shear, rivet bearing and tearing out of the rivets to the edge of the sheet should be provided.

VIII. MISCELLANEOUS TESTS

25. *Slip of Joints.*—The slip of joints was measured as previously discussed under Chapter II, page 12. For lap joints, the slip between the two sheets was determined by the use of apparatus shown in Fig. 2. The slip for the double-strap butt joints was determined by the use of the same apparatus, but the holes were drilled as shown in Fig. 3.

The results of the slip tests are shown by the diagrams of Figs. 27 to 31, inclusive. The following conclusion is based upon these diagrams:

The minimum load that produced an appreciable slip (0.001 in.) equaled or exceeded 7 500 lb. per sq. in. shear on the rivets for nearly all specimens, and was 10 000 to 15 000 lb. per sq. in. shear on the rivets for many specimens. The specimens for which the minimum load producing a slip of 0.001 in. was less than 7 500 lb. per sq. in. shear on the rivets were a combination of large rivets and thin sheets, a combination that gives a relatively large ratio of bearing to shear on the rivets. There was some evidence that, for joints of balanced design, a combination of thick sheets and large rivets resulted in slip at a smaller load than a combination of thin sheets and small rivets.

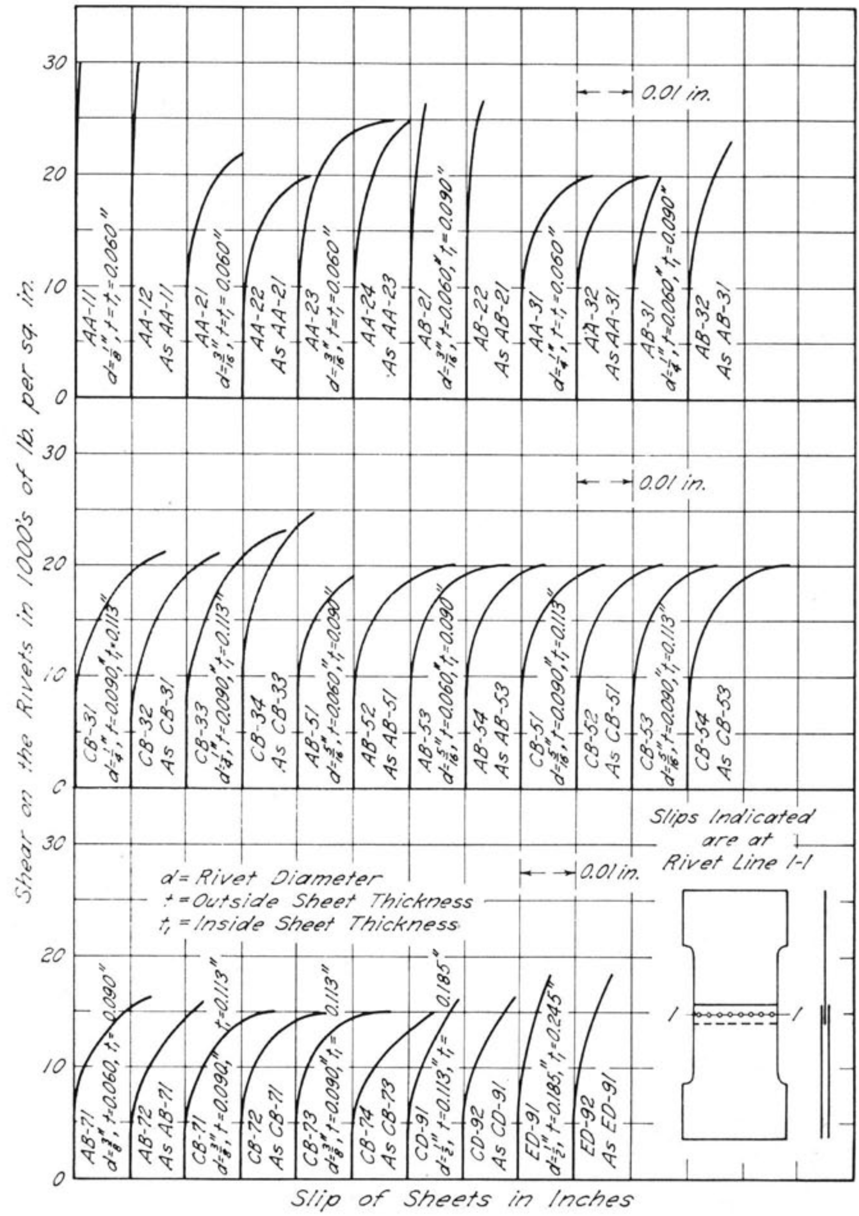


FIG. 27. LOAD-SLIP DIAGRAMS FOR SPECIMENS, SERIES I-2

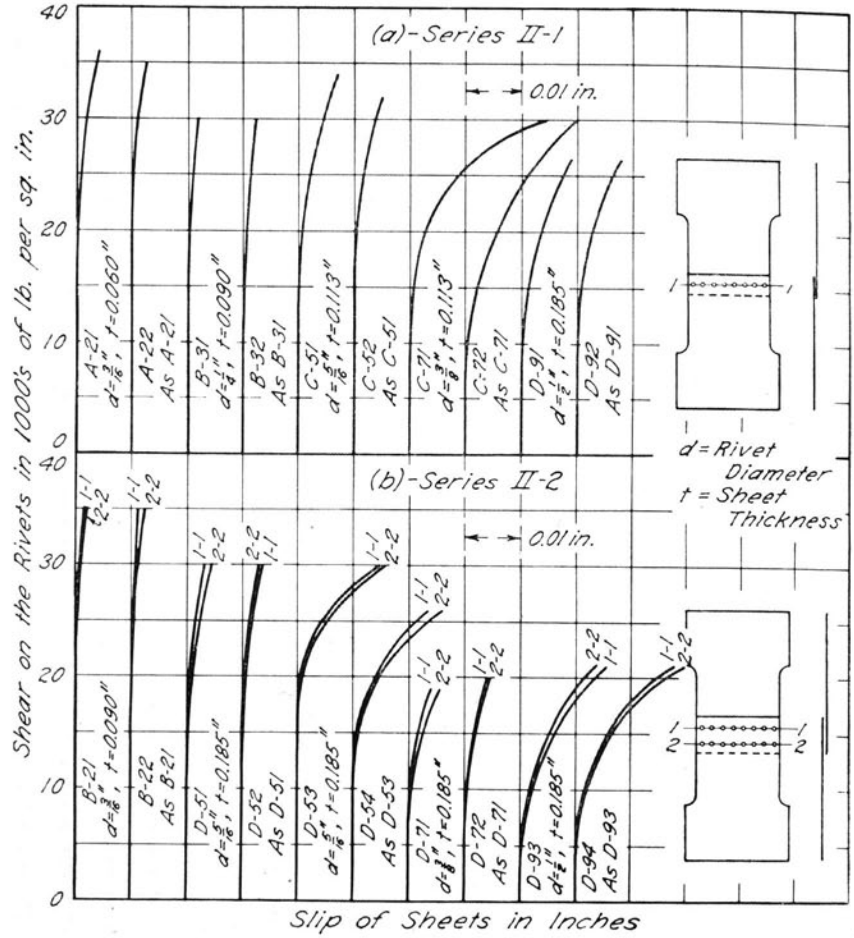


FIG. 28. LOAD-SLIP DIAGRAMS FOR SPECIMENS, SERIES II

26. *Separation of Sheets.*—The separation of the sheets of the joints was measured with the thickness gage as previously discussed under Chapter II and shown in Fig. 4. The readings were taken at three points along the edge of each sheet, one at each end and one in the middle.

The sheet separation was measured for both the lap and the butt joints but, for the latter, the separation was so small, not over 0.004 in.,

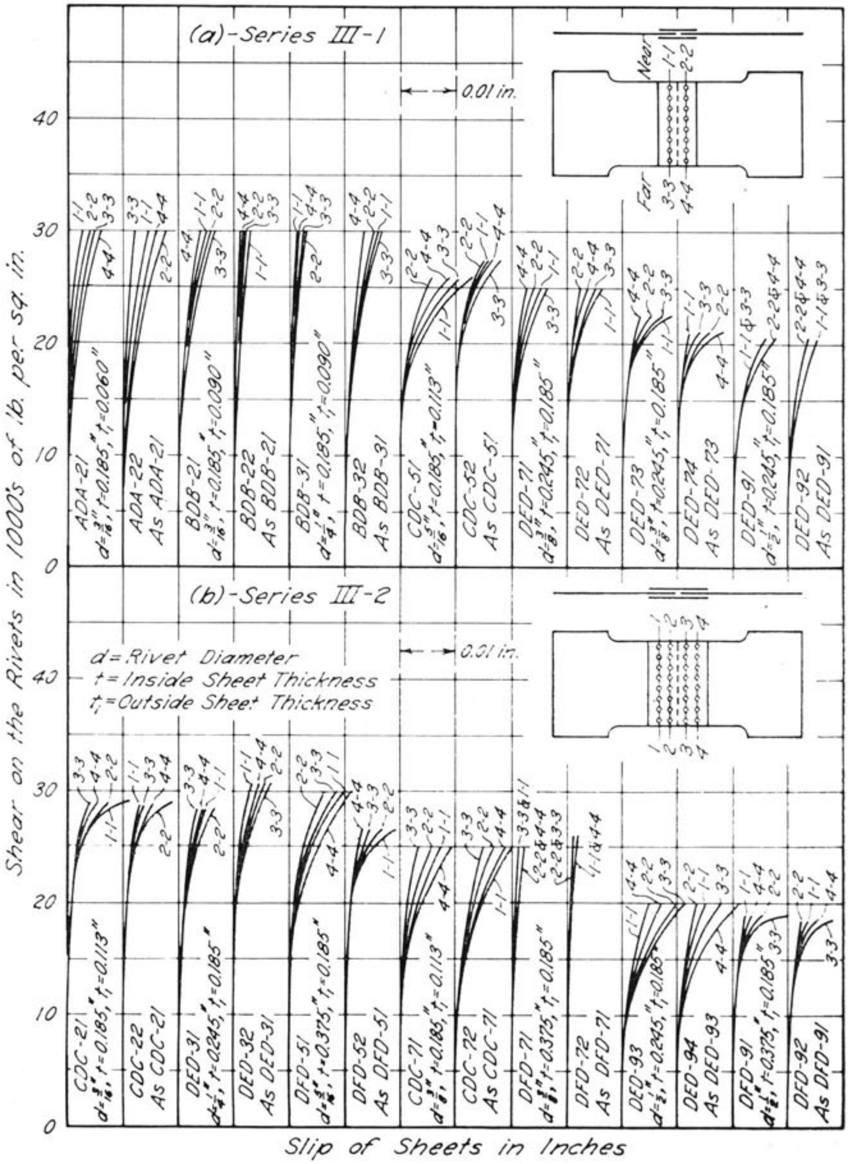


FIG. 29. LOAD-SLIP DIAGRAMS FOR SPECIMENS, SERIES III

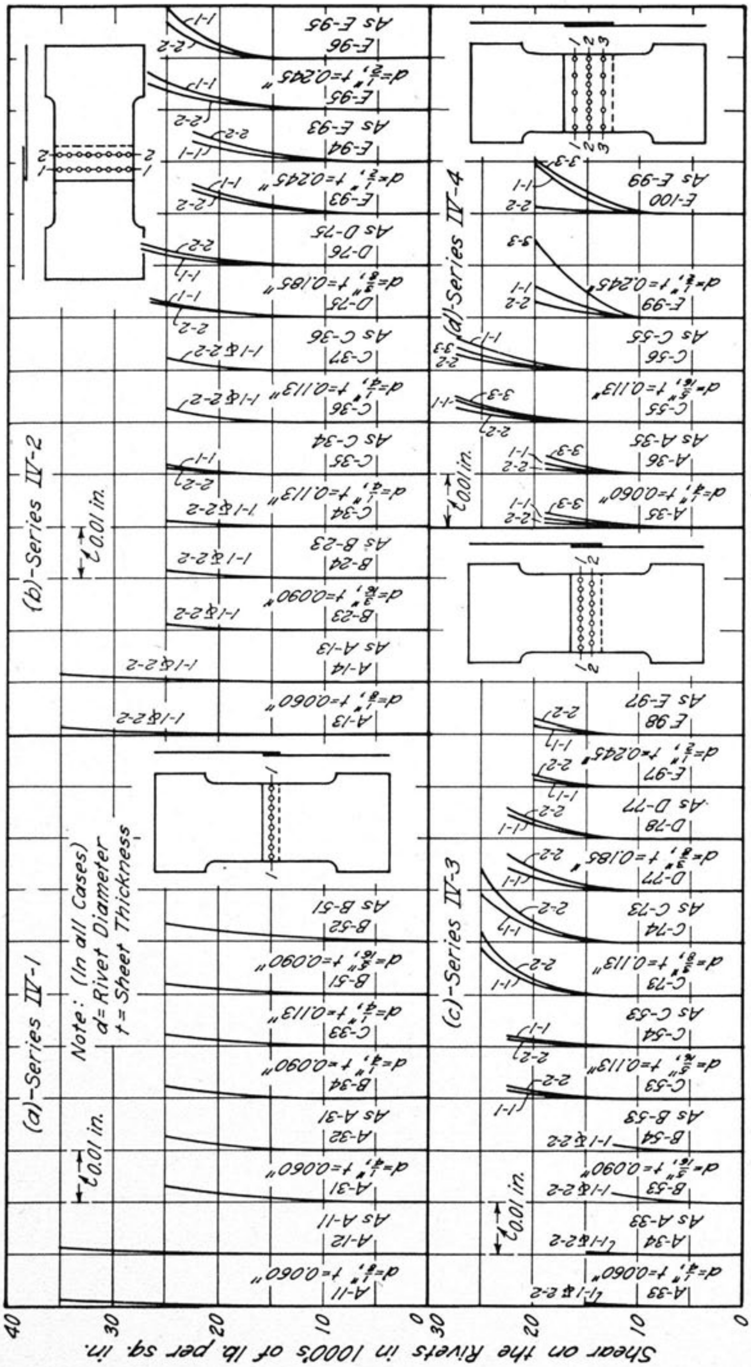


FIG. 30. LOAD-SLIP DIAGRAMS FOR SPECIMENS, SERIES IV

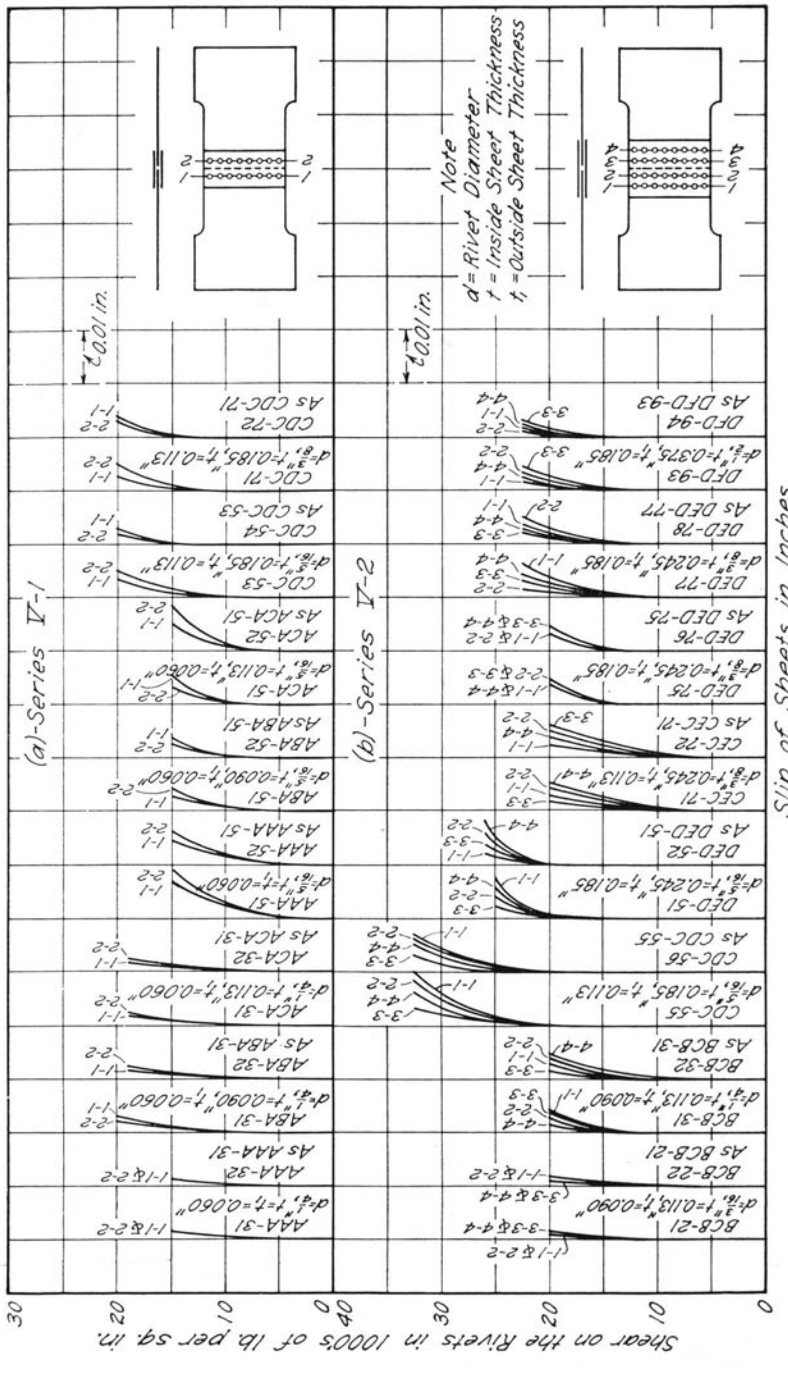


FIG. 31. LOAD-SLIP DIAGRAMS FOR SPECIMENS, SERIES V

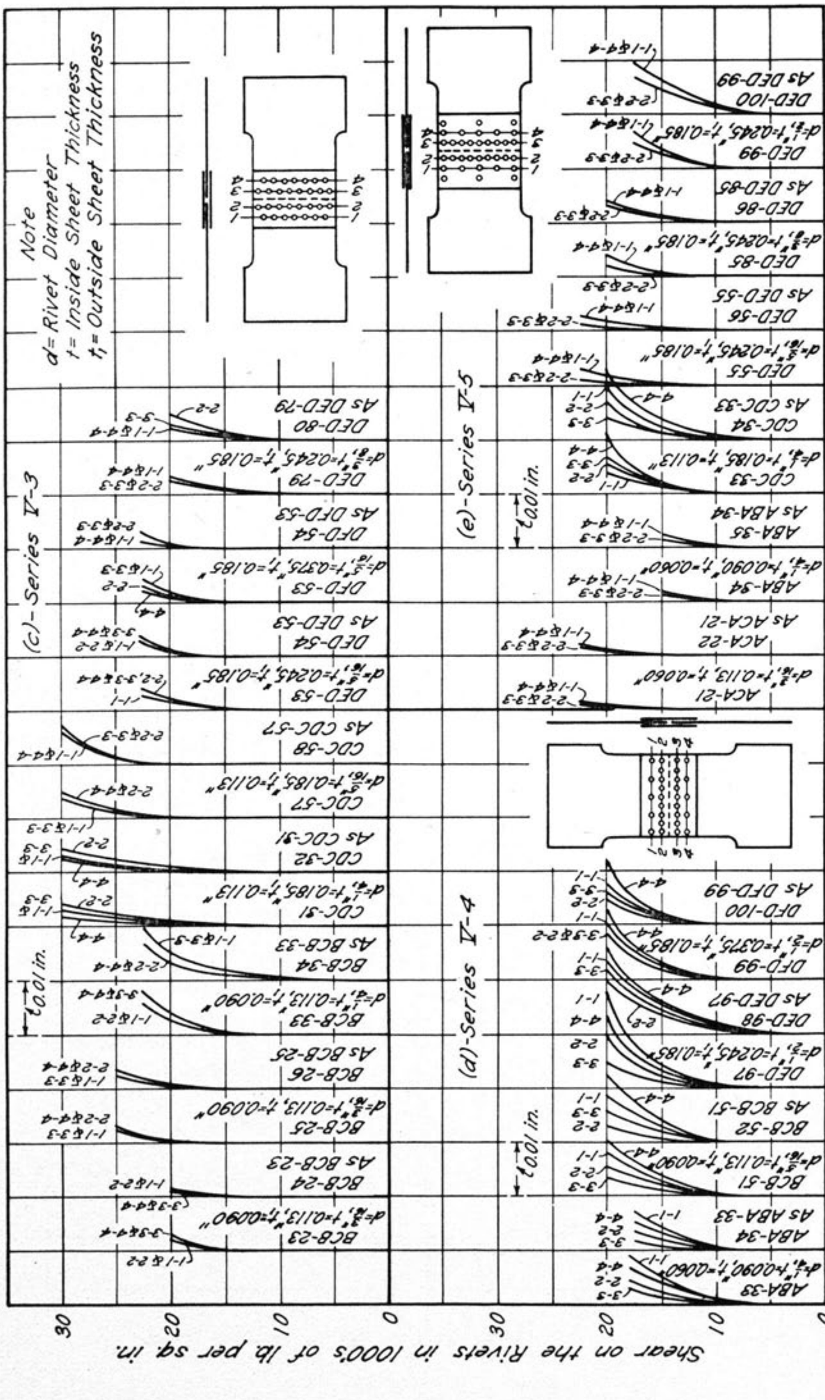


FIG. 31. LOAD-SLIP DIAGRAMS FOR SPECIMENS, SERIES V (CONCLUDED)

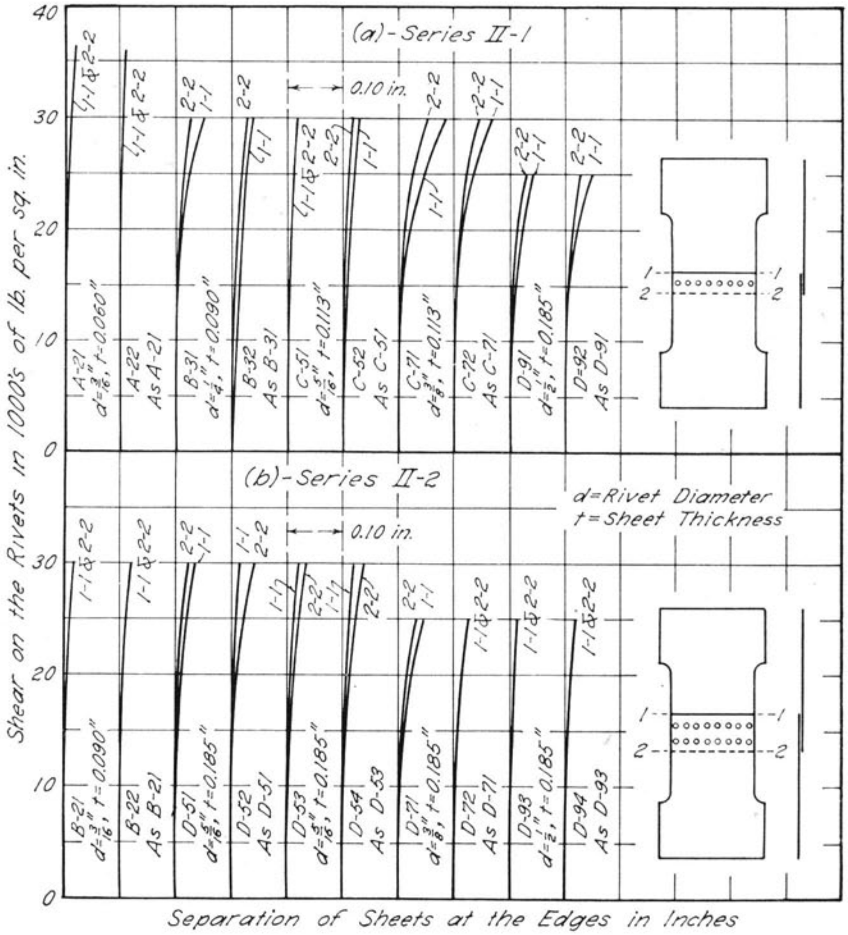


FIG. 32. LOAD-SEPARATION DIAGRAMS FOR SPECIMENS, SERIES II

that its magnitude has not been reported for the individual series. The separation for the lap joints is shown by the curves of Figs. 32 and 33.

The results of separation tests for various joints in the five series lead to the following conclusions:

(1) The separation of the edges of the sheets was very small, less than 0.004 in., for butt joints; for lap joints it was somewhat greater.

(2) The separation of the edges of the sheets was not significantly different for the single-row and the double-row joints. The separation

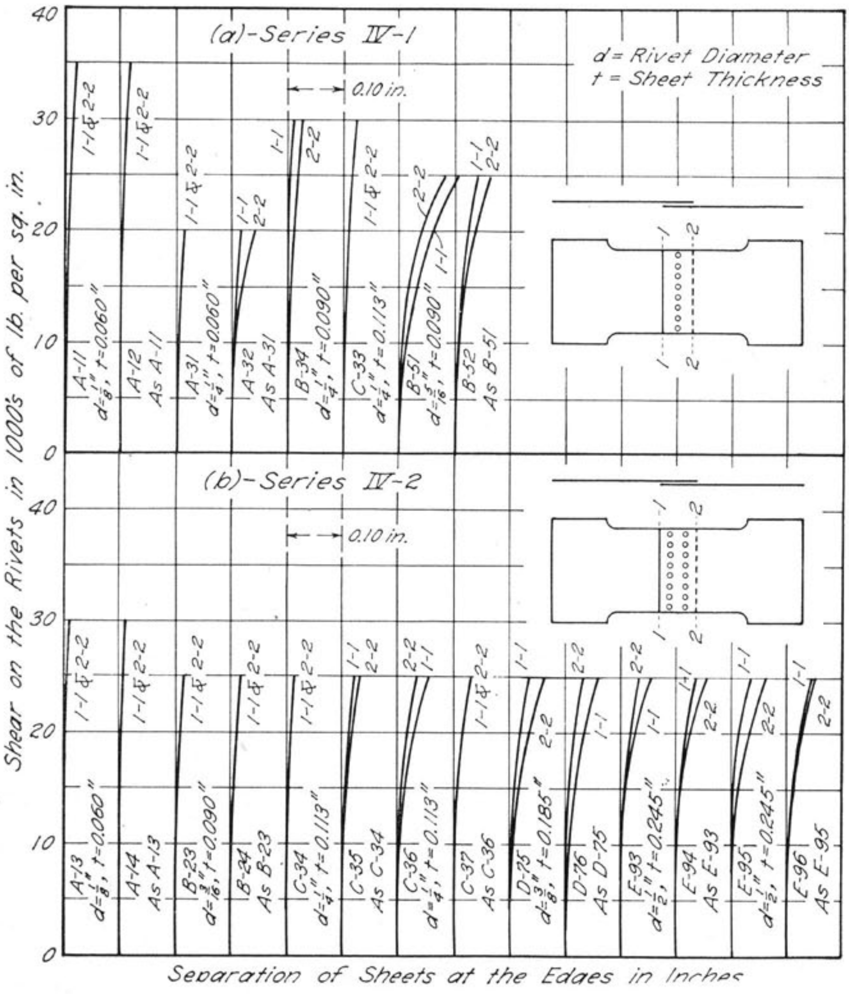


FIG. 33. LOAD-SEPARATION DIAGRAMS FOR SPECIMENS, SERIES IV-1 AND IV-2

exceeded 0.005 in. at a rivet shear of 10 000 lb. per sq. in. for only 6 of the 42 lap joints for which it was measured.

IX. SUMMARY

27. *Summary.*—The tests described in this bulletin appear to justify the following statements:

(1) For double-strap riveted butt joints designed to fail by tearing out of rivets to the edge of the outside sheet (butt straps), the sheet shear at failure varied from 26 000 to 31 300 lb. per sq. in. This was for joints with a rivet edge distance of $1\frac{1}{2}d$ and with sheets having a coupon strength in tension of approximately 50 000 lb. per sq. in. The joints had a range of sheet thickness of from 0.060 in. to 0.113 in. and a range of rivet diameter of from ¼ in. to ½ in. The total capacity of joints (as distinguished from the unit shear) that failed by tearing out of rivets to the edge of the outside sheet was from 5 to 10 per cent greater for joints with an edge distance of $2d$ than it was for joints with an edge distance of $1\frac{1}{2}d$. For the rivet-diameter sheet-thickness combinations tested, increasing the edge distance above $2d$ would not increase the strength of the joint by a significant amount, because of the liability of failure by rivet bearing. The unit sheet shear given in the foregoing is the total load per rivet divided by $4et$, in which t is the thickness of the outside sheets, and e is the distance from the center of the rivets to the edge of the outside sheet.

(2) For double-strap riveted butt joints, designed to fail by tearing out of rivets to the edge of the inside sheet, the sheet shear at failure for joints with a rivet edge distance of $2d$, adjusted to a coupon strength in tension of the sheets of 50 000 lb. per sq. in., varied from 20 500 to 27 700 lb. per sq. in. This was for joints with a range of sheet thickness of from 0.060 in. to 0.245 in. and a range of rivet diameter of from ⅛ in. to ½ in. The total load carried by the joint was from 10 to 37 per cent greater for joints with an edge distance of $3d$ than it was for joints with an edge distance of $2d$. The bearing pressure at failure for the rivets with an edge distance of $2d$ varied from 78 200 to 106 000 lb. per sq. in. The bearing pressure at failure for the rivets with an edge distance of $3d$ varied from 96 150 to 134 000 lb. per sq. in. Failure, however, was by tearing out the rivet to the edge of the sheet for all specimens.

(3) The ratio of the shearing strength of the rivets of a riveted joint to the shearing strength of undriven rivets varied from approximately 1.00 for ½-in. rivets to a value of the order of 1.25 for $\frac{3}{16}$-in. rivets. The shearing strength of undriven rivets varied for different lots of rivets. For the rivets used in these tests, the strength of undriven rivets in single shear varied from 25 900 lb. per sq. in. for $\frac{3}{16}$-in. rivets to 22 900 lb. per sq. in. for ½-in. rivets; the corresponding strength of undriven rivets in double shear varied from 26 500 lb. per sq. in. for $\frac{3}{16}$-in. rivets to 24 200 lb. per sq. in. for ½-in. rivets.

For Lap Joints

(4) The computed efficiency and the ratio of the efficiency by test to the computed efficiency of the lap joints, both increased with the rivet pattern in the following order: single row, double row and triple row of rivets, alternate rivets being omitted from the outer rows of the latter. Moreover, of the lap joints with a double row of rivets and with a given rivet diameter and spacing, those with a chain pattern and those with a stagger pattern had approximately the same efficiency.

(5) The ratio of the actual to the computed efficiency of the joints was of the order of 0.90 to 0.95 for lap joints with a single row of rivets, and of the order of 0.95 to 1.00 for lap joints with a double row of rivets and also for lap joints with a triple row of rivets with alternate rivets being omitted from the outer rows.

(6) The efficiency by test had values ranging from 0.56 for the least efficient of the lap joints with a single row of rivets to 0.85 for the most efficient of the lap joints with a triple row of rivets with alternate rivets omitted from the outer rows.

For Double-Strap Butt Joints

(7) The ratio of the efficiency by test to the computed efficiency was least for joints with a single row of rivets and for joints with a triple row of rivets with spacing four times as great for the outer as for the inner row. The ratio had approximately the same value for all of the double-row types of joints, and its value was approximately 5 per cent greater for the double-row types than it was for the single-row and triple-row types.

(8) The computed value of the efficiency for joints of balanced design increased with the rivet pattern in the following order: single row, double row, double row with alternate rivets being omitted from the outer row, and triple row with spacing four times as great for the outer as for the inner row.

(9) The efficiency by test had values ranging from 0.55 for the least efficient of the double-strap butt joints with a single row of rivets to 0.87 for the most efficient double-strap butt joints with a triple row of rivets and with spacing four times as great for the outer as for the inner row.

(10) The computed efficiency of a joint with a given sheet thickness and type of rivet pattern can be increased by increasing the rivet spacing and the rivet diameter until a "balanced design" is obtained that is equally liable to fail by rivet shear, tearing out of rivet to the

edge of sheet, rivet bearing, and sheet tension. However, the cost is so much less for increasing the strength of a joint in rivet shear, rivet bearing, and tearing out of rivet to the edge of sheet, than it is for increasing the strength of the sheet in tension, that some excess strength in rivet shear, rivet bearing, and tearing out of the rivets to the edge of the sheet should be provided.

Slip of Joints

(11) The minimum load that produced an appreciable slip (0.001 in.) equaled or exceeded 7 500 lb. per sq. in. shear on the rivets for nearly all specimens and was 10 000 to 15 000 lb. per sq. in. shear on the rivets for many specimens. The specimens for which the minimum load producing a slip of 0.001 in. was less than 7 500 lb. per sq. in. shear on the rivets were a combination of large rivets and thin sheets, a combination that gives a relatively large ratio of bearing to shear on the rivets. There was some evidence that, for joints of balanced design, a combination of thick sheets and large rivets resulted in slip at a smaller load than a combination of thin sheets and small rivets.

Separation of Sheets

(12) The separation of the edges of the sheets was very small, less than 0.004 in., for butt joints; for lap joints it was somewhat greater.

(13) The separation of the edges of the sheets was not significantly different for the single-row and the double-row joints. The separation exceeded 0.005 in. at a rivet shear of 10 000 lb. per sq. in. for only 6 of the 42 lap joints for which it was measured.

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