ARR No. 4I15

W-55

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

September 1944 as
Advance Restricted Report 4I15

FATIGUE TESTS OF RIVETED JOINTS

PROGRESS REPORT OF TESTS OF 17S-T AND 53S-T JOINTS

By E. C. Hartmann, J. O. Lyst, and H. J. Andrews
Aluminum Company of America

NACA

WASHINGTON

W-55

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

FATIGUE TESTS OF RIVETED JOINTS

PROGRESS REPORT OF TESTS OF 17S-T AND 53S-T JOINTS

By E. C. Hartmann, J. O. Lyst, and H. J. Andrews

INTRODUCTION

A comprehensive program of fatigue tests of riveted joints in aluminum alloys was started in 1935 at the Aluminum Research Laboratories in order to learn as much as possible about the best method of designing aluminum-alloy structures to resist failure from repeated loading. The scope of this investigation was made broad enough to include not only actual joints in which load is transferred from one plate to another, but also specimens in which rivets carry little or no stress, as might be the case in parts of a structure where the rivets are used only for the purpose of holding two or more pieces in contact. The machines used in making the tests have previously been described. (See reference 1.)

This report presents the fatigue data obtained at the Aluminum Research Laboratories, from tests of various types of 17S-T and 53S-T specimens. These specimens were large enough to represent actual service conditions, but the repetition of loading was more rapid than would occur in ordinary service. This higher rate of loading was necessary to shorten the testing time.

Two plate materials, three rivet materials, twenty-nine types of specimens, and four different stress ratios have been employed in the tests described herein. This large number of variables has been justified because the study of fatigue of riveted joints was so new that it was necessary to branch out in different directions to obtain a comprehensive knowledge of the fatigue strength of riveted aluminum-alloy structures.

Tests of 486 specimens will be covered in this progress report. In addition to tests of actual joint specimens, 72 of these 486 tests have been made using single plate specimens which either were solid or contained open holes or idle rivets.

MATERIALS

The specimens for this investigation were constructed from 1- by 7½-inch rolled rectangular bar of aluminum alloys 17S-T (Federal Specification QQ-A-351) and 53S-T (Federal Specification QQ-A-331). The mechanical properties of the bar of both alloys were above the specified values with the exception of the yield strength of 53S-T, which was slightly low (1.2 percent).

By using small polished specimens cut longitudinally from the bar stock, the direct-stress fatigue properties of one lot of 17S-T were determined. As shown in figure 1, the endurance limit for stresses varying from zero to a maximum in tension is 22,000 psi based on 500 million cycles of stress.

Button-head rivets of 17S-T, 53S-W, and steel were used. The sizes were 1/4, 3/8, 1/2, and 5/8 inch. Bolts of 17S-T having a diameter of 5/8 inch and pins of 17S-T having diameters of 1, 1¼, and 2½ inches were also used.

Although this investigation is confined to tests of only two aluminum alloys, it is believed that the results, insofar as they deal with effect of arrangement of rivets and types of joints, are generally applicable to the other aluminum alloys.

DESCRIPTION OF JOINTS

Detailed sketches of the reduced section of the various types are shown in figures 2 and 3. The different types of specimens may be classified in three general groups. The first includes types OX, G, GX, and K, which are single plates either solid, with holes, or with idle rivets. The second includes the lap or single-shear joints, designated types A, A_1, A_2, A_3, B, C, CX, E, H, S, P, and R. The third includes the butt or double-shear joints, types J-1, L-1, LL, M, CY, M-1, Q-1, Q-2, T, U, U-1, U-2, and W-1.

The reduced section of each specimen was obtained by machining to the desired thickness in a milling machine using a 4-inch diameter helical milling cutter 10 inches long. The milling was done with the cutter normal and the travel of the carriage parallel to the length of the specimen. In this way any minute marks left by the machining operation were parallel to the direction of stress, which would minimize their effect on the fatigue strength of the specimen. The keyways of each specimen were carefully machined in a shaper-planer so as to be parallel after assembly of the specimen.

The rivets in the various specimens were driven using the following combinations of conditions:

Rivet material	Rivet diameter (in.)	Hole diameter (in.)	Driving condition	Type of driven head
Al alloy	1/4, 3/8, 1/2, and 5/8	17/64, 25/64, 33/64, and 41/64	Cold	Cone-point
Al alloy	3/8	25/64	Cold	Button
Al Alloy	3/8 and 5/8	13/32 and 21/32	Hot	Button
Steel	3/8 and 5/8	25/64 and 41/64	Cold	Flat
Steel	5/8	21/32	Hot	Button

The cold-driven 17S-T rivets were driven with 1/2 hour or less of room-temperature aging between heat treatment and driving. The cold-driven 53S-W rivets were driven after several weeks of room-temperature aging. The hot-driven 17S-T and 53S-W rivets were heated in a lead bath at temperatures of 950° and 970° F, respectively, and were driven as quickly as possible after removal from the bath. The cold-driven steel rivets were annealed first by heating to 1220° F for 3 hours and then cooling slowly in the furnace overnight. The hot-driven steel rivets were heated in a gas-fired furnace and were driven at a temperature of approximately 1800° F.

When bolts or pins were used, the holes into which they were fitted were reamed to size with just enough clearance so that the bolts and pins could be inserted easily. Aluminum-alloy washers were used under the heads and nuts of all bolts, and the torque used in tightening each bolt was 610 inch-pounds. Only 5/8-inch bolts were used.

TEST PROCEDURE

The tests in this investigation were made in the fatigue machines shown in figure 4, which were designed especially for testing riveted joints. (See reference 1.) The machines were so constructed that the specimens may be subjected to cycles of direct stress from any value in tension or compression to any other value in tension or compression, provided the maximum loads are within the capacity of the machine being used. For two of the machines the nominal capacity is 40,000 pounds, and for the other four, 50,000 pounds.

The testing machines have been calibrated as described previously (reference 1), and, in addition, considerable experimental work has been done to evaluate inertia effects occurring under the various conditions of testing used throughout the scope of the investigation. Corrections obtained from these dynamic calibration studies have been made wherever necessary in the fatigue data reported.

The test specimen is placed in the machine in a vertical position about 15 inches from the fulcrum end of the machine. One end of the specimen is keyed and bolted to the bed of the machine, and the other end is similarly fastened to the horizontal loading beam. This loading beam acts as a second-class lever having a ratio of approximately 10:1. When the specimen is bolted in place and the crank (not being set at zero throw) is turned, movement of the loading beam up and down applies either tension or compression to the specimen. As load is applied, the deflection of the loading beam is proportional to the load.

The tensile or compressive load to be applied to any specimen is computed from the product of the desired stress and the minimum net cross-sectional area of the specimen through the reduced section.

Each fatigue-testing unit is equipped with limit switches to stop the motor when a specimen breaks. At failure of a specimen the stress in the loading beam is automatically relieved and the deflection of the beam changes sufficiently to operate the limit switches. These switches are sensitive enough so that they usually break the circuit with the development of only a small crack in the specimen. When a visible crack forms in a specimen, the test is considered completed.

In the majority of tests, the range of fatigue stresses in the plates was from zero to a maximum in tension, but in some tests the range was from some stress in either tension or compression to some other stress in tension. For convenience the tests were run in groups, all tests in any one group having the same ratios of minimum to maximum stress. In using these stress ratios, tensile stresses were considered positive and compressive stresses negative. For any test the maximum stress is the one having the largest algebraic value, and not necessarily the one having the largest numerical value. Following is a complete list of stress ratios used, together with examples of corresponding stress ranges:

Stress ratio	Example of stress range (psi)
0.75	15,000 to 20,000 tension
.50	10,000 to 20,000 tension
0	0 to 20,000 tension
-1.00	20,000 compression to 20,000 tension

Unless definitely stated otherwise, all discussion in subsequent parts of this report pertains to tests in which a zero stress ratio was used. Also, unless stated otherwise, all fatigue strengths are based upon 2 million cycles of stress. This number of cycles was used by Prof. W. M. Wilson (references 2 and 3) and by Otto Graf (reference 4) in similar tests.

The results of the fatigue tests were plotted in the form of S-N diagrams (stress-number of cycles). The stresses plotted were average values and did not take into account any nonuniform distribution of stress in the specimens. Some of the fractured specimens are shown in figures 5 to 9. A few representative S-N curves (figs. 10 to 12) are included with this paper. A summary of the results of the tests is given in tables I to IV.

Most of the tests were continued to failure, but 38 specimens were removed from the machine before failure because the number of cycles had reached a prearranged maximum number, usually 25 million, which was considered sufficient in this investigation. In the S-N diagrams, the latter tests are indicated accordingly.

SUMMARY OF RESULTS

The following summary is based on the fatigue tests reported herein on aluminum-alloy joints of 17S-T (Federal Specification QQ-A-351) and 53S-T (Federal Specification QQ-A-331). No effort is made in this summary to cover all the different stress ratios tested or the full range of numbers of cycles of stress used, since it is impractical to summarize the results taking into account all the variables included. Instead, the strength of the various types of specimens are compared principally on the basis of "fatigue strength," which is defined as the maximum stress on the net section of the plates (P/A) to which the joint can be subjected for 2 million cycles, the stress in each cycle varying from zero to a maximum tensile stress.

1. Open holes and idle rivets reduce the fatigue strengths of aluminum-alloy plates considerably, the strengths obtained being from 11 to 42 percent of the nominal static strengths. The effect usually is greater (1) with an open hole than with an idle rivet, (2) with four idle rivets than with only one, and (3) with hot-driven than with cold-driven rivets.

2. In general, idle rivets are less harmful to the fatigue strength of a plate than rivets used to transfer load.

3. In the tests of lap joints with 1/4-inch plates and 5/8-inch rivets, about 86 percent failed by fracture of the plates through the rivet holes. Of the remainder, one joint failed by shearing the rivets, and the others by the rivet heads' being broken off as a result of the prying action exerted on them during the eccentric loading.

4. In the tests of lap joints with 1/4-inch plates and 3/8-inch rivets, only 33 percent failed in the plates. Most of the remainder failed by shearing the rivets, although a few failed by the rivet heads' breaking off.

5. In the tests of butt joints with 1/4-inch plates and 5/8-inch rivets, about 97 percent of the failures were in the plates, the remainder being by shearing of the rivets.

6. In the tests of butt joints with 1/4-inch plates and 3/8-inch rivets, about 44 percent of the failures were in the plates, the remainder being by shearing of the rivets.

7. In the tests of joints in which the fatigue failure occurred by tensile failure in the plate and in which the stresses varied from zero to a maximum tension, the tensile fatigue strengths ranged between 7 and 46 percent of the static tensile strength of the material.

8. In the tests of joints in which the fatigue failure occurred by shearing of the rivets, and in which the stresses varied from zero to a maximum in one direction, the shear fatigue strengths ranged from about 38 to 73 percent of the nominal static shear strengths of the driven rivets. Since these ratios for shear strengths are considerably higher than those given in the preceding conclusion for tensile strengths, it is evident that shear fatigue is not as important in ordinary design as tensile fatigue.

9. The fatigue strengths of the aluminum-alloy joints range from 13 to 73 percent of the calculated static strength for lap joints, and from 10 to 55 percent for butt joints. For each of these two general types, the highest percentages were obtained when testing 53S-T plates with cold-driven 53S-W rivets.

10. The fatigue strengths of the type C lap joints and type M butt joints, for different combinations of plate and rivet materials, are as follows:

Plate material (1/4 in.)	Rivets (5/8 in.)	Fatigue strength* (psi)	Fatigue strength* (lb)
Lap joints (type C)			
17S-T	Cold-driven - 17S-T	9,800	12,100
17S-T	Hot-driven - 17S-T	7,700	9,400
17S-T	Cold-driven - Steel	9,300	11,500
17S-T	Hot-driven - Steel	6,600	8,000
53S-T	Cold-driven - 53S-W	7,100	8,800
53S-T	Hot-driven - 53S-W	6,700	8,200
Butt joints (type M)			
17S-T	Hot-driven - 17S-T	16,500	20,100
17S-T	Cold-driven - 17S-T	14,300	17,600
17S-T	Hot-driven - Steel	5,600	6,800
53S-T	Hot-driven - 53S-W	15,700	19,100
53S-T	Cold-driven - 53S-W	11,400	14,100

*Tension on net section of plates, based on 2 million cycles of stress, from zero to a maximum in tension.

11. In general, butt joints have higher fatigue strengths than lap joints, even though both fail in the plates rather than in the rivets. For example, in joints with 1/4-inch 17S-T plate containing a single row of four 5/8-inch cold-driven 17S-T rivets (types C and M), the fatigue strength of lap joints is about 68 percent of that of butt joints. The lower strength of the lap joints is attributed mostly to the flexing action resulting from eccentricity of loading.

12. Increasing the resistance to flexing of lap joints by increasing the thickness of one of the plates is beneficial in increasing the fatigue strength of the thinner plate. For example, in some comparative tests in which the thickness of one plate was doubled, the strength of the thinner plate was increased about 65 percent.

13. The use of multiple rows of a given size of rivet, with the same number of rivets per row, increases the fatigue strength of lap joints even though all failures are in the plate. For example, the strength of a lap joint with 1/4-inch 17S-T plates containing a single row of 5/8-inch 17S-T rivets was increased 21 percent by adding another row of the same number and size of rivets. This improvement probably can be attributed mostly to the added stiffness resulting from the increased lap. Another factor is the smaller load transferred by each rivet.

14. For the same total number of rivets, lap joints have higher fatigue strengths, in pounds per square inch on the net section of the plate, when the rivets are spaced closely in a single row than when spaced more widely in two or more rows. For example, in lap joints with 1/4-inch 17S-T plates and 3/8-inch cold-driven 17S-T rivets, the fatigue strength in pounds per square inch of net section of the plate was 10 percent higher when six rivets were used in a single row than when they were used in two rows of three each. When fatigue strength is expressed in pounds, however, the joint with a single row of rivets was about 12 percent weaker than the other.

15. The different types of lap joints with 1/4-inch 17S-T plates containing cold-driven 5/8-inch 17S-T rivets may be rated as follows, beginning with the one having the highest fatigue strength:

Type of joint	Rivets			Fatigue strengths*	
	Total number	No. of rows	Number per row	Tension in plates (net section) (psi)	Total load (lb)
H	9	3	3	12,700	17,700
E	6	2	3	10,200	14,200
C	4	1	4	9,800	12,100
B	3	1	3	8,400	11,700
R	4	2	2	6,700	10,400
A	2	1	2	5,800	9,000
P	3	2	1,2	5,000	7,800

*Based on 2 million cycles of stress, with zero minimum stress.

16. In general, the fatigue strength of aluminum-alloy lap joints is higher when cold-driven rivets are used than

when hot-driven rivets are used. This difference is greater when steel rivets are used.

17. As would be expected from a knowledge of relative basic fatigue strengths, joints of 53S-T plate using hot- or cold-driven 53S-W rivets had lower fatigue strengths than similar joints of 17S-T plate with hot- or cold-driven 17S-T rivets.

18. For a given spacing and arrangement of cold-driven 17S-T rivets in 1/4-inch 17S-T plates, the fatigue strength of a lap joint increases as the size of the rivets is increased, even though most of the failures occur as tensile fractures of the plate rather than as shear failures of the rivets. This statement is true whether the fatigue strength is expressed in pounds per square inch of net area or in total load in pounds. The above statement is generally true also for butt joints. However, as noted in the following table of butt joints, going from 1/2-inch to 5/8-inch rivets in the type M joint caused a reduction in fatigue strength based on stress on the net area and also in total load on specimen in pounds. Going from a 1½-inch pin to a 2½-inch pin in the type Q-2 joint gave a reduction in fatigue strength based on total load.

		Rivets or pins						
Type	Plate alloy	Diam. (in.)	Alloy	Driving condition	No. of rows	No. per row	Fatigue strength (psi)	Fatigue strength (lb)
U-1	17S-T	5/8	17S-T	Cold	1	2	11,400	17,700
U-1	17S-T	1/2	17S-T	Cold	1	2	8,600	13,900
U-1	17S-T	3/8	17S-T	Cold	1	2	4,600	7,700
L-1	17S-T	5/8	17S-T	Cold	2	4	17,800	22,000
L-1	17S-T	1/2	17S-T	Cold	2	4	16,400	22,300
L-1	17S-T	3/8	17S-T	Cold	2	4	9,800	14,500
W-1	17S-T	1/2	17S-T	Cold	3	4	14,200	19,300
W-1	17S-T	3/8	17S-T	Cold	3	4	9,200	13,700
M	17S-T	5/8	17S-T	Cold	1	4	14,300	17,600
M	17S-T	1/2	17S-T	Cold	1	4	15,700	21,400
M	17S-T	3/8	17S-T	Cold	1	4	9,700	14,400
Q-2	17S-T	2½	17S-T	Cold	1	1	9,400	11,800
Q-2	17S-T	1½	17S-T	Cold	1	1	9,400	14,100
Q-2	17S-T	1	17S-T	Cold	1	1	8,500	13,800

In terms of load in pounds on the specimen a limiting value of fatigue strength seems to be reached when the rivet diameter is increased to about one-third the rivet spacing.

19. As would be expected from a general knowledge of the fatigue of metals, the greater the ratio of minimum to maximum stress, the greater the maximum fatigue stress which a joint will withstand.

20. The stress concentration factors, determined by comparing the fatigue strengths for all the various types of specimens in which failure occurred in the plates with the basic fatigue strengths of the plate materials, ranged between 1.3 and 9.3. It is concluded, therefore, that it is impossible to arrive at any satisfactory average stress concentration factor for riveted members in general.

21. The strongest two aluminum-alloy lap joints, based both on unit stress on the net section of the plate and on total load in pounds, are types H and CX with 1/4-inch 17S-T main plates and 5/8-inch 17S-T rivets. The other details of these joints and the fatigue strengths are given in the following table:

Type of joint	Rivets			Fatigue strengths*	
	Driving condition	Number of rows	Number per row	Tension in plates (net section) (psi)	Total load (lb)
H	Cold	3	3	12,700	17,700
CX	Hot	1	4	12,700	15,500

*Based on 2 million cycles of stress, with zero minimum stress.

22. The strongest butt joint when based on either the net section of the plates or total load in pounds was the type M with 1/4-inch 17S-T plates containing 5/8-inch diameter 17S-T bolts. The fatigue strength of this specimen was 21,400 psi corresponding to a load of 26,800 pounds. The second strongest butt joint on this same basis was the type U-2 with 1/4-inch 17S-T plates and $1\frac{1}{4}$-inch 17S-T pins which had a fatigue strength of 18,100 psi corresponding to a load of 22,600 pounds.

23. For a given spacing, size, and number of rivets double shear butt joints are superior to single shear butt joints and lap joints even though failures occur as tensile fracture of the plates. Values obtained for joints with 1/4-inch 17S-T plates and 5/8-inch cold-driven rivets are given below:

Type of joint	Rivets		Fatigue strengths*	
	Number of rows	Number per row	Tension in plates (net section) (psi)	Total load (lb)
Double shear butt, M	1	4	14,300	17,650
Lap, C	1	4	9,800	11,600
Single shear butt, CY	1	4	7,000	8,600

*Based on 2 million cycles of stress, with zero minimum stress.

Aluminum Research Laboratories,
Aluminum Company of America,
New Kensington, Pa., June 24, 1944.

REFERENCES

1. Templin, R. L.: Fatigue Machines for Testing Structural Units. Proc., A.S.T.M., vol. 39, 1939, pp. 711-721.

2. Wilson, Wilbur M., and Thomas, Frank P.: Fatigue Tests of Riveted Joints. Univ. of Ill. Bull. No. 302, May 31, 1938.

3. Wilson, W. M.: Fatigue Tests of Riveted Joints. Civil Engineering, vol. 8, no. 8, Aug. 1938, p. 513.

4. Graf, Otto: On Endurance Experiments with Flat Bar and Riveted Joints of Light Metal. Der Stahlbau 8, 132, Aug. 16, 1935.

5. Schaechterle, K.: On the Fatigue Strength of Riveted and Welded Joints and the Design of Dynamically Stressed Structural Members Based on Conclusions Drawn from Fatigue Tests. Publications of the Int. Assoc. for Bridge and Structural Engineering, vol. 2, 1933-34, pp. 312-379.

6. Schulz, E. H., and Buchholtz, H.: On the Fatigue Strength of Riveted and Welded Joints Made of ST52 Steel. Publications of the Int. Assoc. for Bridge and Structural Engineering, vol. 2, 1933-34, pp. 380-399.

7. Holbrook, Raymond H.: Some Problems of the Materials and Methods of Joining Used in Strong Light Structures. The Daniel Guggenheim Airship Inst. Rep. on Airship Forum, July 25-28, 1935, p. 64.

8. Spraragen, W., and Claussen, G. E.: Fatigue Strength of Welded Joints - A Review of the Literature to Oct. 1, 1936. The Engineering Foundation, Welding Res. Committee.

9. Valyi, Imre: Investigation on the Riveting of Aluminum Alloys of the Al-Cu-Mg Type. Aluminum Archives, vol. 8, Diss., 1937.

10. Lea and Whitman: The Failure of Girders under Repeated Stresses. Jour., Inst. of Civil Engineers, London, Nov. 1937, p. 119.

11. Goodyear-Zeppelin Corp.: Preliminary Fatigue Studies on Aluminum Alloy Aircraft Girders. NACA TN No. 637, 1938.

12. Bleakney, Wm. M.: Fatigue Testing of Wing Beams by the Resonance Method. NACA TN No. 660, 1938.

13. A.S.T.M. Standard Specifications for Steel for Bridges (A7-34).

14. Structural Aluminum Handbook (1938 and 1940 ed.), table 5, p. 25.

15. Frocht, M. M., and Hill, H. N.: Stress-Concentration Factors around a Central Circular Hole in a Plate Loaded through Pins in the Hole. Jour. Appl. Mechanics, March 1940.

16. Hartmann, E. C.: Fatigue Test Results, Their Use in Design Calculations. Product Engineering, Feb. 1941.

17. Howland, R. C. J.: On the Stresses in the Neighborhood of a Circular Hole in a Strip under Tension. Phil. Trans. Roy. Soc., London, ser. A, vol. 229, Jan. 6, 1930, pp. 46-86.

18. Wilson, W. M., Bruckner, W. H., and McCrackin, T. H.: Tests of Riveted and Welded Joints in Low-Alloy Structural Steels. Univ. of Ill. Bull. 337, Sept. 22, 1942.

19. Battelle Memorial Inst.: Prevention of the Failure of Metals under Repeated Stress. John Wiley and Sons, Inc., 1941.

20. Templin, R. L., and Hartmann, E. C.: Static and Repeated Load Tests of Aluminum Alloy and Steel Riveted Hull Splices. Tech. Paper No. 5, Aluminum Res. Lab., Aluminum Co. of Am., 1941.

TABLE I

SUMMARY OF RESULTS OF FATIGUE TESTS OF RIVETED JOINTS

Type of Specimen	Plate Material	Rivets				Stress Ratio	Failures Encountered at Various Number of Cycles of Stress			Tensile Stress at Failure,* psi			Corresponding Shear Stress, psi			Corresponding Bearing Stress, psi		
		Material	Diameter, in.	Type of Driven Head	Driving Condition		10^5 Cycles	$2x10^6$ Cycles	10^7 Cycles	10^5 Cycles	$2x10^6$ Cycles	10^7 Cycles	10^5 Cycles	$2x10^6$ Cycles	10^7 Cycles	10^5 Cycles	$2x10^6$ Cycles	10^7 Cycles
Lap Joints:																		
A	17S-T	17S-T	5/8	Cone-point	Cold	0	Head#	Tensile	Tensile	9 700	5 800	4 700	23 400	14 000	11 300	47 100	28 200	22 800
A	17S-T	17S-T	5/8	Button head	Hot	0	Head#	Tensile	Tensile	9 700	4 800	3 300	22 200	11 000	7 600	45 700	22 700	15 600
A	17S-T	17S-T	3/8	Cone-point	Cold	0	Shear	Shear	Shear	3 900	2 400	2 000	27 300	16 800	14 300	33 500	20 700	17 200
A	17S-T	17S-T	3/8	Cone-point	Cold	-1.00	Shear	Shear	Shear	2 100	1 800	1 000	14 600	10 900	7 000	18 100	13 800	8 600
A	17S-T	Steel	3/8	Flat	Cold	0	Shear	Tensile	Tensile	7 200	4 000	2 300	50 300	28 000	16 100	61 800	34 500	19 800
A	53S-T	53S-W	3/8	Cone-point	Cold	0	Shear	Shear	Shear	3 200	2 600	2 200	22 700	18 200	15 400	27 600	22 400	19 000
B	17S-T	17S-T	5/8	Cone-point	Cold	0	Tensile	Tensile	Tensile	15 600	8 400	5 600	22 500	12 100	8 100	45 300	24 500	16 300
B	17S-T	17S-T	5/8	Button head	Hot	0	Head#	Tensile	Tensile	13 800	6 500	5 200	18 800	8 800	7 100	38 900	18 300	14 700
B	17S-T	17S-T	1/2	Cone-point	Cold	0	Shear	Tensile	Tensile	11 700	7 000	4 800	27 900	16 700	11 400	45 000	26 900	18 500
C	17S-T	17S-T	5/8	Cone-point	Cold	0	Tensile	Tensile	Tensile	18 400	9 800	5 500	17 700	9 400	5 300	35 600	18 900	10 600
C	17S-T	17S-T	5/8	Button head	Hot	0	Tensile	Tensile	Tensile	20 500	7 700	6 100	18 500	6 900	5 500	38 100	14 300	11 400
C	17S-T	17S-T	5/8	Button head	Hot	+0.50	Tensile	Tensile	Tensile	25 200	11 200	8 400	22 700	10 100	7 600	46 800	20 800	15 600
C	17S-T	17S-T	5/8	Button head	Hot	+0.75	–	Tensile	Tensile	–	21 300	13 700	–	19 200	12 300	–	39 600	25 500
C	17S-T	17S-T	5/8	Button head	Hot	-1.00	Tensile	Tensile	Tensile	13 300	5 900	3 700	12 000	5 300	3 300	24 800	11 000	6 900
C	17S-T	Steel	5/8	Flat	Cold	0	Tensile	Tensile	Tensile	20 600	9 300	6 000	19 800	8 900	5 800	39 800	18 000	11 600
C	17S-T	Steel	5/8	Button head	Hot	0	Tensile	Tensile	Tensile	16 500	6 600	5 000	14 900	5 900	4 500	30 700	12 300	9 300
C	17S-T	Steel	5/8	Button head	Hot	+0.50	Tensile	Tensile	Tensile	30 500	11 000	8 400	27 500	9 900	7 600	56 800	20 500	15 600
C	17S-T	Steel	5/8	Button head	Hot	+0.75	–	Tensile	Tensile	–	23 700	12 000	–	21 300	10 800	–	44 100	22 300
C	17S-T	Steel	5/8	Button head	Hot	-1.00	Tensile	Tensile	Tensile	10 300	4 200	2 200	9 300	3 800	2 000	19 100	7 800	4 100
C	17S-T	17S-T	3/8	Cone-point	Cold	0	Shear	Head#	Tensile	7 800	5 700	5 000	24 200	17 600	15 500	29 600	21 600	19 000
C	17S-T	17S-T	3/8	Button head	Cold	0	Shear	Shear	Shear	8 400	6 600	5 500	25 900	20 400	17 000	31 800	25 500	20 900
C	17S-T	Steel	3/8	Flat	Cold	0	Shear	Tensile	Tensile	12 700	6 300	5 000	39 200	19 500	15 500	48 200	23 900	19 000
C	17S-T	(5/8-in.dia.17S-T bolts)				0	Tensile	Tensile	Tensile	20 000	9 000	6 800	20 400	9 200	6 900	40 000	18 000	13 600
C	17S-T	(5/8-in.dia.17S-T bolts)				-1.00	Tensile	Tensile	Tensile	9 100	6 400	5 500	9 300	6 500	5 600	18 200	12 800	11 000
C	53S-T	53S-W	5/8	Cone-point	Cold	0	Tensile	Tensile	Tensile	13 600	7 100	4 900	13 100	6 800	4 700	26 200	13 700	9 500
C	53S-T	53S-W	5/8	Button head	Hot	0	Tensile	Tensile	Tensile	13 900	6 700	4 400	12 500	6 000	4 000	25 900	12 500	8 200
C	53S-T	53S-W	5/8	Button head	Hot	-1.00	Tensile	Tensile	Tensile	7 100	4 500	3 000	6 400	4 000	2 700	13 200	8 400	5 600
C	53S-T	53S-W	3/8	Cone-point	Cold	0	Shear	Shear	Shear	6 900	4 700	3 700	21 400	14 400	11 300	26 200	17 900	14 000
CX	17S-T	17S-T	5/8	Button head	Hot	0	Tensile	Tensile	Tensile	22 500	12 700	9 700	20 200	11 400	8 700	41 800	23 600	18 100
S	17S-T	17S-T	3/8	Cone-point	Cold	0	Tensile	Tensile	Tensile	13 700	6 700	5 400	24 500	12 000	9 700	30 200	14 800	11 900
S	53S-T	53S-W	3/8	Cone-point	Cold	0	Tensile	Tensile	Tensile	10 400	5 900	4 100	18 600	10 600	7 300	22 900	13 000	9 000
P	17S-T	17S-T	5/8	Cone-point	Cold	0	Tensile	Tensile	Tensile	10 700	5 000	4 200	17 200	8 100	6 800	34 700	16 200	13 600
P	17S-T	17S-T	5/8	Button head	Hot	0	Tensile	Tensile	Tensile	12 700	6 200	3 200	19 400	9 500	4 900	40 000	19 500	10 100
R	17S-T	17S-T	5/8	Cone-point	Cold	0	Tensile	Tensile	Tensile	13 500	6 700	5 700	16 300	8 100	6 900	32 800	16 300	13 800
R	17S-T	17S-T	5/8	Button head	Hot	0	Tensile	Tensile	Tensile	14 700	6 400	4 100	16 900	7 400	4 700	34 700	15 100	9 700
E	17S-T	17S-T	5/8	Cone-point	Cold	0	Tensile	Tensile	Tensile	19 600	10 200	6 800	14 100	7 300	4 900	28 400	14 800	9 900
E	17S-T	17S-T	1/2	Cone-point	Cold	0	Tensile	Tensile	Tensile	14 200	8 300	6 000	16 900	9 900	7 100	27 300	16 000	11 500
E	17S-T	17S-T	3/8	Cone-point	Cold	0	Shear	Tensile	Tensile	10 600	6 100	4 800	23 300	13 400	10 500	28 600	16 500	13 000
H	17S-T	17S-T	5/8	Cone-point	Cold	0	Tensile	Tensile	Tensile	21 200	12 700	10 200	10 200	6 100	4 900	20 600	12 300	9 900
H	17S-T	17S-T	1/2	Cone-point	Cold	0	Tensile	Tensile	Tensile	18 600	9 800	7 500	14 700	7 700	5 900	23 800	12 500	9 600
H	17S-T	17S-T	3/8	Cone-point	Cold	0	Tensile	Tensile	Tensile	13 400	6 400	4 600	19 700	9 400	6 800	24 100	11 500	8 300

* Tensile stress; load divided by net area.
\# Rivet heads broke off.

TABLE I (cont'd)

SUMMARY OF RESULTS OF FATIGUE TESTS OF RIVETED JOINTS

Butt Joints;

Q-1	17S-T	17S-T	5/8	Cone-point	Cold	0	Shear	Shear	Tensile	6 500	5 000	4 200	16 800	13 300	11 200	67 500	53 600	45 100
Q-2	17S-T	17S-T pin	2-1/2	Flat	Cold	0	Tensile	Tensile	Tensile	16 400	9 400	8 600	2 100	1 200	1 100	32 800	18 800	17 200
Q-2	17S-T	17S-T pin	1-1/2	Flat	Cold	0	Tensile	Tensile	Tensile	13 600	9 400	8 600	5 900	4 000	3 700	54 400	37 600	34 400
Q-2	17S-T	17S-T pin	1	Flat	Cold	0	Tensile	Tensile	Tensile	11 500	8 500	7 300	12 000	8 800	7 600	74 800	55 300	47 500
U	17S-T	17S-T	5/8	Button head	Hot	0	Shear	Tensile	Tensile	13 600	8 400	6 300	15 500	9 600	7 200	64 200	39 700	29 700
U-1	17S-T	17S-T	5/8	Cone-point	Cold	0	Tensile	Tensile	Tensile	15 300	11 400	9 400	18 500	13 800	11 400	74 500	55 500	45 800
U-1	17S-T	17S-T	1/2	Cone-point	Cold	0	Shear	Tensile	Tensile	11 400	8 600	7 200	22 100	16 700	14 000	71 400	54 000	45 200
U-1	17S-T	17S-T	3/8	Cone-point	Cold	0	Shear	Tensile	Tensile	6 800	4 600	4 000	23 900	16 100	14 000	58 600	39 800	34 500
U-2	17S-T	17S-T pins	1-1/4	Flat	Cold	0	Tensile	Tensile	Tensile	29 800	18 100	13 500	7 800	4 700	3 500	59 600	36 200	27 000
M	17S-T	17S-T	5/8	Cone-point	Cold	0	Tensile	Tensile	Tensile	28 600	14 300	10 700	12 800	6 900	5 100	51 300	27 600	20 600
M	17S-T	17S-T	5/8	Button head	Hot	0	Tensile	Tensile	Tensile	28 600	16 500	12 300	12 900	7 400	5 500	53 200	30 700	22 800
M	17S-T	17S-T	5/8	Button head	Hot	+0.50	Tensile	Tensile	Tensile	41 600	27 400	15 400	18 700	12 300	6 900	77 300	51 000	28 700
M	17S-T	17S-T	5/8	Button head	Hot	-1.00	Tensile	Tensile	Tensile	20 400	11 900	10 600	9 200	5 400	4 800	37 900	22 200	19 700
M	17S-T	Steel	5/8	Button head	Hot	0	Tensile	Tensile	Tensile	13 800	5 600	4 300	6 200	2 500	1 900	25 600	10 400	8 000
M	17S-T	Steel	5/8	Button head	Hot	+0.50	Tensile	Tensile	Tensile	24 400	13 000	9 700	11 000	5 800	4 400	45 300	24 200	18 100
M	17S-T	Steel	5/8	Button head	Hot	-1.00	Tensile	Tensile	Tensile	12 300	4 600	3 600	5 500	2 100	1 600	22 900	8 600	6 700
M	17S-T	17S-T	1/2	Cone-point	Cold	0	Tensile	Tensile	Tensile	25 300	15 700	12 300	20 500	12 700	10 000	66 600	41 400	32 500
M	17S-T	17S-T	3/8	Cone-point	Cold	0	Shear	Shear	Shear	14 200	9 700	7 800	22 000	15 100	12 000	53 800	36 800	29 600
M	17S-T	(5/8-in.dia.17S-T bolts)				0	Tensile	Tensile	Tensile	30 700	21 400	13 000	15 700	10 900	6 600	61 400	42 800	26 000
M	53S-T	53S-W	5/8	Cone-point	Cold	0	Tensile	Tensile	Tensile	21 000	11 400	8 500	10 100	5 500	4 100	40 600	22 000	16 400
M	53S-T	53S-W	5/8	Button head	Hot	0	Tensile	Tensile	Tensile	22 800	15 700	9 800	10 300	7 100	4 400	42 400	29 200	18 100
M	53S-T	53S-W	5/8	Button head	Hot	-1.00	Tensile	Tensile	Tensile	16 300	4 000	7 000	7 300	4 100	3 100	30 400	16 700	13 000
M	53S-T	53S-W	3/8	Cone-point	Cold	0	Shear	Shear	-	12 000	6 900	6 700	18 600	10 700	10 900	45 500	26 200	25 400
M-1	17S-T	17S-T	5/8	Cone-point	Cold	0	-	Tensile	-	-	16 000	-	-	7 700	-	-	30 900	-
CY	17S-T	17S-T	5/8	Cone-point	Cold	0	Tensile	Tensile	Tensile	13 200	7 000	5 400	12 700	6 700	5 200	25 500	13 500	10 400
T	17S-T	17S-T	3/8	Cone-point	Cold	0	Tensile	Tensile	Tensile	22 600	13 700	10 300	20 300	12 300	9 300	49 700	30 100	22 700
T	53S-T	53S-W	3/8	Cone-point	Cold	0	Tensile	Tensile	Tensile	17 400	9 200	4 600	15 700	8 300	4 100	38 300	20 200	10 100
L-1	17S-T	17S-T	5/8	Cone-point	Cold	0	Tensile	Tensile	Tensile	31 000	17 800	11 300	7 400	4 300	2 700	29 800	17 100	10 800
L-1	17S-T	17S-T	1/2	Cone-point	Cold	0	Tensile	Tensile	Tensile	27 400	16 400	10 600	11 200	6 700	4 300	36 200	21 600	14 000
L-1	17S-T	17S-T	3/8	Cone-point	Cold	0	Tensile	Tensile	Tensile	23 600	9 800	7 300	18 200	7 500	5 600	44 800	18 600	13 900
LL	17S-T	17S-T	5/8	Cone-point	Cold	0	Tensile	Tensile	Tensile	23 400	10 600	5 400	11 200	5 100	2 600	22 400	10 200	5 200
LL	17S-T	17S-T	5/8	Button head	Hot	0	-	Tensile	Tensile	-	13 300	10 200	-	6 000	4 600	-	12 400	9 500
LL	17S-T	17S-T	5/8	Button head	Hot	+0.50	-	Tensile	Tensile	-	18 800	15 700	-	8 500	7 100	-	17 500	14 600
LL	17S-T	Steel	5/8	Button head	Hot	0	Tensile	Tensile	Tensile	13 600	6 300	3 700	6 100	2 800	1 700	12 700	5 900	3 400
LL	17S-T	Steel	5/8	Button head	Hot	+0.50	Tensile	Tensile	-	20 600	11 000	-	9 300	5 000	-	19 200	10 200	-
J-1	17S-T	17S-T	1/4	Cone-point	Cold	0	Tensile	Tensile	Tensile	22 700	9 500	6 100	12 500	5 200	3 300	20 700	8 700	5 500
W-1	17S-T	17S-T	1/2	Cone-point	Cold	0	Tensile	Tensile	Tensile	27 000	14 200	10 200	7 300	3 800	2 800	23 800	12 500	8 900
W-1	17S-T	17S-T	3/8	Cone-point	Cold	0	Tensile	Tensile	Tensile	17 700	9 200	7 600	9 200	4 800	4 000	22 500	11 700	9 700

* Tensile stress; load divided by net area.
\# Rivet heads broke off.

TABLE II

SUMMARY OF RESULTS OF FATIGUE TESTS OF SOLID PLATE SPECIMENS

Types OX, G and K, with or without Idle Rivets

Type of Specimen	Plate Material	Rivets			Stress Ratio	Tensile Stress at Failure, psi*		
		Material	Diameter, in.	Driving Condition		10^5 Cycles	$2x10^6$ Cycles	10^7 Cycles
OX	17S-T	-	-	-	0	-	32 400	31 400
G	17S-T	17S-T	5/8	Cold	0	29 200	25 200	24 300
G	17S-T	17S-T	5/8	Hot	0	-	22 200	19 000
G	17S-T	Steel	5/8	Hot	0	21 300	13 900	10 500
G	17S-T	(21/32-in.dia.drilled open hole)			0	17 600	9 900	9 800
G	53S-T	53S-W	5/8	Cold	0	21 500	15 800	14 700
G	53S-T	53S-W	5/8	Hot	0	18 600	14 500	13 600
G	53S-T	53S-W	3/8	Cold	0	21 700	15 300	11 700
G	53S-T	(21/32-in.dia.drilled open hole)			0	16 500	10 700	-
G	53S-T	(21/32-in.dia.punched open hole)			0	14 300	8 400	7 600
G	53S-T	(25/64-in.dia.drilled open hole)			0	15 700	9 700	-
K	17S-T	17S-T	5/8	Cold	0	37 600	21 000	†
K	17S-T	17S-T	5/8	Hot	0	34 400	23 400	†
K	17S-T	Steel	5/8	Hot	0	18 500	9 500	9 000
K	53S-T	53S-W	5/8	Hot	0	19 700	13 000	11 700

* Tensile stress = load divided by net area.

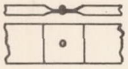
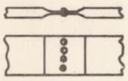
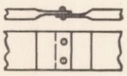
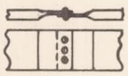
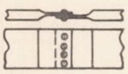
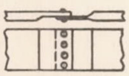
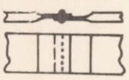
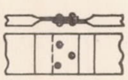
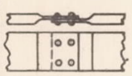
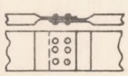
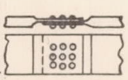
† Insufficient tests.

W-55

TABLE III

COMPARISON OF THE STATIC AND FATIGUE STRENGTHS OF THE VARIOUS TYPES OF SPECIMENS TESTED

Ratio $\frac{\text{Minimum Stress}}{\text{Maximum Stress}} = 0$

Type of Speci-men	Sketch	Plate Material	Rivets, Bolts or Pins: Material	Rivets, Bolts or Pins: Hole Diameter, in.	Rivets, Bolts or Pins: Driving Condition	Static: Computed Strength*, lb	Static: Type of Failure	Fatigue: Strength at 2×10^6 Cycles, lb	Fatigue: Type of Failure	Ratio F.S./S.S.
Single Plates:										
OX		17S-T	-	-	-	71 400	Tensile	40 500	Tensile	0.57
G		17S-T	17S-T	41/64	Cold	102 900	Tensile	43 200	Tensile	0.42
G		17S-T	17S-T	21/32	Hot	102 700	Tensile	38 000	Tensile	0.37
G		17S-T	Steel	21/32	Hot	102 700	Tensile	23 800	Tensile	0.23
G		17S-T	(21/32-in.dia.drilled open hole)			102 700	Tensile	17 100	Tensile	0.17
G		53S-T	53S-W	41/64	Cold	66 800	Tensile	27 100	Tensile	0.41
G		53S-T	53S-W	21/32	Hot	66 700	Tensile	24 800	Tensile	0.37
G		53S-T	53S-W	25/64	Cold	69 300	Tensile	27 200	Tensile	0.39
G		53S-T	(21/32-in.dia.drilled open hole)			66 700	Tensile	18 300	Tensile	0.27
G		53S-T	(21/32-in.dia.punched open hole)			66 700	Tensile	14 300	Tensile	0.21
G		53S-T	(25/64-in.dia.drilled open hole)			69 300	Tensile	17 300	Tensile	0.25
K		17S-T	17S-T	41/64	Cold	74 200	Tensile	25 900	Tensile	0.35
K		17S-T	17S-T	21/32	Hot	73 200	Tensile	28 500	Tensile	0.39
K		17S-T	Steel	21/32	Hot	73 200	Tensile	11 600	Tensile	0.16
K		53S-T	53S-W	21/32	Hot	47 600	Tensile	15 900	Tensile	0.33
Lap Joints:										
A		17S-T	17S-T	41/64	Cold	22 600	Shear	9 000	Tensile	0.40
A		17S-T	17S-T	21/32	Hot	23 000	Shear	7 400	Tensile	0.32
A		17S-T	17S-T	25/64	Cold	8 400	Shear	4 000	Shear	0.48
A		17S-T	Steel	25/64	Cold	10 800	Shear	6 700	Tensile	0.62
A		53S-T	53S-W	25/64	Cold	6 000	Shear	4 400	Shear	0.73
B		17S-T	17S-T	41/64	Cold	33 800	Shear	11 700	Tensile	0.34
B		17S-T	17S-T	21/32	Hot	34 500	Shear	9 000	Tensile	0.26
B		17S-T	17S-T	33/64	Cold	21 900	Shear	10 400	Tensile	0.47
C		17S-T	17S-T	41/64	Cold	46 400	Shear	12 100	Tensile	0.26
C		17S-T	17S-T	21/32	Hot	46 000	Shear	9 400	Tensile	0.20
C		17S-T	Steel	41/64	Cold	58 200	Shear	11 500	Tensile	0.20
C		17S-T	Steel	21/32	Hot	60 800	Shear	8 000	Tensile	0.13
C		17S-T	17S-T	25/64	Cold	16 800	Shear	8 500	Rivet Heads	0.51
C		17S-T	Steel	25/64	Cold	21 600	Shear	9 400	Tensile	0.44
C		17S-T	17S-T bolts	5/8	-	44 200	Shear	11 300	Tensile	0.26
C		53S-T	53S-W	41/64	Cold	32 200	Shear	8 800	Tensile	0.27
C		53S-T	53S-W	21/32	Hot	24 400	Shear	8 200	Tensile	0.34
C		53S-T	53S-W	25/64	Cold	12 000	Shear	7 000	Shear	0.58
CX		17S-T	17S-T	21/32	Hot	46 000	Shear	15 500	Tensile	0.34
S		17S-T	17S-T	25/64	Cold	25 200	Shear	8 600	Tensile	0.34
S		53S-T	53S-W	25/64	Cold	18 000	Shear	7 600	Tensile	0.42
P		17S-T	17S-T	41/64	Cold	32 800	Shear	7 800	Tensile	0.24
P		17S-T	17S-T	21/32	Hot	34 500	Shear	9 600	Tensile	0.28
R		17S-T	17S-T	41/64	Cold	43 800	Shear	10 400	Tensile	0.24
R		17S-T	17S-T	21/32	Hot	46 000	Shear	9 900	Tensile	0.22
E		17S-T	17S-T	41/64	Cold	67 800	Shear	14 200	Tensile	0.21
E		17S-T	17S-T	33/64	Cold	43 800	Shear	12 400	Tensile	0.28
E		17S-T	17S-T	25/64	Cold	25 200	Shear	9 700	Tensile	0.38
H		17S-T	17S-T	41/64	Cold	83 700	Tensile	17 700	Tensile	0.21
H		17S-T	17S-T	33/64	Cold	65 800	Shear	14 600	Tensile	0.22
H		17S-T	17S-T	25/64	Cold	37 800	Shear	10 100	Tensile	0.27

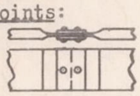
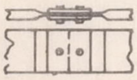
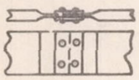
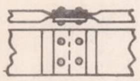
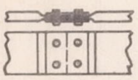
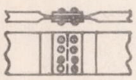
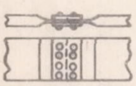
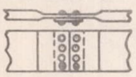
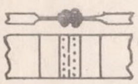
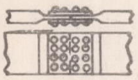
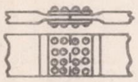
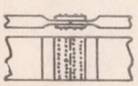
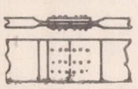
* Based upon values for shearing, bearing, and tensile strengths as included in Structural Handbook (1940 edition).

TABLE III (cont'd)

W-55

COMPARISON OF THE STATIC AND FATIGUE STRENGTHS OF THE VARIOUS TYPES OF SPECIMENS TESTED

Ratio $\frac{\text{Minimum Stress}}{\text{Maximum Stress}} = 0$

Type of Speci-men	Sketch	Plate Material	Rivets, Bolts or Pins			Static		Fatigue		Ratio $\frac{F.S.}{S.S.}$
			Material	Hole Diameter, in.	Driving Condition	Computed Strength* lb	Type of Failure	Strength at 2×10^6 Cycles, lb	Type of Failure	
Butt Joints:										
Q-1		17S-T	17S-T	41/64	Cold	16 800	Bearing	8 600	Shear	0.51
Q-2		17S-T	17S-T Pin	2-1/2	Cold	67 500	Bearing	11 800	Tensile	0.17
Q-2		17S-T	17S-T Pin	1-1/2	Cold	40 500	Bearing	14 100	Tensile	0.35
Q-2		17S-T	17S-T Pin	1	Cold	26 200	Bearing	13 800	Tensile	0.53
U		17S-T	17S-T	21/32	Hot	33 400	Bearing	13 000	Tensile	0.39
U-1		17S-T	17S-T	41/64	Cold	33 600	Bearing	17 700	Tensile	0.53
U-1		17S-T	17S-T	33/64	Cold	27 100	Bearing	13 900	Tensile	0.51
U-1		17S-T	17S-T	25/64	Cold	16 800	Shear	7 700	Tensile	0.46
U-2		17S-T	17S-T Pins	1-1/4	Cold	64 100	Bearing	22 600	Tensile	0.35
M		17S-T	17S-T	41/64	Cold	67 200	Bearing	17 600	Tensile	0.26
M		17S-T	17S-T	21/32	Hot	66 800	Bearing	20 100	Tensile	0.30
M		17S-T	Steel	21/32	Hot	70 700	Bearing	6 800	Tensile	0.10
M		17S-T	17S-T	33/64	Cold	54 200	Bearing	21 400	Tensile	0.39
M		17S-T	17S-T	25/64	Cold	33 600	Shear	14 400	Shear	0.43
M		17S-T	17S-T Bolts	5/8		67 500	Bearing	26 800	Tensile	0.40
M		53S-T	53S-W	41/64	Cold	46 200	Bearing	14 100	Tensile	0.30
M		53S-T	53S-W	21/32	Hot	35 400	Bearing	19 200	Tensile	0.54
M		53S-T	53S-W	25/64	Cold	23 000	Shear	12 800	Shear	0.55
M-1		17S-T	17S-T	41/64	Cold	67 200	Bearing	19 800	Tensile	0.30
CY		17S-T	17S-T	41/64	Cold	46 400	Shear	8 600	Tensile	0.19
T		17S-T	17S-T	25/64	Cold	50 400	Shear	17 700	Tensile	0.35
T		53S-T	53S-W	25/64	Cold	36 000	Shear	11 900	Tensile	0.33
L-1		17S-T	17S-T	41/64	Cold	74 100	Tensile	22 000	Tensile	0.27
L-1		17S-T	17S-T	33/64	Cold	81 600	Tensile	22 300	Tensile	0.29
L-1		17S-T	17S-T	25/64	Cold	67 200	Shear	14 500	Tensile	0.22
LL		17S-T	17S-T	41/64	Cold	148 300	Tensile	26 200	Tensile	0.18
LL		17S-T	17S-T	21/32	Hot	146 400	Tensile	32 400	Tensile	0.22
LL		17S-T	Steel	21/32	Hot	146 400	Tensile	15 400	Tensile	0.11
J-1		17S-T	17S-T	17/64	Cold	72 600	Tensile	11 500	Tensile	0.16
W-1		17S-T	17S-T	33/64	Cold	81 600	Tensile	19 300	Tensile	0.24
W-1		17S-T	17S-T	25/64	Cold	89 200	Tensile	13 700	Tensile	0.15

* Based upon values for shearing, bearing, and tensile strengths as included in Structural Handbook (1940 edition).

TABLE IV

STRESS CONCENTRATION FACTORS FOR 17S-T BUTT JOINTS CONTAINING 17S-T RIVETS, PINS OR BOLTS

Type of Specimen	Rivets, Bolts or Pins			Proportions of Joint			Fatigue Strength of Joints, psi (Average Stress on Net Area)			Stress Concentration Factors					
	Diameter, in.	Number Each Side of Joint	Driving Condition	Hole Diameter, in.	Width Per Hole, in.	Ratio Diameter/Width	10^5 Cycles	$2x10^6$ Cycles	10^7 Cycles	From Fatigue Strengths#			From Mathematical Analysis and Photoelastic Measurements*		
										10^5 Cycles	$2x10^6$ Cycles	10^7 Cycles	10^5## Cycles	$2x10^6$## Cycles	10^7 Cycles
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
G	(Solid specimen with open hole)			21/32	7-1/2	0.09	17 600	9 900	9 800	2.8	3.6	3.1	2.0	2.5	2.7
Q-1	5/8 rivet	1	Cold	41/64	7-1/2	0.09	6 300	5 000	4 200	7.7	7.4	7.1	5.9	9.0	9.7
Q-2	2-1/2 pin	1	Cold	2-1/2	7-1/2	0.33	16 400	9 400	8 000	2.9	3.9	3.8	2.7	3.7	4.0
U	5/8 rivet	2	Hot	21/32	3-3/4	0.17	-	8 400	6 300	-	4.4	4.8	-	4.9	5.3
U-1	5/8 rivet	2	Cold	41/64	3-3/4	0.17	15 300	11 400	9 400	3.2	3.2	3.2	3.5	5.0	5.4
U-1	1/2 rivet	2	Cold	33/64	3-3/4	0.14	-	8 600	7 200	-	4.3	4.2	-	5.6	6.0
U-1	3/8 rivet	2	Cold	25/64	3-3/4	0.11	-	4 600	4 000	-	8.0	7.5	-	6.8	7.4
U-2	1-1/4 pin	2	Cold	1-1/4	3-3/4	0.33	29 800	18 100	13 500	1.6	2.0	2.2	2.1	2.7	2.9
M	5/8 rivet	4	Cold	41/64	1-7/8	0.34	26 600	14 300	10 700	1.8	2.5	2.8	2.0	2.6	2.8
M	5/8 rivet	4	Hot	21/32	1-7/8	0.35	28 600	16 500	12 300	1.7	2.2	2.4	2.0	2.5	2.7
M	1/2 rivet	4	Cold	33/64	1-7/8	0.28	25 300	15 700	12 300	1.9	2.3	2.4	2.4	3.2	3.4
M	5/8 bolts	4	-	5/8	1-7/8	0.33	30 700	21 400	13 000	1.6	1.7	2.3	2.1	2.7	2.9
T	3/8 rivets	6	Cold	25/64	1-1/4	0.31	22 600	13 700	10 300	2.1	2.7	2.9	2.1	2.8	3.0

These stress concentration factors were determined by comparing the fatigue strength of the specimens to the following fatigue strengths of the plate material (Fig. 1): 48 400, 36 800 and 30 000 psi for 100 000, 2 000 000 and 10 000 000 cycles of stress, respectively.

* The factor for the type G specimen was determined from formulas in reference 17; all other values were determined from photoelastic tests described in reference 15. Factors for specimens with two or more rivets were determined by taking 80 per cent of the corresponding value for a single rivet, a procedure suggested in reference 15 for the case of two rivets.

The factors in these two columns are adjusted for plastic action in accordance with an empirical method suggested in reference 16. No adjustment was necessary for the factors at 10^7 cycles because all stresses are within the elastic range.

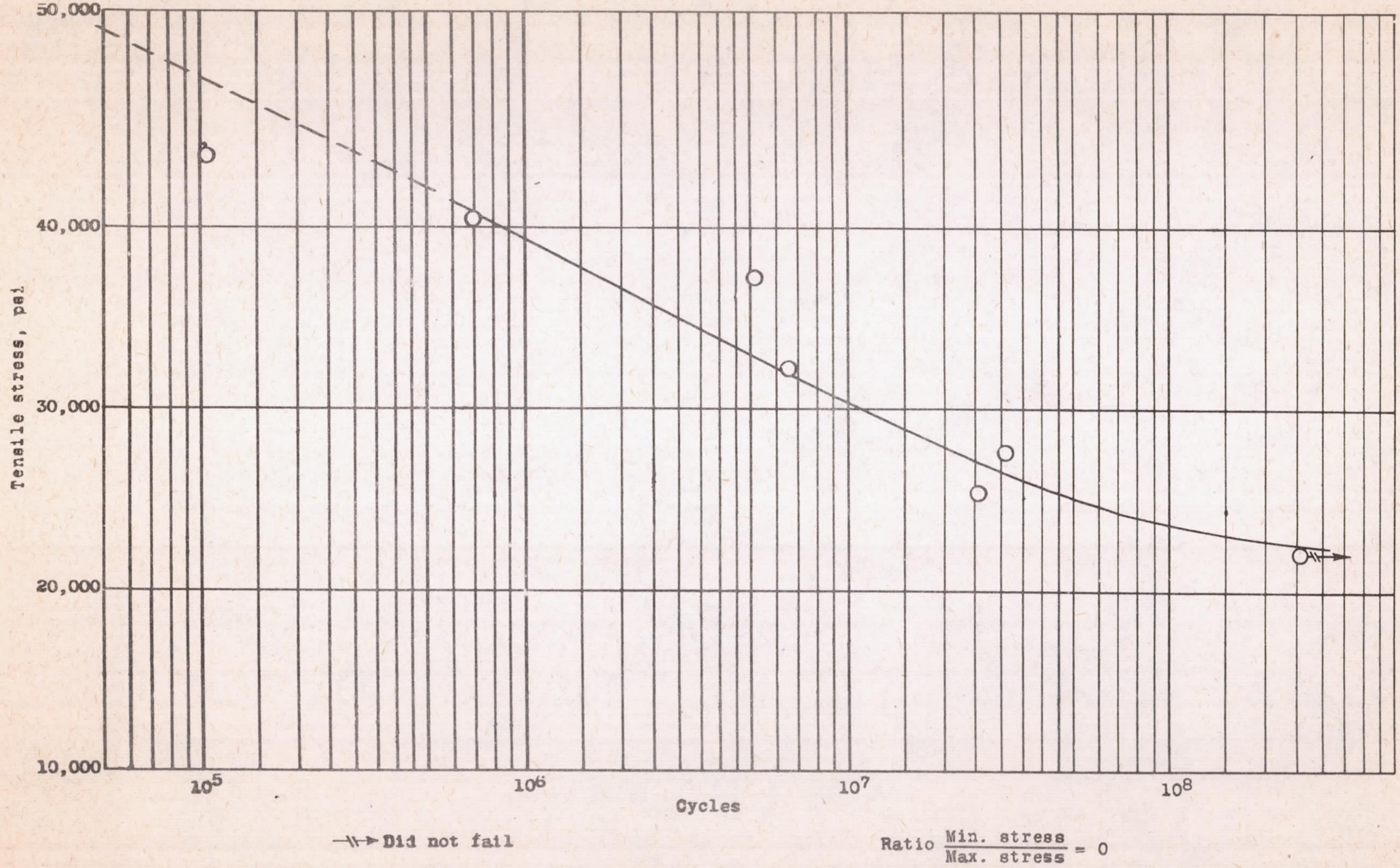


Figure 1.- Direct-stress fatigue curve for 17S-T rolled rectangular bar (1" x 7.5").

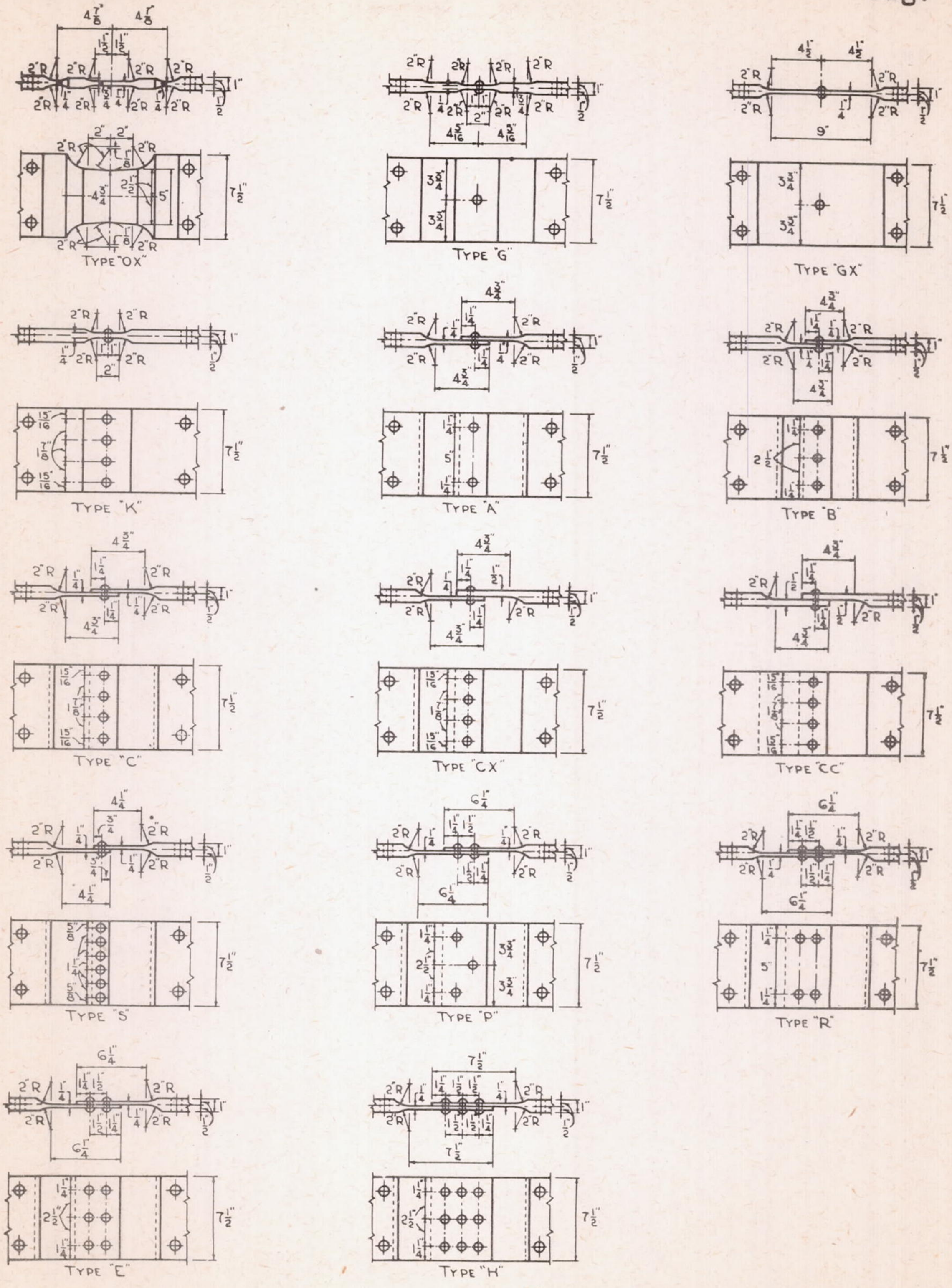
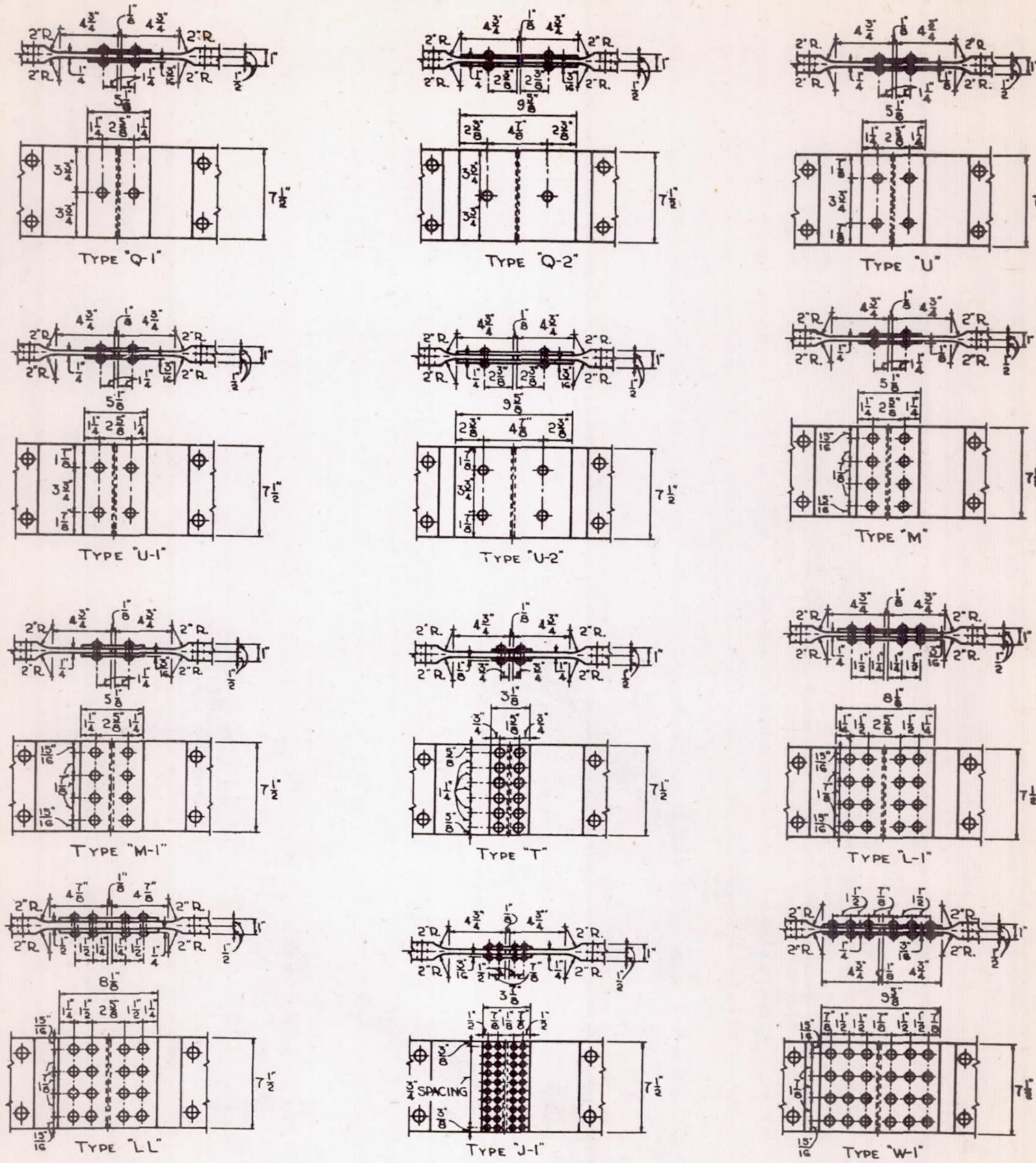


Figure 2.- Single plate and lap joint fatigue test specimens.

W-55



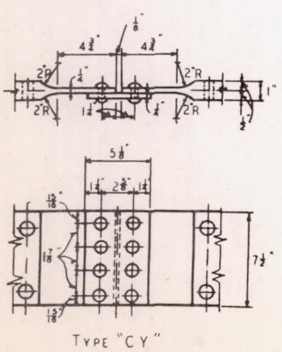


Figure 3.- Butt joint fatigue test specimens.

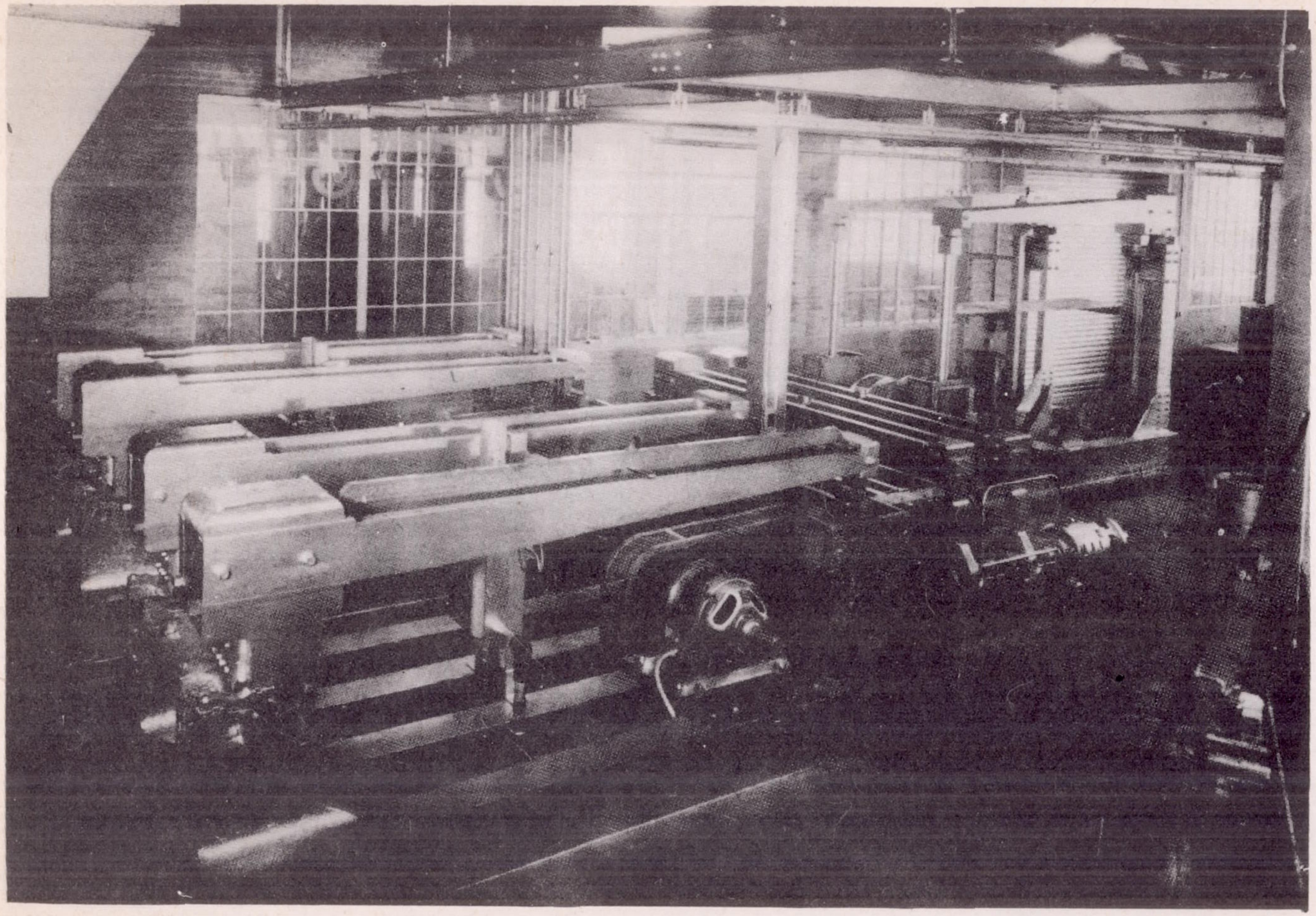


Figure 4.- Riveted joint fatigue testing machines.

W-55

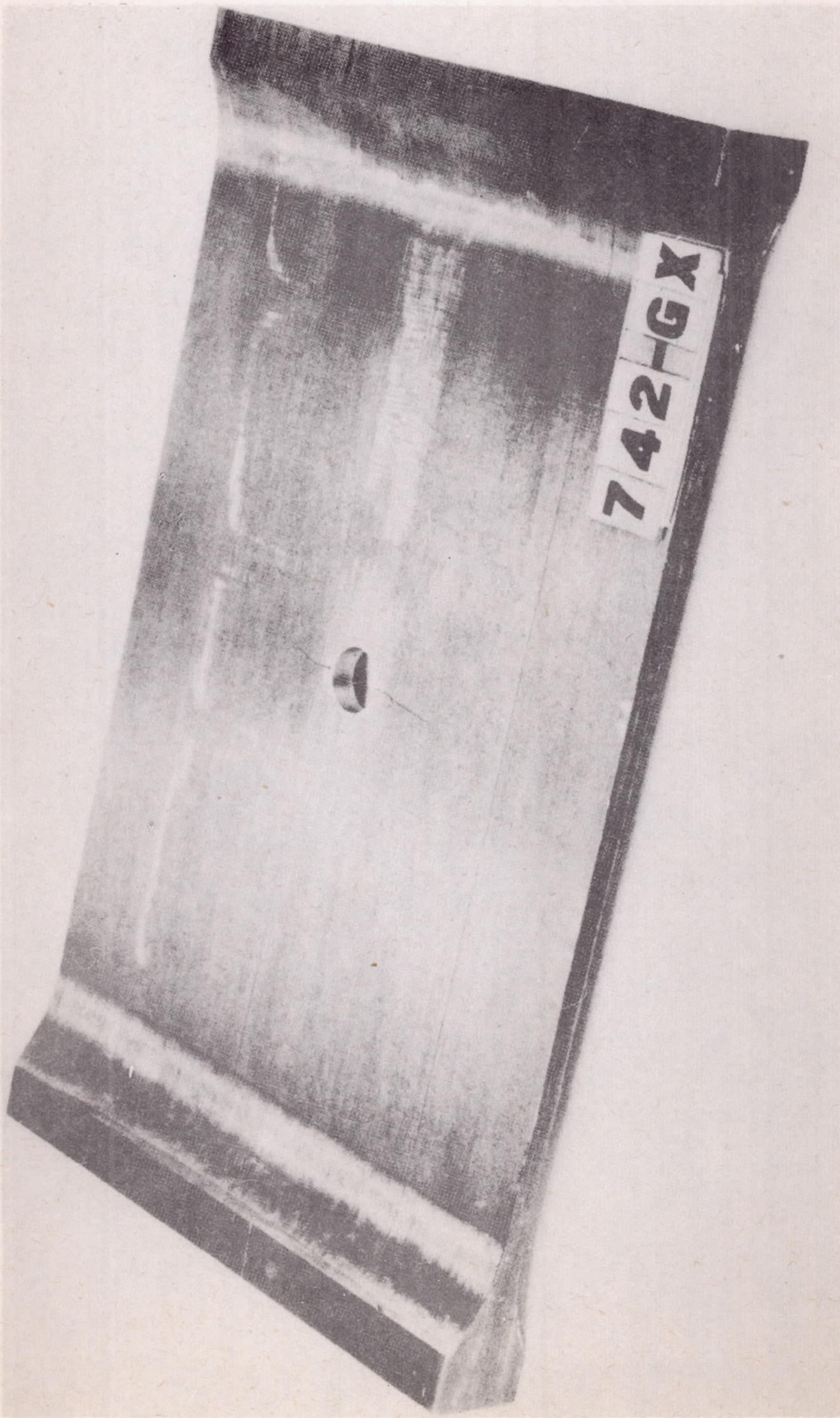


Figure 5.- Typical failure of type GX specimen.

W-55

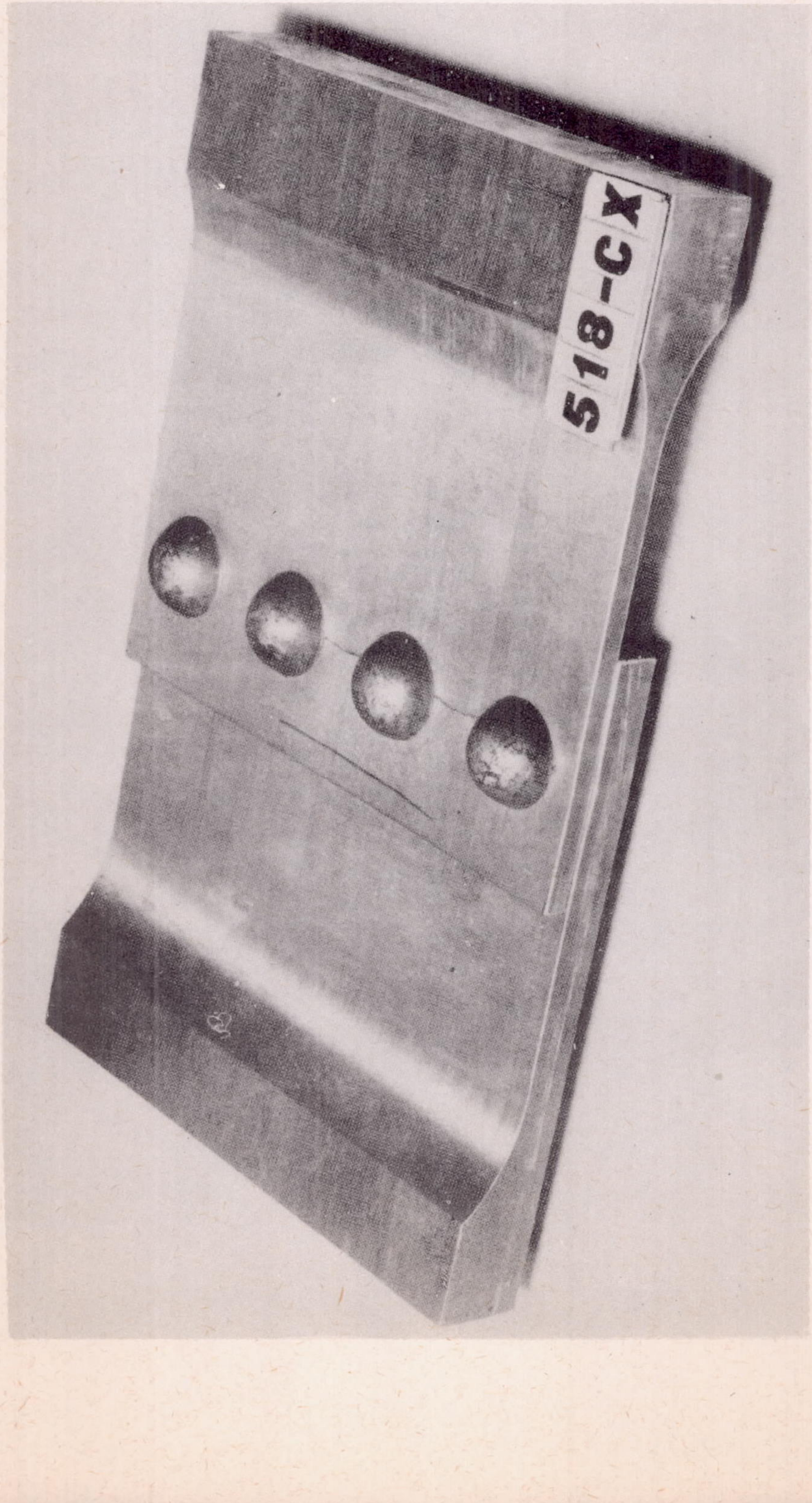


Figure 6.- Typical fracture of type CX specimen.

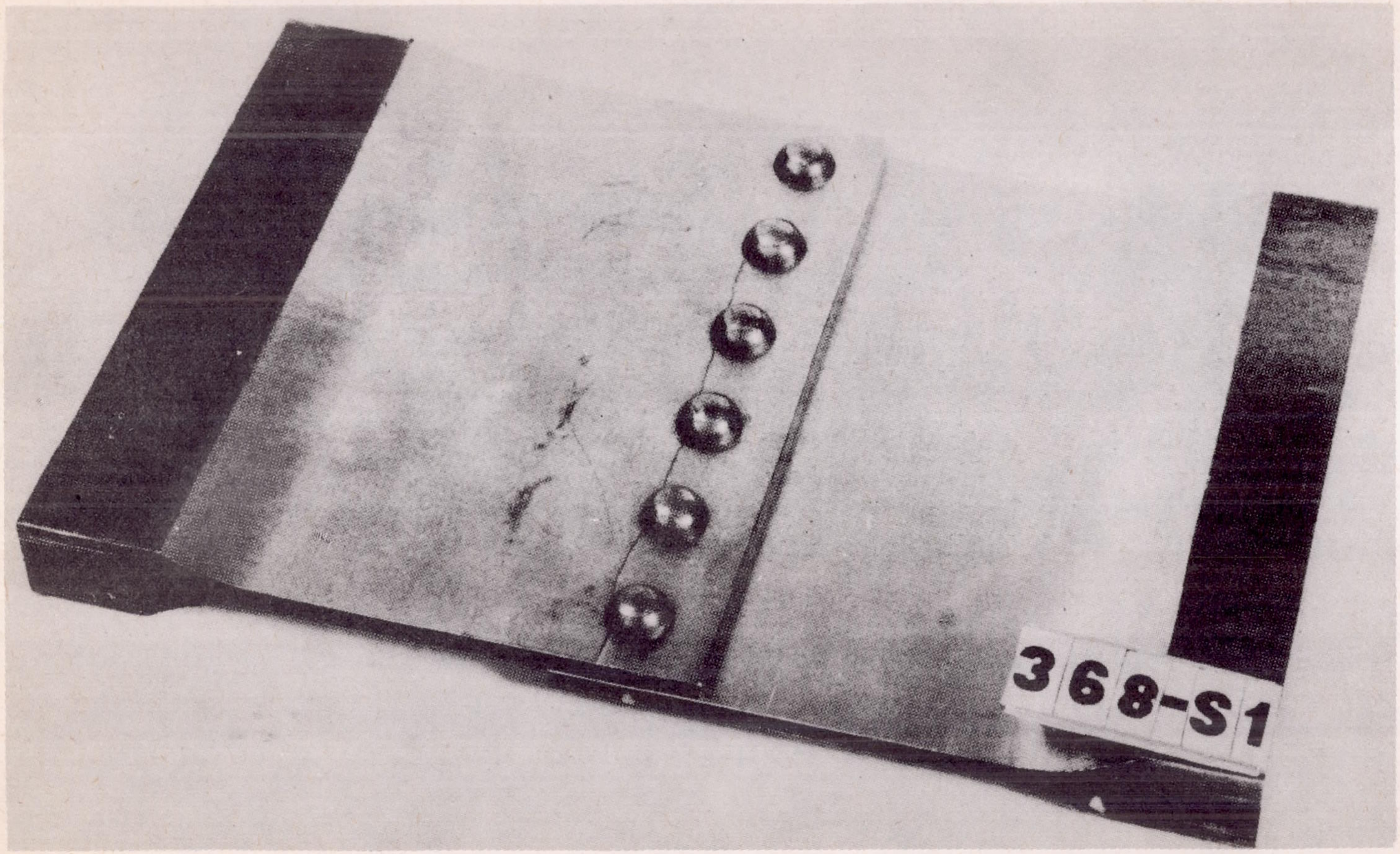


Figure 7.- Fracture of type S specimen showing failure in plate at edge of rivet heads.

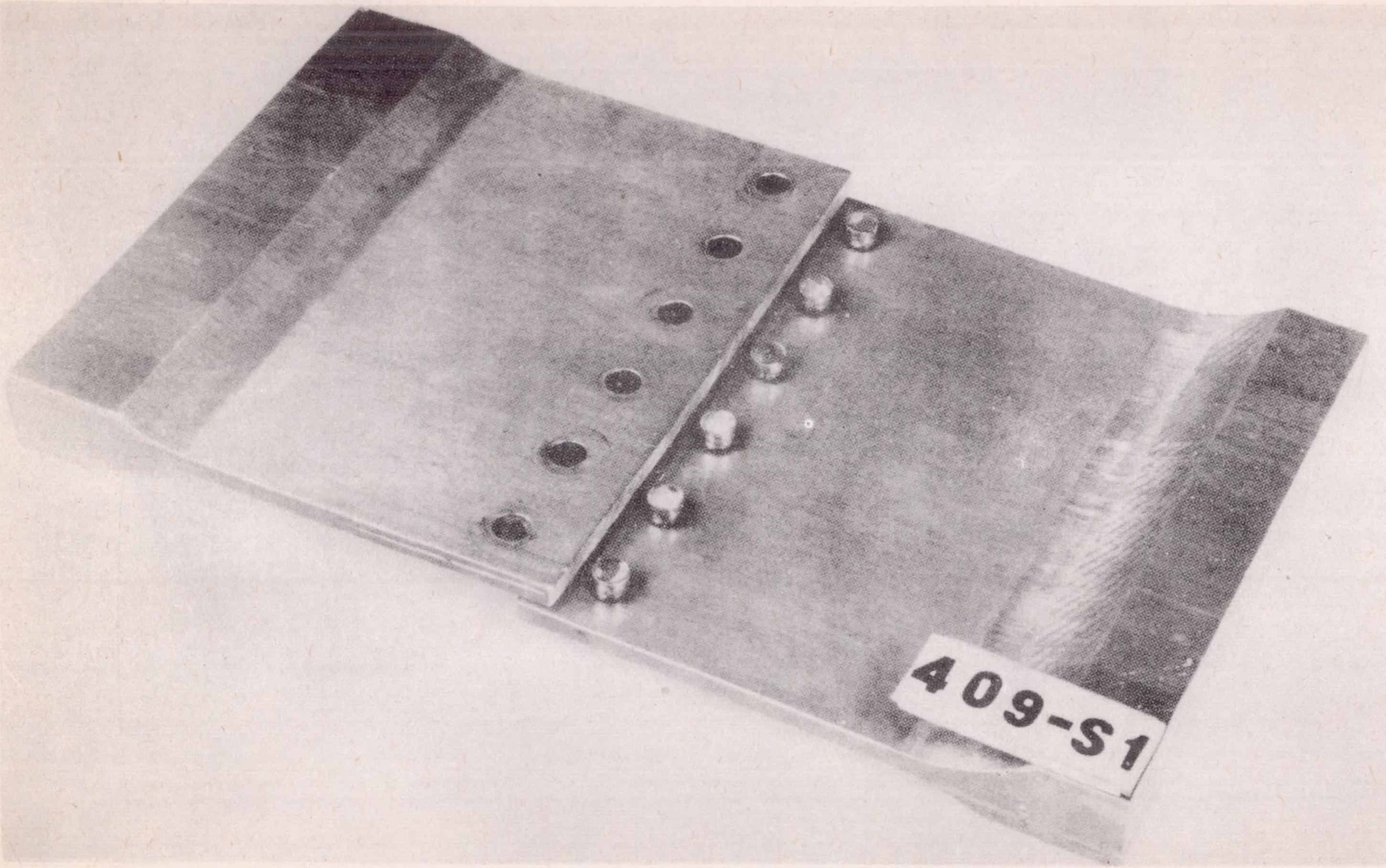


Figure 8.- Fracture of type S specimen. Rivet heads pried off during test.

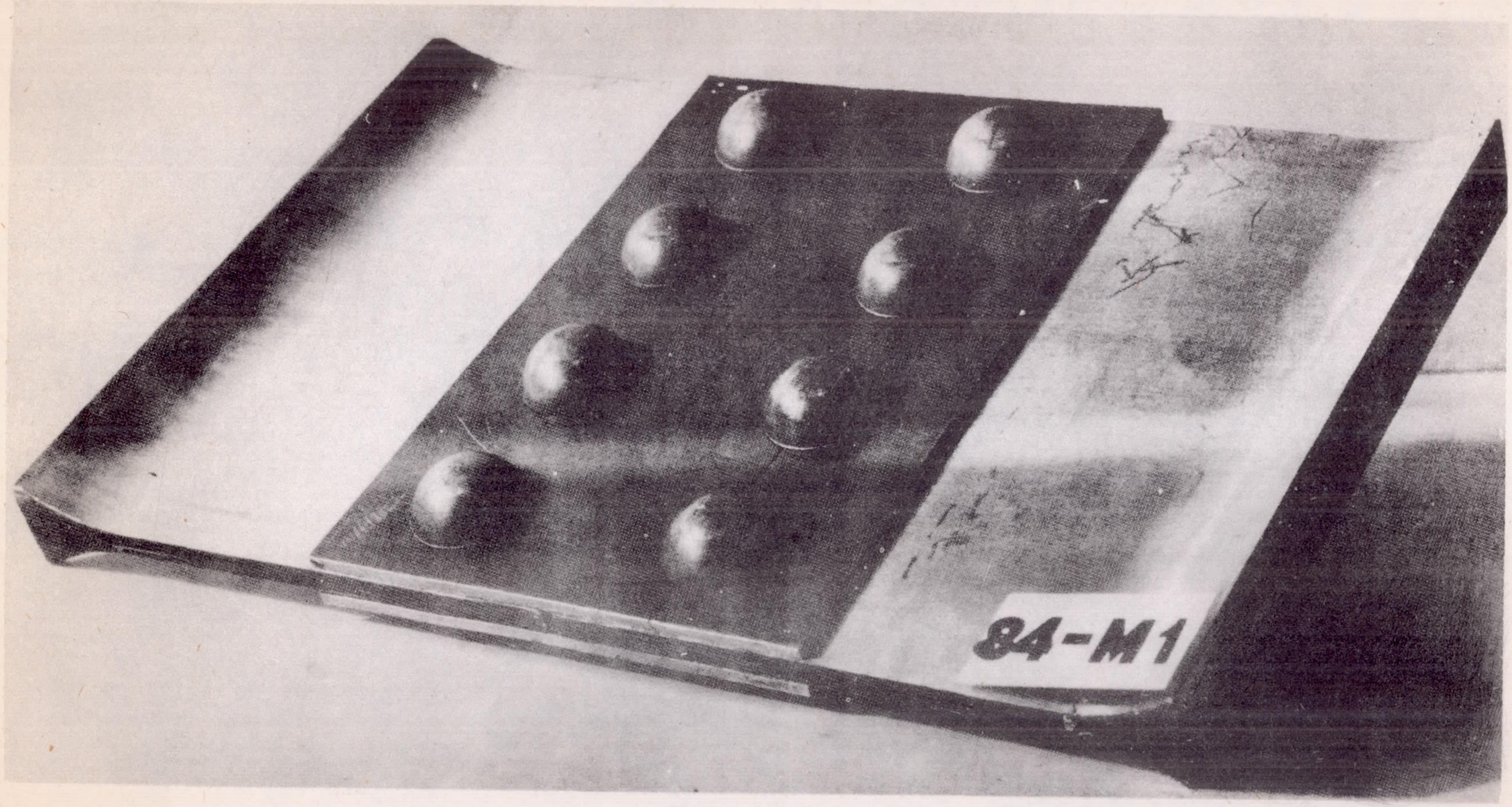


Figure 9.- Typical fracture of type M specimen with failure in cover plate.

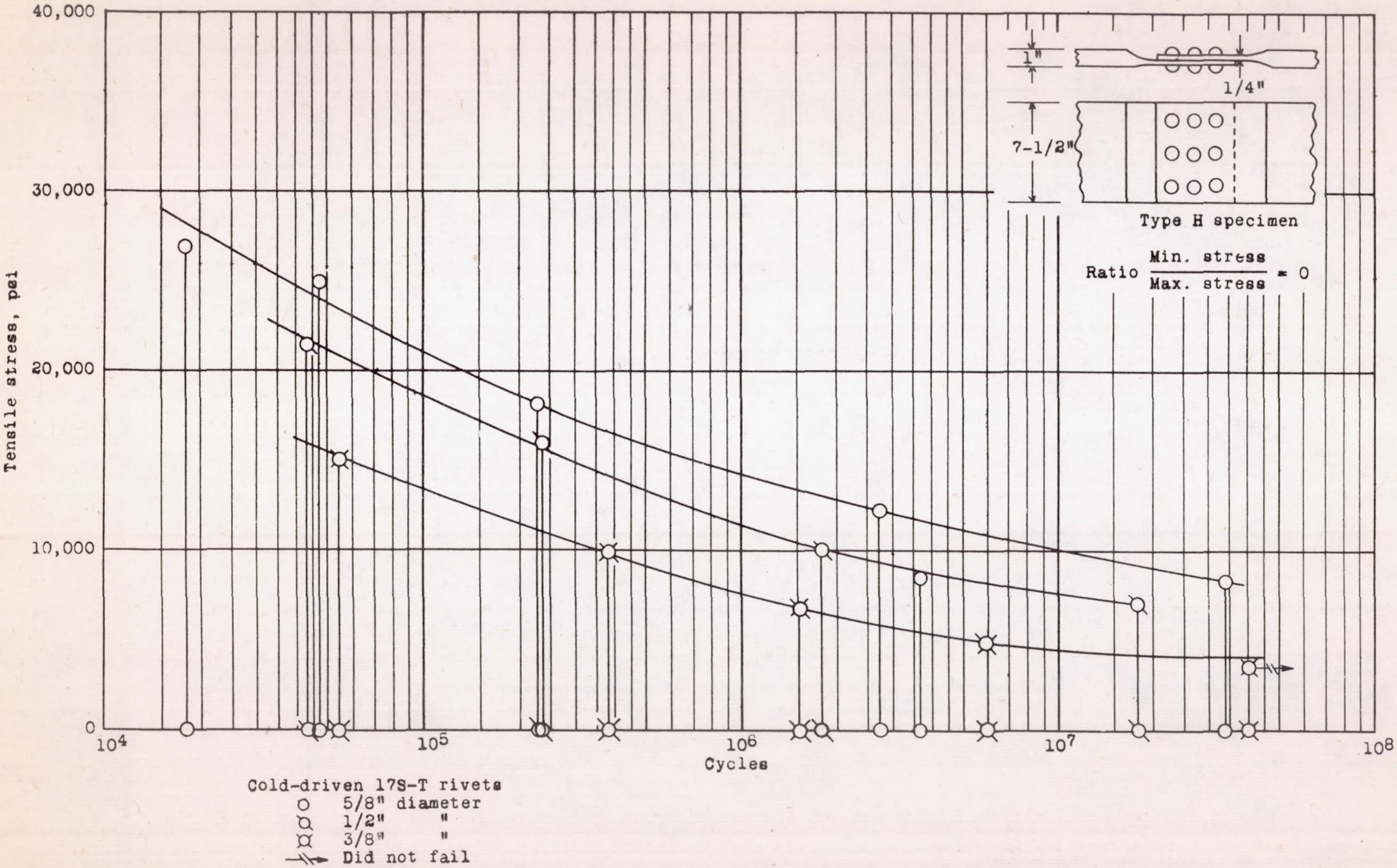


Figure 10.- Direct-stress fatigue curves for riveted joints. Type H, 17S-T plate, and 17S-T rivets.

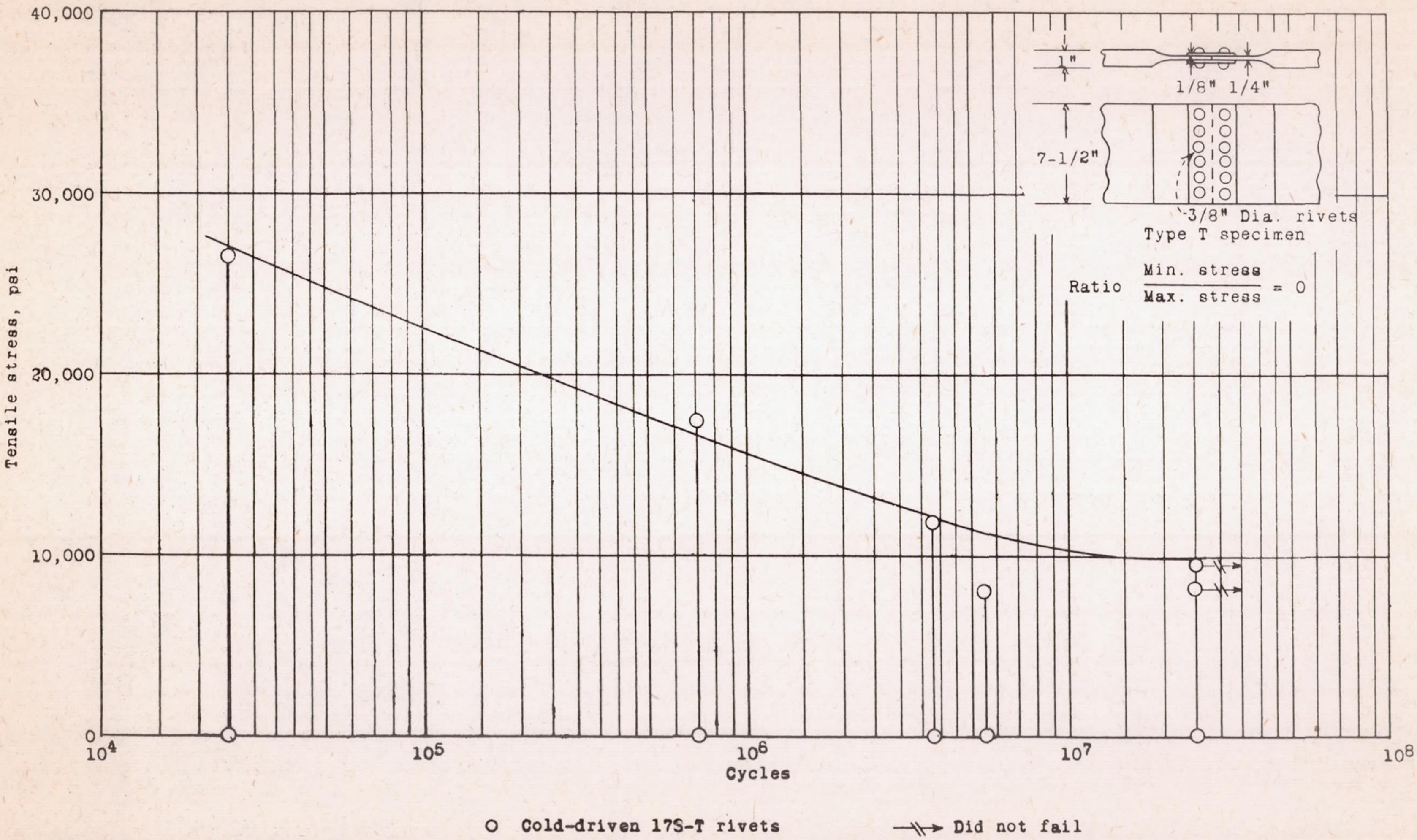


Figure 11.- Direct-stress fatigue curve of riveted joints. Type T, 17S-T plate, and 17S-T rivets.

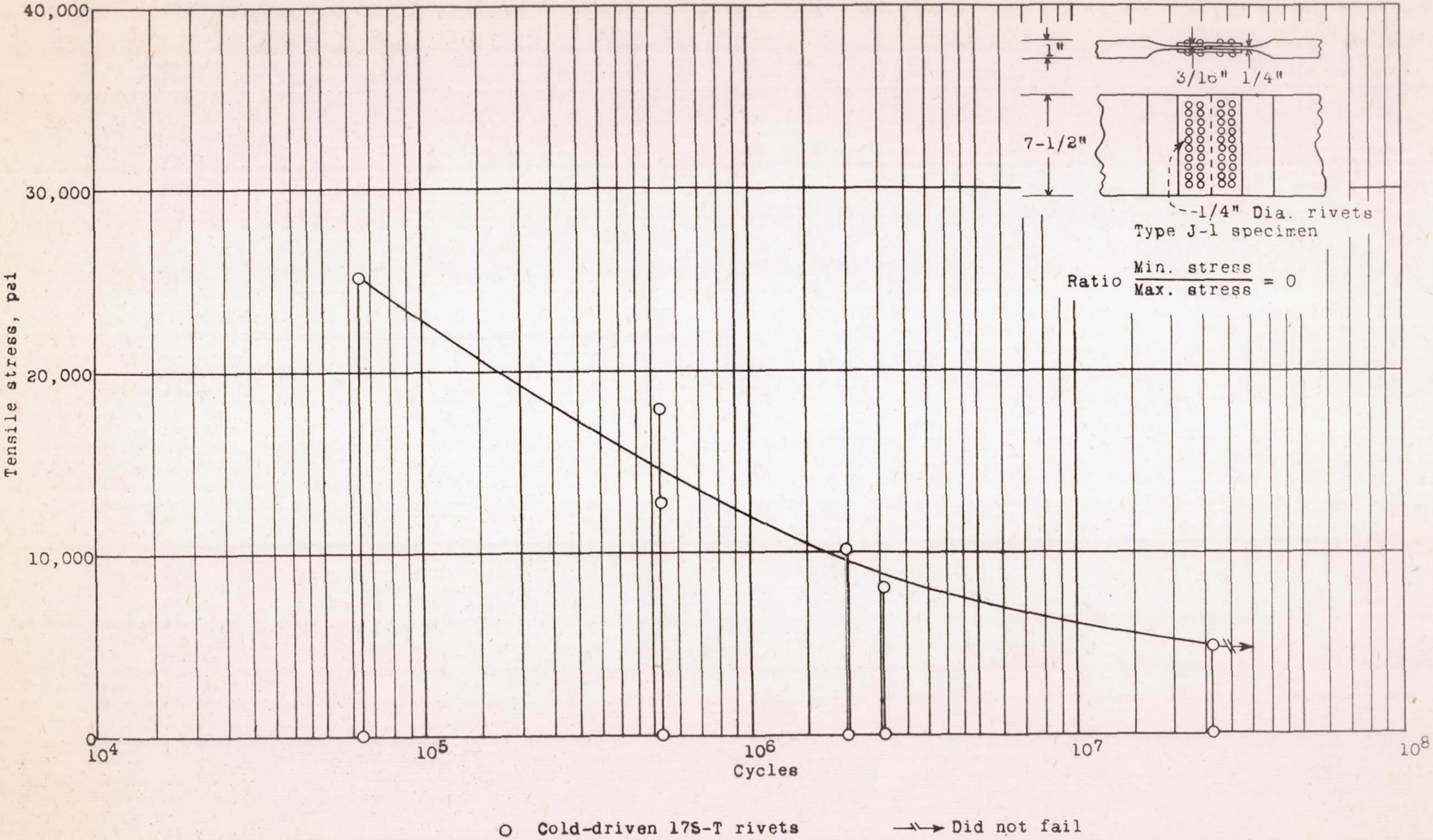


Figure 12.- Direct-stress fatigue curve of riveted joints. Type J-1, 17S-T plate, and 17S-T rivets.