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A Comparison of Rivet Shear Strengths Obtained from Two-Rivet Specimens and from Multi-Rivet Specimens at Room Temperature and 150°C

by

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A COMPARISON OF RIVET SHEAR STRENGTHS OBTAINED FROM TWO-RIVET SPECIMENS AND FROM MULTI-RIVET SPECIMENS AT ROOM TEMPERATURE AND 150°C

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SUMMARY

Comparative tests were made to investigate the strength per rivet obtained in a two-rivet tandem lap joint specimen and a multi-rivet lap joint specimen approximating to a realistic joint as used in aircraft. Tests were made on snaphead-riveted aluminium alloy specimens at room temperature, with and without prior soaking at temperature, and also at an elevated temperature of 150°C with prior soaking. The soaking condition used was 150°C for 1000 hours.

The tests showed that there is little difference in strength per rivet between the two types of specimen, but heat factors obtained for the proof conditions on the two-rivet specimen might be optimistic. No corrosion protection was applied and the results of these tests might be modified by the addition of an interlayer compound.

Replaces R.A.E. Tech Note No. Structures 360-A.R.C. 26393.

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ILLUSTRATIONS

1 INTRODUCTION

This paper gives the results of tests made to compare the static shear strength of snaphead rivets in a simple riveted lap joint specimen having two rivets in tandem, with that of rivets in a multi-rivet lap joint more representative of actual aircraft construction. The purpose of the tests was to check that design strength values obtained from the simpler two-rivet-in-tandem type of lap joint in aluminium alloy were acceptable.

The tests were made:-

(a) at room temperature, both with and without prior soaking of the specimens at 150°C for 1000 hours

(b) at 150°C, with prior soaking of the specimens at 150°C for 1000 hours.

The tests showed that rivet strengths in static shear obtained from the two-rivet lap-joint specimens did not differ significantly from those obtained from the multi-rivet lap joints, at both room temperature and 150°C, but that heat factors* obtained for the proof conditions on the two-rivet specimen might be optimistic.

2 TEST SPECIMENS AND TEST PROGRAMME

The two-rivet specimen is shown in Fig. 1, and the multi-rivet specimen in Fig. 2. Both types of specimen were constructed from 16 S.W.G. aluminium alloy sheet material to B.S. L.73, and 5/32" diameter aluminium alloy snaphead rivets to B.S. S.P.80 (B.S. L.86 rivet wire). Extracts from these specifications are given in Appendix 1.

Thirty six specimens of each type were prepared in such a way that the direction of test loading was transverse to the final rolling direction of the sheet material. No corrosion protection was applied to the joints before assembly.

The test programme is given in Table 1.

3 TEST EQUIPMENT

3.1 Test machines

The two-rivet specimens were tested at room temperature on the 0-3000 lb range of a 15,000 lb Denison test machine and at elevated temperature on the 0-2000 lb range of a 10,000 lb Mohr and Federhaff test machine.

The multi-rivet specimen tests at room and elevated temperatures were made on the 0-10 ton range of a 50 ton Avery test machine. All test machines were to Grade A of B.S.1610.

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* $$\text{Heat factor} = \frac{\text{Strength after exposure to elevated temperature}}{\text{Strength at room temperature}}$$

3.2 Furnace equipment for hot tests

The two-rivet joint specimens were tested in a Davall furnace, approximately $1\frac{1}{2}$" x 3" working cross-section and 8.5" deep. This furnace had separate heaters for the top and bottom halves, each separately controlled by a variable transformer. The gaps between the furnace and the specimen were plugged with asbestos in such a way that convection currents were reduced without introducing constraint on the specimen.

The multi-rivet specimens were tested in a "book" type furnace, fitted with two separate pairs of heating elements. The current to each pair could be independently adjusted. The furnace had slots on each side to accommodate the extensometer clamps. These slots were not sealed, but the gaps between the furnace and the specimen were plugged in the same way as for the two-rivet specimens.

3.3 Extensometers

The extension of the two-rivet specimens at room temperature was measured by an R.A.E. dial extensometer, with the dial gauge reading to 0.0001"; and at elevated temperature, a modified Lamb-type optical roller extensometer was used.

The extension of the multi-rivet specimen was measured by a special extensometer consisting of four clamps, two on each side of the specimen, spanning the joint at the edge of the sheet (Fig. 3). Dial gauges (reading to 0.0001") between each pair of clamps registered the extensions on each edge of the specimen. The mean of the readings from each side was taken to be the extension of the specimen. The validity of this assumption was investigated on a few specimens by making additional comparative measurements (with a Southern Instruments Limited "Magna Gage" inductance transducer) of the relative movement of two small brackets attached at the centre line, on one side of the specimen, one on each side of the lap.

4 METHOD OF TEST

4.1 Loading and extension

For both room and elevated temperature tests, the load was applied to each specimen in increments of 100 lb (reducing to 25 lb at high loads) for the two-rivet specimens, and in increments of 0.1 ton for the multi-rivet specimens. Extension measurements were made at each increment of load until the load corresponding to a total permanent joint extension of 4% of the nominal rivet diameter (the r_{20} proof value) had been exceeded. The load was then increased continuously until failure occurred, the failing load being recorded. The proof strengths were calculated on the assumption that the permanent set was equal to the offset of the load extension curve from the continuation of the linear part of the curve.

4.2 Heating of the specimens

Before any tests were made at elevated temperature, dummy specimens (not used in subsequent tests) were used to adjust the apparatus to the correct temperature distribution, as follows.

4.2.1. Two-rivet specimens

Three thermocouples, one at each end of the lap joint and one in the centre of the lap, were attached to the specimen, each thermocouple wire being independently "welded" to the specimen on the centre line. (See Fig. 1.) The voltage outputs of the thermocouples were measured on a potentiometer and the readings converted to temperature. The current in the windings of the furnace was adjusted so that the temperature distribution as indicated by the above thermocouples, was within the limits 150°C ± 3°C. During the tests, the temperature of each specimen was checked by thermocouples attached at the same positions as were used on the dummy specimen. The time taken for each specimen to reach a stable temperature of 150°C was about one hour.

4.2.2 Multi-rivet specimens

Five thermocouples, with each wire independently "welded" to the dummy specimen, were attached as follows. (See Fig. 2.)

(i) One thermocouple on the centre line of the specimen mid-way between the rivet rows.

(ii) Two thermocouples symmetrically placed about the centre line 4.5" apart, 2" above the rivets.

(iii) Two thermocouples symmetrically placed about the centre line 4.5" apart, 2" below the rivets.

As before, the voltage outputs of the thermocouples were measured on a potentiometer, the readings converted to temperature, and the currents in the furnace windings adjusted so that the temperature distribution, as indicated by the thermocouples, was within the limits of 150°C ± 3°C.

Each of the specimens used in the tests had three thermocouples attached, at the points shown in Fig. 2. These thermocouples were used to check the temperature of the specimens during test. The time for each specimen to reach a stable temperature of 150°C was about 1¼ hours.

5 DISCUSSION OF RESULTS

Table 2 gives the r_{10} and r_{20} proof loads and the ultimate load, R, for each specimen, and also the mean values and coefficients of variation for each group of results. Table 3 summarizes the results and gives the percentage difference in strength-per-rivet between the two-rivet and the multi-rivet joints.

Fig. 4 shows typical curves of load-per-rivet against extension for both types of specimen for each of the three test conditions. It may be noted that there is a marked difference in slope of these curves for the two types of specimen, due to the tension stress in the sheet portion of the specimen being higher in the multi-rivet specimens than in the two-rivet specimens. As, however, these tension stresses were below the elastic limit in all cases, and thus produced no permanent extension, this difference in slope does not affect the proof strength values obtained in the tests.

Fig. 5 shows curves of load against extension at room temperature for the multi-rivet specimen, with extensions measured both by dial gauges indicating extension at each side of the specimen, and also by an inductance transducer measuring extension at the centre of the specimen. The mean extension obtained from the readings of the two dial gauges did not entirely agree with the extension shown by the inductance transducer, but the proof strengths derived from the two sets of measurements were in good agreement, so that it is considered that the readings of the dial gauges are valid for the purposes of this investigation.

Fig. 6 is a pictorial summary of the results and shows that in general for each test condition the difference between the strengths-per-rivet obtained from the two types of specimen is small.

At room temperature, with no prior heat soaking, the multi-rivet specimen was the stronger, particularly for the proof conditions. After heating for 1000 hours at 150°C, the tests at room temperature showed that there was little difference in strength between the two types of specimen but, for the proof conditions, the two-rivet specimen had higher heat factor values than the multi-rivet specimen. Testing at 150°C after a similar heating period gave a small strength advantage to the two-rivet specimen and, for the proof conditions, heat factors higher than those for the multi-rivet specimen. For both test conditions after prior heat soaking, the heat factors for the ultimate condition were similar for both types of joint. In all the tests the coefficients of variation were quite low for this type of test.

The strength differences between the two types of joint were small. However, the stronger proof values changing from one type of specimen to the other with exposure to elevated temperature had a more marked effect on the heat factors. A possible explanation is that at room temperature without prior heat soaking, there is more clamping between the two sheets of the multi-rivet specimen giving enhanced proof values but not affecting the ultimate strength. There is a reduction in this clamping pressure after exposure to elevated temperature, possibly due to creep in tension of the rivets. This is more marked in the case of the multi-rivet specimens thereby giving lower heat factors than on the two-rivet specimen. The heat factors greater than unity for the proof conditions indicate that the sheet material as recieved was not fully aged. This is a normal condition of supply and does not affect the validity of the comparisons made between the two types of specimen.

6 CONCLUSIONS

The differences in strength-per-rivet between two-rivet and multi-rivet joint specimens for the test conditions investigated were small. For the tests involving prior heat soaking, the heat factors for the proof conditions were lower for the multi-rivet specimen than for the two-rivet specimen.

For the types of joint investigated the differences are sufficiently small to warrant the use of rivet shear strength data obtained from the two-rivet type of joint in the design of multi-rivet joints within the range of temperature used in the tests. Presentation of these data in heat factor form could be optimistic. No corrosion protection was applied and the results of these tests might be modified by the addition of an interlayer compound.

The strength values given in this Note should not be used as design strengths, as they were obtained from tests on material in an unknown age-hardened condition, and may therefore be optimistic.

SYMBOLS

R = Failing load per rivet* in lb

r_{10} = Proof load per rivet in lb to give a permanent set of the whole joint equal to 2 per cent of the rivet diameter.

r_{20} = Proof load per rivet in lb to give a permanent set of the whole joint equal to 4 per cent of the rivet diameter.

$\bar{x}$ = Mean strength.

n = No. of results.

v = Coefficient of variation $= \frac{1}{\bar{x}}\sqrt{\frac{\Sigma(x-\bar{x})^2}{(n-1)}}$

* = The load per rivet is taken as

$$= \frac{\text{Total load on the specimen}}{\text{Number of rivets in the joint}}$$

APPENDIX 1

EXTRACTS FROM B.S. SPECIFICATIONS L.73 AND L.86

L.73

Aluminium coated aluminium - copper - magnesium - silicon - manganese alloy sheet and strips having the following chemical composition:-

Copper	not less than 3.8% nor more than 4.8%
Magnesium	" " " 0.55% " " " 0.85%
Silicon	" " " 0.6% " " " 0.9%
Iron	not more than 1.0%
Manganese	not less than 0.4% nor more than 1.2%
Nickel	not more than 0.2%
Zinc	" " " 0.2%
Lead	" " " 0.05%
Tin	" " " 0.05%
Titanium and/or Chromium	" " " 0.3%
Aluminium	the remainder

Solution treated at 505 ± 5°C and quenched in water not exceeding 40°C. Artificially aged at between 160°C and 190°C.

Mechanical properties:- 0.1% proof stress not less than 21 tons/sq in. (thicker than 25 S.W.G.)
Ultimate stress not less than 27 tons/sq in.
Elongation not less than 8%.

L.86

Aluminium - copper - magnesium alloy wires for solid, cold forged rivets having the following chemical composition:-

Copper	not less than 1.5% nor more than 3.0%
Magnesium	" " " 0.2% " " " 0.5%
Silicon	not more than 0.7%
Iron	" " " 0.7%
Manganese	" " " 0.5%
Nickel	" " " 0.2%
Zinc	" " " 0.1%
Lead	" " " 0.05%
Tin	" " " 0.05%
Titanium	" " " 0.3%
Aluminium	the remainder

Supplied annealed and subsequently cold drawn to secure a reduction in cross-sectional area of not less than 20% and not more than 40%.

Solution treated at 495 ± 5°C and quenched in water not exceeding 40°C. Naturally aged at room temperature for not less than 48 hours.

Mechanical properties:- Ultimate stress not less than 17 tons/sq in.

TABLE 1

TEST PROGRAMME

Specimen No.	Soaking temperature	Soaking time	Test temperature
TWO-RIVET SPECIMENS			
1 - 12	150°C	1000 hrs	150°C
13 - 24	150°C	1000 hrs	Room temp
25 - 36	None		Room temp
MULTI-RIVET SPECIMENS			
1 - 12	150°C	1000 hrs	150°C
13 - 24	150°C	1000 hrs	Room temp
25 - 36	None		Room temp

TABLE 2

VALUES OF r_{10} AND r_{20} PROOF LOADS, AND FAILING LOAD, R, FOR ALL SPECIMENS

	Soaked 150°C for 1000 hrs test at 150°C				Soaked 150°C for 1000 hrs test room temp				No heat soaking test at room temp			
	Specimen No.	Proof r_{10}	Proof r_{20}	Failure R	Specimen No.	Proof r_{10}	Proof r_{20}	Failure R	Specimen No.	Proof r_{10}	Proof r_{20}	Failure R
Two-rivet specimens	1	Used for temp distbn		620 lb	13	586 lb	640 lb	670 lb	25	525 lb	582 lb	660 lb
	2	Insufficient readings		540	14	568	608	650	26	550	620	695
	3	485	522	537	15	570	610	665	27	560	610	695
	4	500	505	507	16	560	596	654	28	530	575	670
	5	Insufficient readings		507	17	566	604	650	29	550	585	695
	6	500	505	540	18	560	620	655	30	520	565	685
	7	490	502	550	19	582	618	660	31	530	575	670
	8	490	522	535	20	590	616	665	32	535	590	690
	9	487	500	500	21	596	620	670	33	550	595	690
	10	486	515	550	22	592	628	675	34	535	585	685
	11	462	500	550	23	584	608	655	35	535	588	690
	12	492	502	545	24	580	612	660	36	530	580	680
	Mean load per rivet	487 lb	508 lb	539 lb		578 lb	615 lb	659 lb		537 lb	587 lb	684 lb
	V%	2.3	1.8	5.7		2.2	1.9	1.3		2.3	2.6	1.7
Multi-rivet specimens	1	Used for temp distribution			13	585 lb	608 lb	660 lb	25	569 lb	605 lb	695 lb
	2	448 lb	476 lb	498 lb	14	589	620	660	26	595	635	700
	3	474	501	520	15	595	624	671	27	586	620	690
	4	467	490	530	16	582	605	660	28	564	609	695
	5	467	490	537	17	573	595	640	29	609	640	700
	6	461	481	520	18	571	590	638	30	574	611	677
	7	Extensometer malfunction		525	19	590	619	660	31	585	624	683
	8	Pre-stressed cold and at 150°C		543	20	569	595	638	32	555	600	676
	9	459	481	525	21	582	608	671	33	578	625	695
	10	Specimen over heated to 170°C. Controller malfunction			22	597	624	676	34	574	602	683
	11	470	490	530	23	562	585	633	35	560	595	674
	12	466	485	517	24	573	594	644	36	574	608	677
	Mean load per rivet	464 lb	487 lb	523 lb		581 lb	605 lb	655 lb		577 lb	617 lb	687 lb
	V%	1.7	1.6	2.3		1.9	2.3	2.3		2.6	2.3	1.4

V = Coefficient of variation

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TABLE 3

COMPARISON OF MEAN r_{10} AND r_{20} PROOF LOADS, AND FAILING LOADS R FOR THE TWO TYPES OF SPECIMEN

	Proof load r_{10}			Proof load r_{20}			Failing load R		
Soaking temp	150°C		Not soaked	150°C		Not soaked	150°C		Not soaked
Soaking time	1000 hours			1000 hours			1000 hours		
Test temp	150°C	R.T.	R.T.	150°C	R.T.	R.T.	150°C	R.T.	R.T.
Two rivet specimen	487 (0.91)	578 (1.08)	537	508 (0.87)	615 (1.05)	587	539 (0.79)	659 (0.96)	684
Multi-rivet specimen	464 (0.80)	581 (1.01)	577	487 (0.79)	605 (0.98)	617	523 (0.76)	655 (0.95)	687
Difference	+23	-3	-40	+21	+10	-30	+16	+4	-3
Difference as a percentage of the mean strength per-rivet of the two-rivet specimens.	+4.7	-0.5	-7.4	+3.9	+1.6	-5.1	+3.0	+0.6	-0.4

R.T. = Room temperature
Figures in brackets are heat factors

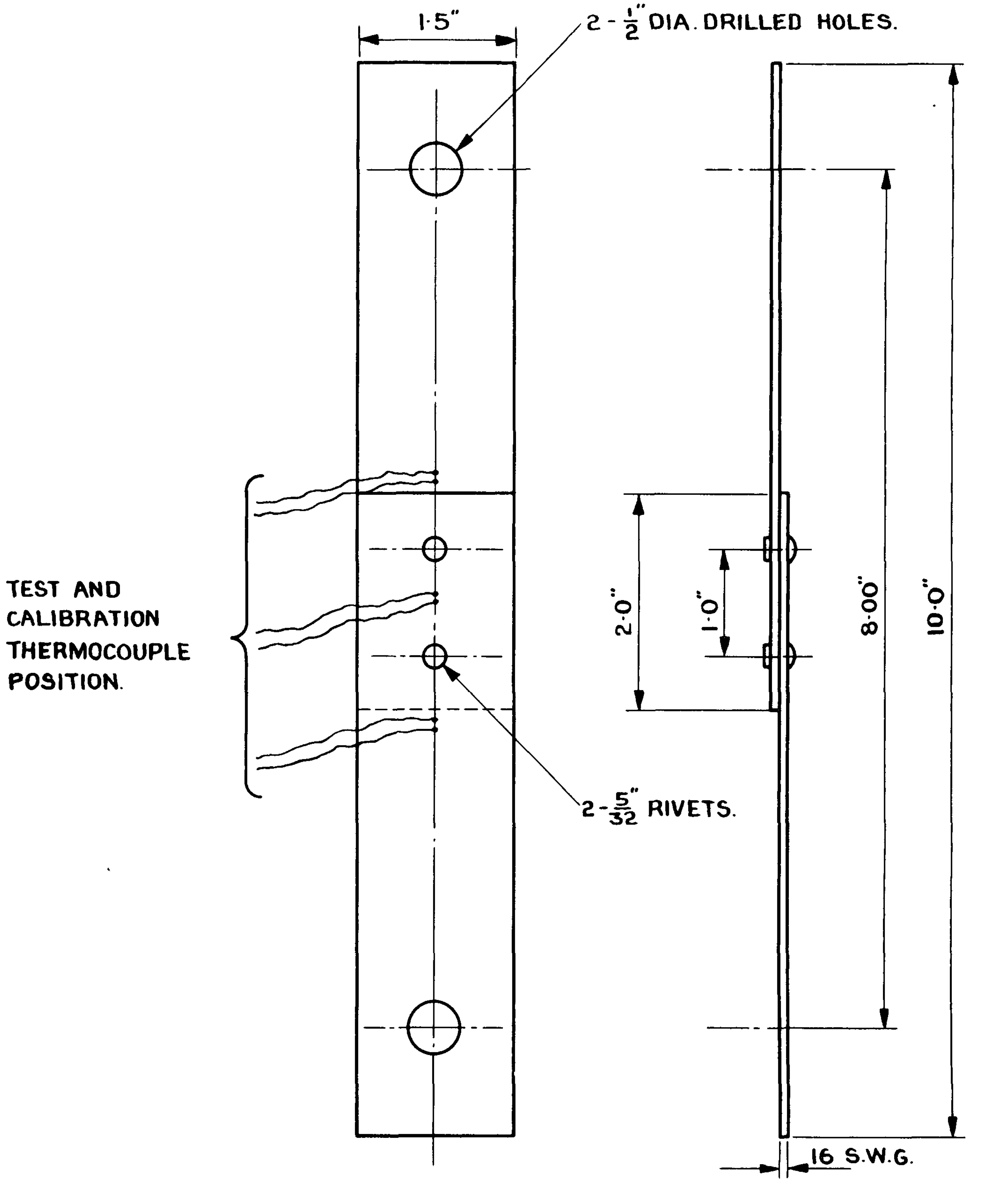

FIG. 1. TWO-RIVET TEST SPECIMEN

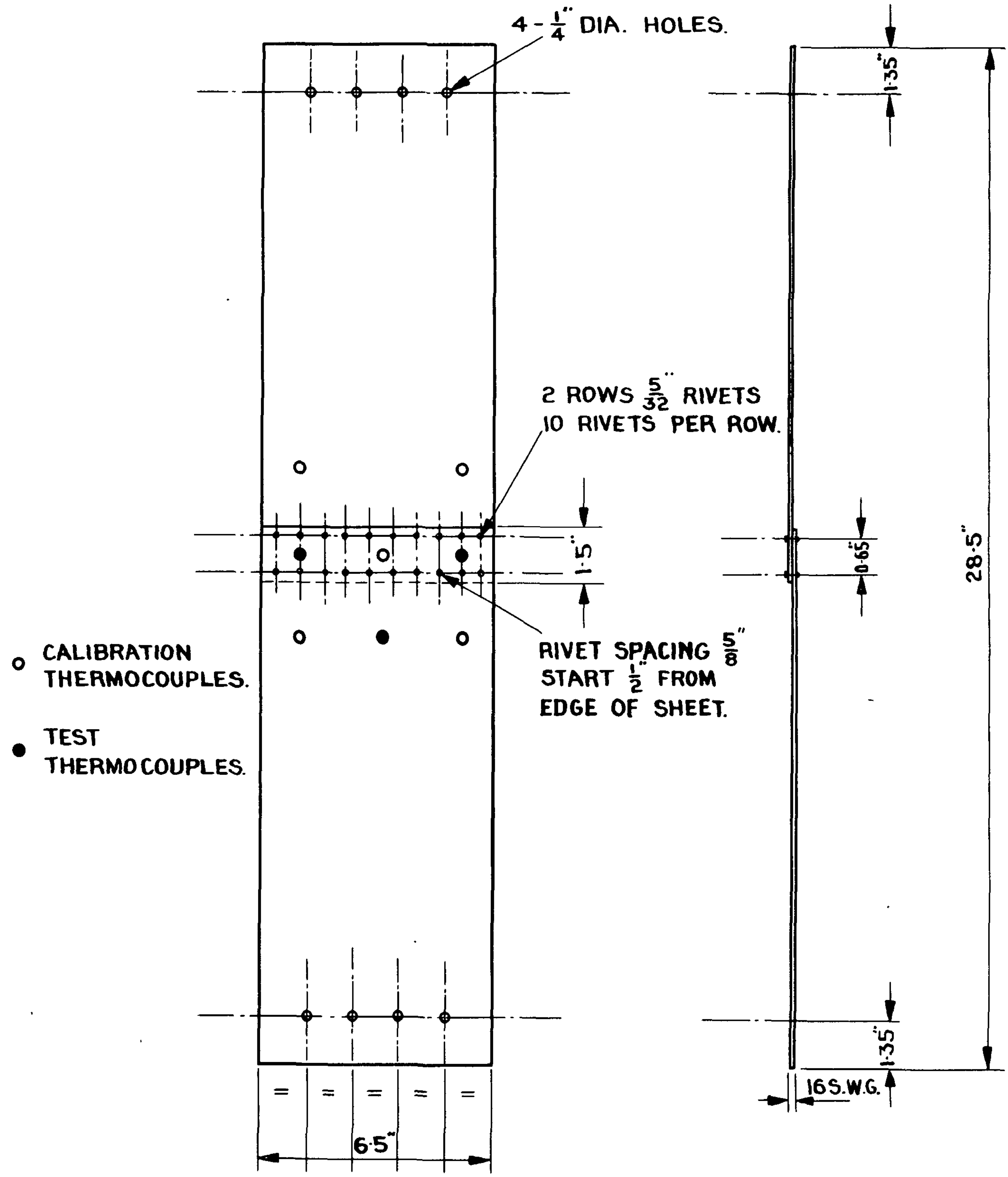

FIG. 2. MULTI-RIVET TEST SPECIMEN

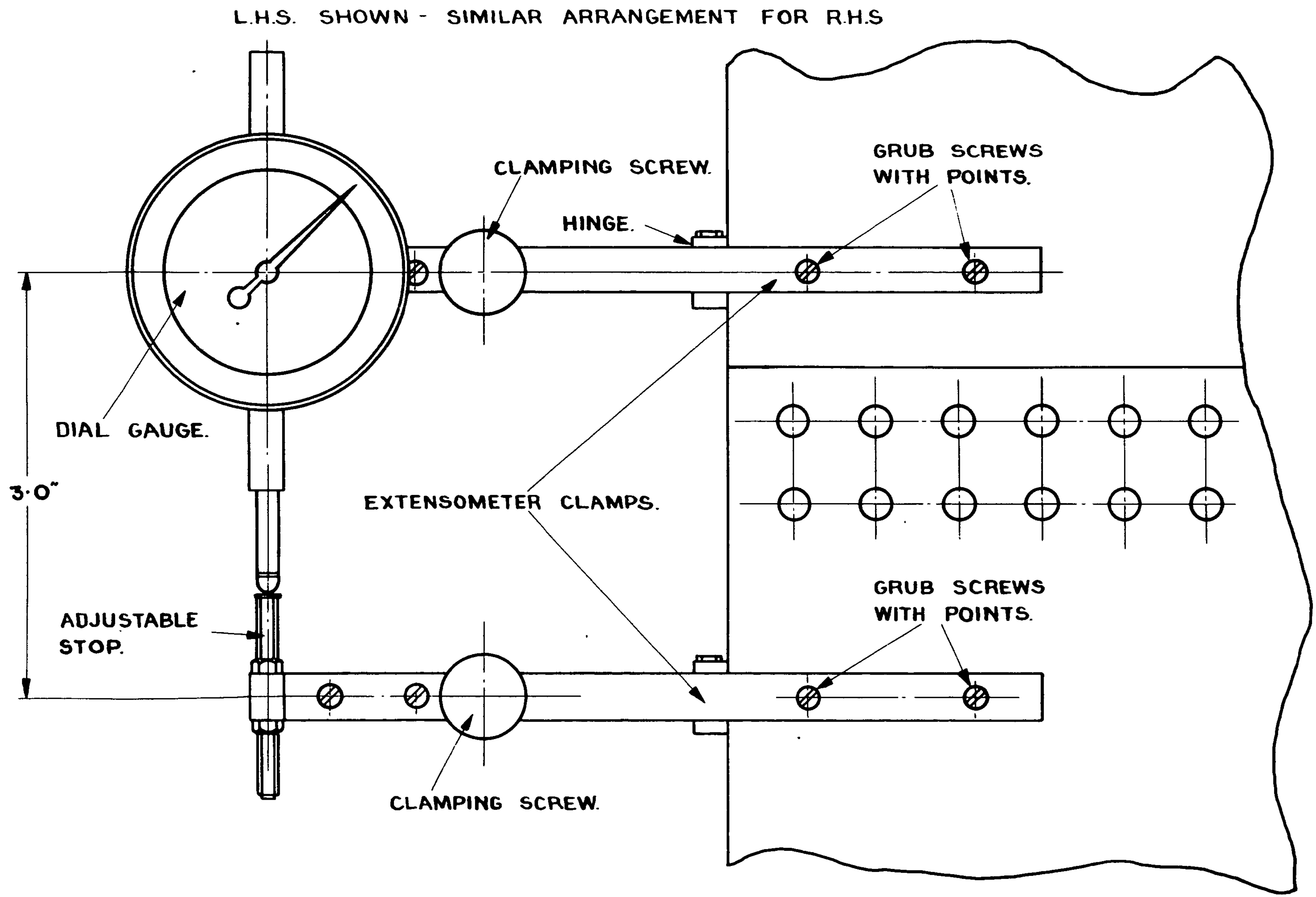

FIG. 3. EXTENSOMETER ARRANGEMENT FOR MULTI-RIVET SPECIMENS

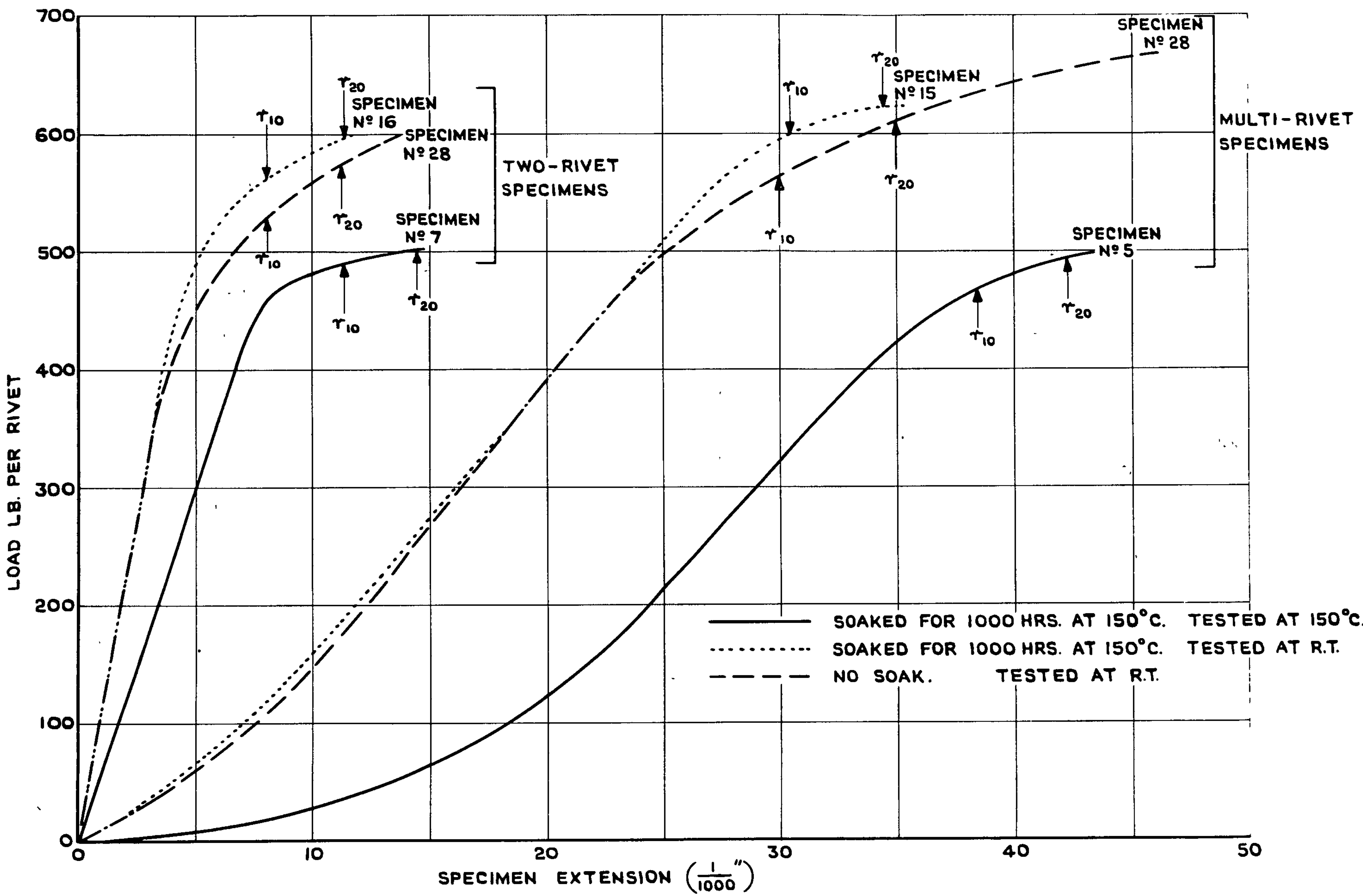

FIG. 4. TYPICAL LOAD—EXTENSION CURVES FOR TWO-RIVET AND MULTI-RIVET SPECIMENS.

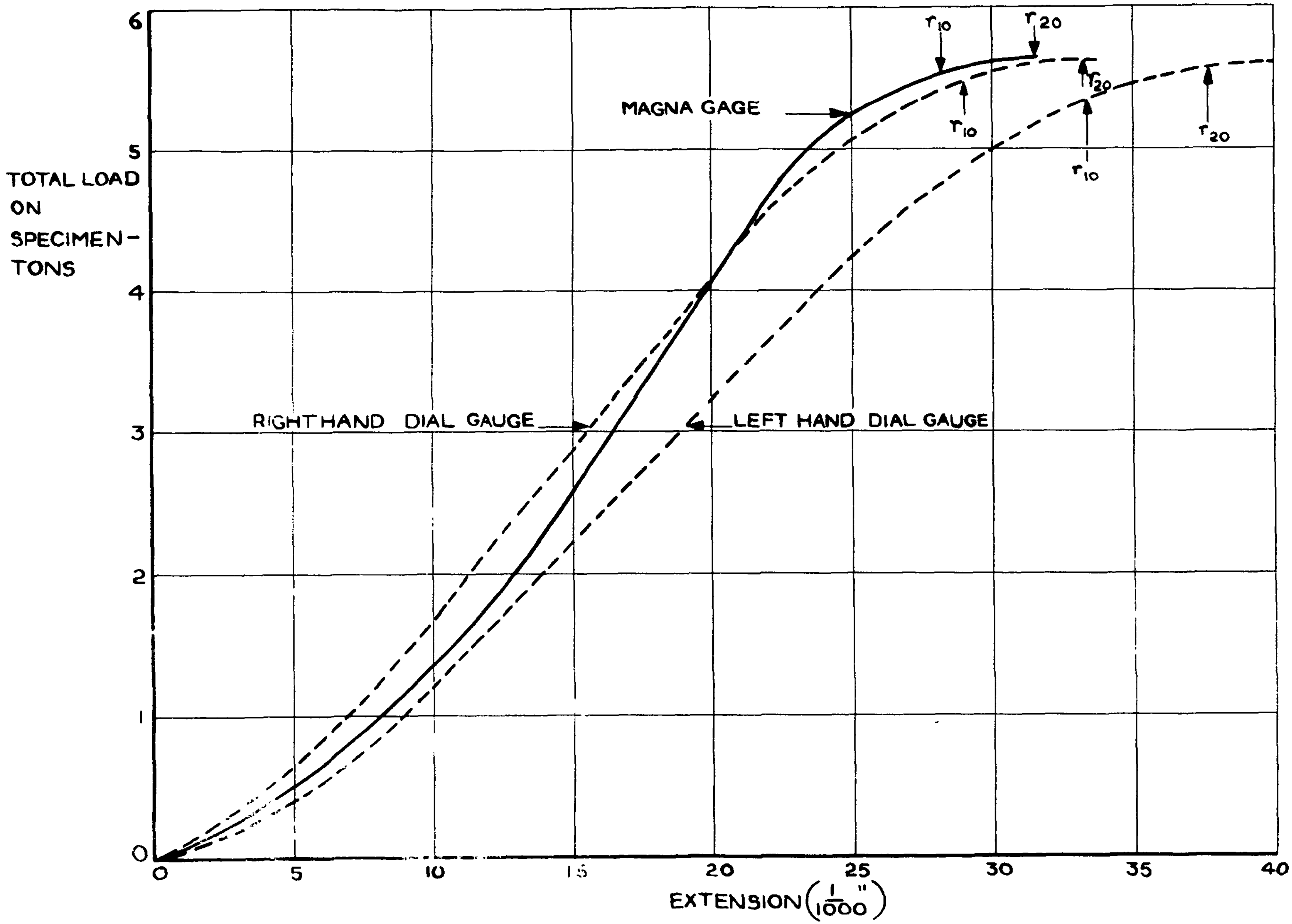

FIG. 5 LOAD EXTENSION CURVES FOR MULTI-RIVET SPECIMEN Nº15 SHOWING 'MAGNA GAGE' CURVE.

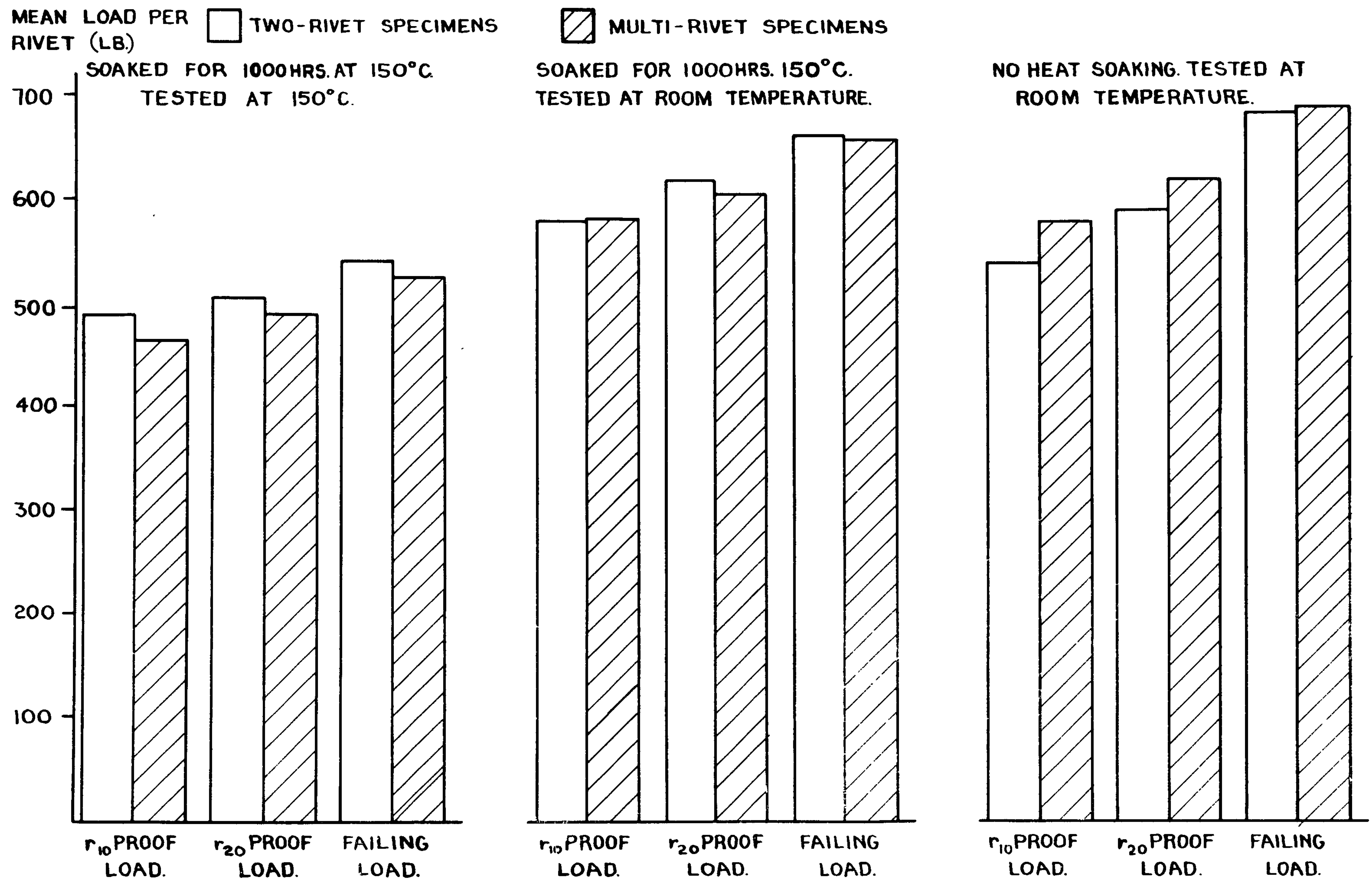

FIG. 6. COMPARISON BETWEEN STRENGTHS FOR TWO-RIVET AND MULTI-RIVET SPECIMENS.

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