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# Static tension tests of bolted lap joints, August 1962

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STATIC TENSION TESTS  
OF BOLTED LAP JOINTS

by

Robert A. Bendigo  
John W. Fisher  
John L. Rumpf

FRITZ ENGINEERING  
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This work has been carried out as part of the Large Bolted Joints Project sponsored financially by the Pennsylvania Department of Highways, the Department of Commerce - Bureau of Public Roads and the American Institute of Steel Construction. Technical guidance is provided by the Research Council on Riveted and Bolted Structural Joints.

Fritz Engineering Laboratory  
Department of Civil Engineering  
Lehigh University  
Bethlehem, Pennsylvania

August 1962

Fritz Engineering Laboratory Report No. 271.9

LEHIGH UNIVERSITY  
BETHLEHEM, PENNSYLVANIA

DEPARTMENT OF CIVIL ENGINEERING  
FRITZ ENGINEERING LABORATORY

288.1

September 7, 1962

Members of Committee 9 - RCRBSJ, E. J. Ruble, Chairman  
"Static Strength of Bolted Structural Steel Joints"

Members of Committee 10 - RCRBSJ, J. L. Rumpf, Chairman  
"Static Strength of Bolted High strength Steel Joints"

Messrs: R. W. Arner            N. G. Hansen            J. L. Rumpf  
         R. Belford            T. R. Higgins           T. W. Spilman  
         J. Giliberto           W. H. Munse            G. S. Vincent  
         F. E. Graves           E. J. Ruble

Fritz Laboratory Report 271.9

Static Tension Tests of Bolted Lap Joints

Gentlemen:

Enclosed herewith is a copy of the above named report for your files. We would be pleased to receive any comments or suggestions you have concerning the report.

The report deals with the performance and behavior of bolted lap joints. The results of these tests have been discussed at various committee meetings in the past.

We intend to include a summary of this material with material from reports 271.8 and 271.15 in a report for publication on "Long Bolted Joints". The "Long Bolted Joints" report is now being prepared and together with the report on compact joints (ASCE paper 2523) will complete the coverage of all work on joints of A-7 steel and A325 bolts.

Sincerely yours

John W. Fisher

Lynn S. Beedle

JWF/va

cc: Messrs: C. D. Jensen            K. Jensen            E. L. Erickson  
             J. L. Stinson            J. L. Durkee           F. H. Dill  
             A. Schwartz            A.L.R. Sanders       J. J. Higgins  
             R. T. Foreman           R. M. Hansen       G. S. Paxson  
             J. H. Swanberg           R. E. Bollen       R. B. Alexander  
             F. N. Wray               J. N. Clary

STATIC TENSION TESTS

OF BOLTED LAP JOINTS

DEPARTMENT OF CIVIL ENGINEERING  
FRITZ ENGINEERING LABORATORY  
LEHIGH UNIVERSITY  
BETHLEHEM, PENNSYLVANIA

SYNOPSIS

The results of tests of four large lap splices connected by two lines of 7/8 inch A325 bolts are reported herein. The major variable in the test program was the joint length. Rotation of the connection due to eccentricity was restrained by an external bracing system.

The tests of the lap splices are compared with the behavior and performance of the double shear tension splices. The results indicate that a lap splice can be considered equivalent to half of a double shear splice of similar dimensions, materials and number of bolts.

INTRODUCTION

Single shear lap joints are simple in their construction but they are generally avoided by engineers because their inherent eccentricity causes them to bend under load. The effect of the combined bending and axial stresses is particularly critical at the net section through the first row of holes. The bending also

complicates the behavior of the fasteners causing a tensile component in addition to the usual shearing component. Furthermore, clearance fit fasteners, such as bolts, tend to cock in the holes presenting an effective single shear area somewhat greater than the nominal shank area.

When lap joints are used designers usually minimize the bending effect by providing restraining diaphragms that restrict the rotation of the joint. The restraints may or may not be an integral part of the connected member. For example, WF bridge hanger connections have restraint provided by the beam web. Although the connection of one flange to the gusset plate is eccentric in itself, the connection to the other flange opposes this eccentricity making the combined unit symmetrical with respect to the beam centerline. If the hanger is built up of four angles, the diaphragm usually consists of a plate perpendicular to gusset plates and limited to the region of the connection.

Traditionally specifications have assigned to rivets a single shear value equal to one half of that for double shear. However, prior to the issuance of the 1960 specifications for structural joints using ASTM A325 bolts<sup>(1)</sup> it seemed advisable to have some experimental confirmation of this relationship for high strength bolts. Accordingly, static tension tests were conducted on four lap joints consisting of one inch thick plates and two lines of 7/8" diameter A325 bolts with from two to ten bolts per line. This was done at a minimum of expense by altering duplicate butt joints from another series of tests.

During testing an external bracing system was employed to reduce the bending of the joint and thus simulate the more usual and desirable practice discussed above.

DESCRIPTION OF TEST JOINTS

1. Design

Tests of compact butt joints<sup>(2)</sup> of A7 plate and A325 bolts have indicated that a balanced ultimate strength design exists when the joint is proportioned for a tension-shear ratio of 1.00/1.10. Long butt joints<sup>(3,4)</sup> designed on that basis showed that balanced design does not exist in longer joints because the non-uniform distribution of load among the bolts causes end bolts to fail "prematurely". Duplicate joints from the latter test series (D Series - Part a) were altered to produce the lap joints in this report.

As the main plate of the butt joint was composed of two one inch plates, it was possible to split the joint lengthwise and provide two lap joints, each consisting of one of the main plates and one of the original one inch splice plates. In this fashion butt joint D102 was disassembled to provide lap joint L10 having two lines of ten bolts and a tension-shear ratio of 1.00/1.10. The other half of D102 was altered by sawing off 3 rows of bolts giving joint L7 with 7 bolts in line. As the plate width was not changed the nominal T/S ratio of L7 became 1.00/1.57. In a like manner joints L2 and L5 were obtained by splitting and removing holes from butt

joints D32 and D62. The resulting nominal T/S ratios were 1.00/1.32 and 1.00/1.65 respectively. These ratios, differing from the balanced design ratio of 1.00/1.10, were considered satisfactory in this case because they insured bolt failures during test.

Complete details and nominal dimensions are shown in Fig. 1.

## 2. Material Properties

Plate - Mechanical properties of the steel plate were determined by tests of standard coupons of as-rolled thickness and 1-1/2 inch width. Details of the testing procedure and values of individual coupon tests are reported in Ref. 2. Ostensibly the material was to have been structural carbon steel meeting the requirements of ASTM A7 but it was found to be below the minimum specified yield point. The mean values and standard deviations of yield points and ultimate strength are as follows:

<u>No. of Coupons</u>	<u>Static Yield Point</u>		<u>Yield Point</u>		<u>Ult. Strength</u>	
	<u>Mean</u>	<u>Std.Dev.</u>	<u>Mean</u>	<u>Std.Dev.</u>	<u>Mean</u>	<u>Std.Dev.</u>
16	28.4 ksi	1.32 ksi	30.1 ksi	1.28 ksi	60.0 ksi	0.93 ksi

The mean elongation was 33.2%.

Bolts - The 7/8" bolts, designated L-lot, had regular semi-finished hexagon heads and were 3-1/2 inches long under head. The 2 inch rolled thread length did not extend into the shearing plane of the joint. Quenched and tempered washers were used under both

head and nut. The nuts were heavy semi-finished hexagon nuts.

The bolts were made to approximately the minimum requirements of ASTM A325. Direct-tension and torque-tension calibration tests were conducted on random samples of the bolts to establish their tension-elongation characteristics. Descriptions of these tests are reported in Ref. 5. Results are plotted in Fig. 2.

Tests were conducted to determine the single shear strength of individual bolts in order to have a basis for comparison with the bolts in the large joints. A test jig was fabricated as shown in Fig. 3. Bolts were inserted in the jig and pretensioned to an elongation equal to the average elongation of bolts in the large joints. The resulting specimens were tested in tension at a speed of 0.05 inches per minute. The unrestrained length of plate between the testing machine grips and the bolts apparently was short enough to prevent significant bending. The average ultimate shear stress was  $\tau_1 = 83$  ksi. The ratio of ultimate shear stress to the ultimate tensile stress was,  $\tau_1/\sigma = 0.70$ , which is comparable to the ratio for A325 bolts tested in double shear.<sup>(6)</sup>

### 3. Fabrication and Assembly

The fabrication of the original butt joints was done at the Bethlehem Steel Company's fabricating shops in Bethlehem.<sup>(3)</sup> The alterations were made at the Fritz Laboratory. Being made from duplicate joints of the D-Series Part a, the faying surfaces of the lap joints also were devoid of mill scale, and quite shiny as described in Ref. 3.



The joints were assembled at the Fritz Laboratory, by a field erection crew of the Bethlehem Steel Company. The turn-of-nut procedure<sup>(7)</sup> was used to install the bolts. All nuts were tightened 1/2 turn from "snug" and the fitting-up bolts received approximately 1/16" additional turn.

The initial clamping force of the bolts in the joints was estimated by measuring the elongations of the bolts caused by tightening the nut and assuming that each bolt followed the mean tension-elongation relationships shown in Fig. 2. Portions of these curves are presented again in Fig. 4 with histograms of the bolt elongations. To be consistent with previous work the initial bolt tensions were read from the direct-tension curve.

#### TESTING PROCEDURE

##### 1. Instrumentation

SR4, type A1, electric strain gages were used in all pitches along the edges of the plates to provide data on strain distribution throughout the length of the joint. Additional gages were placed on the face of the plates to assist in controlling the bending of the joint by means of the external bracing system.

A mechanical, slide-bar extensometer was used to measure the elongation of each 3-1/2 inch pitch along the edges of the plates.

This instrument was valuable in the plastic and strain hardening range when the SR4 gages were no longer effective.

Dial gages (0.001") mounted on each face of the joint near the free ends of the plates were used to record the slip between the two plates.

Two other dial gages (0.001") on the centerline of each face measured the overall elongation of the joint between gage points one pitch beyond each end row of bolts.

The instrumentation is visible in Fig. 5. More detailed descriptions are given in Ref. 3 for similar installations.

## 2. Equipment

The static tension tests of the lap joints were conducted at Fritz Laboratory in the 5 million pound hydraulic testing machine. Wedge grips were used to hold the specimens.

The external bracing system (Fig. 5) used to minimize the bending of the joints consisted of upper and lower cross beams spanning between the main columns of the testing machine and two one inch diameter rods with turn-buckles extending from each cross beam to reaction bars that made contact with the joint in the vicinity of the end of each lap plate. As the joint tended to rotate under load the turn-buckles were adjusted to keep it in a plumb position. Plumbness of the joint was judged with the aid of a micrometer leveling device.

### 3. Procedure

The testing procedure was similar to that used for the static tension testing of butt joints<sup>(3)</sup> except for the use of the adjustable bracing system. When a load increment was reached the plumbness of the joint between the reaction bars was checked by means of the micrometer leveling device and the turn-buckles were adjusted until the connection was exactly plumb. Then readings were taken.

## TEST RESULTS AND ANALYSIS

The results of the tests are summarized in Table 1. Bolt failures occurred in all cases. In joints L5 and L10 testing was stopped after one end bolt sheared whereas in the case of L2 and L7 simultaneous and rapid shearing of all bolts occurred before it was possible to unload the specimen.

### 1. Effect of Bending

Though an external bracing system was used it was not possible to eliminate all bending effects from the test. The plates beyond the region of the reaction bars of the bracing system, that is, outside of the bolted connection, were subjected to bending as well as axial strains even after the turnbuckles were adjusted. However, the bolted connection itself was maintained in a plumb position. The

SR4 gages on the face of the plates showed that the bending strains with the bracing system in use were only a small fraction of those in the plates when a partial test without bracing was conducted. Furthermore, details of steel construction, like the built-up hanger described in the introduction, often restrict rotation of the connection but permit some bending outside of it in the main material.

## 2. Slip

All joints slipped in a gradual fashion under increasing load until the bolts were in bearing. For purposes of computation the slip load has been taken at the first marked change in slope of the load-elongation curve. There was no instances of noisy, sudden and complete slip occurring at one load as has been experienced previously with many butt joints.<sup>(2,3,4)</sup> It is not known whether this gradual slip is a phenomenon related to lap joints or whether it also depends on the shiny, semipolished surface condition of the plates.

Even though these plates were devoid of mill scale and quite polished in spots, slip occurred at an average bolt shear stress greater than the allowable stress of  $F_v = 15$  ksi specified for friction type joints by the American Institute of Steel Construction.<sup>(8)</sup> The factor of safety against slip varied from 1.19 to 1.94. In three cases slip did not even occur until the working load for a bearing-type connection had been exceeded.

The slip resistance of the connection may also be expressed in terms of the slip coefficient,  $K_s$ , expressed as follows:

$$K_s = \frac{P_s}{mn \bar{T}_i}$$

where  $P_s$  = slip load

$m$  = number of bolt shear planes

$n$  = number of bolts

$\bar{T}_i$  = average initial bolt tension (or clamping force).

Using the average bolt tension as read from the direct-tension calibration curve in Fig. 4 the calculated slip coefficients vary between 0.21 and 0.33. This is exactly the range determined from the tests of the 8 butt joints of D-Series - part a, which were made of the same semi-polished plate.

### 3. Ultimate Strength

Working stresses for fasteners used in bearing-type joints are derived from the ultimate shearing strength of the connection. For this reason it is necessary to carry the tests until destruction of the joint occurs. Because the division of load among the fasteners depends upon the joint configuration and because different strength bolts may be used in different joints the "unbuttoning factor" has been used to compare the performance of different connections at ultimate load. The "unbuttoning factor",  $U$ , is an efficiency factor defined as

$$U = \tau_u / \tau_1$$

where  $\tau_u$  = average shear stress on the bolts in a joint when  
the first bolt shears

$\tau_1$  = shear strength of a single bolt of the same lot.

The unbuttoning factors calculated for the four lap joints are plotted in Fig. 6 with the length of the joint as an argument. It may appear that the bolts of the lap joints performed in a fashion equal to or better than those in the butt joints which are plotted for comparison. However, care must be exercised in interpreting this data because some of the lap joints had tension-shear ratios differing from the "balanced design" ratio of 1.00/1.10.

Only L10 had a nominal T/S = 1.00/1.10 and the unbuttoning factor of 0.75 is in good agreement with those for butt joints with 10 bolts in line. Because L10 was made from the same plate and from bolts of a strength level comparable to those in butt joint D101 these two connections may be compared directly. The data shows that L10 failed at 748 kips, almost exactly half of the 1506 kip failure load for D101.

Joint L2 had only two bolts in line and the distribution of load among the fasteners is statically determinate. In this case it is to be expected that each bolt will carry an equal share of the load and that the average shear stress will equal the strength of a single bolt. The test showed this to be true within the variation of strength reasonably expected in any lot of bolts, 82.1 ksi versus 83. ksi.

Joints L7 and L5, with nominal T/S = 1.00/1.57 and 1.00/1.32 respectively, had more net section area than required by the "balanced design" ratio of 1.00/1.10. Thus, at any given load the stress level and the strains in the plate were less than in the comparable butt joint. Since it is the differential strains in the plates that are instrumental in causing the bolts to shear it is to be expected that the lap joints L7 and L5 would perform better and that the unbuttoning factors would be above the general line established for the unbuttoning of butt joints with T/S = 1.00/1.10. A more complete theoretical discussion of this matter is included in Ref. 9.

#### SUMMARY AND CONCLUSIONS

The following conclusions are derived from the results of static tension tests of four, single shear, lap joints fabricated of structural carbon steel and 7/8" A325 high strength bolts and from similar tests of double shear butt joints reported previously. (2,3,4) Bending caused by the inherent eccentricity of a lap joint was minimized by use of an external bracing system.

a. The frictional resistance and the ultimate strength of bolted, single shear lap joints are equal to one-half of those quantities for comparable double shear butt joints. The difference is a function of the number of contact friction surfaces or the number of shearing planes.

b. The "unbottoning" behavior of long lap joints is similar to that for long butt joints.

#### ACKNOWLEDGEMENTS

The work described in this report is part of an investigation of large bolted joints conducted at the Fritz Engineering Laboratory of Lehigh University under the direction of Dr. Lynn S. Beedle. This project is sponsored financially by the Pennsylvania Department of Highways, the Department of Commerce-Bureau of Public Roads and the American Institute of Steel Construction. Technical guidance is provided by an advisory committee of the Research Council on Riveted and Bolted Structural Joints.

The authors wish to acknowledge the assistance, guidance and advice of the advisory committee, E. J. Ruble, Chairman; the Bethlehem Steel Company, particularly E. F. Ball, K. de Vries and J. J. Higgins for their assistance in the fabrication of test specimens, and W. R. Penman and A. Schwartz of the Lebanon Plant for furnishing the bolts; and S. J. Errera, K. R. Harpel and the staff of technicians at the Fritz Engineering Laboratory.



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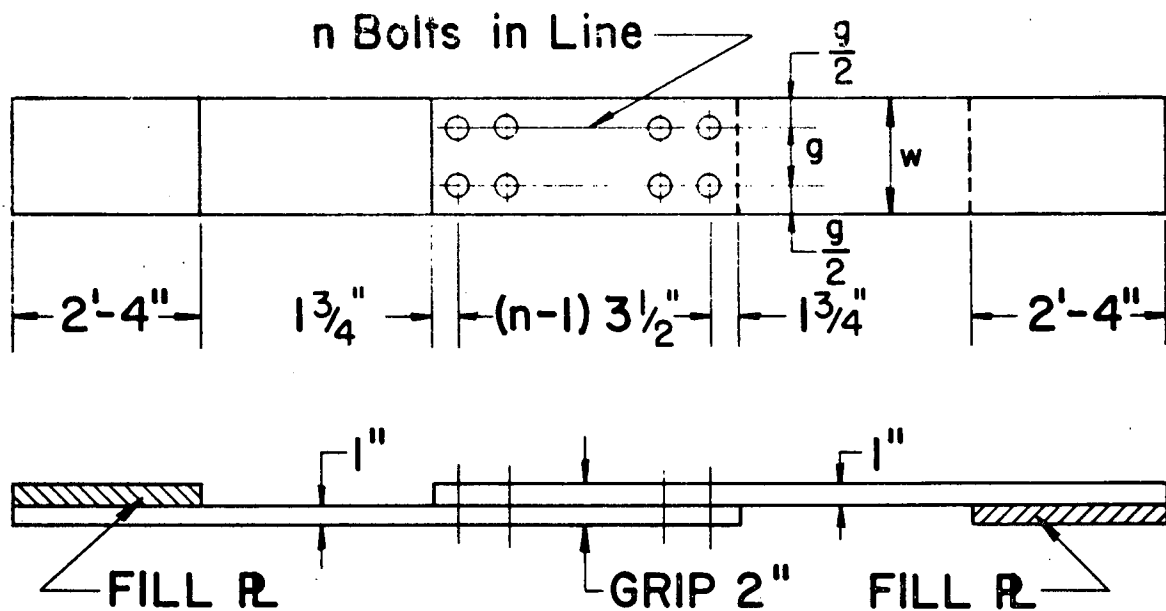
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TABLE 1

SUMMARY OF RESULTS

## Lap Joints (L-Series)

	<u>UNITS</u>	<u>L10</u>	<u>L7</u>	<u>L5</u>	<u>L2</u>
<u>PATTERN</u>					
All holes drilled 15/16"Ø					
All pitches 3 1/2"					
Gage = 1/2 width					
<u>BOLTS</u>					
No. in line		10	7	5	2
No. of 7/8" A325 Bolts		20	14	10	4
Nominal shear area (= Actual)	sq.in.	12.02	8.41	6.01	2.40
<u>PLATE</u>					
See Fig. 1 for nominal plate dimensions					
Actual (measured) width	in.	15.00	15.02	9.79	5.80
Actual (measured) thickness	in.	0.993	0.993	0.984	0.993
Actual gross area	sq.in.	14.90	14.92	9.63	5.76
Actual net area	sq.in.	13.02	13.04	7.75	3.88
<u>T/S RATIO (As/An)</u>					
Nominal		1:1.10	1:1.57	1:1.32	1:1.65
Actual		1:1.08	1:1.55	1:1.29	1:1.62
<u>WORKING LOAD</u>					
Friction Type Joint, $F_v = 15$ ksi	kips	180	126	90	36
Bearing Type Joint, $F_v = 22$ ksi	kips	264	185	132	53
<u>SLIP LOAD</u>					
	kips	350	195	107	62
Bolt shear stress	ksi	29.1	23.2	17.8	25.8
Avg. ext. of bolts	in.	.0435	.0445	.0409	.0428
Clamping force per bolt	kips	52.3	52.5	52.0	52.2
Slip coefficient		.33	.27	.21	.30
<u>TYPE OF FAILURE</u>					
		1 bolt sheared	All bolts sheared	1 bolt sheared	All bolts sheared
<u>LOAD AT BOLT FAILURE</u>					
	kips	748	640	446	197
Bolt shear stress	ksi	62.2	76.1	74.2	82.1



All bolts  $\frac{7}{8}$ " dia.

All holes drilled  $\frac{15}{16}$ " dia. (=  $d_H$ )

MARK	n	GAGE g, in.	WIDTH w, in.	$g/d_H$	SHEAR AREA sq. in.	NET AREA sq. in.	T/S
L 10	10	7.55	15.10	8.06	12.02	13.20	1:1.10
L 7	7	7.55	15.10	8.06	8.41	13.20	1:1.57
L 5	5	4.90	9.80	5.23	6.01	7.92	1:1.32
L 2	2	2.92	5.84	3.11	2.40	3.96	1:1.65

FIG. 1 NOMINAL DIMENSIONS OF JOINTS  
L-SERIES

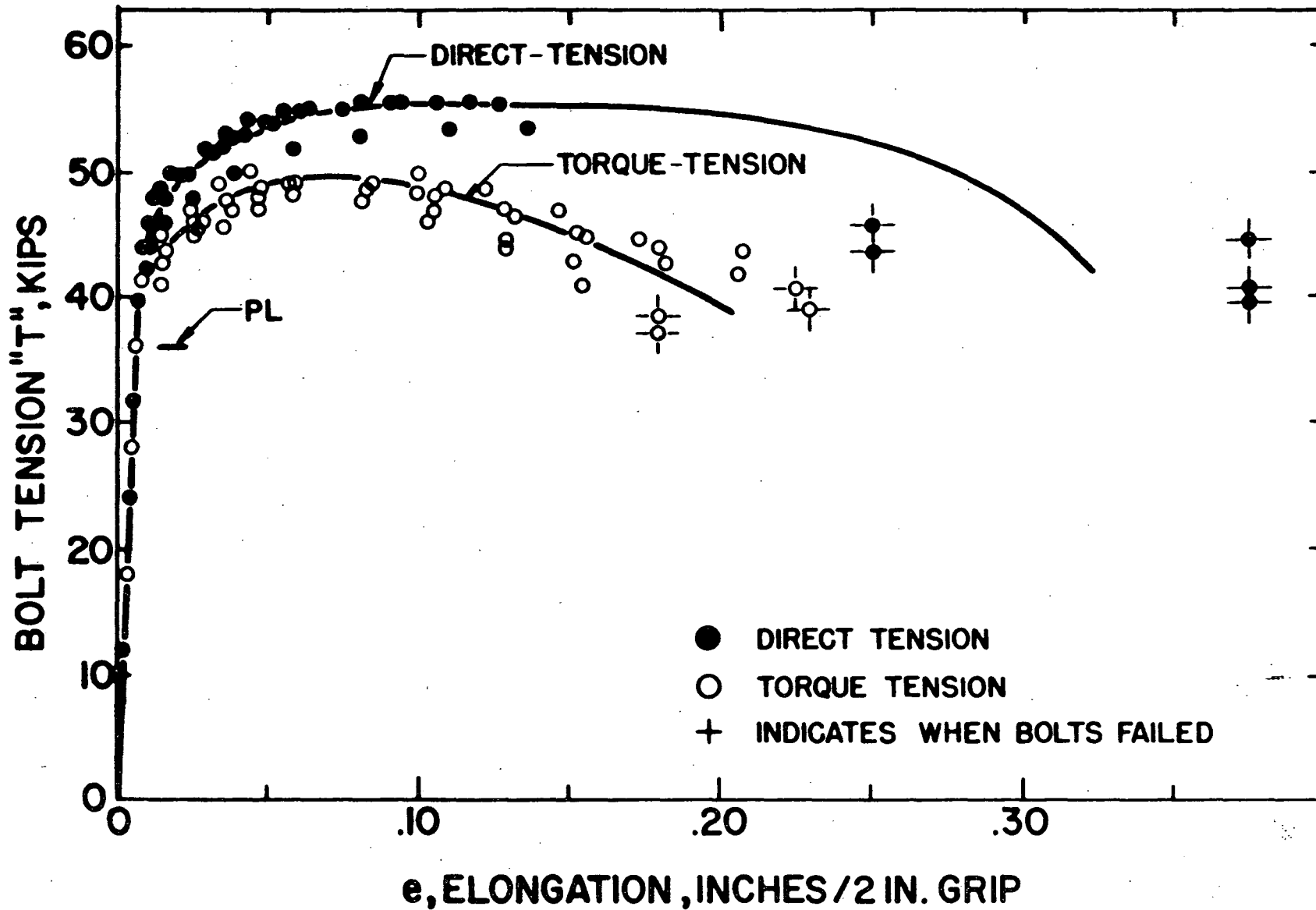


FIG. 2 BOLT CALIBRATION CURVES, L-LOT

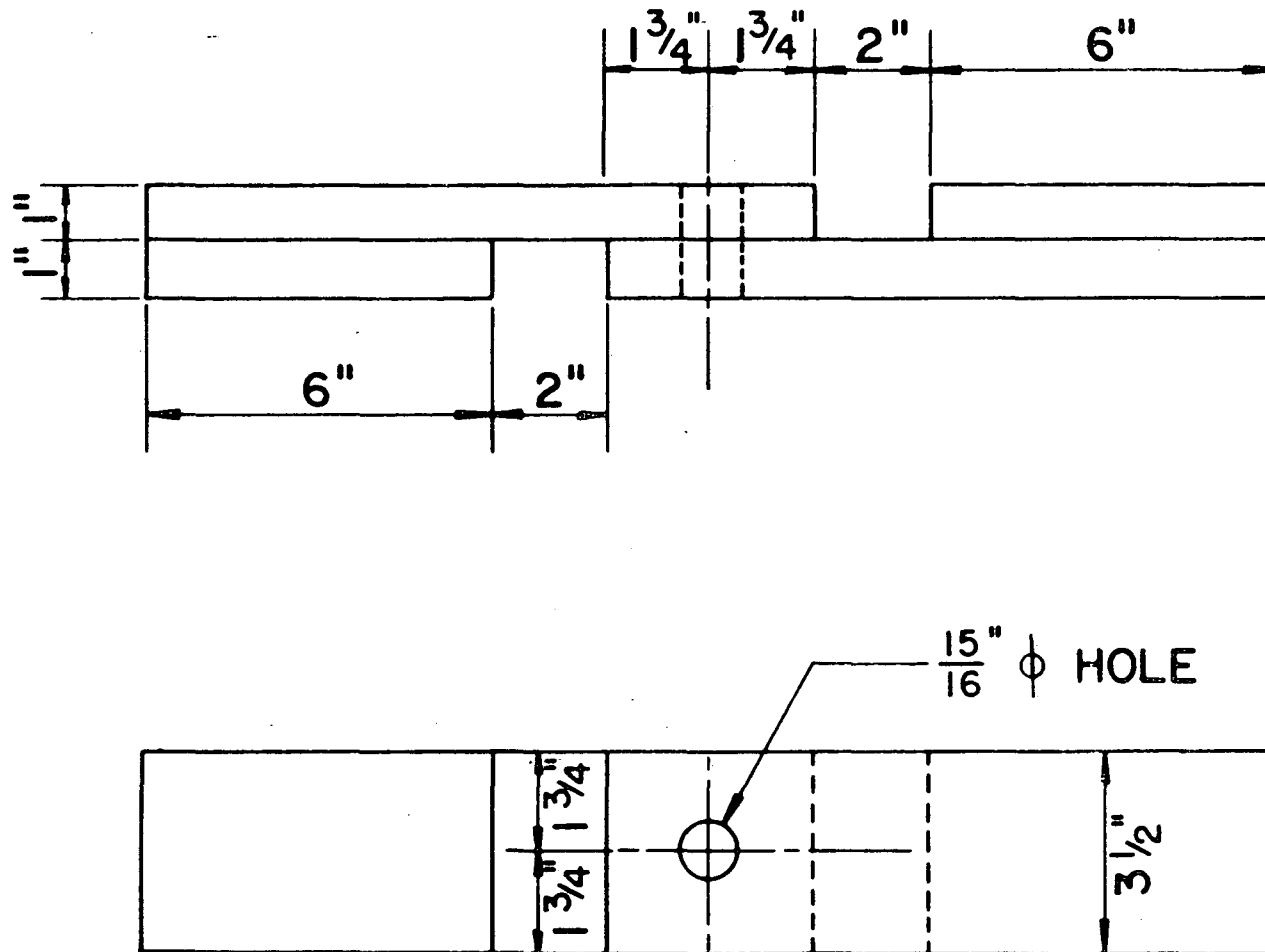
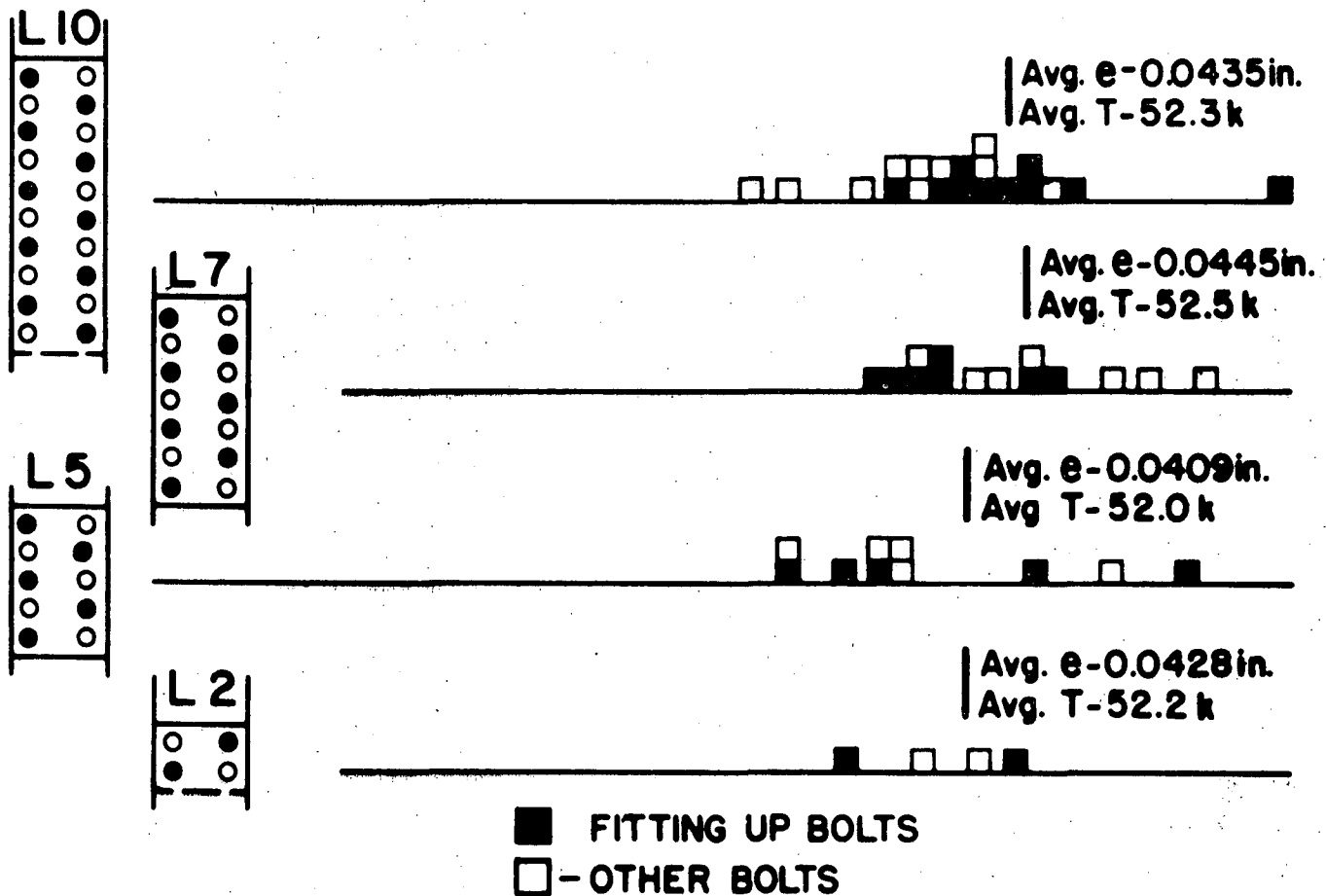
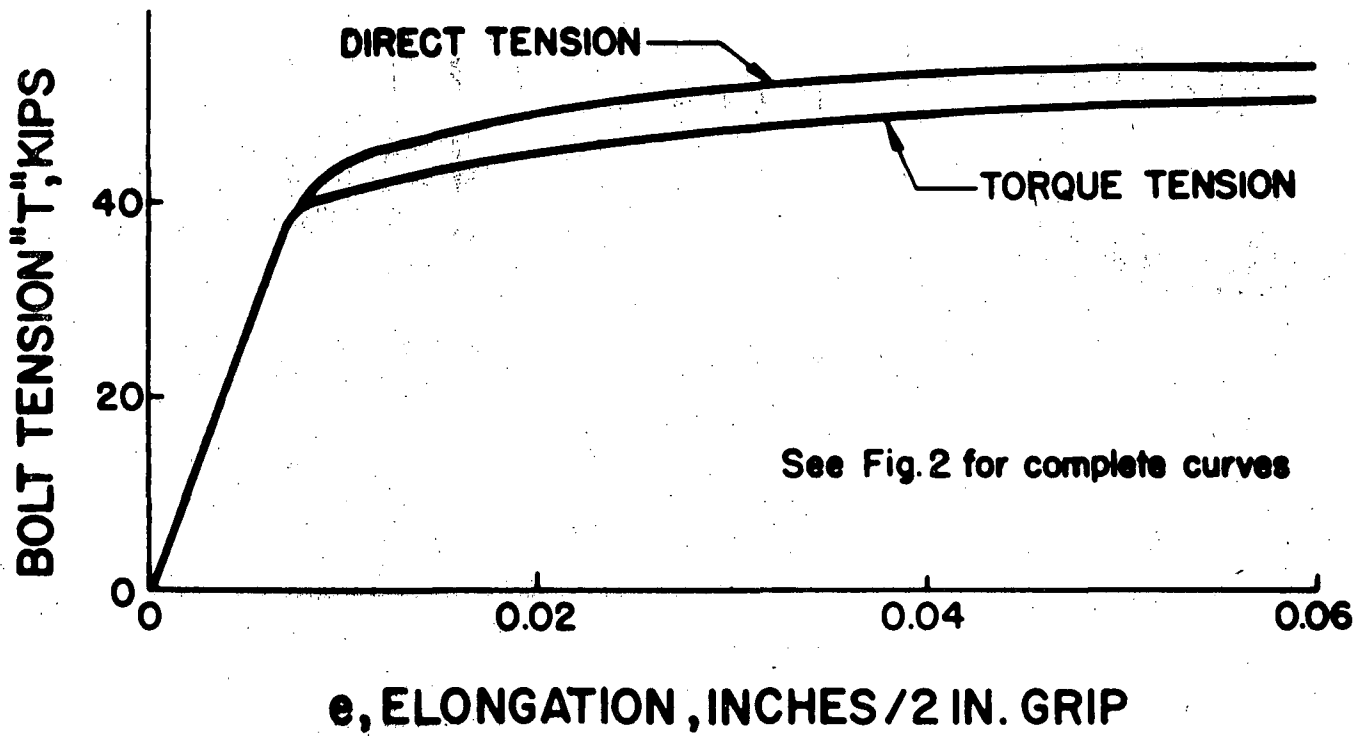
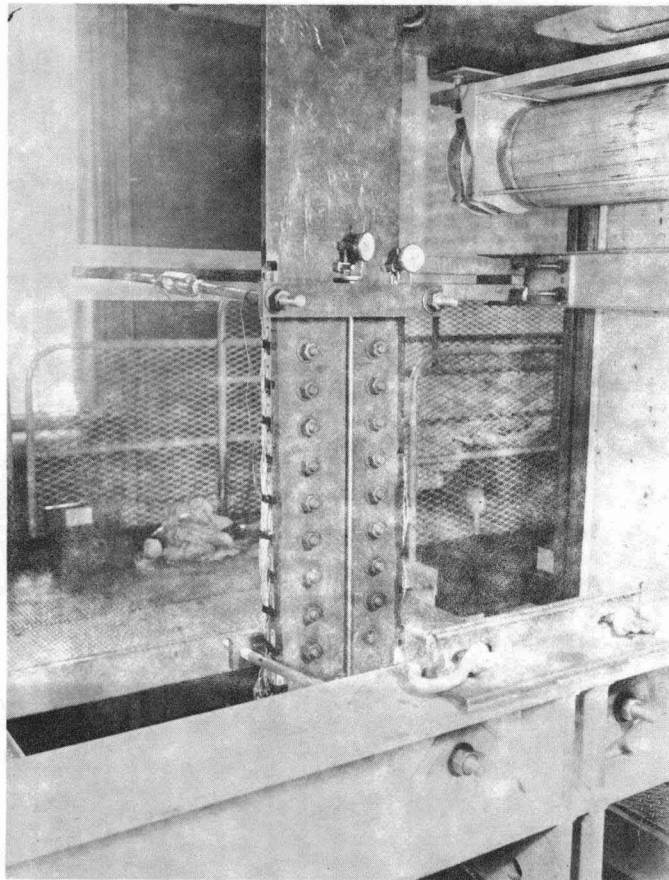


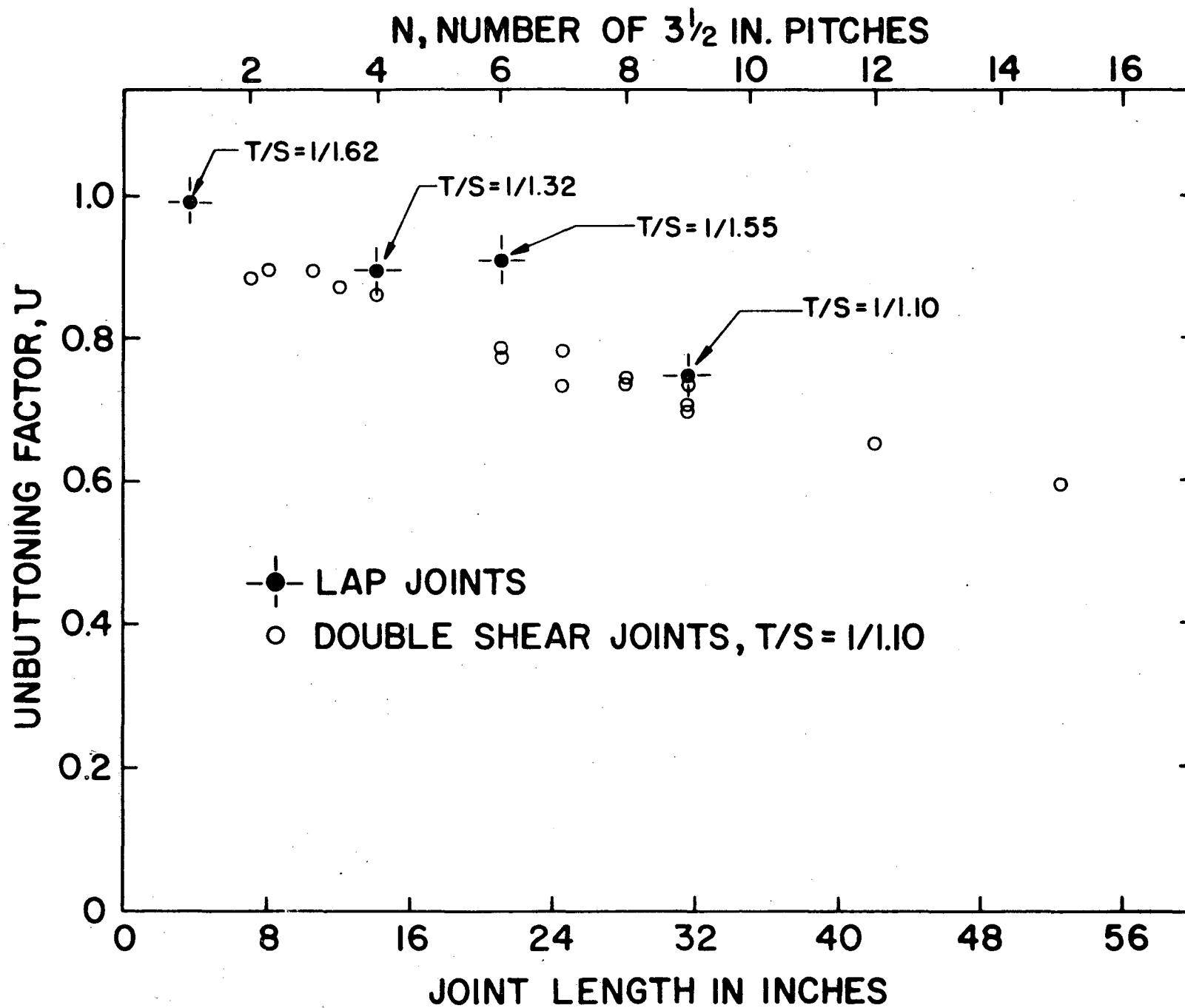
FIG. 3 SINGLE SHEAR BOLT JIG



**FIG. 4 BOLT TENSION DISTRIBUTION**



**FIG. 5 INSTRUMENTATION AND BRACING  
SYSTEM ATTACHED TO JOINT**



**FIG. 6 UNBUTTONING FACTOR**