LARGE BOLTED JOINTS

SUMMARY REPORT TO
THE RESEARCH COUNCIL ON
RIVETED AND BOLTED
STRUCTURAL JOINTS

by

Project Staff

(Not for publication)

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               R. N. Allan, G. L. Kulak
               J. H. Lee

December 1966

Fritz Engineering Laboratory Report No. 317.6
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<td>Summary of progress in Project 318</td>
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## BOLTED HIGH-STRENGTH STEEL JOINTS, PROJECT 317
### LEHIGH UNIVERSITY STATUS OF VARIOUS PHASES

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<thead>
<tr>
<th>Phase and Topic</th>
<th>Remarks</th>
<th>Tests Performed</th>
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<tbody>
<tr>
<td><strong>I. Quenched &amp; Tempered Steel (ASTM A514)</strong>&lt;br&gt; Joints Fastened With A490 Bolts</td>
<td>Authorization: Committee 10 Minutes 10/1/65 Active</td>
<td>Pilot Studies Six Tests. Full size tests 8 large joints.</td>
<td>None</td>
<td>Ultimate strength, load distribution, slip behavior</td>
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<td><strong>II. Hybrid Connections</strong>&lt;br&gt; Two or more different grades of steel are joined</td>
<td>Authorization: Committee 10 Minutes Active</td>
<td>12 shear jig tests of A36-A514 steels with A325 and A490 bolts, and A36-A440 steels with A325 bolts</td>
<td>5 joints to be tested</td>
<td>Ultimate strength and load distribution studies</td>
<td>317.3 317.5</td>
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<td><strong>III. Quenched and Tempered Steel</strong>&lt;br&gt; Joints Fastened With A325 Bolts</td>
<td>Authorization Committee 10 Minutes Active</td>
<td>Tension shear jigs tested, Pilot Tests J42a, J42b, J42c, J42d</td>
<td>4 joints to be tested</td>
<td>Ultimate strength and load distribution studies</td>
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**Phases Now Active**

<table>
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<th>Phase</th>
<th>Description</th>
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<tr>
<td>Phase I</td>
<td>Analysis and confirming static tests of quenched and tempered steel (ASTM A514) joints fastened with A490 bolts.</td>
</tr>
<tr>
<td>Phase II</td>
<td>Analysis and confirming static tests of connections in which two or more different grades of steel are joined (hybrid connections).</td>
</tr>
<tr>
<td>Phase III</td>
<td>Analysis and confirming static tests of quenched and tempered steel joints fastened with A325 bolts.</td>
</tr>
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</table>
PROJECT 317

Summary of Reports - to December 1966

Fritz Lab Report

317.1 Project Staff
"Summary Report to Committees 10 and 23"
September, 1965

317.2 Project Staff
"Summary Report to the Research Council on Riveted and Structural Joints"
March, 1966

317.3 R. Kormanik
"The Behavior of Hybrid Bolted Connections"

317.4 Project Staff
"Summary Report to the Research Council on Riveted and Structural Joints"
July, 1966

317.5 R. Kormanik and J. W. Fisher
"Bolted Hybrid Joints"
September, 1966
<table>
<thead>
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<th>Analytical Work</th>
<th>Reports</th>
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<tr>
<td>I. Out-of-Flat Large Joints</td>
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<td>8 joints</td>
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<td>III. Effect of slotted and oversize holes upon joint behavior</td>
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<td>21 joints with oversize and slotted holes</td>
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<td>Slip behavior and ultimate strength studies</td>
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Phases Now Active

Phase I
Analysis and pilot tests of large joints which are out-of-flat. Test pieces of large plates, some of which have been purposely warped from true flatness, will be used. Both A325 and A490 bolts would be used in conjunction with these pieces.

Phase II
Analysis and pilot tests of smaller joints to determine the effect of controlled variation of the faying surface on the slip resistance of the joints.

Phase III
Analysis and pilot tests of the effect of slotted and oversize holes upon joint behavior.
Fritz Lab Report

318.1 E. Nester
"Influence of Variation of the Contact Area Upon Slip Resistance of a Bolted Joint"
A514 STEEL JOINTS FASTENED BY A490 BOLTS

1. Introduction

An extensive theoretical and experimental investigation into the behavior of constructional alloy steel joints fastened by high strength bolts has been carried out under this phase of Project 317. A review of the experimental program and some of the conclusions reached as a result of the theoretical study are given in this report.

2. Description of Test Specimens

2.1 Pilot Tests

Ten compact joints of A514 steel fastened by high strength bolts were examined. All were four-bolt-in-line specimens in which a total thickness of 4-in. of plate was gripped by the fasteners. The geometry of these joints is shown in Fig. 1. Four of the ten joints used 1-in. diameter A325 bolts. (Although the latter are not within the scope of this Phase, they will be reported herein so that their slip behavior can be compared to the A514/A490 joints). All plate in these joints came from the same rolling and all fasteners of a given size and type came from the same lot of bolts. The test program examined both the slip behavior and ultimate strength characteristics of these joints. Complete details and test results of the pilot joints are shown in Table 1.
2.2 Large Joints

Although a considerable number of tests have been performed in the past on large, bolted plate splices, these were all made on joints of structural carbon (A7 and A36) or high strength (A440) steels. It has been shown that joints of constructional alloy steel behave in a significantly different manner from those grades previously investigated. To verify these theoretical predictions, it was felt that an extensive experimental investigation using full size joints was required. Although the pilot tests did provide valuable information, particularly with regard to the slip behavior of A514 steel joints, it has been shown that one of the most important variables affecting joint behavior is joint length. Thus, the test program involving large joints was set up:

The large joint test series consisted of eight specimens. All used A490 bolts, of various grips, to fasten A514 steel plates. Seven of these specimens used 7/8-in. diameter fasteners and one used 1-1/8-in. diameter fasteners. All plate in these joints came from the same rolling. The geometry of the joints is shown schematically in Fig. 1 and complete details and test results are shown in Table 2.

Two joints each of seven, 13, 17 and 25 fasteners in line were tested. The first six specimens were paired, one of each pair
designed to fail by tearing of the plates, the other by shearing of the fasteners. The mode of failure is governed by the relative proportions of the plate and fasteners. This can be described by means of the $An/As$ ratio, where $An$ is the net area of either the main or lap plates and $As$ is the total associated shear area of the fasteners. These six joints, then, bracket the plate failure - fastener failure boundary line.

The remaining two specimens, those of 25 bolts in line, were both designed to fail in the fasteners. In A514 steel joints, it is not until one gets to joints of this length that any substantial amount of load redistribution occurs among the fasteners. Since it was necessary that the mathematical models developed for determining this effect be verified, these long joints were chosen.

3. **Analytical Studies of Ultimate Strength**

3.1 **Basis of the Examination.**

In examining the application of the theory that has been developed for determining the ultimate strength of constructional alloy steel joints fastened by high strength bolts, it is appropriate to base the approach on the use of plate and fasteners of minimum strength. A lower bound to the behavior of such joints will result.
3.2 Location of the Plate Failure - Fastener Failure Boundary

The first step in the determination of the ultimate strength of a bolted joint must be to establish the mode of failure. The location of the boundary between plate failure and fastener failure is most conveniently found by a converging process from above. At a given joint length, the ultimate strengths of joints with decreasing values of An/As are computed. The process must start in the fastener failure region, that is, at a value of An/As high enough to ensure this failure mode. With each calculation, the ultimate load so computed is compared to the ultimate load of the plates, as represented by An \( \cdot \sigma_u \) at that step. If these two loads are equal, or within an acceptable limit, a point on the boundary has been obtained. This process is repeated for other joint lengths until the complete curve has been obtained for the desired range.

The plate failure - fastener failure boundary shown in Fig. 2 has been computed on the basis of 7/8-in diameter A490 bolts of minimum strength connecting a total of four inches of minimum strength A514 plate. The fastener pitch was taken as 3.5 inches. The effects of different grips, pitches, and fastener diameter will be examined but are not discussed further in this report. Their effect on the location of the boundary or on ultimate joint strength is expected to be minor.
The dashed horizontal line extending across the graph in Fig. 2 at a shear stress value of 91.5 ksi represents the "ideal" joint, that is, one in which all the fasteners carry an equal load. This occurs, of course, only at a value of An/As = ∞. Shown between this limiting line and the other limit, the plate failure boundary, are joint strength curves for An/As values of 1.00, 0.80, 0.70, and 0.60.

Two important facts are observable from these curves. First, when A514 steel is connected by A490 bolts, it is unlikely that joint proportions will be such that failure will occur in the fasteners. For example, using an allowable stress value of 60 ksi for A514 plate in combination with the allowable stress value for A490 bolts used in buildings, an An/As of 0.53 results. As shown in Fig. 3 where the same boundary is plotted as An/As vs. joint length, at these stress levels the joint would have to be longer than about 84-in. before the fasteners would be critical. Recently, an allowable stress of 40 ksi has been suggested for A490 bolts used in bearing connections. The An/As value in this case would be 0.67. Examining Fig. 3 again, it can be seen that plate failure would control up to a joint length of 60-in.

The second observation that can be made from Fig. 2 concerns the effect of the spacing of the fastener failure curves shown.
For example, at a joint length of 70-in, the limiting $\frac{A_n}{A_s}$ curves of 0.62 and $\omega$ cover a range of shear stress values of only 78.5 ksi to 91.5 ksi. This means that the load carried by a joint with $\frac{A_n}{A_s} = 0.62$ will not be greatly less than a joint at the same length with, say, $\frac{A_n}{A_s} = 1.00$. The theoretical values of load for this illustration would be 1915 kips and 2258 kips, respectively. In other words, although the plate area was increased 61%, the load that could be carried increased only 18%. The effect of adding more plate area in order to make the fasteners work at a higher stress level does not seem particularly advantageous.

3.3 Behavior of Fastener Failure Joints

In specimens in which joint proportions are such that fastener failure is expected, the load level among the bolts will be fairly uniform. The very high yield level of A514 steel means that inelastic deformation will occur to some extent in all bolts while the plate material is still elastic and relatively rigid. As an example, referring again to the behavior of minimum strength 7/8-in diameter A490 bolts in minimum strength A514 plate, the average shear stress in the fasteners of a 17-bolt joint ($\frac{A_n}{A_s} = 0.80$) at time of failure is only about 8% less than the maximum shear stress in a single bolt.

4. Test Results and Analysis

4.1 Load - Deformation Behavior

Complete load-deformation data were taken for each joint described in Section 2. Typical results are shown for a long joint
in Fig. 4 where the behavior of Specimen J171 is illustrated. The load-deformation response is nearly linear up to the point of major slip. At this load, which was a well-defined point in all tests except one, the main and lap plates moved relative to one another a little less than the amount of the hole clearance. This movement was always sudden and was accompanied by a sharp "bang" as some or all of the fasteners came into bearing.

Following major slip, the load-deformation response was again linear for a short time until a second, minor slip occurred. Inelastic deformations in both plate and bolts then began to occur. For those specimens failing by fracture of the plates, such as the one illustrated in Fig. 4, the curve became very flat as the eventual failure load was approached. Specimens designed to fail by fastener shear approached the failure load on a much steeper slope because of their relatively greater plate area.

The exception to this general behavior among the large joints was Specimen J251. Here, slip occurred in three almost equal increments at greatly different loads. After bolting up, this specimen had a large initial curvature. Because of this behavior, the data from this test were not used in analyzing the slip behavior of these joints.

The pilot joints behaved in a very similar fashion to that described here. None, however, showed the second, minor slip that was observed in most of the large joint tests.
4.2 Slip Behavior

The slip behavior of bolted joints has customarily been examined on the basis of a "slip coefficient" (Ks). This is defined as

\[ K_s = \frac{P_s}{m n T_i} \]

where \( P_s \) is the slip load, \( m \) is the member of faying surfaces, \( n \) is the number of bolts, and \( T_i \) is the average clamping force per bolt. Slip coefficients computed on this basis are shown in Tables 1 and 2 for the pilot and large joint tests, respectively.

Variations in the value of the slip coefficient appear to be random, that is, they are independent of joint length or width, or magnitude of clamping force. For example, Specimens J131 and 132, which have the same joint length and differ only slightly in width, have identical values of \( K_s \) in spite of a large difference in clamping force. Specimens J172 and F42e have approximately the same clamping force per bolt but lengths of 56-in. and \( 10\frac{1}{2} \)-in. respectively. The values of \( K_s \) for these two joints also are identical.

The mean value of \( K_s \) for the seventeen joints included in the study is 0.33 with a standard deviation of 0.04. The results are shown graphically in Fig. 5. It should be pointed out that all of the plate used in these tests was blast-cleaned with chilled steel grit.
Although this is not an unusual shop procedure for alloy steel plate, it probably results in a slip coefficient that is on the conservative side.

The average shear stresses at time of major slip and depending upon fastener type are shown in Fig. 6. Also shown are the working stress levels for the two types of bolts when used in buildings, according to currently used specifications. Based on mean values, the factors of safety against slip are 1.48 and 1.86 for A325 and A490 bolts, respectively. The recommended values for structures designed according to AISC Specifications are 1.40 for A325 bolts and 1.44 for A490 bolts.

4.3 Ultimate Load Behavior

a. Pilot Tests

The four pilot joints fastened by A490 bolts were all expected to fail by shearing of the fasteners. The theoretical studies showed that almost no redistribution of load would occur among the fasteners in joints of this short length. Hence, predicted ultimate loads were simply multiples of the individual fastener strengths. The maximum error on predictions so computed was only 2.3%. All predicted and actual ultimate loads are shown in Table 1.

b. Large Joints

The use of a plate - with - holes coupon to predict the ultimate load of the plate failure specimens gave values virtually
identical to the actual loads. All joints failed in the mode predicted
and failure was always through an end bolt hole, either in the main
plates or in the lap plates.

The analytical method which has been developed to predict
the ultimate load of A514 steel joints failing by fastener shear also
gave excellent results. The maximum error in ultimate load predic-
tions of the five large joints tested was 5.3%. All test results are
shown in Table 2.

Specimens J072, J132, J172 and J252 all failed by an
apparent simultaneous shearing of all of the fasteners. Although the
end fasteners theoretically should, and probably did, fail first, the
high level of load in the remaining bolts meant that they were not
able to carry the additional load from the first failed fastener.
That the failure was as hypothesized has been observed from re-
assembled sheared bolts. Although failure was by apparent simultan-
eous shear of all fasteners, it is obvious from the bolt deformations
that an end fastener was governing.
REFERENCES

1. Fisher, J. W., Kulak, G. L., Beedle, L. S.
   BEHAVIOR OF LARGE BOLTED JOINTS
   Fritz Engineering Laboratory Report No. 288.31 A
   August, 1965

2. Kulak, G. L.
   THE ANALYSIS OF CONSTRUCTIONAL ALLOY BOLTED PLATE SPLICES
   Ph.D Dissertation, Lehigh University, Bethlehem, Pennsylvania.
   (In Preparation)

3. Fisher, J. W., and Beedle, L. S.
   CRITERIA FOR DESIGNING BEARING TYPE BOLTED JOINTS

4. Fisher, J. W.
   THE ANALYSIS OF BOLTED BUTT JOINTS
   Ph.D. Dissertation, Lehigh University, Bethlehem, Pennsylvania, 1964

5. Research Council on Riveted and Bolted Structural Joints
   SPECIFICATIONS FOR STRUCTURAL JOINTS USING ASTM A325
   OR A490 BOLTS, 1964
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### TABLE 2

**JOINT DIMENSIONS AND TEST RESULTS**

**LARGE JOINTS**

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*NOT DEFINED
JOINT WAS WARPED*
Pilot Joints

Large Joints

Fig. 1 Geometry of Test Joints
Minimum Strength

\[
\frac{7}{8}\text{ in Dia. A490 bolts}
\]
\[
A514\text{ plate}
\]

Fig. 2 Plate Failure - Fastener Failure Boundary, \(\tau\) vs. L.
Fig. 3 Plate Failure - Fastener Failure Boundary, An/As vs. L.

Minimum Strength:

\[ \frac{7}{8} \text{ in. dia. A490 bolts} \]

A 514 plate
Fig. 4  Typical Load - Deformation Response
Fig. 5 Slip Coefficient
Fig. 6 Slip Resistance