LARGE BOLTED JOINTS

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

by

Project Staff
(Not for publication)

This work has been carried out as part of the Large Bolted Connections 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.


March 1966

Fritz Engineering Laboratory Report No. 317.2
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Project 288
Final Summary of Reports

Fritz Lab Report

* 288.1 Project Staff
"Summary Report to Committees 9 and 10"
January, 1962

+ 288.2 Project Staff
"Summary Report for RCRBSJ"
March, 1962

288.3 Project Staff
"Large Bolted Joints Project 288-Manual"
(Contains the "File system, Summary and Phases, Test Preparation and Procedure, Standard Data Forms and Standard Project Forms" of Project 288)

# 288.4 J. W. Fisher, P. O. Ramseier, L. S. Beedle
"Static Tension Tests of A440 Steel Joints Connected With A325 Bolts"
(Reports on results of six pilot tests, five long joint tests and three wide joint tests fabricated at a tension shear ratio of 1/1.0. Published, Publications, IABSE, Vol. 23, 1963. Fritz Lab Reprint No. 245)

# 288.5 J. L. Rumpf, J. W. Fisher
"Calibration and Installation of A325 Bolts"
(Revision of Report 271.11 plus additional studies on the heavy head A325 in conjunction with the tests of large joints. Published, Journal of the Structural Division, ASCD, Vol. 89, St. 6, 1963, (Fritz Lab Reprint No. 232)

* 288.6 Project Staff
"Summary Report to Committees 9 and 10"
November, 1962

* 288.7 J. W. Fisher, L. S. Beedle
"Criteria for Designing Bolted Joints (Bearing Type)"
, February, 1963
* 288.7A  J. W. Fisher, L. S. Beedle
"Criteria for Designing Bolted Joints (Bearing Type)"*, July, 1964
Published, *Journal of the Structural Division, ASCE*, Vol. 91, St. 5, 1965

+ 288.8  Project Staff
"Summary Report for RCRBSJ"
March, 1963

+ 288.9  R. J. Christopher, J. W. Fisher
"Calibration of A354 Bolts"
March, 1963 (Preliminary Report)

+ 288.10  J. W. Fisher
"The Analysis of Bolted Place Splices"
Ph.D. Dissertation, Lehigh University, 1964

288.11  R. J. Christopher
"Calibration of Alloy Steel Bolts"
Master of Science Thesis, June, 1964

288.12  J. J. Wallaert
"The Shear Strength of A325 and Alloy Steel Structural Bolts"
Master of Science Thesis, June, 1964

"The History of Internal Tension in Bolts Connecting Large Joints"
December, 1964
(This report, which was distributed in February, presents the results of measurements of changes in bolt tension during tests of large joints.)

"What Happens to Bolt Tension in Large Joints?"
May, 1965
Published in *Fasteners*, Vol. 20, No. 3, 1965, pp. 8-12

* 288.14  Project Staff
"Summary Report to Committee 10 of RCRBSJ"
December, 1963

* 288.15  Project Staff
"Test of A490 Bolts"
February, 1964 (Preliminary Report)
* 288.16  Project Staff
"Summary Report to RCRBSJ"
March, 1964

+ 288.17  J. W. Fisher, J. L. Rumpf
"The Analysis of Bolted Butt Joints"
September, 1964
(Published, Journal of the Structural
Division, ASCE, Vol. 91, No. St. 5, 1965)

288.18  J. W. Fisher
"On the Behavior of Fasteners and Plates With
Holes"
December, 1964
Published, Journal of the Structural Division,
ASCE, Vol. 91, No. St. 6, December, 1965

+ 288.19  R. J. Christopher, J. W. Fisher
"Calibration of Alloy Steel Bolts"
September, 1964

288.19A  R. J. Christopher, G. L. Kulak, J. W. Fisher
"Calibration of Alloy Steel Bolts"
July, 1965
(This report is a revision of 288.19. For
publication by the ASCE in the Journal of
the Structural Division, Vol. 92, No. St. 2,
April, 1966.)

+ 288.20  J. J. Wallaert, J. W. Fisher
"The Shear Strength of High-Strength Bolts"
July, 1964
(This report was published by the ASCE in
the Journal of the Structural Division,
Vol. 91, No. St. 3, June, 1965.)

288.21  R. J. Christopher, J. J. Wallaert
"Project Summary Report"
June, 1964
(This report gives the location of various
material, status of various phases, etc. It
is intended only for internal use.)

288.22  J. W. Fisher, L. S. Beedle
"High Strength Bolting in the U. S. A."
August, 1964
(A talk given at the 7th Congress of IABSE
in Rio de Janeiro. Presents a summary of
American design concepts and summarizes tests
of bolted connections and the development of
installation procedures.)
J. W. Fisher
"Calibration Tests of A490 High-Strength Bolts"
August, 1964
(This report, written in cooperation with the University of Illinois, includes all the data contained in Fritz Laboratory Report 288.15 and the University of Illinois SRS No. 280. It was published in the Journal of the Structural Division, ASCE, Vol. 91, No. St. 5, 1965.)

J. W. Fisher
"Bolted Joints of High Strength Steel"
October, 1964
(A talk given at the Structural Connection Session at the Annual Meeting of ASCE in New York, October 22, 1964)

Project Staff
"Summary Report to Committee 10 of "RCRBSJ"
November, 1964

G. H. Sterling, J. W. Fisher
"Tests of Long A440 Steel Bolted Butt Joints"
February, 1965

G. H. Sterling
"A440 Steel Butt Joints Connected With High Strength Bolts or Rivets"

Project Staff
"Summary Report to the RCRBSJ"
March, 1965

G. H. Sterling, J. W. Fisher
"A440 Steel Joints Connected by A490 Bolts"
August, 1965
(The report has been accepted for publication by ASCE.)

J. W. Fisher, G. L. Kulak, L. S. Beedle
"Behavior of Large Bolted Joints"
August, 1965
(This report summarizes the work on large bolted connections conducted at Lehigh University. It was submitted to Committee 10 and received approval for publication. This report was presented at the 45th Annual Meeting of the Highway Research Board in January, 1966.)
* Indicates distribution to sub group, Pennsylvania Department of Highways, Bureau of Public Roads and certain interested parties.

+ Indicates distribution to RCRBSJ, Pennsylvania Department of Highways, Bureau of Public Roads and certain interested parties.

# Indicates published reports. Reprints distributed to RCRBSJ, Pennsylvania Department of Highways and Bureau of Public Roads.
### BOLTED HIGH-STRENGTH STEEL JOINTS, PROJECT 317
### LEHIGH UNIVERSITY STATUS OF VARIOUS PHASES

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<tr>
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<th>Tests to Be Completed</th>
<th>Analytical Work</th>
<th>Reports</th>
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| **I. Quenched & Tempered Steel (ASTM A514)**  
Joints Fastened With A490 Bolts | Authorization:  
Committee 10  
Minutes 10/1/65  
Active | Calibration of A490 Bolts | Specimens being fabricated | Ultimate strength and load distribution |         |
| **II. Hybrid Connections**  
Two or more different grades of steel are joined | Authorization:  
Committee 10  
Minutes  
Active | 12 shear jig tests of A36-A514 steels with A325 and A490 bolts, and A36-A440 steels with A325 bolts | Ultimate strength and load distribution studies |         |         |
| **III. Quenched and Tempered Steel**  
Joints Fastened With A325 Bolts | Authorization:  
Committee 10  
Minutes  
Active | Tests to be developed |         |         |         |
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<th>Remarks</th>
<th>Tests Performed</th>
<th>Tests to Be Completed</th>
<th>Analytical Work</th>
<th>Reports</th>
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<td>Minutes 10/1/65 Active</td>
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<td></td>
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<td>II. Effects of the Variation of the faying surface on the slip resistance of the joints</td>
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<td>III. Effect of slotted and oversize holes upon joint behavior</td>
<td>Authorization: Committee 10</td>
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**PROJECT 317**

**Phases Now Active**

**Phase I**
Analysis and confirming static tests of quenched and tempered steel (ASTM A514) joints fastened with A490 bolts.

**Phase II**
Analysis and confirming static tests of connections in which two or more different grades of steel are joined (hybrid connections).

**Phases III**
Analysis and confirming static tests of quenched and tempered steel joints fastened with A325 bolts.

**PROJECT 318**

**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.
CONSTRUCTIONAL ALLOY STEEL JOINTS
CONNECTED BY HIGH STRENGTH BOLTS

INTRODUCTION

A proposal for test specimens of A514 steel joints connected by A490 bolts was presented to the members of Committee 10 at their meeting held on October 1, 1965 at Lehigh University. After discussion and some revision of the test program, a schedule of test specimens was approved. The Committee also gave consideration to future studies in this area and recommended that the studies be extended to include tests of A325 bolted joints.

REVIEW OF PREVIOUS WORK

The load distribution and deformation characteristics of steel tension splices of ASTM grades A36 through A440 when fastened with A325 or A490 bolts are now well established.\(^{1,2,3}\) Constructional alloy steels, however, possess mechanical properties qualitatively as well as quantitatively different from those of mild carbon and high strength steels. Because of these differences, notably the low ultimate stress vs. yield stress ratio, it was found that the mathematical models previously developed are not satisfactory for use with constructional alloy steel tension splices.

Pilot tests of compact joints of T-1 steel connected by A325, A354 BC, and A354 BD bolts were performed under Project 288 at Lehigh University. The results of these tests are available for correlation with the present test series.
PROPOSED TEST SPECIMENS

The proposed test specimens are shown in Table 1. The joints are being fabricated and the bolts have been obtained and calibrated. All joints in this series will be fastened with A490 bolts.

The first six specimens have been chosen for defining the plate failure - fastener failure boundary. The first specimen of each pair is expected to fail by tearing of the plate while the second is expected to fail in the fasteners. This plate failure - fastener failure boundary has been established analytically and is shown in Figure 1. It is worth noting that present allowable bolt stresses for buildings in combination with recently suggested allowable stress values for A514 steel result in an $\frac{A_n}{A_s}$ ratio of $\frac{32}{60} = 0.53$. This is shown in Figure 1 and suggests that at present stress levels, all A514 steel joints of reasonable length fastened by A490 bolts may be expected to fail in the plate.

Specimens J251 and J252 have been chosen for the specific purpose of evaluating the newly developed mathematical models. Substantial redistribution of load is expected to occur in a joint of this length.

Joint J132 will be fabricated using 1-1/8" bolts. This choice reflects the growing practical importance of larger diameter fasteners.

FUTURE WORK

The mathematical models developed in this study should be
readily adaptable for use in analyzing A514 steel joints connected by A325 bolts. Some confirming tests of this combination would be desirable.

Of considerably more complexity is the problem of connecting A514 and other grades of steel in combination—hybrid joints. A large amount of analytical work has already been done on this problem and, again, confirming tests are desirable.

REFERENCES

1. Fisher, J. W., and Rumpf, J. L.
THE ANALYSIS OF BOLTED BUTT JOINTS
Journal of the Structural Division, ASCE,

2. Fisher, J. W., and Beedle, L. S.
CRITERIA FOR DESIGNING BOLTED JOINTS (BEARING TYPE)
Journal of the Structural Division, ASCE,

A440 STEEL JOINTS CONNECTED BY A490 BOLTS
Fritz Engineering Laboratory Report No.

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

<table>
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<tr>
<th>Specimen No.</th>
<th>No. of Fasteners</th>
<th>Joint Length Inches</th>
<th>Gage &quot;g&quot; Inches</th>
<th>Grip Inches</th>
<th>$A_n/A_s$</th>
<th>Predicted Ult. load kips</th>
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<td>JO71</td>
<td>7</td>
<td>21.0</td>
<td>3.89</td>
<td>4</td>
<td>0.70</td>
<td>736</td>
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<tr>
<td>JO72</td>
<td>7</td>
<td>21.0</td>
<td>4.73</td>
<td>4</td>
<td>0.90</td>
<td>855</td>
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<tr>
<td>J131</td>
<td>13</td>
<td>42.0</td>
<td>6.41</td>
<td>4</td>
<td>0.70</td>
<td>1365</td>
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<tr>
<td>J132</td>
<td>13</td>
<td>42.0</td>
<td>7.00</td>
<td>8</td>
<td>0.90</td>
<td>2565</td>
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<td>J171</td>
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<td>56.0</td>
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<td>J172</td>
<td>17</td>
<td>56.0</td>
<td>10.13</td>
<td>4</td>
<td>0.90</td>
<td>2035</td>
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<td>J251</td>
<td>25</td>
<td>84.0</td>
<td>6.95</td>
<td>8</td>
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<td>J252</td>
<td>25</td>
<td>84.0</td>
<td>9.20</td>
<td>8</td>
<td>1.10</td>
<td>2975</td>
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</table>

Note: All fasteners shall be 7/8"$\phi$ ASTM A490 bolts except for J132 where they shall be 1-1/8"$\phi$ ASTM A490 bolts. All plate material shall be ASTM A514.
A514 Plate - 7/8" Ø A490 Bolts

Fastener failure

Plate failure

\[ \frac{A_n}{A_s} = 0.53 \]

Joint Length, inches

Figure 1
BEHAVIOR OF HYBRID BOLTED CONNECTIONS

I. Scope of Investigation

1. Introduction

Up to the present time, investigations of riveted and bolted joints were mainly concerned with only one type of material being connected. However, as the structure becomes larger, for example, a multi-story building or a large bridge, the magnitude of the forces necessitate utilizing higher strength steels. Hence, it is of interest to examine the connections where two different kinds of steel are joined together. Neither analytical studies or existing tests provide any information on the behavior of such joints. It is of interest to examine the ultimate strength and load partition of hybrid steel connections. The following discussion will deal with this problem of the effect on ultimate strength of a joint when using two or more types of steel, or a hybrid connection.

2. Variables Studied

Previous studies have indicated that there were two main variables which effect joint behavior. (1) The first is joint length, or the number of bolts in line, and the second variable of importance is the $A_n/A_s$ ratio, or the ratio of the net area of steel material to the total bolt shear area.

In a hybrid connection, or a connection where two or more types of steel are fastened, there are two such $A_n/A_s$ ratios because there are...
two steels in the connection. The components of the joint are proportioned for the same load, and since the two steels have different yield stresses, the net areas for the two corresponding steels will differ.

In any combination of two steels, the material with the lowest yield point was selected as the base material. An initial $A_n/A_s$ ratio was chosen for the base material, which directly corresponds to an allowable bolt design stress, along with a number of bolts in line for any given joint. Once these two quantities were selected, the net area of the second material was then proportioned on the basis of its allowable stresses.

The two mentioned variables were studied using both A325 and A490 high strength bolts. The steels which were used in the analytical studies were A36, A440, and the A514. The steels were investigated in the following combinations, and with the higher strength bolts as indicated: A36-A440-A325, A36-A514-A325, A440-A514-A490, and A490-A514-A490.

3. Bolt Calibrations

Bolt calibrations had to be completed in order to proceed with the analytical studies, as the load deformation relationship is necessary initial information. The shear jig was designed so that the yield load would be the same both in the lap and main plates, in the same manner as a full size joint would be designed. The results of these calibration tests confirmed previous studies which showed that the shear strength was not affected by the connected materials. The only change
was in the deformation of the fasteners and this was a characteristic that was expected when using two different steels in the same joint.

II. Analytical Studies

1. Effect of Joint Length

   a. A325 Bolts

   One of the major variables was the influence of joint length on strength. Previous theoretical and experimental studies of joints of only one kind of steel showed that as the joint length (number of bolts in line) was increased, the average shear strength of the fasteners decreased.\(^1\) Figure 1 compares the theoretical studies of homogeneous A36 steel joint and the A440 homogeneous steel joint with the hybrid joints of A36 and A514 steel, and A36 and A440 steel fastened with A325 bolts. It is apparent that similar behavior exists for the hybrid connections.

   The theoretical studies summarized in Figure 1 are for geometric proportions which correspond to the bolt shear area being equal to the net plate area for A36 steel; i.e., \( \frac{A_n}{A_s} = 1.0 \). Also drawn is the curve for the homogeneous A440 steel joint at an \( \frac{A_n}{A_s} \) ratio of 0.80. These curves correspond to an allowable bolt stress of 22 ksi. As demonstrated in Figure 1, the only apparent difference in the various curves is what joint length the curves begin. This is due to the shifting of the plate failure boundary for the hybrid joints away from the previous location for the homogeneous joints. This behavior which is consistent in the studies conducted will be explained in detail further in the report.
b. A490 Bolts

Figure 2 summarizes the behavior of hybrid joints fastened with A490 bolts. In this case, the homogeneous joint is A440 steel with an $A_n/A_s$ ratio of 1.16 corresponding to an allowable bolt stress of 32 ksi. As was observed with the A325 bolt, an increase in joint length was accompanied by a decrease in the average shear strength of the fastener. The comparison is typical of the predicted behavior of hybrid joints of other geometric configurations.

2. Effect of Variation in $A_n/A_s$ Ratio

Previous experimental and theoretical investigations have shown that as the $A_n/A_s$ ratio decreased for any given joint length, the average shear strength of the fasteners also decreases. Similar behavior was expected for hybrid joints. In Figure 3, the homogeneous A440 steel joints are compared with the hybrid A36-A440 steel joints. The curves drawn correspond to allowable bolt stresses of 22 ksi, 30.25 ksi, and 41.25 ksi. Both the homogeneous and hybrid steel joint curves are referenced to the A440 steel material. As was expected, with a decrease in the $A_n/A_s$, the shear strength of the joints decreased. It is important to note that the hybrid joints and the homogeneous joints behaved in a similar fashion as long as the bolt failure occurred. The only significant difference was the location of the plate failure boundaries. The plate failure boundary defines the region at which an increase in net plate area will result in a bolt failure or where a decrease in net area results in failure by tearing of the plate. As the joint length
is increased and the geometric proportions are maintained, bolt failures occur. If the joint length is decreased, plate failure will occur. As indicated in Figure 9, the plate failure boundary has shifted to the right, indicating more joints will fail by plate failure than with the homogeneous joint. This is a result of the improved load distribution among the fasteners in the hybrid joint. This is reasonable because as the ultimate load is approached in the A440 steel plate, the A36 steel plates have not undergone as much inelastic deformation. As a result, the total differential deformations are less and the bolts are able to effect a more favorable redistribution and carry more load. This can perhaps be illustrated by Figure 4, in which factor of safety against failure (ultimate stress/allowable stress) is plotted against joint length. The two curves for the homogeneous joints, A36 and A440, are plotted. The dashed line curve is the hybrid joint, A36-A440. As previously explained, the hybrid joint's plate failure curve shifted to the right of the homogeneous A440 curve. This shift means a greater factor of safety is achieved in the hybrid joint, as shown in the curve, for a greater joint length compared to the homogeneous A440 joint. This reiterates the better performance of the A36-A440 combination of steels than the homogeneous A440 joint. These curves again are for the A325 bolt stress equal to 22 ksi.

III. Conclusions

The following summation of the analytical studies performed will be concerned with the hybrid joints A36-A440, A440-A514, and A36-A514 fastened with A325 bolts, and A440-A514, fastened with A490 bolts.
1. The hybrid joints behaved similarly to homogeneous joints. With an increase in joint length a decreasing average shear strength occurred. Also a decrease in the $A_n/A_s$ ratio caused a decrease in the average shear strength.

2. The average shear strength of high strength bolts used in a hybrid connection is at least as great as the shear strength of the bolt in homogeneous joints.

3. The major affect observed in the analytical studies was a shifting of the location of the plate failure boundary in the hybrid investigations. The direction and amount of shift depends directly on the hybrid materials in the joint.

IV. References

FIGURE 1

A36 AN/AS = 1.0

A325 BOLT: $F_v = 22$ ksi

A36 PLATE FAILURE BOUNDARY

SINGLE BOLT

A36 - A36

A440 - A440

(AN/AS = 0.80)

A36 - A514

JOINT LENGTH, INCHES
A440: AN/AS = 1.16

A490 bolts: $F_v = 32$ ksi

Figure 2
A325 BOLTS

FIGURE 3