1964

Summary report to Committee 10 of RCRBSJ, November 1964

Fritz Lab

LEHIGH UNIVERSITY INSTITUTE OF RESEARCH

Large Bolted Connections

SUMMARY REPORT TO COMMITTEE 10
OF THE RESEARCH COUNCIL ON RIVETED
AND BOLTED STRUCTURAL JOINTS

by

Project Staff

November 13, 1964

Fritz Engineering Laboratory Report No. 288.25

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LEHIGH UNIVERSITY
BETHLEHEM, PENNSYLVANIA, 18015

DEPARTMENT OF CIVIL ENGINEERING
FRITZ ENGINEERING LABORATORY

288.1 September 10, 1964

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

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

Gentlemen:

The chairman of Committee 10 has called a meeting for Friday, November 13, 1964 to be held here at Lehigh.

We would like to discuss at that time work completed during the past year and work that is currently in progress.

Several reports now in preparation will be distributed prior to the meeting and it is anticipated that these will be discussed. Also, as indicated in our letter of August 3, 1964 we would like to discuss report 288.7A "Criteria for Designing Bolted Joints (Bearing-Type)" at this meeting.

A copy of the agenda for the meeting will be mailed as a reminder, two or three weeks prior to November 13, 1964.

Sincerely yours,

John W. Fisher

John W. Fisher

JWF/va
cc: Messrs: C. D. Jensen, E. G. Wiles, R. C. Updegraff, J. L. Stinson, J. W. Burdell, Jr.
Members RCRBSJ

LEHIGH UNIVERSITY
BETHLEHEM, PENNSYLVANIA, 18015

DEPARTMENT OF CIVIL ENGINEERING
FRITZ ENGINEERING LABORATORY

288.1 October 30, 1964

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

Messrs:

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

Gentlemen:

RE: November 13, 1964 meeting of Committee 10, RCRBSJ

Attached is a copy of the agenda for the November 13, 1964 meeting to be held here at Lehigh. The meeting is scheduled to commence at 9:15 AM.

The meeting will convene in the University Center as was the case last year.

We would appreciate your returning the enclosed post-card indicating whether or not you plan to attend in order that we can make suitable luncheon arrangements. Also, please notify us if you desire hotel reservations.

Sincerely yours,

John W. Fisher

John W. Fisher

JWF/va
Encl:
cc: Messrs.

C. D. Jensen	K. H. Jensen	W. A. Milek
J. L. Stinson	E. G. Wiles	B. F. Kotalik
F. H. Dill	J. W. Burdell, Jr.	R. C. Updegraff

LARGE BOLTED JOINTS

SUMMARY REPORT TO COMMITTEE 10
OF THE RESEARCH COUNCIL ON
RIVETED AND BOLTED
STRUCTURAL JOINTS

by

Project Staff

(Not for publication)

This work has been carried out at 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.

Project Staff: L. S. Beedle, G. L. Kulak,
J. W. Fisher, G. H. Sterling,
R. Kormanik

December 1964

Fritz Engineering Laboratory Report No. 288.25

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LARGE BOLTED JOINTS, PROJECT 288, LEHIGH UNIVERSITY
STATUS OF VARIOUS PHASES

Phase and Topic	Remarks	Tests Performed	Tests to Be Completed	Analytical Work	Reports
I. Compact Joints of A440 Steel and A325 Bolts. E Series	Authorization: Committee 10 Minutes 4/19/60 11/19/61 Completed	6 Joints E41a, E41b E41c, E41e E41f, E41g	None		288.4 (IABSE) 288.7 288.7A 288.10 288.17
II. Long Joints of A440 Steel and A325 Bolts Variable width E Series	Authorization: Committee 10 Minutes 4/19/60 1/19/61 Completed	12 Joints E41, E46, E71 E74, E741, E721, E722, E101, E131, E161, E163, E164	None		288.4 (IABSE) 288.7 288.7A 288.10 288.17
III. Inspection of Bolts Tightened by the turn-of-nut method E Series	Authorization: Committee 9 Minutes 1/30/60 Committee 10 Minutes 1/30/62 Dormant	Torque Measurements with a hand torque wrench on bolts of phase II	Tests to determine the "breakaway" and kinetic torque		288.1 288.2
IV.(a) Calibration of A325 Bolts E and F Series	Authorization: Committee 10 Minutes 1/30/62 Committee 10 Minutes 11/7/62 Completed	Direct and Torqued Tension tests of 170-A325 bolts	None		271.21 (ASCE) 288.5 (ASCE)

Phase and Topic	Remarks	Tests Performed	Tests to Be Completed	Analytical Work	Reports
IV.(b) Calibration of A354 and A490 Bolts J&K Series	Authorization: Committee 10 Minutes 1/30/62 11/7/62 Completed	Direct and Torqued Tension tests of 7/8" and 1" dia. bolts	None		288.9 288.11 288.19
V. Shear Tests of A354 and A490 Bolts in A440 and Constructional Alloy Steel Jigs J&K Series	Authorization: Committee 10 Minutes 11/7/62 Completed	42 Compression Jig Tests 39 Tension Jig Tests	None		288.14 288.12 288.20
VI. Joints of Constructional Alloy Steel Connected with A325 Bolts F Series	Authorization: Committee 10 Minutes 11/7/62 Active	6 Joints F42a, F42b, F42c, F42d, F42e, F42f	Long Joints to be specified	Prediction of the behavior of T1 plates with holes	None
VII. Joints of Constructional Alloy Steel Connected With A490 Bolts J Series	Authorization: Committee 10 Minutes 11/7/62 Active	4 Joints J42a, J42b, J42c, J42d	Long joints to be specified	Prediction of the behavior of T1 plates with holes	None
VIII. Joints of A440 Steel Connected With A490 Bolts K Series	Authorization: Committee 10 Minutes: 11/7/63 Active	K42a, K42b, K42c, K42d	Long joints specified in proposal to Committee 10, September 28, 1964	Computer analysis of the effect of pitch, joint length and A_s/A_n on joint strength. Based on method given in 288.10. This is now in progress	288.7A

Phase and Topic	Remarks	Tests Performed	Tests to Be Completed	Analytical Work	Reports
IX. Co-operative Study with the University of Illinois Calibration of A490 Bolts	Authorization: Committee 15 Minutes: 2/14/63 Completed	50 tests of 7/8" x 5-1/2" and 7/8" x 9-1/2" A490 bolts, in direct and torqued tension	None		288.14 288.15 288.23
X. Joints of A440 Steel Connected With High-Strength Rivets H Series	Authorization: Annual proposal to the Pennsylvania Department of Highways Active	None	Shear tests of Rivets in A440 Steel	Computer analysis of the effect of pitch, joint length, and A_s/A_n. Comparisons to be made to the behavior of A440 steel fastened with high strength bolts	None
XI. Hybrid Connections Two or more different steel types fastened with high strength bolts I series	Authorization: Annual proposal to the Pennsylvania Department of Highways Active	None	Shear tests of A490 bolts in A440-T1 jigs and of A325 bolts in A440-T1, A440-A7 and A7-T1 jigs	Computer analysis of the effect of pitch, joint length, and A_s/A_n on joint strength.	None

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Phases Now Completed

Phases I, II	Joints of A440 steel and A325 bolts. E series.
Phase IV(a)	Calibration of A325 bolts, E and F series.
Phase IV(b)	Calibration of A354 and A490 bolts, J and K series.
Phase V	Shear Tests of A354 and A490 bolts in A440 and constructional alloy steel, J and K series.
Phase IX	Co-operative study with the University of Illinois. Calibration of A490 bolts.

Phases Now Active

Phase VI	Joints of constructional alloy steel connected with A325 bolts. F series.
Phase VII	Joints of constructional alloy steel connected with A490 bolts. J series.
Phase VIII	Joints of A440 steel connected with A490 bolts, K series.
Phase X	Joints of A440 steel with high strength rivets. H series.
Phase XI	Hybrid connections in which two or more different grades of steel are fastened. I series.

Phases Not Initiated

Series C	Static tests of shingle joints fastened with A325 bolts.
Series S	Tests of large diameter bolts.

Phases Not Yet Formulated:

(a) Effect of punched holes
(b) Tightness and coefficient of friction as influenced by broomed joints
(c) Fatigue of large joints

Project 288

Summary of Reports - To November 1964

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, <u>Publications</u>, 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, <u>Journal of the Structural Division</u>, ASCE, 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 (This report is an expanded version of 288.7, and includes new concepts and analysis).

+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 Plate 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

288.13 J. J. Wallaert, G. H. Sterling, J. W. Fisher
"The History of Internal Tension in Bolts Connecting Large Joints"
(In preparation)

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

*288.15 G. H. Sterling, J. W. Fisher
"Tests 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
(Summarizes portions of 288.10 and 271.14 and is intended for publication by ASCE).

288.18 J. W. Fisher
"Predicting the Behavior of Plates and Fasteners"
(In Preparation)
(Will present the development of the mathematical models used to predict the behavior of plates and bolts throughout the elastic and inelastic ranges. This will summarize portions of 288.10 and will be intended for publication by ASCE).

+288.19 R. J. Christopher, J. W. Fisher
"Calibration of Alloy Steel Bolts"
September, 1964
(A report intended for publication by ASCE. It includes all the material reported in 288.9 and 288.11).

+288.20 J. J. Wallaert, J. W. Fisher
"The Shear Strength of High-Strength Bolts"
July 1964.
(A report intended for publication. It includes all the material reported in 288.12).

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 Janiero. Presents a summary of American design concepts and summarizes tests of bolted connections and the development of installation procedures).

+288.23 G. H. Sterling, E. W. J. Troup, E. Chesson, Jr., J. W. Fisher
"Calibration Tests of A490 High Strength Bolts"
August 1964
(This report gives the results of a test series carried out in co-operation with the University of Illinois. It includes all the data given in 288.15).

288.24 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.

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

*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.

TESTS OF LONG A440 STEEL BOLTED BUTT JOINTS

Introduction:

Phase II of the Large Bolted Connections project at Lehigh is concerned with Long Joints of A440 Steel and A325 Bolts. The results of several tests from this phase have been reported[1] in a recent publication, but since that time four additional tests of long joints have been conducted. The data from these tests have not yet been made generally available, although the results were briefly mentioned in a recent Fritz Laboratory Report[2].

DESCRIPTION OF TESTS

i. General:

In all previous E series tests of Phase II, Large Bolted Joints, the ratio of net plate area (A_n) to total bolt shear area (A_s) was maintained constant, at a value of 1.0. In the tests reported here both the A_n/A_s ratio and number of bolts in line were varied. Of the four joints tested two had an A_n/A_s ratio of 0.8. The remaining two had an A_n/A_s ratio of 1.2. Two joints had seven bolts in line, the remaining two having sixteen bolts in line. Since the pitch was 3-1/2" for all four joints this corresponded to joint lengths of 21" and 52-1/2". The joints with 16 bolts in line had nominal grips of 8 inches, whereas those with 7 bolts in line had grips of 4 inches. All four joints had two lines of 7/8" diameter bolts.

ii. Material Properties:

The A440 steel plate used in these joints was from the same heat used for the previous E Series tests. This plate material had an average static yield stress of 43 ksi and an ultimate strength of 76 ksi. The behavior of plate elements with holes was predicted by the method outlined in Reference 2. Consequently no actual calibration tests of plates with holes were required.

The 8A and H lot A325 bolts used as fasteners had been calibrated in both direct and torqued tension[3] as well as in double shear[4].

iii. Fabrication:

All shop work necessary for the fabrication of these joints was done by a local firm. The plates were flame cut to rough size, and milled to final dimension. These final dimensions were accurate to within 99.5% as shown by subsequent measurements. All oil and grease was removed from the plates to establish a clean faying surface.

Alignment of holes was assured by clamping all the plates in a particular joint and drilling through the entire assembly. All holes were drilled to 15/16" diameter to allow 1/16 inch clearance for the 7/8 inch bolts. Included in Table 2 are the dimensions of all these joints.

iv. Assembly:

The bolting up operation was done at Fritz Lab by technicions on the lab staff. The bolts were installed by the turn-of-the-nut method. All bolts were installed by turning 1/2 turn from snug.

Complete records of bolt elongations were taken. These elongations were related to the load-deformation curves to determine actual preload in the bolts installed in each joint.

v. Instrumentation:

The instrumentation used was similar to that described in previous work[1]. These are briefly mentioned below, and shown schematically in Figure 1.

(1) electric strain gages (SR-4) to measure strains in inner and outer plates.

(2) slide bar extensometers to measure plate elongations between each transverse row of holes.

(3) dial gages for measuring slip between the main and lap plates, and for measuring total joint elongation.

TEST PROCEDURE

The test procedure used in these tests was essentially the same as described in Reference 1. However, two days each were required to test the two longer joints, E163 and E164. On the first day of testing the joint was loaded beyond slip and up to the yield regions. The load was then reduced to initial gripping load (about 25 kips) and held overnight. On the second day the load was increased rather rapidly to the highest load of the previous day, and then increased in specified increments until joint failure occurred. The joint elongation, pitch elongations and slip between main and lap plate data were recorded at each load increment.

Joints E721 and E722 were tested in the same manner, but required only one day for completion.

TEST RESULTS

The test results are summarized in Table 1. The load-deformation characteristics of each joint are shown in Figures 2 and 3.

Joint E721, with an A_n/A_s ratio of 0.8, slipped under a load of 366 kips, which corresponded to a slip coefficient of 0.28. The "shear stress" in the bolts at slip was 21.7 ksi. This joint reached an ultimate load of 1070 kips, and failed by a single fastener unbuttoning. The average bolt shear stress at failure was 69.4 ksi.

After joint E722 had been installed in the testing machine it was noted that the entire joint was slightly warped. As load was applied the strain gage readings indicated that 55% of the load was being transferred through the west lap plate to the west main plate. The last strain gage readings were taken at a joint load of 300 kips, only 28 kips below the major slip load. However, for consistency, the reported slip coefficient of 0.24 is based on an assumed equal load transfer. This gave a "shear stress" at slip of 19.4 ksi.

Joint E722 was the only one of this series that behaved in this manner. Strain gage readings taken on joints E721 and E164 indicated that one side of the joint was carrying 50.5% of the load, just prior to slip. For joint E163 the transfer of load was exactly symmetrical.

An ultimate load of 1270 kips was reached by E722. The joint failed by sudden shearing of all fasteners, at an average shear stress of 75.2 ksi. The joint had elongated 0.55", in a total gage length of 28", at ultimate load.

Joint E163, A_n/A_s of 0.8, slipped under a joint load of 796 kips.

This corresponded to a slip coefficient of 0.27, and an average "shear stress" of 20.7 ksi. This joint reached an ultimate load of 2180 kips, at a deformation of 1.05" in a gage length of 59.5", and failed by a single fastener unbuttoning. The average shear stress at ultimate load was 56.5 ksi.

Major slip for joint E164 occurred under a load of 850 kips. This gave a slip coefficient of 0.29, and an average "shear stress" of 22.4 ksi. This joint, having an A_n/A_s ratio of 1.2, reached 2785 kips as an ultimate load, and failed with a single fastener unbuttoning. The joint had elongated 0.88", in a length of 59.5", at failure.

Joints E721, E722, E163 slipped into complete bearing very suddenly, and with a loud noise. Joint E164 did slip suddenly, as can be seen in Figure 4, but did not go into complete bearing immediately. There was no doubt, however, that major slip had occurred.

ANALYSIS OF RESULTS

i. Joint Slip:

Slip coefficient is defined by the equation $K_s = \frac{P_s}{M\Sigma T_i}$, where K_s is the slip coefficient, P_s is the major slip load, M is the number of slip planes, and ΣT_i is the sum of the initial bolt tensions. In these tests the values for M, ΣT_i were known, P_s was measured, and then K_s was calculated.

At the Research Council meeting in Chicago, March, 1964, some questions were raised[5] about the variations between slip coefficients reported by Lehigh and the University of Washington. Lehigh's data has been consistently higher than the Washington investigators had reported. For this reason special precautions were taken to determine the load-deformation characteristics of the joints up to slip, as well as beyond the slip load.

The joints were loaded to within 10 to 15% of the expected slip load, and then unloaded to determine if any permanent set had taken place. As can be seen from Figures 4 and 5 some permanent set, as indicated by the slip gages, had indeed taken place. However, as is evident from the overall joint deformation curves shown in Figures 2 and 3 the influence of this initial movement had no significant influence on the joint load-deformation behavior. This permanent set, measured by the very sensitive 1/10,000 dials, was not, in fact, even detected on the 1/1,000 dials used to measure joint elongation, as is shown in Figure 5.

The strain compatibility conditions indicate that larger deformations are occurring at the joint ends and that eventually there is a relative displacement of certain contact points on the faying surfaces near the ends of the joint[6]. This expected behavior is observed in our data. As the additional load is applied this slip zone proceeds inward from the joint ends. When the maximum static frictional resistance is reached over the entire faying surface major slip occurs.

Apparently the cause of the difference between Lehigh's data and the results reported by the University of Washington lies in the definition of the term "slip". In Reference 5 "slip" was defined as first movement of a 1/1,000 "dial, installed in a manner similar to the gages used at Lehigh. Thus the "first movement" of these dials were recording the relative displacements that occur near the ends of the joint before the maximum static frictional resistance is exceeded. These small end displacements, shown as departure from linearity in Figures 4 and 5, occur at loads considerably below the major slip load. As additional load was applied a sudden major slip, which are usually 15 to 25 times this small "first movement", occurred. This major sudden movement of the plates, a feature common to all our tests, has been taken as the slip load on the Lehigh data.

Also, it is important to note that the gages used to detect slip movement in the Lehigh tests gave readings to the closest 1/10,000 inch. This contrasts to the 1/1,000 inch gages used by Washington, and points up the obvious, but important, fact that "first dial movement" automatically ties the slip load to the gaging system, not to the joint behavior.

For the four tests being discussed the slip coefficient varied from 0.29 to 0.24. These values were slightly below the average values determined in the previous E series tests, as can be seen from Figure 6. One possible reason for the lower values is that the oxide film, formed on the plate surface during the storage period since the last E series test, may have caused slightly less frictional resistance.

Figure 6a gives a bar graph of these slip coefficients and compares these joints to the previous E Series joints. Figure 6b shows the average shear stress at the slip load for the same joints. All of these tests indicated a slip resistance above the currently specified[7] value of 15 ksi for static loading. Most of these tests gave a slip resistance above the 20 ksi specified for static and wind loading.

ii. Ultimate Joint Strength

The ultimate strengths of these joints had been predicted by using the computer solution discussed in Reference 2. The predicted values are compared to the actual test results both in Table 1, and in Figures 1 and 2. The largest variation was for joint E163, where the actual test result gave 100 kips greater load, or an increase of 4.7%, over the predicted value. In all these tests ultimate strength was considered to be the point at which there was a sudden failure of one fastener, or more.

The effect of joint length on the average bolt shear stress at failure is shown in Figure 7. As the joint length was increased from 21" to 52.5" the average shear stress at ultimate load decreased. This was predicted, as is seen by the solid lines, and again points out the accuracy of the solution presented in Reference 2.

CONCLUSIONS

The results of these tests have helped to support the conclusions reached in previous publications[1,2]. The important ones are summarized below.

1. The test results have shown excellent agreement with the predicted ultimate load values. This supports the validity and accuracy of the method outlined in Reference 2.

2. These tests gave slip coefficients varying from 0.24 to 0.29. There was no apparent variations caused by changing joint length or width.

3. An increase in the net section plate area, for a given shear

area, caused an increase in the ultimate load carrying capacity of the joint. This increase was of the order of 33% for the joints with 16 bolts in line, and about 20% for the joints with 7 bolts in line, when the A_n/A_s ratio was increased from 0.8 to 1.2.

REFERENCES

1. Fisher, J. W., Ramsier, P. O., Beedle, L. S.
STRENGTH OF A440 STEEL JOINTS FASTENED WITH A325 BOLTS
23rd Vol. of the "publication", International Association for Bridge and Structural Engineering, 1963

2. Fisher, J. W., Rumpf, J. L.
THE ANALYSIS OF BOLTED BUTT JOINTS
Fritz Engineering Laboratory Report No. 288.17, September, 1964

3. Rumpf, J. L., Fisher, J. W.
CALIBRATION OF A325 BOLTS
Proceedings ASCE, #3731, Vol. 89, ST.6, 1963

4. Wallaert, J. J., Fisher, J. W.
THE SHEAR STRENGTH OF HIGH STRENGTH BOLTS
Fritz Engineering Laboratory Report 288.20, July 1964

5. Chiang, K. H., Vasarhelyi, D. D.
THE COEFFICIENT OF FRICTION IN BOLTED JOINTS MADE WITH VARIOUS STEELS AND WITH MULTIPLE CONTACT SURFACES
University of Washington, College of Engineering, 1964

6. Steinhardt, O., Mohler, K.
VERSUCHE ZUR ANWENDUNG VORGESPANNTEN SCHRAUBEN IM STAHLBAU
II. Teil, Stahlbau-Verlags, 1959

7. Specifications for
STRUCTURAL JOINTS USING ASTM A325 OR A490 BOLTS
March, 1964

TABLE 1. TEST RESULTS

Item:	Units	E721	E722	E163	E164
Bolts: 7/8" dia., A325 heavy head, one washer.					
No. in line, n		7	7	16	16
Plates: A440					
Joint width	in.	8.59	12.02	9.06	13.42
pitch	in.	3.50	3.50	3.50	3.50
grip	in.	4.0	4.0	8.0	8.0
joint length	in.	21	21	52.5	52.5
A_n/A_s:					
Design	-	0.80	1.20	0.80	1.20
Actual	-	0.805	1.21	0.805	1.20
Slip Load	kips	366	328	796	850
Ave. "Shear Stress" at Major Slip	ksi	21.7	19.4	20.7	22.4
Slip Coefficient	-	0.28	0.24	0.27	0.29
Ultimate Load					
Predicted	kips	1078	1270	2080	2720
Actual	kips	1070	1270	2180	2785
Type of Failure	-	One bolt unbutton-ed	All bolts sheared	One bolt unbutton-ed	One bolt unbutton-ed
Ave. Shear Stress at Ultimate Load	ksi	69.4	75.2	56.5	72.2
Ultimate Shear Stress of a single bolt (in a tension jig)	ksi	77.0	77.0	79.0	79.0

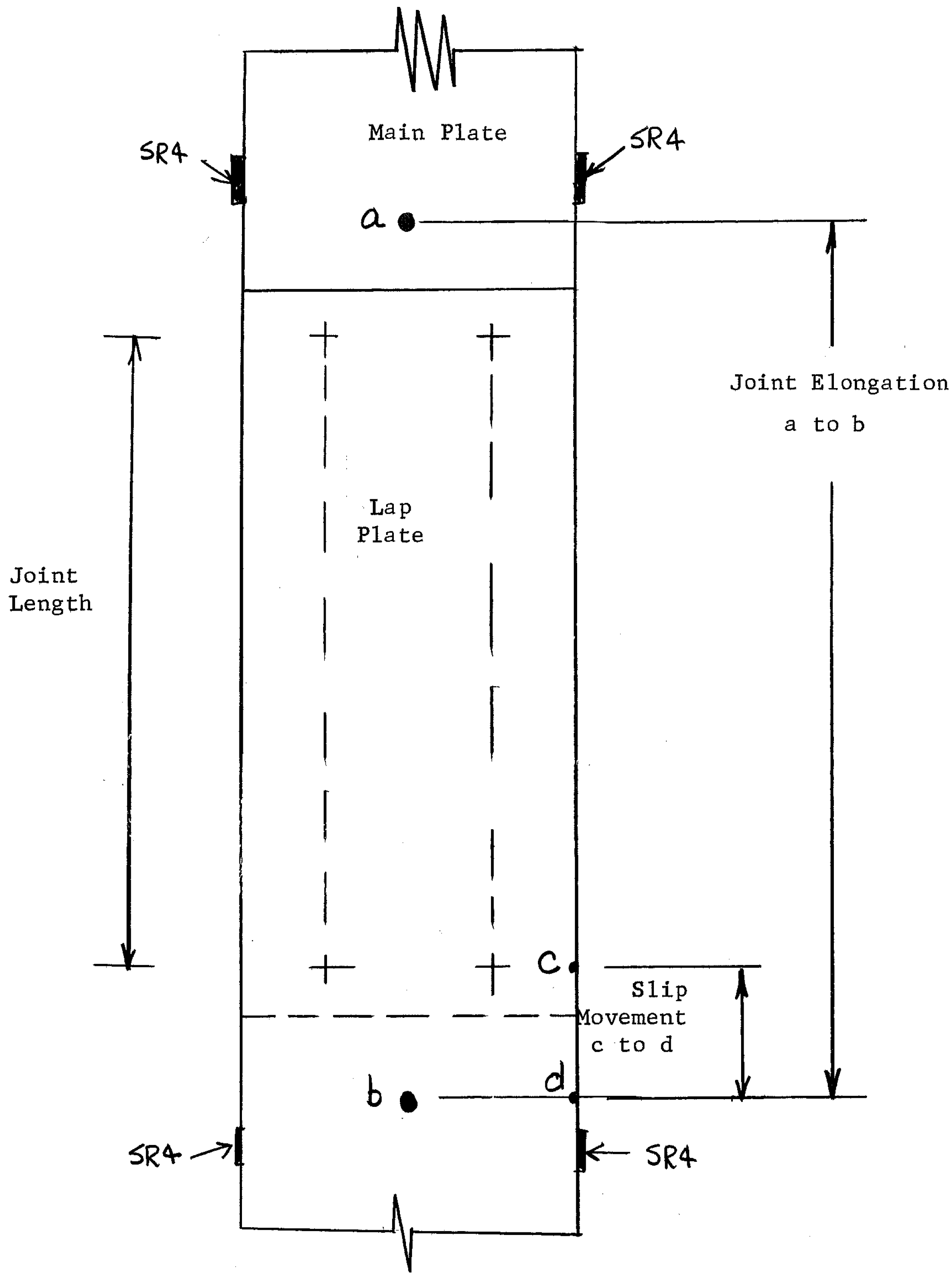


Figure 1. Meaning of terms "joint length", "joint elongation", and "slip movement" as used in the following figures. Also the location of the SR4 strain gages.

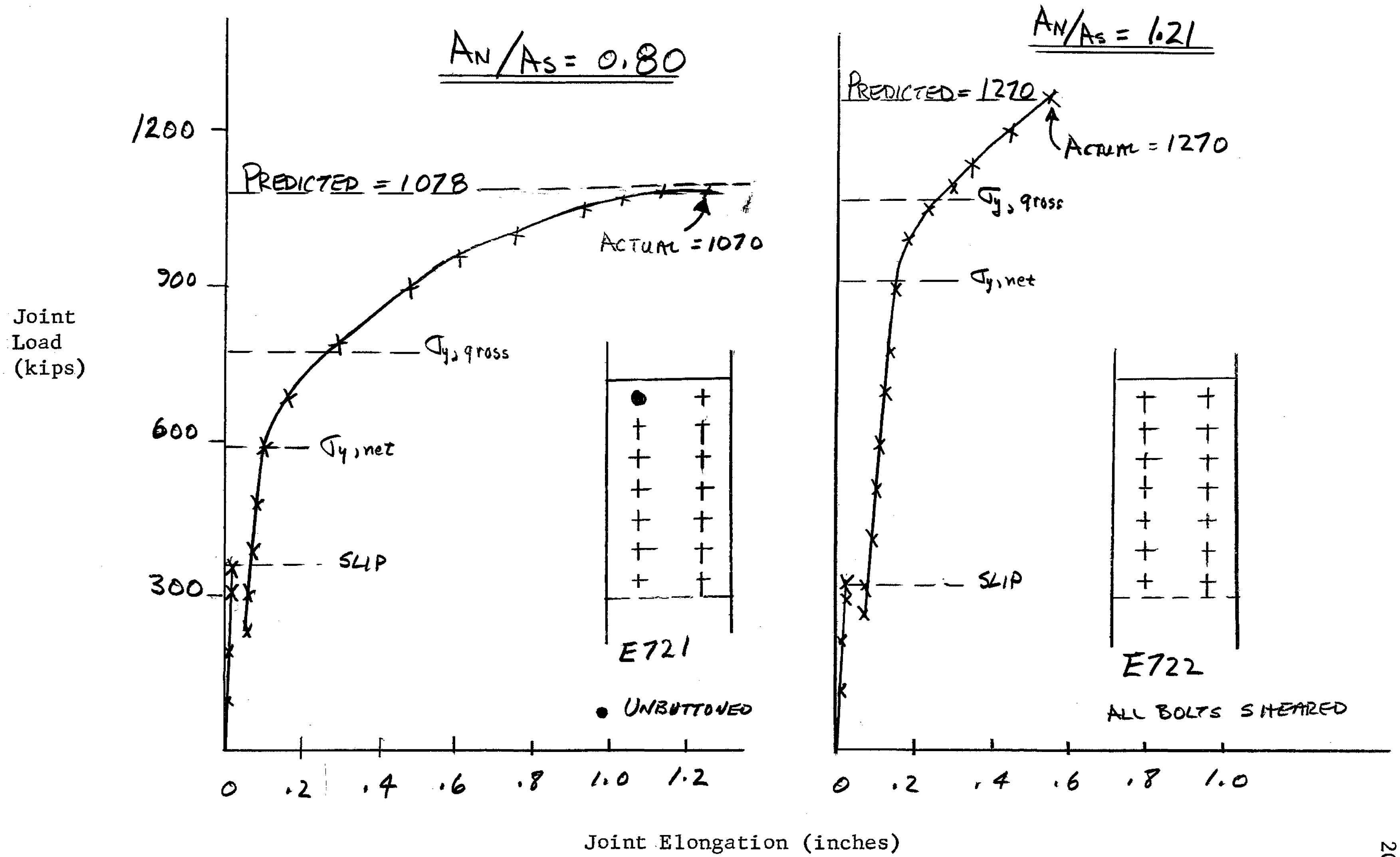


Figure 2. Joint load-joint elongation relationships for joints E721 and E722.

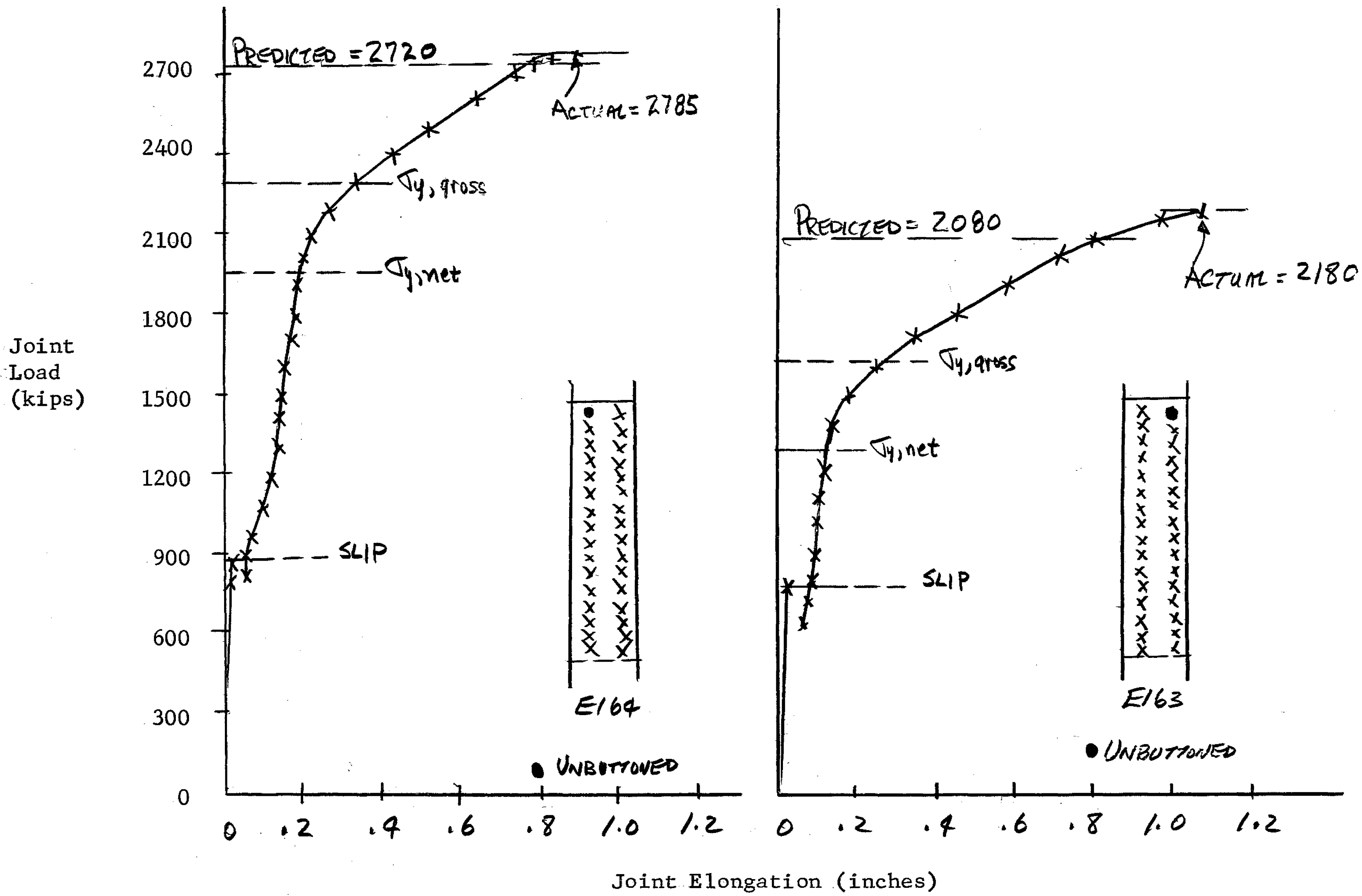


Figure 3. Joint load-joint elongation relationship for Joints E163, E164.

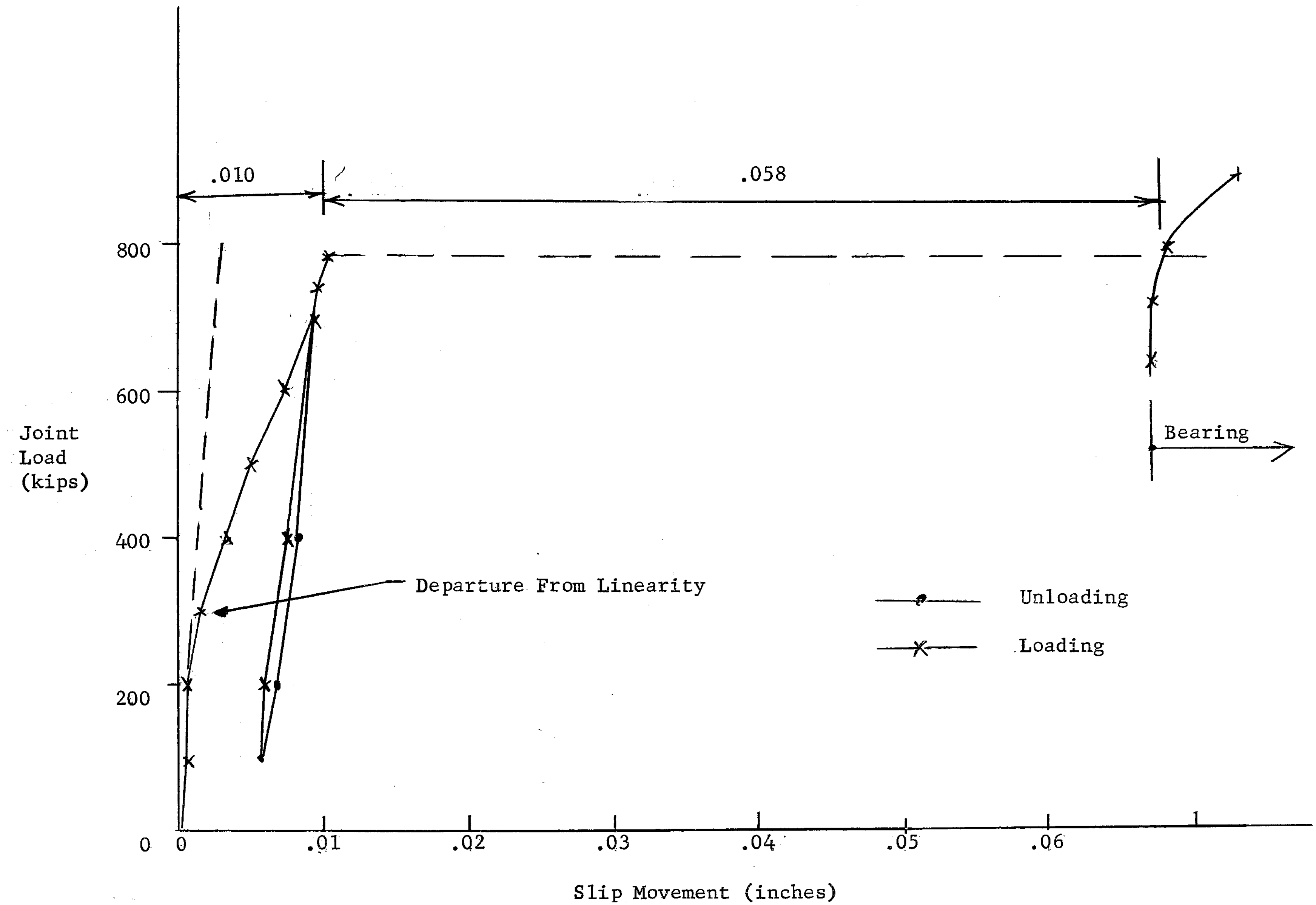


Figure 4. Joint E163. Joint Load vs. slip movement.

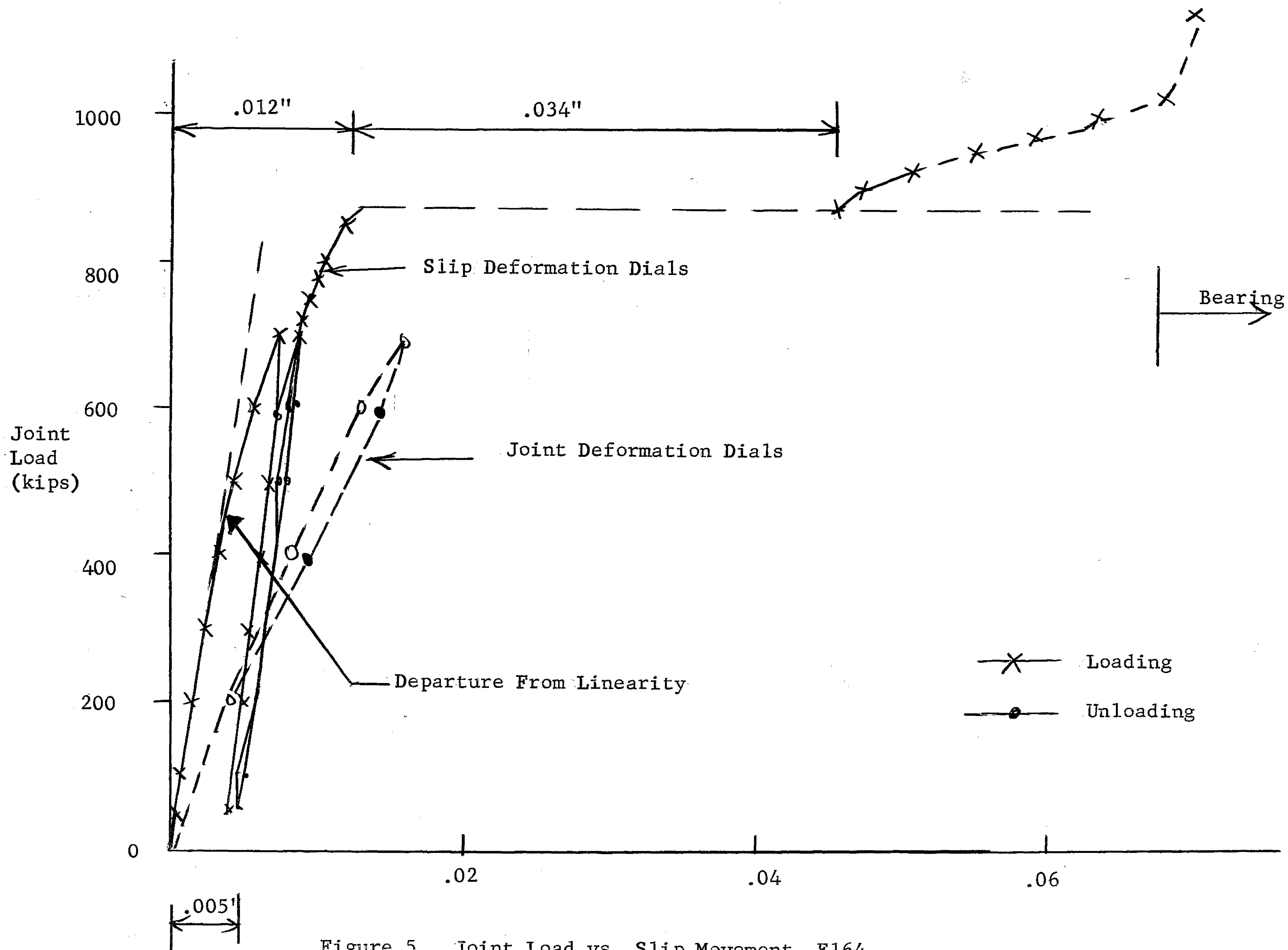


Figure 5. Joint Load vs. Slip Movement, E164

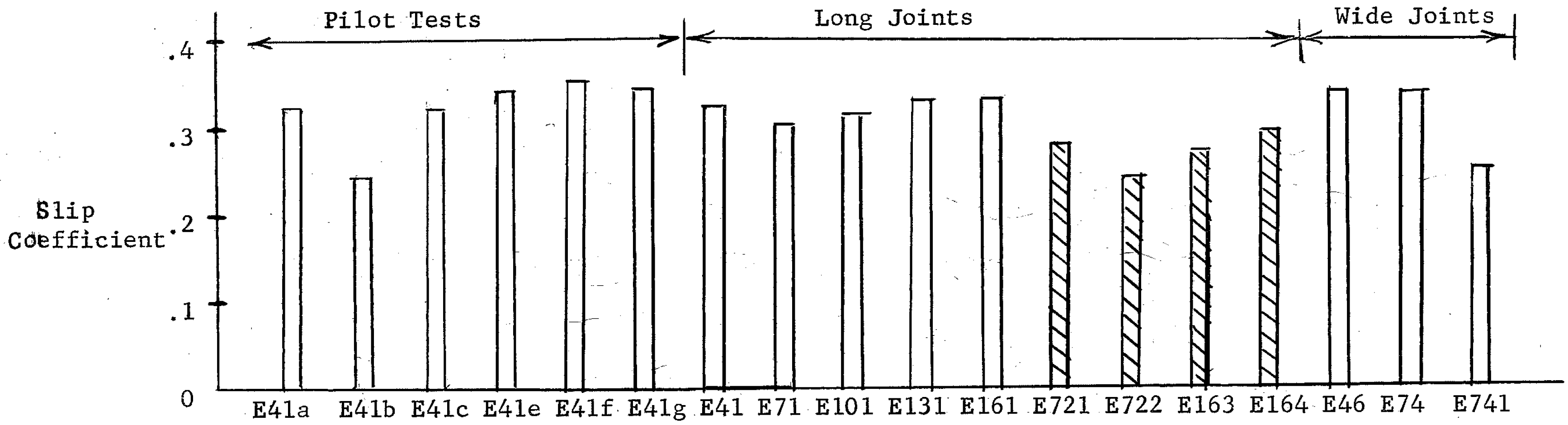


Figure 6a

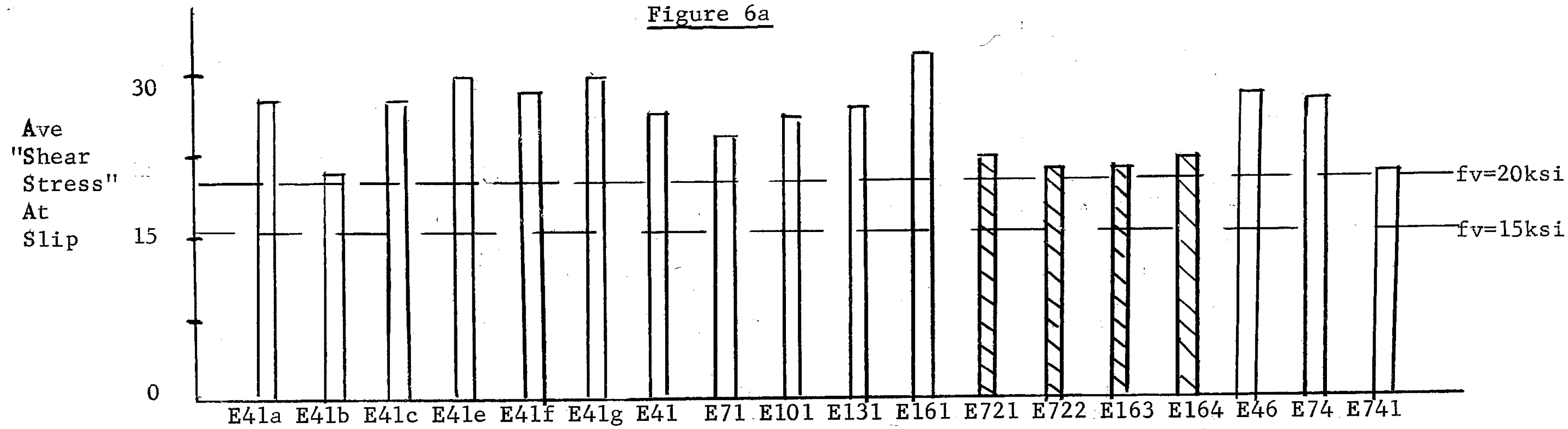


Figure 6b

Figure 6. Slip Resistance of Bolted Joints

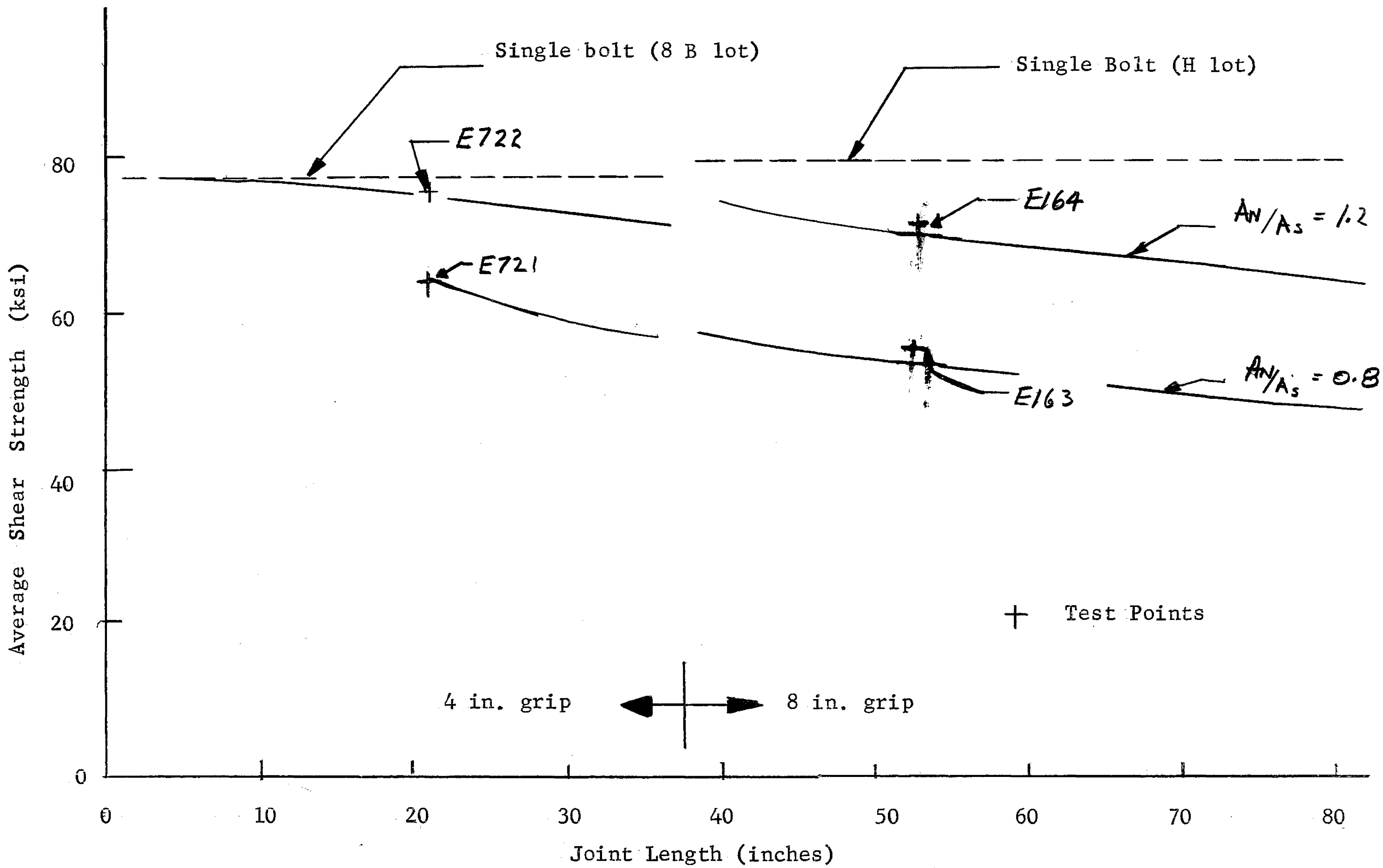


Figure 7. Effect of Variation in A_n/A_s. A440 steel-A325 bolts.

Constructional Alloy Steel Joints Connected with High-Strength Bolts

Introduction

The equations governing the partitioning of load among fasteners in a mechanically fastened joint are dependent upon the load-deformation relationships for the bolt and for the connected material. It has been found that the type of connected material does not affect the ultimate capacity of the fastener. Thus, in extending the present analytical expressions for load partitioning, it is felt that we need only examine the change in the plate load-deformation relationship due to the change in plate material.

The analytical model used in Reference 1 gave excellent results when used to predict the stress-strain relationship of the plate calibration coupon when this material was ASTM A 7 or A 440 steel. However, it has been found that it does not fit the test data obtained when constructional alloy steel was used.

Tests to Date

A considerable number of plate calibration tests have been performed on material of constructional alloy steel. These tests are summarized below:

Designation	Thickness in.	Width in.	Hole Dia. in.
J 42 A	1.03	3.43	1.07
J 42 B	1.03	3.59	1.08
J 42 C	1.02	3.74	1.07
J 42 D	1.02	3.89	1.07
F 42 A	1.03	2.78	1.21
F 42 B	1.03	3.19	1.21
F 42 C	1.03	3.37	1.21
F 42 D	1.03	3.58	1.21
F 42 E	1.03	3.79	1.21
F 42 G	1.03	3.98	1.21

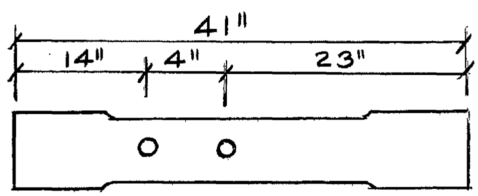


Plate Calibration Specimen

The model used in Reference 1 was:

$$\sigma = \sigma_y + (\sigma_u - \sigma_y)\left[1 - e^{-(\sigma_u - \sigma_y)\left(\frac{g}{g-d}\right)\frac{e}{d}}\right]^{3/2} \qquad \text{(Eqn. 1)}$$

Without defining each term, we may note that the expression on the right-hand side of the equation is a function of -

1. σ_y , the yield point stress.
2. σ_u , the ultimate stress.
3. g/(g-d) , the plate-hole geometry.
4. e/p = total deformation in pitch/pitch length = strain.

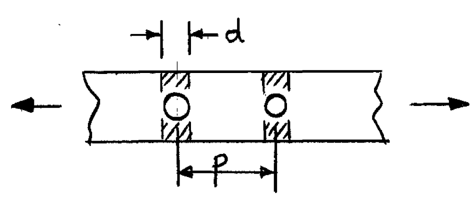
Although this model did not enable us to predict the calibration curves for the constructional alloy steel tests, it could reasonably be expected that any future model would follow the same general form.

Development of the Analytical Model

It was particularly noted during the constructional alloy steel tests that yielding was confined to relatively narrow bands extending from the holes to the plate edges at approximately 90^{o} to the load axis. This is in contrast to the yield bands at 45^{o} to the load axis that were observed during the plate calibration tests of A7 and A 440 steels. In other words, with constructional alloy steel, the region between the holes remained elastic from the onset of yielding up to the time of ultimate strength.

For high-strength alloy steel plate calibration specimens then, the total strain in a pitch length can be thought of in two parts. One is the elastic strain occuring in the region between the holes, the other the plastic strain. The former will be small in comparison to the plastic strain for normal pitch lengths and will be neglected for the time being. The plastic strain can be expressed as;

$$\epsilon_p = \frac{e - e_y}{d}$$



where e = measured deformation in pitch

e_y = elastic deformation

d = hole diameter

The model proposed on this basis is

$$\sigma = \sigma_y + (\sigma_u - \sigma_y)\left[1 - e^{-(\sigma_u - \sigma_y)\epsilon_p}\right]^c \qquad \text{(Eqn. 2)}$$

-note that $g/(g - d)$ is absent: plate-hole geometry is thought to have no significant effect.

-C is a constant to be evaluated from a regression analysis eventually, trial-and-error at this stage.

This expression was used in conjunction with the test data previously obtained. Using a value of C = 1/3, good correlation was obtained for all cases except J 42 A and J 42 B. A typical curve is shown in Figure 1. Specimens J 42 A and J 42 B were the first and third pieces tested in the program and the results were open to question. Therefore, two specimens of identical geometry and from the same material as J 42 A and J 42 B were made and tested. The analytical model closely predicted the results from these duplicate specimens.

Future Work

It is proposed that analytical studies now be started to determine load-partitioning among fasteners in hypothetical joints of constructional alloy steel. If this is undertaken, it is hoped that some experimental work could be done in order to verify the theory.

References:

1. "The Analysis of Bolted Plate Splices", by John W. Fisher, Fritz Engineering Laboratory Report No. 288.10, Feb., 1964.

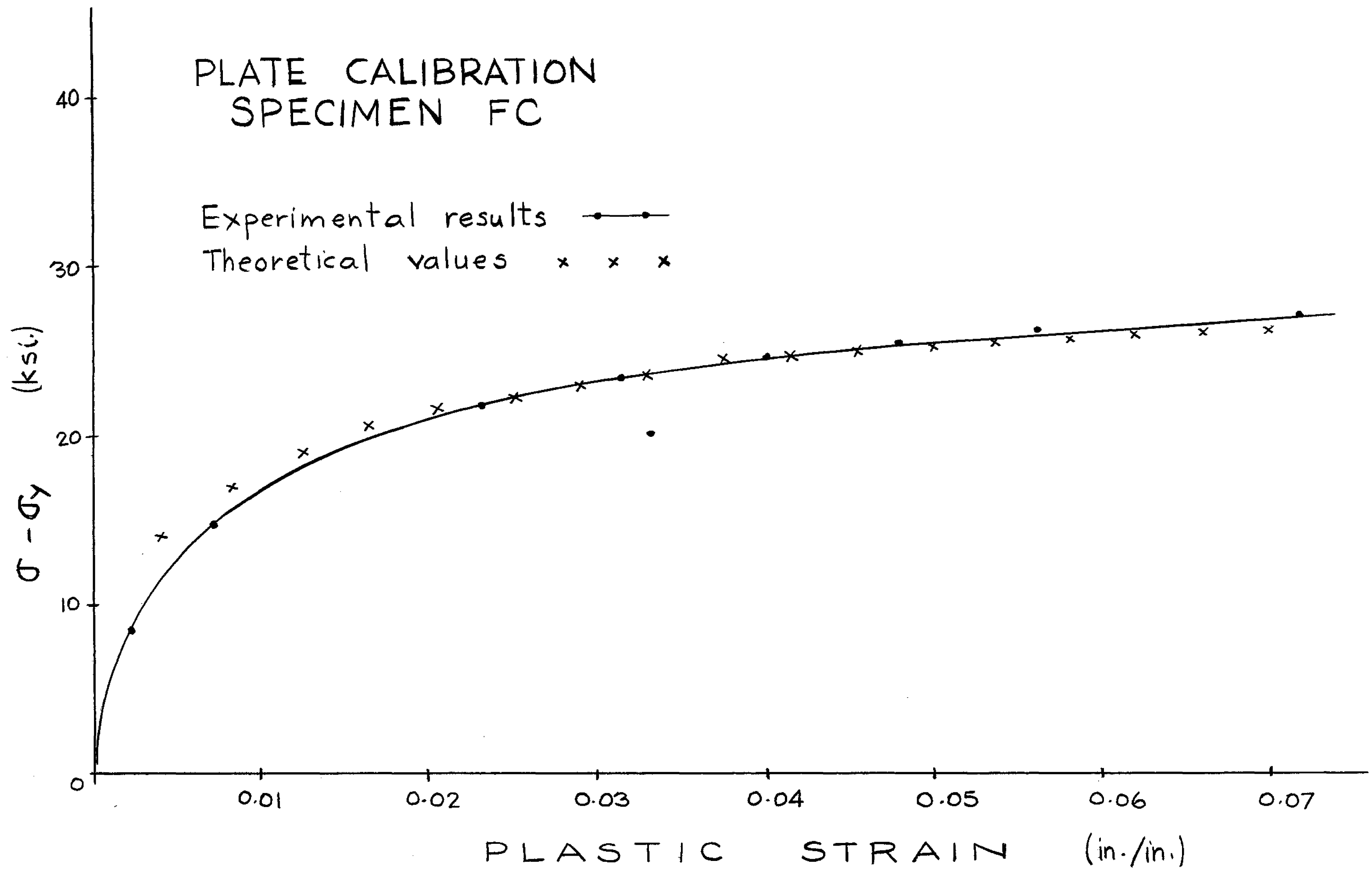


FIG. 1 PLATE CALIBRATION CURVE

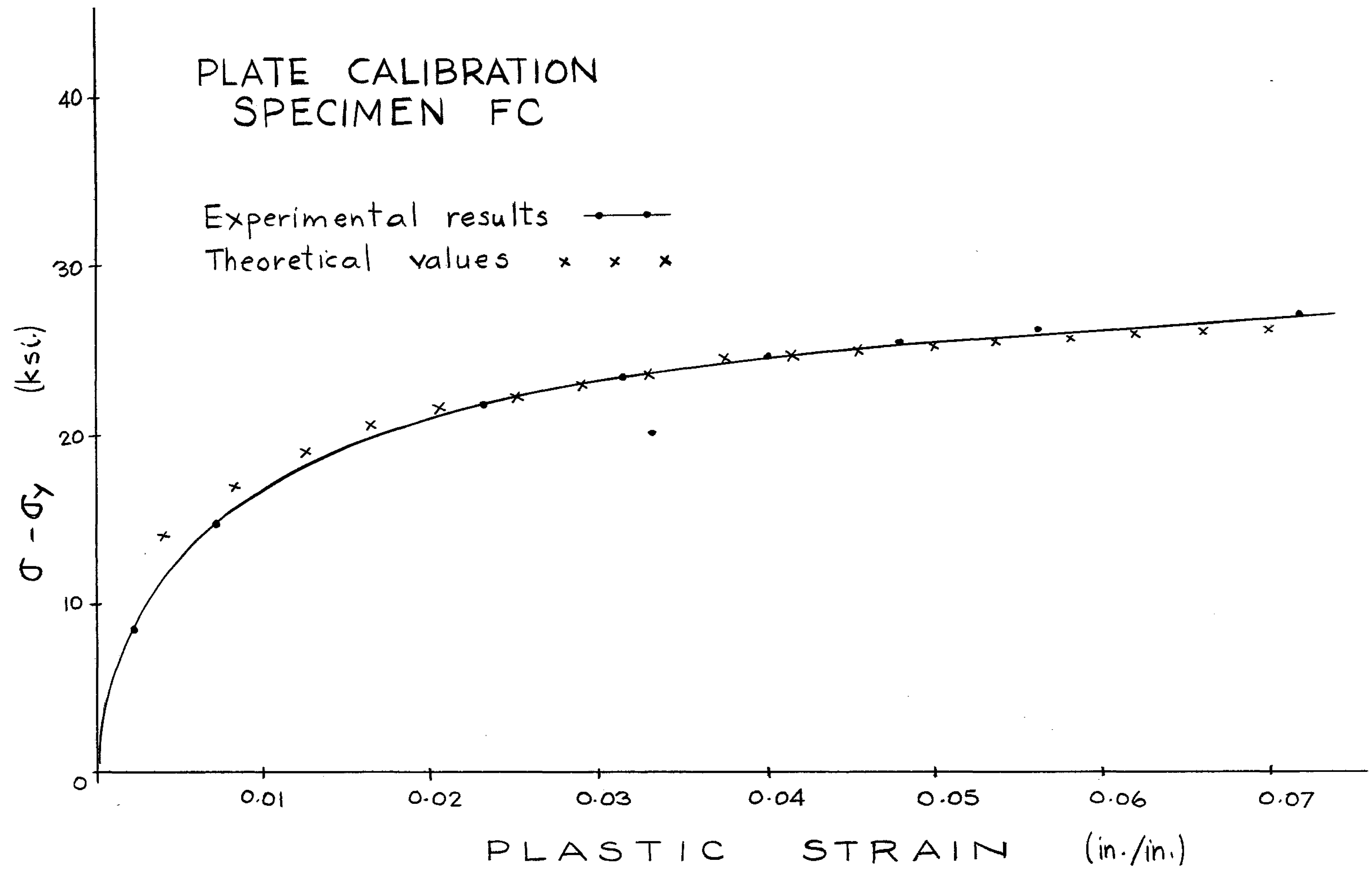


FIG. 1 PLATE CALIBRATION CURVE

STUDIES OF A440 STEEL JOINTS CONNECTED WITH A490 BOLTS

INTRODUCTION

A discussion of A440 steel joints connected by A490 bolts was given in a recent proposal(1) to Committee 11. Tests of compact joints were discussed as well as several variables which could be expected to influence joint behavior. Four large joints were proposed for testing, and analytical studies were outlined.

ANALYTICAL WORK

Several hypothetical joints were analyzed to determine the effect caused by varying the pitch, varying the joint length and changing the A_n/A_s ratio. The A440 steel plate was assumed to have a yield stress of 43 ksi and an ultimate strength of 76 ksi. This was the same as the material used in the proposed test joints. These hypothetical joints were assumed to be connected with K lot bolts, whose shear properties are reported in Ref. 2. All the hypothetical joints so far analyzed were considered to be fastened with 7/8 in. diameter fasteners.

The results of the analytical studies are shown graphically in Figs. 1 and 2. Figure 1 shows the relationship between average bolt shear stress at ultimate joint load and joint length, with the pitch length being varied. This figure indicates that changing the pitch length, in itself, does not cause a major change in the average shear stress. The important factor is joint length which is, of course, controlled by pitch length. This is not to say that the ultimate load capacity of the joints with 10 bolts at a pitch of 3½ inches is the same as a joint with 10 bolts at a pitch of 5¼ inches. This figure merely shows that, with A_n/A_s equal to 1.50, at a joint length of 48" the average shear stress at ultimate load is about 92 ksi for all joints.

Figure 2 shows the effect of varying the A_n/A_s ratio, on the average shear stress at ultimate joint load. This figure gives typical values for connection of A440 steel and A490 bolts. In this figure the A_n/A_s values of 0.82 and 1.16 are of interest. These values correspond to allowable bolt shear stresses of 22.5 ksi and 32 ksi respectively, and an allowable tensile stress of 27.5 ksi in the A440 plate. These values are currently specified for friction and bearing type joints, respectively, in the most recent specification(3). Also plotted in this figure is the expected behavior of the proposed test connections.

Future analytical work will establish the relationship between average bolt shear stress and joint length for a wide variation in A_n/A_s values, as well as for variations in pitch length and joint length. Also, comparative studies between joints of A7 steel and A490 bolts, and A440 steel and High Strength Rivets, will be made. These latter two studies will be strictly analytical; however, four joints of A440 steel connected with A490 bolts have been ordered and will be tested to verify the analytical work.

FUTURE TESTS

Based on the above preliminary analysis four test joints have been designed and ordered. These joints should be received and tested prior to March, 1965. The specimens were described in Ref. 1.

Joints K133 and K191 have gage widths of 8.36 inches, or about 9½ bolt diameters. The analytical model used to predict the ultimate joint load depends on the accuracy with which the load-deformation relationship of plates with holes can be given. There is good reason to believe that this model is accurate for all gage widths. Consequently the joint width itself is not expected to alter the accuracy of the ultimate load prediction. Admittedly these joints are somewhat wider than would be currently encountered in structural connections. However, if the allowable shear stress for A490 bolts is increased to 45 ksi for example, joints of this width will certainly be required for anything over 12 bolts in line. Indeed a joint with twenty 7/8" A490 bolts in line designed according to the 1964 Specification[3] would be 7.94" wide.

The predicted ultimate load values, given in Fig. 3, are based on shear properties of the K lot bolts. In actual fact these joints will be connected with the AB lot 7/8 inch diameter bolts[4]. The shear properties of these bolts have yet to be determined, but they will likely be very similar to the K lot used in the analyses.

The expected results are plotted on Fig. 2. These test results will be used to verify the analytical work, and to determine if width and length have caused any unexpected variations.

Joints K131 and K132 will be compared to determine the effect of pitch when the number of bolts and joint width (hence A_n/A_s) are kept the same, but joint length varies. The effect of pitch when joint length and A_n/A_s are kept constant will be shown by comparing joints K132 and K191. Joint K133 will be compared with Joint 191 to determine the effect of pitch when joint width and length are the same, but A_n/A_s varies. Also joint K133 will be compared with K132 to determine the effect of varying A_n/A_s, length and pitch being constant.

REFERENCES

1. PROPOSAL FOR ANALYSIS AND TESTS OF LONG JOINTS
(A440 STEEL, A490 BOLTS)
sent to Committee 11 on Sept. 28, 1964

2. Wallaert, J. J. and Fisher, J. W.
THE SHEAR STRENGTH OF HIGH STRENGTH BOLTS
Fritz Lab. Report 288.20, July 1964

3. SPECIFICATIONS FOR STRUCTURAL JOINTS USING ASTM
A325 OR A490 BOLTS, 1964
Research Council on Riveted and Bolted Structural
Joints of the Engineering Foundation

4. Sterling, G. H., Troup, E. W. J., Fisher, J. W. and Chesson, E. Jr.
CALIBRATION TESTS OF A490 HIGH STRENGTH BOLTS
Co-operative Report by Lehigh University and the
University of Illinois, 1964

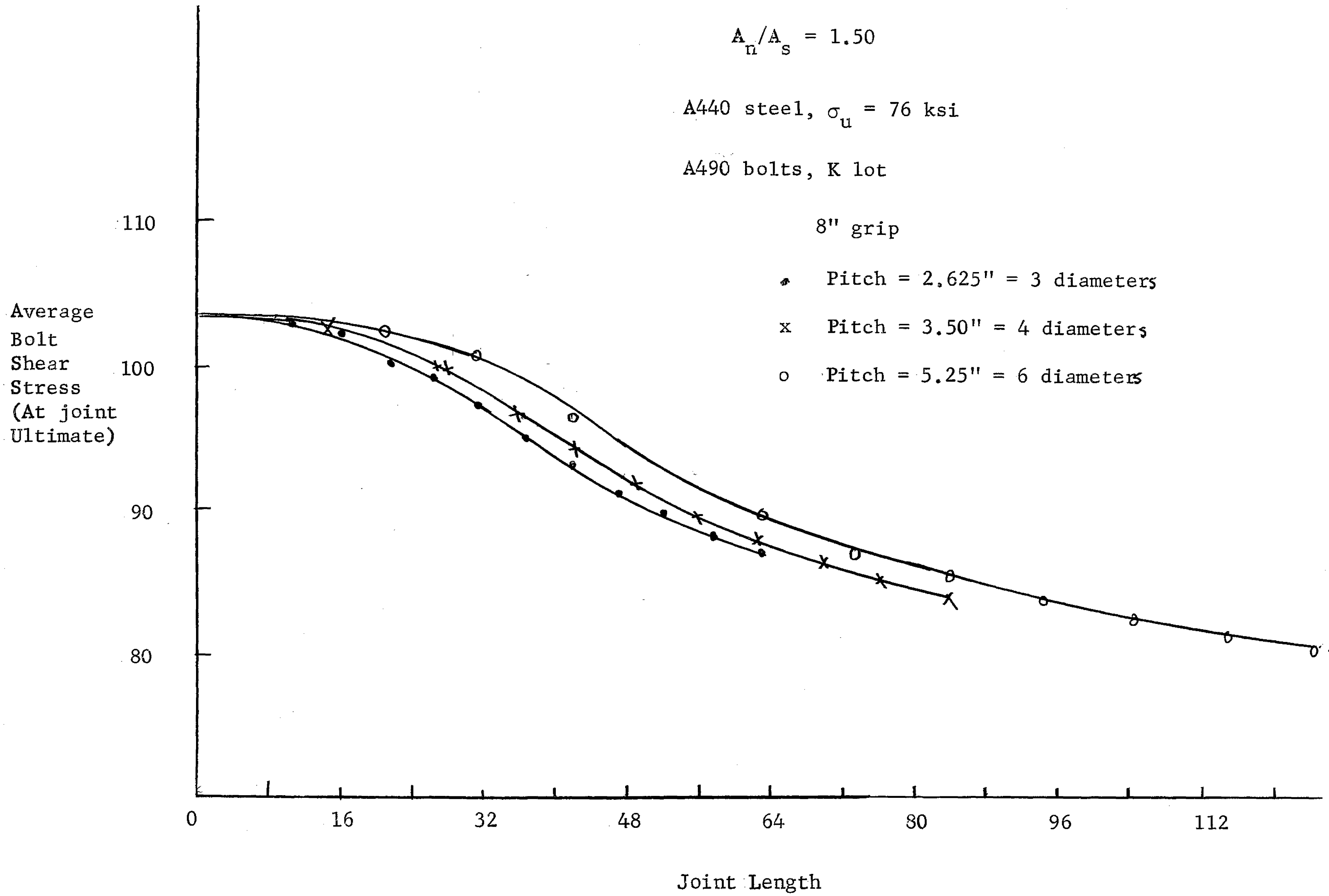


Figure 1. Effect of Varying Pitch Length, Constant A_n/A_s

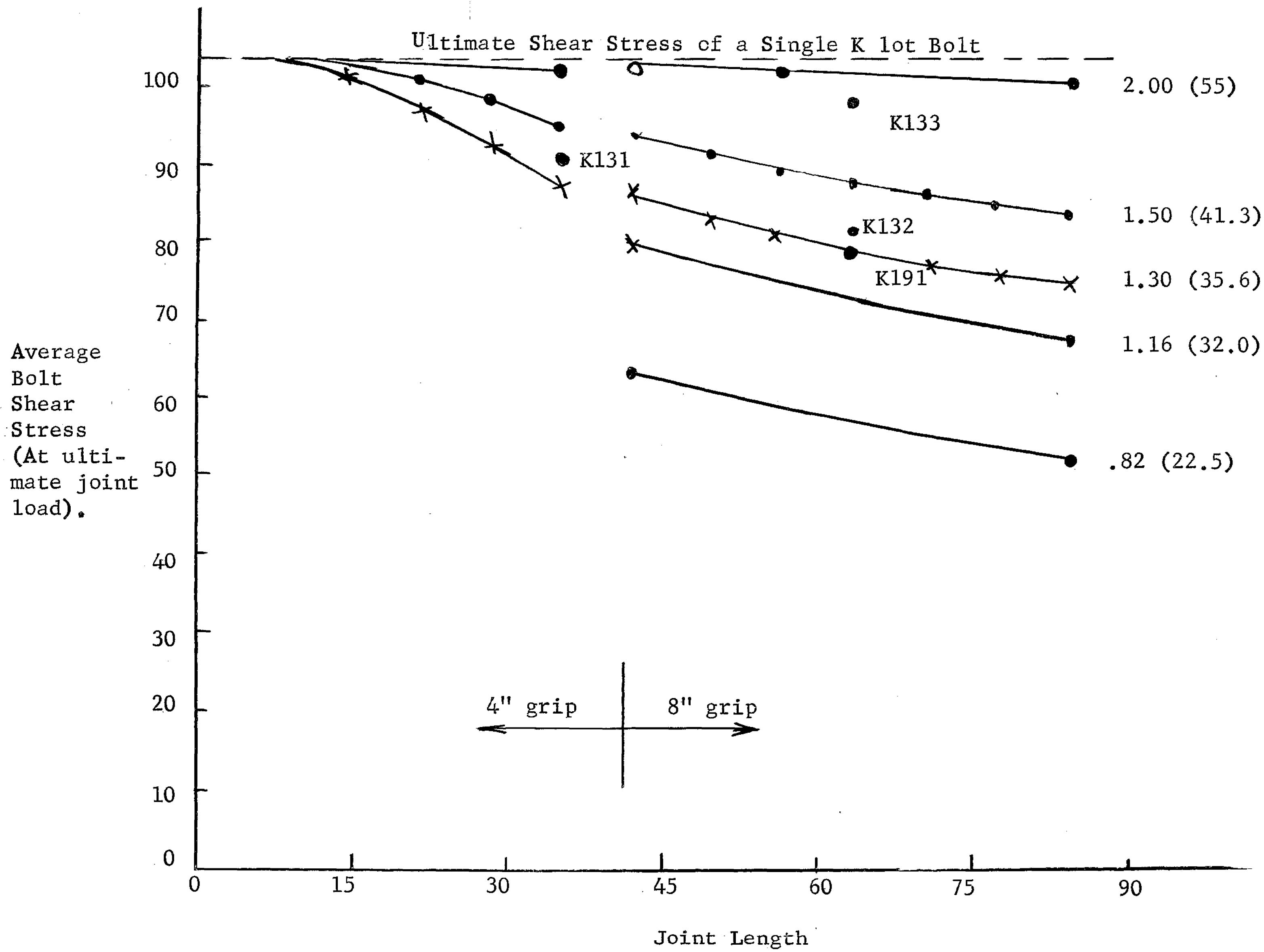


Figure 2. Effect of Varying (A_n/A_s)

PROJECT 288
FINANCIAL SUMMARY
October 31, 1964

ITEM		PDH	AISC, RCRBSJ
Year 1	July 1, 1961 - June 30, 1962		
	Grant	37,000.00	$1493.64
	Expenditures	30,850.65	1376.76
	Unexpended	6,149.35	166.88
Year 2	July 1, 1962 - June 30, 1963		
	Carry Over	0.00	166.88
	Grant	38,000.00	2000.00
	Expenditures	38,000.00	2071.54
	Unexpended	0.00	95.34
Year 3	July 1, 1963 - June 30, 1964		
	Carry Over	0.00	95.34
	Grant	44,420.00	6600.00
	Expenditures	44,420.00	8978.40
	Unexpended	0.00	(2283.06)
Year 4	July 1, 1964 - June 30, 1965		
	Carry Over	0.00	(2283.06)
	Grant	44,980.00	3200.00
	Expenditures to Oct. 31, 1964	15,724.42	211.46
	Unexpended	29,255.58	705.48

LEHIGH UNIVERSITY
BETHLEHEM, PENNSYLVANIA, 18015

DEPARTMENT OF CIVIL ENGINEERING
FRITZ ENGINEERING LABORATORY

288.1 November 19, 1964

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

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

Gentlemen:

Enclosed herewith is a copy of the minutes of the Committee 10 meeting that was held at Lehigh on November 13, 1964.

Please advise us if we have overlooked an item of interest or misinterpreted the discussion.

Sincerely yours,

John W. Fisher

John W. Fisher

JWF/va
Encl: Minutes

cc: Messrs. C. D. Jensen	K. H. Jensen	W. A. Milek
J. L. Stinson	E. G. Wiles	B. F. Kotalik
F. H. Dill	J. W. Burdell, Jr.	R. C. Updegraff

MINUTES OF MEETING, NOVEMBER 13, 1964
Committee 10 "Static Strength of Bolted High-Strength Steel Joints"
Research Council on Riveted and Bolted Structural Joints
Held at Lehigh University
University Center
Bethlehem, Pennsylvania

The meeting of Committee 10 "Static Strength of Bolted High-Strength Steel Joints", Research Council on Riveted and Bolted Structural Joints, convened at 9:30 AM at the University Center of Lehigh University on November 13, 1964.

Present were:

Members

J. L. Rumpf (Chairman) - Drexel Institute of Technology
L. S. Beedle - Lehigh University
F. E. Graves - Russell, Burdsall, and Ward Bolt and Nut Co.
N. G. Hansen - Headquarters, Department of the Army
R. G. Hansen - The Lamson & Sessions Co.
T. R. Higgins - American Institute of Steel Construction
W. H. Munse - University of Illinois

Guests

F. H. Dill - American Bridge Division, U. S. Steel
C. D. Jensen - Pennsylvania Department of Highways
B. R. Kotalik - Pennsylvania Department of Highways
E. G. Wiles - Bureau of Public Roads
D. C. Briggs - Bureau of Public Roads
M. Deuterman - Bureau of Public Roads

Staff

J. W. Fisher
R. Kormanik
G. L. Kulak
G. H. Sterling

Dr. Rumpf called the meeting to order. The minutes of the December 5, 1963 meeting were reviewed and approved. Dr. Beedle welcomed the members and guests on behalf of Lehigh University. He accounced that Dr. Fisher had been appointed Director of the Project. A moment of Silence was held for Mr. R. W. Arner, a member of this Committee who passed away on August 11, 1964.

Review of Work Completed or in Progress

Dr. Fisher introduced the new members of the project staff. He then reviewed the work completed or in progress and summarized the status of Reports up to November, 1964.

Shear Strength of High-Strength Bolts

Mr. Kulak reviewed the changes that had been made to Fritz Laboratory Report 288.20, "The Shear Strength of High Strength Bolts." He stated that these had resulted from suggestions made by Committee members and from some additional tests which had been performed after publication of the original report.

Mr. Dill questioned the meaning of bolt tensile strength. He pointed out also that the stress area as defined for an A325 bolt perhaps cannot be extrapolated for use with the A490 bolt. Both Mr. Dill and Prof. Munse questioned the value of including the ratios of average ultimate shear stress to bolt tensile strength in the report. Dr. Fisher pointed out that the issues in question had been reported in the paper only in a very general way. Dr. Kumpf mentioned that the report had already been approved by the Committee and submitted to the ASCE for publication. Mr. N. Hansen moved that, prior to publication, statements of ratios of shear stress to tensile stress be deleted. The motion was seconded and carried.

Calibration of Alloy Steel Bolts

Mr. Sterling discussed Fritz Engineering Laboratory Reports 288.19, "Calibration of Alloy Steel Bolts," and 288.23, "Calibration Tests of A490 High-Strength Bolts." He limited his comments to the results of tests obtained under torqued tension and under repeated torquing.

Dr. Fisher pointed out that the conclusions regarding retightening of bolts applied only to alloy steel bolts. He stated that it is not advisable to reinstall A490 bolts by the turn-of-the-nut method. Mr. Dill stated that these tests have pointed out the need for further examination of lubrication of the threaded parts of A490 bolts. Both Mr. Graves and Mr. R. Hansen pointed out that certain other industries require waxed nuts as the form of lubrication. Mr. Higgins moved that a short study into the effect of lubrication upon torqued tension be undertaken and the results be presented at the next Council meeting. Motion carried. It was generally agreed that the details of the program could be left to Dr. Fisher's discretion.

Messrs. Dill and R. Hansen stated that the Arbitration method of hardness testing should have been used and suggested that this be performed on a few bolts, if possible.

Approval of the Report 288.19 was withheld pending the results of the lubrication study. Report 288.23 is being handled by the University of Illinois and has been approved for publication by Committee 15. Dr. Chesson is handling the arrangements for this report.

Criteria for Designing Bearing-Type Bolted Joints

Dr. Fisher discussed the basis of Fritz Engineering Laboratory Report 288.7A, "Criteria for Designing Bolted Joints (Bearing-Type)." He noted that there is no justification for the assumption that a high strength steel joint will behave better than one of carbon steel if the design is on the basis of shear strength. He suggested that the basis of design should be the strength of the fasteners, noting the effect of increasing joint length, and that it was logical therefore, to suggest increases in the allowable shear stress for A325 bolts. It was also pointed out that the current report had incorporated numerous suggestions received during the past year. Mr. Higgins moved approval of the report. Carried.

Dr. Fisher stated that further comments on the report would still be appreciated. He intended to submit the report to ASCE near the end of December, 1964.

Analysis of Bolted Butt Joints

Dr. Fisher discussed the analysis of bolted butt joints and commented on Fritz Engineering Laboratory Report 288.17, "The Analysis of Bolted Butt Joints." Dr. Rumpf pointed out that it was important to get this report published as soon as possible in view of its place in the sequence of previously published, related reports.

Mr. N. Hansen moved that Report 288.17 be approved subject to further comments until January 1, 1964. Motion carried.

Special E-Series Joint Test

Mr. Sterling discussed in particular the definition of "slip" in bolted joints and the various methods of measurement. Dr. Fisher emphasized that although relative displacement does occur at the ends of the joint at low loads, the overall joint-deformation gage should show no movement at these loads unless the fictional resistance is exceeded all along the length of the joint and major slip occurs. Small displacements near the ends of joints are to be expected as the frictional resistance is exceeded at discrete points. Upon loading, a small residual displacement remains because the frictional resistance is not exceeded in the opposite sense. The resulting local deformations are balanced out but have no influence on the overall joint behavior and deformation. Consequently, it was stated again that all Lehigh tests define slip as the first sudden major movement of the plates, always a well-defined point. Mr. N. Hansen felt that it was important that the Committee recognize some definition of major slip. It was agreed that the Lehigh staff should prepare a definition of joint slip and circulate this to the Committee at a later date.

The agreement of the E-Series tests with predicted values was also commented upon by Mr. Sterling.

Current and Proposed Studies of Constructional Alloy Steel Joints

The extensions necessary to enable the use of present theory regarding load partitioning among fasteners for use in constructional alloy steel joints were reviewed by Mr. Kulak

Mr. R. Hansen moved that approval be indicated for further analytical studies in joints fastened with A325 or A490 high strength bolts. These are similar to the analytical studies made for A440 steel joints. Motion carried.

Studies of A440 Steel Joints Connected by A490 Bolts

Mr. Sterling gave the results of analytical studies of several hypothetical joints of A440 steel connected by A490 bolts. Pitch, joint length, and the ratio of A_n/A_s were varied. The test pieces needed to verify the theory were described.

Prof. Munse noted that A_n/A_s has been commonly referred to as the "tension-shear ratio." Dr. Beedle agreed, but pointed out such terminology had meaning only in balanced design. He stated that the connotation now was based on geometry of the joint rather than stresses.

Hybrid Connections

The use of fasteners in butt joints where the main and lap plates were of dissimilar steels was outlined by Mr. Kormanik. A proposal for analytical work was presented.

Mr. Dill suggested that ASTM A-36 be substituted for the A-7 suggested in the proposal. It was agreed that this would be better.

Mr. Higgins moved that the Committee give approval for analytical studies to determine load-distribution and deformation characteristics in hybrid steel joints. Carried.

High Strength Steels Fastened with High Strength Rivets

Mr. Sterling outlined the analytical studies proposed for joints of A440 steel fastened with A502-64T, grade 2 rivets. Shear jig tests as well as coupons of driven and undriven rivets are to be tested to determine the basic material properties. The shear calibration tests are needed before undertaking the analytical work.

Mr. Dill said that since only one rivet would be driven in a single jig, it should be recognized that these proposed tests would provide no information on such things as initial tension. He mentioned also that it may be difficult to rivet up such small test specimens.

Prof. Munse suggested that if the proposed test set-up is not adequate, perhaps a new jig could be designed having an additional bolt that could be removed after riveting. Dr. Beedle commented on the importance of testing the rivets themselves.

Mr. R. Hansen moved that approval be given to the undertaking of an analytical program into the shear stresses in high-strength rivets when used in high strength steel joints. Motion carried.

Future Work

Dr. Fisher reviewed the work that would be undertaken during the current year. Most of the effort will be devoted to analytical studies. This will involve phases VI, VII, VIII, X, and XI. Experimental work will involve phases VIb and VIII. He pointed out that several reports were in preparation.

It was also pointed out that this was the fourth and final year of the project on Bolted Joints of High-Strength Steels. By the end of this fourth year the following will have been established: (1) The behavior of A325 bolts in A440 steel joints was determined, (2) The behavior of A490 bolts in A440 steel joints will be determined, (3) A workable theoretical analysis of load partitioning and ultimate strength was effected, (4) A more rational design approach was suggested, (5) Extensive calibration studies aimed at installation and behavior of single bolts were completed, (6) Pilot studies of constructional alloy steel joints were completed, (7) Preliminary analytical studies were undertaken on constructional alloy steel joints, hybrid connections and high-strength riveted joints.

He indicated that a new program on Bolted Connections of Higher Strength Steels would be proposed. This program would provide the experimental verification for large constructional alloy steel joints, hybrid connections, high strength riveted joints and large diameter fasteners. Additional analytical studies would also be undertaken. It was estimated that a curtailed program of about two years duration would be involved.

A second program involving the behavior of joints at working load was anticipated. This program would consider the influence of such factors as out-of-flat joints, frictional behavior and the fatigue behavior of long joints.

Mr. N. Hansen, in commenting on the outline of future work, mentioned the desirability of investigating joints under fatigue, where joint slip would be appreciable. Mr. Higgins said that in tests of this type, specimen heating caused considerable difficulties in measurement. Previous testing along this line was reviewed by Prof. Munse.

Dr. Fisher suggested that it would be desirable to prepare a summary report of the work done at Lehigh during the past seven years for presentation to the Highway Research Board in January, 1966. It would be necessary to submit the report to the HRB for consideration during the summer of 1965. It was the concensus of the Committee that this should be done.

A financial statement of Project 288 was reviewed after which the meeting was adjourned at 3:40 PM.

G. L. Kulak

G. L. Kulak

GLK/va