1962

Summary report large bolted connections, 1962

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LEHIGH UNIVERSITY INSTITUTE OF RESEARCH

LARGE BOLTED JOINTS

SUMMARY REPORT To
COMMITTEES 9 and 10
(Project 288)

by
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January 1962

FRITZ ENGINEERING LABORATORY REPORT NO. 288.1

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

LARGE BOLTED JOINTS PROJECT 271, LEHIGH UNIVERSITY
SUMMARY OF WORK COMPLETED

January, 1962

Phase and Topic	Authorization	Tests Performed	Tests to be Done	Additional Material on Hand	Reports*
I Compact Butt Joints A,B,G Series BR Series	Orig.proposal subgroup min. 3/7/57 and 4/11/58	8 Bolted Joints B1-B6, A3, G1 1 Riveted Joint BR2	None	Joint A1 at FL, fab. & bolted. Plate for 4 joints at BS Co. Bolts: 0-7/8 B Lot 72-1 A Lot 68-11/8 G Lot 60-7/8 Rivets	271.1 271.2 271.6 271.6 (Rev.) 271.12 ASCE 2523
II Long Butt Joints D Series, Variable Width	Orig.proposal subgroup min. 9/25/58	8 Joints D101 - D31	None	Joint D82, 42 at FL fab, but not bolted Bolts 64-7/8 D Lot	271.8 271.13 271.14 271.19
II Long Butt Joints D Series, Part b Variable Grip	Orig.proposal subgroup min. 9/25/58	4 Joints D1001 - D701	None	Plate for 4 Joints at BS Co. Bolts: 29-7/8 T Lot 32-7/8 U Lot 34-7/8 V Lot 34-7/8 W Lot	271.8 271.19
II Long Butt Joint D Series, Part c Variable Width	Committee 9 Minutes	3 Joints D10 D13 D16	None	Bolts: 11-7/8 C Lot	271.15 271.17 271.19
III Long Riveted Butt Joints DR Series, Variable Width	Committee 9 4/19/60	3 Joints DR 71 DR 101 DR 131	None	Rivets: 25-7/8 at BS Co. 7-7/8 at LU	271.17 271.20

* See Report Summary for Title of Report

Large Bolted Joints Project 271, Lehigh University
Summary of Work Completed

January 1962

Phase and Topic	Authorization	Tests Performed	Tests to be Done	Additional Material on Hand	Reports*
III Shear Strength of Single Bolts	Subgroup min. 4/11/58 1/12/59	Double Shear Tests Comp. Load, 4" Grip 90-7/8, 1, 1 1/8 bolts 9-7/8 rivets Tens. load, 4" grip 6-7/8 bolts Comp. load, Var. grips 36-7/8 bolts Single Shear Tests, Tens. Load, 4" grip 2-7/8 bolts	None, except as required for evaluation of bolts in future joint tests	Shear Jigs: 1-1" 4" grip 1-7/8, 4 3/4 grip 1-7/8, 5 1/4 1-7/8, 6 1-7/8, 6 3/4 1-7/8 (Riveted) 4° grip	271.3 271.4 271.10
IV Bolt Calibration	Subgroup min. 9/25/58	Direct Tension 59-7/8, 1, 1 1/8 bolts Various lots Torqued 66-7/8, 1 1 1/8 bolts Various lots	None, except at required for evaluation of bolts in future joint tests		271.5 271.7 271.11 271.11 (Rev.)
V Lap Joints L Series	Subgroup min. 7/28-29/59	4 Joints L10, 7, 5, 2	None	Joints L6, 3 at FL fab. but not bolted Bolts 82-7/8 L lot	271.9

PROJECT 271

SUMMARY OF REPORTS - TO JANUARY 1962

Fritz Lab Report	
* 271.1	R. T. Foreman and J. L. Rumpf "Static Tension Tests of Bolted Joints" Progress Report No. 1, December 1958 (Tests of six bolted joints and 1 riveted joint using 7/8" fasteners)
* 271.2	J. L. Rumpf "Further Static Tension Tests of Bolted Joints" December 1958 (Tests of two joints, one using 1" bolts and one 1 1/8" bolts)
* 271.3	J. L. Rumpf "Shear Resistance of High Strength Bolts" December 1958 (Simplified summary of double shear tests of single bolts)
271.4	S. Kaplan "Double Shear Tests of High Strength Bolts" April 1959 (This report, submitted for course credit in CE 404 - Structural Research, presents the complete results of the tests summarized in 271.3. Only 4 copies exist. The results of further tests must be added and the report edited and partially rewritten before publication can be made.)
271.5	R. A. Bendigo "Bolt Calibration Study" June 1959 (This report, submitted for course credit in CE 406, presents the partial results of the calibration work carried out in conjunction with the tests of the large joints. Only five copies exist.)

Fritz Lab Report	
* 271.6	R. T. Foreman and J. L. Rumpf "Static Tension Tests of Compact Bolted Joints" July 1959 (This report is a condensation of 271.1 and 271.2.)
271.6 (Rev.)	R. T. Foreman, and J. L. Rumpf "Static Tension Tests of Compact Bolted Joints" August 1959 (Following comments and suggestions by the subgroup, Report 271.6 was revised before submitting to ASCE for publication in the Proceedings as Paper No. 2523 Journal of Structural Division, June 1960. Five copies only: 1 - BPR; 3 - ASCE; 1 - LU)
* 271.7	R. A. Bendigo, J. L. Rumpf "Calibration and Installation of High Strength Bolts" September 1959 (Contains the work of 271.5 plus additional work done during summer of 1959. Reports on tension-elongation relations for over 100 bolts and includes effect of direct-tension, torqued-tension, length of grip and thread, re-use of bolts and some observations on the turn-of-nut procedure.)
* 271.8	R. A. Bendigo, J. L. Rumpf "Static Tension Tests of Long Bolted Joints" February 1960 (Reports on tests of twelve long butt joints with two lines of from three to ten 7/8" dia. A325 bolts. The joints were fabricated of A-7 steel at a tension-shear ratio of 1/1.10. Studies: 1) Effect of joint length on fastener performance; 2) Joint slip characteristics; 3) Possible ultimate strength design procedures.)

Fritz Lab Report	
271.9	R. A. Bendigo, J. L. Rumpf "Static Tension Tests of Bolted Lap Joints" (Reports results of 4 tests of single shear joints restrained from bending.)(in preparation)
271.10	R. M. Hansen, J. L. Rumpf "Double Shear Strength of A325 Bolts" (Contains the work of 271.3 and 271.4 plus additional double shear tests of single bolts.) (in preparation)
* 271.11	R. A. Bendigo, J. L. Rumpf "Calibration and Installation of High Strength Bolts" June 1960 (Revision of F.L.Report 271.7 for consideration by Committee 9, RCRBSJ.)
271.11 (Rev.)	R. A. Bendigo, J. L. Rumpf "Calibration and Installation of High Strength Bolts" (Following comments by Committee 9, Report 271.11 was revised before submitting to ASCE for possible publication in the Proceedings. Limited number of copies 6 - BPR, 1 - PDH, 3 - ASCE, 1 - LU) Rejected by ASCE; will be resubmitted after revisions.
271.12	R. T. Foreman, J. L. Rumpf, L. S. Beedle "Tests of Large Bolted Joints" June 1960 (Report 271.6 (Rev.) rewritten for oral presentation at the ASCE Convention in Reno, Nev., June 1960)
271.13	S. T. Marcin "Load Distribution in Bolted Joints" June 1960 This report, submitted for course credit in CE 103, determines the force on each bolt in four test joints at ultimate load by comparing the deformed bolt contours to those of a control bolt.

Fritz Lab Report	
271.14	J. L. Rumpf "The Ultimate Strength of Bolted Connections" September 1960 (This doctoral dissertation presents a theoretical solution for the partition of load among the bolts of long connections. Correlation with 8 joints of Report 271.8 is shown. A limited number of copies exist.)
* 271.15	"Further Static Tension Tests of Long Bolted Joints" (This report contains the results of the tests of joints with 13 and 16 bolts in line - D-Series, Part C.)
271.16	"The Ultimate Strength of Bolted Connections" (A condensation of J.L. Rumpf's Ph.D. Dissertation is being prepared.)
* 271.17	"The Effect of Fastener Pitch in Long Structural Joints" (Contains a theoretical study of ten hypothetical long structural joints and includes both A141 rivets and A325 bolts as fasteners. Four joints are compared to test results as a check of the analytical study.)
271.18	"Long Structural Joints of A-7 Steel" (Summarizes all work on long A-7 steel joints. This report is being prepared for submission to ASCE for publication.)
271.19	"Long Structural Joints of A-7 Steel" (This oral presentation was given at the ASCE Convention in New York. October 1961)
271.20	"Static Tension Tests of Long Riveted Joints" (A report of the comparison of riveted joints is being prepared.)

* Indicated distribution to subgroup, Pennsylvania Department of Highways, Bureau of Public Roads and certain other interested parties.

BOLT CALIBRATION STUDY

At the meeting, on January 19, 1961 of the Research Council on Riveted and Bolted Structural Joints held at Lehigh University, a question was raised as to whether the conclusions of Report 271.11, "Calibration and Installation of High Strength Bolts," would be affected by the recent changes in bolt geometry. The particular combination of the new short thread length with an A325 bolt whose strength is on the high side of the specification came under discussion.

The committee agreed that a pilot investigation should be initiated in order to get an indication of the existence of any difficulty due to the conditions noted above. The exact nature and extent of this investigation was to be determined by the Lehigh University staff.

Because of the advanced stage of report 271.11, it was agreed that any modifications to the conclusions would be handled best by means of a discussion addended to the original paper. However, report 271.11 was rejected for publication. As a result, the material will now be incorporated into a revised report, to be resubmitted for publication.

The investigation of the new type bolt covered the following facets of bolt calibration:

(1) Direct tension vs. torqued tension

(2) Effect of thread length under nut

(3) An evaluation of the turn-of-nut method when used with the new type bolt

(4) Comparison of old bolt and new bolt in

   (a) Direct tension

   (b) Torque tension

(5) An evaluation of the turn-of-nut procedures for grip lengths in excess of 5"

SUMMARY OF BOLT CALIBRATION STUDY

1. DIRECT TENSION VS. TORQUE CALIBRATION

a. Illustration - Fig. (1) Direct Tension vs. Torque Tension for new type bolt
b. Conclusion - The results of these tests verify the conclusion of report 271.11 which state: "The method used to induce the internal tension in a bolt has no effect on the tension-elongation relationship in the elastic portion of the graph"; beyond the proportional limit, however, an average decrease in ultimate of approximately 16.2% was observed.

2. EFFECT OF THREAD LENGTH UNDER NUT

a. Illustration - Fig. (2) Torqued Calibration
b. Conclusions - The results also verify the conclusions of report 271.11 in which the thread length in the grip area is chiefly responsible for increased elongations.

3. EVALUATION OF THE TURN-OF-NUT METHOD WHEN USED WITH THE NEW TYPE BOLT

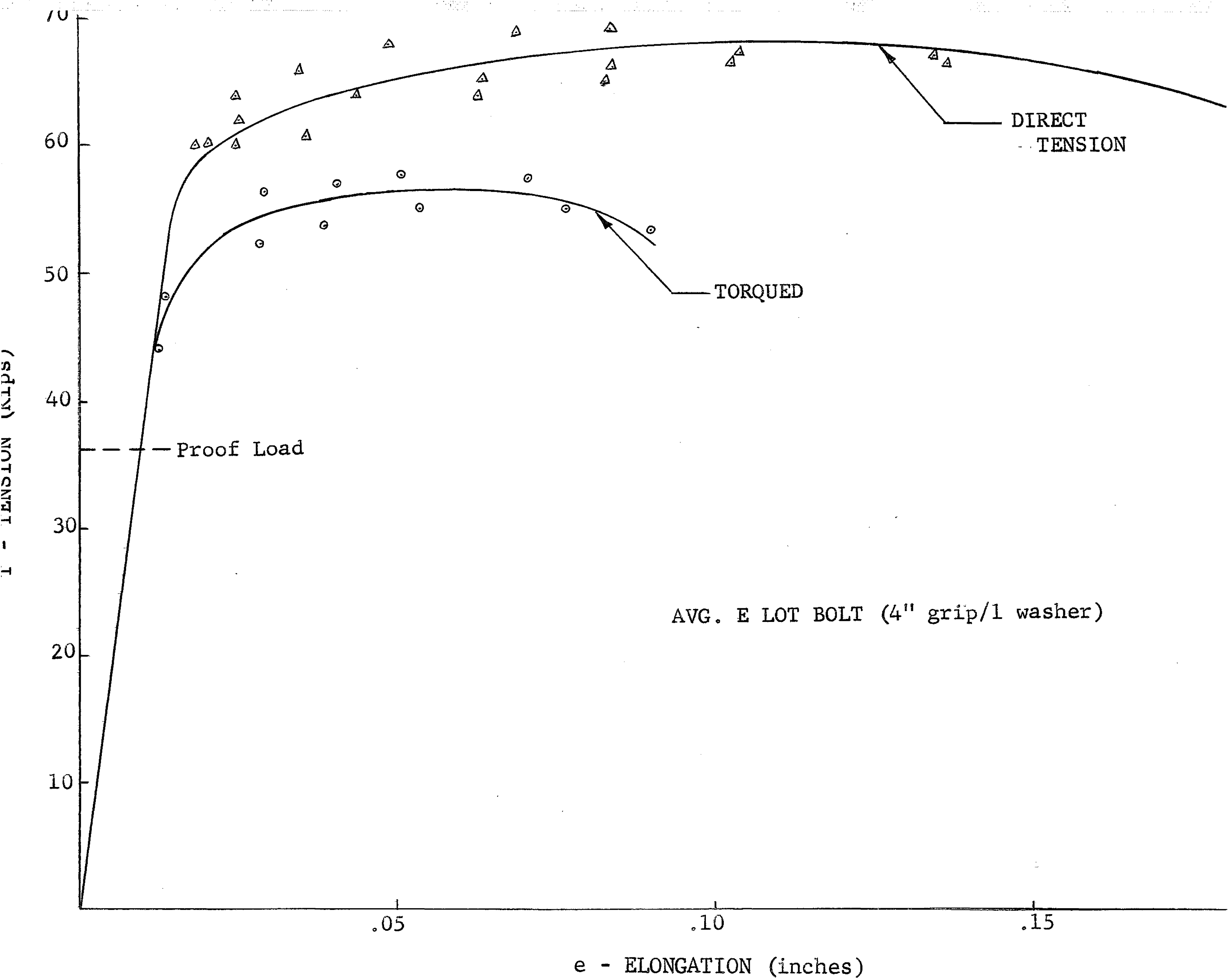
a. Illustration - Fig. (2) Torque Tension Curve
b. Conclusions - The one-half turn-of-nut method for installing the new type high strength bolts produced adequate and consistent bolt tensions in the elastic-plastic range. Bolts tightened to one half turn-of-nut from snug developed approximately 85% of the available strength for bolts on both the high and low side of the specification. The factor of safety against twisting off was approximately 3.

4. COMPARISON OF OLD BOLT AND NEW BOLT

a. Illustration - Fig. (3,4) Torque Tension and Direction Tension Curves
b. Conclusions - The difference in behavior of the old and new type bolts is directly related to item 2, thread length under head. The decrease in elongation at failure for the new bolt was due to the decrease in thread length under the nut. However, the new type bolt was still able to sustain at least 1-1/2 turns before failure. This results in a factor of safety against twisting off of approximately 3.

5. EVALUATION OF THE TURN-OF-NUT PROCEDURE FOR A GRIP LENGTH IN EXCESS OF 5 IN.

a. Illustration - Fig. (5) Torque Tension Curve
b. Conclusions - Grip length had no appreciable effect on the tension-elongation characteristics of the new type bolt as long as the free thread under the nut was approximately the same. The tests also indicated that nut rotations greater than one-half turn from snug for long grip bolts are not necessary. Little is gained in additional clamping force, whereas an appreciable decrease in the factor of safety against twisting off is realized.



T - TENSION (Kips)
70
60
50
40
30
20
10
.05
.10
.15
DIRECT TENSION
TORQUED
Proof Load
AVG. E LOT BOLT (4" grip/1 washer)
e - ELONGATION (inches)

FIGURE 1

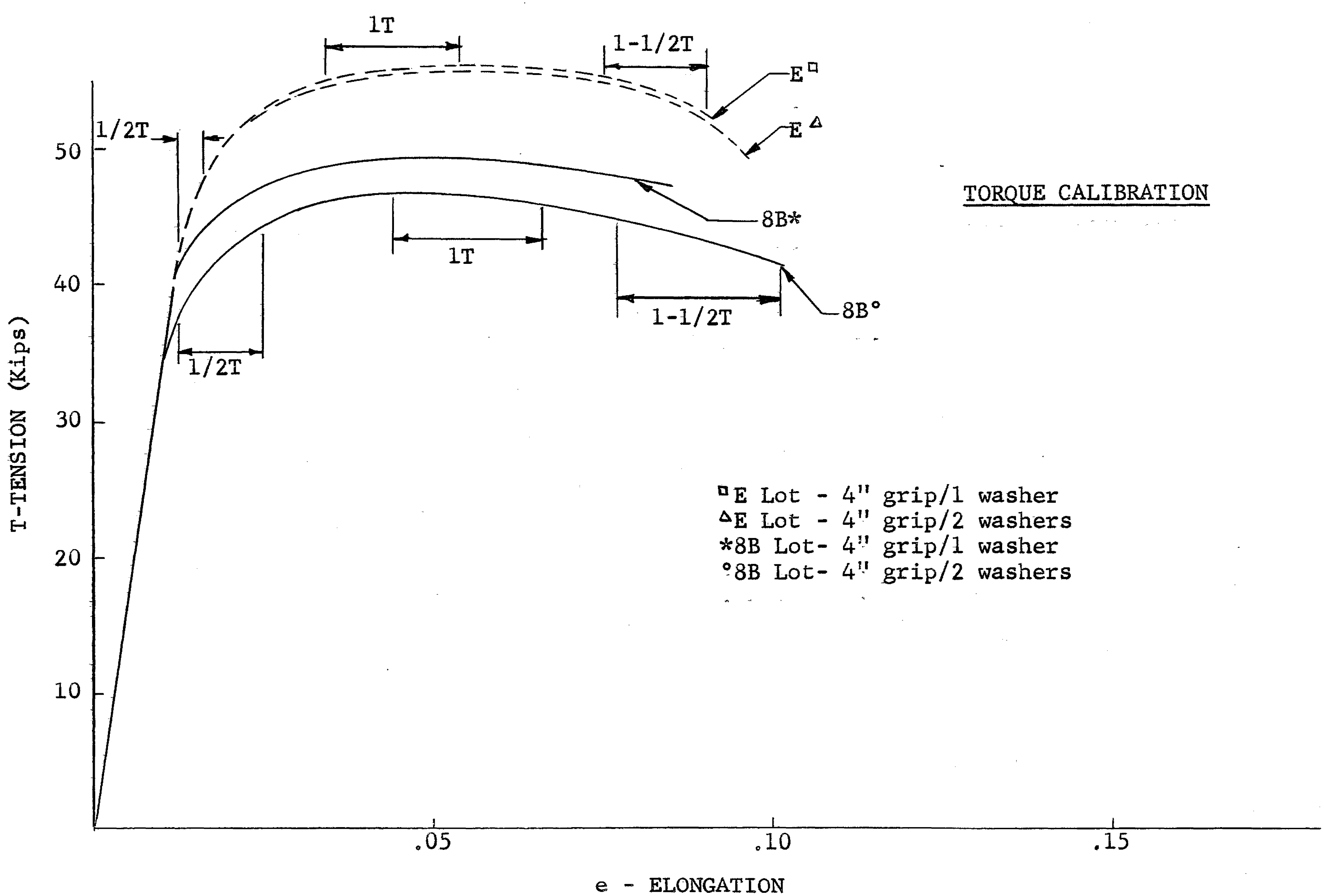

TORQUE CALIBRATION
T-TENSION (Kips)
e - ELONGATION
10
20
30
40
50
.05
.10
.15
1/2T
1T
1-1/2T
E□
E△
8B*
8B°
□E Lot - 4" grip/1 washer
△E Lot - 4" grip/2 washers
*8B Lot- 4" grip/1 washer
°8B Lot- 4" grip/2 washers

FIGURE 2

DIRECT TENSION

OLD BOLT (Q) VS. NEW BOLT

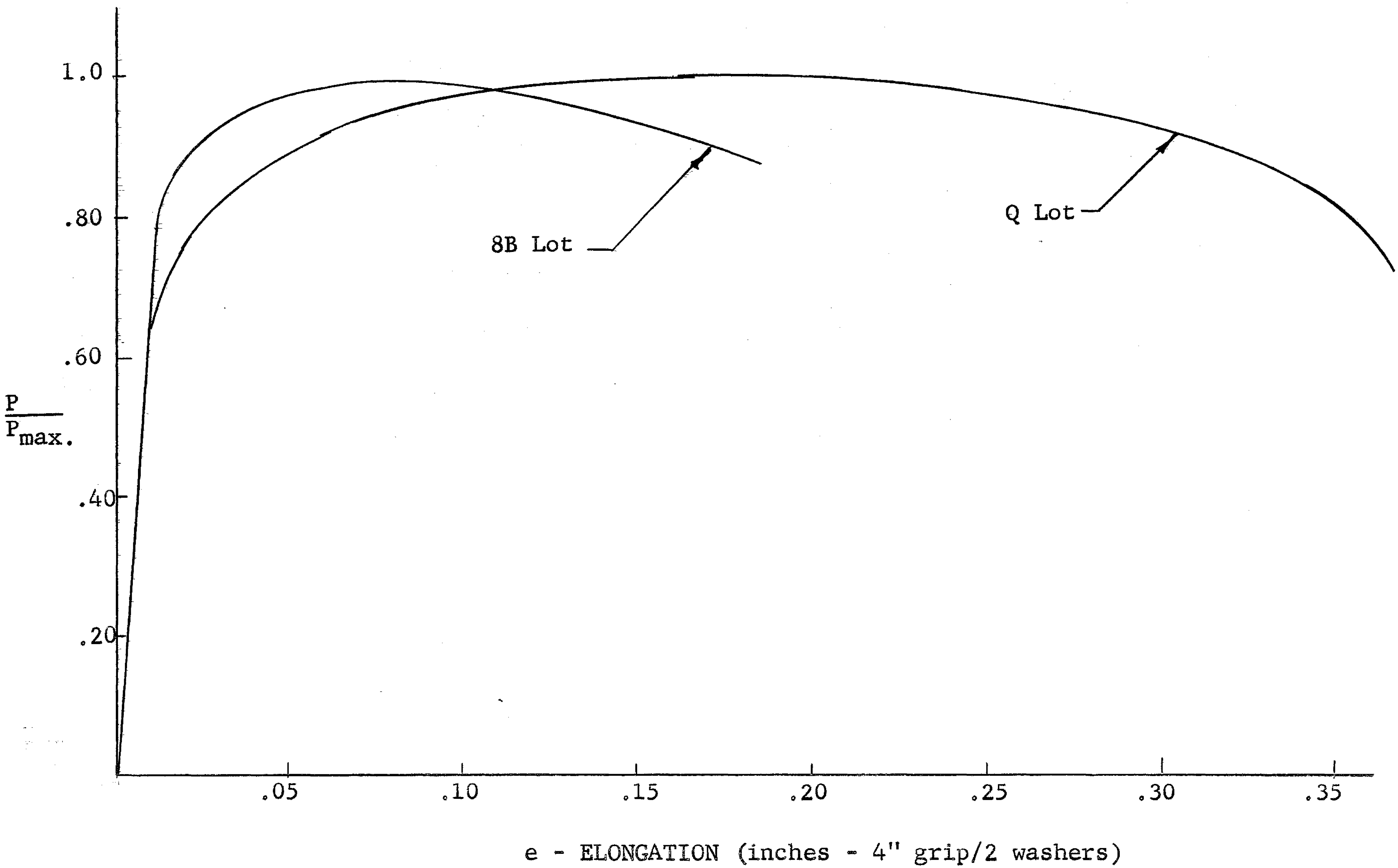


FIGURE 3

TORQUE CALIBRATION

OLD BOLT (Q LOT) VS. NEW BOLT (8B LOT)

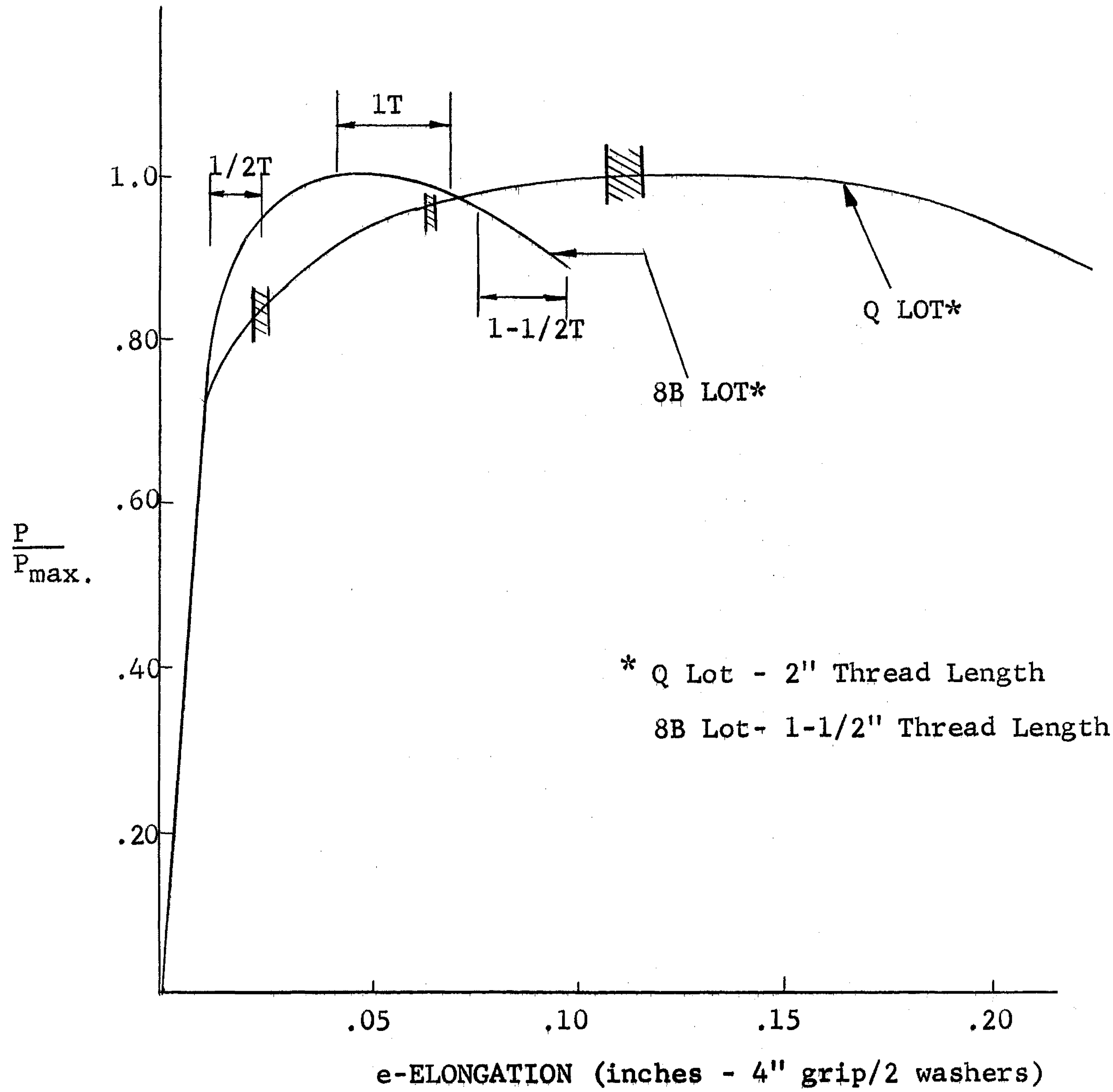


FIGURE 4

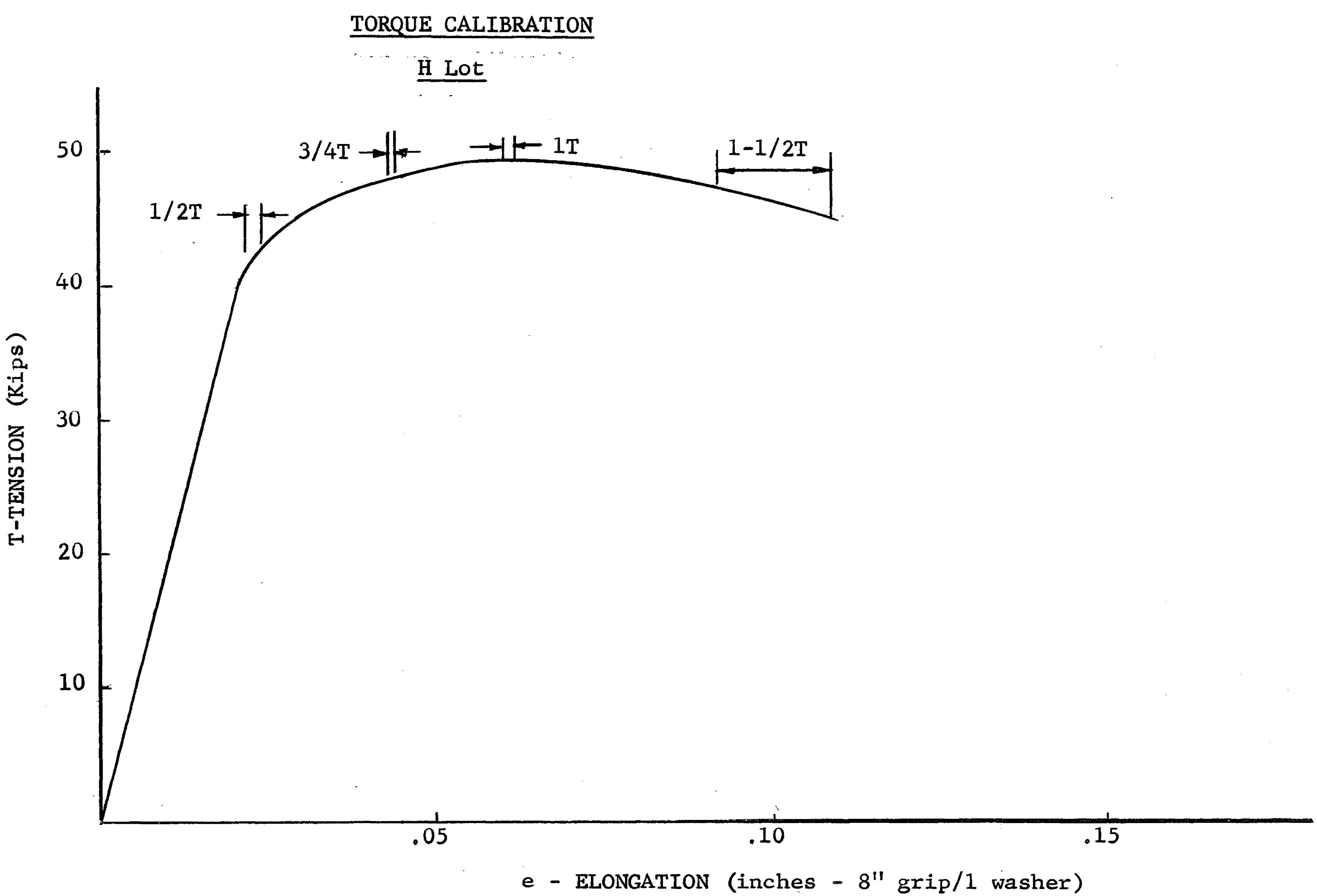
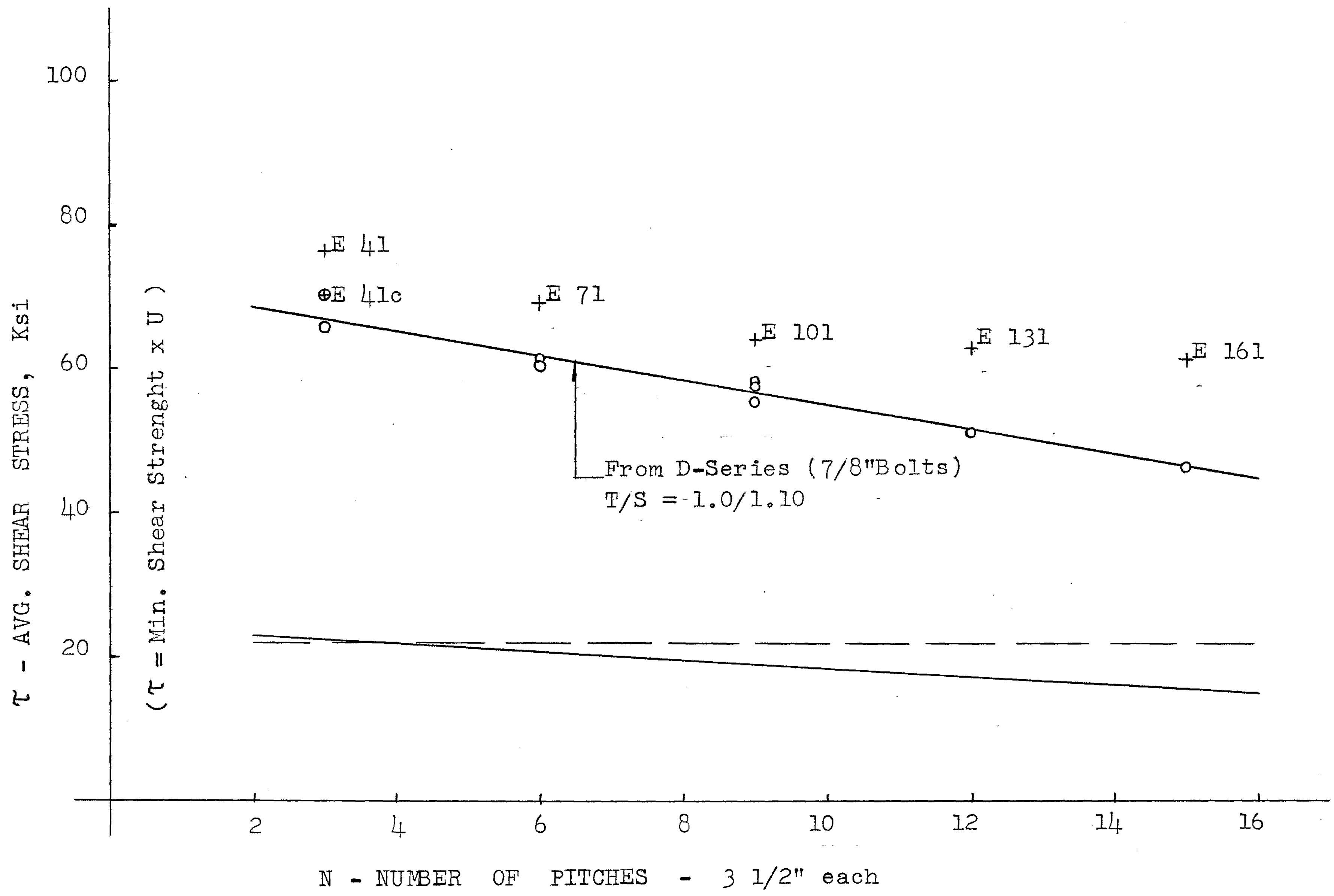

TORQUE CALIBRATION
H Lot
3/4T
1T
1-1/2T
1/2T
50
40
30
20
10
T-TENSION (Kips)
.05
.10
.15
e - ELONGATION (inches - 8" grip/1 washer)

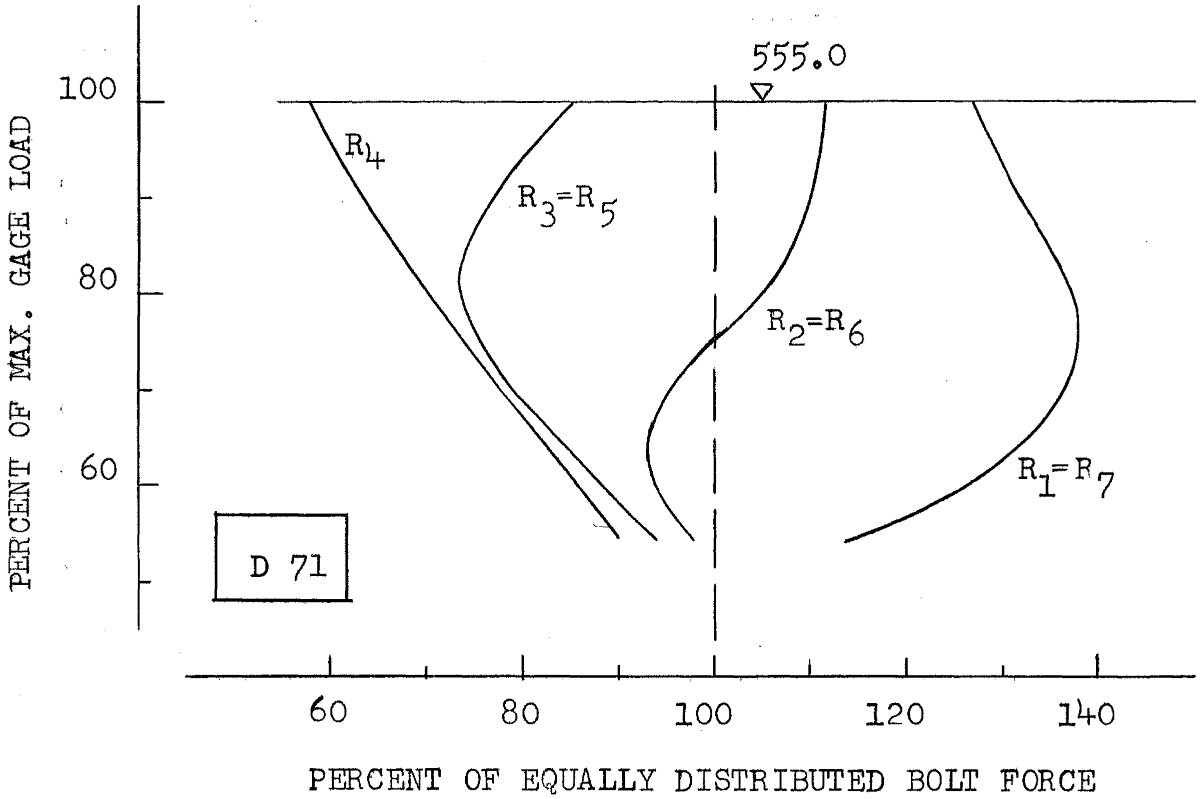
FIGURE 5

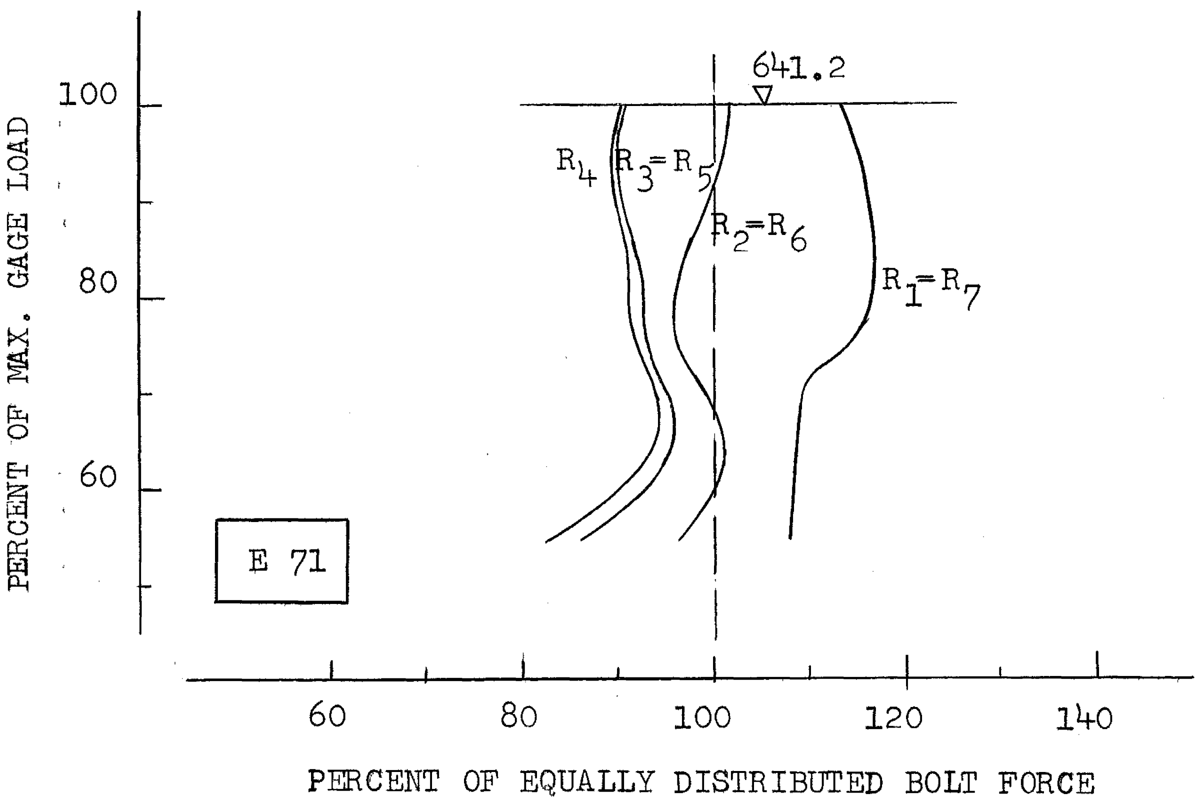
RESULTS OF BOLT CALIBRATION

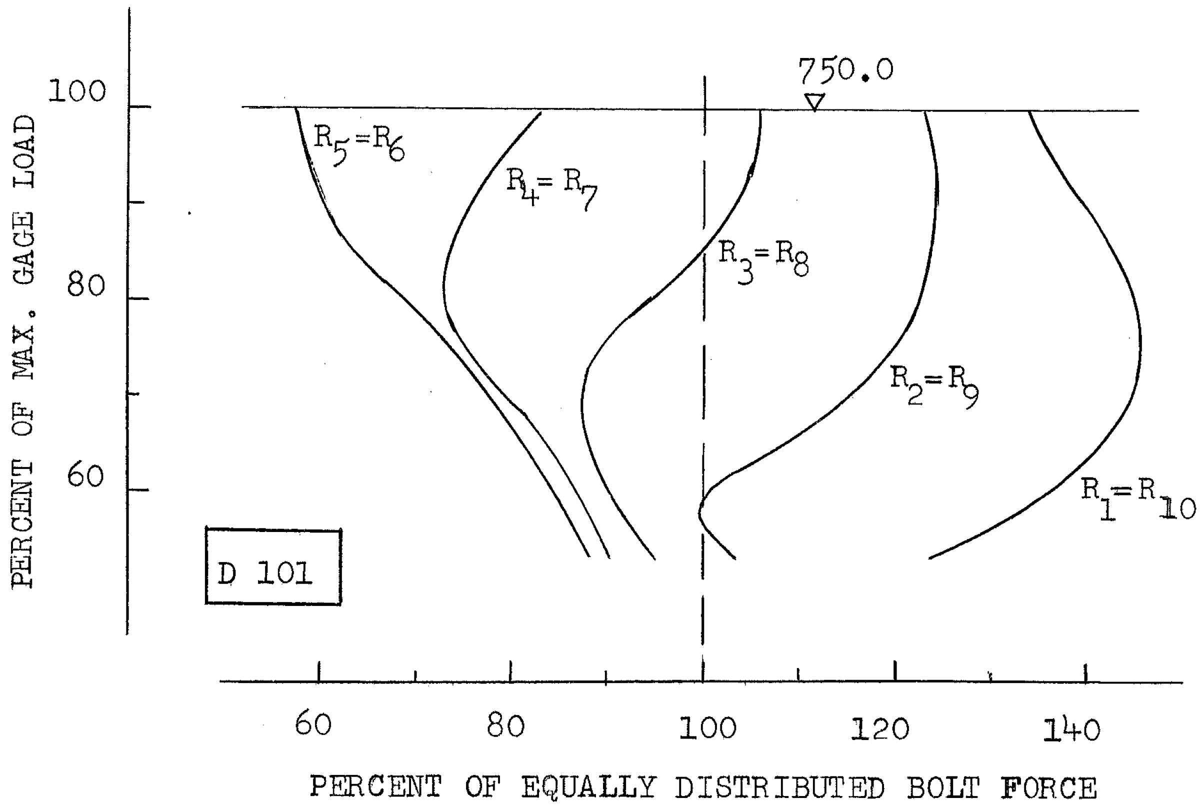
	Units	H	8A	8B	8B	E	E	Q
Size(nominal length)	in.	7/8	7/8	7/8	7/8	7/8	7/8	7/8
Total Grip Length (4" or 8" + washers)	in.	8-1/8	4	4-1/4	4-1/8	4-1/4	4-1/8	4-1/4
Thread Length	in.	1-1/2	1-1/2	1-1/2	1-1/2	1-1/2	1-1/2	2
Length Under Head	in.	9.50	5.25	5.50	5.50	5.50	5.50	5.50
Stress Area	sq.in.	0.462	0.462	0.462	0.462	0.462	0.462	0.462
Spec.Min.Proof Load	kips	36.1	36.1	36.1	36.1	36.1	36.1	36.1
Spec.Min.Ultimate Load	kips	53.2	53.2	53.2	53.2	53.2	53.2	53.2
Mill Report Ultimate Load	kips	53.8				66.7	66.7	55.9
DIRECT TENSION CALIBRATION								
Number Tested		5	5	5	5	4	5	3
Ultimate Load	kips	58.2	59.3	54.1	55.5	65.2	67.5	54.0
% of Spec.Min.Ult.Load	%	108	111	102	104	122.5	127	101.5
Rupture Load	kips	48.5	51.6	48.0	49.0	60.6	62.1	42.5
Elongation at EPL	in.	0.018	0.010	0.011	0.010	0.0107	0.0104	0.011
Elongation at Ult.Load	in.	0.118	0.1172	0.099	0.077	0.0109	0.112	0.16
Elongation at Rupture Load	in.	0.280	0.3120	0.188	0.188	0.188	0.188	0.36
TORQUED CALIBRATION								
Number Tested		3	5	4	5	3	3	4
Ultimate Load	kips	49.6	52.2	46.7	49.3	55.3	55.8	50.0
% of Spec.Min.Ult.Load	%	93.3	98.0	87.9	92.7	104	105	94.0
Elongation at EPL	in.	0.019	0.011	0.011	0.011	0.011	0.011	0.115
Elongation at Ult.Load	in.	0.056	0.0549	0.0550	0.0523	0.0553	0.0592	0.12
Elongation at Rupture Load	in.	0.110	0.0993	0.1066	0.086	0.0960	0.090	0.228
% Reduction in Strength from Direct Tension Ultimate	%	14.8	12.0	13.7	11.2	15.2	17.3	7.4

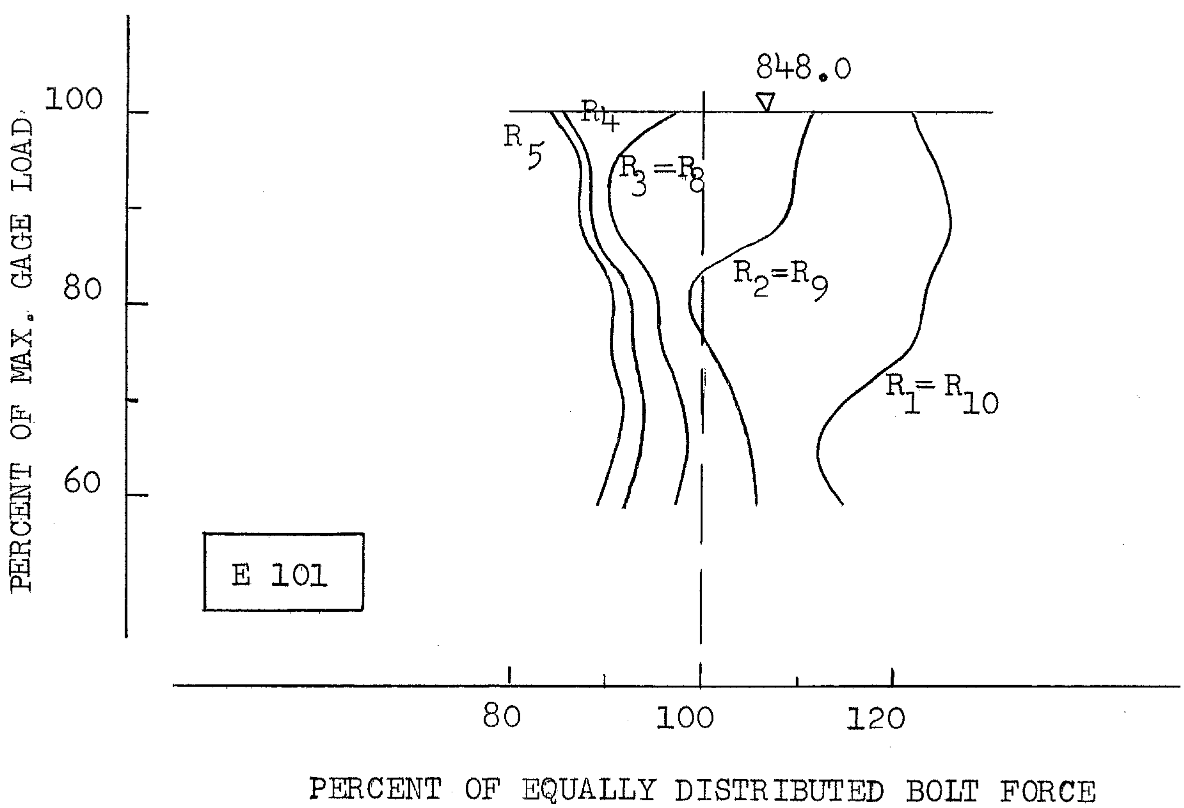


τ - AVG. SHEAR STRESS, Ksi
(τ = Min. Shear Strenght x U)
100
80
60
40
20
+E 41
⊕E 41c
+E 71
+E 101
+E 131
+E 161
From D-Series (7/8"Bolts)
T/S = 1.0/1.10
2
4
6
8
10
12
14
16
N - NUMBER OF PITCHES - 3 1/2" each


555.0
100
80
60
R_4
R_3=R_5
R_2=R_6
R_1=R_7
D 71
PERCENT OF MAX. GAGE LOAD
60
80
100
120
140
PERCENT OF EQUALLY DISTRIBUTED BOLT FORCE


641.2
100
80
60
R_4
R_3=R_5
R_2=R_6
R_1=R_7
E 71
PERCENT OF MAX. GAGE LOAD
60
80
100
120
140
PERCENT OF EQUALLY DISTRIBUTED BOLT FORCE


750.0
100
80
60
PERCENT OF MAX. GAGE LOAD
$R_5 = R_6$
$R_4 = R_7$
$R_3 = R_8$
$R_2 = R_9$
$R_1 = R_{10}$
D 101
60
80
100
120
140
PERCENT OF EQUALLY DISTRIBUTED BOLT FORCE


848.0
100
80
60
PERCENT OF MAX. GAGE LOAD
R_5
R_4
$R_3 = R_8$
$R_2 = R_9$
$R_1 = R_{10}$
E 101
80
100
120
PERCENT OF EQUALLY DISTRIBUTED BOLT FORCE

RELATIONSHIP BETWEEN TORQUE AND INTERNAL BOLT TENSION

In structural joints connected with high strength bolts it is generally assumed that working loads are resisted by frictional forces acting on the faying surfaces of the composed material. These forces are created by the internal bolt tension induced as the nut is tightened against the gripped material. Therefore, it is very important to have at least a minimum preload in each bolt of the joint. On the other hand, after the tightening procedure, there exists only one way of determining the amount of preload, if the inspector doesn't know how much the nut was rotated.

The suggested way to inspect bolts for tightness using a torque wrench is given in the commentary of the RCRBSJ Specifications.

> "Three bolts of the same type, size and condition of thread as those to be inspected are tightened individually, in a device capable of measuring bolt tension, to the required minimum bolt tension given by the specifications. In this tightened condition the inspector's torque wrench is used to rotate the nut slowly a small amount in the tightening direction and the torque required to turn the nut, after it has been set in motion, is recorded."

The object of this study was to determine the preload by measuring torque with a calibrated hand torque wrench for bolts installed by the turn-of-nut method in the E-Series joints. This investigation covers only one size bolt (7/8") with one washer under the turning surface, and two grip-lengths. The work also consisted of calibrating the hand torque wrench with each lot of bolts using the Skidmore-Wilhelm calibrator to find the bolt tension vs. torque relationship.

The bolt was preloaded to 8 kips in the S-W to simulate the "snug" position of the turn-of-nut method. Using the torque-wrench the nut was rotated in about 50 ft. lbs. torque increments until the specified 1/2 or 3/4 turn from snug position was reached. After this rotation only a negligible increase in torque was observed with an additional 1/4 turn.

Using the calibrated torque wrench each bolt of the joints was torqued using a modified procedure. This inspection was executed about four weeks after the joints were bolted up using the turn-of-nut method. Torque was applied gradually until the friction was overcome and the nut turned a small amount. The maximum torque was taken as the test reading. Immediately afterwards the nut was torqued a second time until it rotated an additional small amount. The maximum torque necessary to move the nut was taken as the second reading. The second trial gave in almost all cases a lower torque reading.

SUMMARY OF TORQUE STUDY

Torque measurements (second reading) indicated less preload than what actually was present as determined from tension elongation relationships. Fig. A

All bolts tightened by the turn-of-nut method had tensions, as indicated by torque, in excess of the specification requirements. Fig. B, Fig. C

High strength bolts inspected some time after being tightened will generally require more torque to turn the nut than that required a short time after tightening. Fig. D

No readily available torque-wrench can determine the kinetic torque which should be recorded in order to follow the specification requirements. However, the modified procedure used in this test series was nevertheless considered successful and indicated bolt tensions that were less than what actually was present. Fig. A

Turning the nut a small amount for inspection purposes does not change the bolt elongation a significant amount. The factor of safety against twisting off will remain approximately the same N = 3.0. Fig. B, Fig. E

When torque is used to determine the preload in the bolts of a joint, the variation or scatter is greater than what actually exists as determined by elongation measurements. Fig. A

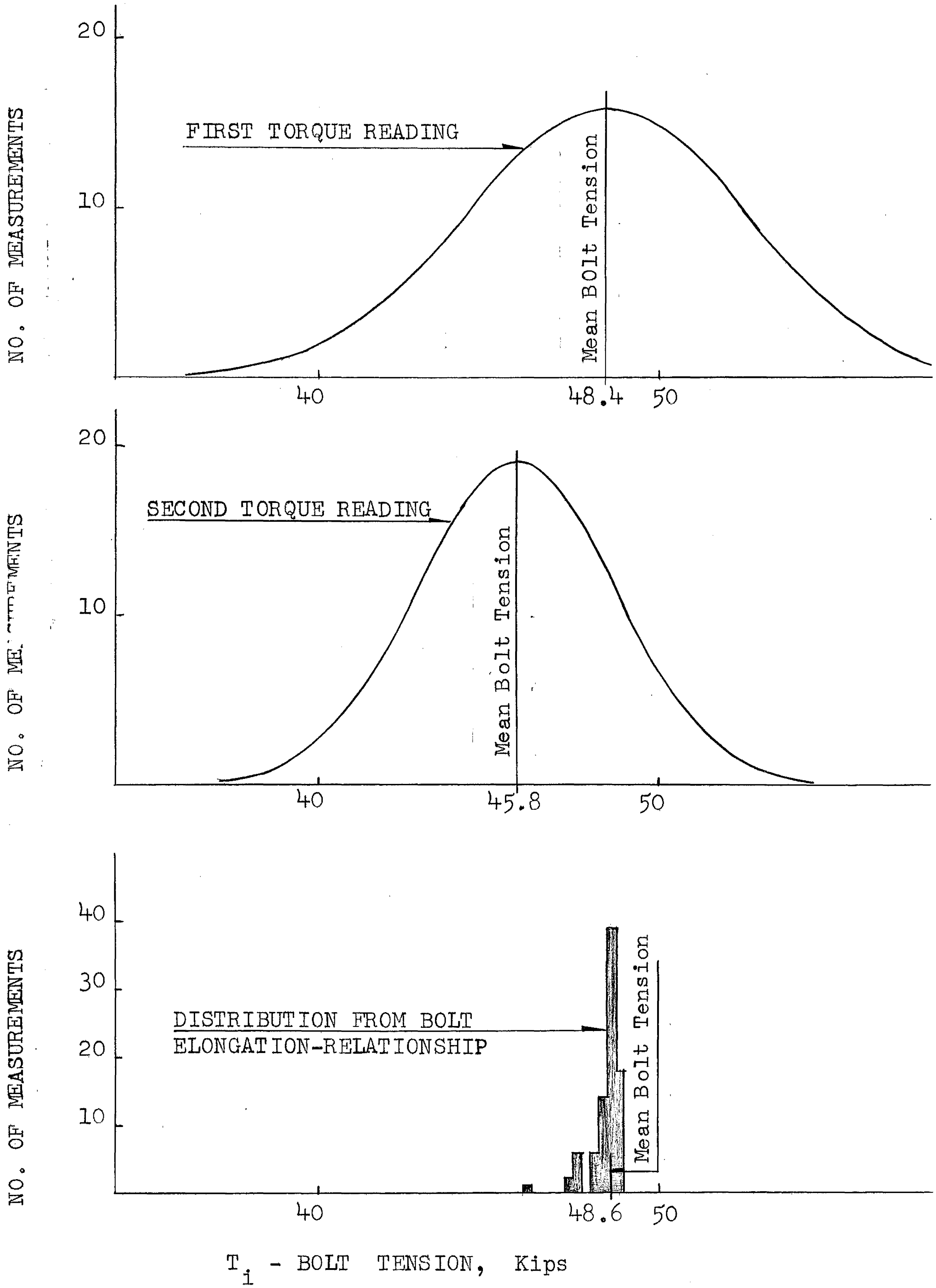


FIG. A - DISTRIBUTION OF BOLT FORCES - SERIES - 8B (7/8"Bolts-4"Grip)

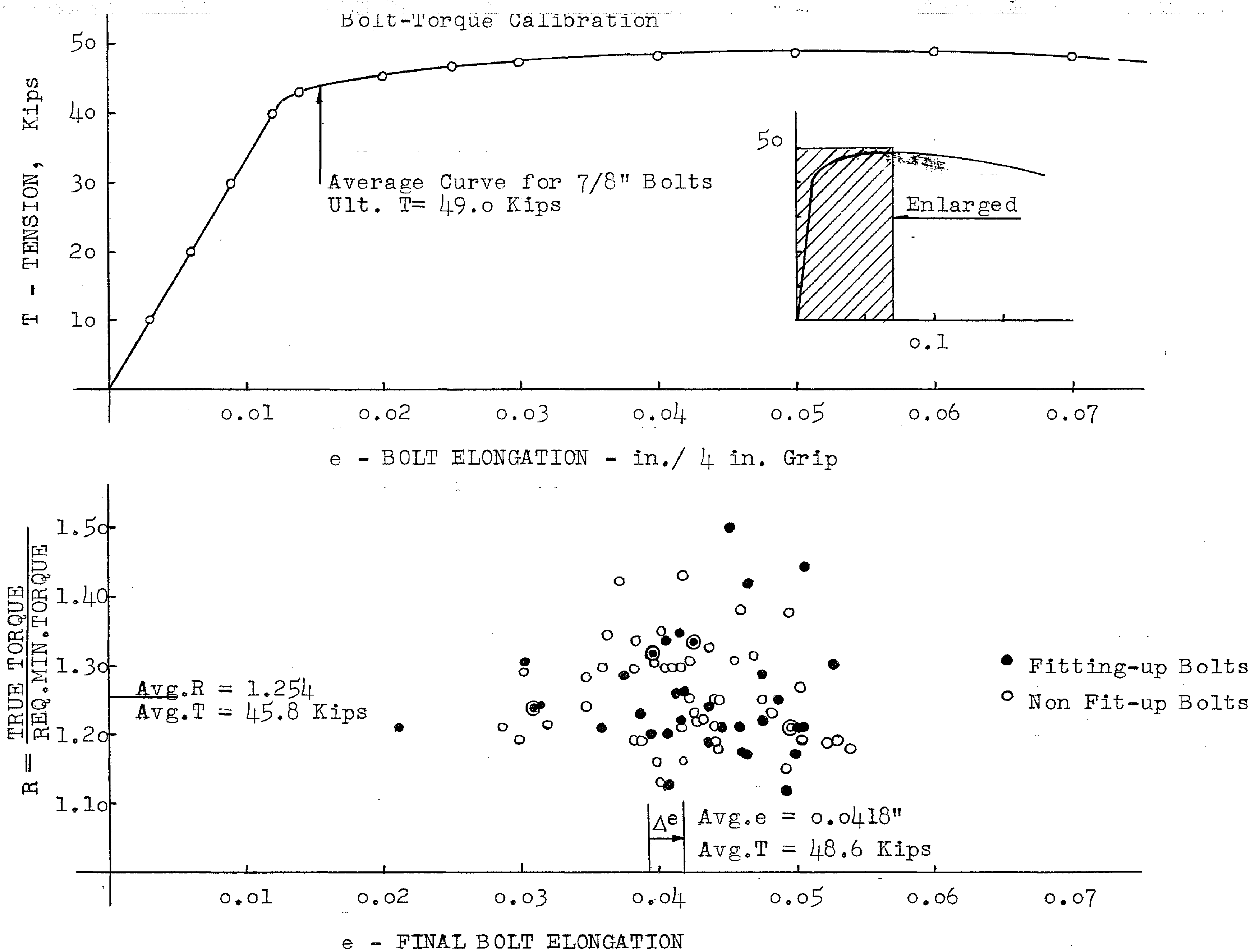


FIG. B - BOLT TORQUE - ELONGATION DISTRIBUTION

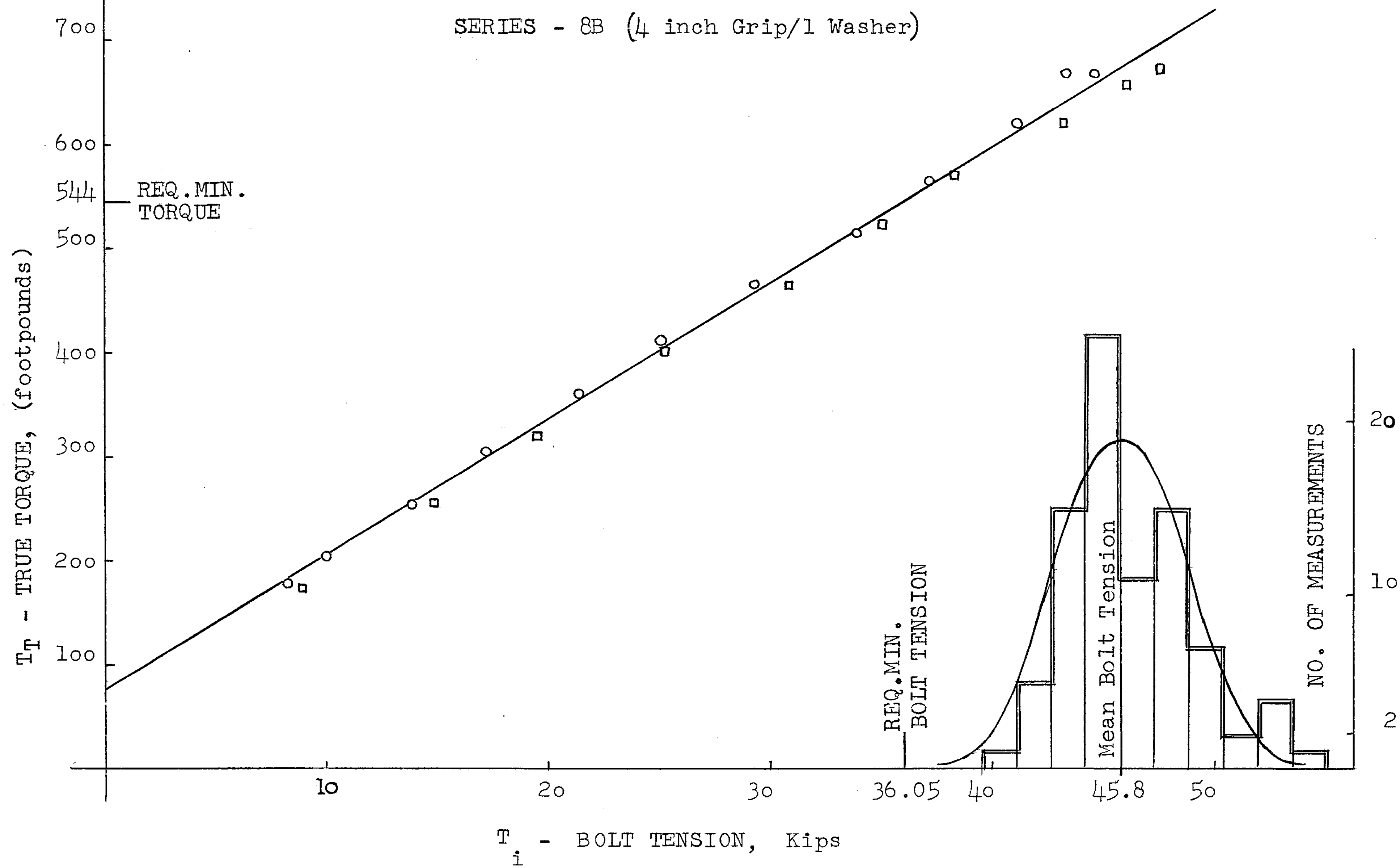
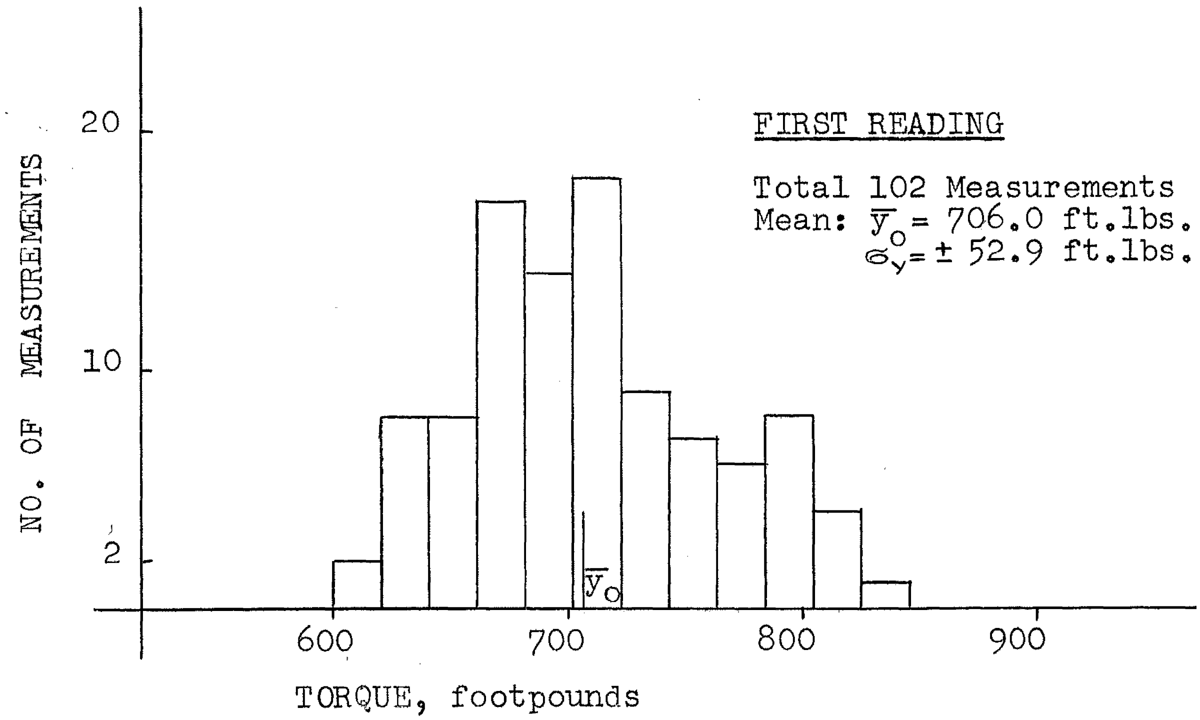


FIG. C - BOLT TORQUE CALIBRATION

SERIES - 8B (4 inch Grip/1 Washer)



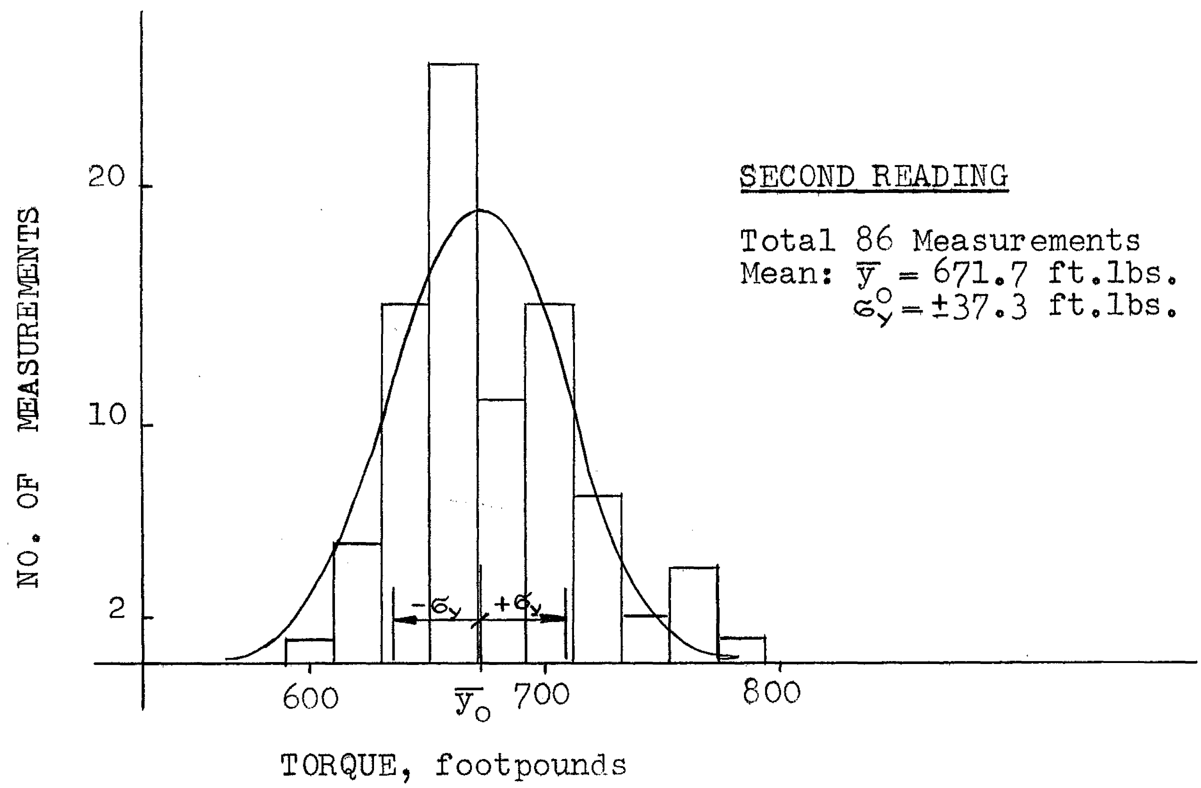
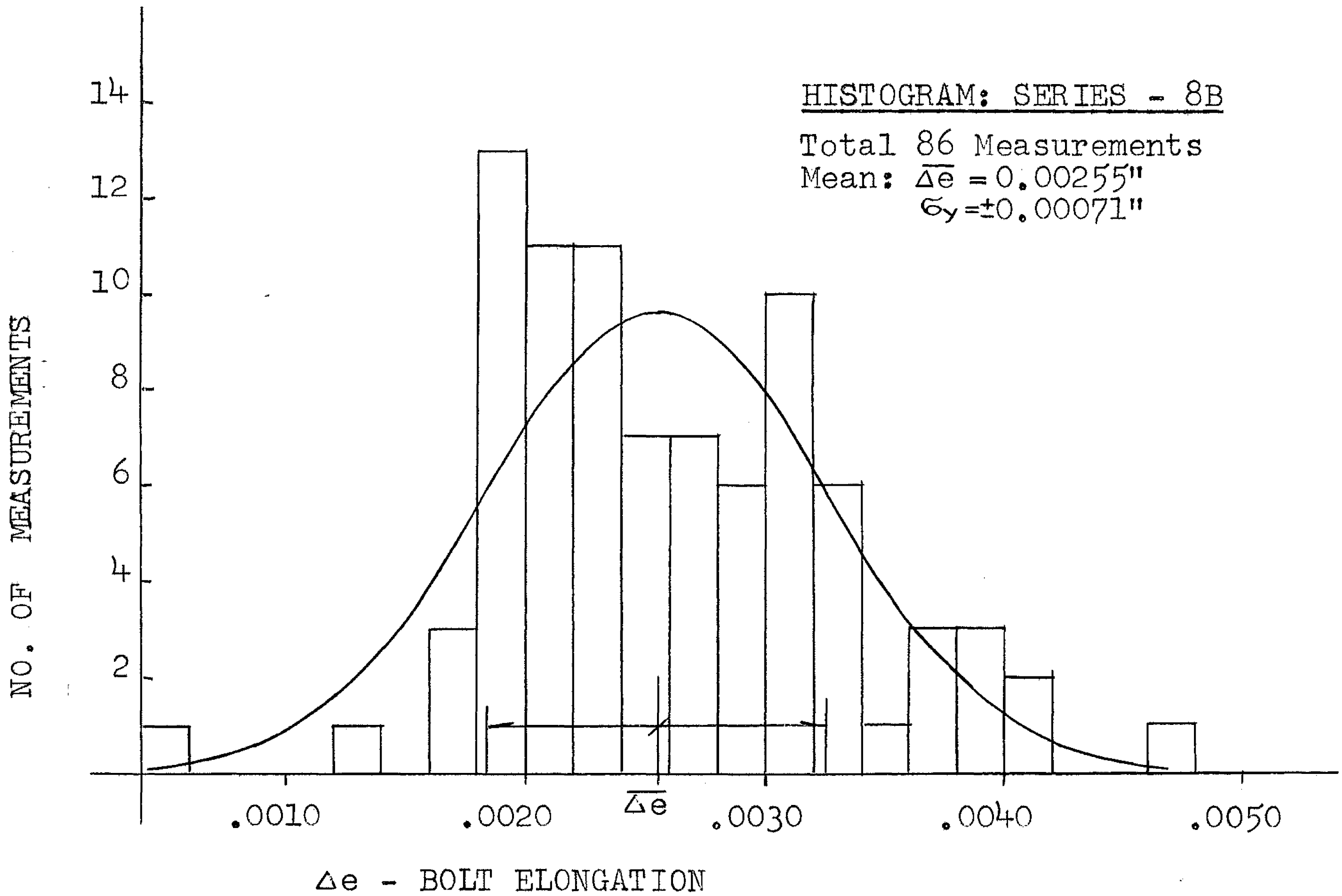


FIG. D - HISTOGRAM SERIES - 8B (7/8" Bolts - 4" Grip)



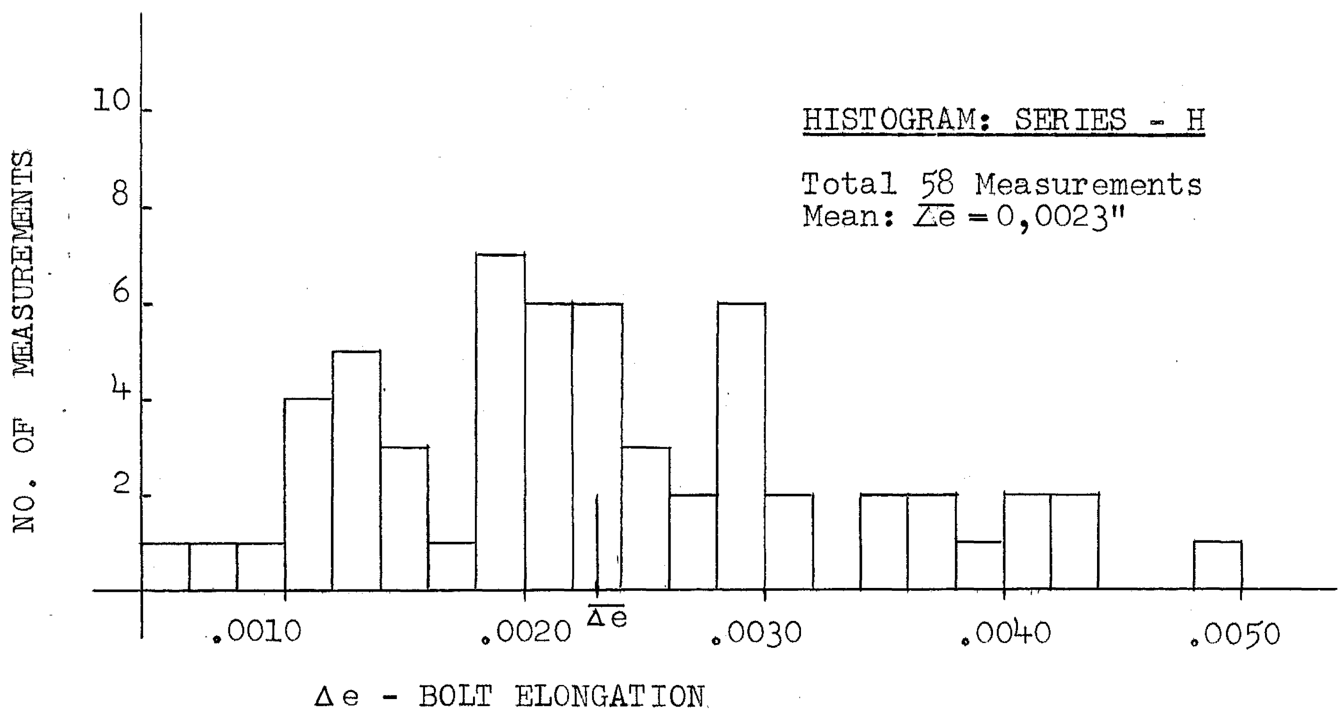


FIG. E - BOLT ELONGATION DUE TO TORQUE-TEST