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OF A490 HIGH-STRENGTH BOLTS

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AUGUST 1964

Fritz Engineering Laboratory Report No. 288.23
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and
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A Report of an Investigation Conducted
by
The Departments of Civil Engineering
LEHIGH UNIVERSITY and the UNIVERSITY OF ILLINOIS
in cooperation with
The Research Council on Riveted and Bolted Structural Joints
The American Institute of Steel Construction
The Illinois Division of Highways
(Project IHR-5)
The Pennsylvania Department of Highways
and
The Department of Commerce -- Bureau of Public Roads

August 1964
CALIBRATION TESTS OF A490 HIGH-STRENGTH BOLTS*

by

Gordon H. Sterling(1), Emile W. J. Troup(2) A.M. ASCE,
Eugene Chesson, Jr. (3) M. ASCE, and
John W. Fisher(4) M. ASCE

SYNOPSIS

Over 100 calibration tests were conducted at Lehigh and Illinois on 7/8 in. diameter ASTM A490 high-strength bolts from the same lots. Each laboratory staff used their own equipment and procedures. Data on bolt tension, elongation, turns of nut, and general behavior were analyzed. Comparison between bolt behavior when torqued in a commercial load cell and in a solid steel block show a significant difference between these two conditions. The general characteristics of the A490 high-strength bolt are similar to those of the familiar A325 bolt, but the physical properties of the new bolt provide greater fastener strength and joint clamping. The effects of different testing techniques and laboratories were inconsequential.

1. Research Assistant, Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pa.
2. Formerly Research Assistant, University of Illinois, Urbana, Illinois.
3. Associate Professor of Civil Engineering, University of Illinois, Urbana, Illinois.
4. Research Assistant Professor, Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pa.
INTRODUCTION

Scope and Purpose:

This investigation was approved by the Research Council on Riveted and Bolted Structural Joints in March 1963. The primary purpose was to provide data on the behavior of bolts with higher strength properties than for A325 fasteners. Such information was necessary for possible revision (in 1964) of the specifications of the Council. Although the ASTM A354 grade BC bolts has been permitted by the 1961 and 1963 editions of the specifications of the American Institute of Steel Construction, it was found that the A354 grade BD bolt offered greater strength at very small additional cost and might prove more economical in structures. The American Society for Testing and Materials acknowledged the need for a structural bolt comparable dimensionally to the ASTM A325 fastener but with material properties similar to those of the ASTM A354 grade BD bolt. This new bolt, described in ASTM A490-64T "Quenched and Tempered Alloy Steel Bolts for Structural Steel Joints" (including nuts and plain hardened washers), was approved by ASTM in 1964. Because acceptance by ASTM of the A490 bolt specification was anticipated, it was necessary to obtain the information required for revisions in the specifications of the Research Council (which approved revisions in March 1964, incorporating the A490 bolt) and of the American Institute of Steel Construction, so that designers would be able to use the new bolt.

A second purpose for this study was to determine whether different testing procedures employed at various laboratories would contribute significantly to experimental scatter. This possible variable was checked by having the University of Illinois and Lehigh University conduct the testing in duplicate. All bolts, nuts, and washers were supplied to Lehigh
University by a well-known manufacturer in sufficient quantities from the same lots. At Lehigh the bolts were identified and selected at random so that Illinois would receive half of each lot. Each university supplied the special equipment for the tests conducted in its laboratory.

Acknowledgments

The tests reported herein were part of investigations resulting from cooperative agreements between the Engineering Experiment Station of the University of Illinois (Department of Civil Engineering), Lehigh University (Department of Civil Engineering), the Research Council on Riveted and Bolted Structural Joints, the American Institute of Steel Construction, the Illinois Division of Highways, the Pennsylvania Department of Highways, and the Department of Commerce — Bureau of Public Roads. W. H. Munse, Professor of Civil Engineering at Illinois and L. S. Beedle, Research Professor of Civil Engineering at Lehigh, were the general supervisors of the tests. The tests at Illinois were conducted by Emile Troup, Research Assistant, working directly with Eugene Chesson, Jr., Associate Professor of Civil Engineering; the tests at Lehigh were conducted by Gordon Sterling, Research Assistant, working directly with John W. Fisher, Research Assistant Professor of Civil Engineering.

The program was planned in cooperation with Committee 15 of the Research Council on Riveted and Bolted Structural Joints. The members of the Committee (1964) are as follows:

T. R. Higgins, Chairman
L. S. Beedle
R. B. Belford
E. Chesson, Jr.
F. H. Dill

W. H. Munse
E. J. Ruble
A. Schwartz, Jr.
T. W. Spilman
D. L. Tarlton
Acknowledgment and appreciation are also due the Bethlehem Steel Company for supplying the test samples.

DESCRIPTION OF TESTS

Materials and Equipment

The tests were conducted on 7/8 in. A490 heavy hexagon head bolts having lengths under head of 5-1/2 in. and 9-1/2 in. The 5-1/2 in. bolts (designated lot LI) had 1-7/16 in. of rolled thread while the 9-1/2 in. bolts (designated lot AB) had 1-3/8 in. of machine cut thread. At Lehigh gage holes were drilled in the centers of both ends of the bolts to accommodate extensometers for length measurements, and lot and bolt numbers were stamped on the bolt heads. The threads of the nuts and of the 9-1/2 in. bolts were well lubricated as received; the threads of the 5-1/2 in. bolts were not so well lubricated. In every test one hardened washer was used under the heavy hexagon ASTM A194 grade 2H nut. The washers had rough mill scale on both surfaces.

A representative sample of twenty bolts and nuts from the AB lot was checked, and found acceptable, with NC2A go and no-go ring gages and NC2B go and no-go plug gages. The LI lot bolts were not checked in this manner.

Skidmore-Wilhelm model M calibrators were used for the torque tests. This device uses hydraulic pressure to determine load measurements. These units were recalibrated at intervals during the testing program to insure that vibrations from pneumatic torquing did not alter their accuracy. Adaptors were used with bolts of both lengths to provide the proper grips
with minimum numbers of plies or parts in the assemblies. All tests of 5-1/2 in. bolts torqued in solid steel were conducted in 4 in. x 4 in. x 4 in. blocks of A440 steel, each with a 15/16 in. diameter hole. Pneumatic impact wrenches were used to tighten all the specimens in the torque tests.

The Lehigh bolt calibrating equipment and the direct reading extensometer used in these tests are described and illustrated in Reference 5(5). At Illinois two different multiplying C-frame extensometers were used for elongation measurements. A large extensometer with a 12-1/2 in. maximum gage length was used for the 9-1/2 in. bolts and a smaller capacity extensometer was used for the shorter bolts. Both extensometers were carefully calibrated with a super-micrometer before testing to determine accurately the multiplication factors(6). The actual changes in bolt elongation were multiplied approximately 4-1/2 times by these lever type extensometers.

In order to assure accurate elongation readings, each of the three extensometers was equipped with a counter-balance which was positioned so that the entire weight of the extensometer and of the counter-balance was carried by the fixed point on the frame. Thus the highly sensitive movable point was influenced solely by the elongation of the bolt, and consistent, uniform seating of the movable point in the bottom gage hole was assured.


Test Variables

The type and number of tests conducted are shown in the following table:

<table>
<thead>
<tr>
<th>Length in., and Lot No.</th>
<th>5-1/2 (LI)</th>
<th>9-1/2 (AB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Grip, in.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4-1/8</td>
<td>4-9/16</td>
</tr>
<tr>
<td></td>
<td>8-1/4</td>
<td>8-11/16</td>
</tr>
<tr>
<td>Thread Length in Grip, in.</td>
<td>1/8</td>
<td>9/16</td>
</tr>
<tr>
<td></td>
<td>1/8</td>
<td>9/16</td>
</tr>
<tr>
<td>University</td>
<td>Illinois</td>
<td>Illinois</td>
</tr>
<tr>
<td></td>
<td>Lehigh</td>
<td>Lehigh</td>
</tr>
<tr>
<td>Direct Tension</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Torqued Tension (Skidmore-Wilhelm)</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Torqued Tension (4 in. square solid steel block)</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

It can be seen that the variables included total grip, thread length in grip, and method of loading. The grip was measured from the underside of the bolt head to the face of the nut in contact with the washer. The thread length under the nut was measured from the beginning of the minimum root diameter of the bolt thread (start of first full thread) to the face of the nut, as shown in the diagram in Figure 1.
Direct Tension Tests:

The direct tension tests were conducted in a 120 kip* Baldwin hydraulic testing machine at Illinois and in a 300 kip Baldwin hydraulic testing machine at Lehigh. The special holders with replaceable inserts used at both universities to accommodate various bolt diameters were similar to those pictured in Reference 5. The differences in test procedures are covered briefly in the following descriptions:

(a) Lehigh: The bolt was first loaded to the specified proof load (55.45 kips), with readings taken at 10 kip increments, and then unloaded to check the ASTM requirements of maximum measured set of 0.0005 in. No bolts were rejected by this test. The bolt was then reloaded at a constant crosshead speed of approximately 0.01 in. per min., and elongation readings were taken at 10 kip intervals until the inelastic range was reached. At this point load readings were taken for every 0.01 in. of elongation in the bolt.

(b) Illinois: In direct tension testing the bolt was taken from a 0.6 kip initial load up to proof load (55.45 kips), with elongation readings recorded at 5 kip increments. (The small initial load was applied to keep the test assembly in good alignment while initial extensometer readings were made). The bolt was unloaded to 0.6 kips and measured to detect any permanent set. The bolt was then taken directly to proof load, this time at a strain rate of about 0.05 in. per min., after which load and elongation readings were taken at various points until the extensometer ran out of travel well beyond the ultimate load. All bolts met the ASTM requirements for measured set and ultimate load. In general, three elongation readings were taken at

* One kip equals 1000 pounds (kilo pound)
each loading increment, and they usually fell within a dial range of 0.001 in. (or within 0.0002 in. actual). The average of these three readings was then converted to the actual change in elongation in inches.

**Torqued Tension Tests -- Calibrator**

Specimens of the 9-1/2 in. and 5-1/2 in. bolts were torqued in the commercial hydraulic calibrators. Special 7/16 in. thick "washers" were used as adaptors at the faces of the calibrators to obtain the longer grips for both lengths of bolts. After packing the calibrator to the required grip with appropriate adaptors, the bolt and nut were installed to a "finger-tight" position. The nut was then tightened with a hand wrench to 5 kips and then to 10 kips ("snug" position); elongation and nut rotation readings were taken at both loads. The nut was tightened from the "snug" position to failure with pneumatic impact wrenches in 30 degree increments (1/12 turn) at Illinois and 45 degree increments (1/8 turn) at Lehigh; load and elongation data were taken at each interval. The extensometers used in the direct tension tests were also used in these tests and were mounted vertically.

**Torqued Tension Tests -- Solid Block**

For these tests, the 5-1/2 in. bolts were tightened in the solid steel blocks. The nut was brought to a "finger-tight" position and then tightened by manual wrenching to the mean "snug" elongation determined in the hydraulic calibrator tests. The nut was then torqued until failure. Elongation measurements were taken at 30 degree increments at Illinois and 45 degree increments at Lehigh. The 7/16 in. thick "washers" were again used in the test set-up to obtain the longer 4-9/16 in. grip. The extensometers were used in a vertical position for these tests, also.
TEST RESULTS AND ANALYSIS

General

A comparison of the test data taken at the two universities is shown in Tables 1 and 2 as well as in the figures which follow. A close study of the data shows that there is excellent agreement in most cases.

The mean elongations at ultimate (maximum) load (line 5, Table 1) for the direct tension tests are the only tabulated data where substantial differences consistently occur. These differences, about 10 percent or less, were caused by two factors. First, the strain rate, which was 0.05 in. per min. at Illinois and approximately 0.01 in. per min. at Lehigh, affected the results. The second and more important factor was the instant at which the extensometers were read for ultimate load. Since the maximum load held for relatively long periods of bolt deformation (as can be seen in Figures 1 and 3) this second factor was the more important.

During the torqued tension tests conducted in the calibrator the bolt tension (read to the nearest 0.2 kips) sometimes remained at the ultimate load value for as much as 3/8 of a turn. In these cases the value of the elongation at ultimate load was determined as the mean of the incremental values. A comparison of these data taken at Illinois and Lehigh (line 7, Table 2) shows excellent agreement.

The only other data in which there are noticeable differences are those most subject to human error. This is apparent in the "Average turns to snug from finger tight" data (lines 10 and 18, Table 2) and "Mean elongation after rupture" data (line 7, Table 1, and lines 8 and 22, Table 2).
In general, the results reported herein are in agreement with other studies of A490 (and A354 BD) bolts \(^{(7)(8)}\).

**Load-Elongation Relationships**

Figures 1 through 4 show the average bolt tension - or bolt load-elongation characteristics of the bolts tested. The close agreement between the data from the two universities indicate that, as would be expected, the load-elongation characteristics of the bolts were not affected by the different testing procedures used at the two laboratories.

Figure 1 shows that the inelastic deformation of the 5-1/2 in. bolts occurred after the prescribed proof load was reached (as required by specification) whereas Figure 2 shows that in torqued tension tests inelastic deformation began slightly below proof load; this behavior under torque was caused by the combined tensile and shear stresses produced by tightening the nut. These observations are also true for the 9-1/2 in. bolts (see Figures 3 and 4).

Figures 5 and 6 summarize the load-deformation relationships for the 5-1/2 and 9-1/2 in. bolts respectively. The effects of thread in grip and method of loading are very evident. In torqued tension tests the 5-1/2 in. bolts achieved about 82 percent of the ultimate load reached in direct tension tests (Figure 5 and Table 2). For the longer bolts (7/8 in. by 9-1/2 in.) the torqued tension ultimate load was about 88 percent of the direct tension ultimate load (Figure 6 and Table 2). These values compare well with the

---


commonly presented value of 85 percent, the value of 82 percent mentioned in Ref. 7 for A354 BD bolts, and the 84 percent from the extensive tests of Ref. 9 with A325 bolts.

It is evident from Figures 5 and 6 that an increase in the thread in grip caused a decrease in the ultimate load in both the direct and torqued tension tests. In addition, greater ductility, or total elongation, was observed in the bolts with 9/16 in. thread in grip. The L1 lot bolts with 1/8 in. thread in the grip reached an ultimate load 5 percent greater than those with 9/16 in. thread in grip. For the longer AB lot bolts this increase was about 8 percent. For both lengths of bolts the elongation at failure in the direct tension tests was more than twice that in the torqued tests.

Figure 7 shows the load-elongation characteristics of the two bolt lots. As was expected, the longer bolts deformed more than the shorter bolts in reaching the same load.

Load-Nut Rotation Relationships:

If the torqued tension-elongation characteristics of a given lot of bolts with a given grip are assumed to be independent of the device in which the bolts are installed, then elongation can be used to determine the load or tension in a bolt torqued in a solid block. Thus, using the nut rotation-elongation relationships plotted on the upper section of Figure 8 and the load-elongation relationships plotted below, the load at any increment of turn can be established for the bolts tested in the solid block. The loads at 1/2 turn from snug for the solid block tests are shown for both

Illinois and Lehigh data. In a similar fashion, the load-rotation data for the shorter grip 5-1/2 in. bolts can be obtained.

From Figure 8 it is readily apparent that the hydraulic calibrator is "softer" than the solid block; that is, a given nut rotation produced in the calibrator a smaller bolt load (as measured by elongation) than was produced in the solid block test. This observation is of special importance to fabricators, erectors, and inspectors of high-strength bolted steel structures. An actual, multiple-ply structural joint may be expected to have a stiffness which lies somewhere between the extremes of a hydraulic cylinder and a solid block, depending on the thoroughness with which the steel has been drawn up during the snugging and assembly operations; the number, thickness, and flatness of the plies; etc.*

This important observation is shown more clearly in Figures 9 and 10 (which were obtained in the manner described for Figure 8). Load-rotation curves are commonly used to determine proper tightening of structural bolts. There is a considerable scatter band of results, as would be expected in this type of data. The reason for the smaller scatter in the solid block data is as follows. For the tests conducted in the hydraulic calibrator actual load-nut rotation data were taken. Thus, the variations in individual bolts are reflected in the scatter bands associated with these tests. However, in the solid block tests the only data that could be taken were nut rotation and elongation measurements. With the method described above, the bolt tension at any specified elongation was determined. Use of a mean curve for load vs. elongation, as in Figure 8 neglects the variations in

* Other examples of this phenomenon are given in a discussion to Ref. 5 by E. Chesson, Jr., ASCE, ST4, Vol. 90, p. 317-319, Aug. 1964.
individual bolts. Thus the small scatter band associated with the solid block tests is somewhat conservative.

However, in both Figures 9 and 10 it is clear that the solid block deformed much less under the bolt forces than did the hydraulic calibrator and that a given amount of nut rotation produced more bolt elongation in the block than in the calibrator. For example, the bolts with 1/8 in. thread in grip (Figure 9) reached proof load at 0.28 turns from snug (mean value) in the solid block and 0.50 turns (mean value) in the hydraulic calibrator.

The mean load-nut rotation curves from Figures 9 and 10 are summarized in Figure 11. When almost 1/2 in. more threads are included in the grip, slightly more turns of the nut are required to reach proof load. The difference produced by this change of the thread in the grip is small compared to the difference between a bolt tightened in a solid block and one tightened in a hydraulic calibrator.

In the analysis of these data another observation can be made. Despite a very broad scatter of results in the nut rotation-elongation data, as plotted in Figure 8, it is obvious that a definite separation of the mean curves obtained by the two universities exists. The major separation of these mean curves occurs beyond 1/2 turn from snug, i.e. in the inelastic range and near ultimate load and beyond, where this difference is not a matter of concern. None-the-less, in Figure 12, the mean curves of load vs. nut rotation obtained in the hydraulic calibrating devices of the respective universities, show a definite trend. It appears that one calibrator is "softer" than the other. This difference (Fig. 12) from calibrator to calibrator is much smaller than the difference shown in Figures 10 and 11 from solid block to calibrator. However, the possible variability in
different hydraulic calibrators should be kept in mind by users. When data from the two universities obtained with the solid block tests were plotted as was done in Figure 12, the two curves were almost identical.

The bolt tension-nut rotation data for the 7/8 in. by 9-1/2 in. bolts are summarized in the average curves of Figure 13. To insure proof load in these longer bolts, it is necessary to apply more than a half turn from snug. These tests were made in a hydraulic calibrator that, as mentioned above, may be thought to represent an upper limit on the "softness" which might be expected in actual structural joints. It might also be pointed out that tests made with experienced steel workers operating pneumatic wrenches have shown that "snug" often will be greater than the 10 kips used herein as a reasonable base from which to calculate turns. These 9-1/2 in. bolts are almost 11 diameters long, or more than the 8 diameters length limit which is included in the 1964 Council specification revision as the maximum length for which only "1/2 turn from snug" will be prescribed; bolts eight diameters or 8 in. long are required to have "2/3 turn from snug."

It might be noted that despite the small differences in behavior for variations in the grip, the average number of turns to failure from "snug" appeared to be only slightly affected by the number of threads in the grip; this difference amounted to approximately one quarter turn more to failure for the longer-thread-in-grip bolts. In this same connection, from Table 2 it can be seen that, for the tests performed in the solid block, the average turns to failure were only about 6 percent less than for those similar tests performed in the hydraulic calibrator.

Description of Failures:

Six thread stripping failures occurred in the twenty direct tension tests on the L1 lot bolts. Five of these occurred in bolts being tested with
1/8 in. thread in grip. This would be expected because that condition gave the higher bolt load. In all cases of thread stripping the nut and bolt threads were so badly damaged that it was impossible to determine which threads had failed first. The remaining L1 lot bolts tested in direct tension, with 9/16 in. thread in grip, failed on a jagged diagonal extending over several threads. Those with 1/8 in. thread in grip failed on a level plane through the thread at the juncture of the thread runout and bolt shank.

All AB lot bolts tested in direct tension also failed on a jagged diagonal extending over several threads. Those tested with 1/8 in. thread in grip had failure planes extending into the nut-bolt interthreading.

All L1 lot bolts tested in torqued tension broke near the nut face. The failure mode was generally a "twisting off" through the first thread under the nut. Some failure surfaces extended over two threads and showed evidence of longitudinal tear, indicating that the final failure occurred in tension. The difference in thread length in grip had little effect on the appearance or texture of the fracture surface.

Six of the AB lot bolts tested in torqued tension failed by thread stripping. With these exceptions the failure modes for the AB bolts in torqued tension were the same as those described above for the L1 bolts. These stripping failures developed after the maximum bolt load appeared to have been reached; maximum loads recorded were similar to those obtained with tensile failures. Measurements of the bolt and nut diameters prior to testing indicated that each thread form was near the extreme permitted for an ASA Class 2 fit and thus a minimum thread engagement occurred.

Comparison with A325 Bolts

The A325 and A490 bolts compared in Figures 14 and 15 had the same dimensions and their ultimate strengths were close to their respective
specified minimums. The AB lot A325 bolts shown in these Figures gave 105 percent of the minimum ultimate load specified for A325 bolts when tested with 1/8 in. thread in grip. The H lot A325 bolts with 1/2 in. thread in grip gave 106 percent of the specified minimum ultimate. The results of these tests are given in Reference 5. As is shown in line 4 of Table 1 the comparative values for the L1 and AB lot A490 bolts were 109 percent and 102 percent respectively.

In Figure 14 it can be seen that the A325 and A490 bolts gave substantially the same load-turns relationships up to the elastic limit of the A325 bolts. At 1/2 turn beyond "snug" the A490 bolts gave about 20 percent greater load than the A325 bolts because of the relative mechanical properties of the bolt steels.

Figure 15 compares the load-elongation characteristics of A490 bolts with those of A325 bolts, when tested in a hydraulic calibrator. The longer bolts gave similar curves, with the A490 bolts going to a higher plateau. Tests of shorter bolts show a quicker load drop-off beyond ultimate load for the A490 bolts than for the A325 bolts. Similar comparisons were shown in Reference 7 for A325 with A354 BD bolts (which have the same mechanical properties as A490 bolts), and in Reference 8 for A325 with A354 BD and A490 bolts.
CONCLUSIONS

Conclusions of a general nature are presented below. Specific values and relationships can be seen from the tables and figures.

1. Decreasing the amount of thread in grip increased the ultimate strength of a bolt in both direct and torqued tension.

2. The effect of loading method was quite pronounced. Bolts tested in direct tension always gave higher (by approximately 20 percent) ultimate loads than those from the same lot tested in torqued tension.

3. Bolts tested in torqued tension with 1/8 in. thread in grip had less ductility and had from 1/4 to 3/8 fewer turns to failure than did those tested with 9/16 in. thread in grip.

4. The load-nut rotation characteristics of bolts tested in a solid steel block differed considerably from those of bolts tested in the hydraulic calibrator. The hydraulic calibrator deformed more under the bolt forces than did the solid block. In these tests the bolts torqued in the solid block reached proof load in just over 1/4 turn from "snug" while those in the calibrator required 1/2 turn or more from the same starting point.

5. There appears to be some small variation in "softness" or flexibility from one hydraulic calibrator to another.

6. The 7/8 in. by 9-1/2 in. bolts had a tension approximately equal to proof load when torqued to 2/3 turns from snug for both 1/8 in. and 9/16 in. thread in grip. The 7/8 in. by 5-1/2 in. bolts had a bolt tension of approximately proof load when torqued to 1/2 turn from snug for both 1/8 in. and 9/16 in. thread in grip. If the gripped material has more "stiffness" than a hydraulic calibrator, proof load will be attained in fewer turns.
7. The A490 bolts gave an increase of about 20 percent in preload over their A325 counterparts when torqued to the specified values of 1/2 turn for the short bolts and 2/3 turn for the long bolts.

8. No significant differences caused by different testing procedures at the two universities were noted.
### TABLE 1
DIRECT TENSION CALIBRATION

<table>
<thead>
<tr>
<th>Lot Designation</th>
<th>Li</th>
<th>Ab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolt Length in.</td>
<td>5-1/2</td>
<td>9-1/2</td>
</tr>
<tr>
<td>Bolt Diameter in.</td>
<td>7/8</td>
<td>7/8</td>
</tr>
<tr>
<td>Thread Length in.</td>
<td>1-7/16</td>
<td>1-3/8</td>
</tr>
<tr>
<td>Specified Proof Load kips</td>
<td>55.45</td>
<td>55.45</td>
</tr>
<tr>
<td>Specified Min. U. Load kips</td>
<td>69.30</td>
<td>69.30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Testing Agency</th>
<th>Illinois</th>
<th>Lehigh</th>
<th>Illinois</th>
<th>Lehigh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Grip in.</td>
<td>4-1/8</td>
<td>4-1/8</td>
<td>4-9/16</td>
<td>4-9/16</td>
</tr>
<tr>
<td>Thread Length in Grip in.</td>
<td>1/8</td>
<td>1/8</td>
<td>9/16</td>
<td>9/16</td>
</tr>
<tr>
<td>No. of Specimens Tested</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Mean Ultimate Load kips</td>
<td>75.9</td>
<td>76.0</td>
<td>72.1</td>
<td>72.1</td>
</tr>
<tr>
<td>Standard Deviation kips</td>
<td>0.45</td>
<td>1.07</td>
<td>0.54</td>
<td>0.57</td>
</tr>
<tr>
<td>% Spec. Min. U. Load</td>
<td>109</td>
<td>109</td>
<td>104</td>
<td>104</td>
</tr>
<tr>
<td>Mean Elong. at U. Load in.</td>
<td>0.047</td>
<td>0.051</td>
<td>0.057</td>
<td>0.065</td>
</tr>
<tr>
<td>Mean Rupture Load kips</td>
<td>68</td>
<td>67</td>
<td>61</td>
<td>59</td>
</tr>
<tr>
<td>Mean Elong. after Rupture in.</td>
<td>0.13</td>
<td>0.14</td>
<td>0.23</td>
<td>0.24</td>
</tr>
<tr>
<td>No. of Bolt Tensile Failures</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>No. of Stripping Failures</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

### TABLE 2
TORQUED TENSION CALIBRATION

<table>
<thead>
<tr>
<th>Lot Designation</th>
<th>Li</th>
<th>Ab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolt Length in.</td>
<td>5-1/2</td>
<td>9-1/2</td>
</tr>
<tr>
<td>Bolt Diameter in.</td>
<td>7/8</td>
<td>7/8</td>
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<table>
<thead>
<tr>
<th>Type of Test</th>
<th>Torqued in Skidmore-Wilhelm</th>
<th>Torqued in Skidmore-Wilhelm</th>
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<tr>
<th>Testing Agency</th>
<th>Illinois</th>
<th>Lehigh</th>
<th>Illinois</th>
<th>Lehigh</th>
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<tbody>
<tr>
<td>Nominal Grip in.</td>
<td>4-1/8</td>
<td>4-1/8</td>
<td>4-9/16</td>
<td>4-9/16</td>
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<tr>
<td>Thread Length in Grip in.</td>
<td>1/8</td>
<td>1/8</td>
<td>9/16</td>
<td>9/16</td>
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<tr>
<td>No. of Specimens Tested</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Mean Load at 1/2 Turn from Snug kips</td>
<td>56.5</td>
<td>54.3</td>
<td>50.0</td>
<td>48.8</td>
</tr>
<tr>
<td>Mean Load at 2/3 Turn from Snug kips</td>
<td>62.0</td>
<td>60.2</td>
<td>59.1</td>
<td>55.8</td>
</tr>
<tr>
<td>Mean Ultimate Load kips</td>
<td>62.3</td>
<td>61.1</td>
<td>60.1</td>
<td>58.4</td>
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<tr>
<td>Standard Deviation kips</td>
<td>3.11</td>
<td>2.80</td>
<td>2.63</td>
<td>3.03</td>
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<tr>
<td>Mean Rupture Load kips</td>
<td>43</td>
<td>40</td>
<td>47</td>
<td>34</td>
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<tr>
<td>Mean Elong. at U. Load in.</td>
<td>0.025</td>
<td>0.026</td>
<td>0.037</td>
<td>0.036</td>
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<tr>
<td>Mean Elong. after Rupture in.</td>
<td>0.09</td>
<td>0.08</td>
<td>0.15</td>
<td>0.11</td>
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<tr>
<td>Mean Elong. at Proof Load in.</td>
<td>0.15</td>
<td>0.16</td>
<td>0.18</td>
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<tr>
<td>Mean turns to snug from finger tight</td>
<td>0.16</td>
<td>0.20</td>
<td>0.26</td>
<td>0.28</td>
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<tr>
<td>Avg. turns to Proof Load from snug</td>
<td>0.08</td>
<td>0.05</td>
<td>0.52</td>
<td>0.57</td>
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<tr>
<td>Avg. turns to failure from snug</td>
<td>1.34</td>
<td>1.33</td>
<td>1.61</td>
<td>1.65</td>
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<tr>
<td>Ratio Direct Tension Ultimate</td>
<td>0.82</td>
<td>0.80</td>
<td>0.83</td>
<td>0.81</td>
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<tr>
<td>No. of stripping failures</td>
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<td>0</td>
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<td>0</td>
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<table>
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<tr>
<th>Type of Test</th>
<th>Torqued in Solid Block</th>
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<tr>
<td>No. of Specimens Tested</td>
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</tr>
<tr>
<td>No. of Stripping Failures</td>
<td>3</td>
</tr>
<tr>
<td>Avg. turns to snug from finger tight</td>
<td>0.16</td>
</tr>
<tr>
<td>Avg. turns to Proof Load from snug</td>
<td>0.28</td>
</tr>
<tr>
<td>Mean Load at 1/2 turn from snug</td>
<td>62.0</td>
</tr>
<tr>
<td>Avg. turns to failure from snug</td>
<td>1.26</td>
</tr>
<tr>
<td>Mean Elong. after Rupture in.</td>
<td>0.09</td>
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</table>
FIG. 1  DIRECT TENSION CALIBRATION—LI LOT A490 BOLTS.
FIG. 2 TORQUED TENSION CALIBRATION—I LOT A490 BOLTS.
FIG. 3 DIRECT TENSION CALIBRATION — AB LOT A490 BOLTS.
FIG. 4  TORQUED TENSION CALIBRATION—AB LOT A490 BOLTS.
FIG. 5 EFFECT OF LOADING METHOD ON LOAD-ELONGATION RELATIONSHIPS; LOT A490 BOLTS.
FIG. 6 EFFECT OF LOADING METHOD ON LOAD-ELONGATION RELATIONSHIPS; AB LOT A490 BOLTS.
FIG. 7 COMPARISON OF LOAD-ELONGATION RELATIONSHIPS OF LI LOT BOLTS WITH AB LOT BOLTS.
FIG. 8 NUT ROTATION-ELONGATION CHARACTERISTICS OF LEHIGH LOT BOLTS; 9/16 INCH THREAD IN GRIP.
Fig. 9 Torqued Tension-Nut Rotation Relationships of 7/8" x 5 1/2" Bolts; 1/8" Thread in Grip.
FIG. 10 TORQUED TENSION-NUT ROTATION RELATIONSHIPS OF LOT A490 BOLTS; 9/16 INCH THREAD IN GRIP.
FIG. II. EFFECT OF GRIPPED MATERIAL ON LOAD-ROTATION RELATIONSHIPS—AVERAGE CURVES.
Fig. 12: Comparison of load-nut rotation data from two universities; showing mean curves.

\( \frac{7}{8} \times 5 \frac{1}{2} \) bolts torqued in hydraulic calibrator.
FIG. 13 LOAD-NUT ROTATION RELATIONSHIPS OF 7/8 INCH x 9-1/2 INCH A490 BOLTS; SHOWING MEAN CURVES.
FIG. 14 COMPARISON OF LOAD-NUT ROTATION RELATIONSHIPS OF A490 AND A325 BOLTS.
FIG. 15 COMPARISON OF LOAD-ELONGATION RELATIONSHIPS OF A490 WITH A325 BOLTS; BOTH TORQUED IN HYDRAULIC CALIBRATOR.