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Large Bolted Joints

TESTS OF A490 BOLTS
(Preliminary Report)

by
Gordon Sterling
John W. Fisher

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SYNOPSIS

Presented in this report are the results of calibration tests of individual ASTM A490 alloy steel bolts. The bolts tested were 7/8 in. nominal diameter. Results of twenty direct tension and thirty torqued tension tests are reported.

This is a preliminary report and will eventually be re-written to include information on similar tests conducted on the same bolt lots at the University of Illinois.

INTRODUCTION

At the February 14, 1963 meeting of Committee 15 of the Research Council on Riveted and Bolted Structural Joints, it was recommended that Lehigh University and the University of Illinois conduct tests on bolts from the same lot to determine if testing procedures constitute a variable. Each university was to test bolts in direct tension and torqued tension using its own standard calibration procedures.

This report discusses the results of the tests conducted at Lehigh. The bolts were purposely ordered near the minimum specified tensile strength.
TEST PREPARATION

Two lots of 7/8 in. diameter, heavy hexagon head, A490 bolts were tested. Before testing, all bolts were stamped with a lot designation and bolt number. In addition, each bolt had holes drilled in the centers of the head and nut ends to accommodate the C-frame extensometer.

Bolts designated as AB lot were 9 1/2 in. long with 1 3/4 in. of cut thread. Those labelled Lot LI were 5 1/2 in. long with 1 1/2 in. of rolled thread. In all tests, one hardened washer was used under an A194 Grade 2H nut (heavy hexagon). Each lot was tested with 1/8 in. and 9/16 in. of thread in the grip. This gave grip lengths of 8, 3/4 in. and 8-11/16 in. for Lot AB bolts, and 4-1/8 in. and 4-9/16 in. grip for the LI bolts.

A representative sample of twenty bolts and nuts from the AB lot were checked for tolerance by using the NC2A go and no-go ring gages and the NC2B go and no-go plug gages. All specimens tested were acceptable. The AB lot bolts were received with a light coating of shipping oil.

The LI lot bolts were received with a greasy film, but were not as well lubricated as the AB bolts. This lot of bolts was not checked with the NC2A gages. The same keg of nuts and washers was used in the tests of both the AB and LI lots.
TEST PROCEDURE

a. TORQUED TENSION TESTS

Specimens from both lots were tested in the Model M Skidmore-Wilhelm calibrating device. Ten bolts from the LI lot were also tested in a solid block of A440 steel.

For all tests conducted in the Skidmore-Wilhelm calibrator the nut was turned by using a hand wrench until a "snug" tension of ten kips was reached in the bolt. Bolt load, elongation and turn-of-the-nut (in degrees) measurements were taken at 5 and 10 kips. The nut was then rotated in 45° increments (1/8 turn-of-the-nut) with a pneumatic impact wrench until failure occurred either by fracture or by thread stripping. Bolt elongation and load data were taken at each 45° increment of nut rotation.

From the tests done in the Skidmore-Wilhelm device a mean elongation at a "snug" load of ten kips was determined for the LI lot specimens. This mean elongation was applied to those specimens being tested to failure in the solid A440 steel block by using a hand wrench to turn the nut. The bolt was then tested by turning the nut, in 45° increments, using a pneumatic impact wrench. Bolt elongation measurements were taken at each position of nut rotation. This procedure allowed a direct comparison of the nut rotation vs. elongation characteristics of bolts tested by torquing in a block of A440 steel and in the less rigid Skidmore-Wilhelm device.
b. DIRECT TENSION TESTS

As a preliminary check the bolt being tested was loaded to the specified proof load and then unloaded to check the ASTM requirement of minimum permissible set (0.0005 in.). No bolts were rejected by this test. The bolt was then reloaded and elongation readings were taken at ten 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. The direct tension tests were conducted in a 300 kip Baldwin hydraulic testing machine at a strain rate of approximately 0.01 in. per minute.

A detailed description of the procedures used in the calibrating of bolts is given in Reference 1. The reader is referred specifically to Figures 1 and 2 of this report for the specific set ups used in the direct and torqued tension tests.

TEST RESULTS

Table 1 and Figures 1 through 12 summarize the test results. The actual test points are given on most figures, and, therefore, Table 1 merely indicates the significant mean values determined from all the tests. The specified proof load for these 7/8 in. diameter, A490 bolts is 55.45

1) John L. Rumpf and John W. Fisher
kips, (i.e. the load to which the bolt may be loaded so that after unloading there is no more than 0.0005 in. permanent set), and the specified minimum ultimate load is 69.3 kips.

Four failure modes were noticed. All the AB lot bolts failed in the direct tension tests on a jagged diagonal through the threads. Two of the AB lot bolts tested in torqued tension with 1/8 in. thread in grip failed by thread stripping as did two LI bolts in direct tension with the same amount of thread under the nut. In all four cases, the nut and bolt thread was so badly damaged that it was impossible to tell which thread had originally failed. The LI specimens tested in direct tension with 9/16 in. thread in grip failed on a jagged diagonal as noticed with the AB direct tension tests. However, three bolts with 1/8 in. thread in the grip failed on a level plane, through the threads, at the juncture of the thread runout and bolt shank. The other two LI bolts failed in the diagonal manner previously noted. All bolts tested in torqued tension (with the exception of the two AB lot bolts that stripped) failed by "twisting off" on a level plane through the first thread under the nut at the time of failure.

Figures 1 through 4 relate the load-elongation characteristics of the bolts tested in direct and torqued tension. In all cases bolts tested with 1/8" thread in grip gave greater ultimate load than bolts from the same lot tested in the same manner with 9/16" thread in grip; however, the specimens with 9/16" thread in grip sustained greater deformations before failure.
Figure 5 shows a typical relationship between the direct and torqued tension tests. Bolts tested in direct tension gave greater ultimate loads and sustained greater deformations to failure than did those tested in torqued tension.

Bolts tested in the solid A440 steel block gave greater loads for fewer turns, as is indicated in Fig. 6. Although there is a broad scatter of the data associated with each test there is a definite separation of the two mean curves.

The bolt load is related to the number of turns from a "snug" bolt load of 10 kips in Figs. 7, 8, 9 and 10. The data shown in Figs. 7 and 8 refers to tests conducted in the Skidmore-Wilhelm calibrator. Figure 8 presents the results of tests done in a solid A440 steel block. The mean curves from Figs. 8 and 9 (with 1/8" thread in grip) are plotted in Fig. 10 to compare with results of tests on A325 bolts(1). The "snug" load for the A325 bolts was 8 kips.

The load-elongation relationship of A490 and A325 bolts torqued in the Skidmore-Wilhelm calibrator are compared in Fig. 11. For the 7/8" x 9 3/4" bolts there is practically no difference at 1/2 turn from snug. (Again, for the A325 bolts "snug" was defined as 8 kips whereas for the A490 "snug" was 10 kips).

The effect of exposed thread under the nut is given in Fig. 12 and compared with results obtained on A325 bolts(1). This plot shows that the A325 bolts sustain slightly more rotation to failure than do the A490 bolts, especially at 9/16" thread in grip.
CONCLUSIONS

The following conclusions are based on the results of 50 tests of individual bolts. (Twenty 7/8" x 9½" bolts and thirty 7/8" x 5½ bolts). These results and conclusions are not greatly different from those reported in a more comprehensive study of A354 alloy steel bolts (2). Similar results and conclusions, based on a limited number of tests, were also reported in Ref. 3.

1. Bolts from the same lot, and with the same amount of thread in grip, gave a greater ultimate strength in direct tension tests than was achieved in torqued tension tests. For the AB lot specimens this increase was 10 to 15 percent of the ultimate torqued tension value, and for the LI lot bolts the increase was about 26 percent.

2. A lesser amount of thread in grip gave an increase in the ultimate bolt strength in both the torqued and direct tension tests. (See Figures 1 to 4).

3. For specimens with 1/8 in. thread in grip the LI lot bolts required an average of 1½ turns from "snug" to failure; the AB lot bolts needed an average of 1-3/8 turns. With 9/16 in. thread under the nut this requirements increased to 1-5/8 and 1-3/4 turns for the LI and AB lot bolts respectively. Thus an increase from 1/8 in. to 9/16 in. thread in grip required an additional 3/8 turn to failure for both bolt lots.

(2) Richard J. Christopher and John W. Fisher

(3) E. Chesson, Jr. and W. H. Munse
"Studies of the Behavior of High Strength Bolts and Bolted Joints", Dept. of Civil Engineering, University of Illinois, Urbana, Illinois, Dec. 1963
4. The average load at \( \frac{1}{2} \) turn from "snug" was less than the specified proof load for both lots tested in the Skidmore-Wilhelm device. Three of the ten 5\( \frac{1}{2} \) in. long LI lot bolts tested did give loads greater than the specified proof load (55.45 kips) at \( \frac{1}{2} \) turn from snug. None of the AB lot bolts reached proof load at \( \frac{1}{2} \) turn from snug. (See Figs. 2 and 4, and 7 and 8).

5. Figure 6 indicates that the LI specimens, with 1/8" thread in grip, torqued in solid steel did reach proof load at \( \frac{1}{2} \) turn from "snug". Also this plot shows that, to achieve the same bolt elongation, fewer turns of the nut are required in specimens torqued in the solid steel block than is required for those tested in the less rigid Skidmore-Wilhelm device. If one assumes that the load vs. elongation characteristics of the bolts, tested in torqued tension, are not influenced by the material gripped, then (from Fig. 6) one observes that the bolt load at \( \frac{1}{2} \) turn is indeed above proof load for those tested in the solid steel block. Figure 8 shows that proof load was also reached at \( \frac{1}{2} \) turn for most specimens torqued in solid steel with 9/16" thread in grip.

6. The A325 and A490 bolts tested in the Skidmore-Wilhelm gave substantially the same load-turns relationship up to the elastic limit of the A325 bolts. (With such a broad scatter of data (see Figs. 7 and 8) it is strictly fortuitous that the mean curves fall on the exact same line ... However, in the elastic range of the bolts one would expect the mean curves to be very close.)

7. The 7/8 x 9\( \frac{1}{2} \)" A490 and A325 bolts (with similar amounts of exposed thread under the nut,) behaved similarly in torqued tension tests, with the A490 bolts merely going to a higher "plateau". However, for the shorter bolts the A490 tests indicate a relatively quick load drop off as compared to the A325 bolts. Note that at \( \frac{1}{2} \) turn from snug the load in the long bolts was approximately the same regardless of type. (See Fig. 11).
TABLE 1
A490 BOLTS - 7/8" DIAMETER

<table>
<thead>
<tr>
<th>Bolt Lot</th>
<th>DIRECT TENSION</th>
<th>TORQUED TENSION (in Skidmore Wilhelm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AB</td>
<td>AB</td>
</tr>
<tr>
<td>Nominal Grip</td>
<td>ins.</td>
<td>8½</td>
</tr>
<tr>
<td>Thread in Grip</td>
<td>ins.</td>
<td>1/8</td>
</tr>
<tr>
<td>No. of Specimens Tested</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>Mean Ult. Load</td>
<td>kips</td>
<td>73.2</td>
</tr>
<tr>
<td>Std. Dev. from Ult. Load</td>
<td>kips</td>
<td>1.59</td>
</tr>
<tr>
<td>Mean Elong. at Ult.</td>
<td>ins.</td>
<td>0.0779</td>
</tr>
<tr>
<td>Mean Rupture Load</td>
<td>kips</td>
<td>65</td>
</tr>
<tr>
<td>Mean Elong. after rupture</td>
<td>ins.</td>
<td>0.12</td>
</tr>
<tr>
<td>Mean Elong. at Proof Load</td>
<td>ins.</td>
<td>0.028</td>
</tr>
<tr>
<td>% Min. Spec. Ult. Load</td>
<td>-</td>
<td>106</td>
</tr>
<tr>
<td>Mean Load at ( \frac{1}{2} ) Turn</td>
<td>kips</td>
<td>-</td>
</tr>
<tr>
<td>Ave. Turns to Failure</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>(Torqued Tension Ult)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>(Direct Tension Ult.)</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>No. of Stripping Failures</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>TORQUED TENSION (in solid block)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LI</td>
<td>LI</td>
</tr>
<tr>
<td></td>
<td>1/8</td>
<td>9/16</td>
</tr>
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<td>0</td>
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<td>.28</td>
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<tr>
<td></td>
<td>1.30</td>
<td>1.44</td>
</tr>
<tr>
<td></td>
<td>0.29</td>
<td>0.41</td>
</tr>
</tbody>
</table>

Note: Proof Load = 55.45 k
Specified Minimum Ult. Load = 69.3 k
FIG. 1 DIRECT TENSION CALIBRATION AB-LOT BOLTS

- \( \frac{7}{8} \) in. x 9 1/2" bolts, Cut Threads
- \( \star \), \( \star \) Fracture of Bolt

BOLT LOAD (kips)

BOLT ELONGATION (inches)
FIG. 2  TORQUED TENSION CALIBRATION AB-LOT BOLTS
FIG. 3 DIRECT TENSION CALIBRATION LI-LOT BOLTS
FIG. 4  TORQUED TENSION CALIBRATION LI-LOT BOLTS
FIG. 5 COMPARISON OF LOAD-ELONGATION CHARACTERISTICS OF LI-LOT BOLTS, FOR DIFFERENT LOADING METHODS
FIG. 6 ELONGATION-NUT ROTATION CHARACTERISTICS OF LI-LOT BOLTS
Comparison of Load-Turns Data for Different Lengths of Thread in Grip, $\frac{7}{8}'' \times 9\frac{1}{2}''$ Bolts
(Tests Conducted in Skidmore-Wilhelm)

AVERAGE NUMBER OF TURNS FROM "SNUG" OF 10 KIPS

Fig. 7
Comparison of Load-Turns Data for Different Lengths of Thread in Grip. $\frac{7}{8} \times 5\frac{1}{2}$ Bolts
(Tests Conducted in Skidmore-Wilhelm)
Comparison of Load-Turns Data for Different Lengths of Thread in Grip. $\frac{7}{8}'' \times 5\frac{1}{2}''$ Bolts

(Tests Conducted in Solid Steel Block)

Fig. 9
Fig. 10  COMPARISON OF LOAD-TURNS DATA FOR 7/8" x 5 1/2" A325 AND A490 BOLTS
Fig. 11 COMPARISON OF LOAD VS. ELONGATION DATA FOR A325 AND A490 BOLTS, TORQUED TENSION TESTS
Fig. 12 EFFECT OF THREAD LENGTH ON ROTATION CAPACITY