Bolt Tension Control with a Direct Tension Indicator

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ACHIEVING THE MINIMUM required bolt tension in a high strength bolted friction-type joint is a primary factor, since the slip resistance of the joint is dependent on the bolt tension. Current specifications[1] require that high strength structural bolts be tightened to at least 70 percent of the minimum required tensile strength.

For the past two decades installation has been primarily controlled by either turn-of-nut or calibrated wrench tightening. The turn-of-nut method depends upon strain control as contrasted to the torque control of the calibrated wrench method.

Since the turn-of-nut method is primarily strain control, the effectiveness of the method depends on the starting point and accuracy of the rotational measurements.[2,3] The variability of torque control is well known and was one of the reasons for the development of the turn-of-nut method.

Bolts tightened by the turn-of-nut method may have the outer face of the nut match-marked with the protruding bolt point before final tightening, so that an inspector can visually note the nut rotation. If an impact wrench is used for tightening, a slight peening of the bolt heads or nuts gives an additional indication that the bolt has been tightened. However, if the need for more inspection of bolt tension is necessary, one must use a calibrated inspection torque wrench with all its uncertainties.

The *Coronet* load indicator is a device that provides a different means of evaluating the induced bolt tension during and after tightening. It is a hardened washer with a series of protrusions on one face, as shown in Fig. 1. The washer is usually inserted between the bolt head and the gripped material with the protrusions bearing against the underside of the bolt, leaving a gap (see Fig. 2). Upon tightening, the protrusions are flattened and the gap is reduced, as shown in Fig. 2. Bolt tension is evaluated from measurements of the residual gap.

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High strength bolted joints installed with *Coronet* load indicators have been used in England for the past 10 years, with reports of significant cost savings over both turn-of-nut and calibrated wrench installations. To date, this system has been employed in two structures in the United States, with similar experience.

This study was made to determine the behavior and performance of *Coronet* load indicators when used with A325 and A490 bolts.

TEST PROGRAM

The test program included the study of the load-gap relationship of *Coronet* load indicators with both A325 and A490 bolts. Three diameters of A325 bolts were tested (7/8-in., 1-in., and 1 1/8-in.) with a 4-in. grip and both parallel and out-of-parallel surfaces. Five bolts with washers were tested for each combination. Two additional test series were undertaken on 7/8-in. A325 bolts with 3/4-in. and 1 3/4-in. grips.

Out-of-parallel surfaces were created by inserting tapered washers under both the head and the nut of the

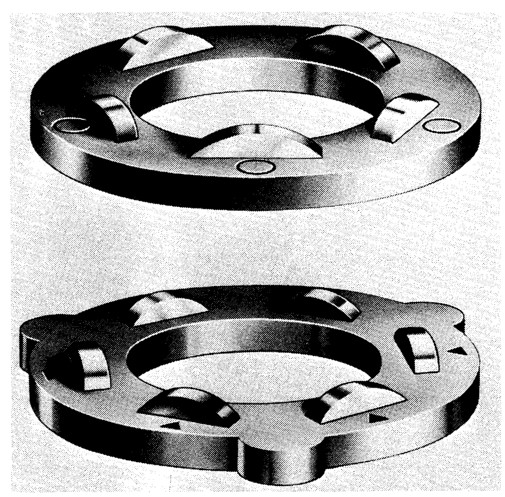
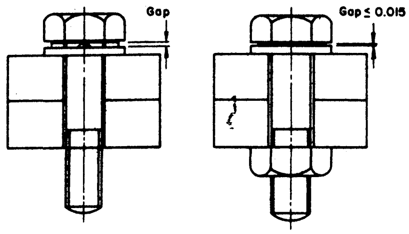
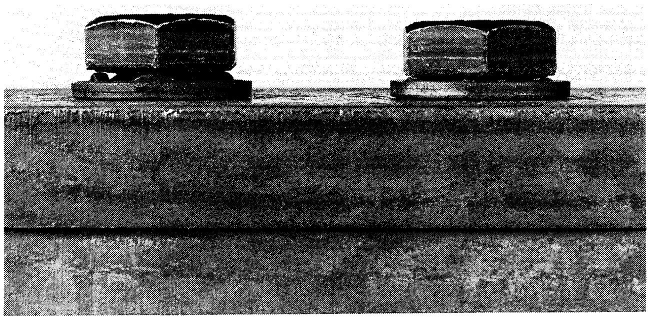


Fig. 1. Coronet load indicators



(*a*)



(*b*)

Fig. 2. Coronet load indicators before and after bolt installation

bolt. The washers had a slope of 5 percent, so that the total difference in slope between the contact surfaces of the bolt head, nut, and tapered washers was equal to 10 percent.

The tests on indicators for A490 bolts were carried out on ⅞-in. and 1⅛-in. bolts with a 4-in. grip. Both parallel and out-of-parallel surface conditions were examined. These tests were all carried out individually in a hydraulic bolt calibrator as shown in Fig. 3. In addition, both A325 and A490 bolts were installed in simulated test joints to evaluate their installation performance and ascertain whether tightening adjacent bolts had any effect on the bolt elongation and gap opening. Table 1 summarizes the experiment design.

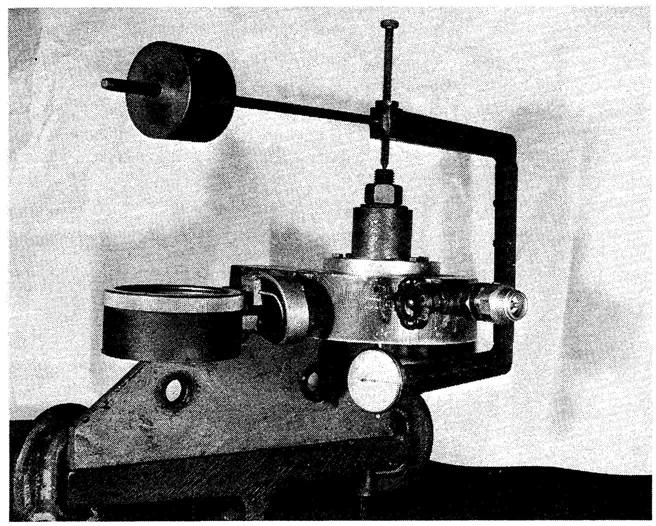


Fig. 3. Calibration of bolts and washers

PREPARATION AND TEST PROCEDURE

Before testing, each bolt was drilled and countersunk at each end in order to accommodate the C-frame extensometer used to measure changes in length during tightening.

Two different hydraulic bolt calibrators were used to measure bolt tension during the torqued tension tests. One, with a capacity of 100 kips, was used to test ⅞-in. and 1-in. bolts. The other, with a capacity of 220 kips, was used for tests of 1⅛-in. bolts.

All bolt elongations were measured with a C-frame extensometer. The gap on the *Coronet* load indicator was determined with feeler gages.

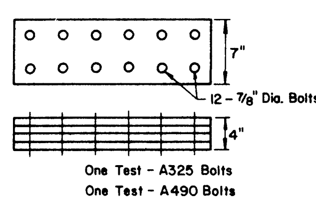
A large capacity pneumatic impact wrench running on a line pressure of about 120 psi was used to tighten the bolts.

Table 1. Summary Experiment Design

Grip Length (in.)	Bolt diameter and Bolt Strength Designation				
	⅞-in.		1-in.	1⅛-in.	
	A325	A490	A325	A325	A490
¾	*p*	—	—	—	—
1¾	*p*	—	—	—	—
4	*p* *np*	*p* *np*	*p* *np*	*p* *np*	*p* *np*

Notes: *p* = parallel surfaces
np = non-parallel surfaces
For each combination, 5 bolts were tested.

(*a*) *Summary bolt calibration tests*



(*b*) *Fitting-up tests*

Each bolt was initially tightened to a snug load of 5 kips and the gap and elongation recorded. Tension was then induced by turning the nut in increments of 45° with load, elongation, and gap recorded at each increment (see Fig. 3). The test was terminated at gap closure. Upon unloading the bolt to 5 kips, the gap rebound was determined.

The ¾-in. grip bolts could not be installed in the hydraulic bolt calibrator. Load in the bolt was determined from the elongation measurements and checked against the gap closure measurements. These bolts were all installed in steel plates.

Several bolts were installed in a simulated joint as shown in Table 1. All bolts were snugged to compact the joint, and bolt elongation and gap closure were recorded. Bolts were then tightened in a sequential pattern to simulate an actual joint installation. The nut was turned until the gap between the washer face of the bolt head and the surface of the load indication was reduced to 0.015 in. or less. After each bolt was tightened, the gap and elongation were measured on the bolt just tightened, as well as adjacent fasteners. This permitted an examination of the loss in bolt preload as determined by changes in gap closure and bolt elongation.

RESULTS AND ANALYSIS

Parallel Surfaces—The test results for the basic series of tests with a 4-in. grip were summarized in the form of bolt tension-gap closure measurements. Figures 4, 5, and 6 show the results for ⅞-in. and 1-in. A325 bolts and ⅞-in. A490 bolts. The mean regression line and the 95 percent confidence limits are also shown. The variation in the test data was nearly uniform at all load levels. The results are directly comparable to measurements made by Cullimore and Boston on high strength bolts with countersunk heads.[4] The only major difference between the tension-gap relationship determined by Cullimore and Boston and this study was the distribution of the test data. The study in Ref. 4 indicated less variability at higher load levels and smaller gaps. In the study on countersunk heads, the *Coronet* load indicator was placed under the nut and a special nut face washer inserted between the nut and the load indicator. This device is not required or used when the load indicator is inserted under the bolt head.

In order to achieve the minimum required bolt tension, the manufacturer recommends tightening until the gap is reduced to 0.015 in. or less. The ⅞-in. A325 bolts had an indicated bolt tension which varied between 37 kips and 46 kips with an average value of 41 kips at the 0.015 in. maximum gap, as shown in Fig. 4. The minimum required tension is 39 kips.[1] At the 0.015-in. gap closure, the bolt tension in the 1-in. A325 bolts varied from 48.5 kips to 53.5 kips with an average value of 51.0 kips, which was equal to the minimum tension (see Fig. 5). The 1⅛-in. bolts varied between 52 kips and 61 kips with an average value of 56.5 kips, which is slightly greater than the minimum required tension.

The ⅞-in. A490 bolts had a tension which varied between 49.5 kips and 55 kips, as illustrated in Fig. 6. The average value of 52.8 kips was in excess of the specified minimum tension of 49 kips. The 1⅛-in. A490 bolts had a bolt tension which varied from 75 kips to 85 kips, with an average value of 80 kips at a gap of 0.015 in.

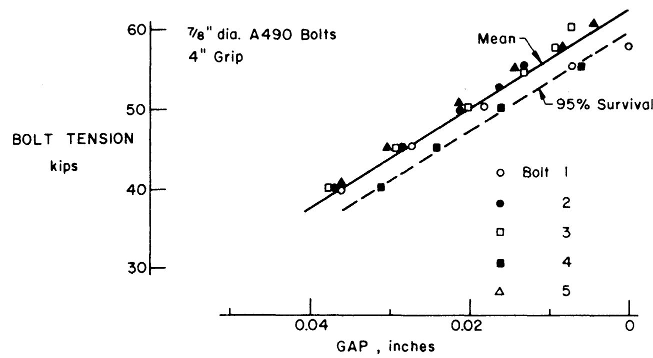


Fig. 4. Calibration of load indicators for ⅞-in. A325 bolts

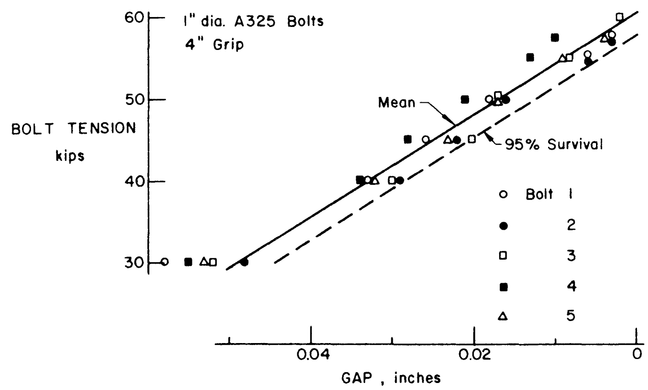


Fig. 5. Calibration of load indicators for 1-in. A325 bolts

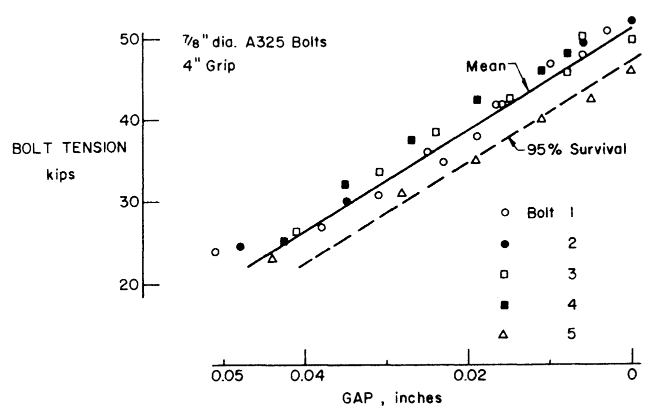


Fig. 6. Calibration of load indicators for ⅞-in. A490 bolts

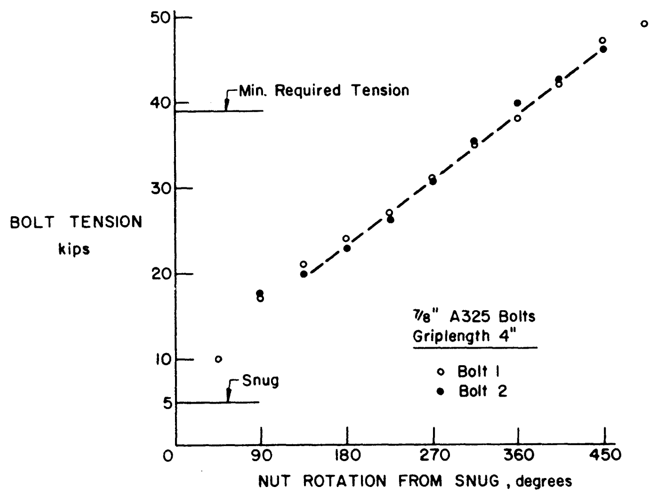


Fig. 7. Nut rotation vs. bolt tension for 7/8-in. A325 bolts with load indicating washer

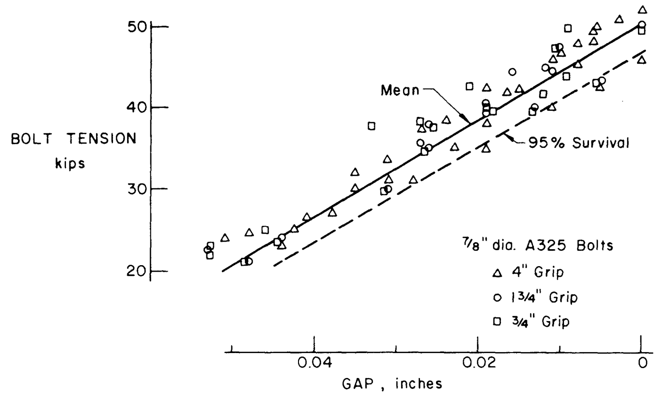


Fig. 8. Calibration of load indicators for 7/8-in. A325 bolts with variable grip length

It is readily apparent in Figs. 4 through 6 that the five load indicator tests undertaken with each bolt diameter were in reasonable agreement. The reliability of the tension indicating device was good.

The nut rotation vs. bolt tension relationship for bolts installed with *Coronet* load indicators differs substantially from the relationships normally observed with the turn-of-nut or calibrated wrench installation, as illustrated in Fig. 7. A much greater rotation is needed to achieve the required minimum bolt tension. This results from the presence of the protrusions on the washers which provide a large deformation capacity as they are flattened during tightening. Test results indicated that not much load was introduced into the bolts until the gap was closed to 0.040–0.050 in. Subsequent closure provides a linear relationship between bolt tension and gap opening as illustrated in Figs. 4 through 6.

Influence of Grip Length—It is well known that substantial changes in grip length require changes in installation procedure. This is reflected by the specifications,[1] which require different amounts of nut rotation for long grip bolts. With short grip lengths, troubles have been encountered with over-turned fasteners. The decreased grip length also reduces the rotational capacity.[2,3]

With the *Coronet* load indicator, the bolt load is determined by the deformation of the washer protrusions. Hence, it is not affected by a change in grip length. This is illustrated in Fig. 8, where the bolt force is plotted as a function of the gap for 7/8-in. A325 bolts and a variable grip length. Although different amounts of nut rotation will be experienced, as well as a difference in the bolt elongation because of the bolt grip (see Fig. 9), these factors do not affect the gap.

Since the gap measurement is the variable employed for controlling the magnitude of the bolt preload, other factors which influence bolt elongation will be compensated for as well. This would include the number of threads in the grip as well as the short grip bolt. The load indicator should provide a more uniform bolt tension in these situations.

Out-of-Parallel Surfaces—The effect of out-of-parallel bolt surfaces on the gap measurement was evaluated for all bolt diameters studied. A 4-in. grip was used for all tests. The bolt tension as a function of the average gap is plotted in Fig. 10. The average gap closure was determined from three readings taken at 60° intervals. The results for all bolt diameters indicated that the average bolt force exceeded the required minimum bolt tension at an average gap of 0.015 in. The variation in bolt force was about the same as observed with the parallel surface

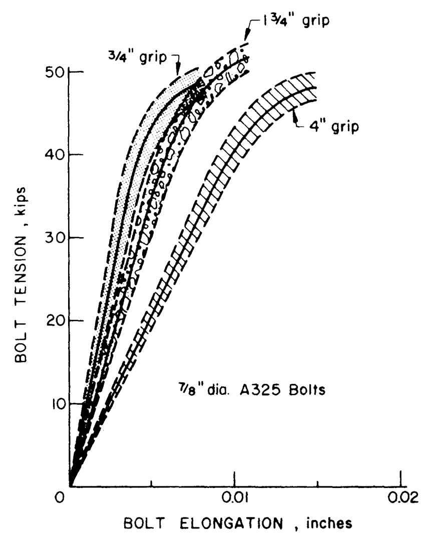


Fig. 9. Torque tension calibration of 7/8-in. A325 bolts with variable grip length

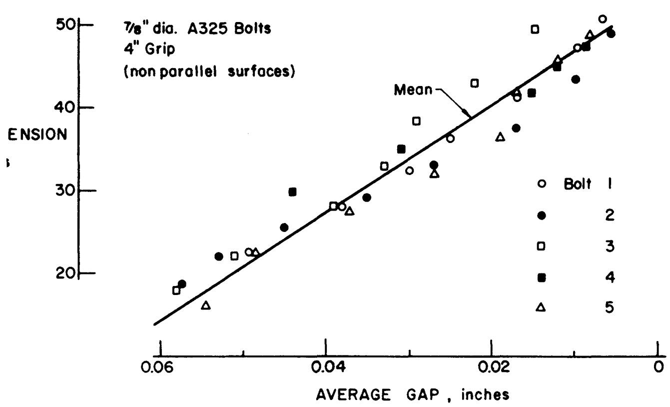


Fig. 10. Calibration of load indicators for $\frac{7}{8}$-in. A325 bolts with non-parallel surfaces

condition. For example, $\frac{7}{8}$-in. A325 bolts had bolt tensions which varied from 39.5 kips to 47.5 kips at 0.015 in. average gap.

Measuring the gap with tapered surfaces was difficult to do. Also judging the gap by eye was not easy. An alternate method of closing the gap on one edge provided average bolt tensions that were nearly identical to the average gap closure. The $\frac{7}{8}$-in. A325 bolts varied from 36.5 kips to 47.5 kips at point of closure and yielded an average value of 41 kips (specified minimum = 39 kips). The $1\frac{1}{8}$-in. A325 bolts varied from 50 kips to 72.5 kips, with an average value of 59 kips vs. the specified minimum of 56 kips. Directly comparable results were obtained for other bolt diameters and the A490 bolts.

For non-parallel surfaces, closure of the gap somewhere around the bolt head seems to be a more practical requirement for field practice, rather than prescribing the average gap closure.

Bolts Installed in Simulated Joints—The $\frac{7}{8}$-in. A325 and A490 bolts were installed in a simulated 12-bolt joint as shown in Table 1. Bolts were first snug tightened with a hand wrench to compact the connected plies. Subsequently each bolt was tightened sequentially to a gap closure of 0.015 in. or less. The bolt elongation and gap closure were measured after each bolt was tightened to determine the effect of the tightening on adjacent fasteners. In this test the point to stop impacting was judged by visual observation of the gap closure, followed by a check with the feeler gage. This would reproduce likely site procedures.

All bolt clamping forces, as determined by gap and bolt elongation, exceeded the specified minimum tension. In general the measured gap after installation was less than 0.015 in. The average value was about 0.011 in. and yielded a bolt force of about 45 kips for the $\frac{7}{8}$-in. A325 bolts. The test with $\frac{7}{8}$-in. A490 bolts yielded an average bolt force of 58 kips.

Only very minor relaxation in bolt force was observed in adjacent bolts after tightening a bolt. The change in bolt tension as determined by a change in bolt elongation was directly comparable to changes observed with the turn-of-nut procedure.[5] A change in the gap could not be detected.

SUMMARY

This examination of *Coronet* load indicators has indicated that, when calibrated in a hydraulic bolt calibrator, the average load reached at a gap of 0.015 in. was always equal to or greater than the specified minimum bolt tension.

Bolts installed in plates with parallel surfaces resulted in an average gap closure of about 0.011 in. This corresponded to a bolt clamping force 10 to 15 percent greater than the specified minimum tension. It would appear that by requiring that the gap be no more than 0.015 in., field installations will always result in bolt tensions which exceed the minimum required bolt tension.

Since the gap closure is independent of grip length, the use of the load indicator should overcome problems related to over-tightening which are encountered at times with short grip fasteners.

Bolts installed in plates or shapes with out-of-parallel surfaces can utilize the average gap closure as an indication of the bolt tension. However, an equally reliable method appears to result when the gap is completely closed at some point around the load indicator.

Care should be taken to avoid complete closure of the gap at all points around the washer. This will prevent the possibility of over-tightening the bolt to an extent causing damage; it will also prevent satisfactory inspection of the bolt, since it is not possible to determine what bolt tension exists in the closure condition.

ACKNOWLEDGMENTS

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REFERENCES

1. *Research Council on Riveted and Bolted Structural Joints* Specifications for Assembly of Structural Joints Using ASTM A325 or A490 Bolts, *April 18, 1972.*
2. *Rumpf, J. L. and Fisher, J. W.* Calibration of A325 Bolts *Journal of the Structural Division, ASCE, Vol. 89, ST6, December 1963.*
3. *Sterling, G. H., E. W. J. Troup, E. Chesson, and J. W. Fisher* Calibration Tests of A490 High Strength Bolts *Journal of the Structural Division, ASCE, Vol. 91, ST5, October 1965.*
4. *Cullimore, M. S. G. and Boston, R. M.* The Performance of High Strength Friction Grip Bolts with Countersunk Heads *Civil Engineering Department, University of Bristol, England, 1971.*
5. *Chesson, E. and Munse, W. H.* Studies of the Behavior of High-Strength Bolts and Bolted Joints *Engineering Experiment Bulletin 469, University of Illinois, Urbana, 1965.*