Field installation of high-strength bolts in North America and Japan

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Field Installation of High-Strength Bolts in North America and Japan

Mise en place sur le chantier des boulons à haute résistance en Amérique du Nord et au Japon

Das Anziehen von hochfesten Bolzen auf der Baustelle in Nord-Amerika und Japan

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SUMMARY

Details are given of the current practice of tightening high-strength bolts in bolted connections. A description of each available method accompanies a discussion of the accuracy, advantages and disadvantages. The relative popularity of each method in North America and Japan is also presented.

RÉSUMÉ

Les pratiques courantes de serrage des boulons à haute résistance sont présentées en détail pour les attaches boulonnées. En plus de la description de chaque méthode, il est fait mention de la précision, des avantages et désavantages. La popularité relative de chaque méthode est présentée également dans le cas de l'Amérique du Nord et du Japon.

ZUSAMMENFASSUNG

Es wird über die üblichen Verfahren für das Anziehen hochfester Bolzen in Schraubverbindungen berichtet. Zu jeder Methode werden Genauigkeit, sowie Vor- und Nachteile angegeben. Schliesslich werden Hinweise gegeben auf die Beliebtheit der verschiedenen Methoden in Nord-Amerika und Japan.

1. INTRODUCTION

1.1 Slip Resistant Joints

A bolted connection can transfer the load by one of two mechanisms - either by bearing and shear in the bolts or by friction between the plates. If the load is transferred primarily by friction the connection is called a slip-resistant joint, but this mechanism requires the use of high strength bolts.

Batho and Bateman [1] were the first to suggest this idea in a report to the Steel Structures Committee of Scientific and Industrial Research of Great Britain. It was concluded that bolts with a minimum yield strength of 372 MPa (54 ksi) could be tightened sufficiently to give an adequate margin of safety against slippage of the connected parts.

In the United States, Wilson [2] found in tests at the University of Illinois that the fatigue strength of high-strength bolts was as great as that of rivets if the nuts were tightened up to give a high tension in the bolt.

However, further development had to await the late 1940's and early 1950's. In the United States the Research Council on Riveted and Bolted Structural Joints (RCRBSJ) was formed in 1947 and sponsored studies on the use of high strength bolts. The American Society for Testing and Materials in conjunction with the RCRBSJ issued a specification for the materials for high-strength bolts in 1949 [3] and the RCRBSJ prepared and issued a specification for structural joints using high strength bolts in January 1951 [4].

By 1956, sufficient experience had been gained in the laboratory and on bridge construction to enable the German Committee for Structural Steelwork (GCSS) to issue a preliminary code of practice [5]. In 1959, the British Standards Institute issued British Standard (BS) 3139 dealing with bolt material and in 1960, BS 3294 established the design procedure and field practice.

1.2 High Strength Bolts

Several grades of high strength bolts are in use. In North America the most commonly used high strength bolts are the ASTM A325 [3] high strength bolt and the ASTM A490 [6] alloy steel bolt. The ASTM A325 bolt is required to have a tensile strength of 827 MPa (120 ksi) minimum for a bolt diameter of 12-25 mm (1/2 - 1 in.) and 725 MPa (105 ksi) minimum for a bolt diameter of 28-38 mm (1-1/8 - 1-1/2 in.). The tensile strength in North America is computed on the stress area defined as:

$$\text{stress area} = \frac{\pi}{4}\left[D - \frac{0.9743}{n}\right]^2 \qquad (1.1)$$

where D = nominal bolt diameter in mm or inches and
n = number of threads per mm or inch

The ASTM A490 bolt is required to have a tensile strength lying between 1030 MPa (150 ksi) and 1170 MPa (170 ksi).

High strength bolts are classified into three grades in Japan according to their strength. These grades are:

- 8T, with a minimum yield stress of 627 MPa (91 ksi) and a minimum tensile strength of 784 MPa (114 ksi)
- 10T, with a minimum yield stress of 882 MPa (128 ksi), and a minimum tensile strength of 980 MPa (142 ksi), and
- 11T, with a minimum yield stress of 931 MPa (135 ksi) and a minimum tensile strength of 1078 MPa (156 ksi).

1.3 Minimum Bolt Tension for Slip Resistant Joints

The slip load of a simple tension splice containing p equally tensioned bolts is given by

$$P_{slip} = k_s \, m \, p \, T \tag{1.2}$$

where k_s = slip coefficient
m = number of slip planes, and
T = bolt tension

Obviously the use of this equation depends on a knowledge of the slip coefficient and the bolt tension. Much research has been done in the United States, Europe and Japan to determine the slip coefficient for various structural steels, surface preparations, degrees of corrosion and joint geometries. These results have been collated and summarized by Fisher and Struik [7].

However, the clamping force T is also of prime importance, but there is currently no precise method of determining the axial force in a high strength bolt. The best available method is to calibrate each bolt prior to installation but this practice is limited to elastic stresses for accuracy and to test specimens for economic reasons.

Current worldwide practice is to specify a minimum bolt tension to which a bolt must be tightened. This tension is either multiplied by a design friction coefficient, μ, to obtain an equivalent shear stress on the nominal bolt area, or in some parts of the world the minimum equivalent shear stress is specified as a value associated with the minimum bolt tension. With an experimental knowledge of the statistical variation in these quantities, the specified values can be chosen to confine the probability of slip to an acceptable level.

In the United States, this specified minimum tension is defined as 70 percent of the minimum tensile strength of the bolt, based on the effective stress area. The Architectural Institute of Japan defines two quantities - a design bolt tension and a standard bolt tension. The design bolt tension which is used as the basis for design allowable shear stress is defined as 85 percent of the yield load on an 8T bolt and 75 percent of the yield load on a 10T or 11T bolt. These loads are also computed using the effective stress area. The standard bolt tension is the tension which is required to be attained in the bolt at the time of installation and is prescribed as 1.1 times the design bolt tension.

The currently available methods of achieving the required tension are described in Section 2 of this report. Section 3 is a discussion of the shortcomings and relatively popularity of each method. Current inspection techniques are reported in Section 4.

2. METHODS OF TIGHTENING

2.1 Calibrated Wrenches

For this method, a wrench is used which is calibrated or adjusted to "stall" when the desired tension is reached. In North America, three bolts of the lot to be installed are tightened in a calibrating device that directly reads the tension in the bolt. The American Institute of Steel Construction (AISC) Specification [4] requires that the wrenches should be calibrated to provide a tension at least 5% in excess of the specified minimum bolt tension. The wrenches are to be calibrated once each day for each bolt diameter being installed and they are to be recalibrated whenever significant changes are made or when a significant difference is noted in the surface condition of the bolts, nuts or washers.

In Japan, the Architectural Institute (AIJ) specifies the tightening torque, T_a. This is defined as

$$T_a = k\ D\ N \tag{2.1}$$

where k = torque coefficient of a bolt set
D = nominal bolt diameter, and
N = standard bolt tension as specified in Section 1.3

The Japan Industrial Standard (JIS) specifies the torque coefficient of a bolt set as lying between 0.11 and 0.19. The bolt sets with torque coefficient of 0.11 - 0.15 are classified as quality A and those with torque coefficient of 0.15 - 0.19 are quality B. The bolt sets with higher strength and larger size are usually produced with quality A and in general, the nuts or the washers of those bolt sets are treated with a chemical coating in order to reduce the frictional resistance between the thread and nut or between nut and washer.

2.2 Turn-of-Nut Method

The theory behind the turn-of-nut method is that a particular rotation of the nut can be specified such that if the nut is turned through that angle from the point at which it stops naturally by some tightening procedure, then the required minimum tension will be attained. The American Association of Railroads (AAR) originally developed the method as a solution to the problem of tightening bolts in remote areas without power tools [8,9]. They found that minimum tension could be reached by turning the nut through one whole turn from the finger tight position.

Bethlehem Steel Corporation [10,11] subsequently developed a modified turn-of-nut method which involved pretightening to a snug position using an impact wrench. The snug position was defined as the point at which the wrench started to impact. From the snug position the nut was given an additional 1/2 or 3/4 turn depending on the length of the bolt.

Extensive studies in this area incorporating new bolt materials, short bolts and bolts in connections with beveled surfaces have been made by a variety of researchers [12-18]. The results have been collated and form the basis of the current RCRBSJ specification [4] for installation of bolts by the turn-of-nut method. The specification requires that enough bolts are first brought to a "snug tight" condition to ensure that the parts of the joint are brought into contact with each other. Snug tight is defined as the tightness attained by a few impacts of an impact wrench or the full effort of a man using an ordinary spud wrench. The specification then requires that each bolt shall be turned an amount specified in Table 1, with tightening progressing systematically from the most rigid part of the joint to its free edges.

Overtightening is a danger with the turn-of-nut method so tolerances are specified for installation by this method. For bolts installed by 1/2 turn or less the tolerance is given as plus or minus 30°; for bolts installed by 2/3 turn and more, it is plus or minus 45°.

Table 1: Nut Rotation from Snug Tight Condition

Bolt length (as measured from underside of load to extreme end of point)	Disposition of Outer Faces of Bolted Parts		
	Both faces normal to bolt axis	One face normal to bolt axis and other face sloped not more than 1:20 (bevel washer not used	Both faces sloped not more than 1:20 from normal to bolt axis (bevel washers not used)
Up to and including 4 diameters	1/3 turn	1/2 turn	2/3 turn
Over 4 diameters but not exceeding 8 diameters	1/2 turn	2/3 turn	5/6 turn
Over 8 diameters but not exceeding 12 diameters	2/3 turn	5/6 turn	1 turn

(Extracted from Research Council on Riveted and Bolted Structural Joints: Specification for Structural Joints using ASTM A325 or A490 Bolts, AISC, New York, New York, 1976)

2.3 Detecting Yield Point Method

In the method developed in Japan, high strength bolts are tightened by a wrench driven by a D. C. motor [19]. The principle of this method is to relate bolt elongation and bolt stress to the rotation of a nut and the amount of electric current in the D. C. motor. Since the amount of electric current in the D. C. motor is proportional to the torque applied to the nut it indirectly indicates the tension in the bolt. The rotation of the nut indicates the elongation of the bolt. The tension-elongation relationship of a bolt (see Fig. 1) can be represented by the current-nut rotation relationship.

When an electronic monitor in the wrench detects nonlinearity of the relationship between the current in the D. C. motor and the rotation angle of a nut it prevents further tightening. The nonlinearity corresponds to the start of yielding in the bolt.

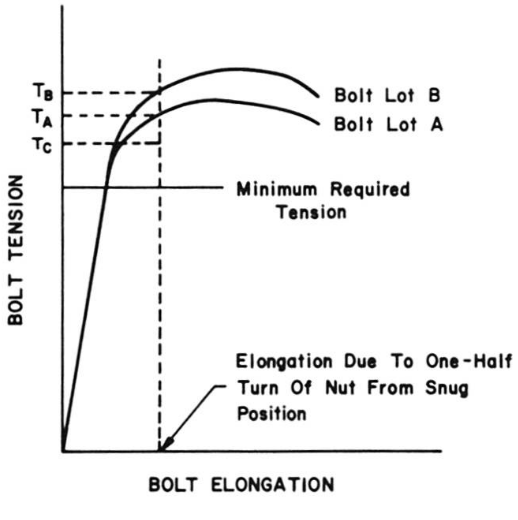

Fig. 1 Influence of Tightening Method on Achieved Bolt Tension from Different Bolt Lots

Work is also underway in the United States and England on a comparable gradient-controlled tightening system [20]. This method uses changes in the gradient of the tightening torque to detect the yield point. However, a standard air motor is used to drive the wrench. Both torque and rotation are also monitored in this method. Use to date has been restricted to laboratory studies. However, production for field installation is scheduled in 1979.

2.4 Special Devices

Several special bolt systems are currently available which give a direct indication of the bolt force.

The TELL-TORQ fastener used in North America has an optical indicator in the bolt head which changes color depending on the bolt load. If tightened only in the elastic range the bolt can be used several times.

The load indicating bolt is a square headed bolt with notches at the corners of the bottom face of the bolt head. If the axial force exceeds a certain load, these notches are stressed beyond their elastic limit and visible deformations occur, indicating that a certain load level has been reached. Because the notches deform plastically, these bolts can be used once only.

A special device to measure bolt tension, called the load indicator washer, has been used in England and North America. The load indicator washer is a hardened circular washer which has a group of protrusions pressed out of the flat surface. The washer is placed on the bolt with the protrusions bearing against the bolt head. The bolt tension causes the protrusions to partially flatten and closes the gap between the washer's flat surface and the bolt head. This gap height provides an indirect indication of bolt tension. The average gap reading around the washer must be used to compensate for the uneven flattening of the protrusions and surface irregularities of the washer and bolt surface. The time required to measure the gap and the cost of the washers has limited the acceptance of this device. These washers have not been generally accepted for use in bridges in North America due to possible corrosion problems as a result of the gap.

The swedge bolt consists of a fastener pin from medium carbon steel and a locking collar of low carbon steel. The pin has a series of annular locking grooves, a breakneck groove and pull grooves. The collar is cylindrical in shape and is swaged into the locking grooves in the tensioned pin by a hydraulically operated driving tool that engages the pull grooves on the pin and applies a tensile force to the fastener. After the collar is fully swaged into the locking grooves, the pin tail section breaks at the breakneck groove when its preload capacity is reached.

A controlled torque bolt called the tor-shear bolt is used extensively in Japan and has been introduced in North America. The tightening torque is controlled by the breaking torque of a groove located at the end of the standard bolt thread. A special electrically powered torque wrench is used for installation. The wrench torque is applied to the nut and a splined shaft which extends beyond the groove on the bolt. The bolt tension at twist off of the splined shaft is controlled by the depth of the groove, the shear strength of the bolt material, and the coefficient of friction of the turning surfaces. The simple and quiet one sided installation and decreased cost of inspection have made them widely used in Japan, especially for building construction.

3. USE OF TIGHTENING METHODS

3.1 Strain and Torque Control of Tension

The turn of nut method primarily controls the strain in the bolt whereas the calibrated wrench method and the tor-shear bolts are primarily methods of controlling the torque applied to the head or nut. However, the two methods do not necessarily achieve the same bolt tension as shown in Fig. 1. Here the influence of the tightening method on the achieved bolt tension is shown for two bolt lots having different mechanical properties. When the calibrated wrench method is used the bolt tension T_c is about the same for both lots since the wrench is adjusted for each lot. However, if the turn of nut method is used the average elongation of the bolts will be about the same for both lots. Consequently, the bolt tensions T_A and T_B will differ as illustrated in Fig. 1.

The detecting yield point method is controlled directly by the bolt tension as are the TELL-TORQ, load indicating and swedge bolt fastener systems.

3.2 Calibrated Wrenches

Since this method is essentially one of torque control, factors such as friction between the nut and the bolt and between the nut and washer are of major importance. Figure 2 shows the influence of lubrication upon the torque-tension relationship. The present North American practice for calibrated wrench installation is to determine the torque required to produce the bolt tension in the field prior to installation. This method has some drawbacks. The water soluble lubrication supplied on the bolts can be degraded by exposure to rain, which results in an erratic torque-tension relationship. This method of installation is also difficult to use in the field when more than one length bolt is used in a connection since two different wrench calibrations are required. Fisher and Struik [7] reported that in an analysis of 231 tests, in which single bolts were subjected to a constant predetermined applied torque, the standard deviation of the recorded bolt tension equalled 9.4% of the required value, or in a five bolt joint the standard deviation of the average bolt clamping force was 5.6% of the required mean value.

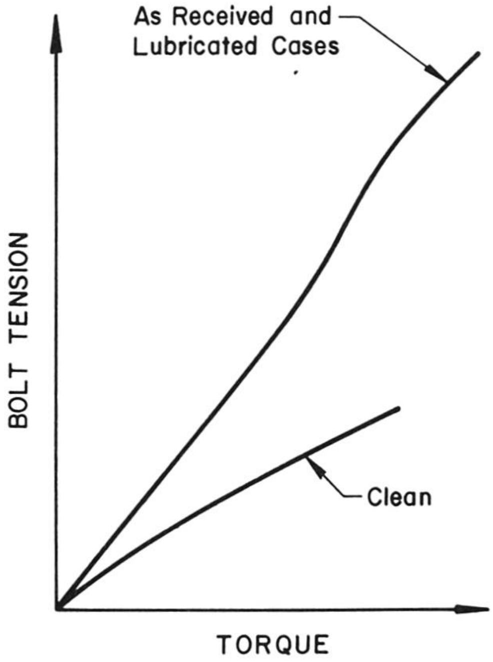

Fig. 2 Schematic Torque Tension Values for Lubricated and Cleaned Bolts

In addition, Fisher and Struik [7] report that installing a bolt in a joint leads to a 5.5% higher tension as compared with torquing a bolt in a hydraulic calibrator. Consequently, the average clamping force in a five bolt joint with bolts installed by the calibrated wrench with a setting 7.5% greater than the required preload is equal to 1.13 times the specified minimum tension. The standard deviation was about 6% and the corresponding frequency curves of the ratio $T/T_{specified}$ are shown in Fig. 3.

In Japan, the nuts or washers of quality A high-strength bolt sets are generally treated with a chemical coating in order to reduce the frictional resistance between the thread and nut or between the nut and washer. However, this chemical coating sometimes causes a variation in the value of the torque coefficient with time or temperature.

Nevertheless, despite these problems, the calibrated wrench method continues to be very popular. It accounts for about 36% of bolt installations in the United States and is the most popular method in Japan. Only casual use of the method is reported in Canada.

3.3 Turn-of-Nut Method

Figure 1 shows that considerable variation in the induced bolt tension results from the nonuniformity in ultimate strength when using this method. An analysis at Lehigh University [7] showed that a least squares fit of the available data gave an induced bolt tension equal to 80% of the tensile strength for torquing the bolt one-half turn from the snug position. In addition, it was shown that since the A325 and A490 bolts used in North America have average tensile strengths exceeding the specified minimum that the average bolt tension for A325 bolts exceeded the required minimum by approximately 35% and for A490 bolts the figure was 26%.

Similarly, the standard deviations of the ratio $T/T_{specified}$ were calculated at Lehigh University [7] and found to be 8% for A325 bolts and 10% for A490 bolts. The distribution curves for $T/T_{specified}$, when bolts are installed by the turn-of-nut method using one-half turn, are shown in Fig. 3. These curves apply to bolts up to 25 mm (1 in.) diameter. For A325 bolts with nominal diameters in excess of 25 mm (1 in.) the ratio of $T/T_{specified}$ is even greater.

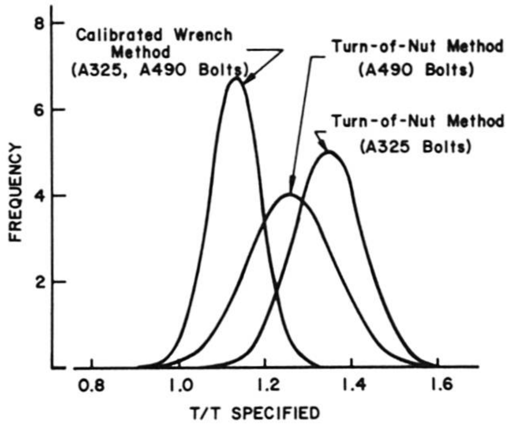

Fig. 3 Distribution Curves $T/T_{specified}$ for Different Installation Procedures

A recent study at the University of Texas to determine the ability of two steel fabricators to install high strength bolts indicate that proper training of installation personnel is lacking. The measured bolt tension in forty bolts of a compression truss splice tightened by each fabricator is summarized in Fig. 4. Fabricator A's average bolt tension was slightly less than the required minimum tension for the 22 mm (7/8 in.) A325 bolts. Fabricator B's average bolt tension exceeded the required minimum tension. Neither fabricator's personnel followed the procedures specified for turn-of-nut installation. Fabricator A's personnel did not use a backup wrench for the unturned element and did not measure the turns. Fabricator B's personnel tightened most of their bolts to over 3/4 of a turn from snug tight. Neither fabricator snugged the bolts properly and followed a coherent tightening sequence. The standard deviation of bolt tension for both fabricators exceeded the values observed in laboratory studies.

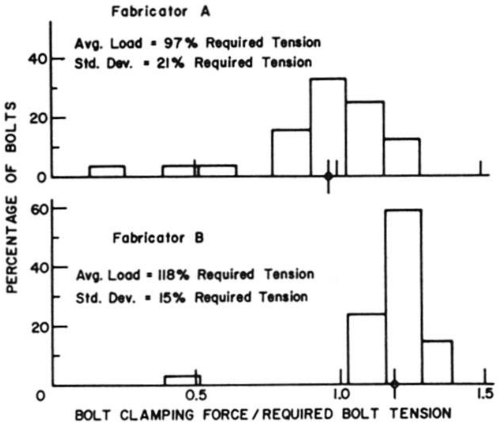

Fig. 4 Bolt Tension in 40 Bolt Truss Joints

As a result of its simplicity and inherent guarantee of achieving the specified tension when specified procedures are followed, the turn-of-nut method is the most popular of all high-strength bolt installation procedures in North America. In the United States it accounts for more than 60% of installation and is the only suitable method recognized by the Canadian Institute of Steel Construction (CISC). The method was adopted only in 1972 by the Japan Road Association and in 1976 by the AIJ. As yet the magnitude of the turn-of-nut has not been fixed in Japan, but the method is expected to be applied more widely in the near future.

3.4 Detecting Yield Point Method

This method has the following advantages:

Since the control of the tightening is not based on the absolute value of applied torque but is based on detecting the change of the slope of the torque nut-rotation relationship variations in friction, torque and yield strength of the bolts does not affect the result. Available laboratory studies all indicate that the variations in the clamping force are substantially reduced and the minimum clamping force increased [19,20]. Table 2 shows the results of studies on two sizes of bolts which was carried out in Japan [19].

Table 2: Bolt Tension Induced by Detecting Yield Point Method

Bolt Size D x ℓ, mm	Number of Samples	Average Bolt Tension KN	Standard Deviation KN	Coefficient of Variation %
22 x 80	176	292	5.87	2.0
20 x 55	56	234	8.16	3.5

Grade of bolts 10T (minimum yield stress: 882 MPa); ℓ = grip length

Inspection of the torque value applied to the nuts can be easily made through a survey of recorded output.

3.5 Special Devices

The tor-shear and swedge bolts inherent advantage is that the bolt tension is not controlled by the installer but by the manufacturer. Laboratory tests of tor-shear bolts using field installation procedures at the University of Texas has shown that the standard deviation of the bolt tesnion is less than 8% of the average bolt tension. Similar results have been found for the swedge bolts. The quality control required to produce bolts which yield consistent bolt tension increases their costs. However, this cost increase may be offset by lower installation costs. A problem of degradation with time and temperature of the friction coefficient of the lubrication used on the tor-shear bolt has been reported in Japan. The swedge bolt has not been used extensively in buildings and bridges due to the cumbersome equipment required for installation.

The load indicating washer has been used chiefly as a visual indicator of bolt tension. The time required to accurately measure the washer gap is too long to be economically feasible. Spot measurements of the gap are normally made. Care must be excercised when using the washer under a turned element. The protrusions must bear against a hardened surface which does not turn. The protrusions will be galled down by contact with a turning surface which gives an incorrect indication of the bolt tension. The washers are useful on bolts where normal installation procedures are not applicable such as high strength anchor bolts.

The TELL-TORQ and load indicating bolt fastener systems are all direct tension-controlled devices but economic considerations generally limit their use to special applications. About 2% only of high-strength bolt installation in the United States is done with load-indicating bolt sets.

4. INSPECTION

4.1 Prescribed and Popular Procedures

Inspection of bolted joints in North America is performed usually by one of two methods - visual or a manual torque wrench.

If the bolts were tightened with an impact wrench the RCRBSJ Specification [4] allows the inspector to identify a slight peening on the nut or bolt head indicating that the wrench was applied to the fastener. Alternatively, the wrench operator may match mark the nut with the protruding bolt before final tightening to afford the inspector a visual means of noting the actual nut rotation.

If a manual torque wrench is used for inspection the RCRBSJ specifies that three bolts of the same grade, length and condition as those under inspection shall be placed in a calibration device capable of indicating bolt tension. For each of these bolts, the torque necessary to turn the nut or head 5 degrees is determined and the average torque for the three bolts is taken as the job inspecting torque. Occasionally, a power wrench is used as an inspection wrench, in which case, the job inspecting torque is that setting which tightens the three test bolts in the calibration device to a tension at least 5% but not more than 10% greater than the specified minimum tension.

Ten percent of the bolts, but not less than two bolts selected at random from each connection, are to be inspected by application of an inspecting wrench and if no nut or bolt head is turned then the connection shall be accepted as properly tightened.

Most contractors in North America have a predetermined system of joint inspection which generally conforms to the RCRBSJ Specification. However, inspection is usually more stringent on larger jobs and in some instances, every bolt is inspected using an inspecting wrench. The specification requires only visual inspection for bearing-type connections but few contractors differentiate in their procedure between bearing and friction-type connections.

4.2 Inspectint Torque Values

For bolt sets installed by the turn-of-nut method and inspected using a torque wrench, the high standard deviation in $T/T_{specified}$ for both methods reported in Sections 3.2 and 3.3 result in a wide variation in torque readings for the same nominal turn-of-nut. Little data is available, however, because:

- There is no requirement to measure the torque in a bolt set, but only to check that it is above a specified minimum value. Since a study of Fig. 2 indicates that for a properly tightened joint the specified minimum torque will almost always be exceeded, the actual torque is simply not measured.
- Torques that are measured are hardly every permanently recorded.

However, data that is available indicates that a variation in torque of ±20% for 22 mm (7/8 in.) diameter A325 bolts is not unreasonable if they are installed by turn-of-nut method.

5. SUMMARY

- A bolted connection transfers its load either by bearing and shear in the bolts or by friction between the plates. A friction joint, also known as a slip-resistant joint requires the use of high strength bolts.

- The slip load of a simple tension splice containing p equally tensioned bolts is given by

  $$P_{slip} = k_s\, m\, p\, T$$

  where k_s = slip coefficient
  m = number of slip planes, and
  T = bolt tension

  Current worldwide practice is to specify a minimum bolt tension chosen to limit the probability of the equivalent shear on the nominal bolt area being less than a specified or calculated minimum value to an acceptable level. This tension varies from country to country. In North America, the minimum bolt tension is 70% of the tensile strength. In Japan, it is either 85% or 75% of the yield strength depending on the type of bolt.

- Four main methods of installing high-strength bolts are currently in use. These are the calibrated wrench method, the turn-of-nut method, the detecting yield point method and special devices. The special devices include the TELL-TORQ fastener, the load indicating bolt, the swedge bolt, the tor-shear bolt, and load indicating washers.

- The turn-of-nut method uses strain control to achieve the specified bolt tension. Calibrated wrench installed bolts and tor-shear bolts are both tightened by controlling the torque applied to the head or the nut. The tension is directly controlled by the TELL-TORQ fasteners, load indicating and swedge bolts and in the detecting yield point method.

- The calibrated wrench method is the most popular of all procedures in Japan and accounts for about 36% of bolt installations in the United States. The turn-of-nut procedure is the most popular in North America accounting for over 60% of installations in the United States and almost 100% in Canada. Economic considerations limit the use of most of the special devices although 2% of bolt installation in the United States is made with direct load indicating bolt sets and 30% of bolt installation on buildings in Japan utilizes tor-shear bolts.

- Inspection usually is performed using a combination of visual and manual torque wrench procedures. The RCRBSJ recommends visually inspecting all bolts and checking the torque on 10% - a practice which has been adopted by most contractors in North America. On larger jobs, inspection tends to be more stringent and may result in all the bolts being checked with a torque wrench.

- Large variations in applied torque are evident for sets installed by the turn-of-nut method. A value of ±20% has been reported for one type of bolt used in North America.

NOTATIONS

D - nominal bolt diameter

k - torque coefficient of a bolt set

k_s - slip coefficient in a friction joint

m - number of slip planes cutting a bolt

n - number of threads per unit length

N - standard bolt tension, as defined by the Architectural Institue of Japan

p - number of bolts in a connection

P_{slip} - slip load of a friction joint

T - actual bolt tension

T_a - torque required to tighten a bolt

$T_{specified}$ - required minimum bolt tension

μ - design friction coefficient

REFERENCES

1. C. Batho and E. H. Bateman, INVESTIGATIONS ON BOLTS AND BOLTED JOINTS, Second Report of the Steel Structures Research Committee, London, 1934.
2. W. M. Wilson and F. P. Thomas, FATIGUE TESTS ON RIVETED JOINTS, Bulletin 302, Engineering Experiment Station, University of Illinois, Urbana, Illinois, 1938.
3. American Society for Testing and Materials, HIGH-STRENGTH BOLTS FOR STRUCTURAL STEEL JOINTS, INCLUDING SUITABLE NUTS AND PLAIN HARDENED WASHERS, ASTM Designation A325-70a, Philadelphia, Pennsylvania, 1970.
4. Research Council on Riveted and Bolted Structural Joints of the Engineering Foundation, SPECIFICATIONS FOR ASSEMBLY OF STRUCTURAL JOINTS USING HIGH STRENGTH BOLTS, originally issued 1951; latest edition: SPECIFICATIONS FOR STRUCTURAL JOINTS USING ASTM A325 or A490 BOLTS, American Institute of Steel Construction, New York, New York, 1976.
5. Deutscher Stahlbau - Verband, PRELIMINARY DIRECTIVES FOR THE CALCULATION, DESIGN AND ASSEMBLY OF NON-SLIP BOLTED CONNECTIONS, Stahlbau Verlag, Cologne, 1956.
6. American Society for Testing and Materials, QUENCHED AND TEMPERED ALLOY STEEL BOLTS FOR STRUCTURAL JOINTS, ASTM Designation A490-70, Philadelphia, Pennsylvania, 1970.
7. J. W. Fisher and J. H. A. Struik, GUIDE TO DESIGN CRITERIA FOR BOLTED AND RIVETED JOINTS, John Wiley and Sons, New York, New York, 1974.
8. American Railway Engineering Association Committee on Iron and Steel Structures, USE OF HIGH STRENGTH STRUCTURAL BOLTS IN STEEL RAILWAY BRIDGES, AREA Vol. 56, 1955.
9. F. P. Drew, TIGHTENING HIGH STRENGTH BOLTS, Proceeding Paper 786, ASCE, Vol. 81, August 1955.
10. E. F. Ball and J. J. Higgins, INSTALLATION AND TIGHTENING OF HIGH STRENGTH BOLTS, Transactions, ASCE, Vol. 126, Part 2, 1961.
11. M. H. Frincke, TURN-OF-NUT METHOD FOR TENSIONING BOLTS, Civil Engineering, Vol. 28, No. 1, January 1958.
12. J. L. Rumpf and J. W. Fisher, CALIBRATION OF A325 BOLTS, Journal of the Structural Division, ASCE, Vol. 89, ST6, December 1963.
13. R. T. Foreman and J. L. Rumpf, STATIC TENSION TESTS OF COMPACT BOLTED JOINTS, Transactions, ASCE, Vol. 126, Part 2, 1961.
14. R. A. Bendigo, R. M. Hansen and J. L. Rumpf, LONG BOLTED JOINTS, Journal of the Structural Division, Vol. 89, ST6, December 1963.
15. J. W. Fisher, P. Ramseier and L. S. Beedle, STRENGTH OF A440 STEEL JOINTS FASTENED WITH A325 BOLTS, Publications, IABSE, VOL. 23, 1963.
16. E. Chesson, Jr. and W. H. Munse, STUDIES OF THE BEAHVIOR OF HIGH-STRENGTH BOLTS AND BOLTED JOINTS, Engineering Experiment Bulletin 469, University of Illinois, Urbana, Illinois, 1965.

17. R. J. Christopher, G. L. Kulak and J. W. Fisher, CALIBRATION OF ALLOY STEEL BOLTS, Journal of the Structural Division, ASCE, Vol. 92, ST2, April 1966.

18. G. H. Sterling, E. J. W. Troup, E. Chesson, Jr. and J. W. Fisher, CALIBRATION TESTS OF A490 HIGH-STRENGTH BOLTS, Journal of the Structural Division, ASCE, Vol. 91, ST5, October 1965.

19. Y. Kaneda, TIGHTENING OF HIGH STRENGTH BOLTS BY DETECTING YIELD POINT METHOD, Proceedings of the Annual Meeting, Architecture Institute of Japan October 1975.

20. J. T. Boys and P. W. Wallace, DESIGN AND PERFORMANCE OF AN AUTOMATIC CONTROL SYSTEM FOR FASTENER TIGHTENING, Proceedings, The Institute of Mechanical Engineers, Vol. 191, 38/77, 1977.