High-Strength Bolting Made Easy

This month's SteelWise takes a closer look at some common and not-so-common questions on high-strength bolted joint design and construction.

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CONFUSION BETWEEN ENGINEERS AND CONTRACTORS CAN ARISE ON JOB SITES WHEN ONE PARTY IS UNCERTAIN OF CORRECT INSTALLATION AND INSPECTION PROCEDURES FOR HIGH-STRENGTH BOLTED JOINTS. To properly address high-strength bolting issues, the Research Council on Structural Connections (RCSC) developed the 2004 edition of the *Specification for Structural Joints Using ASTM A325 or A490 Bolts* (a free download from **www.boltcouncil.org**). This specification examines the design, inspection, and material requirements for high-strength bolted joints. In addition, Chapter J of the 2005 AISC *Specification for Structural Steel Buildings* (free at **www.aisc.org/2005spec**) addresses bolting design requirements, in conjunction with the RCSC specification.

This article will briefly address fastener problems that have been observed in the field, as well as common questions associated with high-strength bolted joint design.

Common Field-Related Questions

How tight is "snug-tight"?

The term "snug-tight" is defined in the RCSC specification as "…the tightness that is attained with a few impacts of an impact wrench or the full effort of an ironworker using an ordinary spud wrench to bring the plies into firm contact." Snug-tightened joints do not have a prescribed installed pretension requirement. This is because the amount of pretension required to achieve a snug-tight joint depends on many factors, including the base material thickness, force applied, and the slope between the bolt and plies. With most applications, snug-tightened joints have the pretension necessary to close gaps between plies in areas adjacent to the bolt or bolt group in bringing the joint into firm contact.

What happens if full contact cannot be achieved between faying surfaces of slip-critical joints?

Slip-critical joints rely on a clamping force (between the faying surfaces) that results from installed pretension in the fasteners. However, in some cases, full or continuous contact between thick faying surfaces may not be possible. Assuming the requirements for the slip-critical joint are met and the fastener group has the required pretension in total, the load will be transferred through the portions of the faying surfaces that are in firm contact. Refer to the commentary found in Section 8.2 of the RCSC specification.

Are bolts considered "overstressed" if they exceed the rotation values in Table 8.2 of the RCSC specification for turn-of-nut pretensioning? If so, is this cause for rejection?

The term "overstress" is often misused when discussing bolt installation. Section 9.2.1 of the RCSC specification states "a pretension that is greater than the value specified in Table 8.1 shall not be cause for rejection."

The RCSC specification requires bolt pretensions to be at least 70% of the specified minimum tensile strength, as shown in Table 8.1. To simplify field installation procedures using the turn-of-the-nut pretensioning method, Table 8.2 of the RCSC specification indicates the amount of bolt rotation required to achieve this minimum pretension. However, field conditions can often make it difficult to achieve the exact amount of prescribed bolt rotation. Upper and lower rotation tolerances are located in the footnotes of Table 8.2 to account for this. While it is obvious that the lower tolerance ensures that fasteners receive the minimum required tension, many engineers misinterpret the upper tolerance.

The upper tolerance is a practical limit to prevent bolts from being broken during the turn-of-the-nut installation process. Laboratory tests confirm that the actual bolt pretension achieved by the turn-of-the-nut method can be substantially greater than the $0.70F_u$ specified minimum installed pretension. The installation process becomes uneconomical if the bolts break during pretensioning. Rotating the nut subjects the fastener to a combination of tension and torsion force during installation. Once the installation process is complete, the

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stress in the bolt decreases due to removal of the torsional force. Therefore, bolts that do not fail during installation are adequate for service from an installation perspective. Rotations greater than those prescribed in Table 8.2 need not be cause for rejection of the bolted joint.

Should light surface corrosion or oxidation be removed from faying surfaces prior to installing high-strength bolts?

After fabrication, steel members often sit idle before they are erected. During this period, light surface corrosion or oxidation often forms on the surfaces of uncoated blast-cleaned steel. This surface corrosion can actually be beneficial to the connection by increasing the slip resistance of the joint. In fact, tests have shown that a Class B slip resistance, which represents the largest mean slip coefficient of all classes, can be preserved after one-year of exposure to normal atmospheric conditions. Refer to the commentary in Section 3.2.2 in the 2004 RCSC specification.

Can galvanized faying surfaces be roughened mechanically?

Galvanized faying surfaces must be hand-roughened rather than mechanically roughened. The purpose of roughening the faying surface is to increase the slip coefficient between surface plies. Mechanical roughening can polish the surface (and sometimes remove the galvanized coating), thereby reducing the slip resistance. Refer to Section 3.2.2 (c) of the RCSC specification.

Bolted joints with long-slotted holes require a 5⁄16" thick washer or continuous bar. Can multiple washers be used if their total thickness is at least 5⁄16"?

The use of multiple washers is unacceptable, as the washer must provide for a non-galling surface. For pretensioned and slip-critical joints, the washer must be capable of transferring bolt pretension over the slotted holes. As such, the washer must have adequate stiffness to properly develop the clamping force. The stacking of washers does not provide the same stiffness as a single 5⁄16" washer, and thus is not an acceptable alternative. Refer to Table 6.1 of the RCSC specification.

Common Design Questions

The bolt holes of a snug-tightened joint are 1⁄16" greater than the standard hole diameter. Is any corrective action necessary?

In this case, bolt hole diameter must be considered oversized if used with the original bolt diameter. This can be costly because one would then have to treat the joint as slip-critical due to the oversized holes, thereby requiring preparation of all faying surfaces. A decrease in the available strength of the bolted joint may also occur. Therefore, additional bolts may be required. Alternatively, a larger bolt diameter can be used and the holes reamed, if necessary. Note that net sections and other connection element limit states must be rechecked for the new hole sizes.

Where are pretensioned or slip-critical requirements located?

Bolted fastener requirements can be found in two documents, the RCSC specification, Sections 4.2 and 4.3, and the AISC *Specification for Structural Steel Buildings*, Chapter J. Both specifications can be downloaded free of charge from **www.boltcouncil.org** and **www.aisc.org/2005spec**, respectively.

Why aren't all joints specified as slip-critical?

Slip-critical joints are designed to transfer loads through a joint without slip at service loads. However, the fabrication and preparation of slip-critical joints can cost three times more than snug-tightened joints. It is important to realize that slip resistance may not be required in every joint. Unnecessary specification of slip-critical joints is simply a waste of money. Refer to Section 4 of the 2004 RCSC specification to determine whether a snug-tightened, pretensioned, or slip-critical joint is required.

Do I need to design for bearing in slip-critical joints?

Slip-critical joints must always be designed for bearing in case the assumed service loads are exceeded. This requirement, in both the AISC and RCSC specifications, ensures that in the event one or more bolts go into bearing, a block shear rupture or bearing deformation failure does not occur.

Are slip-critical joints mandatory for bolted joints used in Seismic Load Resisting Systems?

The AISC *Seismic Provisions* (**www.aisc.org/seismic**) require that the joint be designed as a pretensioned joint, but prepared as slip-critical (all faying surfaces must have a Class A or better slip resistance). The design strength used in structural calculations is based on bearing joints rather than the smaller design values associated with slip-critical joints because slip at ultimate load generally cannot and need not be prevented.

Must the installed pretension be added to the tension or shear load when designing a bolted joint?

It is important to remember that pretension (i.e. installation tension) is always ignored when determining the design strength of a bolted joint. The initial pretension is reduced to zero (or near zero) as a bolt is loaded to failure in shear and/or tension. This effect is due to the deformations that occur prior to bolt failure.

As mentioned in commentary Section 5.1 of the RCSC specification "measurements taken in laboratory tests confirm that the pretension that would be sustained if the applied load were removed is essentially zero before the bolts fails in shear (Kulak et al., 1987). Thus, the shear and tensile strengths of a bolt are not affected by the presence of an initial pretension in the bolt."

In the case of a tension connection, the initial pretension and the external tension add up to the point of separation of the connected parts. However, this increase is relatively small and is customarily ignored, as it occurs prior to bolt failure.

How much torque is required to achieve 70% of the specified minimum tensile strength of a bolt? Is there a simple equation or table to correlate installation tension and torque?

There is no recognized quantitative relationship between torque and pretension in a bolt. Theoretical relationships developed for an installation torque versus installed pretension can be significantly unreliable. In fact, a variation of as much as 40% can exist between torque and pretension unless the relationship is established individually for each bolt lot, diameter, and fastener condition.

Many factors can greatly influence the amount of friction in a fastener assembly, resulting in higher torque values. Such factors include the finish and tolerance of threads, the amount or quality of lubrication, corrosion products, dirt, or dust from job-site conditions. Besides friction, the ability of the wrench to provide accurate and consistent measurements must also be verified to prevent additional variations.

To ensure there is an accurate correlation between the torque and tension values, the RCSC specification contains set calibration guidelines when using a torque wrench for pretensioning. Prior to installing fasteners, each wrench must be calibrated on a daily basis for individual assembly lots when an assembly lot is relubricated, when changes in the fastener surface condition are noted, and when wrench components are changed. Use of an uncalibrated wrench is prohibited due to the large number of variables affecting torque. A calibrated wrench installation method can be used as outlined in Section 8.2.2. Other pretensioning methods, such as turn-of-the-nut, the use of twist-off-type tension-control bolts, and direct tension indicators, are discussed in Section 8.2.

What grade of bolt is suitable to replace a rivet?

Repair or remediation efforts often require old rivets to be replaced with bolts. Tests have shown that the strength of some rivets may exceed that of standard ASTM A307 bolts. In lieu of testing rivets, ASTM A325 bolts can be used to prevent any loss of the joint capacity as long as fatigue issues have been investigated. Referring to a February 2005 AISC Steel Interchange question (**www.aisc.org/steelinterchange**) by Professor Geoff Kulak:

> "Whether or not riveted joints are considered to be slip-critical is an interesting question, but perhaps only of academic interest now. In support of the position that they were slip-critical is that they were designed that way when repetitive loads were present, if only by implication. Putting it another way, there is a fatigue category for riveted joints. Are such joints in bearing or are they slip-critical? If they are indeed in bearing, then the fatigue category customarily selected for this case is significantly non-conservative. The 'stress category' used in the AISC LRFD specification (typical) is D. If the rivets are truly in bearing, the stress category will be much less than D. The selection of D comes from test results and those test results are from riveted joints that in fact transmit the load by a combination of friction and bearing; some rivets are in bearing and there is enough tensile force in the rivet to provide slip resistance as well. By the way, whatever rivet tension is present arises as the heated rivet shrinks against the connected material as cooling takes place."

If you are looking for information beyond that provided in this article or in the AISC and RCSC specifications, look for AISC's *Design Guide 17—High Strength Bolts: A Primer for Structural Engineers* (available to purchase at **www.aisc.org/epubs**) and RCSC's *Guide to Design Criteria for Bolted and Riveted Joints* (free from **www.boltcouncil.org**). AISC's Steel Solutions Center is always willing to help, as well, and can provide an answer to your questions within one business day. Contact the Solutions Center by phone at 800.ASK.AISC or by e-mail at solutions@aisc.org.