

A look at the nuts and bolts—of nuts and bolts.

WHILE BOLTING STANDARD PRACTICE has remained fairly consistent over the years, there have been some recent changes thanks to new research and innovation in fastener products and specifications.

As such, it's a good idea to become familiar with these updates as well as review some terminology and take a look at a few exactitudes of bolting.

So what's changed? With the publication of the 2009 Edition of the Research Council on Structural Connections (RCSC) *Specification*, there was a slight change in the title that you may not have noticed. The new title, *Specification for Structural Joints Using High-Strength Bolts*, removes the focus from A325 and A490 bolts and acknowledges that the RCSC *Specification* focuses on high-strength bolts in general. This specification recognizes ASTM A325 or A490 heavy hex-head bolts, as well as ASTM F1852 and F2280 twist-off type bolts, which have strengths equivalent to A325 and A490, respectively. It also permits the use of alternative design fasteners if they meet the material and strength properties of A325 or A490 bolts (further discussion is provided in RCSC *Specification* Section 2.8).

Pre-Installation Verification

When a bolt is specified to be pretensioned, each of the four installation methods (discussed below under "Installation Methods") found in RCSC *Specification* Section 8 requires pre-installation verification testing in conformance with Section 7. This requirement is found in Section 8.2, which states, "Pre-installation testing shall be performed for each fastener assembly lot prior to the use of that assembly lot in the work. The testing shall be done at the start of the work. For calibrated wrench pretensioning, this testing shall be performed daily for the calibration of the installation wrench."

According to the RCSC *Specification* Commentary, pre-installation verification is intended to verify the suitability of the fastener assembly, verify that the installation procedures are properly used and ensure that a minimum pretension is being achieved during installation. It is important that the condition of the bolts used in the pre-installation verification testing is representative of those that will be pretensioned in the structure. This testing should be conducted whenever there are changes to the lot, size or equipment used for installation to verify that proper procedures are being followed and to obtain the expected level of pretensioning required. The pre-installation verification procedures require an installed pretension that is greater than or equal to 1.05 times the minimum bolt pretension. The target installed pretension for pre-installation verification testing (1.05 times the minimum installed pretension) is now tabulated in a new in 2009 Table 7.1 for convenience (see "Better than 100%" sidebar).

Better than 100%

The reason for the 105% requirement in pre-installation verification testing is explained in the Commentary to RCSC Section 7.2, which states, "It is recognized in this *Specification* that a natural scatter is found in the results of the pre-installation verification testing that is required in Section 8. Furthermore, it is recognized that the pretensions developed in tests of a representative sample of the fastener components that will be installed in the work must be slightly higher to provide confidence that the majority of fastener assemblies will achieve the minimum required pretension as given in Table 8.1. Accordingly, the minimum pretension to be used in pre-installation verification is 1.05 times that required for installation and inspection."

Pretension in the actual work is required to meet the values given in Table 8.1 (100%, not 105%).

What is Pretension?

Minimum pretension values are set at 70% of the minimum tensile strength of the fastener using a specific calculation of the stress area through the bolt threads. This accounts for both the thread type and pitch. Minimum pretension values are stated in AISC *Specification* Table J3.1 and RCSC *Specification* Table 8.1.

AISC and RCSC do not recognize the use of prescribed torque values as a valid means of applying proper pretension. Friction coefficient can vary a great deal between projects, and even between the variety of fasteners used within a project. The torque that corresponds to a value of pretension will vary depending on the thread fit, nut surface condition and

Erin Criste is a staff engineer with AISC and can be reached at criste@aisc.org.



What about Washers?

Washer requirements are covered in Section 2.5 of the RCSC *Specification* (a free download at www.boltcouncil.org). A few highlights:

- ▶ ASTM F436 flat and beveled washers are specifically addressed. A reference to Table 6.1 includes structural grade plate washers.
- ▶ Note that lock washers are not specifically addressed in either the RCSC (or AISC) specifications, and these products are not used in structural bolting. RCSC *Specification* Section 3.1 states that “compressible materials shall not be placed within the grip of the bolt.” The Commentary further explains that “the presence of gaskets, insulation or any compressible materials other than the specified coatings within the grip would preclude the development and/or retention of the installed pretensions in the bolts, when required.” Lock washers could be considered a compressible material, and the installation methods in the RCSC *Specification* are not formulated or developed to accommodate lock washers.
- ▶ The washer requirements for pretensioned joints prevent local yielding of the material around the hole, which can lead to loss of pretension in the bolt.

More information on the background for washer requirements in the AISC and RCSC specifications can be found in the *Guide to Design Criteria for Bolted and Riveted Joints*, a free download at www.boltcouncil.org.

grip surface condition adjacent to the nut, among other things. Both specifications recognize the calibrated wrench method of installation, which is a torque-based method, but the required torque is established by measuring the installed pretension—calibrated. The calibration must be redone each day and any time one of the many variables in the procedure is changed.

Pre-installation verification is not required for snug-tightened joints. There are no requirements related to torque, tension or number of turns for a snug-tightened installation.

Joint Types

There are three joint types: snug-tightened, pretensioned and slip-critical. Since the pretensioning methods are the same for pretensioned and slip-critical joints, slip-critical joints are really a special case of pretensioned joint in which the faying surfaces are specifically prepared to meet a specified level of slip resistance.

All connections will have some slip resistance, the magnitude of which is dependent on the pretension present and roughness of the faying surfaces. However, not all connections are required to be slip-critical. AISC *Specification* Chapters J1.10 and J3.2, as well as RCSC Sections 4.2 and 4.3, outline when a connection should be specified as pretensioned or slip-critical, respectively. These include connections:

- ▶ with oversized holes
- ▶ with slotted holes when the direction of the slot is not perpendicular to the direction of the load, unless slip is the intended function of the joint
- ▶ subject to fatigue (without load reversal for pretension but including load reversal for slip critical)
- ▶ subject to significant load reversal
- ▶ in which welds and bolts share in transmitting shear loads at a common faying surface

Additional requirements can be found in AISC *Specification* Sections J1.10 and J3.2, as well as in RCSC *Specification* Sections 4.2 and 4.3.

Snug-tightened joints can be used when pretensioned and slip-critical joints are not required. As can be seen from the list above, the majority of bolted connections in steel structures can be specified as snug-tightened.

Installation Methods

Joints that are specified as pretensioned or slip-critical must meet the installation requirements of RCSC *Specification* Section 8.2. There are four acceptable installation methods to obtain the pretension values for bolting: turn-of-nut method (with or without match marking), calibrated wrench method, twist-off-type tension-control bolt method and direct tension indicator method. Each of these methods is assumed to be used independent of the others.

All pretensioning methods begin from the snug-tightened condition. Section 8.1 of the RCSC *Specification* states that “snug tight is the condition that exists when all of the plies in a connection have been pulled into firm contact by the bolts in the joint and all of the bolts in the joint have been tightened sufficiently to prevent the removal of the nuts without the use of a wrench.” This wording has changed somewhat over the years but the intent has remained the same: to get the plies together and solidly seat the nut on the bolt. The bolts in snug-tightened joints are always assumed to be bearing against the base material, and this is defined as a bearing connection.

Pretensioned joints progress from the snug-tightened joint condition by the induced pretension to a defined level. Pretensioned joints are still considered bearing-type joints, and the shear strength design parameters are identical to those of a snug-tightened joint. Slip-critical joints are pretensioned joints that have faying surfaces prepared to achieve a defined level of slip resistance, and they transfer service-load shear through frictional resistance of the bolted plies.



Inspection

Turn-of-nut pretensioning with match marking, twist-off-type tension-control bolt pretensioning and direct tension indicator pretensioning are relatively simple pretensioned installation methods that allow for verification of proper installation based on visual inspection after installation. Turn-of-nut pretensioning without match marking and calibrated wrench pretensioning require inspection during installation to assure the proper methods are being followed (see Chapter N in the *AISC Specification* for further information).

It is important to realize that regardless of the method used, proper bolting requires proper handling and storage of fastener components and proper tightening sequence. Chapter N in the *AISC Specification* provides the criteria for inspection of bolted joints, mainly by reference to requirements in Section 9 in the *RCSC Specification*. Inspection criteria are given for each method of pretensioning:

- ▶ For direct-tension indicator pretensioning there are criteria for compression of the protrusions and a maximum gap permitted. The DTIs may begin to compress as the snug-tight condition is achieved but must not be completely compressed during this operation. Then during pretensioning, the direct-tension indicator protrusions are compressed to a gap that is less than the job inspection gap per manufacturer instructions and in concert with the *RCSC Specification*. After pretensioning at least half of the protrusions should be compressed. This is verified using a feeler gage, which must be refused in more than half of the spaces between the protrusions.
- ▶ Turn-of-nut pretensioning with match marking results in uniform bolt pretensioning and an easy visual inspection after installation. However, proper implementation depends on joint compactness and securely holding the bolt head while turning the nut.
- ▶ Calibrated wrench pretensioning requires routine observation, and the required torque varies based on many factors (see *RCSC Specification Commentary* Section 8.2.2).
- ▶ Twist-off-type tension-control bolt pretensioning has a splined end that is severed using a specially designed wrench chuck when a specific torque is achieved. This method is also subject to the same variability of the calibrated wrench method (except for calibrating of the wrench) but the variations are controlled by using the fastener assemblies provided as a unit by the manufacturer.

Faying Surfaces

There are sometimes concerns about paint under the head or nut of pretensioned bolts. Unqualified paint (and galvanizing) is permitted under the bolt head and nut even in slip-critical connections. These surfaces are not faying surfaces. Only the faces of the plies in contact are considered faying surfaces. In slip-critical connections, these surfaces require the preparation to achieve the friction coefficient described in *RCSC Specification* Section 3.2.2. This topic is also addressed in FAQ #6.7.1 on AISC's website (www.aisc.org/faq).



Threads: In or Out?

The design limit state for shear on a bolt depends on the inclusion or exclusion of the threads in the shear plane. The design bolt shear strength is reduced if the threads are located within the shear plane. The values for shear are indicated in Part 7 of the *AISC Manual*. These tables have a column differentiation for thread condition, which indicates either "N" for included or "X" for excluded. This is the reason that you will sometimes see a designation for a bolt described at A325X, which means an A325 bolt detailed with the threads excluded from the shear plane. Note that there is no physical difference between this bolt and the one used in an A325N application. The only difference is the location at which the shear plane falls along the shank.

Limit States

If you are new to the 2010 *AISC Specification*, you might have noticed an increase in the bolt shear strength values. In the 2005 *Specification*, a 20% reduction factor was used to account for the uneven stress distribution found in end-loaded connections, such as lap splices, up to 50 in. in length—and an additional 20% deduction was required after that. This initial reduction has been reduced to 10% in the 2010 *Specification*, and the interval at which further reduction is required was reduced from 50 in. to 38 in. This change is reflected in Table J3.2 and its footnotes and will result in an increased strength for all connections where bolt strength governs. A detailed discussion of this change can be found in "Bolt Shear Design Considerations" in the First Quarter 2010 *AISC Engineering Journal*.

As another improvement, the slip-critical bolting requirements in the 2010 *AISC Specification* have been reduced to one equation for slip resistance, and the designer no longer must decide whether to design for slip at service loads or factored loads. This is based on new research and a reexamination of existing data. The discussion and research are cited in the 2010 *Specification Commentary* to Section J3.8.

In this same section, another change that occurred based on more recent research is that there is now a reduction in slip resistance when multiple fills are present in the grip, such as may be the case in truss chord splices at changes in member size. A reduction factor of 0.85 is applied unless the fills are developed.

These are just a few changes and clarifications we've seen in the AISC Steel Solutions Center for the 2009 *RCSC Specification* and AISC's usage of that standard. Do you have questions or need further information? The Steel Solutions Center is here to help answer your questions (and not just on bolting!). Contact us at solutions@aisc.org or 866.ASK.AISC.

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