steelwise

When—and when not—
to specify slip-critical connections.

SPECIFY WITH CARE

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LET'S FACE IT. Slip-critical connections are specified too often.

It is important to understand how slip-critical connections behave and when they are actually required in order to avoid unnecessary fabrication and erection costs.

Transferring Shear

What is a slip-critical connection? It's one that transmits shear via friction between the faying surfaces. This is in contrast with bearing-type connections, in which bolt shear and bearing are responsible for transferring shear force (see Figure 1). Slip-critical connections are required to have a minimum amount of tension in the bolt, called "pretension," which creates a normal force between the connected elements. This normal force results in friction between the two surfaces in contact, which is utilized to resist shearing forces. As with any frictional force, the amount of force that can be transmitted is primarily a function of the amount of pretension and the slip surface. This is reflected in the available strength equation for slip-critical connections, from AISC *Specification* Section J3.8:

$$R_n = \mu D_u h_f T_b n_s$$

The essence of the equation is a coefficient of friction, μ, multiplied by a normal force equal to the bolt pretension. AISC *Specification* Section J3.8 gives further information on this equation. AISC Design Guide 17: *High Strength Bolts – A Primer for Engineers* by Geoffrey Kulak is a good reference on bolted connections.

Slip-critical connection required	Slip-critical connection NOT required
➤ Joints that use oversized holes ➤ Joints that are subject to fatigue load with reversal of the loading direction ➤ Joints that use slotted holes with the applied load parallel to the direction of the slot ➤ Joints in which slip at the faying surfaces would be detrimental to the performance of the structure (e.g., sensitive machinery) ➤ Joints that use partial-length cover plates per AISC *Specification* Section F13.3	➤ Just because bolts are pretensioned ➤ Just because tension-control bolts are used ➤ Just because slotted holes are used ➤ Just because bolts are part of the seismic force resisting system ➤ The bolted web connection of a direct welded moment connection ➤ Vertical and horizontal bracing connections ➤ Joints subject to fatigue without reversal of the loading direction ➤ When bolts see only tension and not shear ➤ Other cases not specifically listed by RCSC and AISC

Because slip can occur when designing a slip-critical connection, the strength of the connection in bearing must also be checked. The bearing strength does not typically control but still must be checked to ensure that the connection is adequate if the bolts were to slip into bearing.

When should a slip-critical connection be specified?

The use of slip-critical connections should be carefully considered. It is estimated that a slip-critical connection costs about three times as much as a snug-tightened, bearing-type connection. The factors that increase cost include lower strength per bolt, surface preparation requirements to achieve the required slip coefficient, and more extensive bolt installation and inspection requirements.

The most common reason slip-critical connections are required is to limit the structural deformations possible when using oversized holes. The adjacent table outlines this case and others when slip-critical connections are required. It includes requirements from Section 4.3 of the RCSC *Specification for Structural Joints using High-Strength Bolts* as well as requirements in the AISC *Specification*.

Strength

As has already been stated, slip-critical connections resist shear through friction at the faying surfaces. Calculating a strength per bolt can be misleading from a theoretical standpoint, but it is convenient both in practical design and when making comparisons between slip-critical and bearing connections.

Table 7-1 of the AISC *Manual* provides the per bolt strength for bearing joints. The strength for a ⅞-in.-diameter A325 X-type bolt is 30.7 kips (LRFD). Table 7-3 provides the per bolt strength for slip-critical joints. The strength for a ⅞-in.-diam-

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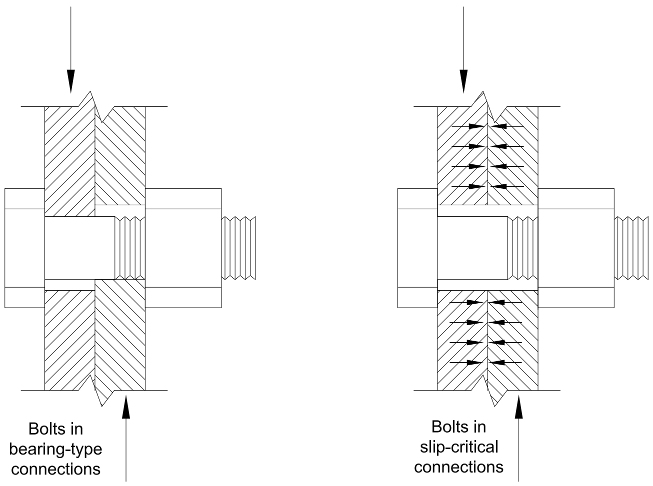

eter A325 with oversize holes and a Class A faying surface is 11.2 kips (LRFD). Depending on which connection limit state governs, these values show that a slip-critical connection may require more than twice as many bolts as a bearing-type connection to resist the same force. This will generally mean that the slip-critical connection will be larger, requiring more material, but the material cost is a secondary concern. The labor costs are the primary concern, and costs become nonlinearly more expensive in cases where more bolts don't fit in the member. As an example, a W21 that works with four bolts in bearing but needs five for slip resistance and must have an extension welded to the bottom flange and flanges coped away to fit the extra bolt. The larger joints can also mean more potential for interfering with other elements, such as mechanical and architectural components.

Combined Shear and Tension

Applied tension in a slip-critical joint is handled differently than in a bearing-type joint, as discussed in the *Engineering Journal* article "Prying Action for Slip-Critical Connections with Bolt Tension and Shear Interaction" (third quarter 2012, available at **www.aisc.org/ej**). In a bolted joint with no pretension, the entire applied tension is transferred to the bolts immediately. In a bolted joint with pretension, some of the applied tension will overcome the pretension in the bolt. Because the compression between the faying surfaces is reduced, the friction force that resists shear is also reduced. For this reason, the shear strength of bolts in slip-critical connections is reduced when there is tension present, per the procedure in AISC *Specification* Section J3.9. This is opposite from bearing-type connections, where the bolt tensile strength is reduced due to the effect of shear forces. This means that in joints that see tension as well as shear, slip-critical connections become even more uneconomical.

Faying Surface Preparation

In order to guarantee adequate friction, the surfaces between the plies of a slip-critical connection are specially prepared, which significantly increases the fabrication cost. Class A surfaces require relatively little prep and therefore have much more variability than Class B surfaces. Class B surfaces must be blast cleaned or blast cleaned *and* coated with an SC-qualified paint. This provides a more predictable surface with a higher slip resistance, but at an additional cost. Routine (non-qualified) paint systems can be used if the faying surfaces are masked, but this adds cost and also there may be a need to clean overspray from faying surfaces.

The requirements for Class A surfaces are less demanding, and can be satisfied by clean mill scale. There also are blast cleaned surfaces with Class A coating that will have similar cost implications to Class B coated surfaces and Class A roughened hot-dip galvanized surfaces. Galvanized faying surfaces must be roughened with hand wire brushing, because power wire brushing tends to polish the surface. Hand-wire brushing is time consuming, but it is also a logistical problem. The beam to be galvanized already has left the fabricator's shop, so the fabricator cannot do it. Typically the erector is responsible, but this involves additional cost in the erection contract.

Pretensioning

Bolts in slip-critical connections require a specified amount of pretension, as given in AISC *Specification* Table J3.1. There are several methods that can be used to apply adequate bolt pretension, but the associated installation requirements for all methods add cost relative to a typical bearing-type connection.

All pretensioning methods begin with bringing the bolts into the snug-tightened condition; the plies are drawn into firm contact to meet the requirements in the RCSC *Specification*. Thereafter, one of the four pretensioning methods provided by RCSC is used:

- Tension-control bolts
- Direct-tension indicator washers
- Turn-of-nut tightening
- Calibrated wrench tightening

All of these methods start with the snug-tightened condition, and so it is easy to see why these extra steps add cost. When the joint could be snug-tightened and not slip-critical (or pretensioned, for that matter), that cost is an unnecessary addition. To say nothing of costs to settle disagreements that might result about the inspection results!

Slip-critical connections involve a lot more work in both fabrication and erection. When specifying a slip-critical joint, additional costs must be considered for surface preparation, pretensioning, preinstallation verification and additional inspection requirements. This is in addition to the heightened cost of the connections due to additional bolts and connection material compared to a bearing-type connection. Use slip-critical connections when they are necessary in certain situations. Otherwise, bearing-type connections should be used. ■