

steelwise

## WHAT'S NEW WITH PREQUALIFIED CONNECTIONS?

BY MICHAEL D. ENGELHARDT, PhD, AND MARGARET A. MATTHEW, PE

A look at the latest version of AISC 358.

**WHEN IT COMES** to the chronicles of steel construction, the concept of prequalified connections is recent history.

The first version of AISC 358 *Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications* was released in 2005, with subsequent major releases in 2010 and now in 2016. Supplements have been issued in between these versions as new prequalified connections were added to the standard.

So how did AISC 358 come to be in the first place? The impetus for its development goes back to damage observed to welded steel moment connections in the 1994 Northridge Earthquake. A major outcome of post-Northridge research was the view that any new steel moment connection detail intended for use in special moment frames (SMFs) or intermediate moment frames (IMFs) should have their seismic performance verified by testing at a realistic scale. AISC 341 *Seismic Provisions for Structural Steel Buildings* adopted performance criteria for SMFs and IMFs connections that required connections be capable of developing a story drift angle of  $\pm 0.04$  rad for SMFs and  $\pm 0.02$  rad for IMFs without significant loss in strength, and required that all moment connections demonstrate conformance with this performance requirement by conducting qualifying cyclic tests.

### Prehistory

To facilitate and simplify conformance demonstration, the concept of “prequalified” moment connections was developed. Prequalified connections were first introduced in the SAC-FEMA program in report FEMA 350: *Recommended Seismic Design Criteria for New Steel-Moment Buildings*, which was released in 2000. Building on the recommendations in FEMA 350, the concept of prequalified moment connections was subsequently incorporated into AISC 341 in 2002. Paraphrasing the commentary to AISC 341, a prequalified connection is one that has undergone sufficient testing, analysis, evaluation and review so that a high level of confidence exists that the connection can fulfill the performance requirements for SMFs and IMFs. Recognizing that prequalifying moment connections require evaluation by a panel of knowledgeable individuals, AISC created the Connection Prequalification Review Panel (CPRP) in the early 2000s. The CPRP was assigned the responsibility to prequalify SMF and IMF connections. In addition to creating the CPRP, AISC also created AISC 358 as a new building standard for prequalified connections (the CPRP is responsible for development and updating of AISC 358).

Basic requirements that a connection must satisfy to become prequalified are specified in AISC 341, and the CPRP is guided by these requirements in prequalifying connections. In AISC 341, requirements for prequalification are specified in Section K1 “Prequalification of Beam-to-Column and Link-to-Column Connections.” While there are numerous requirements, the most basic requirement for prequalification is the need for cyclic testing of the connection in accordance with AISC 341, Section K2 “Cyclic Tests for Qualifying of Beam-to-Column and Link-to-Column Connections”; it is not possible for a connection to become prequalified without large-scale testing. Further, Section K2 provides strict limits for extrapolating test results to larger member sizes, and the CPRP adheres to these size extrapolation limits in AISC 358.

### The New 358

AISC 358-16 has 13 chapters and two appendices. Chapters 1 through 4 contain general requirements that pertain to all prequalified connections. Each subsequent chapter (5 through 13) contains requirements for specific prequalified connections. As new connections are prequalified, new chapters are added to the standard.



**Michael D. Engelhardt** ([mde@mail.utexas.edu](mailto:mde@mail.utexas.edu)) is a professor at the University of Texas at Austin and chair of AISC's Connection Prequalification Review Panel (CPRP) and also serves on the Committee on Specifications, TC8 (Design for Fire) and TC9 (Seismic Provisions). **Margaret A. Matthew** ([matthew@aisc.org](mailto:matthew@aisc.org)) is a senior engineer with AISC, editor of *Engineering Journal* and secretary of the CPRP and the Bender/Roller Committee.

Table 1 provides a listing of prequalified connections in AISC 358 and the corresponding chapter for each connection. Several of the prequalified connections, identified with an (\*) in the table, are proprietary connections. These are connections for which a patent is held, and designers must work with the patent-holder in the use of these connections in building construction projects. The rest of the connections are nonproprietary.

While the contents of each prequalified connection chapter varies somewhat, there are a number of common features of each connection:

- ▶ a general description of the connection and intended location of inelastic action
- ▶ systems for which connection is prequalified (SMFs and/or IMFs)
- ▶ prequalification limits (limits on beam and column sizes and types for which the connection is prequalified)
- ▶ additional prequalification limits (beam-column relationships, connection components, welding and bolting requirements, etc.)
- ▶ detailing and fabrication requirements
- ▶ design procedure

One of the most useful features of AISC 358 is that each prequalified connection has a detailed step-by-step design procedure, greatly facilitating the use of these connections.

Table 1 – Prequalified Connections in AISC 358-16

AISC 358-16 Chapter	Connection
5	Reduced Beam Section
6	Bolted Unstiffened And Stiffened Extended End-Plate
7	Bolted Flange Plate
8	Welded Unreinforced Flange – Welded Web
9	Kaiser Bolted Bracket*
10	ConXtech ConXL*
11	SidePlate*
12	Simpson Strong-Tie Strong Frame*
13	Double Tee

\* proprietary connection

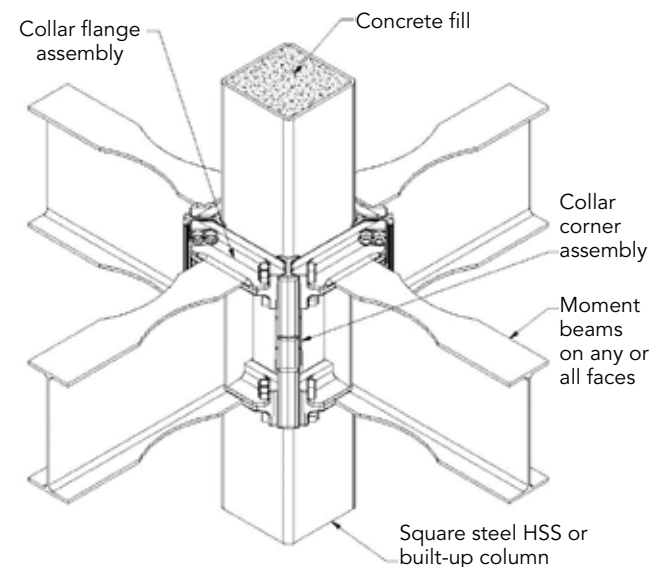
When AISC 358-10 was issued, there were five prequalified connections (Chapter 5 through 9). Since 2010, four additional prequalified connections have been added to the standard in Chapters 10 through 13. These recent additions to AISC 358 are briefly described below. The descriptions below highlight only a few key features of each connection. The reader is referred to AISC 358 for complete details, limitations and requirements.

### ConXL Moment Connection

ConXtech ConXL is a proprietary moment connection that was first added in AISC 358-10 Supplement No. 1 in June 2011 (a schematic of the connection is shown in Figure 1). This system connects wide-flange beams to 16-in. concrete-filled

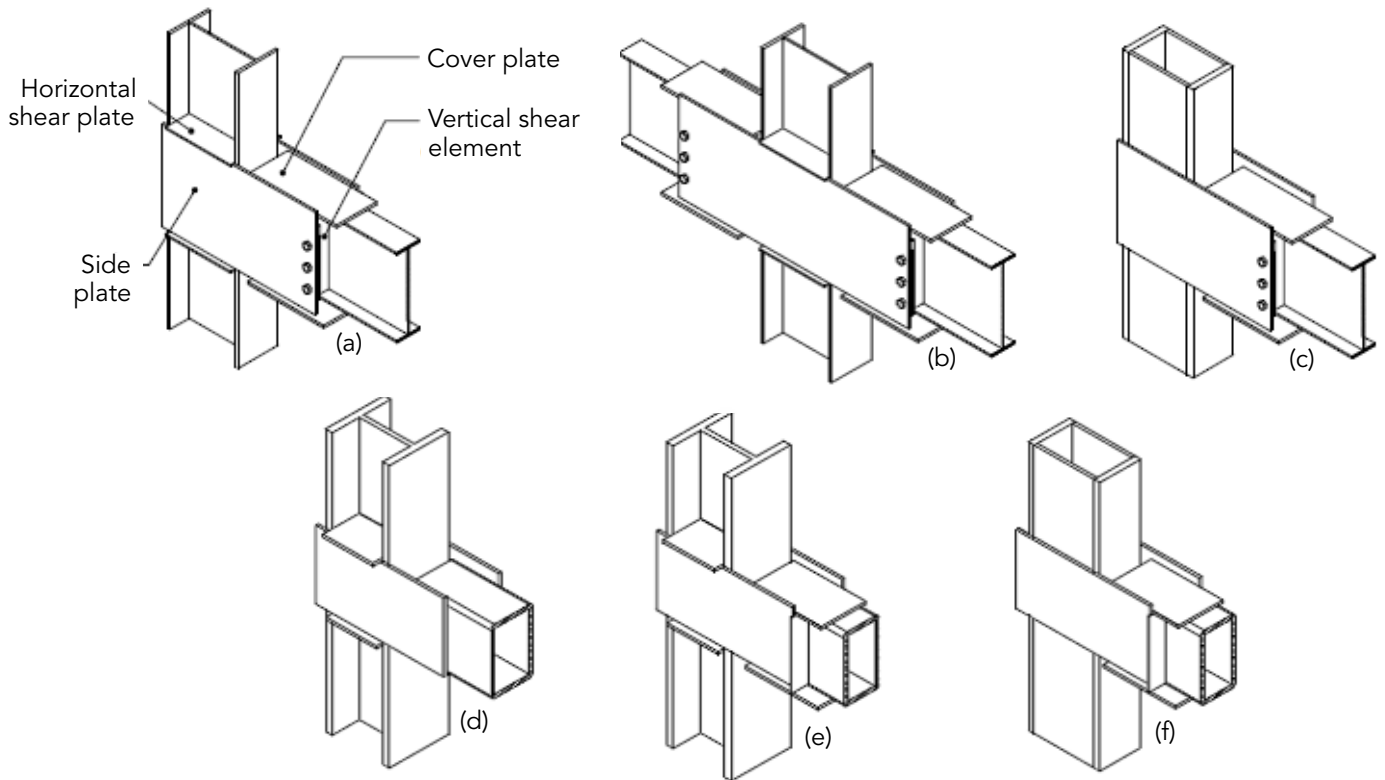
square or built-up box columns using a completely field-bolted collar assembly. Reduced beam section (RBS) cutouts are provided in the beam flanges, as needed, to satisfy strong column-weak beam criteria. Portions of the collar assembly (collar corner assemblies) are shop-welded to the columns, and the remaining portions (collar flange assemblies) are shop-welded to the beam ends. In the field, the collar flange assemblies are bolted to the column corner assemblies. When the connection first appeared in AISC 358, both the collar corner assemblies and the collar flange assemblies were specified to be made of forged parts. Subsequently, in AISC 358-10 Supplement No. 2, the collar corner assemblies were specified to be made of cast or forged parts. Requirements for casting and forging are specified in Appendices A and B of AISC 358. Changes in AISC 358 for the ConXL connection will allow the flanges and webs of built-up box columns to be connected using partial joint penetration groove welds, previously specified as complete joint penetration groove welds. Requirements for welds are specified in Chapter 10 of AISC 358.

The ConXL moment connection is prequalified for use in SMFs and IMFs as well as in planar moment-resisting frames or in orthogonal intersecting moment-resisting frames. In typical applications, these connections are used to provide biaxial moment connections at nearly every beam-column joint in the structure, essentially providing a complete 3D moment frame system.



▲ Figure 1. An assembled ConXtech ConXL Moment Connection. (Figure 10.1 from AISC 358-16)

The ConXL connection is prequalified for rolled wide-flange or built-up I-shape members up to W30 in depth, beam flange thickness up to 1 in. and beam flange width up to 12 in. Columns for this system are always 16-in. square HSS or 16-in. square built-up box sections. The columns are completely filled with structural concrete. Additional prequalification limits are listed in Chapter 10 of AISC 358.



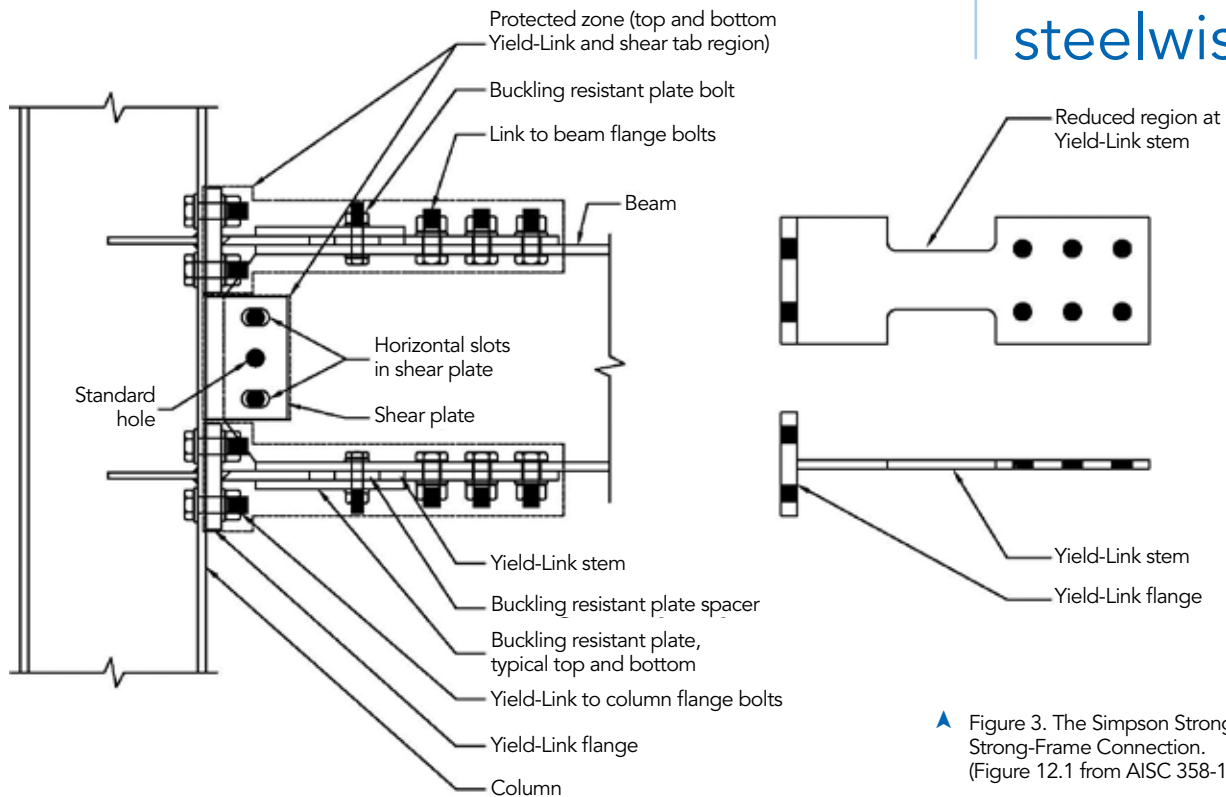
▲ Figure 2. Assembled SidePlate Moment Connections. (Figure 11.1 from AISC 358-16)

### SidePlate Moment Connection

The SidePlate moment connection is a proprietary connection that was first added in AISC 358-10 Supplement No. 2 in February 2014. (A schematic of the connection, when used with planar moment frames, is shown in Figure 2.) With this connection, the beam is not directly connected to the face of the column; there is, in fact, a gap between the end of the beam and the face of the column. Forces are transferred from the beam to the column through parallel side plates that sandwich the beam and column. The beam is welded to the side plates using horizontal beam flange cover plates and vertical shear elements, and the side plates are welded directly to the column flanges and welded to the column web through horizontal shear plates. Thus, forces at the beam ends are transferred to the side plates and then from the side plates into the column. A key feature of this connection is that all welds are

fillet welds; the only exception is when HSS beams are connected to the side plates using flare bevel groove welds at the rounded edges of the HSS section. In addition to the planar moment frame SidePlate connections shown in Figure 2, the SidePlate connection can also be used in biaxial configurations where beams connect orthogonally to columns. SidePlate is prequalified for both SMFs and IMFs.

The connection is prequalified for rolled wide-flange or built-up I-shape members up to W40 in depth and beam flange thickness up to 2.5 in. SidePlate is also prequalified for HSS beams for depths up to HSS10 for SMFs and HSS12 for IMFs. Beam weight is limited to 302 lb/ft. Columns can be rolled wide-flange or built-up I-shaped sections up to W44 in depth, flanged cruciform sections or built-up box sections with a width not exceeding 24 in. Additional prequalification limits are listed in Chapter 11 of AISC 358.



▲ Figure 3. The Simpson Strong-Tie Strong-Frame Connection. (Figure 12.1 from AISC 358-16)

### Strong-Frame Connection

The Simpson Strong-Tie Strong Frame connection is a newly prequalified proprietary connection in AISC 358 (a schematic of the connection is shown in Figure 3). The Strong-Frame connection is the first moment connection classified as partially restrained to be prequalified in AISC 358. The term “partially restrained moment connection” is defined in AISC 360 as “a connection capable of transferring moment with rotation between connected members that is not negligible.” This means that the connection’s rotation flexibility must be included in the structural analysis model used to predict frame drift and frame member and connection forces. Detailed guidance is provided in Chapter 12 of AISC 358 on how to include connection flexibility in the building frame model. In addition to being classified as partially restrained, the connection can also be considered a partial-strength connection, as the connection’s flexural capacity is typically well below  $M_p$  of the connected beam.

A key feature of the Strong-Frame Connection is the “Yield-Link” used to connect the beam flanges to the column flange. The Yield-Link (shown in the right portion of Figure 3) is a modified T-stub that has a reduced section in the stem. The stem of this link is bolted to the beam flange, and the link’s flange is bolted to the column flange. The connection is designed so that during a severe earthquake, yielding occurs within the reduced section of the Yield-Link and the beams remain essentially elastic, which differs from all other prequalified connections, where yielding is intended to occur primarily in the beams. When the stem of the Yield-Link goes into compression, buckling of the Yield-Link is prevented by a separate buckling restraint plate that is bolted over the reduced section of the Yield-Link. Also note that construction of the Strong-Frame connection in the field requires no welding; all components are field-bolted.

One of the challenges faced by the CPRP in prequalifying the Strong-Frame connection for SMFs applications is that it did not fit the definition of an SMF connection in AISC 341-10. According to AISC 341-10 Section E3.2, SMFs “are intended to provide significant inelastic deformation capacity through flexural yielding of the SMF beams and limited yielding of the column panel zone.” The Strong-Frame connection did not meet this definition, as inelastic deformation capacity is provided through yielding of connection elements and not through yielding of the beam or column panel zone. Further, AISC 341-10 requires that beam-to-column connections, when subject to cyclic loading tests, demonstrate a measured flexural resistance of at least  $0.8M_p$  of the connected beam at a story drift angle of 0.04 rad. Again, the Strong-Frame connection did not satisfy this requirement, as its flexural capacity is intentionally significantly less than  $M_p$  of the connected beam. Finally, AISC 341-10 provided no guidance on the use of partially restrained moment connections in SMF.

Because of the unique nature of the Strong-Frame connection, being both a partially restrained and partial-strength connection, the CPRP requested two supplemental studies to be completed as part of the prequalification process. These studies were intended to ensure that moment-resisting frames constructed with the Strong-Frame connection provide seismic performance similar to more conventional SMF. To this end, comparisons were made between frames constructed with this connection and more conventional SMFs constructed with RBS connections. The first study examined connection performance equivalency following procedures specified in Report FEMA P795: *Quantification of Building Seismic Performance Factors – Component Equivalency Methodology*, which examined the equivalency of the Strong-Frame connection with the RBS connection. The

second supplemental study requested by the CPRP examined overall system behavior—and again compared systems using Strong-Frame connections with more conventional SMF systems using RBS connections. A series of nonlinear time-history analyses using a suite of strong ground motions were conducted to compare the systems, and both supplemental studies indicated that frames constructed with Strong-Frame connections provided performance that is essentially the same as an SMF with RBS connections. These studies were a key part of the successful prequalification of the Strong-Frame connection.

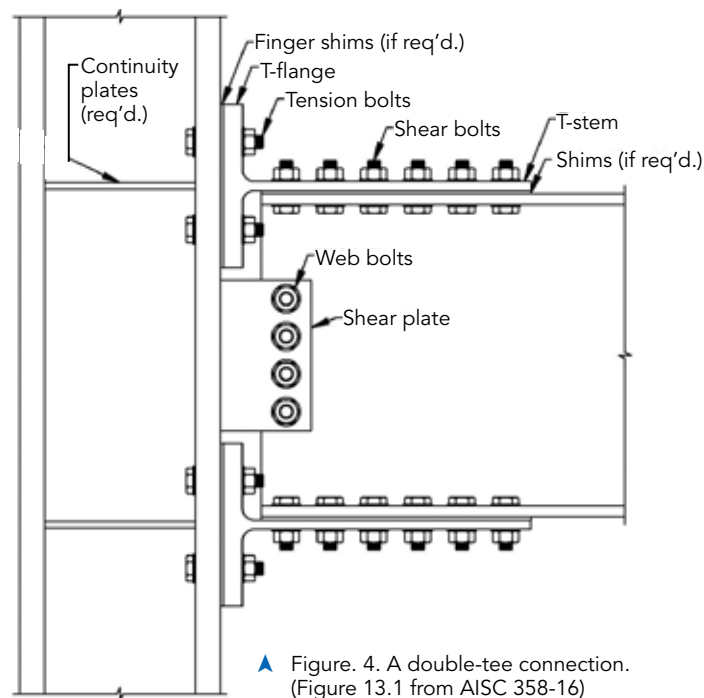
The connection is prequalified for both SMFs and IMFs and is prequalified for rolled wide-flange or welded built up I-shaped sections; beam depth is limited to W16 or less. Because beams are expected to remain essentially elastic in this system, they are not required to satisfy the compactness limits or lateral bracing requirements for SMFs specified in AISC 341. Rather, the beams need only satisfy the compactness and bracing requirements in AISC 360. This reduction in beam lateral bracing requirements is useful when providing such bracing is difficult, as may be the case with a steel SMF that is integrated in a wood structure. The Strong-Frame connection is further prequalified for use with rolled or built-up column sections up to W18 in depth, and the beam must be connected to the column flange. Additional prequalification limits are listed in Chapter 12 of AISC 358.

It should be noted that following the prequalification of the Strong-Frame connection in AISC 358, changes were made to the SMF requirements in Section E3 of AISC 341-16. This section now permits SMFs where inelastic deformation capacity is provided by yielding within the connection “where equivalent performance of the moment frame system is demonstrated by substantiating analysis and testing.”

## Double-Teer Connection

The double-tee connection is a new nonproprietary connection in AISC 358 (a schematic of the connection is shown in Figure 4). This is an all-field-bolted connection wherein the beam flanges are connected to the column flange using T-stubs cut from rolled sections, and the beam web is connected to the column using a single plate shear connection. The double-tee connection was the subject of significant research and testing in the SAC-FEMA program. This work was subsequently extended with additional research and testing, leading ultimately to prequalification in AISC 358.

The connection is designed such that in the event of a strong earthquake, yielding occurs in the beam near the ends of the T-stubs. Like all other prequalified connections, with the exception of the Strong-Frame connection, the double tee is considered to be a fully restrained moment connection. This means that connection flexibility need not be included in the analysis model. As part of the design procedure for the double-tee connection in Chapter 13 of AISC 358, equations are provided to check that the connection has adequate rotational stiffness to ensure that it behaves as fully restrained.



▲ Figure 4. A double-tee connection. (Figure 13.1 from AISC 358-16)

The double-tee moment connection is prequalified for use in SMFs and IMFs and for rolled wide-flange or welded built-up I-shaped members. Beam depth is limited to a maximum of W24, beam weight is limited to a maximum of 55 lb/ft and beam flange thickness is limited to a maximum of  $\frac{5}{8}$  in. Columns can be rolled wide-flange shapes, welded built-up I-shapes or flanged cruciform columns. Column depth is limited to W36 when a concrete structural floor slab is present and is otherwise limited to W14. Beams must be connected to the column flange. Additional prequalification limits are listed in Chapter 13 of AISC 358.

## More Choices

With these four connections that have been prequalified since the release of AISC 358-10, there are now a total of nine prequalified connections in AISC 358, providing designers with many choices for beam-to-column moment connections in SMFs and IMFs. As we’ve provided only a few brief highlights here, we urge you to peruse the new AISC 358 for complete details and requirements for these and other prequalified connections. And remember that designers are not restricted to only using prequalified connections in SMFs and IMFs. AISC 341 also permits connections in SMFs and IMFs that have been qualified by testing but that have not necessarily been prequalified. Nonetheless, AISC 358 can be a valuable resource for designers by providing prequalified connections that are deemed to satisfy the connection performance requirements for SMFs and IMFs in AISC 341.

AISC 358-16 is expected to become available this month and will be posted at [www.aisc.org/epubs](http://www.aisc.org/epubs) in the “Specifications, Codes and Standards” section. ■