Steel Connections: Proprietary or Public Domain?

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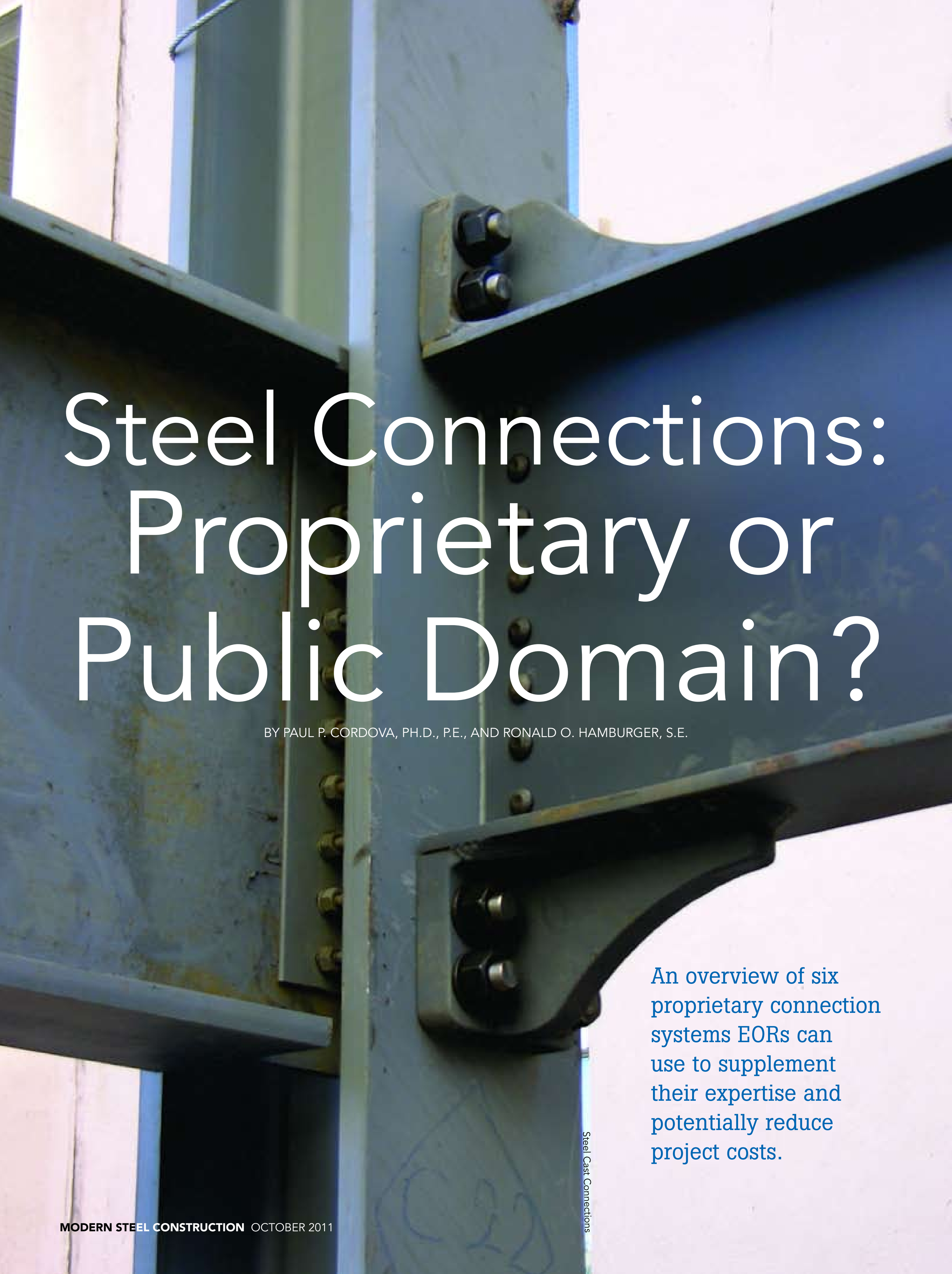

Steel Cast Connections

An overview of six proprietary connection systems EORs can use to supplement their expertise and potentially reduce project costs.

FOR MANY YEARS, steel designers in the U.S. could be broadly split into two groups: those who believe the engineer of record should take responsibility for and include complete design of framing connections on their design drawings, and those who preferred to delegate connection design to a licensed engineer working on behalf of the fabricator. Until the 1994 Northridge earthquake, the first group generally encompassed engineers in the western U.S. who felt that to properly design a structure for seismic resistance, it was necessary for the engineer of record to design the connections. Engineers in the eastern U.S., not burdened with seismic design, felt comfortable delegating connection design responsibility. However, following the 1994 Northridge earthquake, a number of proprietary connection technologies, with design furnished by the licensor, began to emerge on the market and to gain acceptance by engineers around the country, including those in the western U.S.

A number of public domain connection designs are available for both moment-resisting and braced frames. For special or intermediate moment frames intended for seismic applications, an engineer can go to ANSI/AISC 358, *Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications*, select and design any of several connection types in accordance with the criteria in that standard, obtain permit approval and have confidence that he or she has conformed to an appropriate standard of care. Prequalified connections have been thoroughly tested and evaluated by an AISC-sponsored standards body, which lends confidence in their expected performance in the next big earthquake. Note that adequate performance may include damage.

Public domain connections with current prequalification include the reduced beam section (RBS), bolted flange plate (BFP), and welded unreinforced flange (WUF-W). A connection using bolted split tees at the beam top and bottom flanges (double-T connection) is anticipated to receive prequalification soon. Similarly, ANSI/AISC 341-05, *Seismic Provisions for Structural Steel Buildings*, specifies design criteria for braced frame connections that can be used for design and with confidence by any engineer.

But is there a cheaper, more efficient way to design steel frame connections? Can this be done in a way that improves the building's performance and perhaps even makes it easier to repair after a large earthquake? These are some of the questions that developers of proprietary connections attempt to address. Each proprietary connection developer claims to provide several advantages over public domain and, of course, competitor's connections. Please note that the authors of this article do not necessarily endorse or ascribe to the licensor claims described below.

◂ Kaiser Bolted Bracket connection.

Improved Ductility and Reliability

Many proprietary connections were developed in response to the 1994 Northridge earthquake after discovery that some steel moment resisting connections experienced brittle fracture at the welded beam-flange-to-column-flange joints of the then common public domain connection. This brittle fracture was unexpected and counter to the intended design philosophy and behavior for these frames, which anticipates energy dissipation through ductile plastic hinge formation in the steel beams. Today, all moment resisting connections used in special or intermediate steel moment frames must be qualified by test using the protocol described in Appendix S of the AISC *Seismic Provisions*. These connection tests are intended to demonstrate that the connection can withstand large inelastic deformation through controlled ductile yielding in specific behavioral modes. Engineers can use prequalified connections that have been demonstrated on a general basis to be capable of acceptable behavior, or can design and test their own connections. AISC 358 lists a number of public domain and proprietary prequalified connections. In addition, some proprietary connection licensors have prequalified their connections through alternative processes and do not list their connections in AISC 358.

Proprietary connections listed in the standard include the Kaiser Bolted Bracket and ConXtech connections. Additional connections currently undergoing consideration by AISC for prequalification include SidePlate, SlottedWeb and Pin Fuse. SidePlate Systems, licensor of the SidePlate connection, advertises enhanced reliability of its connection because it uses only fillet welds and no complete joint penetration groove welds. In addition, SidePlate has conducted blast and progressive collapse testing of its connection and claims improved resistance of their technology for such applications. SSDA, the licensor of SlottedWeb, advertises that its connection has significantly enhanced low-cycle fatigue resistance and is capable of surviving multiple earthquakes. The Pin Fuse connection uses a fuse mechanism that purports to replace material yielding with friction slip to dissipate energy without structural damage up to preset rotational levels.

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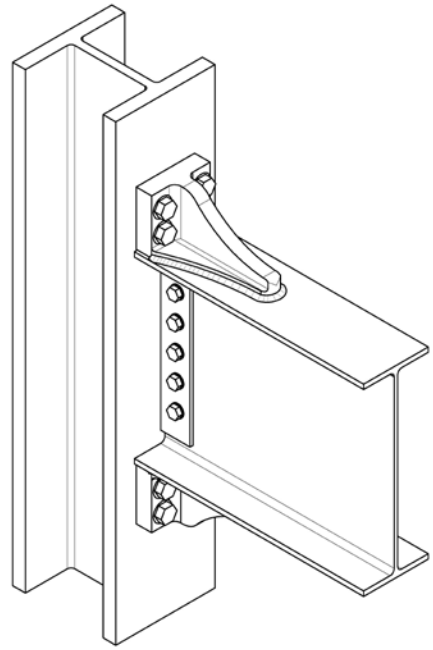


Kaiser Bolted Bracket connection, W-series.

Improved Constructability and Cost Savings

In addition to improved performance, proprietary connection developers variously claim to provide the cheapest and quickest way to construct steel frames. These claims include:

- Minimizing or eliminating expensive and time-consuming field welding. Complete joint penetration welds at the beam-to-column flange can take several hours to complete in the field and also require inspection and nondestructive testing.
- Improving constructability and efficiency. Creating new and easier ways to put frames together and moving the critical fabrication phases out of the field and into the shop where processes can be more controlled and efficient.
- Reducing steel weight. Several connections are approved for deeper and lighter steel members than public domain connections, which can provide stiffer frames with less steel. Also, some licensors claim their connection provides stiffer frames which can be an advantage in the often drift-controlled design of steel moment resisting frames.

Technical Support

The technical support offered by the licensors is perhaps one of the biggest advantages in favor of using these connections. Generally these companies have staffs of licensed structural engineers that are experts in all aspects of the connection and also moment resisting frames in general. They help the engineer of record maneuver through building code provisions, computer modeling, and lateral design and optimization of the connections and frames. In some cases, they provide stamped connection design drawings and calculations and also assist during a project's plan check phase. This all provides an additional layer of quality assurance and benefit to the project since they are essentially acting as a peer reviewer and value engineer supporting the engineer of record.

Why Not?

Some engineers prefer to have control over the entire design and do not want to give up control of connection design. Licensors can provide varying degrees of support and will work together with the engineer of record, but still some may be uncomfortable—call it engineer's pride.

Also, some question the actual cost savings claimed by the licensors. There is also the licensing fee, which can be assessed to the fabricator or the engineer. Despite this fee, licensors argue they provide net project savings and are willing to assist with comparative cost studies for projects.

If you have gotten this far in the article, perhaps you are willing to explore what's out there. So, what is out there?

Kaiser Bolted Bracket

The Kaiser bolted bracket (KBB) moment connection uses cast high-strength steel brackets that are fastened to each beam flange and bolted to the column flange. The brackets are proportioned to develop the full moment capacity of the beam and can be either welded (W-series) or bolted (B-series) to the beam flange. When subjected to large earthquake-induced deformation, the connection forces yielding and plastic hinge formation into the beam, beyond the tip of the brackets and away from the column face.

Manufactured by Steel Cast Connections, each bracket undergoes a rigorous quality control process prior to shipment to the project's steel fabricator. The brackets are fastened to the beam in the shop and bolted to the column in the field, eliminating all field welding. To provide erection tolerance, the bracket column bolt holes are vertically short-slotted and the column bolt holes are slightly oversized.

The B-series brackets can also be used in retrofit applications to strengthen moment frames constructed with pre-Northridge connection detailing or to increase resiliency and redundancy in progressive collapse resistance upgrades. Implementation of a bolted bracket retrofit within the confines of an occupied building eliminates the health and fire hazards associated with a welded retrofit alternative. Eliminating field welding generally also reduces costs associated with fabrication and inspection.

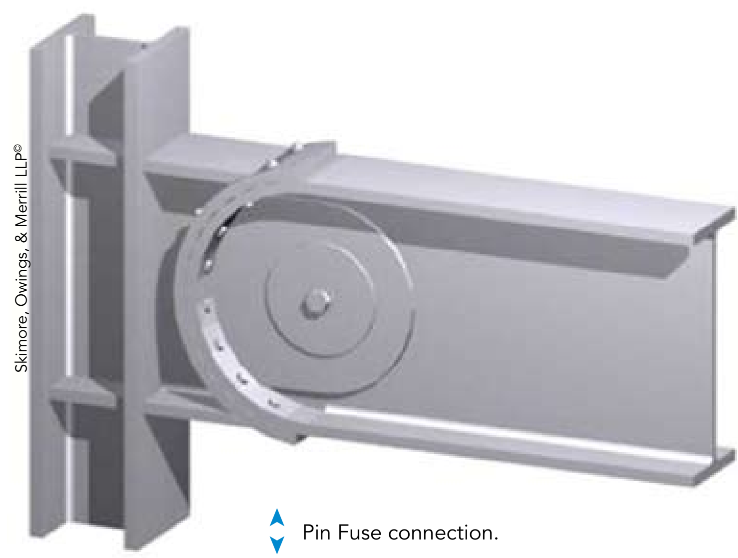
There is no licensing fee to use the KBB connection, but the bracket must be fabricated by Steel Cast Connections. For more information, go to **www.steelcastconnections.com**.

Pin-Fuse Joint

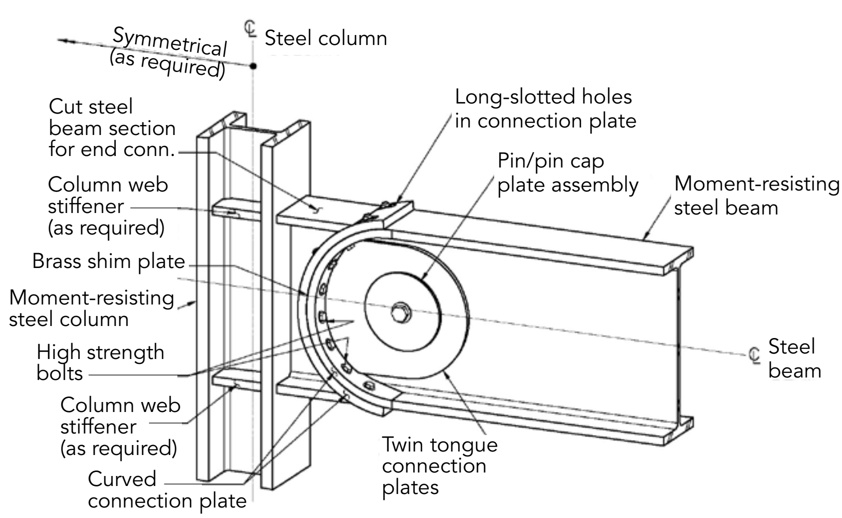
Just beginning its prequalification process is the Pin-Fuse Joint created by Skidmore, Owings & Merrill (SOM) . The joint incorporates a curved plated end connection using slip-critical bolts and a steel pin or hollow pipe adjacent to the beam column joint. The nested curved steel plates with brass shims between them can move relative to one another forming a rotational hinge with the pin as the center of rotation. The slip-critical bolts clamp the curved plates and shims together and provide the rotational resistance to sustain the imposed beam moments. The pin resists the beam's shear and axial load. The bolts are designed to maintain joint rigidity during wind and moderate seismic events. For larger seismic events, the bolts are designed to slip within slotted holes allowing the joint to rotate dissipating the earthquake's energy through frictional resistance. This joint acts as the "fuse" for the system and the steel frame can be designed to remain elastic throughout these excursions. After the earthquake, the structural frame remains relatively undamaged and also has the ability, perhaps with some help (i.e., loosening and retightening bolts), to return close to its initial position thereby reducing the potential for permanent residual displacements. The frame and joint maintain their structural integrity and reduce the need for costly structural repairs.

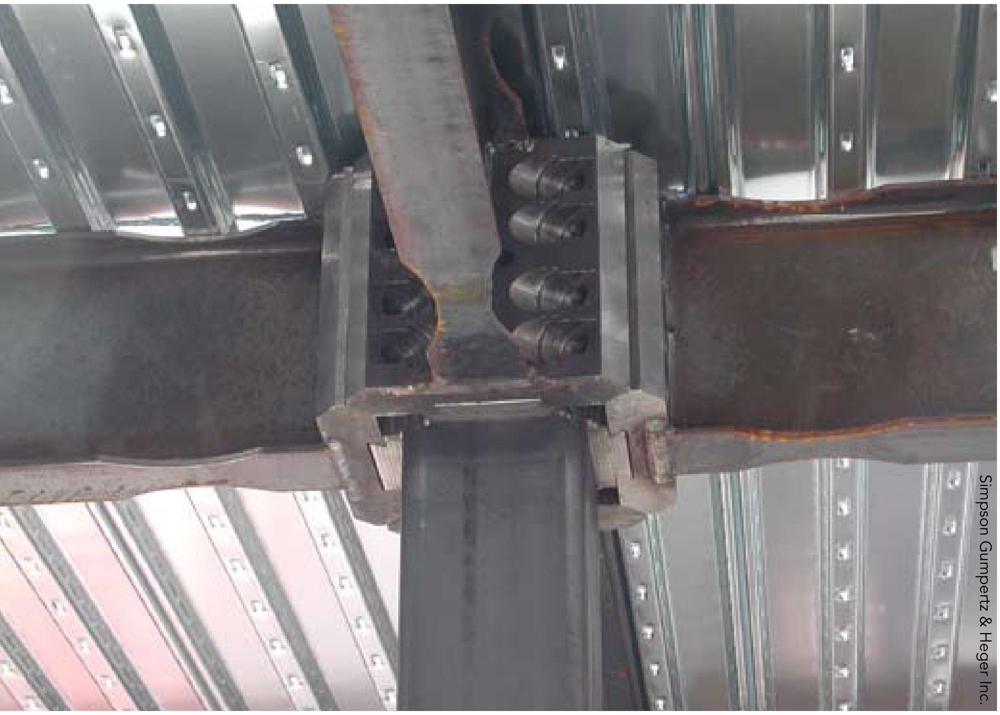
The developers contrast this behavior with that of typical well-behaved public domain steel moment frames where we expect significant plastic hinging and local flange and web distortions throughout a majority of the moment resisting beams. This performance can lead to permanent building drifts, expensive repairs, and can decrease the frame's stiffness and strength affecting its ability to withstand subsequent extreme loading events.

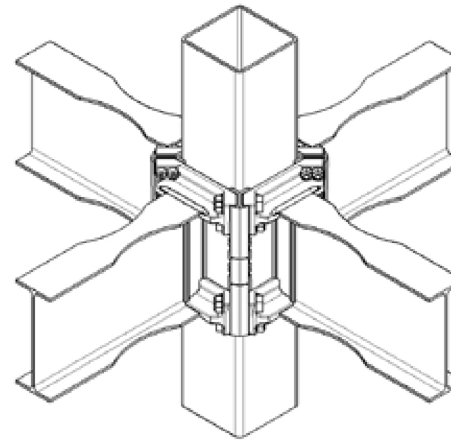
The Pin-Fuse Joint is an all-field-bolted connection. Columns are prefabricated with short beam stubs and a circular plated end connection. Beams are prefabricated with the matching circular connection at each end and are hoisted and pinned to the beam stub. Depending on construction tolerances and sequencing, it may be necessary to splice the beam along its length. The connection also has the ability to accommodate brace and damper member attachment to moment-connected joints. For more information, go to **www.som.com/content.cfm/pin_fuse_joint**.



Pin Fuse connection.







◄ ▲ ConXtech biaxial connector with RBS steel beams. Above: XL type. Left: XR type.

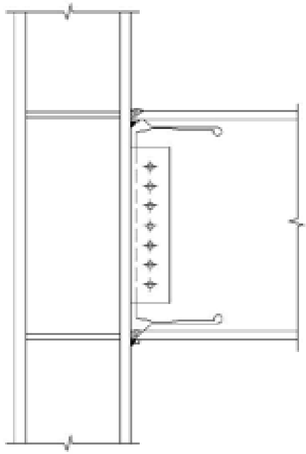
ConXtech

ConXtech's ConXL moment connection consists of column and beam collar assemblies that form a compression collar connection using high-strength pretensioned bolts providing rigid bi-axial fixity between square HSS/built-up box columns and wide-flange beams with no field welding. The column collars (Corner Collars) are welded in the shop to all four corners of a square column and include a 3D taper for ease of erection when accepting the beam collar (Collar Flange) that is tapered to match the contacting surfaces of the Collar Corners. Collar Flanges are welded in the shop to the top and bottom flanges of wide-flange beams. The connection can accept up to four moment-connected beams, one on each face of the column.

Concrete-filled, square HSS or box columns are prefabricated with the Collar Corners at the floor levels. Columns are erected and wide-flange beams prefabricated with the Collar Flanges at each end are lowered into and restrained by the Corner Collars creating a plumb, stable structure with only the gravity interface. Once all beams are in place at the beam-column joint, the Collar Flanges are interconnected to one another with pretensioned high-strength bolts diagonally along their adjacent edges, with the Collar Corners acting as an interior ply between the Collar Flanges, thereby, completing the full capacity of the moment-resisting collar connection around the HSS/built-up box column.

In addition to the ConXL connection, applicable to beam spans of 18 ft and longer, ConXtech also offers the ConXR connection intended for shorter bay applications of 8 ft to 20 ft. Collars are designed to experience minimal yielding and with enough strength to force beam hinging. A reduced beam section can also be fabricated in the beam if needed to satisfy column-beam strength ratio limits for SMFs. Only the ConXL connection is presently prequalified by AISC, although ConXtech does have ICC-ES qualification for the ConXR connection.

Both ConXtech connections have been qualified for use in bi-axial moment-resisting frame applications and allow the use of every beam-column joint to provide lateral resistance, resulting in reduced member sizes and foundation loads. This redundancy also provides advantages for frames intended to provide progressive collapse resistance. ConXtech claims the ease of system detailing, fabrication, speed of erection and lack of field welding can greatly reduce time and total installed cost. For more information, go to **www.conxtech.com**.



Seismic Structural Design Associates, Inc.

SlottedWeb connection.

SlottedWeb

Seismic Structural Design Associates (SSDA) has developed the SlottedWeb connection, which creates a horizontal slot in the beam web just inboard of the flange to separate the beam's web and flange. This slot isolates the beam section such that shear is resisted entirely by the web and the flanges provide the primary couple force to resist the beam moment. SSDA claims that its SlottedWeb promotes controlled ductile beam yielding and prolongs the connection's fatigue life by:

- Reducing the large stress and strain gradient across and through the beam flange providing a biaxial stress state.
- Reducing prying on weld and column flange.
- Eliminating lateral torsional buckling in the connection region by allowing the web and flange to buckle independently.
- Reducing residual weld stresses because of the long separation between the vertical and horizontal welds.
- Eliminating limitations on panel zone strength relative to beam.

Analytical studies and experimental programs have shown that the SlottedWeb develops the full plastic moment capacity of the beam and does not reduce its elastic stiffness. Subassembly tests have also shown compliance with requirements in the AISC *Seismic Provisions*.

Construction using the SlottedWeb connection is similar to that of RBS frame where beam flanges and webs are CJP groove welded to the column flange. There is also a shear plate that can be shop welded to the column flange and fillet welded to the beam in the field. SSDA claims that SlottedWeb beam fabrication is economical because the connection involves fewer additional parts and cuts, and work is done in the thinner web material. For more information, go to **www.slottedweb.com**.

SidePlate FRAME

SidePlate uses a series of flange and web plates with horizontal shop and field fillet welds to create a rigid, fixed connection between wide-flange columns and beams. In the shop, beam flange cover plates are fillet welded to the top and bottom of the beam and erection angles are fillet welded to the web. Column side plates and horizontal shear plates are fillet welded to the column web.

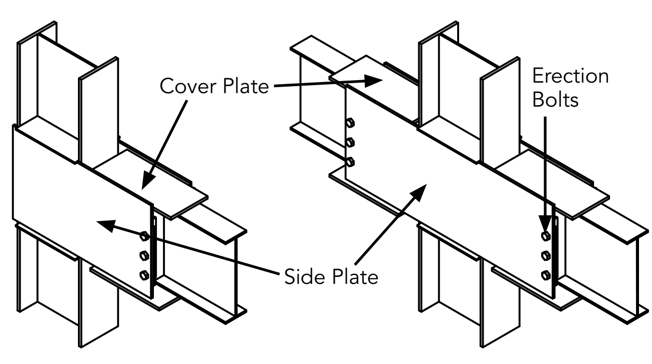
In the field, column trees are erected and beams are hoisted into place between the two column side plates. The beams are bolted to the side plates and four horizontal fillet welds are applied to finalize the beam column connection. SidePlate is a 100% fillet welded connection and eliminates the need for complete joint penetration welds.

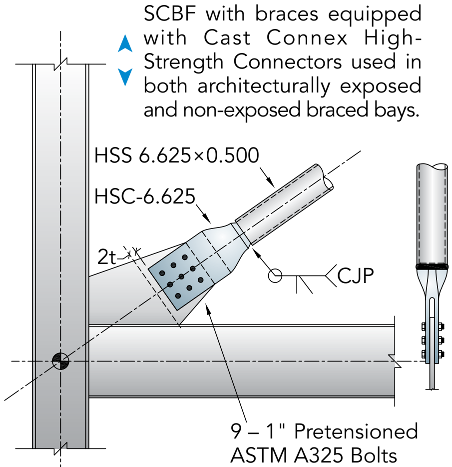
In 2010, SidePlate transitioned from the original SidePlate connection, which included a beam stub in a column tree assembly and required a field CJP beam splice. The new connection, referred to as the SidePlate FRAME, has eliminated the beam stub, CJP splice, and reduced the fillet weld sizes by about half of the original connection. These improvements, developed from an extensive analytical and experimental testing program, have reduced shop fabrication time and improved constructability.

SidePlate claims no limit on column or beam size, which allows the use of deeper and lighter sections that can reduce the total steel weight and cost. SidePlate also recommends that panel zones are modeled as completely rigid and to include the increased beam stiffness provided by the column side plates, resulting in substantial savings in steel frame weight. Another important benefit of SidePlate connections is that the side plates can be extended to permit attachment of braces for dual systems, and dampers for energy dissipated structures. There are no public domain moment-resisting connections that have been qualified for use where braces or other diagonal members intersect the beam-column joint. For more information, go to **www.sideplate.com**.

SidePlate Systems, Inc.

SidePlate Frame Connection.





SCBF with braces equipped with Cast Connex High-Strength Connectors used in both architecturally exposed and non-exposed braced bays.

Cast Connex

Cast Connex has developed cast high-strength steel connectors for round hollow structural section brace members in concentrically braced frames. The connector is a single cast piece with a solid circular end that is shop welded (CJP) to round HSS braces. The circular section gradually tapers to two adjacent plates that accommodate a bolted (double-shear) connection. Connectors are attached at both ends of the round HSS brace and are field bolted (or welded, if needed) to a gusset plate.

This provides for substantially more compact field-bolted connections than would otherwise be possible with typical bolted connections using splice plates (i.e., requiring half the number of bolts with less fabrication and field work). This approach also eliminates the need for typical welded details such as slotted HSS members and net-section reinforcement.

The connector is designed to develop the probable tensile capacity of the bracing member and has been rigorously tested showing its ability to force brace and gusset buckling and hinging.

The developer also fabricates clevis-type universal pin connectors and customizable cast steel components to connect multiple members in three dimensions. All of its High-Strength Connectors provide a unique connection aesthetic that is suitable for architecturally exposed structural steel (AESS).

Cast Connex has also developed a yielding fuse connector for concentric braced frames, called the Scorpion Yielding Brace System, that relies on flexural yielding of finger-like plates that are specially designed to dissipate energy while keeping the brace and other frame elements essentially elastic. While there is no licensing fee for specifying any of these connections, fabricators must purchase the connectors from Cast Connex. For more information, go to **www.castconnex.com**.

Conclusion

While these six proprietary systems all offer viable approaches to connection design, other options exist as well. Engineers will likely never agree as to whether it is best for the engineer of record to design connections or for a properly qualified third party to do so. For those willing to consider connection design by others, proprietary connections are out there and offer some real advantages for particular applications. They have many years of research and development behind them to demonstrate their proof of concept. They are a tool that can be considered on projects to, by licensor's claims, increase constructability, provide savings, and improve structural performance. Their use also can reduce the burden on the engineer of record. MSC