BRBFs provide superior seismic response, but SCBFs are still a viable bracing option in many seismic applications.

Ample Seismic Protection

BY CARLOS DE OLIVEIRA AND JEFFREY A. PACKER, PH.D., P.ENG.

SOME EXCELLENT RESEARCH on special concentrically braced frames (SCBFs) is making its way from university laboratories all over North America to the drawing tables of consulting engineering firms all over the world.

The research, some of which has yet to be published, is reminding us that, yes, buckling-restrained braced frames (BRBFs) provide improved seismic response over SCBFs—but with appropriate brace member selection and detailing, SCBF structures without buckling-restrained braces also can provide ample seismic protection. And when you factor in simplicity in design and construction, it's no wonder that SCBFs still have their place as the preferred lateral force resisting system in medium- to low-rise steel structures. This is especially true in design-build projects, where involving additional consultants and meeting stringent testing requirements, as required for BRBF structures, can add too much additional time to a project.

Cyclical in Nature

Unlike in BRBFs, the bracing elements in SCBFs are meant to cyclically yield in tension and buckle in compression in an earthquake. In fact, the cyclic brace yielding and buckling is how the system absorbs energy imparted by strong ground motion. As such, the cross-sectional shape, cross-sectional slenderness, and overall slenderness of the brace members in an SCBF determine the building's overall response in an earthquake. So it's no wonder that the effects of these parameters on the response of SCBF are being studied by so many researchers and are the subject of such hot debate within code committees.

In 2007, Uriz, Sabelli, and Mahin submitted a report on the design implications of the preliminary results of ongoing research on SCBF systems to AISC. Since then, as can be seen in a recently published draft of the AISC 2010 *Seismic Provisions*, the AISC Technical Committee 9 (Seismic) has adopted the Uriz et al recommendation to tighten the permitted cross-section slenderness of round hollow structural sections (HSS) to D/t ≤ 0.038 E/Fy from the previous limit of D/t ≤ 0.044E/Fy.

In 2006, Packer suggested the use of round HSS over rectangular HSS for energy-dissipating braces. New research by Fell, Kanvinde, Deierlein, and Myers published in the January 2009 ASCE *Journal of Structural Engineering* supported this and suggests that wide-flange sections and round HSS or pipe braces provide a more desirable SCBF response than rectangular HSS braces. Fell et al. point out that in these superior sections, local buckling occurs more gradually and thereby delays fracture initiation at the central plastic hinging point of the brace.

From a practical standpoint, the Fell et al. results can be applied by engineers today. It is commonly accepted that HSS are efficient for carrying compressive loading. Since we must size SCBF bracing elements to carry compressive forces, it makes sense to specify round HSS (produced to ASTM A500 or CAN/CSA G40.20/21) or pipe (produced to ASTM A53) bracing elements whenever possible. Once the compressive forces become too large to be carried by round HSS or pipe elements (i.e., the axial compressive capacity of the available sections that meet the stringent cross-sectional and overall member slenderness requirements for SCBF is not sufficient), then we should move to wide-flange braces.

Connections for Round Hollow Braces

Regardless of the cross-sectional shape of the steel brace section used in an SCBF, brace connections must be detailed such that they can resist tensile loads greater than or equal to the expected yield strength of the brace (given by $R_y F_y A_g$). A slotted HSS-to-gusset connection is the most common detail used for connecting HSS brace members to the beam-column intersection. This type

Welding a Cast ConneX High-Strength Connector to a round HSS brace element for use in an SCBF.

Photos (this page and next): Carlos de Oliveira

Full-scale cyclic testing of a round HSS brace assembly equipped with High-Strength Connectors at Ecole Polytechnique in Montreal.

of connection induces shear-lag in the hollow section, which can lead to connection facture at loads that are lower than the expected yield strength of the brace. Thus, the AISC *Seismic Provisions* require the addition of net-section reinforcement in slotted hollow section bracing connections.

As discussed above, round HSS or pipe elements provide better energy absorbing bracing than do rectangular HSS, but the reinforcement of round sections requires the use of curved plate, channels, angles, or segments of other round sections, which can make detailing and fabricating the reinforced connection more onerous. Further complicating the issue, the slots that are cut or burned into the HSS itself must have smooth edges, as notches in the slots can become sites for crack initiation and propagation in the connection during an earthquake.

Commonly, field welding of the demand-critical fillet welds between the slotted HSS and gusset is specified, which can be costly and requires substantial quality control and field inspection. If field bolting is desired, the connections must be spliced as the load path must remain concentric, thus requiring a significant number of bolts, all of which must be pretensioned. In many cases, the number of bolts required is prohibitive.

Cast ConneX High-Strength Connectors offer a practical solution for SCBF brace connections for round HSS or pipe. The connectors, which are shop-welded to the bracing, allow for bolted installation of the brace members. They accommodate a double-shear bolted connection, so the number of bolts required can be drastically reduced. Alternatively, if site fit-up becomes an issue, or if the connections are to be exposed and the architect would like to avoid bolted connections, the connectors can be field welded to the gussets.

These connectors were developed by Packer, Christopoulos, and de Oliveira at the University of Toronto (de Oliveira et al., 2008) and braces equipped with these connectors have undergone testing at both the University of Toronto and Montreal's Ecole Polytechnique. (For more information, visit **www.castconnex.com**.)

Ongoing Research

Hold on to your hats because a lot more SCBF research is currently underway. Watch for more publications by Roeder (Washington), Kanvinde (Univeristy of California - Davis), Deierlein (Stanford), Tremblay (Ecole Poly-

An SCBF with round HSS bracing equipped with High-Strength Connectors.

technique, Montreal), and Packer (Toronto), just to name a few. These studies will no doubt improve our understanding of SCBF and should shed more light on how practicing engineers should be designing seismic-resistant braced structures for optimal performance. Also, the AISC HSS Committee has been working on developing a new higher-performance manufacturing specification for HSS. This is being submitted to ASTM this year and is intended to be another alternate production standard, *in addition to* ASTM A500. This will feature tighter control of geometric tolerances and improved mechanical properties (including a notch toughness requirement and a restricted yield stress range), thus making it ideal for seismic design. MSC

Carlos de Oliveira is CEO of Cast ConneX Corporation, and Jeffrey A. Packer is a professor at the University of Toronto.

References

de Oliveira, J.-C., Packer, J. A., Christopoulos, C., 2008, "Cast Steel Connectors for Circular Hollow Section Braces Under Inelastic Cyclic Loading," ASCE *Journal of Structural Engineering*, 134(3), pp. 374-383

Fell, B.V., Kanvinde, A.M., Deierlein, G.G., and Myers, A.T., 2009, "Experimental investigation of inelastic cyclic buckling and fracture of steel braces," ASCE *Journal of Structural Engineering*, 135 (1), pp. 19-32

Packer, J.A., 2006, "Tubular brace member connections in braced steel frames," 11th. International Symposium on Tubular Structures, Québec City, Canada, Proceedings pp. 3-11

Uriz, P., Sabelli, R. and Mahin, S.A., 2007, "Design implications of recent research on SCBF," Advisory Notice submitted to AISC