SEISMIC-RESISTANT CONCENTRICALLY BRACED FRAMES

It is no secret that concentrically braced frames (CBF) are amongst the most popular lateral force resisting systems for medium to low-rise steel structures. This is mainly due to design and erection simplicity and to the increased stiffness that CBF provide in comparison to other lateral force resisting systems. In Canada, seismic-resistant CBF that are detailed for a ductile response come in two flavours: Moderately Ductile (Type MD) Concentrically Braced Frames and Braced Steel Frames with Limited Ductility (Type LD).

In the event of a design-level earthquake, Type MD and Type LD CBF dissipate seismic energy through the cyclic yielding and inelastic buckling of their brace members. It should be no surprise then, that the cross-sectional shape, cross-sectional slenderness, and overall slenderness of the brace members in both Type MD and Type LD frames determine the building’s overall response in an earthquake.

In 2006, Packer suggested the use of round HSS or Pipe over rectangular HSS for energy-dissipating brace elements. New research by Fell et al. (2009) supports this and suggests that wide-flange sections and round hollow section braces provide a more desirable seismic-resistant braced frame response than rectangular HSS braces. The authors 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.

Practicing engineers can apply these principals to aid in the design of efficient ductile braced frames. It is commonly accepted that HSS are the most efficient structural shape for carrying compressive loading. Since bracing elements must be sized to carry compressive forces (excluding braces in tension-only systems), and given the aforementioned research findings, it makes sense to specify round HSS (produced to CAN/CSA G40.20/21 or ASTM A500) or Pipe (produced to ASTM A53) for the bracing elements in both Type MD and Type LD braced frames 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 Type MD or Type LD frames is not sufficient), then wide-flange brace members should be specified.

These research findings, in addition to work previously done by Fell et al. (2006) and as a result of recommendations made by Uriz et al. (2007), are also behind the changes seen in the cross-sectional slenderness requirements for rectangular and round HSS seismic-resistant bracing in the newly published CSA steel design specification (2009) and the recent draft of the AISC seismic specification (2008).

The seismic response of CBF, characterized by cyclic yielding and buckling of their brace members, imparts arduous loading on the end connections of the activated braces. Consequently, CAN/CSA-S16 requires that all bracing connections in seismic-resistant CBF be detailed such that they are significantly stronger than the nominal cross-sectional capacity of the brace member. Specifically, for bracing elements in both Type MD and Type LD frames, the factored resistance of the brace connections must exceed both the probable tensile capacity of the bracing members in tension (given by $T_u = A_g R_y F_y$), and the probable compressive capacity of the bracing members in compression ($C_u$, given by the lesser of $A_g R_y F_y$ and $1.2 C_r / f$ where $C_r$ is computed using $R_y F_y$ and the probable post-buckling compressive resistance of bracing members). Detailing connections to provide this strength can be rather difficult, particularly when dealing with HSS.

SEISMIC-RESISTANT HSS BRACE CONNECTIONS

A slotted HSS-to-gusset connection is the most common detail used for connecting HSS brace members to the beam-column intersection. This type of connection induces shear lag in the hollow section, which can lead to connection fracture at loads that are lower than the expected yield strength of the brace. Thus, it is good practice to provide net-section reinforcement in slotted hollow section bracing connections in ductile CBF. As discussed above, round HSS or Pipe elements make better energy absorbing bracing than rectangular HSS sections do, 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 com-
plicating the issue, the next edition of CAN/CSA-S16 will require the use of a probable yield stress, $R_y$, of at least 460 MPa when designing HSS bracing connections, regardless of the specified minimum yield stress in the HSS being used. This change will significantly increase the size (and associated materials, labour and hence cost) of all HSS brace connections and brings our standard more in line with the AISC Seismic Provisions which have required the use of higher $R_y$ values for HSS bracing for a number of years.

In terms of brace member fabrication, 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 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 pre-tensioned. In many cases, the number of bolts required for spliced, slip-critical brace end connections is prohibitive.

At one end, High-Strength Connectors are designed with a circular shape and preparation, which allows them to be shop welded to a round HSS brace. The circumferential weld eliminates the occurrence of shear lag in the connection, and with a complete-joint penetration weld, the joint is inherently as strong as the brace itself, regardless of the actual overstrength of the HSS element. Further, the tapered preparation on the nose of the connector accommodates any HSS of a given outer diameter, regardless of the section’s wall thickness – thus standardization of the connector is achieved. This standardization leverages casting manufacturing’s inclination to mass production, making the connectors commercially practical.

On their other end, the connectors accommodate a double-shear bolted connection to the gusset plate. This bolt group can be detailed to provide a resistance commensurate with the probable tensile resistance of the particular HSS member being used. As the connectors are supplied without any bolt holes, the connection designer has the freedom to use whatever bolt pattern, grade, and diameter of bolt desired. Additionally, if slip-critical connections are warranted, the faying surfaces on the High-Strength Connectors are rough, reducing the number of bolts required as Class B slip-resistance can be assumed with the appropriate treatment of the gusset plate. 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.

Having been developed in a university setting, braces equipped with High-Strength Connectors have been subjected to rigorous full-scale testing to prove their effectiveness in a design-level earthquake. This testing was carried out in the structures laboratories at both
University of Toronto and École Polytechnique de Montréal and has been well documented (de Oliveira et al, 2008a, de Oliveira et al, 2008b, Tremblay et al, 2008).

The first project to feature braces equipped with these innovative connectors was a four-storey office building (expandable to six-storey) designed and constructed by CISC member Canam Group Inc. (Boucherville, Québec) and Les Architectes Odette Roy et Isabelle Jacques (St-Georges, Québec). The office building is to become the main administration building for Sandoz Canada Inc. and is part of a large new development which includes 40,000 square feet of manufacturing space, 10,500 square feet of warehousing space, and 17,000 square feet for administrative support. The site is located in Boucherville, Québec near the St-Lambert region of Montréal, which is a region of moderately high seismicity.

The Canam Group’s Sandoz project, representing years of research and commercialization efforts, helped make the University of Toronto researchers and Cast Connex Corporation the inaugural winners of the Canadian Society for Civil Engineering’s “Excellence in Innovation in Civil Engineering Award” in 2009. This prestigious award, presented by peers in the civil engineering community, recognizes outstanding innovation in civil engineering that has the potential for significant and far-ranging beneficial impact on the prosperity and well-being of society.

An additional design time-saving feature of the Cast ConneX® High-Strength Connectors: Cast Connex Corporation is about to launch a Design Manual that provides fully detailed double-shear bolted connections for every connector-to-brace combination possible for both bearing-type and slip-critical connections and for a variety of bolt diameters and grades. The manual also discusses everything from the full-scale product testing carried out by the company to a discussion on best practices for fitting, drilling, and welding to their connectors.

To pre-order your free digital copy, e-mail HSCmanual@castconnex.com.

REFERENCES


