Easily replaceable after a seismic event, this brace is equally well suited to new construction and retrofits.

A New Brace Option for Ductile Braced Frames

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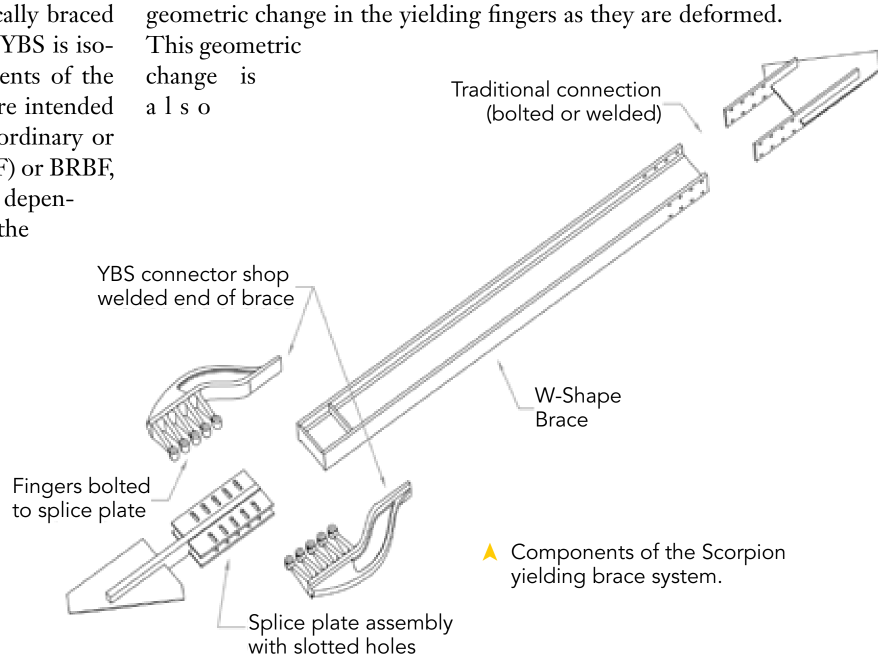
THE BUCKLING RESTRAINED BRACED FRAME (BRBF) is one of the more innovative new technologies to have been developed in the construction industry in recent years. Introduced to the U.S. engineering community in 1999, it became a codified system in less than a decade. Because thinking outside the box is the best way to solve complex problems, it's no surprise that the wheels of science and innovation have continued to churn, resulting in a new system. The industry is now being offered a completely novel yielding brace for braced frames—the Cast ConneX® Scorpion™ Yielding Brace System (YBS).

The YBS, developed at the University of Toronto by Constantin Christopoulos, Jeffrey Packer and Michael Gray, provides enhanced seismic performance for concentrically braced frames. In an earthquake, non-linear response in a YBS is isolated to the brace assembly while the other elements of the frame, such as beams, columns and gusset plates, are intended to remain predominately elastic. So, just as in an ordinary or special concentrically braced frame (OCBF or SCBF) or BRBF, the performance and response of a YBS frame is dependent primarily on the performance and response of the bracing elements comprising it.

The Scorpion Brace

A brace in a YBS frame consists of two cast steel connectors connected to the end of a W-shape or other structural member. Each connector is made up of an arm and a series of fingers and is produced from a highly ductile, notch-tough cast steel grade. In a brace assembly, the fingers of both connectors are bolted to a splice plate which is connected to the beam-column intersection through a traditional gusset plate connection. The other end of the brace is connected to the beam-column intersection with a conventional gusset-to-W-shape connection that can either be field welded or bolted. The Scorpion moniker comes from the brace's resemblance to a scorpion, with the connectors forming the creature's claws.

Energy dissipation in the brace is provided through the flexural yielding of the connector's fingers. Like the 1993-vintage triangular added damping and stiffness system (TADAS), the fingers of the YBS connectors are triangular in shape to promote the spread of plasticity along their entire length. As the fingers are expected to undergo large deformations during a design level earthquake, the ends of the yielding fingers are bolted to long slotted holes in the splice plate, which accommodate the geometric change in the yielding fingers as they are deformed. This geometric change is also



Components of the Scorpion yielding brace system.

responsible for the system's distinct post-yield increase in strength and stiffness at large deformations.

Full-Scale Structural Testing

After the system was conceived, a prototype connector assembly was designed for a 250 kip yield load and the assembly was component tested as well as tested in a full-scale braced frame at the University of Toronto Structural Testing Facility. Two prototype brace assemblies successfully completed a displacement protocol in the braced frame based on the requirements of Section K of ANSI/AISC 341-10, with a design level brace elongation, Δ_{bm}, of 1.5 in. The resulting hysteresis exhibited very full, symmetric loops with the distinct post-yield stiffness at large deformations.

The prototype that was designed and tested represents only one potential connector configuration. Yielding finger geometry can be altered and the number of fingers varied, which together provide the ability to achieve a variety of combinations of elastic stiffness and yield load in the connector. Additional information on the initial development of the connectors and the subsequent testing is available in the conference proceedings from the 2010 U.S./Canadian Conference on Earthquake Engineering. The proceedings are available for purchase at **http://2010eqconf.org**.

Scorpion Connector Series

The YBS technology was specifically conceived to be well suited as an off-the-shelf line of products. With the successful testing of the prototype having been completed, an initial series of connectors has been developed for a range of yield forces (see table at right); additional connectors are planned for assemblies having yield forces exceeding 500 kips. The initial connector series is based on five unique connector designs that can fill a range of 12 different yield forces by removal of up to four yielding fingers in the five base assemblies. Because the device is a connector, a single YBS design can work for nearly any unique building geometry without requiring a significant change in the typical details.

Performance Benefits

A main drawback of a BRBF is that its stiffness is linked to its yield force. The primary method of increasing stiffness is increasing core area, which also increases the yield strength of

Device*	Nominal Yield Force[1] [kips]	k_{device}[2] [kips/in]
YBS-50-6	50	834
YBS-100-6	75	1,182
YBS-150-6	90	1,336
YBS-100-8	100	1,576
YBS-150-8	120	1,776
YBS-215-6	129	1,542
YBS-150-10	150	2,221
YBS-215-8	172	2,061
YBS-310-6	186	2,044
YBS-215-10	215	2,575
YBS-310-8	248	2,729
YBS-310-10	310	3,415

* Each color represents a unique connector design, each with a different number of yielding fingers. Shaded cells highlight the five unique connector geometries.

[1] Cast ConneX recommends using a resistance factor, ϕ, of 0.9 in conjunction with the Nominal Yield Force when designing for strength requirements.

[2] The axial stiffness of the Scorpion brace assembly is calculated by combining the stiffnesses of the YBS device and that of the brace member per the following equation:

$$k_{assembly} = \frac{1}{\left(1/k_{device} \right) + \left(L/AE \right)_{brace}}$$

➤ The Scorpion yielding brace system.

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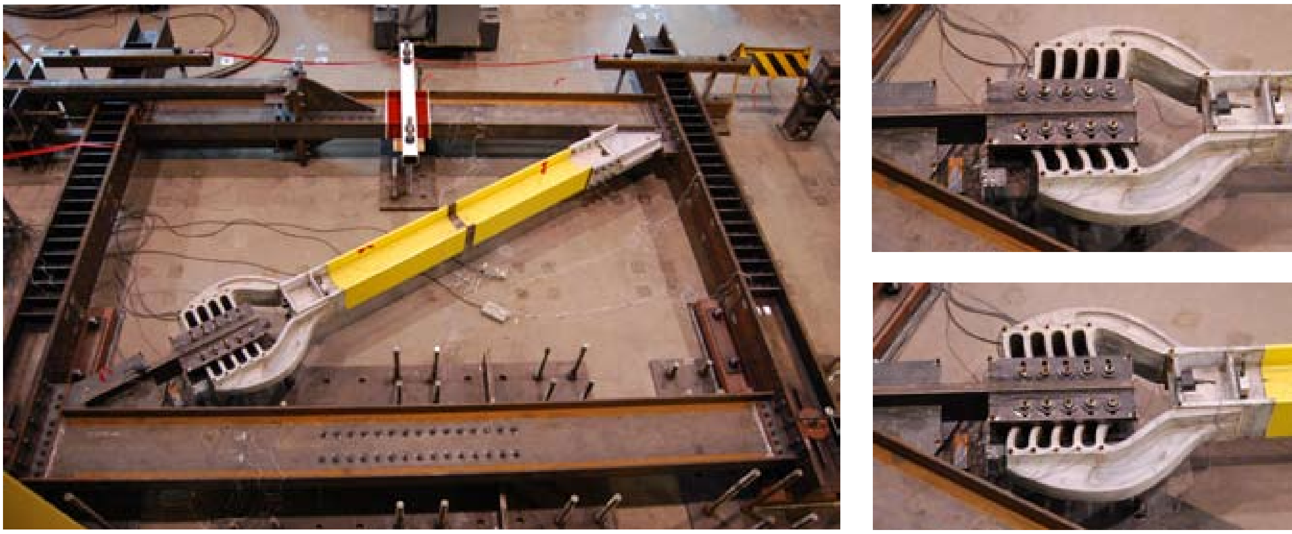


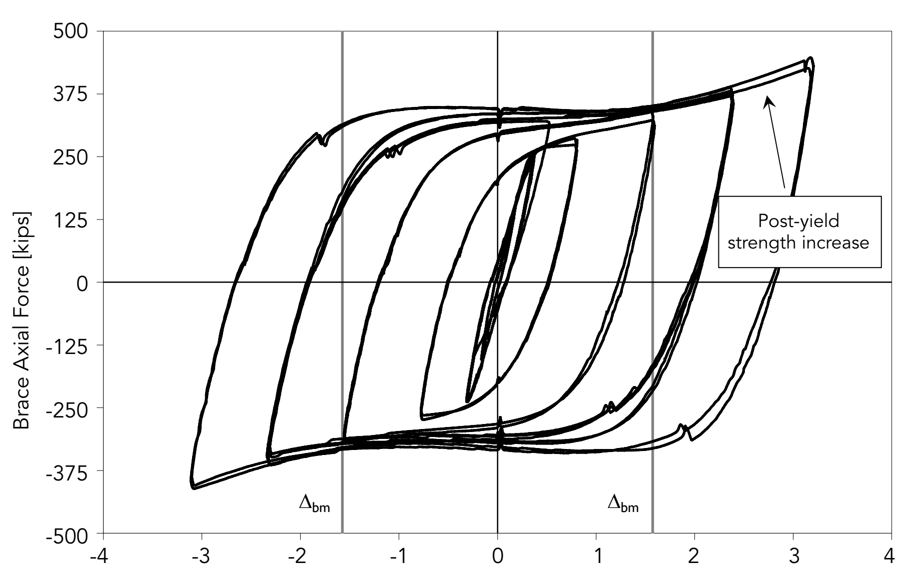
The full-scale test frame at the University of Toronto with the Scorpion brace in the neutral position. A short video of the frame being tested aired on the Discovery Channel and can be viewed at **http://bit.ly/gvji3U**.

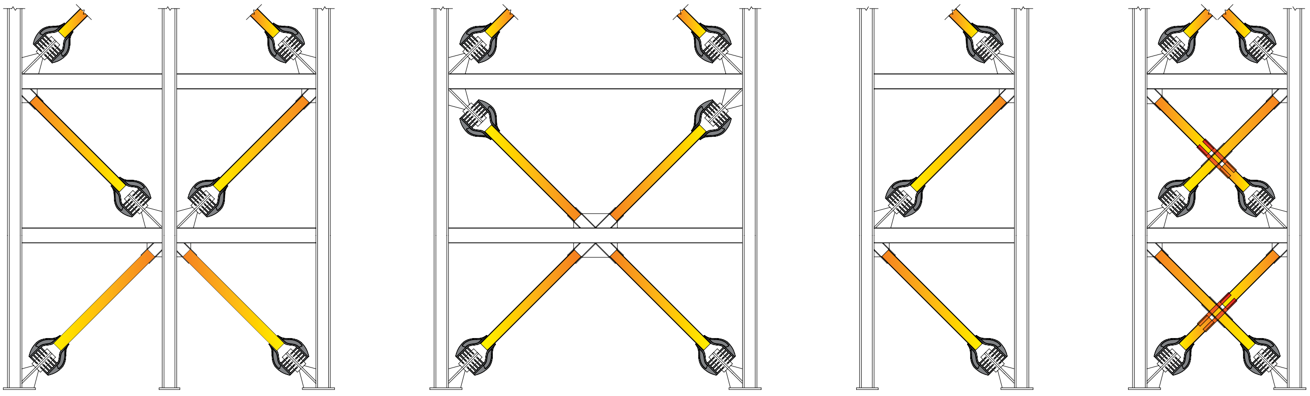
the brace. Consequently, taller buildings and buildings with strict drift requirements often are designed with stronger than necessary braces and thus these structures do not take full advantage of the available ductility of the system. When capacity designing the other structural members of the frame, overdesign of the braces can lead to significantly larger members and thus elevated tonnage and cost.

Engineers employing Scorpion braces avoid this problem because the devices have relatively high elastic stiffnesses in the brace axis direction. Depending upon brace length and the brace section selected, Scorpion braces can be as much as twice as stiff as a buckling-restrained brace of the same activation force. A designer need only select the appropriate connector size to satisfy strength requirements and then use capacity design principles to select an appropriate brace member. The stiffness of the Scorpion brace assembly is easily computed by adding the flexibilities of the connector and the brace, just as one combines stiffnesses for any structural elements in series. If the resulting design does not provide the required stiffness, the designer has the freedom to select a brace member that is stiffer, which will increase the assembly stiffness without changing the yield force of the brace. Thus, stiffness and strength can be independently adjusted to provide the desired structural performance.

An additional benefit of the YBS is its unique post-yield response. As previously noted, at large deformations the YBS exhibits post-yield strengthening and stiffening due to second-order geometric effects. This stiffening behavior allows for a better distribution of yielding in braces over a building's height at large drift levels. In the event that deformations begin to collect in a single story, the system's post-yield stiffening and strengthening will cause braces in adjacent stories to be

A graph of the test hysteresis based on a 1.5-in. brace elongations, Δ_{bm}, shows very full, symmetric loops with distinct post-yield stiffness at large deformations.





▲ Various possible YBS configurations.

activated, thereby reducing the likelihood of the formation of a "soft-story". Neither of these advantages is available in systems that exhibit little or no post-yield stiffness. Further, after a significant seismic event, the yielding fingers of the connectors are fully accessible and can be easily inspected for signs of severe inelastic deformations or damage.

Scorpion connectors are produced through a highly controlled steel casting process that ensures excellent quality control and a high repeatability of geometry and mechanical properties. It is envisioned that each unique connector from the series will be subjected to full-scale structural testing to confirm the mechanical response of the standardized component. Then, the performance of subsequent production components can be assured through non-destructive examination of each part and the physical and chemical testing of steel produced from every heat.

Also For Retrofit

The combination of high stiffness and low activation force also makes the YBS ideal for retrofitting seismically deficient structures. The high elastic stiffness of the system can reduce the drift levels of older building frames while lower activation forces reduce costly remediation of members, connections and foundations. In fact, the YBS is currently being considered for use in the seismic retrofit of a school in the Charlevoix region of Quebec, Canada's most severe seismic region.

Furthermore, because all of the inelasticity in the brace is confined to the Scorpion connectors, engineers using the system have the flexibly to employ a wider range of brace configurations than can be accommodated with other yielding brace systems. For example, a single-bay, single-story X configuration can be employed to reduce the number of frames which are lost or obstructed. In the case of retrofit, this configuration can reduce the cost of the removal and replacement of building envelope and finishes.

For more information regarding the Scorpion YBS including typical details, recommended design level deformations for each connector, or for design assistance, contact AISC member Cast ConneX (www.castconnex.com). MSC