A Solution to Seismic Bracing Restrictions

Expanding the Acceptance of New Large HSS Sections

By John W. Lawson, S.E.

Concentric Braced Frames of steel hollow structural sections (HSS) have a long history of providing efficient designs to resist lateral forces especially in seismic zones. The workhorse material standard, ASTM A500, has provided tubular sections with a good history of performance. However, with the adoption of the 2006 edition of the International Building Code (IBC) in conjunction with the AISC 341-05 *Seismic Provisions for Structural Steel Buildings*, it has become difficult to utilize these sections in taller clear-height buildings and heavily loaded applications due to the current scope of the ASTM A500 standard. Expanding the scope of ASTM A500 to include the thicker wall sections currently being produced will provide engineers more seismically compact sections to choose from and result in more efficient designs.

In the seismically active Western United States, very large distribution/warehouse facilities of 100,000 square-feet to over two-million square-feet incorporate large concentric braced frames. The inverted-V-type bracing configuration, in conjunction with an Ordinary Concentric Braced Frame system (OCBF), has been preferred in the past by allowing material handling flow beneath and simplified bracing connections at the expense of higher design base shear. *Figure 1* was taken last year at a facility in Southern California and depicts a completed 1,400,000 square-foot distribution warehouse for a national brand undergarment manufacturer. This large building consists of concrete tilt-up walls with a hybrid panelized flat roof system. The building's interior utilizes large Hollow Structural Sections for the columns (HSS 10x10x0.3125) and for the seismic resisting braced frame diagonals (HSS 14x14x0.500).

With the adoption of the 2006 IBC and referenced AISC 341-05, tubular sections larger than 10 inches no longer meet the new limits for seismically compact sections. For an OCBF as used in this example building, the allowable width/thickness ratio for square bracing members $b/t < 110\sqrt{(F_y)}$ was relatively low under the 1997 UBC through 2003 IBC. For these larger cross-sections, thinner wall sections were permitted under the code and complying HSS members were widely available. In the 2006 IBC, the braces for OCBF and Special Concentric Braced Frames (SCBF) both have a limited width/thickness ratio of $b/t < 0.64\sqrt{(E/F_y)}$ for square and rectangular bracing members.

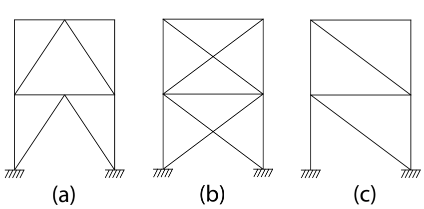

Figure 2: Examples of concentrically braced frames.

The background of this building code change can be traced to the Northridge Earthquake in 1994 and the subsequent width/thickness ratios incorporated into the 1997 UBC. Ongoing research has shown that brace ductility is in large part determined by the prevention of fracture due to local buckling behavior under low cycle fatigue. HSS sections are susceptible to localized buckling. Because both OCBFs and SCBFs are expected to undergo some limited buckling under severe ground motions, the braces are required to meet the special width/thickness ratios for seismic compactness. Unlike compactness defined for gravity shapes where local buckling is prevented before the onset of strain-hardening, seismic compactness provides resistance to local buckling when stressed into the inelastic range.

Initially, a new width/thickness ratio limit was applied only to SCBF by the adoption of IBC 2003, but because SCBFs require special detailing and because large sections meeting the seismic compactness criteria were not available, heavily loaded and larger clear-height buildings continued to use OCBFs. X-type bracing configurations (*Figure 2b*) were avoided due to perceived erection complexity, the larger number of connections, and brace obstruction closer to floor level. Until recently, the inverted-V-type configurations (*Figure 2a*) have been preferred in single story large clear height buildings.

Researchers cautioned that Hollow Structural Sections (HSS) under seismic loading should be avoided unless more restrictive seismic compactness limitations were adopted. Under the 2006 IBC (AISC 341-05), width/thickness ratios for OCBFs now are identical to SCBF systems. The use of HSS under gravity and wind loading was unaffected by these changes.

Figure 1: Large HSS shapes have been common in braced frames in the seismically active western United States. Expanding the scope of ASTM A500 will allow use of these shapes that already comply with the new seismic compactness requirements.

An unexpected consequence of the more restrictive width-to-thickness ratio is the elimination of all HSS sections larger than 10 inches square for use in concentric braced frames. Currently, only ASTM A500 sections are available for square braces in seismic applications. Because the current ASTM A500 standard limits its scope to a maximum wall thickness of approximately ⅝ inch, 12-inch, 14-inch and 16-inch square sections are unable to comply with seismic compactness, despite thicker walled sections being available from Japan.

One Japanese manufacturer, Nippon Steel & Sumikin Metal Products Co., Ltd (NSMP), is producing large HSS products and exporting them to the United States. According to Masao Sonoda, General Manager of Building Products Development, NSMP is regularly producing 12-, 14-, 16-, 18-, 20- and 22-inch square sections with 0.750-inch and 0.875-inch wall thicknesses. As *Table 1* shows, these large HSS with thicker walls could give structural engineers a new tool to comply with the tighter restrictions under the 2006 IBC. By providing heavier walls, 12- and 14-inch square sections can once again be used for concentric seismic bracing to accommodate heavy loads or long bracing situations.

In gravity or wind loading situations where braces or columns are not required to be seismically compact, cross sections larger than 16-inch square may be desired; however, ASTM A500's scope currently limits section perimeters of 64 inches or less. While not yet being produced by North American steel manufacturers, Japan's NSMP is manufacturing 18-, 20- and 22-inch square sections that could comply with ASTM A500 if the Standard's scope were to expand. Without being subject to the special seismic compactness restrictions, these extra large HSS shapes provide many additional opportunities for architects and engineers.

In an effort to continue providing concentric braced frames in large clear-height buildings, some engineers have experimented with using round pipes (HSS16x0.625) as a substitute, but it is difficult to obtain seismically complying material. And, the reduced radius of gyrations in these sections increases the slenderness and thus restricts their use to shorter applications.

Another unorthodox option is to fill the 12-, 14- and 16-inch tubes with concrete to stabilize their walls. However, in addition to the extra material costs, it is undesirable to bring a concrete subcontractor back out to the job so late in the process and pump concrete upwards of 40 feet.

A better approach to the conflict between the current ASTM A500 standard and AISC's compactness limitations is to expand the standard's scope of regulation. Currently, there are applications where these large HSS sections are being used despite being outside the dimensional scope of ASTM A500 but equivalent in quality. At the current time, some US service centers have started to stock them in their warehouses for limited uses.

Unfortunately, ASTM A500 currently regulates its scope to "total periphery up to 64 inches, wall thickness up to 0.625 inches". An increase in this standard's scope would once again provide a larger range of bracing sections available for engineers to utilize. At this time, NSMP has submitted a proposal to ASTM to expand the dimensional scope to 88-inch periphery and 0.875-inch wall thickness. With the opportunity for foreign and domestic producers to supply larger, thicker HSS material complying with ASTM A500, more efficient structural systems can provide tall, open spaces as well as accommodate heavily loaded seismic bracing conditions.▪

Table 1: Seismic Compactness.

Size (in.)	Nominal Wall thickness (in.)					
	0.250	0.375	0.500	0.625	0.750	0.875
4 x 4	OK	OK	OK			
6 x 6	×	OK	OK			
8 x 8	×	×	OK	OK		
10 x 10	×	×	×	OK		
12 x 12	×	×	×	×	OK	
14 x 14		×	×	×	×	OK
16 x 16		×	×	×	×	×
18 x 18			×	×	×	×
20 x 20			×	×	×	×
22 x 22					×	×

Shaded areas indicate availability, but not meeting the scope of ASTM A500.

Compactness Requirements:

Width/Thickness Ratio = b/t

(1) Earthquake loading:

$b/t < 0.64\sqrt{(E/F_y)}$ Seismically Compact

(2) Gravity, Wind loading:

$b/t < 1.12\sqrt{(E/F_y)}$ Compact

E= Young Modulus F_y=Yield Strength

t = 0.93 times the nominal wall thickness

b = the clear distance of flat portion between corners.

The outside corner radius equates to 1.5 times of the wall thickness.

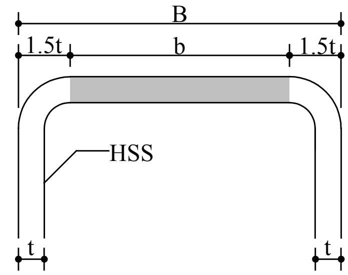

Figure 3.

*John W. Lawson S.E. is a practicing Structural Engineer and Assistant Professor in the Architectural Engineering Department at California Polytechnic State University, San Luis Obispo. He can be reached at **jwlawson@calpoly.edu**.*