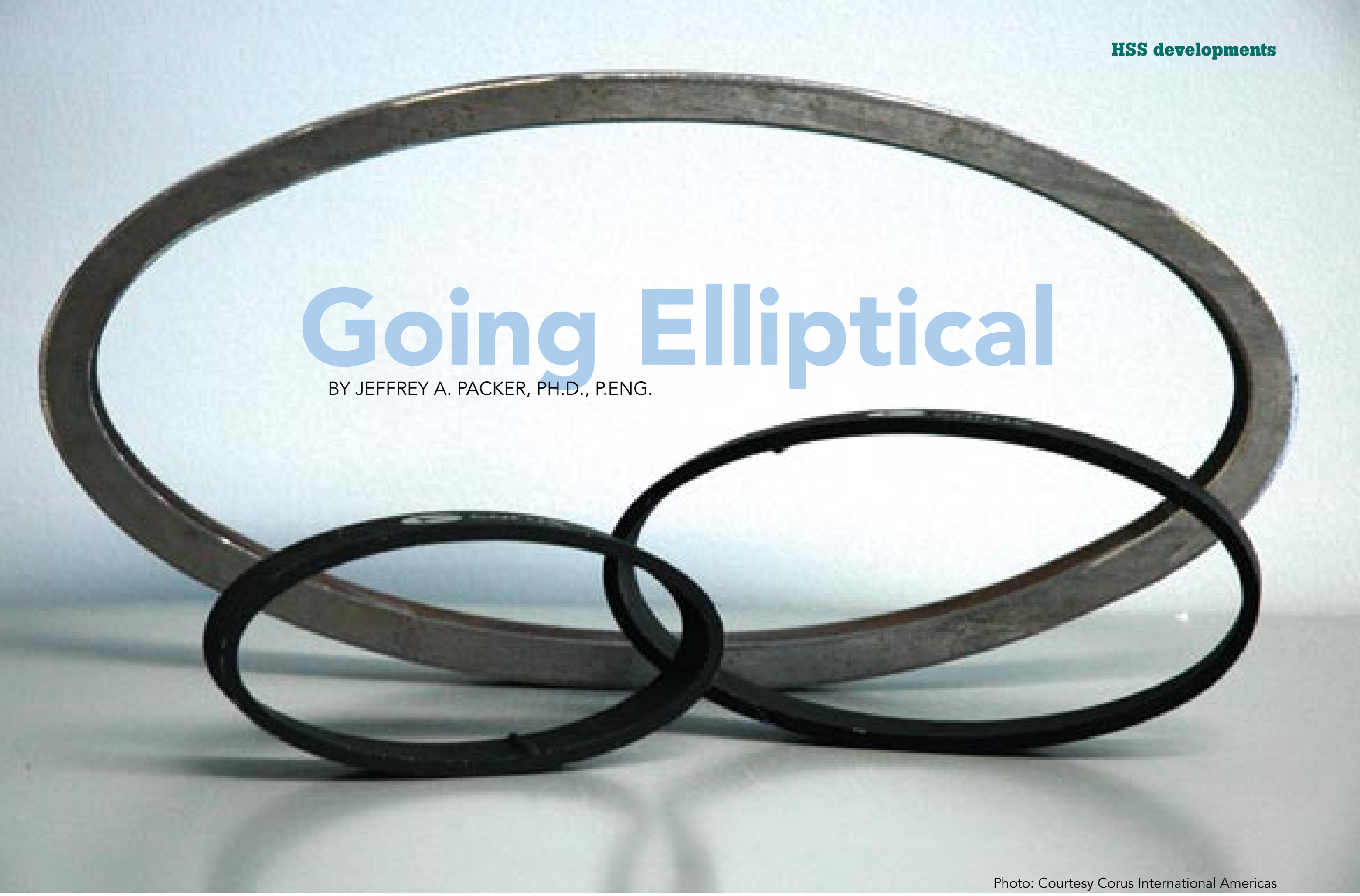

Going Elliptical

BY JEFFREY A. PACKER, PH.D., P.ENG.

Photo: Courtesy Corus International Americas

Elliptical hollow sections are making inroads in North America, and experts worldwide are making efforts to promote this latest of HSS types.

LIKE ANY OTHER FAMILY, the hollow structural section family has grown over the years. It began with circular shapes, and then expanded to square and rectangular sections.

The newest member is the elliptical hollow section (EHS). It was introduced in France in 1994 by Tubeurop (which has since become a part of Arcelor Tubes, which in turn has since become a part of Condesa), along with its companion section, semi-elliptical (D-shaped). These shapes are now produced by other companies as well, including Corus in the UK—under the label Celsius 355 Ovals—and Ancofer Stahlhandel GmbH (Germany).

Gaining Momentum

The elliptical product has grown progressively in stature, with architects employing these sections in numerous structures with exposed steelwork for aesthetic purposes. EHS have greater bending capacity than circular hollow sections (CHS) of the same area or weight, due to having strong and weak axis directions, but still maintain a smooth closed shape. There is also reduced visual intrusion compared to CHS, if the member is viewed from one common direction. The principal application of EHS has been as structural supporting members for glass roofs and glass façades. Other applications include columns, electricity transmission line pylons, pedestrian bridges, and wind turbine masts.

Examples of all of these applications are spread across Europe, but the shape has made the trip across the Atlantic as well. In Canada, EHS columns have already been employed in two structures, both of which have won design awards: the skylight of the Electronic Arts stair in Vancouver and the Legends Centre in Oshawa, Ontario.

EHS are produced, with major-to-minor outside dimensions of 2:1, as hot-formed hollow structural sections to EN 10210 (CEN 2006a, 2006b). They are commonly available in the grade S355J2H, which has a minimum yield strength of 355 MPa (about 50 ksi) up to 16 mm (0.63 in.) wall thickness and a Charpy impact resistance of 27 Joules at -20 °C.

Being manufactured only via the hot-finishing process, EHS thus meet CAN/CSA-G40.20-04/G40.21-04 (2004) Class H or ASTM A501 (2001) in North America. Hence, they inherently have minimal residual stresses, excellent welding capability, and inherent toughness. As a mark of their acceptance into the community of structural sections, the most recent (2006) European production standard for hot-formed structural hollow sections (CEN 2006a, 2006b)

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This test sample of an EHS failed by local buckling.

includes EHS in the scope, with formulae for section properties and calculated values for EHS ranging from 120 mm by 60 mm by 3.2 mm (4.75 in. by 2.36 in. by 0.125 in.) to 500 mm by 250 mm by 16.0 mm (19.7 in. by 10 in. by 0.63 in.). As for other hollow sections produced to EN 10210, there is a -10% tolerance on thickness and a ±6% tolerance on mass. The outside dimension tolerance is ±1%, with a minimum of ±0.5 mm (0.02 in.), except this tolerance may be doubled for EHS with a major axis dimension less than 250 mm (10 in.).

Such noncorporate publication of mechanical and geometric properties will serve to increase the market and utilization of EHS. However, their use has been hindered by a lack of other structural engineering design guidance—in particular, section classification information. This very fundamental deficiency has recently been tackled in the UK. On the basis of experimental and numerical (finite element) studies at Imperial College, London, and University of Southampton, experts L. Gardner, T.M. Chan, and A. Ministro have classified EHS into Classes 1,2,3 and 4 (per Eurocode 3, CEN 2005) with limiting wall slenderness ratios for various aspect ratios. Their system for cross-section classification covered all loading cases: axial compression, bending about both principal axes, and combined compression plus bending. The Eurocode 3 class limits for CHS were shown to be applicable to EHS, but using new proposed cross-section slenderness parameters with an EHS "effective diameter," D_e, defined by:

$D_e = 2(a^2/b)$ for axial compression and minor axis bending (Equation 1), and

$D_e = 1.3(a^2/b)$ for major axis bending, with aspect ratios of 2:1 (Equation 2)

where
a = half the larger EHS dimension
b = half the smaller EHS dimension

Y. Zhu and T. Wilkinson in Australia also independently proposed Equation 1 for the load case of axial compression, based on finite element models calibrated against EHS stub column tests performed in Canada. Interestingly, Gardner at Imperial College now aims to extend his EHS section classification work to stainless steel EHS, which have also recently become available as structural sections.

Connections always represent a potential problem in tubular construction due to the high flexibility of the hollow section walls, and only recently have there been any studies on welded EHS connections. Bortolotti et al. (2003) and Pietrapertosa and Jaspart (2003) in Liège, Belgium performed the first laboratory tests on truss-type N- and X- connections, with EHS branches welded to the wide side of the EHS chord, followed by numerical modeling of the same connections. Choo et al. (2003) in Singapore extended the finite element modeling of EHS-to-EHS X-connections by studying branches welded to both the wide and narrow sides of the chord, and with the branch also oriented in both orthogonal directions for each chord orientation. They concluded that … "with appropriate orientations of the elliptical brace and chord sections, axially loaded EHS X-joints can provide higher strength than CHS joints with the same brace and chord sectional areas."

A recent study in Canada on EHS connections consisted of gusset plates and through plates (both longitudinal and transverse) welded to both the wide and narrow sides of an EHS chord (Willibald et al. 2006b). In the analysis of these tests, the notion of using EHS dimensions in established formulae for CHS and RHS connections was attempted, as had also been tried by Bertolotti et al. (2003). The design of CHS and RHS welded connections is now based on over 40 years of international research, so the prospect of repeating this research volume for EHS members is daunting—hence the quest to relate EHS connection design to other established design procedures for hollow steel sections.

Finally, if EHS members are used as diagonal bracings in braced steel frames, or as truss web members connected via gusset plates to the truss chord, a convenient and simple connection method can be achieved by slotting the gusset plate into the EHS member end, or by inserting the EHS into a slotted gusset plate. Both of these connection options have been studied, both experimentally (Willibald et al. 2006a) and numerically (Martinez-Saucedo et al. 2005). Simple design procedures for these connection types, based on the limit state of circumferential fracture of the EHS induced by shear lag, and on the limit state of tear out (block shear) of the EHS, have recently been advocated (Martinez-Saucedo and Packer 2006). MSC

References

ASTM. 2001. "Standard specification for hot-formed welded and seamless carbon steel structural tubing," ASTM A501-01, ASTM International, West Conshohocken, Pa., U.S.A.

Bortolotti, E., Jaspart, J.P., Pietrapertosa, C., Nicaud, G., Petitjean, P.D., Grimmault, J.P. and Michard, L. 2003. "Testing and modelling of welded joints between elliptical hollow sections," 10th. International Symposium on Tubular Structures, Madrid, Spain, Proceedings pp. 259-264.

CEN. 2005. "Eurocode 3: Design of steel structures – Part 1-1: General rules and rules for buildings," EN 1993-1-1:2005(E), European Committee for Standardization, Brussels, Belgium.

CEN. 2006a. "Hot finished structural hollow sections of non-alloy and fine grain steels – Part 1: Technical delivery conditions," EN 10210-1:2006(E), European Committee for Standardization, Brussels, Belgium.

CEN. 2006b. "Hot finished structural hollow sections of non-alloy and fine grain steels – Part 2: Tolerances, dimensions and sectional properties," EN 10210-2:2006(E), European Committee for Standardization, Brussels, Belgium.

Chan, T.M. and Gardner, L. 2006. "Experimental and numerical studies of Elliptical Hollow Sections under axial compression," 11th. International Symposium on Tubular Structures, Québec City, Canada, Proceedings pp. 163-170.

Choo, Y.S., Liang, J.X. and Lim, L.V. 2003. "Static strength of elliptical hollow section X-joint under brace compression," 10th. International Symposium on Tubular Structures, Madrid, Spain, Proceedings pp. 253-258.

CSA. 2004. "General Requirements for rolled or welded structural quality steel/structural quality steel," CAN/CSA-G40.20-04/G40.21-04, Canadian Standards Association, Toronto, Canada.

Gardner, L. and Chan, T.M. 2006. "Cross-section classification of elliptical hollow sections," 11th. International Symposium on Tubular Structures, Québec City, Canada, Proceedings pp. 171-177.

Gardner, L. and Chan, T.M. 2007. "Cross-section classification of elliptical hollow sections," *Steel & Composite Structures*, in press.

Gardner, L. and Ministro, A. 2004. "Testing and numerical modelling of structural steel oval hollow sections," Research Report No. 04-002-ST, Imperial College, London, U.K.

Martinez-Saucedo, G. and Packer, J.A. 2006. "Slotted end connections to hollow sections," CIDECT Report 8G-1%6, University of Toronto, Canada.

Martinez-Saucedo, G., Packer, J.A., Willibald, S. and Zhao, X.L. 2005. "Finite element modelling of gusset plate-to-tube slotted connections," 33rd. Annual General Conference of the Canadian Society for Civil Engineering, Toronto, Canada, Proceedings paper GC-115.

Pietrapertosa, C. and Jaspart, J.-P. 2003. "Study of the behaviour of welded joints composed of elliptical hollow sections," 10th. International Symposium on Tubular Structures, Madrid, Spain, Proceedings pp. 601-608.

Willibald, S., Packer, J.A. and Martinez-Saucedo, G. 2006a. "Behaviour of gusset plate connections to ends of round and elliptical hollow structural section members," *Canadian Journal of Civil Engineering*, Vol. 33, pp. 373-383.

Willibald, S., Packer, J.A., Voth, A.P. and Zhao, X. 2006b. "Through-plate joints to elliptical and circular hollow sections," 11th. International Symposium on Tubular Structures, Québec City, Canada, Proceedings pp. 221-228.

Zhu, Y. and Wilkinson, T. 2006. "Finite element analysis of structural steel elliptical hollow sections in pure compression," 11th. International Symposium on Tubular Structures, Québec City, Canada, Proceedings pp. 179-186.