24

Steel Design Guide

Hollow Structural Section Connections

Steel Design Guide

24

Hollow Structural Section Connections

JEFFREY PACKER, Ph.D., D.Sc., P.Eng.
University of Toronto
Toronto, Ontario

DONALD SHERMAN, Ph.D., P.E.
University of Wisconsin–Milwaukee
Milwaukee, Wisconsin

MAURA LECCE, Ph.D.
University of Toronto
Toronto, Ontario

AMERICAN INSTITUTE OF STEEL CONSTRUCTION

by

American Institute of Steel Construction

The information presented in this publication has been prepared in accordance with recognized engineering principles and is for general information only. While it is believed to be accurate, this information should not be used or relied upon for any specific application without competent professional examination and verification of its accuracy, suitability and applicability by a licensed professional engineer, designer or architect. The publication of the material contained herein is not intended as a representation or warranty on the part of the American Institute of Steel Construction or of any other person named herein, that this information is suitable for any general or particular use or of freedom from infringement of any patent or patents. Anyone making use of this information assumes all liability arising from such use.

Caution must be exercised when relying upon other specifications and codes developed by other bodies and incorporated by reference herein since such material may be modified or amended from time to time subsequent to the printing of this edition. The Institute bears no responsibility for such material other than to refer to it and incorporate it by reference at the time of the initial publication of this edition.

Printed in the United States of America

Authors

Jeffrey Packer, Ph.D., D.Sc., P.Eng., is a Bahen/Tanenbaum Professor in Civil Engineering at the University of Toronto. He has a bachelor's degree from the University of Adelaide, Australia (1972), a master's degree from the University of Manchester, U.K. (1975), and doctorates from the University of Nottingham, U.K. (1978, 2006). His research and publications have concentrated on the behavior and design of hollow structural section (HSS) connections.

Donald Sherman, Ph.D., P.E., is professor emeritus at the University of Wisconsin–Milwaukee. He has bachelor's and master's degrees from Case Institute of Technology (1957, 1960) and a Ph.D. from the University of Illinois (1964). His research and publications include HSS member behavior and simple connections to HSS columns.

Maura Lecce, Ph.D. is a postdoctoral fellow at the University of Toronto. She has bachelor's and master's degrees from the University of Toronto (2000, 2001) and a Ph.D. from the University of Sydney, Australia (2006). Her research and publications include HSS connections and stainless steel light gage members.

Preface

This Design Guide is a supplement to the 13th edition of the American Institute of Steel Construction (AISC) *Steel Construction Manual* and its companion CD. The *Manual* contains sections on bolting to hollow structural sections (HSS), welding considerations for HSS, simple shear connections to HSS columns, fully restrained moment connections to HSS columns, and design considerations for HSS-to-HSS truss connections. The companion CD has seven examples of simple shear connections to HSS columns. Therefore, this Guide does not have a chapter on simple shear connections. The CD also has examples of a transverse plate on a rectangular HSS, a longitudinal plate on a round HSS, and HSS braces with end gusset plates, as well as examples of the design of cap plates, base plates and end plates on HSS members.

The examples in this Guide conform to the 2005 AISC *Specification for Structural Steel Buildings.* Both load and resistance factor design (LRFD) and allowable strength design (ASD) solutions are presented. References are given to applicable sections of the *Specification* and to design tables in the *Manual.* This Guide contains a few additional tables that are applicable to HSS connections. It is recommended that readers of this Guide first become familiar with the *Specification* provisions for HSS connections and the accompanying *Specification Commentary.*

Some of the material in this Guide is based on the AISC *Hollow Structural Sections Connections Manual* published in 1997. However, because the AISC Specification has evolved from that in effect in 1997, the 13th edition *Manual* and this Guide supersede the previous *HSS Manual.*

Chapter K of the *Specification* presents the criteria for forces (axial force, in-plane moment and out-of-plane moment) in branch members framing into a main member. In this Guide, these same equations appear in a tabular format with drawings showing the connection configuration. This format is easier to follow than the descriptive text in the *Specification.* The design examples of direct HSS-to-HSS connections refer to both the appropriate tables in this Guide and the *Specification* equations.

Table of Contents

Chapter 1
Introduction

In recent years, the popularity of hollow structural sections (HSS) has increased dramatically. The pleasing aesthetic appearance generated by architecturally exposed hollow sections is much favored by architects, and HSS also can provide reduced weight and surface area when compared to equivalent open sections. Some stunning examples of exposed HSS in building interiors are shown in Figure 1-1.

Connections usually have been the challenging aspect for the designer of structures that involve HSS. This AISC Design Guide demonstrates design methods for a wide range of connection types. Note that, in many cases, the local strength of the HSS at the connection is an integral part—and perhaps a limitation—of the design. Moreover, note that reinforcing the connections of HSS assemblies often is not an available option, for either architectural or fabrication reasons.

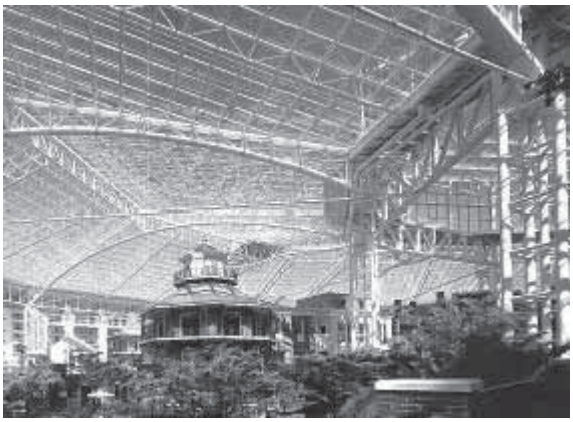
1.1 HSS AND BOX-SHAPED MEMBERS

HSS manufactured according to American Society for Testing and Materials (ASTM) standard A500 (ASTM, 2007a) are cold-formed in tube mills, and have an electric resistance welded (ERW) continuous seam weld. This "weld" is produced without the addition of any additional consumable. The weld bead on the outside is always removed, but the weld bead that results on the inside of the HSS is generally left in place. However, this inside weld bead can be removed at the point of manufacture if this requirement is specified to the tube mill; this may be desirable if one HSS is inserted into another, for example with telescoping poles.

Round, square and rectangular HSS produced in accordance with the ASTM A500 Grade B standard are readily available throughout North America. Rectangular HSS are also frequently termed "shaped" sections. ASTM A500 Grade C is increasingly available, and many HSS products are now dual-certified as meeting the requirements in both ASTM A500 Grade B and Grade C. The relative material strengths of these ASTM A500 HSS are shown in Table 1-1. Note that a particular grade has different yield strengths for round versus rectangular shapes.

In some parts of the United States, various pipe products are readily available and used in lieu of round HSS. ASTM A53 (ASTM, 2007c) Grade B pipe, which is included in the American Institute of Steel Construction (AISC) *Specification for Structural Steel Buildings,* hereafter referred to as the AISC *Specification* (AISC, 2005a), has a lower yield strength than its ASTM A500 counterpart (see Table 1-1). All load tables in the 13th edition AISC *Steel Construction Manual,* hereafter referred to as the AISC *Manual* (AISC, 2005b), for HSS are based on ASTM A500 Grade B strengths, and the load tables for pipe use ASTM A53 Grade B strengths.

Other North American HSS products that have properties and characteristics similar to the approved ASTM products are produced in Canada (CSA, 2004). This standard allows for two types of finished product: Class C (cold-formed) and Class H (cold-formed and stress relieved by heat treatment). Class H HSS have reduced levels of residual stress, which enhances their performance as compression members and may provide better ductility in the corners of rectangular HSS.



(a) Opryland Hotel, Nashville, Tennessee.

(b) Interior of Rock and Roll Hall of Fame, Cleveland, Ohio.

Fig. 1-1. Contemporary examples of HSS in construction.

Table 1-1. North American Manufacturing Standards for HSS with Mechanical Properties of Common Grades					
Product	**Specification**		**Grade**	**F_y, ksi (MPa)**	**F_u, ksi (MPa)**
Cold-formed HSS	ASTM A500	Round	B	42 (290)	58 (400)
			C	46 (315)	62 (425)
		Rectangular	B	46 (315)	58 (400)
			C	50 (345)	62 (425)
Pipe	ASTM A53		B	35 (240)	60 (415)
Hot-formed HSS	ASTM A501		B	50 (345)	70 (483)
Cold-formed and cold-formed stress-relieved HSS	CAN/CSA-G40.20/G40.21		350W	51 (350)	65 (450)

It should also be noted that very large diameter tubular sections are available to American Petroleum Institute (API) specifications; many different grades are available, and specified outside diameters range from 0.405 in. to 84 in. (API, 2007).

The designation used to identify square and rectangular HSS is, for example:

HSS8×4×¼

In this designation, the whole numbers are the height and width, and the fraction is the nominal thickness. Decimal numbers are used for the outside diameter and nominal thickness in the designation of round HSS, for example:

HSS6.000×0.375

The designation for pipe is a traditional form for three grades, including:

Standard; Std.
Extra Strong; x-strong
Double Extra Strong; xx-strong

The diameter designated for pipe is a nominal value between the specified inside and outside diameters, for example:

Pipe 8 x-strong

The dimensions and geometric properties of HSS and pipe are included in Part 1 of the AISC *Manual* in the following tables:

Table 1-11: Rectangular HSS
Table 1-12: Square HSS
Table 1-13: Round HSS
Table 1-14: Pipe

Dimensional tolerances of the products are also included in the following tables:

Table 1-27: Rectangular and Square HSS
Table 1-28: Round HSS and Pipe

The ASTM cold-formed material standard tolerances permit the wall thickness to be 10% under the nominal wall thickness. Consequently, the mills consistently produce HSS with wall thicknesses less than the nominal wall thickness. Section B3.12 in the AISC *Specification* accounts for this by designating a design wall thickness of 0.93 times the nominal thickness. The design wall thickness is included in the tables of dimensions and properties in the AISC *Manual,* and all properties (*A, D/t, I, Z, S, etc.*) are based on the design wall thickness.

Round, square and rectangular HSS manufactured according to the ASTM A500 standard are available in perimeters up to 64 in. and in thicknesses up to ⅝ in. Larger sizes in square and rectangular sections are classified as box-shaped members in the AISC *Specification.* A standard product line of these box sections up to 128-in. perimeter is produced by placing two flat strips in a brake press to form two identical halves of a finished tube size. A backing bar is tack welded to each leg of one of the half sections. Then, the two half sections are fitted together toe-to-toe and submerged arc welded together to complete the square or rectangular section. These sections are produced with the full nominal thickness so that the design wall thickness of 0.93*t* does not apply.

The standard sizes of HSS and larger box-shaped members produced appear in HSS availability listings on the AISC website (www.aisc.org) and periodically in AISC's *Modern Steel Construction* magazine. Tables of dimensions and section properties for larger box-shaped members can be obtained from the manufacturer.

The ASTM A501 standard (ASTM, 2007b) for hot-formed tubing is included in the AISC *Specification* even though these products have not been produced in North America for several decades. However, ASTM A501 has recently been revised to add Grade B, which is a hot-finished product with the mechanical properties shown in Table 1-1. The manufacturing process is similar to cold-formed HSS, but the final shaping and sizing are completed after the steel has been heated to a full normalizing temperature. These products are made by European manufacturers in round, square, rectangular and elliptical shapes (Packer, 2008). Such sections are essentially produced to the European standard EN10210 Parts 1 and 2 (CEN, 2006a, 2006b), and the elliptical hollow sections have a major-to-minor axis dimension ratio on the order of 2:1.

Sections up to 16-in. square and 0.625-in. thick are produced with ERW seams and are available in several sizes. There is also a product line of jumbo HSS in sizes up to 32-in. square and thicknesses up to 2.36 in. For thicknesses up to 1 in., the sections are manufactured with ERW seams. For greater thicknesses, submerged arc welding (SAW) is used for the seams. SAW box sections can be produced from plate material (such as ASTM A572 Grade 50 as used in Example 3.3), but they generally are of a size that exceeds the 64-in. periphery limitation in ASTM A500. As such, these cross sections do not necessarily meet the requirements in ASTM A500. The specifier should contact the producer(s) of such cross sections to determine the cross sections that are made, as well as their cross-sectional properties and applicable production requirements. This information is also available in the EN10210 standard (CEN, 2006a, 2006b).

1.2 HSS CONNECTION DESIGN STANDARDS AND SCOPE

The 2005 AISC *Specification* supersedes all previous AISC Specifications, including the 1999 *Load and Resistance Design Specification for Structural Steel Buildings* (AISC, 1999), the 1989 *Specification for Structural Steel Buildings – Allowable Stress Design and Plastic Design* (AISC, 1989) including Supplement No. 1, and the 2000 *Load and Resistance Factor Design Specification for Steel Hollow Structural Sections* (AISC, 2000). Direct HSS-to-HSS welded connections are now covered in Chapter K of the 2005 AISC *Specification.* Framing connections use the criteria in Chapter K for concentrated loads and applicable portions of Chapter J for welding, bolting and connecting elements. Some aspects of HSS connection design, such as prying action, do not appear directly in the AISC *Specification,* but use guidelines from the AISC *Manual* or published research.

The scope of the AISC *Specification,* and hence this Design Guide, for HSS connections is limited to:

- Static design
- Single planar design
- Symmetry perpendicular to the plane (no offset elements)
- Unfilled and unreinforced HSS

Guidelines for conditions outside the scope of the AISC *Specification* appear in other codes and design guides:

- Fatigue (AWS, 2008; Zhao et al., 2001)
- Seismic design (Kurobane et al., 2004)
- Multiplanar connections (AWS, 2008; Packer and Henderson, 1997)
- Offset connections (AWS, 2008)
- Connections to concrete-filled HSS (Kurobane et al., 2004)

1.3 ADVANTAGES OF HSS

HSS are very efficient sections for torsion and compression loading. For compressive loading, this is due to the favorable weak-axis radius of gyration, which often controls the available compressive strength.

It is not possible to make direct cost comparisons with other shapes because prices vary with time, application and geographic location. However, Table 1-2 compares two of the key factors that influence cost: weight and surface area that may require some type of preparation. The comparisons are between ASTM A992 wide-flange shapes, ASTM A500 Grade B round HSS, and ASTM A500 Grade B square HSS. Sections are selected for a particular length and load using AISC *Manual* Tables 4-1, 4-4 and 4-5. The load and resistance factor design (LRFD) load is 1.5 times the allowable strength design (ASD) load, and because this is the calibration load ratio in the AISC *Specification,* the same sections are determined in LRFD and ASD. The selected sections have comparable depths and available strengths. Data is provided for two cases: a compression member with moderate length (KL = 16 ft) and load, and a longer compression member (KL = 32 ft) with a higher load.

The wide-flange section is used as the basis for comparison and is assigned 100% for weight and surface area. It is apparent from Table 1-2 that these example HSS are 10 to 20% lighter than the corresponding wide-flange members, and have one-third to one-half less surface area. The latter is particularly influential for decreasing painting costs. Moreover, one should also bear in mind that this section comparison is performed using ASTM A500 Grade B material, which is readily available. If ASTM A500 Grade C material (with higher yield strength) were used, the advantage is even greater.