The Future of HSS Connection Design

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Chapter K of the 2005 specification represents a dramatic advance in recommendations for the design of HSS and box member connections.

When the HSS *Connections Manual* was published in 1997, it ushered in a new era in the use of hollow structural connections in the U.S. Now, with the inclusion of Chapter K ("Design of HSS and Box Member Connections") in the new 13th Edition *Steel Construction Manual*, every designer will have ready access to the information.

At this year's NASCC: The Steel Conference, Jeffrey A. Packer, one of the world's leading experts on tubular steel structures and a professor at the University of Toronto, and AISC Regional Engineer Tabitha S. Stine, presented a paper on "HSS Connection Design After 2005." The following information was gleaned from that paper. AISC members can view the full paper, which includes a discussion of ongoing research, at no charge by visiting www.aisc.org/bookstore after February 15.

CHAPTER K OF THE 2005 SPECIFICATION HAS BEEN COMPLETELY REWRITTEN. Dedicated solely to the design of HSS and box member connections, it covers member strength design considerations pertaining to members of uniform wall thickness. The additional requirements of bolting to HSS members are covered in Chapter J, "Design of Connections."

Concentrated Forces on HSS

The first section of Chapter K deals with concentrated forces on HSS, whether it be point loads from gusset plates of hangers connected to an HSS member or beam flanges (transverse plates) from a moment connection to an HSS column. Step by step, the section first addresses the definition of parameters and then looks at the limits of applicability. For instance:

1. Strength: $F_y \leq 52$ ksi (360 MPa) for HSS
2. Ductility: $F_y/F_u \leq 0.8$ for HSS
3. Other limits apply for specific criteria

The section specifically addresses the criteria for rectangular or round HSS sections with either concentrated forces distributed transversely or concentrated forces distributed longitudinally at the center of the HSS diameter or width, and acting perpendicular to the HSS axis. Sections K1.3 and K1.4, although pertaining to all concentrated forces on HSS, are particularly oriented toward plate-to-HSS welded connections.

Section K1.5 pertains to shear forces acting parallel to the HSS section. Note that over a wide range of connection types that have been tested, only one limit state has been identified: punching shear failure related to end rotation of the beam, when a thick shear plate is joined to a relatively thin-walled HSS. By satisfying the requirement of equation K1-10, where $F_{yp}t_p \leq F_u t$, the punching shear requirement has been satisfied.

The final section of K1 deals with concentrated axial forces on the ends of a rectangular HSS section with a cap plate, K1.6. Two limit states are checked for this situation, wall local yielding due to tension or compressive forces and wall local crippling due to compressive loads only.

HSS-to-HSS Connections

The specification addresses these connections, which are defined as connections that consist of one or more branch members that are directly welded to a continuous chord that passes through the connection. They can be classified as either K (which includes N), Y (which includes T), or cross (also known as X) connections, which are based on the method of force transfer in the connection, not on the physical appearance of the connection. Common examples of particular HSS connection classification are shown in the figure (next page).

Different limit states govern whether the section is a round or rectangular HSS section. The specification begins by stating all limits of applicability, in terms of joint eccentricity, branch angle, chord wall, tension branch wall, compression branch wall slenderness, width ratio, strength, and ductility, just to name a few, for either round or rectangular HSS connections. Based on these parameters all being satisfied, the design strengths can then be calculated based on the specification requirements. In the case of round HSS (section K2.2), depending on the type of classification of the connection, limit

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states for both chord plastification as well as shear yielding (punching) are checked. As with the entire specification, the respective ϕ (LRFD) and Ω (ASD) are given for the specific equations depending on the limit state and connection classification. Section K2.3 addressed the criteria for rectangular HSS sections. Similar limits of applicability apply, and again as these are satisfied, the design strength can be checked. For T-, Y-, and X-connections, the design strength of the branch, ϕP_n, or the allowable strength of the branch, P_n/Ω, shall be the lowest value obtained according to the limit states of chord wall plastification, shear yielding (punching), sidewall strength, and local yielding due to uneven load distribution.

HSS-to-HSS Moment Connections

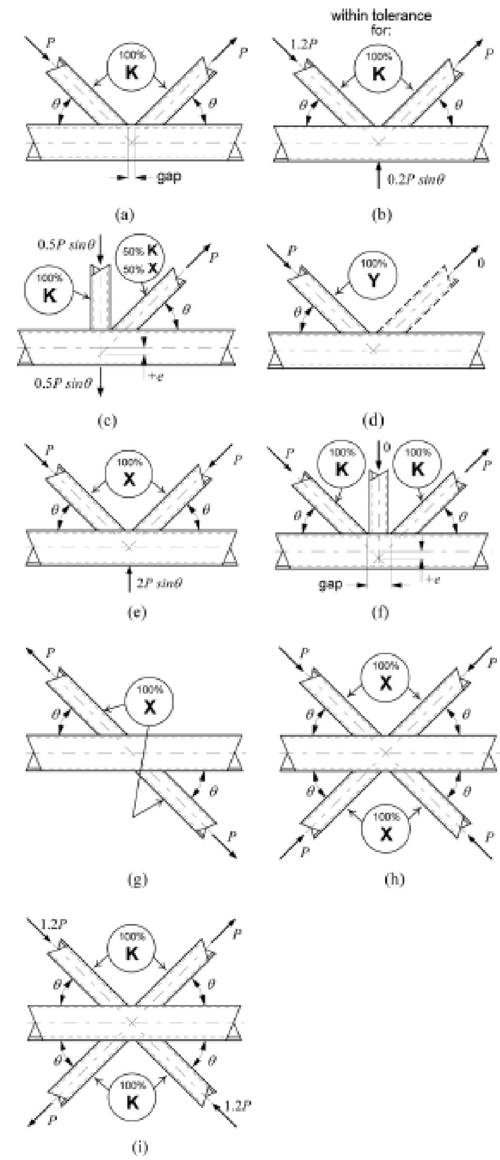
HSS-to-HSS moment connections are defined as connections that consist of one or two branch members that are directly welded to a continuous chord that passes through the connection, with the branches loaded by bending moments. A connection shall be classified as either a T-connection when there is one branch and it is perpendicular to the chord and as a Y-connection when there is one branch but it is not perpendicular to the chord, or as a cross connection when there is a branch on each opposite side of the chord. Note that this section applies to connections under moment loading in frames with PR or FR moment connections, such as Vierendeel girders. These provisions are not applicable to typical planar triangulated trusses. Therefore, K-connections with moment loading on the branches are not covered by this specification.

Other Resources

Note that Chapter K deals only with the static design of particular HSS-to-HSS and plate-to-HSS welded connections for building construction. Other resources provide information on the fatigue design of on-shore HSS welded connections, most notably the draft international standard ISO/WD 14347. It also is anticipated that AWS D1.1 (2008) will provide guidance on fatigue design of HSS welded connections using the "Hot Spot Stress" approach.

Another useful publication is CIDECT's recent 9th design guide on connections to hollow section columns, which covers simple (shear), semi-rigid, and rigid (moment) connections. Of particular note is that this book contains an extensive treatment of wide-flange beam-to-HSS column connections for seismic applications. The connection methods utilize through diaphragms or external diaphragms welded to the column, which are popular in Japan, yet meet FEMA (2000a) Design Criteria. The improved details recommended are equivalent to pre-qualified connections conforming to the FEMA (2000b) Acceptance Criteria.

Fire resistance is a very popular issue at the moment and CIDECT has released software to evaluate the fire stability of unprotected concrete-filled hollow section columns. The program, produced in France by CTICM, is called "Potfire" and is a free download from **www.cidect.com**. Although calculations are performed in accordance with the Eurocodes and a standard ISO fire, it serves as a good indicative fire resistance check for a variety of composite columns.

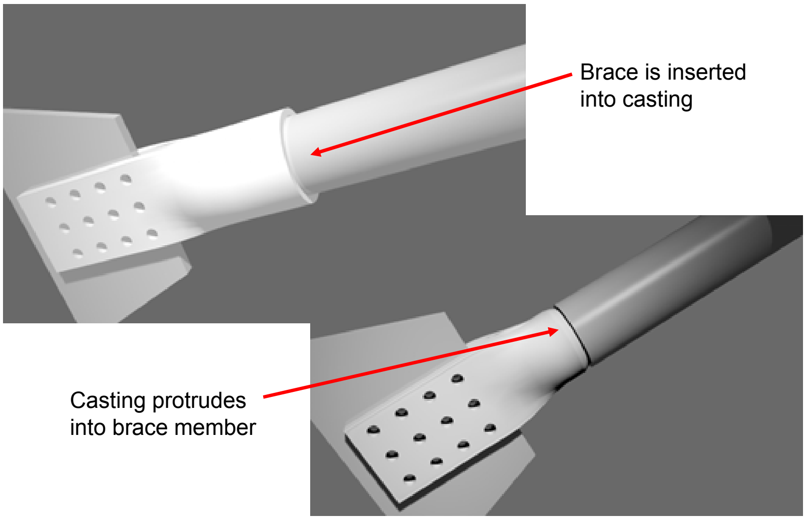


Common HSS connection classifications.

What About Cast Connections?

Cast steel joints have enjoyed a renaissance in Europe in conjunction with tubular steel construction, mainly as truss-type nodes in dynamically-loaded pedestrian, highway, and railway bridges where fabricated nodes would have been fatigue-critical. Another popular application has been in tree-like tubular roof structures where the smooth lines of a cast node have great architectural appeal. The use of cast steel connectors to tubular braces under severe seismic load conditions has not been considered, but cast steel connections represent a solution to the design dilemma of fabricated bracing member connections. These can be specially shaped to provide material where it is particularly needed. Types currently under investigation at the University of Toronto are shown in the figure, right. By mass-producing cast end connectors to suit popular round HSS bracing member sizes, an economic and aesthetic solution can be reached that still allows the use of regular HSS members and avoids the use of alternatives like buckling-restrained braces. This represents another exciting development that can be anticipated in tubular steel construction.

Further research on cast steel nodes, oriented to wide-flange beam-to-column moment connections and primarily for seismic applications, is also underway at present at the University of Arizona. Another innovative connection solution for wide flange beam-to-HSS columns has been launched by California-based ConXtech Inc., termed the SMRSF. With this, a pre-engineered collar connection is fitted around 4" or 8" square HSS columns and bolted together on site, resulting in very fast construction times. Although it uses machined components that are shop-welded in place, rather than cast components, this connection is also prequalified for use as a fully restrained Special Moment Resistant Frame connection under the latest FEMA and AISC seismic provisions. Novel connection solutions such as these herald a potential paradigm shift in HSS construction technology.



These cast connections for HSS are currently under investigation at the University of Toronto.