HSS

ARTICLE

WELDED TRUSS CONNECTIONS BETWEEN HSS BRANCHES AND I-SHAPED CHORDS

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There are instances in which designers elect to use planar trusses composed of HSS web members and wide-flange (or I-shaped) chord members. Welded truss-type connections are the result, typically arranged as shown in Figure 1, with branches welded to the chord flange. This "specialty case" is not covered by AISC 360-16 (AISC, 2016), nor by AISC Design Guide No. 24 (Packer et al., 2010). Experimental research has been performed on such hybrid connections (Wardenier and Mouty, 1979; Wardenier, 1982) and it has been shown that, in many respects, the behavior of connections between open sections and hollow sections is comparable to that of connections between rectangular HSS (Wardenier et al., 2010).

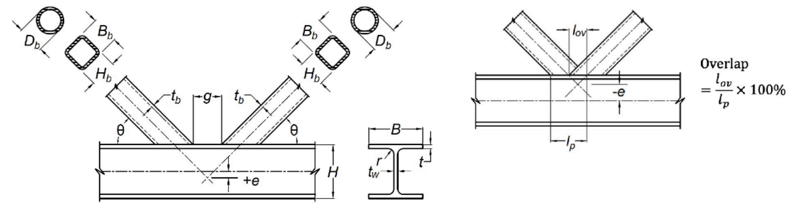

Figure 1: Gapped and overlapped K-connections between HSS branches and I-shaped chord members

LIMIT STATES

The possible connection failure modes or limit states for T-, Y-, Cross- and K-connections are: (i) branch failure due to uneven load distribution (leading to premature yielding of a tension branch or a compression branch); (ii) chord web failure (by local yielding); (iii) chord shear yielding; and (iv) chord local buckling. Local buckling of a compression branch member or a compression chord member can be avoided by choosing appropriate diameter-, width- and depth-to-thickness ratios, thus by applying suitable limits of applicability to geometric parameters. These failure modes are shown diagrammatically, for hollow section chord connections, in Fig. C-K3.1 (c) to (f) of the Commentary to Section K3 of AISC 360-16 (AISC, 2016). Note that chord plastification does not occur since this can only take place after excessive yielding of the chord web. Thus, the governing failure modes for HSS branch-to-I shape chord connections can be reduced to: (i) branch failure; (ii) chord web failure; and (iii) chord shear failure (Wardenier et al., 2010).

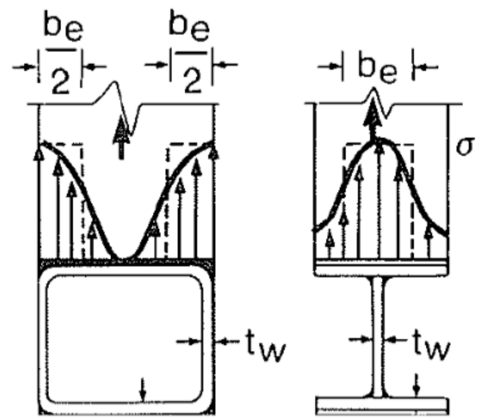

Figure 2: Distribution of stress in the transverse wall of an axially loaded HSS branch, welded to an HSS chord member versus an I-section chord member (Davies and Packer, 1982)

LIMIT STATE OF LOCAL YIELDING OF BRANCH(ES) DUE TO UNEVEN LOAD DISTRIBUTION

The distribution of stress in the transverse wall of an axially loaded HSS branch member, welded to either an open or tubular section, is generally very non-uniform, as shown in Figure 2. This is particularly so for connections to rectangular HSS chords where the chord wall slenderness (*B*/*t*) is high. For all sections the branch peak stress will occur adjacent to the stiff point(s) of the chord connecting face; for an I-shape chord this will be next to the central web, whereas for a rectangular HSS chord this will be next to the two outer webs/corners. For both round and rectangular branch HSS-to-I shape chord connections there will be two portions of branch effective width/length, b_e, as shown in Figure 3. Hence, the branch nominal strength, P_n, is given by (Wardenier et al., 2010):

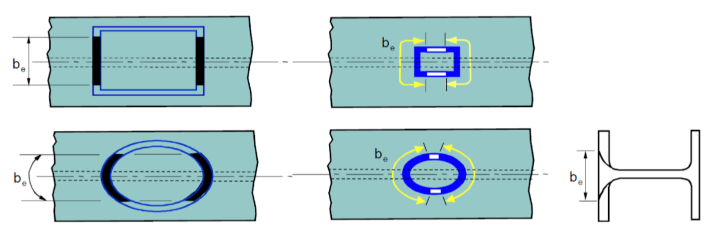

Figure 3: Effective width model for branch local yielding (Wardenier et al. 2010)

$$P_n = 2F_{yb}t_bb_e$$

Equation 1

where F_{yb} is the HSS branch yield stress, t_b is the HSS branch design thickness (Figure 1), and

$$b_e = t_w + 2r + 7t\frac{F_y}{F_{yb}} \leq B_b + H_b - 2t_b$$

Equation 2

where t_w is the I-section chord web thickness (Figures 1 and 2), r is the radius of the web-to-flange fillet (Figure 1), t is the chord flange thickness (Figure 1) and F_y is the chord yield stress. For a rectangular branch, if $b_e > B_b$ it is conservatively proposed to follow the branch perimeter, as shown in Figure 3(b). The failure criterion of branch local yielding is also used as the design limit state for overlapped HSS K-connection branches welded to an I-section chord, in an analogous manner to rectangular HSS-to-HSS overlapped K-connections (see Table K3.2 of AISC 360-16).

LIMIT STATE OF LOCAL YIELDING OF CHORD WEB

As can be visualized from Figure 3, the branch load transferred to the chord web is – for a rectangular HSS branch – mainly concentrated beneath the transverse walls of the branch (Figure 3(a)), unless the branch is small relative to the chord (Figure 3(b)). An effective length of the

The web nominal strength, $P_n$sin0, is then given by (Wardenier et al., 2010):

$$P_n \sin\theta = F_y t_w b_w$$

Equation 3

Where

$$b_w = \left(\frac{H_b}{\sin\theta}\right) + 5(t + r) \leq \left(\frac{2t_b}{\sin\theta}\right) + 10(t + r)$$

Equation 4

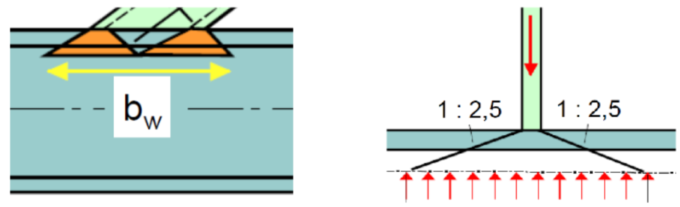

Figure 4: Analytical model for chord web yielding (Wardenier et al., 2010)

and H_b is the branch depth, measured in the plane of the connection (Figure 1). This model assumes that the force in a branch transverse wall disperses at a slope of 2.5:1 to the k-line of the I-section (i.e. to a depth of $t + r$ in the chord member), as shown in Figure 4.

LIMIT STATE OF SHEARING OF CHORD CROSS SECTION

If a chord member is subject to a shearing force across the member, a failure mode of cross-section shearing is possible, as illustrated in Figure 5. For I-shaped members, the nominal shear strength is specified by Section G2.1 of AISC 360-16 (AISC, 2016) and – for nearly all ASTM A6 W, S and HP shapes with F_y = 50 ksi (a User Note to AISC 360-16 Section G2.1(a) provides the 8 exceptions) – is given by:

$$P_n \sin\theta = 0.6 F_y A_v$$

Equation 5

where A, is the chord shear area, of Ht_w (see Figure 1).

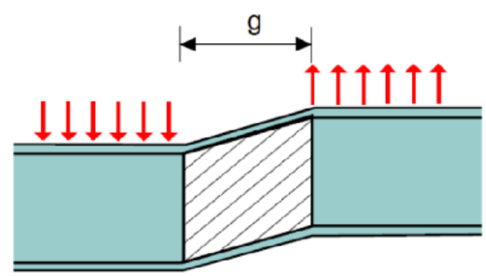

Figure 5: Shear failure in the chord gap region of a K-connection

Design provisions for these three limit states, along with the pertinent limits of applicability, per ISO 14346 (2013), are summarized as connection available strengths for LRFD and ASD, in Tables 1 and 1A.

Table 1. Available Strengths of HSS Branch-to-I Shape Chord Connections

Connection Type	Connection Available Strength
T-, Y-, Cross- and Gapped K-Connections	Limit State: Local Yielding of the Branch/Branches due to Uneven Load Distribution
	$$P_n = 2F_{yb}t_b b_e$$
	ϕ = 0.95 (LRFD) Ω = 1.58 (ASD)
	Limit State: Local Yielding of the Chord Web
*To be checked for gapped K-connections and for Cross-connections with cosθ_b > H_b/H.	$$P_n \sin\theta = F_y t b_w$$
	ϕ = 1.00 (LRFD) Ω = 1.50 (ASD)
*Also check for axial force + shear force interaction in the gap region of the chord member, if axial force is significant	Limit State: Shear of the Chord Cross Section*
	$$P_n \sin\theta = 0.6F_y A_v$$
	ϕ = 1.00 (LRFD) Ω = 1.50 (ASD)
Overlapped K-Connections	Limit State: Local Yielding of the Branch/Branches due to Uneven Load Distribution
Subscript *i* refers to the overlapping branch Subscript *j* refers to the overlapped branch	$$P_{n,overlappingbranch} = F_{ybi}t_{bi}I_{b,eff}$$ $$P_{n,overlappedbranch} = P_{n,overlappingbranch}\left(\frac{F_{ybj}A_{bj}}{F_{ybi}A_{bi}}\right)$$
	ϕ = 0.95 (LRFD) Ω = 1.58 (ASD)

Functions

	Rectangular HSS Branches	Round HSS Branches
b_e	$$b_e = t_w + 2r + 7t\frac{F_y}{F_{yb}} \leq B_b + H_b - 2t_b$$	$$b_e = t_w + 2r + 7t\frac{F_y}{F_{yb}} \leq 0.5\pi(D_b - t_b)$$
b_w	$$b_w = \left(\frac{H_b}{\sin\theta}\right) + 5(t+r) \leq \left(\frac{2t_b}{\sin\theta}\right) + 10(t+r)$$	$$b_w = \left(\frac{D_b}{\sin\theta}\right) + 5(t+r) \leq \left(\frac{2t_b}{\sin\theta}\right) + 10(t+r)$$
A_v	$$A_v = Ht_w$$	$$A_v = Ht_w$$
$I_{b,eff}$	For 25% ≤ O_v < 50%: $$I_{b,eff} = \left(\frac{O_v}{50}\right)2H_{bi} + B_{ei} + B_{ej} - 4t_{bi}$$ $$B_{ei} = t_w + 2r + 7t\frac{F_y}{F_{ybi}} \leq B_{bi}$$ $$B_{ej} = \left(\frac{10}{B_{bj}/t_{bj}}\right)\left(\frac{F_{ybj}t_{bj}}{F_{ybi}t_{bi}}\right) \leq B_{bi}$$	For 25% ≤ O_v < 50%: $$I_{b,eff} = \frac{\pi}{4}(2D_{bi} + D_{ei} + D_{ej} - 4t_{bi})$$ $$D_{ei} = t_w + 2r + 7t\frac{F_y}{F_{ybi}} \leq D_{bi}$$ $$D_{ej} = \left(\frac{12}{D_{bj}/t_{bj}}\right)\left(\frac{F_{ybj}t_{bj}}{F_{ybi}t_{bi}}\right) \leq D_{bi}$$
	For 50% ≤ O_v < 100%: $$I_{b,eff} = 2H_{bi} + B_{ei} + B_{ej} - 4t_{bi}$$ B_{ei} and B_{ej} as defined above	For 50% ≤ O_v < 100%: $$I_{b,eff} = \frac{\pi}{4}(2D_{bi} + D_{ei} + D_{ej} - 4t_{bi})$$ D_{ei} and D_{ej} as defined above
	For O_v = 100%: $$I_{b,eff} = 2H_{bi} + B_{bi} + B_{ej} - 4t_{bi}$$ B_{ej} as defined above	For O_v = 100%: $$I_{b,eff} = \frac{\pi}{4}(2D_{bi} + 2D_{ej} - 4t_{bi})$$ D_{ej} as defined above

Table 1A. Limits of Applicability for Limit States in Table 1

Connection eccentricity:	$-0.55 \le e/H \le 0.25$ for K-connections
I-Chord cross section:	Compact, if chord in compression
I-Chord web size:	$H - 2t - 2r \le 15.75$ in., if chord in compression
Rectangular branch cross section:	$(H_b - 3t_b)/t_b$ and $(B_b - 3t_b)/t_b \le 193/\sqrt{F_{yb}}$ for compression branch(es) H_b/t_b and $B_b/t_b \le 40$ for tension branch(es)
Round branch cross section:	$D_b/t_b \le 1705/F_y$ for compression branch(es) $D_b/t_b \le 50$ for tension branch(es)
Width ratio:	B_b/B and $D_b/B \ge 0.25$ for overlapped K-connections
Branch width ratio:	B_{bi}/B_{bj} and $D_{bi}/D_{bj} \ge 0.75$ for overlapped K-connections, where subscript i refers to the overlapping branch and subscript j refers to the overlapped branch
Thickness ratio:	t_{bi}/t_0 and $t_{bj}/t_0 \le 1.0$ for overlapped K-connections, where subscript i refers to the overlapping branch and subscript j refers to the overlapped branch
Branch thickness ratio:	$t_{bi}/t_{bj} \le 1.0$ for overlapped K-connections, where subscript i refers to the overlapping branch and subscript j refers to the overlapped branch
Rectangular branch aspect ratio:	$0.5 \le H_b/B_b \le 2.0$ for gapped K-, T-, Y- and cross-connections $H_b/B_b = 1.0$ for overlapped K-connections
Gap size:	$g \ge t_{b\ compression\ branch} + t_{b\ tension\ branch}$ for gapped K-connections
Overlap:	$O_v \ge 25\%$ for overlapped K-connections
Material strength:	F_y and $F_{yb} \le 52$ ksi; $F_{yb} \le F_y$
Ductility:	F_y/F_u and $F_{yb}/F_{ub} \le 0.8$ Note: ASTM A500 Grade C is acceptable

Note: Refer to the AISC 360 *Specification* for definitions of symbols not described herein.

REFERENCES

AISC. 2016. "Specification for Structural Steel Buildings", ANSI/AISC 360-16, and Commentary, American Institute of Steel Construction, Chicago, IL.

Davies, G. and Packer, J.A. 1982. "Predicting the Strength of Branch Plate-RHS Connections for Punching Shear", Canadian Journal of Civil Engineering, Vol. 9, pp. 458-467.

ISO. 2013. "Static Design Procedures for Welded Hollow-Section Joints – Recommendations", ISO 14346, 1st. edition, International Organization for Standardization, Geneva, Switzerland.

Packer, J.A., Sherman, D. and Lecce, M., 2010. "Hollow Structural Section Connections", Steel Design Guide No. 24, American Institute of Steel Construction, Chicago, IL.

Wardenier, J. 1982. "Hollow Section Joints", Delft University Press, Delft, The Netherlands.

Wardenier, J. and Mouty, J. 1979. "Design Rules for Predominantly Statically Loaded Welded Joints with 14346Hollow Sections as Bracings and an I- or H-section as Chord", Welding in the World, Vol. 17, No. 9/10.

Wardenier, J., Packer, J.A., Zhao, X.L. and van der Vegte, G.J. 2010. "Hollow Sections in Structural Applications", 2nd. edition, CIDECT, Geneva, Switzerland.

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