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Parametric finite element study on slotted rectangular and square HSS tension connections

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ABSTRACT

A parametric finite element analysis study was carried out on slotted rectangular and square hollow structural section (HSS) tension connections without welding at the end of the gusset plate for different weld length ratio, slot orientation, weld size and level of HSS corner strength compared to its flat segment. Finite element models for the parametric study were developed and validated against test results of the connection with the tube slotted. The modified weld length ratio was found to be a better parameter than the modified eccentricity ratio in characterizing the net section efficiency of a slotted HSS tension member when the weld length is short. Improvements to provisions in CSA-S16-01 and ANSI/AISC-360-05 for slotted tubular tension connections were proposed based on results of the study.

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1. Introduction

Hollow structural sections (HSS) are widely used in bracing and trusses. A slotted connection for a hollow structural section can be made by slotting the tube longitudinally and inserting a gusset plate into the slot. The gusset plate is then welded to the tube by longitudinal fillet welds as shown in Fig. 1. Welding may or may not be provided around the end of the gusset plate. Consequently, the stress across the section is not distributed uniformly and the net cross section may not be fully effective in carrying the load because of shear lag. The effect of shear lag has been found to be related to the ratio of the weld length (L) to the circumferential distance between the longitudinal welds or edges of HSS wall at the opening (w), and the ratio of the net section area eccentricity ($\bar{x}$) to the weld length (L). These parameters are shown in Fig. 1. In general, the adopted definitions of these parameters may vary slightly in different studies.

For the same weld length ratio, the effect of shear lag is expected to be less critical for the connection with end welding than the one without. Thus, this paper focuses mainly on parametric finite element analyses of slotted HSS connections without end weld. In this study, finite element models were first developed and validated against test data. Based on the validated models, parametric finite element analyses were carried out and results of the analyses are compared to the values given by Canadian and American design standards, CSA-S16-01 [1] and ANSI/AISC-360-05 [2], and improvements are proposed.

2. Design provisions for shear lag in HSS connections

Both CSA-S16-01 [1] and ANSI/AISC-360-05 [2], have provisions to account for the effect of shear lag in calculating the capacity of a tension member. In CSA-S16-01 [1], the effect of shear lag is accounted for in calculating the effective net area, which is a function of the weld length ratio (L/w). The factored tensile resistance, T_r, of a tension member is taken as

$$T_r = 0.85\phi A_{ne} F_u, \tag{1}$$

where ϕ is the resistance factor, A_{ne} is the effective net section area and F_u is the specified minimum tensile strength. When an element of a tension member is connected by longitudinal welds along two parallel edges, the effective net area for that element is taken as

$$\begin{aligned} A_{n2} &= 1.00wt, \quad \text{for } L \geqslant 2w, \\ A_{n2} &= 0.50wt + 0.25Lt, \quad \text{for } 2w > L \geqslant w, \\ A_{n2} &= 0.75Lt, \quad \text{for } w > L, \end{aligned} \tag{2}$$

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Notations

A_e	effective net section area
A_{fmid}	cross-section area based on mid-section dimension
A_g	gross section area
A_m	current average cross-section area
A_{mid}	area based on mid-point dimensions
A_n	net section area
A_{n2}	effective net section area with longitudinal weld along two edges
A_{ne}	effective net section area
A_{nm}	net section area of the HSS connection model
A_{nt}	cross-section area in direct tension
A_{nw}	net cross-section excluding cross-section area in direct tension
A_o	initial undeformed cross-section area
b_o	geometric dependent parameter for U calculation with no corner strength increase
b_{28}	geometric dependent parameter for U calculation with 28% corner strength increase
b_{wo}	geometric independent parameter for U calculation with no corner strength increase
b_{w28}	geometric independent parameter for U calculation with 28% corner strength increase
B	overall height of HSS in the direction perpendicular to the plane of gusset plate;
C_p	parameter for power law material equation
D	outside diameter of round HSS
F_u	ultimate strength
F_{uc}	ultimate strength based on assumed HSS corner material
F_y	yield strength
G_L	slot opening length
G_W	slot opening width
G_S	straight segment of opening length
H	overall width of HSS in the direction parallel to the plane of gusset plate
L	longitudinal weld length
n	parameter for power law equation
P_{assm}	peak load predicted by the finite element model with an assumed higher strength corner
P_{test}	measured tension capacity
t	thickness of the flat segment of HSS
t_p	thickness of gusset plate
T	tension capacity
T_r	factored tension resistance
U	net section efficiency
U_{assm}	predicted net section efficiency of a HSS connection model with a higher strength corner
U_{test}	test efficiency
w	distance between welds
w'	modified distance between welds
w_h	fillet weld size
w_{nt}	width of the HSS wall that transfers the load by tension
W_P	width of gusset plate
$\bar{x}$	net section area eccentricity
$\bar{x}^*$	modified net section area eccentricity
$\bar{x}_s$	the eccentricity of a square (round) or an equivalent square (round) HSS
ε^p	true plastic strain
ε_c^p	critical equivalent plastic strain limit
ε_o^P	true plastic strain at the start of strain hardening
σ^t	true stress
σ_o^t	true stress at the start of strain hardening
ϕ	resistance factor

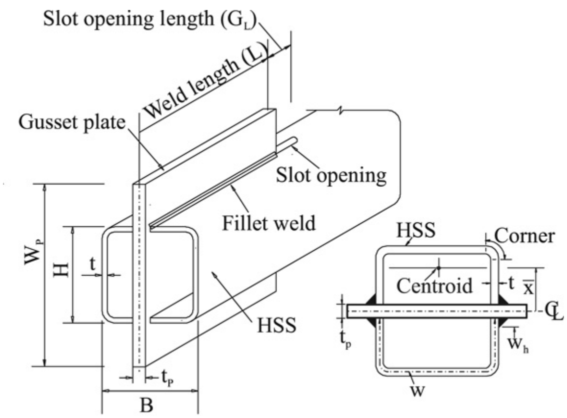

Fig. 1. Slotted HSS connection with a gusset plate and no end weld.

where t is the thickness of the tension member. For a slotted HSS connection with no end welding, the effective net section area, A_{ne}, is twice that given by A_{n2} in Eq. (2). Thus, the net section efficiency (U) is A_{ne}/A_n where $A_n = 2wt$.

In ANSI/AISC-360-05 [2], the effective area of a tension member is determined from the net area (A_n) by

$$A_e = A_n U, \tag{3}$$

where U is the shear lag factor or the net section efficiency. For a rectangular HSS with a single concentric gusset plate that has a weld length (L) not less than H, this factor is defined as

$$U = 1 - \frac{\bar{x}}{L} \quad \text{and} \tag{4}$$

$$\bar{x} = \frac{B^2 + 2BH}{4(B + H)} \tag{5}$$

where B is the overall height of the HSS perpendicular to the plane of the gusset plate and H is the overall width of the HSS parallel with the plane of the gusset plate.

3. Research on slotted HSS connections

There has been a number of experimental and finite element analysis studies carried out on slotted HSS tension connections. Numerous tests on rectangular (RHS) and square (SHS) slotted HSS tension members have been carried out by Zhao and Hancock [3], Korol [4], Zhao et al. [5], Wilkinson et al. [6], Huang [7] and Zhao [8]. All specimens tested by Zhao and Hancock [4], Zhao et al. [5] and Wilkinson et al. [6] failed in block shear. Based on results of the test, Korol proposed a net section efficiency coefficient for shear lag

$$\begin{aligned} &U = 1.0, \quad \text{for } \frac{L}{w} > 1.2, \\ &U = 0.9, \quad \text{for } 1.0 < \frac{L}{w} \leqslant 1.2 \quad \text{and} \\ &U = 0.4 + 0.5\frac{L}{w} \quad \text{for } 0.6 \leqslant \frac{L}{w} \leqslant 1.0. \end{aligned} \tag{6}$$

Below a L/w ratio of 0.61, the failure mode was found to switch from net section fracture (circumferential crack) to block shear failure. Korol also proposed another net section efficiency equation based on the net section eccentricity ($\bar{x}/L$) as

$$U = 1 - 0.4\frac{\bar{x}}{L}. \tag{7}$$

Girard et al. [9] conducted a finite element analysis study of slotted rectangular and square HSS connections, but the predicted capacity was found to be significantly lower than the test [4]

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