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Course Description

March 20, 2013 - HSS Connections

Based on the AISC Design Guide 24: Hollow Structural Section Connections, this live webinar will provide practical, up-to-date information on the design of structures with HSS and simplifying connections in construction. The presentation will give an overview of the design guide and discusses several HSS connections including moment connections, tension and compression connections, and HSS-to-HSS truss connections. Design examples will be presented.

Learning Objectives

At the end of this program, participants will be able to:

- Gain familiarity with the design of structures using HSS.
- Gain familiarity with AISC Design Guide 24: Hollow Structural Section Connections.
- Gain an understanding of HSS connections including moment connections, tension and compression connections, and HSS-to-HSS truss connections.
- Gain an understanding of the design of an HSS connection through a presented example.

There's always a solution in steel.

HSS Connections

Presented by
Jeff Packer
Professor, University of Toronto
Toronto, Canada

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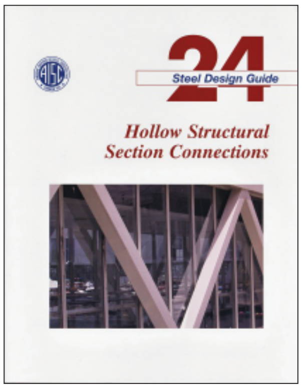
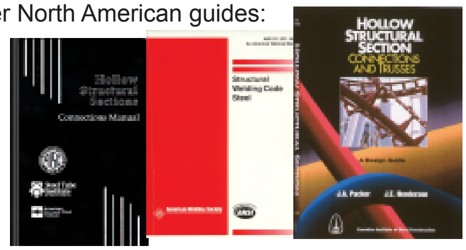
AISC Design Guide on HSS – 2010

Basis of this presentation is DG24 … available from www.aisc.org



"Design Guide for Hollow Structural Section Connections", by J.A. Packer, D.R. Sherman and M. Lecce

Some older North American guides:



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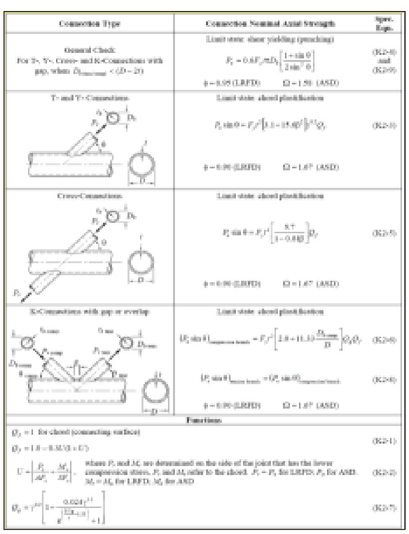
AISC DG24 – Format Example


Connection Type
Connection Nominal Axial Strength
Spec. Eqn.
General Check
T- and Y-Connections
Cross-Connections
K-Connections with gap or overlap
Functions

- Written in accordance with the AISC 360-05 Steel Building Specification, but has the table format of AISC 360-10
- For statically loaded connections only
- Presented in LRFD and ASD formats, using a connection "nominal strength" approach
- 22 design examples

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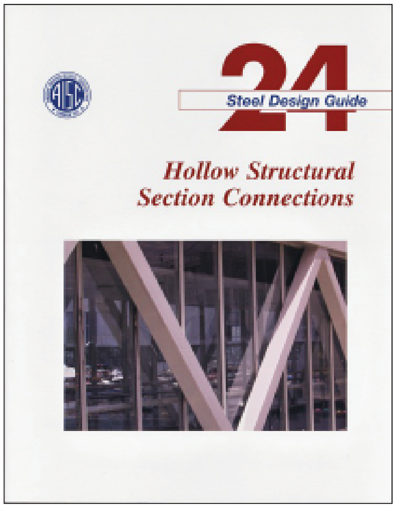
AISC DG24 – Contents



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Chapter 1 – Introduction

- HSS steel grades
- Shapes, designations, tolerances
- Connection design standards
- Advantages of HSS

Rock and Roll Hall of Fame, Cleveland, OH

- High compressive strength-to-weight ratio, resulting in lighter columns and trusses
- Extremely high torsional strength
- Highly aesthetic → excellent for exposed steelwork

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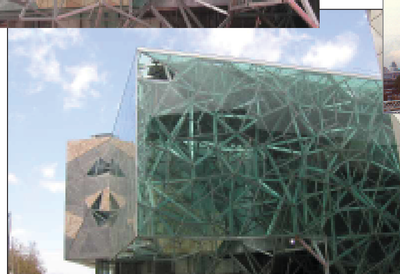
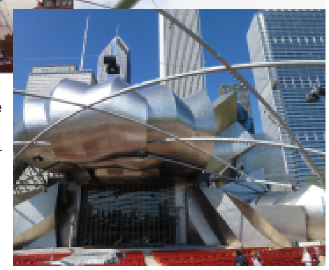
Chapter 1 – Introduction



Free-form HSS architecture, Melbourne, Australia



HSS are highly suitable for bending and curving …

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Chapter 1 – Introduction

• HSS available steel grades and “design wall thickness” concept

Table 1-1. North American Manufacturing Standards for HSS, with Mechanical Properties of Common Grades

Product	Specification	Grade	Minimum Yield Stress, F_y, ksi (MPa)	Minimum Ultimate Tensile Stress, F_u, ksi (MPa)
Cold-formed HSS	ASTM A500 Round	B	42 (289)	58 (400)
	ASTM A500 Round	C	46 (317)	62 (427)
	ASTM A500 Rectangular	B	46 (317)	58 (400)
	ASTM A500 Rectangular	C	50* (345)	62* (427)
Pipe	ASTM A53	B	35 (241)	60 (415)
Hot-formed HSS	ASTM A501	B	50 (345)	70 (482)
Cold-formed and cold-formed stress relieved HSS (Class C & Class H)	CAN/CSA-G40.20/G40.21	350W	51 (350)	65 (450)

*F_y/F_u ratio for Gr. C rectangular = 0.806 > permitted 0.8 in AISC 360-05, but subsequently permitted in AISC 360-10
** New, higher performance, ASTM A1xxx HSS product likely available in 2013

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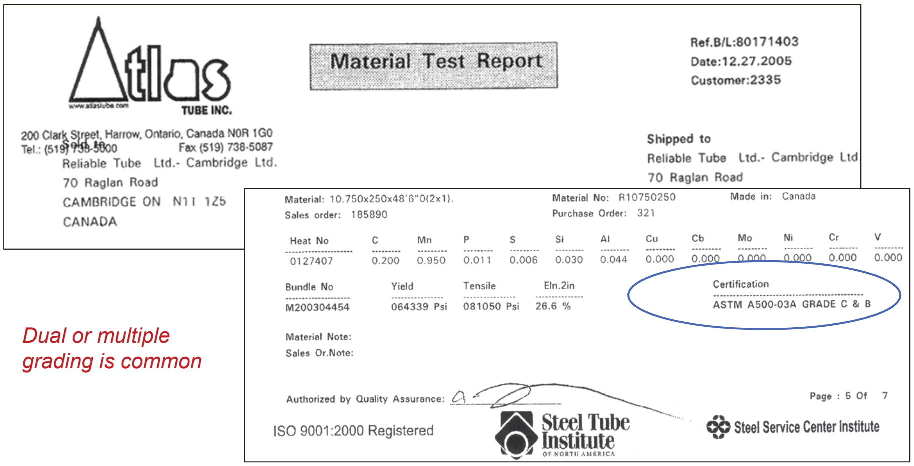
Chapter 1 – Introduction

- A “*one size fits all*” approach to manufacturing HSS



Atlas TUBE INC.
www.atlastube.com

Material Test Report

Ref.B/L:80171403
Date:12.27.2005
Customer:2335

200 Clark Street, Harrow, Ontario, Canada N0R 1G0
Tel.: (519) 738-5000 Fax (519) 738-5087

Sold to
Reliable Tube Ltd.- Cambridge Ltd.
70 Raglan Road
CAMBRIDGE ON N1I 1Z5
CANADA

Shipped to
Reliable Tube Ltd.- Cambridge Ltd
70 Raglan Road

Material: 10.750x250x48'6"0(2x1). Material No: R10750250 Made in: Canada
Sales order: 185890 Purchase Order: 321

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V
0127407	0.200	0.950	0.011	0.006	0.030	0.044	0.000	0.000	0.000	0.000	0.000	0.000

Bundle No	Yield	Tensile	Eln.2in	Certification
M200304454	064339 Psi	081050 Psi	26.6 %	ASTM A500-03A GRADE C & B

Material Note:
Sales Or.Note:

Authorized by Quality Assurance:

Page : 5 Of 7

ISO 9001:2000 Registered

Steel Tube Institute OF NORTH AMERICA

Steel Service Center Institute

Dual or multiple grading is common

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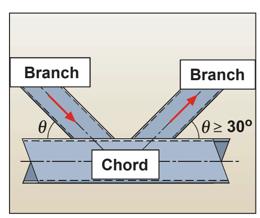
Chapter 2 – Welding

- Weld Design for HSS-to-HSS connections can be performed using either of the following two design philosophies/methods:

1. The weld may be proportioned to develop the yield strength of the connected branch wall, at all locations around the branch (an upper bound on weld size),

or



2. The weld may be proportioned to resist the applied branch forces, with adjustments for uneven stress distributions along the length of the weld (a “fit-for-purpose” approach). This entails the use of weld effective lengths, which are covered in Section K4 of AISC 360-10.

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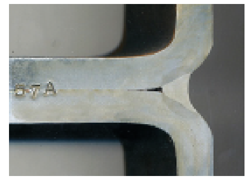
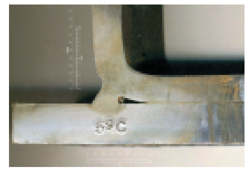
Chapter 2 – Welding

- Weld **TYPES**:
  - Fillet welds, skewed fillet welds
  - Flare-bevel- and Flare-V-groove welds
  - PJP groove welds
  - CJP groove welds → generally try to avoid
    - (i) With backing, for statically-loaded structures, where backing is left in place
    - (ii) Without backing, for cyclically loaded structures, welded from one side using a highly qualified welder (likely 6GR)
- Effective fillet weld size (tabulated equations)
- Weld inspection, as applied to HSS

Also refer to AISC Design Guide 21: "Welded Connections – A Primer for Engineers" (Miller, 2006)





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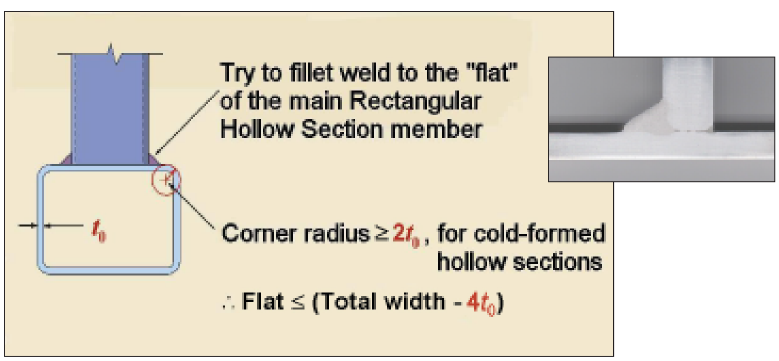
Chapter 2 – Welding



1. Maintain same weld effective throat around the connection
2. For "matched width" (β = 1.0) rectangular HSS-to-HSS connections, a flare bevel PJP groove weld is required along the chord rounded edges.

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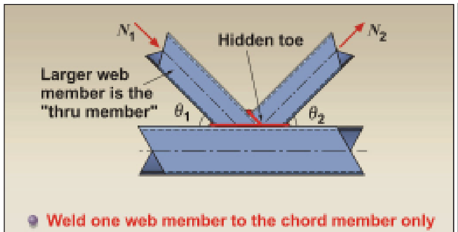
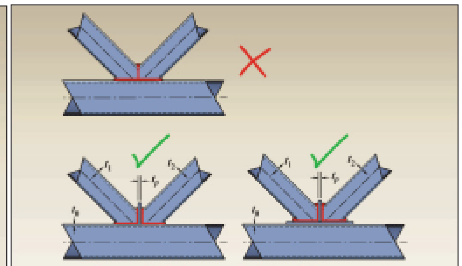
Chapter 2 – Welding

• Detailing in overlapped K-connections



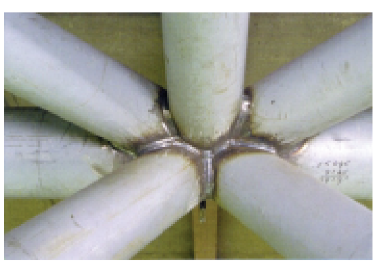
Note: The "hidden weld" toe under an overlapping branch may be omitted (left just tacked) provided:
(i) The branch member force components normal to the chord (i.e. $N_1\sin\theta_1$ and $N_2\sin\theta_2$) differ by no more than 20%, and
(ii) The remaining welds to the overlapped branch everywhere develop the full capacity of the overlapped branch member walls.

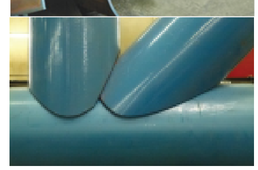


Acceptable types of plate reinforcement, if the HSS branch member ends <u>have</u> been double-mitered

Chapter 2 – Welding

• Tube profiling, for round-to-round HSS connections

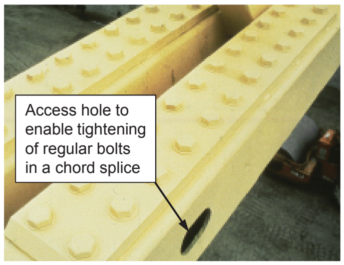


- CNC tube-and-pipe-profiling machines (e.g. by Vernon Tool, CA) are very beneficial, producing clean, accurate cuts *with correct bevels on the edges*
- Portable machines available
- Cutting by oxy-acetylene or plasma torch
- Equipment varies with number of axes of movement

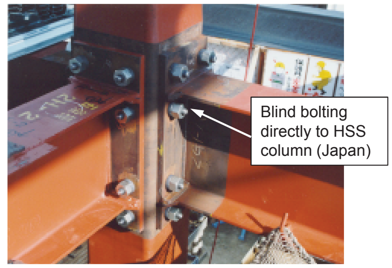
Chapter 3 – Mechanical Fasteners

- HSS connections with fasteners in shear or in tension



Fasteners in shear

vs.



Fasteners in tension

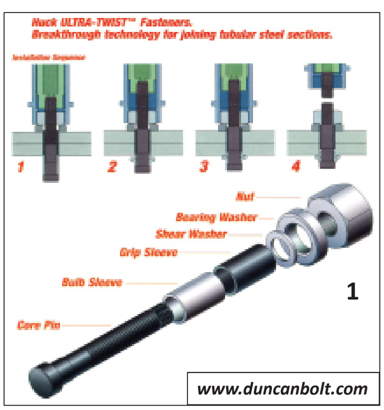
In addition to the normal limit states for bolts:

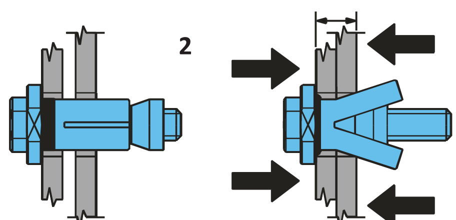
HSS Limit States
- Bolt bearing
- Block shear

HSS Limit States
- Chord wall plastification
- Pull out through HSS wall

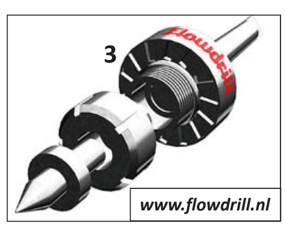
Chapter 3 – Mechanical Fasteners

- "Blind Bolting" from outside the HSS





Lindapter Hollo-bolt
www.lindapter.com

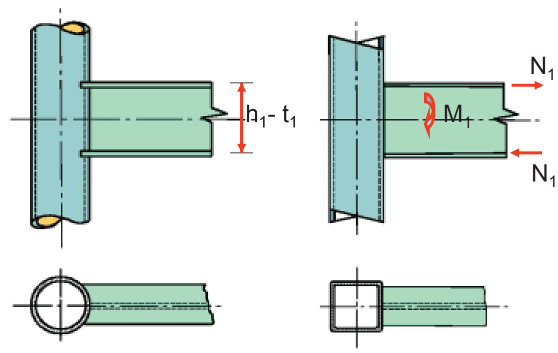


With Blind Bolts:
- **Check availability**
- **Be careful with equivalence to ASTM A325 bolts**

Chapter 4 – Moment Connections

Beam-to-HSS Column Moment Connections

Note: Unstiffened connections are only partially-rigid



Acceptable for low static moment loads; strength related to the flange connections by treating it as two plates:

$$M_1 = N_1\ (h_1 - t_1)$$

- Similar limit states are checked as for axially loaded connections, using transverse plate-to-HSS checks

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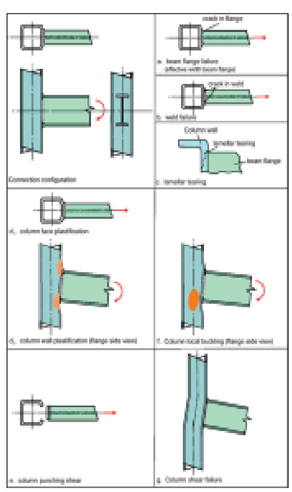
Chapter 4 – Moment Connections

Beam-to-HSS Column Moment Connections

Failure Modes



- Limit States:
  - (a) Beam flange local yielding ("effective width")
  - (b) Weld failure ("effective width")
  - (c) Lamellar tearing (highly unlikely)
  - (c) Column wall plastification
  - (d) Column punching shear
  - (e) Column wall local buckling
  - (f) Column shear failure

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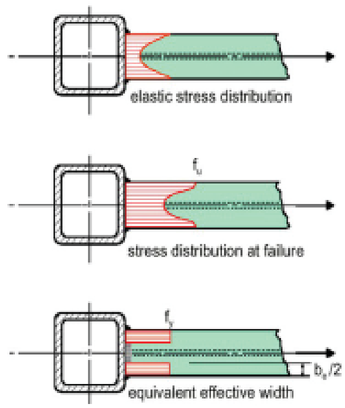
Chapter 4 – Moment Connections

Beam-to-HSS Column Moment Connections

- Limit States of
  (a) Beam flange local yielding ("effective width") & (b) Weld failure ("effective width")

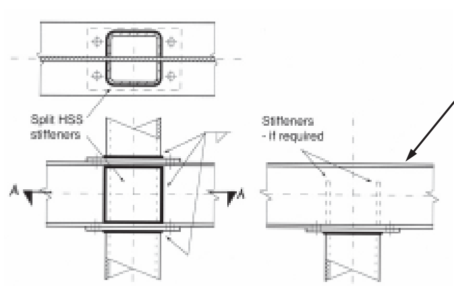


$N_1 = b_e\, t_1\, F_{y1}$

Rigid Moment Connections

Beam-to-HSS Column Moment Connection Concepts

- **Continuous beam-to-column connection**

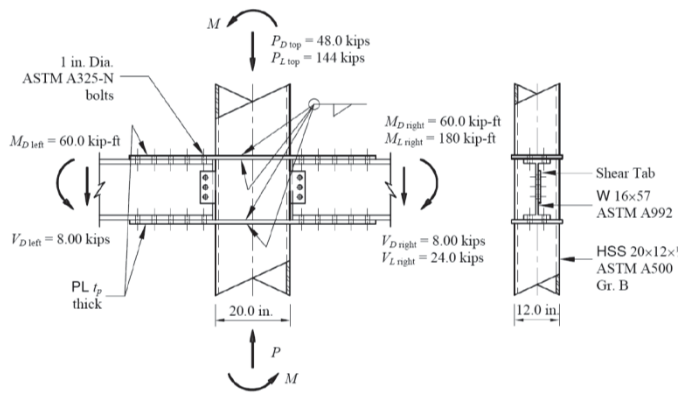


Beam over Column

Rigid Moment Connections

Beam-to-HSS Column Moment Connection Concepts

- **Through-Plate Moment Connection**



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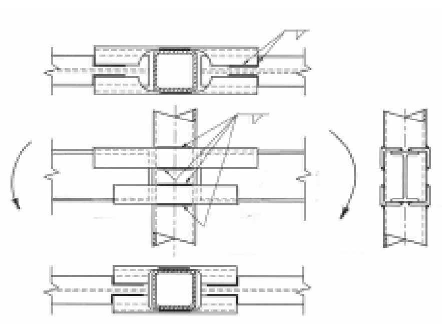
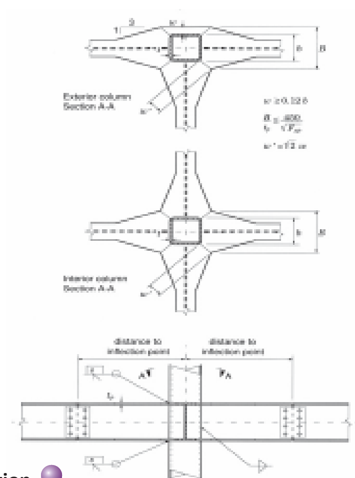
Rigid Moment Connections

Beam-to-HSS Column Moment Connection Concepts



- **Strap Angle moment connection**



- **Flange Diaphragm moment connection**

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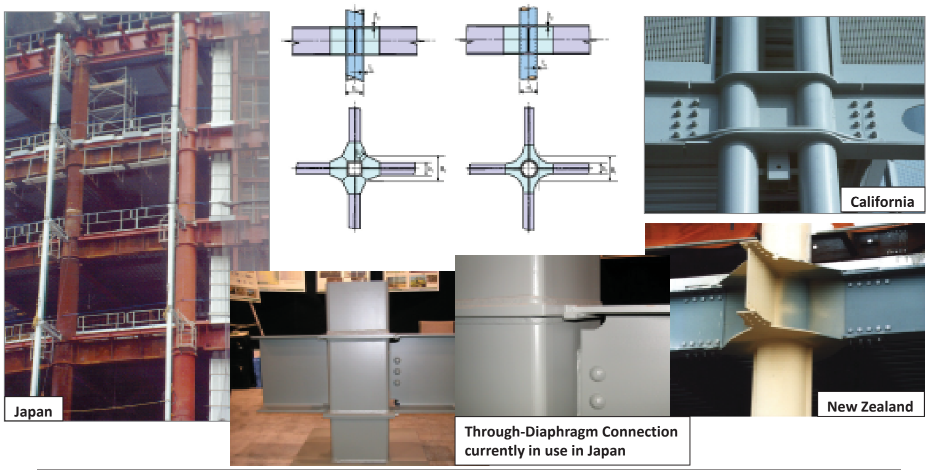
Seismic Moment Connections

- *Exterior and Interior Diaphragm concepts (from Japan) – not prequalified in the US, and perceived to be expensive*



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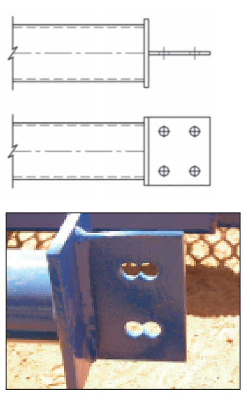
Chapter 5 – Tension and Compression Connections

- *End Connections commonly used for HSS Bracing Members*

End Tee Connections to Round or Rectangular HSS



Limit States:

- *Weld shear*
- *HSS local yielding, wall crippling*
- *T-flange shear yielding, shear rupture*
- *Bolting bearing, bolt shear*
- *Stem yielding, rupture, block shear, buckling*

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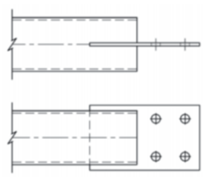
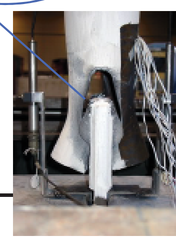
Chapter 5 – Tension and Compression Connections

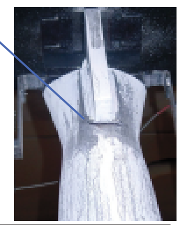
• *End Connections commonly used for HSS Bracing Members*

Slotted HSS-to-Gusset Plate Connections to Round or Rectangular HSS



Limit States:
- *Weld shear and base metal shear*
- *Bolt bearing, bolt shear*
- *Gusset plate yielding, rupture, block shear*
- *HSS ~~local yielding~~, shear lag, HSS block shear*

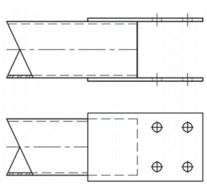


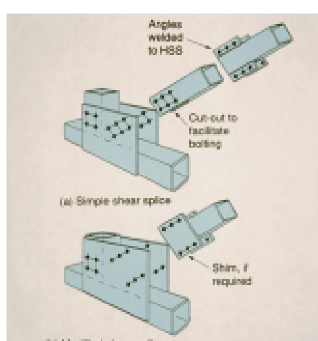


Chapter 5 – Tension and Compression Connections

• *End Connections commonly used for HSS Bracing Members*

Side Gusset Plate Bolted Connections to Rectangular HSS

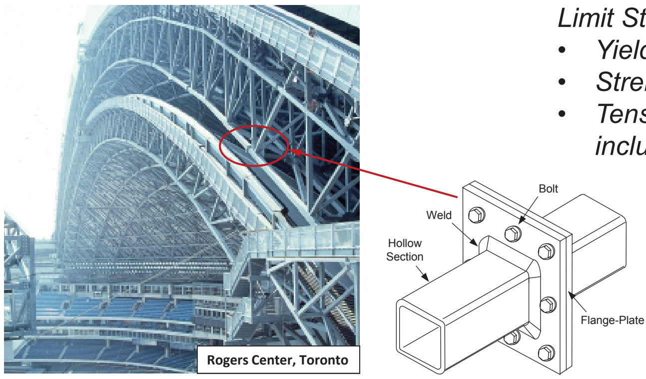




Chapter 5 – Tension and Compression Connections

• ***End Connections commonly used for HSS Bracing & Chord Members***

Bolted Flange-Plate (End-Plate) Connections



Limit States:

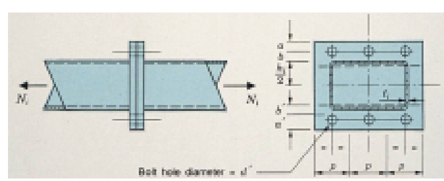
- *Yielding of end plate*
- *Strength of welded joint*
- *Tensile strength of bolts, including prying*

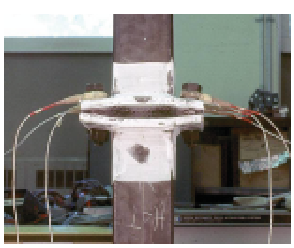
Chapter 5 – Tension and Compression Connections

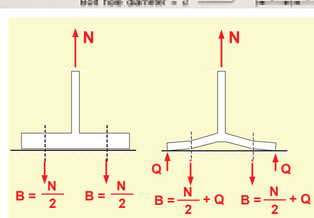
• ***End Connections commonly used for HSS Bracing & Chord Members***

Bolted Flange-Plate (End-Plate) Connections

With bolts along 2 sides of a rectangular HSS, connection behavior is representative of 2-dimensional prying models. Analysis is based on a connection slice of width p, where the pitch p ~ 4d to 5d, and d = bolt diameter.







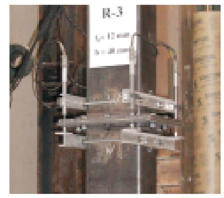
Chapter 5 – Tension and Compression Connections

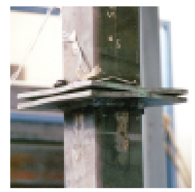
- ***End Connections commonly used for HSS Bracing & Chord Members***

Bolted Flange-Plate (End-Plate) Connections

With bolts along 4 sides of a rectangular HSS:

(a) Bolts should be located beside the RHS walls (where the tension load is transmitted), not at the plate corners. Keep the bolts "within the HSS width". If the bolts are close to each other, prying action is reduced.
(b) Bolts should be located as close to the HSS walls as practical (low b = distance from bolt line to HSS face), to reduce prying action.
(c) As fillet weld leg size increases, connection capacity increases. (Applies to *all* bolted flange plate connections).
(d) Analyze using a 2D model, with a connection slice of width p, in both orthogonal directions; most critical direction governs.





Chapter 5 – Tension and Compression Connections

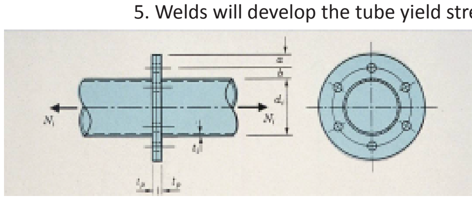
- ***End Connections commonly used for HSS Bracing & Chord Members***

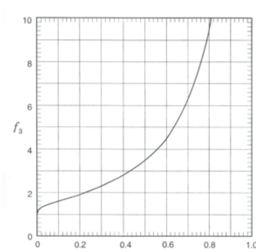
Bolted Flange-Plate (End-Plate) Connections

With bolts arranged radially around a round HSS:

A simple design method is available based on a plastic mechanism (Igarashi et al., 1980s, Japan)

<u>Assumptions:</u>
1. Flange is continuous (although a center hole is permissible, if galvanizing)
2. Bolts are arranged symmetrically
3. a = b, and b is as low as possible
4. Prying of 33% allowed (at ultimate)
5. Welds will develop the tube yield strength

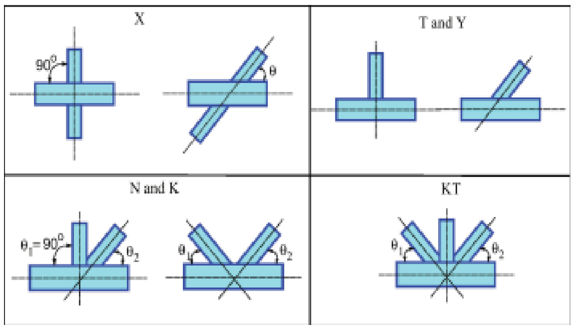




Chapter 6 – Branch Loads on HSS

- Description of classic failure modes for HSS welded connections
- Principal limit states considered in Chapters 7 (Plate-to-HSS), and Chapters 8 and 9 (HSS-to-HSS)

Typical "truss-type" (or "alphabet") connections, with branch members subject to predominantly axial loads



But connection type is not just dictated by appearance …

Chapter 6 – Branch Loads on HSS

Classification into T-, K- and Cross-connections

HSS-to-HSS truss connections 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, and are classified as (AISC 360-10):

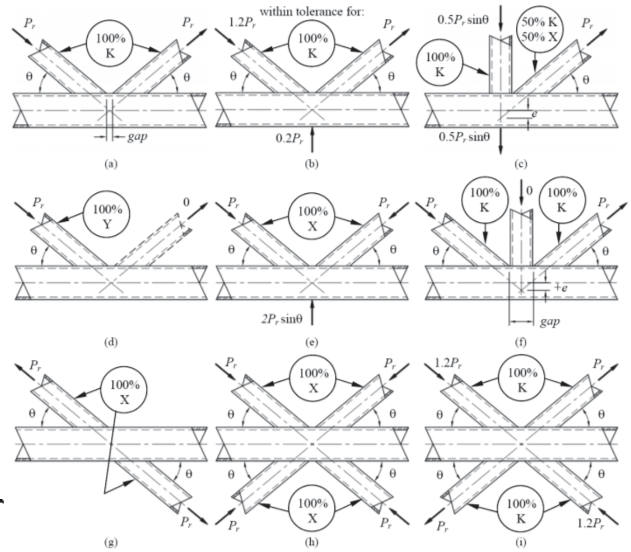
- **A T-connection when the punching load, Nsinθ or $P_r$sinθ, in a branch member is equilibrated by beam shear in the chord member (when the branch is perpendicular to the chord, otherwise it is a Y-connection).**
- **A K-connection when the punching load, Nsinθ or $P_r$sinθ, in a branch member is essentially equilibrated (within 20%) by loads in other branch member(s) on the same side of the connection. The relevant gap is between the primary branch members whose loads equilibrate.**
- **A Cross-connection (or X-connection) when the punching load, Nsinθ or $P_r$sinθ, is transmitted through the chord member and is equilibrated by branch member(s) on the opposite side.**

When branch members transmit part of their load as K-connections and part as T-, Y- or Cross-connections, the adequacy of the connections shall be determined by interpolation on the portion of the available resistance of each in total.

Chapter 6 – Branch Loads on HSS

Classification into T-, K- and Cross-connections

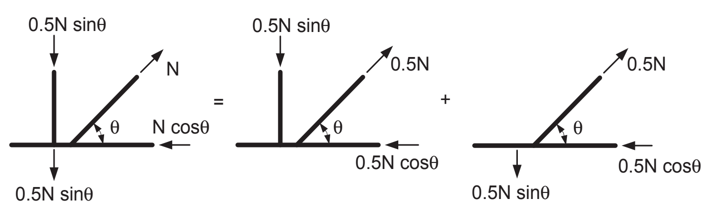
Examples



Chapter 6 – Branch Loads on HSS

Classification into T-, K- and Cross-connections

Example of an imbalanced K-connection
(Note that an N-connection is just a special case of the K-connection)

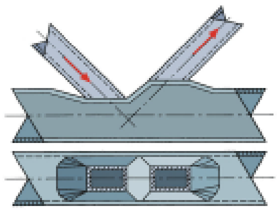


For the tension diagonal:

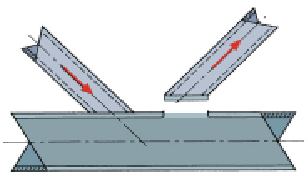
$$\frac{0.5\ \text{N}}{\text{K-conn. resistance}} + \frac{0.5\ \text{N}}{\text{X-conn. resistance}} \leq 1.0$$

Chapter 6 – Branch Loads on HSS

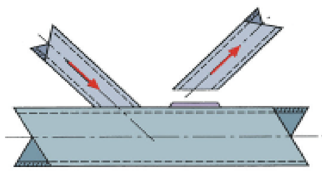
Potential Failure Modes for HSS connections



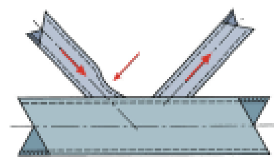
Mode A: Plastification of the Chord Face



Mode B: Punching Shear Failure of the Chord Face (out or in)



Mode C: Tension Failure of the Branch



Mode D: Local Buckling of the Branch

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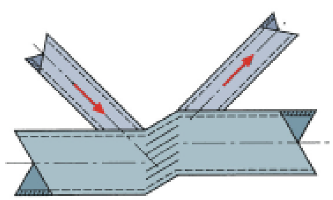
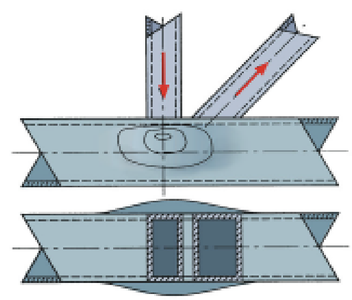
Chapter 6 – Branch Loads on HSS

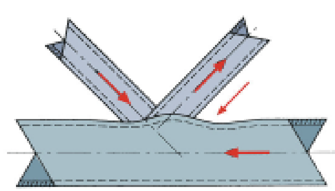
Potential Failure Modes for HSS connections



Mode E: Overall Shear Failure of the Chord



Mode F: Local Buckling of the Chord Walls (or Local Yielding in Tension)



Mode G: Local Buckling of the Chord Connecting Face

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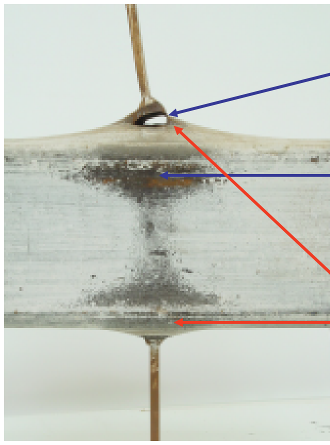
Chapter 6 – Branch Loads on HSS

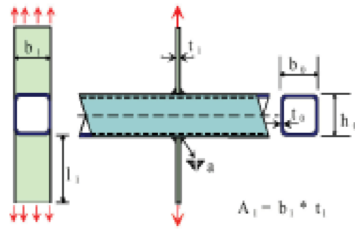
Examples of some Chord Failure Modes:
Plate-to-RHS Chord Connection



Chord punching shear
Mode B

Chord local yielding in tension
Mode F

Chord face plastification
Mode A



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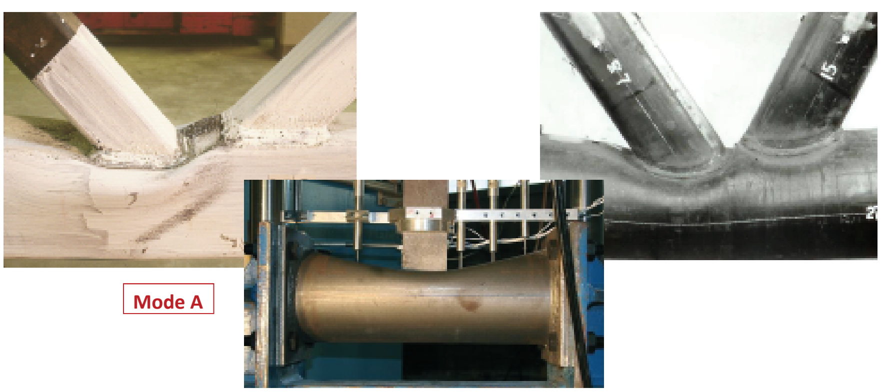
Chapter 6 – Branch Loads on HSS

Examples of some Chord Failure Modes:

Limit State of Chord Face Plastification

– prevalent in connections due to the flexible nature of the HSS connecting face



Mode A

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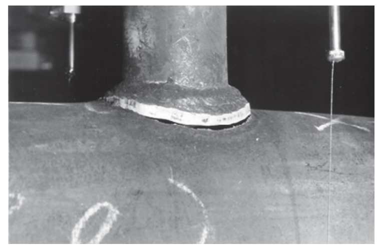
Chapter 6 – Branch Loads on HSS

Examples of some Chord Failure Modes:

Limit State of Chord Shear Yielding (Punching)

– may govern with medium-to-high branch-to-chord width ratios (β)
– failure can occur under a tension or compression branch, provided that there is space to shear through the chord wall



Mode B

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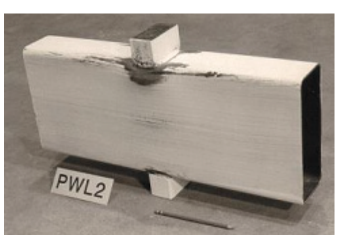
Chapter 6 – Branch Loads on HSS

Examples of some Chord Failure Modes:

Limit State of Chord Sidewall Failure

– may occur in rectangular HSS "matched box" connections
– failure can occur under a tension or compression branch, causing yielding or buckling



Mode F

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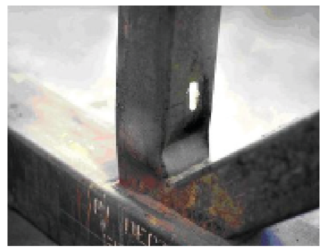
Chapter 6 – Branch Loads on HSS

Examples of some Branch Failure Modes:

Limit State of Branch Premature Failure due to Local Yielding (or Uneven Load Distribution)

– applies to transverse plates or transverse walls of rectangular HSS, under both tension and compression loading
– the dominant failure mode for overlapped K-connections (Mode D below)

Branch in Tension: Mode C



Branch in Compression: Mode D

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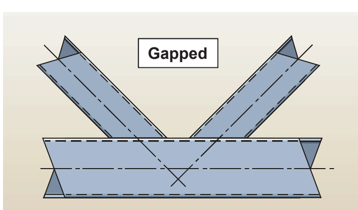
Chapter 6 – Branch Loads on HSS

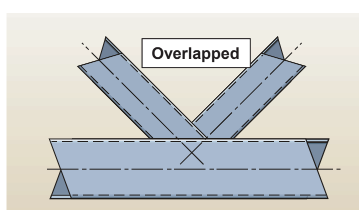
Gapped versus Overlapped Connections

Design Tips to Optimize Welded HSS Connection Design

- **Select relatively stocky chords**
- **Select relatively thin branches**
- **Consider the virtues of gapped K-connections**



- **Easier and cheaper to fabricate**



- **Higher static & fatigue strength, usually**
- **Produces a stiffer truss (reduces deflections)**

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Chapter 6 – Branch Loads on HSS

Axial Load + Bending on Branches

Note: K connections will typically only have axial forces in the branch (web) members, due to the recommended methods of analysis.
T-, Y- and Cross-connections may have axial load & bending moment applied to the branches (e.g. Vierendeel frames)

- For planar connections with Round HSS chord, check each branch for:

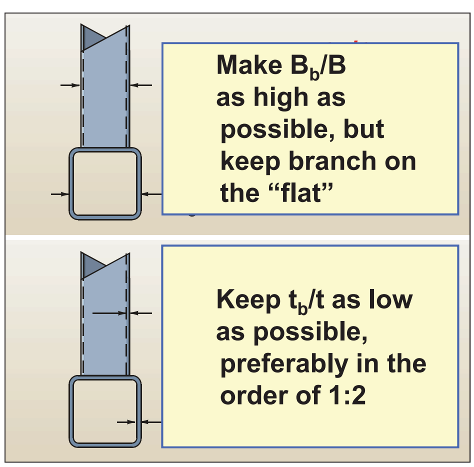
(Axial force/Axial resistance) + (In-plane bending moment/in-plane bending resistance)^2 + (Out-of-plane bending moment/out-of-plane bending resistance) $\leq$ 1.0

- For planar connections with Rectangular HSS chord, check each branch for:

(Axial force/Axial resistance) + (In-plane bending moment/in-plane bending resistance) + (Out-of-plane bending moment/out-of-plane bending resistance) $\leq$ 1.0

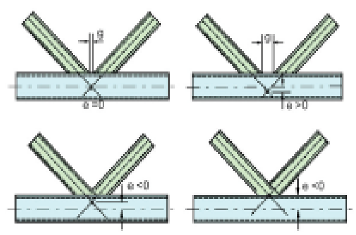
Chapter 6 – Branch Loads on HSS

Golden Rules for Connection Design



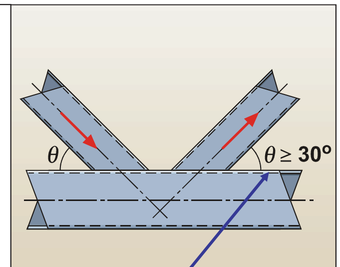
Parameter Limits of Validity

Eccentricity (e)



$-0.55 \le \frac{e}{h_o}$ or $\frac{e}{d_o} \le 0.25$

Branch (web) Angles



Within this range, any effect of eccentricity on connection strength can be ignored. Moments due to eccentricity always have to be taken into account when designing chord members.

This is a "good practice" limitation to ensure sound welds in the heel position, particularly for rectangular HSS connections. Although smaller angles *may* be possible, particularly for round HSS connections because the angle "opens up" away from the crown, such welds are not pre-qualified and not within the application limits of AISC 360-10 Chapter K.

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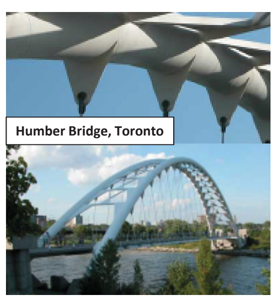
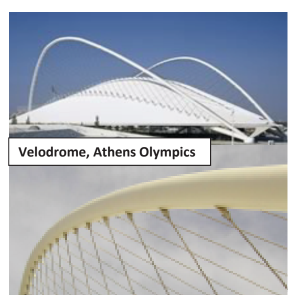
Chapter 7 – Line Loads and Concentrated Forces on HSS

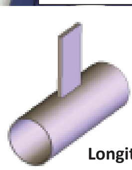
Ratner Center, Chicago



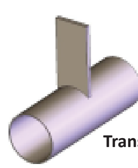
Humber Bridge, Toronto



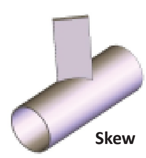
Velodrome, Athens Olympics



Longitudinal



Transverse



Skew

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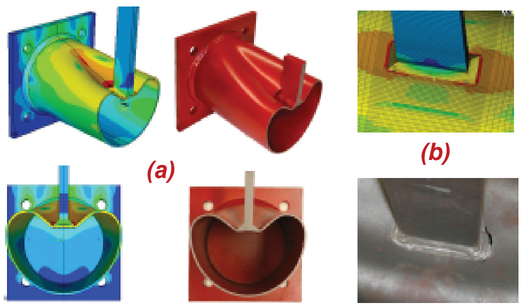
Chapter 7 – Line Loads and Concentrated Forces on HSS

AISC Design Guide follows Chapter K Section K1 of AISC 360 Specification

Covers:

- ***Local plate loads on the face of round HSS (longitudinal or transverse) Typical failure modes are: (a) HSS Plastification; (b) Punching Shear***



For round HSS, the connection is much stronger in branch tension than compression, but not in AISC formulas.

→ The much lower compression strength is used.

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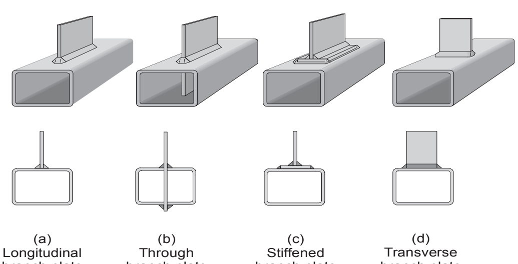
Chapter 7 – Line Loads and Concentrated Forces on HSS

AISC Design Guide follows Chapter K Section K1 of AISC 360 Specification

Covers:

- ***Local plate loads on the face of rectangular HSS (longitudinal, transverse or through). Tension & Compression Branch loading have same effect.***



Strength of (b) = 2 (a)

Strength (d) >> (a)
Also represents the flange of a beam

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Chapter 7 – Line Loads and Concentrated Forces on HSS

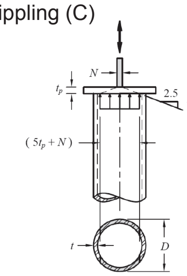
AISC Design Guide follows Chapter K Section K1 of AISC 360 Specification

Covers:

- ***Shear Tab Connections***
  - Relatively thin shear tabs & non-slender HSS are required
  - Limit states of plate yielding and HSS punching shear

Simple rule:
$t_p \leq (F_u/F_{yp})t$

- ***Cap Plate Connections***
  - Limit state of local yielding of HSS considering shear lag (C/T)
  - Limit state of HSS sidewall local crippling (C)



Chapter 8 – HSS Truss Connections

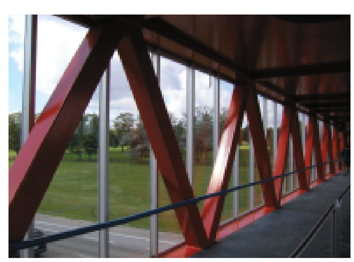
AISC Design Guide follows Chapter K Section K2 of AISC 360 Specification

Covers:

- Planar truss type connections between HSS (or box sections)
- T-,Y-,Cross-, K- (or N-) gapped or overlapped connections
- Tabulated design criteria for:
  - round-to-round HSS
  - rectangular-to-rectangular HSS

Methods of Truss Analysis:

- Fully pinned
- Continuous chord + pin-connected webs



Chapter 8 – HSS Truss Connections

Design Example: Square HSS Gapped K-Connection and Unbalanced Branch Loads

Given:
A planar roof truss contains the planar HSS 45° "gapped K-connection" shown in Figure 8–10. Note that the chord moment is necessary for equilibrium because of the noding eccentricity. Since the vertical components of the branch member forces differ by more than 20%, the connection must be treated as a combination of two types: a K-connection and a Cross-connection (see Spec. K2(b)), as demonstrated below. The loads shown consist of Live Load and Dead Load in the ratio 3:1. Determine the adequacy of the HSS connection

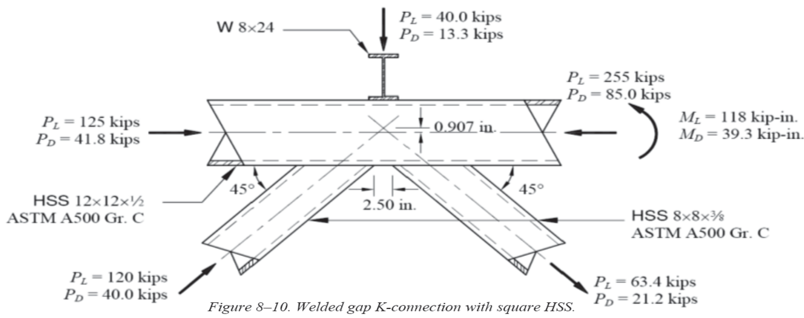


Figure 8–10. Welded gap K-connection with square HSS.

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Chapter 8 – HSS Truss Connections

Design Example

Solution:

Material Properties:

All members	ASTM A500 Gr. C	$F_y = 50$ ksi	$F_u = 62$ ksi	Manual Table 2-3

Geometric Properties:

HSS12×12×½	$B = 12.0$ in.	$H = 12.0$ in.	$t = 0.465$ in.	$A = 20.9$ in.^{2}	Manual Table 1-12
HSS8×8×⅜	$B_b = 8.00$ in.	$H_b = 8.00$ in.	$t_b = 0.349$ in.	$A_b = 10.4$ in.^{2}	

$$P_{\text{compression branch}} = 120 \text{ kips} + 40.0 \text{ kips} = 160 \text{ kips}$$

$$P_{\text{tension branch}} = 63.4 \text{ kips} + 21.2 \text{ kips} = 84.6 \text{ kips}$$

$$0.8 \le \frac{P_{\text{compression branch}} \sin\theta_{\text{compression branch}}}{P_{\text{tension branch}} \sin\theta_{\text{tension branch}}} = \frac{160 \text{ kips}(\sin 45^\circ)}{84.6 \text{ kips}(\sin 45^\circ)} = 1.89 \text{ but} > 1.2$$

Reference to AISC Manual Tables

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Chapter 8 – HSS Truss Connections

Design Example

Hence, treat the connection as shown in Figure 8–11:

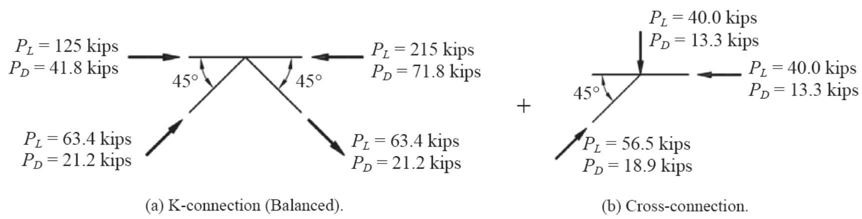

Figure 8–11. Loads for balanced K-connection (a) and Cross-connection (b).

Analysis of K-Connection (Balanced) (see Figure 8–11(a)):

Check the limits of applicability of Specification Section K2 (also see Table 8.2A)

Reference to AISC 360-10 Table K2.2A & Design Guide Tables

Chapter 8 – HSS Truss Connections

Design Example

Table 8.2A Limits of Applicability of Table 8.2

Joint eccentricity:	$-0.55 \le e/H \le 0.25$ for K-connections
Branch angle:	$\theta \ge 30°$
Chord wall slenderness:	B/t and $H/t \le 35$ for gapped K-connections and T-, Y- and Cross-connections
Branch wall slenderness:	$B/t \le 30$ for overlapped K-connections
	$H/t \le 35$ for overlapped K-connections
	B_b/t_b and $H_b/t_b \le 35$ for tension branch
	$\le 1.25\sqrt{\frac{E}{F_{yb}}}$ for compression branch of gapped K-, T-, Y- and Cross-connections
	≤ 35 for compression branch of gapped K-, T-, Y- and Cross-connections
	$\le 1.1\sqrt{\frac{E}{F_{yb}}}$ for compression branch of overlapped K-connections
Width ratio:	B_b/B and $H_b/B \ge 0.25$ for T-, Y-, Cross- and overlapped K-connections
Aspect ratio:	$0.5 \le H_b/B_b \le 2.0$ and $0.5 \le H/B \le 2.0$
Overlap:	$25\% \le O_v \le 100\%$ for overlapped K-connections
Branch width ratio:	$B_{bi}/B_{bj} \ge 0.75$ 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
Material strength:	F_y and $F_{yb} \le 52$ ksi (360 MPa)
Ductility:	F_y/F_u and $F_{yb}/F_{ub} \le 0.8$
Additional limits for gapped K-connections	
Width ratio:	$\frac{B_b}{B}$ and $\frac{H_b}{B} \ge 0.1 + \frac{\gamma}{50}$
	$\beta_{eff} \ge 0.35$
Gap ratio:	$\zeta = g/B \ge 0.5(1-\beta_{eff})$
Gap:	$g \ge t_{b\,\text{compression branch}} + t_{b\,\text{tension branch}}$
Branch size:	smaller $B_b \ge 0.63$(larger B_b), if both branches are square
Note: Maximum gap size will be controlled by the e/H limit. If gap is large, treat as two Y-connections.	

Table 8.2A gives "Limits of Applicability" of Table 8.2 (for Rectangular HSS-to-HSS Truss Connections)

Chapter 8 – HSS Truss Connections

Design Example

Analysis of K-Connection (Balanced) (see Figure 8–11(a)):

Check the limits of applicability of Specification Section K2 (also see Table 8.2A)

Connection gap, $g = 2.50$ in.

$$\text{Eccentricity, } e = \frac{\sin\theta_{b1}\sin\theta_{b2}}{\sin(\theta_{b1}+\theta_{b2})}\left(\frac{H_{b1}}{2\sin\theta_{b1}} + \frac{H_{b2}}{2\sin\theta_{b2}} + g\right) - \frac{H}{2}$$

$$= \frac{(\sin 45^\circ)^2}{\sin 90^\circ}\left(\frac{8.00\text{ in.}}{2\sin 45^\circ} + \frac{8.00\text{ in.}}{2\sin 45^\circ} + 2.50\text{ in.}\right) - \frac{12.0\text{ in.}}{2}$$

$$= 0.907\text{ in.}$$

$-0.55 \le e/H = 0.0756 \le 0.25$ **o.k.**

Checks for Limits of Applicability as applied to a Gapped K-connection

As the noding eccentricity satisfies this limit, the resulting eccentricity moment that it produces ($M_L + M_D$=118 kip-in. + 39.3 kip-in. = 157 kip-in.) can be neglected with regard to connection design. (However, it would still have an effect on chord member design, in general).

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Chapter 8 – HSS Truss Connections

Design Example

$\theta_{b1} = \theta_{b2} = 45^\circ \ge 30^\circ$ **o.k.**

$B/t = H/t = 25.8 \le 35$ **o.k.**

$B_b/t_b = H_b/t_b = 22.9$ for tension branch ≤ 35 **o.k.**

$B_b/t_b = H_b/t_b = 22.9$ for compression branch $\le 1.25\sqrt{\frac{E}{F_{yb}}} = 30.1 \le 35$ **o.k.**

$0.5 \le H_b/B_b = H/B = 1.00 \le 2.0$ **o.k.**

$F_y = F_{yb} = 50$ ksi ≤ 52 ksi **o.k.**

$F_y/F_u = F_{yb}/F_{ub} = 0.806 \simeq 0.8$ **acceptable**

$B_b/B = H_b/B = 0.667 \ge 0.1 + \gamma/50 = 0.36$ **o.k.**

$\beta_{eff} = \frac{4(8.00\text{ in.})}{4(12.0\text{ in.})} = 0.667 \ge 0.35$ **o.k.**

$\zeta = g/B = \frac{2.50\text{ in.}}{12.0\text{ in.}} = 0.208 \ge 0.5(1-\beta_{eff}) = 0.167$ **o.k.**

$g = 2.50\text{ in.} \ge t_{b\text{ compression branch}} + t_{b\text{ tension branch}} = 0.349\text{ in.} + 0.349\text{ in.} = 0.698\text{ in.}$ **o.k.**

smaller $B_b = 8.00\text{ in.} \ge 0.63(\text{larger } B_b) = 5.04$ in. **o.k.**

Checks for Limits of Applicability as applied to a Gapped K-connection

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Chapter 8 – HSS Truss Connections

Design Example

Calculate the required strength, for K-part (expressed as a force in a branch)

LRFD	ASD
For compression branch and tension branch, $P_u = 1.2(21.2 \text{ kips}) + 1.6(63.4 \text{ kips})$ $= 127 \text{ kips}$	For compression branch and tension branch, $P_a = 21.2 \text{ kips} + 63.4 \text{ kips}$ $= 84.6 \text{ kips}$

Load and Resistance Factor Design

Allowable Stress Design

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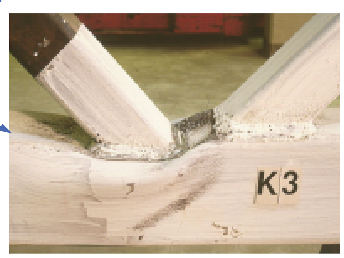
Chapter 8 – HSS Truss Connections

Design Example

Calculate the required strength, for K-part (expressed as a force in a branch)

LRFD	ASD
For compression branch and tension branch, $P_u = 1.2(21.2 \text{ kips}) + 1.6(63.4 \text{ kips})$ $= 127 \text{ kips}$	For compression branch and tension branch, $P_a = 21.2 \text{ kips} + 63.4 \text{ kips}$ $= 84.6 \text{ kips}$

Check the limit state of chord wall plastification



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Chapter 8 – HSS Truss Connections

Design Example

Table 8.2. Nominal Strengths of Rectangular HSS-to-HSS Truss Connections

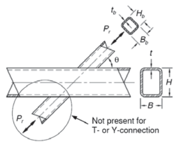
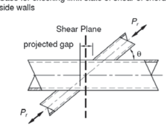
Connection Type	Connection Nominal Axial Strength	Spec. Eqn.
T-, Y- and Cross-Connections 	Limit state: chord wall plastification, when $\beta \le 0.85$	
	$P_n \sin\theta = F_y t^2 \left[\frac{2\eta}{(1-\beta)} + \frac{4}{\sqrt{1-\beta}}\right] Q_f$	(K2-13)
	$\phi = 1.00$ (LRFD) $\Omega = 1.50$ (ASD)	
	Limit state: shear yielding (punching), when $0.85 < \beta \le 1 - 1/\gamma$ or $B/t < 10$	
	$P_n \sin\theta = 0.6 F_y t B \left[2\eta + 2\beta_{eop}\right]$	(K2-14)
	$\phi = 0.95$ (LRFD) $\Omega = 1.58$ (ASD)	
	Limit state: local yielding of chord side walls, when $\beta = 1.0$	
	$P_n \sin\theta = 2 F_y t \left[5k + N\right]$	(K2-15)
	$\phi = 1.00$ (LRFD) $\Omega = 1.50$ (ASD)	
	Limit state: local crippling of chord side walls, when $\beta = 1.0$ and branch is in compression, for T- or Y-connections	
	$P_n \sin\theta = 1.6 t^2 \left[1 + \frac{3N}{H-3t}\right] \sqrt{E F_y} Q_f$	(K2-16)
	$\phi = 0.75$ (LRFD) $\Omega = 2.00$ (ASD)	
	Limit state: local crippling of chord side walls, when $\beta = 1.0$ and branches are in compression, for Cross-connections	
Case for checking limit state of shear of chord side walls 	$P_n \sin\theta = \left[\frac{48 t^3}{H-3t}\right] \sqrt{E F_y} Q_f$	(K2-17)
	$\phi = 0.90$ (LRFD) $\Omega = 1.67$ (ASD)	
	Limit state: local yielding of branch/branches due to uneven load distribution, when $\beta > 0.85$	
	$P_n = F_{yb} t_b \left[2H_b + 2b_{eoi} - 4t_b\right]$	(K2-18)
	$\phi = 0.95$ (LRFD) $\Omega = 1.58$ (ASD)	
	$b_{eoi} = \frac{10}{B/t}\left(\frac{F_y t}{F_{yb} t_b}\right) B_b \le B_b$	(K2-19)
	Limit State: shear of chord side walls, for Cross-connections with $\theta < 90°$ and where a projected gap is created (see figure). Determine $P_n \sin\theta$ in accordance with Spec. Section G5.	
Gapped K-Connections	Limit state: chord wall plastification, for all β	
	$P_n \sin\theta = F_y t^2 \left[9.8 \beta_{eff} \gamma^{0.5}\right] Q_f$	(K2-20)
	$\phi = 0.90$ (LRFD) $\Omega = 1.67$ (ASD)	
	Limit state: shear yielding (punching), when $B_b < B - 2t$ Do not check for square branches	
	$P_n \sin\theta = 0.6 F_y t B \left[2\eta + \beta + \beta_{eop}\right]$	(K2-21)
	$\phi = 0.95$ (LRFD) $\Omega = 1.58$ (ASD)	

Table 8.2. Nominal Strengths of Rectangular HSS-to-HSS Truss Connections

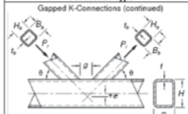
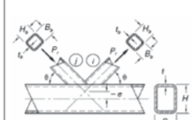
Gapped K-Connections

Limit state: chord wall plastification

Chapter 8 – HSS Truss Connections

Design Example

Table 8.2 (continued)

Connection Type	Connection Nominal Axial Strength	Spec. Eqn.
Gapped K-Connections (continued) 	Limit state: shear of chord side walls in the gap region. Determine $P_n \sin\theta$ in accordance with Spec. Section G5. Do not check for square chords.	
	Limit state: local yielding of branch/branches due to uneven load distribution. Do not check for square branches or if $B/t \ge 15$	
	$P_n = F_{yb} t_b \left[2H_b + B_b + b_{eoi} - 4t_b\right]$	(K2-22)
	$\phi = 0.95$ (LRFD) $\Omega = 1.58$ (ASD)	
	$b_{eoi} = \frac{10}{B/t}\left(\frac{F_y t}{F_{yb} t_b}\right) B_b \le B_b$	(K2-23)
Overlapped K-Connections 	Limit state: local yielding of branch/branches due to uneven load distribution.	
	$\phi = 0.95$ (LRFD) $\Omega = 1.58$ (ASD)	
	For $25\% \le O_v < 50\%$:	
	$P_{n,\,overlapping\ branch} = F_{ybi} t_{bi} \left[\frac{O_v}{50}(2H_{bi} - 4t_{bi}) + b_{eoi} + b_{eov}\right]$	(K2-24)
	For $50\% \le O_v < 80\%$:	
	$P_{n,\,overlapping\ branch} = F_{ybi} t_{bi} \left[2H_{bi} - 4t_{bi} + b_{eoi} + b_{eov}\right]$	(K2-25)
	For $80\% \le O_v \le 100\%$:	
	$P_{n,\,overlapping\ branch} = F_{ybi} t_{bi} \left[2H_{bi} - 4t_{bi} + B_{bi} + b_{eov}\right]$	(K2-26)
Note that the force arrows shown for overlapped K-connections may be reversed; i and j control member identification	where: $b_{eoi} = \frac{10}{B/t}\left(\frac{F_y t}{F_{ybi} t_{bi}}\right) B_{bi} \le B_{bi}$	(K2-27)
	$b_{eov} = \frac{10}{B_{bj}/t_{bj}}\left(\frac{F_{ybj} t_{bj}}{F_{ybi} t_{bi}}\right) B_{bi} \le B_{bi}$	(K2-28)
	Subscript i refers to the overlapping branch Subscript j refers to the overlapped branch	
	$P_{n,\,overlapped\ branch} = P_{n,\,overlapping\ branch}\left(\frac{A_{bj} F_{ybj}}{A_{bi} F_{ybi}}\right)$	

FUNCTIONS

$Q_f = 1$ for chord (connecting surface) in tension	
$Q_f = 1.3 - 0.4\frac{U}{\beta} \le 1.0$ for chord (connecting surface) in compression, for T-, Y-, and Cross-connections	(K2-10)
$Q_f = 1.3 - 0.4\frac{U}{\beta_{eff}} \le 1.0$ for chord (connecting surface) in compression, for gapped K-connections	(K2-11)
$U = \left\lvert\frac{P_r}{AF_c} + \frac{M_r}{SF_c}\right\rvert$, where P_r and M_r are determined on the side of the joint that has the higher compression stress. P_r and M_r refer to loads in the chord. $P_r = P_u$ for LRFD; P_a for ASD. $M_r = M_u$ for LRFD; M_a for ASD.	(K2-12)
$\beta_{eff} = \left[(B_b + H_b)_{compression\ branch} + (B_b + H_b)_{tension\ branch}\right]/4B$	
$\beta_{eop} = \frac{5\beta}{\gamma} \le \beta$	

Table 8.2. Nominal Strengths of Rectangular HSS-to-HSS Truss Connections (continued)

Functions

Chapter 8 – HSS Truss Connections

Design Example

Check the limit state of chord wall plastification

$$P_n \sin\theta = F_y t^2 \left[9.8\beta_{eff}\gamma^{0.5}\right] Q_f$$

$$\gamma = B/2t = 12.9$$

$$Q_f = 1.3 - 0.4\frac{U}{\beta_{eff}} \leq 1.0 \text{ for chord in compression}$$

$$U = \left|\frac{P_r}{AF_c} + \frac{M_r}{SF_c}\right|$$

Equations used to check the limit state of chord wall plastification

Spec. Eqn. K2-20 and Table 8.2

Spec. Eqn. K2-11 and Table 8.2

Spec. Eqn. K2-12 and Table 8.2

Reference to Equations in the AISC 360-05 Specification and Guide Tables

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Chapter 8 – HSS Truss Connections

Design Example

LRFD	ASD
$P_r = P_u = 1.2(71.8 \text{ kips}) + 1.6(215 \text{ kips})$ $= 430$ kips in chord on side of joint with higher compression stress	$P_r = P_a = 71.8 \text{ kips} + 215 \text{ kips}$ $= 287$ kips in chord on side of joint with higher compression stress
$F_c = F_y = 50$ ksi	$F_c = 0.6F_y = 30.0$ ksi
$U = \left\lvert\frac{430 \text{ kips}}{20.9 \text{ in.}^2(50 \text{ ksi})}\right\rvert = 0.411$	$U = \left\lvert\frac{287 \text{ kips}}{20.9 \text{ in.}^2(30.0 \text{ ksi})}\right\rvert = 0.458$
$Q_f = 1.3 - 0.4\left(\frac{0.411}{0.667}\right) = 1.05 \geq 1.0$	$Q_f = 1.3 - 0.4\left(\frac{0.458}{0.667}\right) = 1.03 \geq 1.0$
so $Q_f = 1.0$	so $Q_f = 1.0$
$P_n = 50 \text{ ksi}(0.465 \text{ in.})^2\left[9.8(0.667)(12.9)^{0.5}\right]$ $\times 1.0/\sin 45^\circ$ $= 359$ kips	$P_n = 50 \text{ ksi}(0.465 \text{ in.})^2\left[9.8(0.667)(12.9)^{0.5}\right]$ $\times 1.0/\sin 45^\circ$ $= 359$ kips
$\phi P_n = 0.90(359 \text{ kips}) = 323$ kips for both branches as θ_b is the same	$P_n/\Omega = \frac{359 \text{ kips}}{1.67} = 215$ kips for both branches as θ_b is the same
Branch utilization $= \frac{127 \text{ kips}}{323 \text{ kips}} = 0.393$	Branch utilization $= \frac{84.6 \text{ kips}}{215 \text{ kips}} = 0.393$

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Chapter 8 – HSS Truss Connections

Design Example

Table 8.2. Nominal Strengths of Rectangular HSS-to-HSS Truss Connections

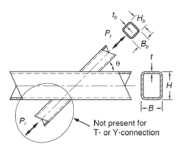
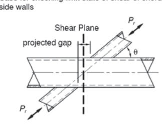
Connection Type	Connection Nominal Axial Strength	Spec. Eqn.
T-, Y- and Cross-Connections 	Limit state: chord wall plastification, when $\beta \le 0.85$ $P_n \sin\theta = F_y t^2 \left[\frac{2\eta}{(1-\beta)} + \frac{4}{\sqrt{1-\beta}}\right] Q_f$ $\phi = 1.00$ (LRFD) $\Omega = 1.50$ (ASD)	(K2-13)
	Limit state: shear yielding (punching), when $0.85 < \beta \le 1 - 1/\gamma$ or $B/t < 10$ $P_n \sin\theta = 0.6 F_y t B \left[2\eta + 2\beta_{eop}\right]$ $\phi = 0.95$ (LRFD) $\Omega = 1.58$ (ASD)	(K2-14)
	Limit state: local yielding of chord side walls, when $\beta = 1.0$ $P_n \sin\theta = 2 F_y t \left[5k + N\right]$ $\phi = 1.00$ (LRFD) $\Omega = 1.50$ (ASD)	(K2-15)
	Limit state: local crippling of chord side walls, when $\beta = 1.0$ and branch is in compression, for T- or Y-connections $P_n \sin\theta = 1.6 t^2 \left[1 + \frac{3N}{H-3t}\right] \sqrt{E F_y} Q_f$ $\phi = 0.75$ (LRFD) $\Omega = 2.00$ (ASD)	(K2-16)
Case for checking limit state of shear of chord side walls	Limit state: local crippling of chord side walls, when $\beta = 1.0$ and branches are in compression, for Cross-connections $P_n \sin\theta = \left[\frac{48 t^3}{H-3t}\right] \sqrt{E F_y} Q_f$ $\phi = 0.90$ (LRFD) $\Omega = 1.67$ (ASD)	(K2-17)
	Limit state: local yielding of branch/branches due to uneven load distribution, when $\beta > 0.85$ $P_n = F_{yb} t_b \left[2H_b + 2b_{eoi} - 4t_b\right]$ $\phi = 0.95$ (LRFD) $\Omega = 1.58$ (ASD) $b_{eoi} = \frac{10}{B/t}\left(\frac{F_y t}{F_{yb} t_b}\right) B_b \le B_b$	(K2-18) (K2-19)
	Limit State: shear of chord side walls, for Cross-connections with $\theta < 90°$ and where a projected gap is created (see figure). Determine $P_n \sin\theta$ in accordance with Spec. Section G5.	
Gapped K-Connections	Limit state: chord wall plastification, for all β $P_n \sin\theta = F_y t^2 \left[9.8 \beta_{eff} \gamma^{0.5}\right] Q_f$ $\phi = 0.90$ (LRFD) $\Omega = 1.67$ (ASD)	(K2-20)
	Limit state: shear yielding (punching), when $B_b < B - 2t$ Do not check for square branches $P_n \sin\theta = 0.6 F_y t B \left[2\eta + \beta + \beta_{eop}\right]$ $\phi = 0.95$ (LRFD) $\Omega = 1.58$ (ASD)	(K2-21)

Table 8.2. Nominal Strengths of Rectangular HSS-to-HSS Truss Connections

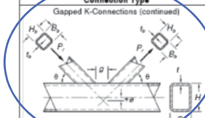
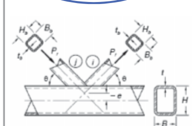
Limit state of shear yielding does not apply (since branches are square)

Gapped K-Connections

Chapter 8 – HSS Truss Connections

Design Example

Table 8.2 (continued)

Connection Type	Connection Nominal Axial Strength	Spec. Eqn.
Gapped K-Connections (continued) 	Limit state: shear of chord side walls in the gap region. Determine $P_n \sin\theta$ in accordance with Spec. Section G5. Do not check for square chords.	
	Limit state: local yielding of branch/branches due to uneven load distribution. Do not check for square branches or if $B/t \ge 15$ $P_n = F_{yb} t_b \left[2H_b + B_b + b_{eoi} - 4t_b\right]$ $\phi = 0.95$ (LRFD) $\Omega = 1.58$ (ASD) $b_{eoi} = \frac{10}{B/t}\left(\frac{F_y t}{F_{yb} t_b}\right) B_b \le B_b$	(K2-22) (K2-23)
Overlapped K-Connections  Note that the force arrows shown for overlapped K-connections may be reversed; i and j control member identification	Limit state: local yielding of branch/branches due to uneven load distribution. $\phi = 0.95$ (LRFD) $\Omega = 1.58$ (ASD) For $25\% \le O_v < 50\%$: $P_{n,\text{overlapping branch}} = F_{ybi} t_{bi} \left[\frac{O_v}{50}(2H_{bi} - 4t_{bi}) + b_{eoi} + b_{eov}\right]$ For $50\% \le O_v < 80\%$: $P_{n,\text{overlapping branch}} = F_{ybi} t_{bi} \left[2H_{bi} - 4t_{bi} + b_{eoi} + b_{eov}\right]$ For $80\% \le O_v \le 100\%$: $P_{n,\text{overlapping branch}} = F_{ybi} t_{bi} \left[2H_{bi} - 4t_{bi} + B_{bi} + b_{eov}\right]$ where: $b_{eoi} = \frac{10}{B/t}\left(\frac{F_y t}{F_{ybi} t_{bi}}\right) B_{bi} \le B_{bi}$ $b_{eov} = \frac{10}{B_{bj}/t_{bj}}\left(\frac{F_{ybj} t_{bj}}{F_{ybi} t_{bi}}\right) B_{bi} \le B_{bi}$ Subscript i refers to the overlapping branch Subscript j refers to the overlapped branch $P_{n,\text{overlapped branch}} = P_{n,\text{overlapping branch}} \left(\frac{A_{bj} F_{ybj}}{A_{bi} F_{ybi}}\right)$	(K2-24) (K2-25) (K2-26) (K2-27) (K2-28)

FUNCTIONS

$Q_f = 1$ for chord (connecting surface) in tension	
$Q_f = 1.3 - 0.4 \frac{U}{\beta} \le 1.0$ for chord (connecting surface) in compression, for T-, Y-, and Cross-connections	(K2-10)
$Q_f = 1.3 - 0.4 \frac{U}{\beta_{eff}} \le 1.0$ for chord (connecting surface) in compression, for gapped K-connections	(K2-11)
$U = \left\lvert \frac{P_r}{A F_c} + \frac{M_r}{S F_c} \right\rvert$, where P_r and M_r are determined on the side of the joint that has the higher compression stress. P_r and M_r refer to loads in the chord. $P_r = P_u$ for LRFD; P_a for ASD. $M_r = M_u$ for LRFD; M_a for ASD.	(K2-12)
$\beta_{eff} = \left[(B_b + H_b)_{\text{compression branch}} + (B_b + H_b)_{\text{tension branch}}\right] / 4B$	
$\beta_{eop} = \frac{5\beta}{\gamma} \le \beta$	

Limit state of shear of chord side walls (does not apply since chord is square)

Limit state of local yielding of branch due to uneven load distribution (does not apply since branches are square)

So analysis of balanced K-connection is all done

Chapter 8 – HSS Truss Connections

Design Example

Analysis of Cross-Connection (see Figure 8–11(b)):

Check the limits of applicability of Specification Section K2 (also see Table 8.2A)

Note that only the compression branch needs to be checked, as this is the only branch that participates in the Cross-connection force transfer.

$\theta_{b1} = 45^{\circ} \geq 30^{\circ}$ **o.k.**

$B/t = H/t = 25.8 \leq 35$ **o.k.**

$B_b/t_b = H_b/t_b = 22.9$ for compression branch $\leq 1.25\sqrt{\dfrac{E}{F_{yb}}} = 30.1$ **o.k.**

$B_b/t_b = H_b/t_b = 22.9 \leq 35$ **o.k.**

$B_b/B = H_b/B = 0.667 \geq 0.25$ **o.k.**

$0.5 \leq H_b/B_b = H/B = 1.00 \leq 2.0$ **o.k.**

$F_y = F_{yb} = 50 \text{ ksi} \leq 52 \text{ ksi}$ **o.k.**

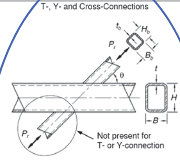
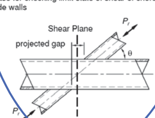
$F_y/F_u = F_{yb}/F_{ub} = 0.806 \doteq 0.8$ **acceptable**

Checks for limits of applicability as applied to a Cross-connection

Chapter 8 – HSS Truss Connections

Design Example

Table 8.2. Nominal Strengths of Rectangular HSS-to-HSS Truss Connections

Connection Type	Connection Nominal Axial Strength	Spec. Eqn.
T-, Y- and Cross-Connections 	Limit state: chord wall plastification, when $\beta \leq 0.85$ $P_n \sin\theta = F_y t^2 \left[\dfrac{2\eta}{(1-\beta)} + \dfrac{4}{\sqrt{1-\beta}}\right] Q_f$ $\phi = 1.00$ (LRFD) $\Omega = 1.50$ (ASD)	(K2-13)
	Limit state: shear yielding (punching), when $0.85 < \beta \leq 1 - 1/\gamma$ or $B/t < 10$ $P_n \sin\theta = 0.6 F_y t B \left[2\eta + 2\beta_{eop}\right]$ $\phi = 0.95$ (LRFD) $\Omega = 1.58$ (ASD)	(K2-14)
	Limit state: local yielding of chord side walls, when $\beta = 1.0$ $P_n \sin\theta = 2 F_y t \left[5k + N\right]$ $\phi = 1.00$ (LRFD) $\Omega = 1.50$ (ASD)	(K2-15)
Cross-connection	Limit state: local crippling of chord side walls, when $\beta = 1.0$ and branch is in compression, for T- or Y-connections $P_n \sin\theta = 1.6 t^2 \left[1 + \dfrac{3N}{H - 3t}\right] \sqrt{E F_y} Q_f$ $\phi = 0.75$ (LRFD) $\Omega = 2.00$ (ASD)	(K2-16)
Case for checking limit state of shear of chord side walls 	Limit state: local crippling of chord side walls, when $\beta = 1.0$ and branches are in compression, for Cross-connections $P_n \sin\theta = \left[\dfrac{48 t^3}{H - 3t}\right] \sqrt{E F_y} Q_f$ $\phi = 0.90$ (LRFD) $\Omega = 1.67$ (ASD)	(K2-17)
	Limit state: local yielding of branch/branches due to uneven load distribution, when $\beta > 0.85$ $P_n = F_{yb} t_b \left[2H_b + 2b_{eoi} - 4t_b\right]$ $\phi = 0.95$ (LRFD) $\Omega = 1.58$ (ASD)	(K2-18)
	$b_{eoi} = \dfrac{10}{B/t}\left(\dfrac{F_y t}{F_{yb} t_b}\right) B_b \leq B_b$	(K2-19)
	Limit State: shear of chord side walls, for Cross-connections with $\theta < 90^{\circ}$ and where a projected gap is created (see figure). Determine $P_n \sin\theta$ in accordance with Spec. Section G5.	
Gapped K-Connections	Limit state: chord wall plastification, for all β $P_n \sin\theta = F_y t^2 \left[9.8 \beta_{eff} \gamma^{0.5}\right] Q_f$ $\phi = 0.90$ (LRFD) $\Omega = 1.67$ (ASD)	(K2-20)
	Limit state: shear yielding (punching), when $B_b < B - 2t$ Do not check for square branches $P_n \sin\theta = 0.6 F_y t B \left[2\eta + \beta + \beta_{eop}\right]$ $\phi = 0.95$ (LRFD) $\Omega = 1.58$ (ASD)	(K2-21)

Limit state of chord wall plastification

Chapter 8 – HSS Truss Connections

Design Example

Calculate the required strength, for Cross-part (expressed as a force in the branch)

LRFD	ASD
For compression branch, $P_u = 1.2(18.9\text{ kips}) + 1.6(56.5\text{ kips}) = 113\text{ kips}$	For compression branch, $P_a = 18.9\text{ kips} + 56.5\text{ kips} = 75.4\text{ kips}$

β for compression branch $= 0.667 \leq 0.85$

Check the limit state of chord wall plastification

$$P_n \sin\theta = F_y t^2 \left[\frac{2\eta}{(1-\beta)} + \frac{4}{\sqrt{1-\beta}}\right] Q_f$$

Spec. Eqn. K2-13 and Table 8.2

$$\eta = \frac{H_b}{B\sin\theta} = \frac{8.00\text{ in.}}{12.0\text{ in.}\left(\sin 45^\circ\right)} = 0.943$$

$$Q_f = 1.3 - 0.4\frac{U}{\beta} \leq 1.0 \text{ for chord in compression}$$

Spec. Eqn. K2-10 and Table 8.2

$$U = \left|\frac{P_r}{AF_c} + \frac{M_r}{SF_c}\right|$$

Spec. Eqn. K2-12 and Table 8.2

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Chapter 8 – HSS Truss Connections

Design Example

LRFD	ASD
$P_r = P_u = 1.2(13.3\text{ kips}) + 1.6(40.0\text{ kips})$ $= 80.0$ kips in chord on side of joint with higher compression stress	$P_r = P_a = 13.3\text{ kips} + 40.0\text{ kips}$ $= 53.3$ kips in chord on side of joint with higher compression stress
$F_c = F_y = 50\text{ ksi}$	$F_c = 0.6F_y = 30.0\text{ ksi}$
$U = \left\|\frac{80.0\text{ kips}}{20.9\text{ in.}^2(50\text{ ksi})}\right\| = 0.0766$	$U = \left\|\frac{53.3\text{ kips}}{20.9\text{ in.}^2(30.0\text{ ksi})}\right\| = 0.0850$
$Q_f = 1.3 - 0.4\left(\frac{0.0766}{0.667}\right) = 1.25 \geq 1.0$	$Q_f = 1.3 - 0.4\left(\frac{0.0850}{0.667}\right) = 1.25 \geq 1.0$
so $Q_f = 1.0$	so $Q_f = 1.0$
$P_n = 50\text{ ksi}(0.465\text{ in.})^2 \times \left[\frac{2(0.943)}{(1-0.667)} + \frac{4}{\sqrt{1-0.667}}\right]\frac{1.0}{\sin 45^\circ} = 193\text{ kips}$	$P_n = 50\text{ ksi}(0.465\text{ in.})^2 \times \left[\frac{2(0.943)}{(1-0.667)} + \frac{4}{\sqrt{1-0.667}}\right]\frac{1.0}{\sin 45^\circ} = 193\text{ kips}$
$\phi P_n = 1.00(193\text{ kips}) = 193\text{ kips}$	$P_n/\Omega = \frac{193\text{ kips}}{1.50} = 129\text{ kips}$
Compression branch utilization $= \frac{113\text{ kips}}{193\text{ kips}} = 0.585$	Compression branch utilization $= \frac{75.4\text{ kips}}{129\text{ kips}} = 0.584$

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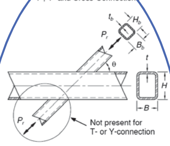
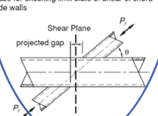
Chapter 8 – HSS Truss Connections

Design Example

Table 8.2. Nominal Strengths of Rectangular HSS-to-HSS Truss Connections

Connection Type	Connection Nominal Axial Strength	Spec. Eqn.
T-, Y- and Cross-Connections	Limit state: chord wall plastification, when $\beta \le 0.85$	
	$P_n \sin\theta = F_y t^2 \left[\frac{2\eta}{(1-\beta)} + \frac{4}{\sqrt{1-\beta}} \right] Q_f$	(K2-13)
	$\phi = 1.00$ (LRFD) $\Omega = 1.50$ (ASD)	
	Limit state: shear yielding (punching), when $0.85 < \beta \le 1 - 1/\gamma$ or $B/t < 10$	
	$P_n \sin\theta = 0.6 F_y t B \left[2\eta + 2\beta_{eop} \right]$	(K2-14)
	$\phi = 0.95$ (LRFD) $\Omega = 1.58$ (ASD)	
	Limit state: local yielding of chord side walls, when $\beta = 1.0$	
	$P_n \sin\theta = 2 F_y t \left[5k + N \right]$	(K2-15)
	$\phi = 1.00$ (LRFD) $\Omega = 1.50$ (ASD)	
Cross-connection	Limit state: local crippling of chord side walls, when $\beta = 1.0$ and branch is in compression, for T- or Y-connections	
	$P_n \sin\theta = 1.6 t^2 \left[1 + \frac{3N}{H - 3t} \right] \sqrt{E F_y} Q_f$	(K2-16)
	$\phi = 0.75$ (LRFD) $\Omega = 2.00$ (ASD)	
	Limit state: local crippling of chord side walls, when $\beta = 1.0$ and branches are in compression, for Cross-connections	
Case for checking limit state of shear of chord side walls	$P_n \sin\theta = \left[\frac{48 t^3}{H - 3t} \right] \sqrt{E F_y} Q_f$	(K2-17)
	$\phi = 0.90$ (LRFD) $\Omega = 1.67$ (ASD)	
	Limit state: local yielding of branch/branches due to uneven load distribution, when $\beta > 0.85$	
	$P_n = F_{yb} t_b \left[2H_b + 2b_{eoi} - 4t_b \right]$	(K2-18)
	$\phi = 0.95$ (LRFD) $\Omega = 1.58$ (ASD)	
	$b_{eoi} = \frac{10}{B/t} \left(\frac{F_y t}{F_{yb} t_b} \right) B_b \le B_b$	(K2-19)
	Limit State: shear of chord side walls, for Cross-connections with $\theta < 90°$ and where a projected gap is created (see figure). Determine $P_n \sin\theta$ in accordance with Spec. Section G5.	
Gapped K-Connections	Limit state: chord wall plastification, for all β	
	$P_n \sin\theta = F_y t^2 \left[9.8 \beta_{eff} \gamma^{0.5} \right] Q_f$	(K2-20)
	$\phi = 0.90$ (LRFD) $\Omega = 1.67$ (ASD)	
	Limit state: shear yielding (punching), when $B_b < B - 2t$ Do not check for square branches	
	$P_n \sin\theta = 0.6 F_y t B \left[2\eta + \beta + \beta_{eop} \right]$	(K2-21)
	$\phi = 0.95$ (LRFD) $\Omega = 1.58$ (ASD)	

All other limit states where $1.0 \ge \beta \ge 0.85$ do not apply because $\beta = 0.667$

Limit state of shear of chord side walls does not apply (because no shear plane is evident)

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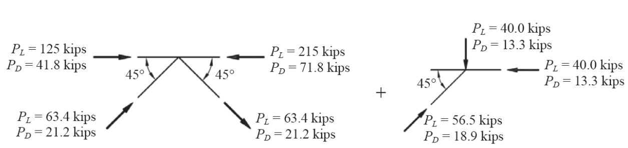
Chapter 8 – HSS Truss Connections

Design Example

Finally, check the total utilization of each branch member:

For compression branch: 0.39 (Balanced K) + 0.59 (Cross) = 0.98 ≤ 1.0 **o.k.**
For tension branch: 0.39 (Balanced K) + 0 (Cross) = 0.39 ≤ 1.0 **o.k.**
(Summations–in this case–are the same for both LRFD and ASD).



(a) K-connection (Balanced). (b) Cross-connection.

Figure 8–11. Loads for balanced K-connection (a) and Cross-connection (b).

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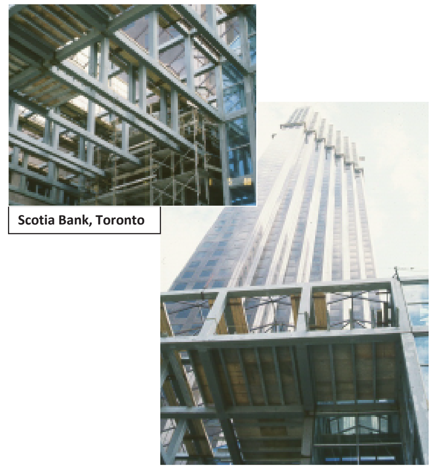
Chapter 9 – HSS Moment Connections

AISC Design Guide follows Chapter K Section K3 of AISC 360 Specification

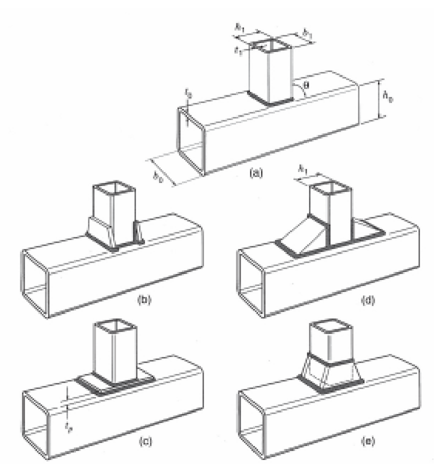
Covers:

- Planar truss type connections between HSS (or box sections)
- T-,Y- and Cross-connections
- Partially or fully restrained moment connections (e.g. Vierendeel frames)
- Tabulated design criteria for:
  - round-to-round HSS
  - rectangular-to-rectangular HSS


Scotia Bank, Toronto

Chapter 9 – HSS Moment Connections

HSS-to-HSS Moment Connection Types under In-plane Bending



- (a) Unreinforced – *only fully rigid if $\beta = 1.0$, $b_0/t_0 \leq 16$ and $t_0/t_1 \geq 2$*
- (b) With branch plate stiffeners
- (c) With chord plate stiffener
- (d) With haunch stiffeners
- (e) With truncated pyramid stiffeners

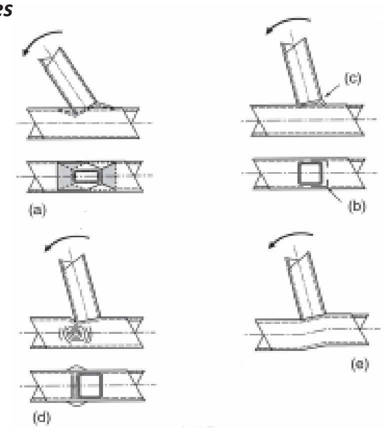
Chapter 9 – HSS Moment Connections

HSS-to-HSS Moment Connections under In-plane Bending

– Possible Failure Modes

– Very similar to branch axial loading limit states
– Very similar for Out-of-Plane Bending

(a) Chord face plastification
(b) Punching shear of the chord face
(c) Premature local yielding of branch ("effective width" failure)
(d) Chord side wall failure (yielding or buckling)
(e) Chord shear failure



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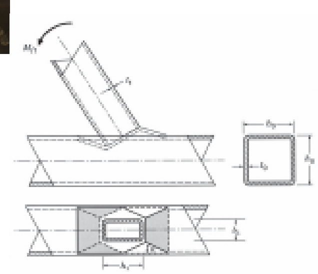
Chapter 9 – HSS Moment Connections

HSS-to-HSS Moment Connections under In-plane Bending
– Failure Modes of Chord Plastification + Punching Shear



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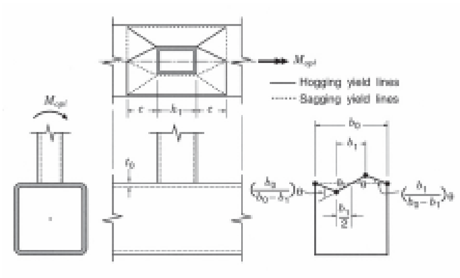
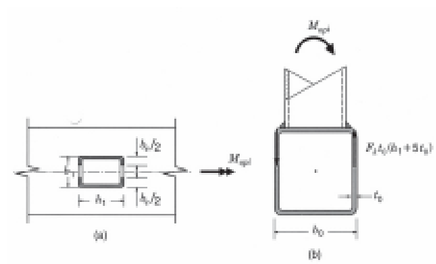
Chapter 9 – HSS Moment Connections

HSS-to-HSS Moment Connections under Out-of--plane Bending





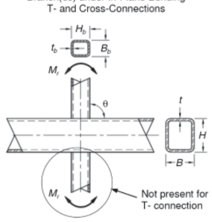
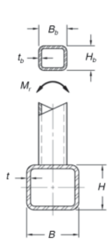
- **Yield line mechanism for chord plastification under out-of-plane bending, for β ≤ 0.85**

- **Basis of design models for:**
  (a)Local yielding of the branch, for β > 0.85
  (b) Chord side wall local yielding, for β > 0.85

Chapter 9 – HSS Moment Connections

AISC DG24 Format

Table 9.2. Nominal Capacities of Rectangular HSS-to-HSS Moment Connections

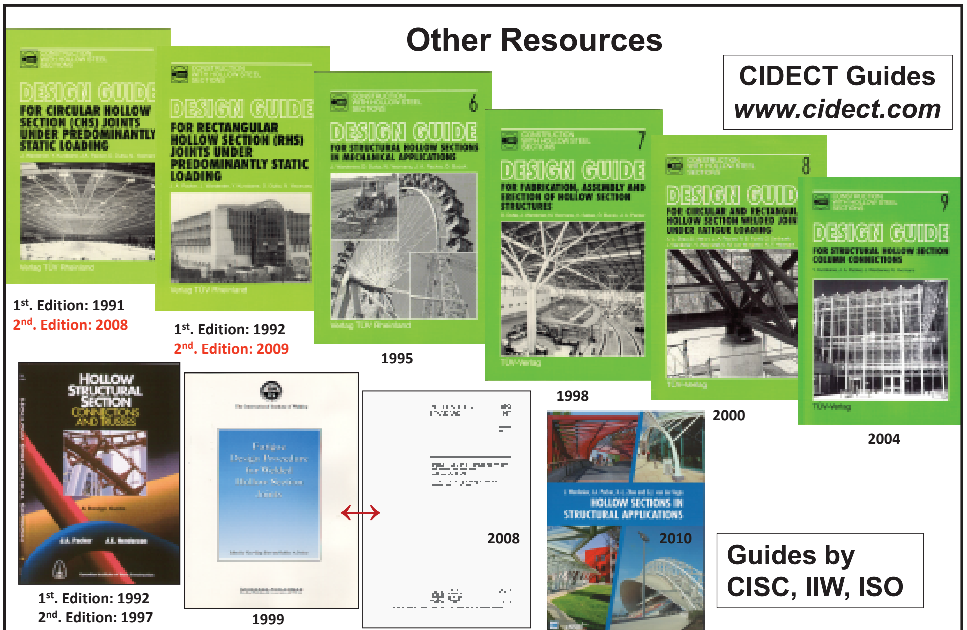
Connection Type	Connection Nominal Moment Capacity	Spec. Eqn.
Branch(es) under In-Plane Bending T- and Cross-Connections  Not present for T- connection	Limit state: chord wall plastification, when $\beta \le 0.85$ $M_n = F_y t^2 H_b \left[\frac{1}{2\eta} + \frac{2}{\sqrt{1-\beta}} + \frac{\eta}{(1-\beta)}\right] Q_f$ $\phi = 1.00$ (LRFD) $\Omega = 1.50$ (ASD)	(K3-11)
	Limit state: sidewall local yielding, when $\beta > 0.85$ $M_n = 0.5 F_y^* t (H_b + 5t)^2$ $\phi = 1.00$ (LRFD) $\Omega = 1.50$ (ASD)	(K3-12)
	Limit state: local yielding of branch/branches due to uneven load distribution, when $\beta > 0.85$ $M_n = F_{yb}\left[Z_b - \left(1 - \frac{b_{eoi}}{B_b}\right) B_b H_b t_b\right]$ $\phi = 0.95$ (LRFD) $\Omega = 1.58$ (ASD)	(K3-13)
Branch(es) under Out-of-Plane Bending T- and Cross-Connections 	Limit state: chord wall plastification, when $\beta \le 0.85$ $M_n = F_y t^2 \left[\frac{0.5 H_b (1+\beta)}{(1-\beta)} + \sqrt{\frac{2BB_b(1+\beta)}{(1-\beta)}}\right] Q_f$ $\phi = 1.00$ (LRFD) $\Omega = 1.50$ (ASD)	(K3-15)
	Limit state: sidewall local yielding, when $\beta > 0.85$ $M_n = F_y^* t (B - t)(H_b + 5t)$ $\phi = 1.00$ (LRFD) $\Omega = 1.50$ (ASD)	(K3-16)
	Limit state: local yielding of branch/branches due to uneven load distribution, when $\beta > 0.85$ $M_n = F_{yb}\left[Z_b - 0.5\left(1 - \frac{b_{eoi}}{B_b}\right)^2 B_b^2 t_b\right]$ $\phi = 0.95$ (LRFD) $\Omega = 1.58$ (ASD)	(K3-17)
	Limit state: chord distortional failure, for T-connections and unbalanced Cross-connections $M_n = 2F_y t\left[H_b t + \sqrt{BHt(B+H)}\right]$ $\phi = 1.00$ (LRFD) $\Omega = 1.50$ (ASD)	(K3-19)

In-Plane bending

Out-of-Plane bending

Other Resources

CIDECT Guides
www.cidect.com



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2nd. Edition: 2009

1995

1998

2000

2004

1st. Edition: 1992
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1999

2008

2010

Guides by CISC, IIW, ISO

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HSS Connection Software

New on-line software, for the analysis of welded HSS truss-type connections and plate-to-HSS connections, in accord with AISC 360-10 Chapter K, suitable for all computer operating systems, will be available in 2013, from the Steel Tube Institute …

HSS_connex
(1999–2012)
for 32-bit computers

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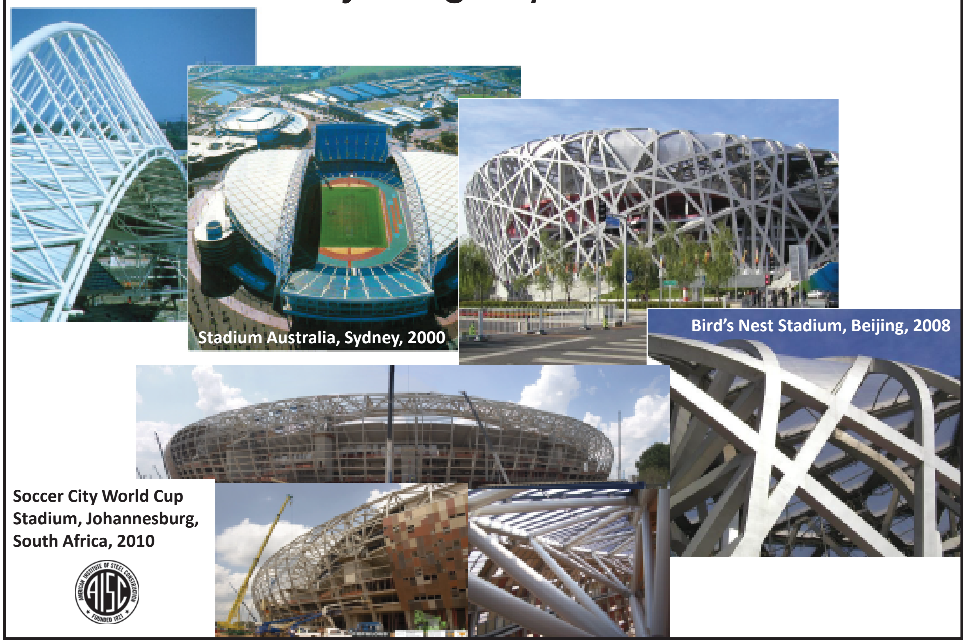
Anything is possible with HSS



Soccer City World Cup Stadium, Johannesburg, South Africa, 2010

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  - Duane K. Miller, Sc.D., P.E., The Lincoln Electric Company.

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- Fundamentals of Stability for Steel Design
- Presented by Members of the Structural Stability Research Council
- Registration opens April 1, 2013.
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