HSS Truss Connections: The T's, Y's and K's Of It All

SEAONY

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Learning Objectives

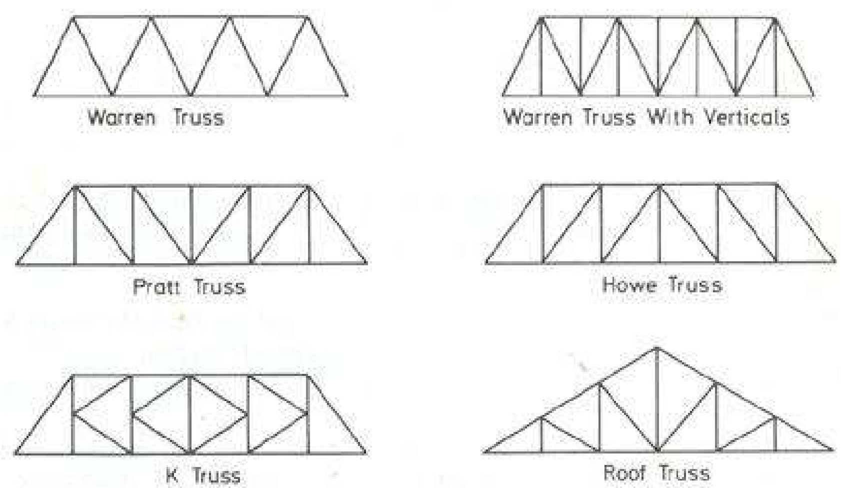
- Identify ways that HSS truss joint configurations relate to the overall strength and stiffness of the truss.
- Understand the different limit states that control the design of different joint configurations.
- Understand that fabrication cost of an HSS truss is directly related to the design of the truss joints and connections, rather than the overall weight of the truss.
- Apply concepts used for planar trusses to the analysis and design of multi-planar trusses

Truss Connections

Connections at the panel points of a planar truss

Trusses are typically analyzed with branch members "pinned"

Truss connections are designed as tension/compression connections



Types of simple Plane truss

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Truss Connections - Nomenclature

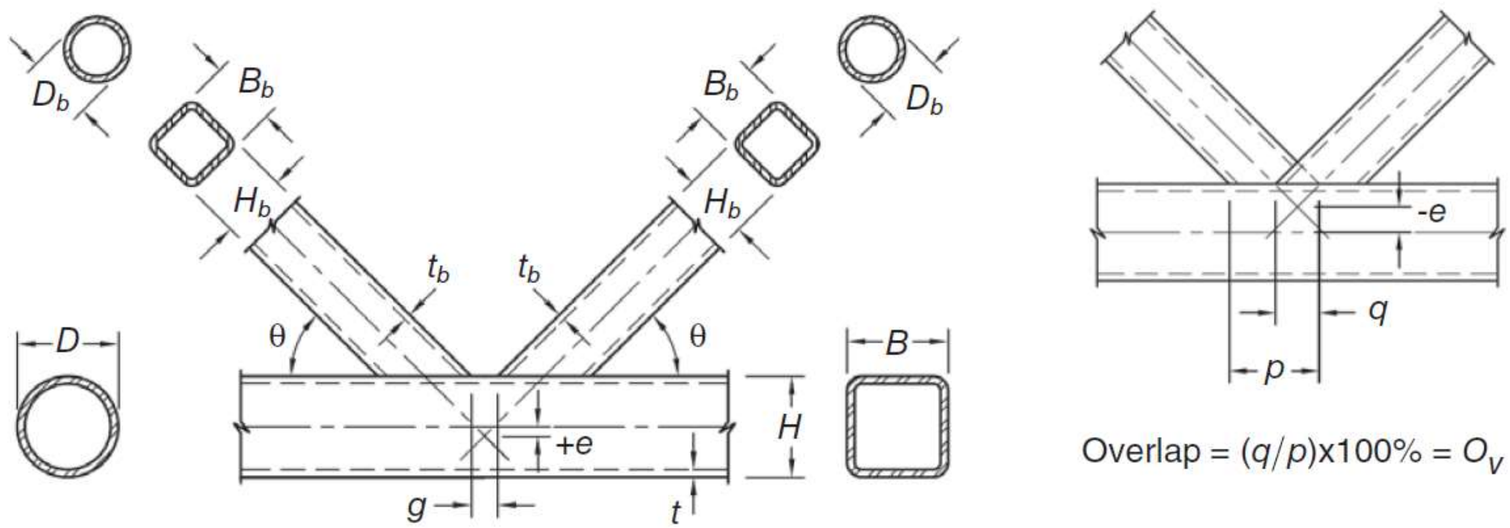

Fig. 8-1. Common notation for HSS truss connections.

Truss Connections - Analysis

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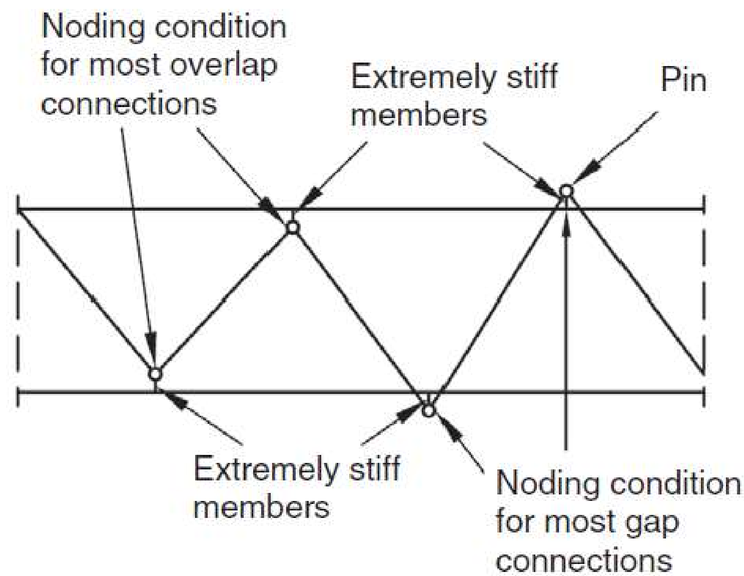
Three options for analysis of planar welded HSS trusses:

1. Pin Jointed Analysis – All members pinned
2. Pin Jointed Web Members, Continuous Chord Members
   - **Extremely stiff members can be used to model the nodal eccentricity, e**
3. Rigid Frame Analysis – Everything fixed



- Method 2 gives best prediction of deflection
- AISC spec does not provide deformation limits however International Institute of Welding (IIW, 2012) gives connection deformation limits

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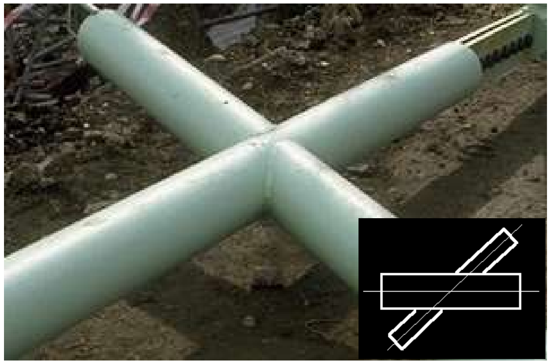
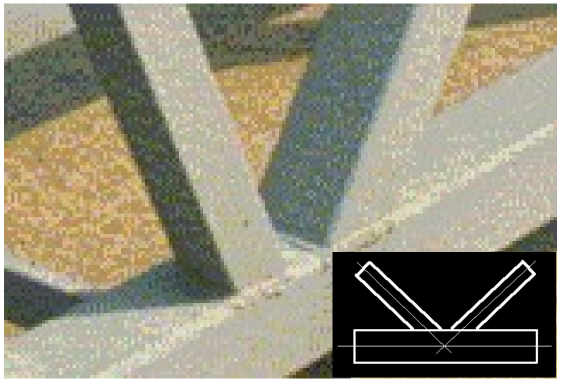
Planar Truss Connections – Joint Types

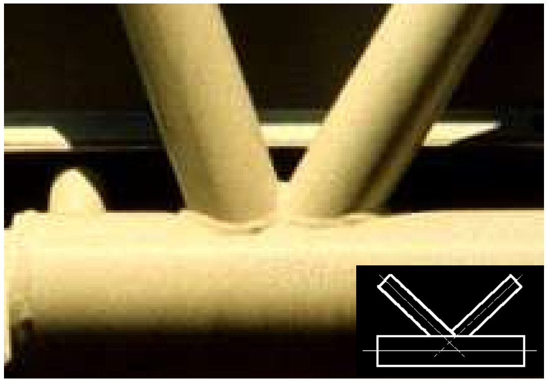
T or Y-Joint



X-Joint or Cross



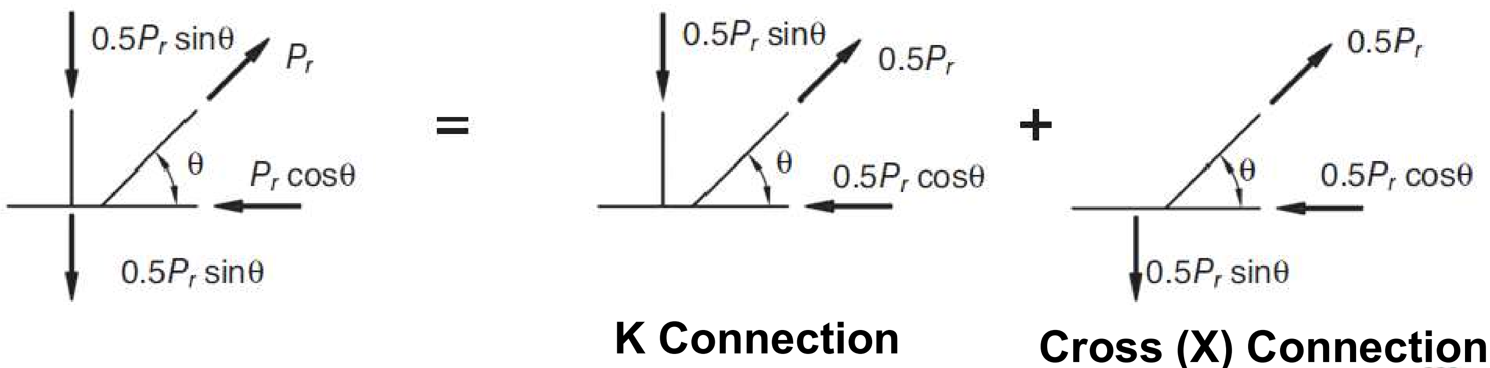
Gap K-Joint
(includes N)



Overlap K-Joint

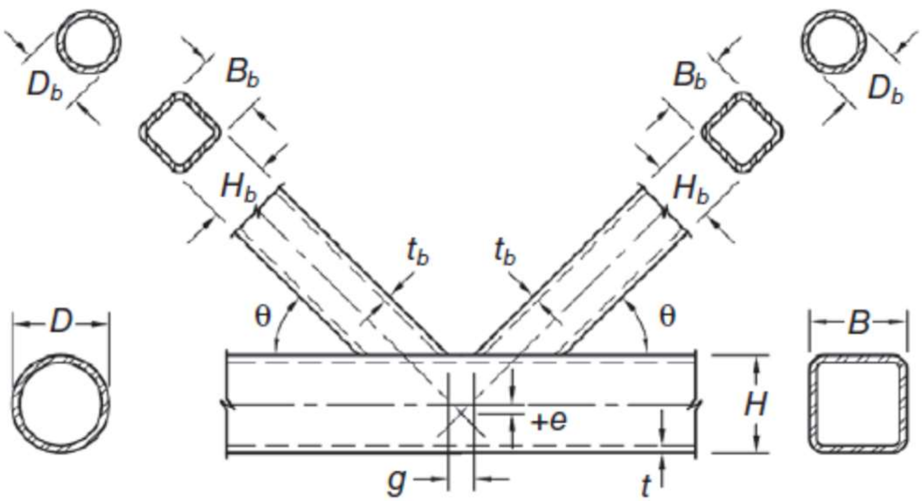
Planar Truss Connections – Joint Types

- Classification of joints is based on method of force transfer in the connection and not the physical appearance of the connection
- When branch members transmit part of their forces as one classification and part as another, then the adequacy of each branch is determined by linear interaction in proportion to how each portion is transferred.



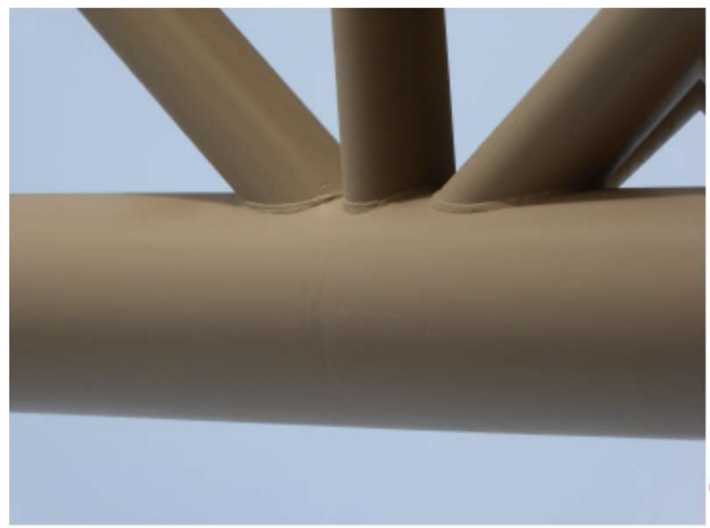
Gapped K Joints

- If gap between branches gets large and the eccentricity limit is violated (e/D or e/H), then treat as two Y connections
- Minimum gap is the sum of the thicknesses of the branch members (t_{b1} + t_{b2}), for ease of fabrication
- If one branch has little or no load, treat it as Y connection for the branch with the load.



KT Joints

- KT joints occur in modified Warren truss where three branch members come together at a joint
- Outside the scope of AISC 360, Chp K.
- Suggested analysis and design technique in Engineering Journal paper: "HSS Truss Connections With Three Branches", Jeffrey A. Packer, AISC Engineering Journal, 3rd Qtr, 2014



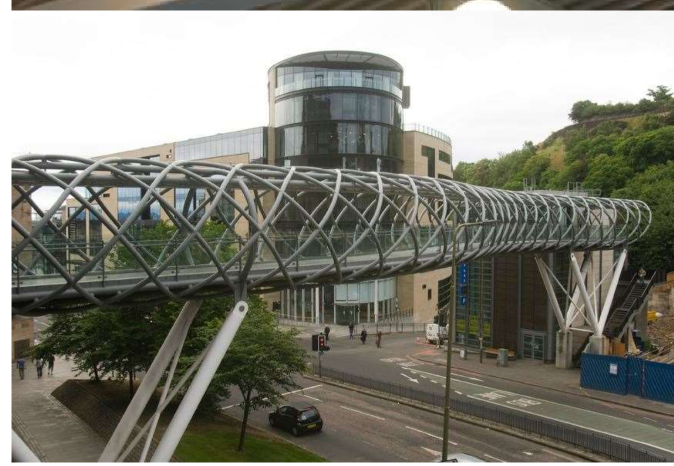
Member Selection – Round vs. Square

Square/Rect sections

- Work best in planar trusses
- Simpler connections
- Lower fabrication costs
- Easier to support decking at chords

Round sections

- Ideal for 3D (multi-planar) trusses
- Higher fabrication costs
- Higher joint strength/stiffness



Truss Connections – Rnd Branch, Sq Chord

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- Not covered by AISC 360-10, Chapter K
- However, Chp K Commentary states you can use "other verified design guidance…"
- Research by Packer, J.A., Mashiri, F.R., Zhao, X.L. and Willibald, S. ("Static and Fatigue Design of CHS-to-RHS Welded Connections using a Branch Conversion Method", Journal of Constructional Steel Research, Vol. 63, No.1, 2007, pp. 82-95.)
- For calculation purposes you "convert" the round sections to square sections and then use the Chp K equations.
- Branches of diameter D are replaced by members of width $B = (\pi/4)*D$ and the same wall thickness is used.

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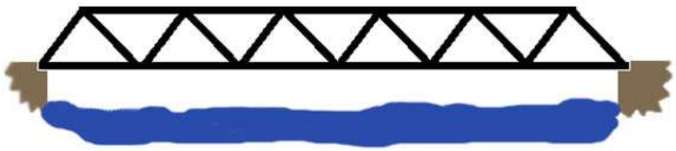
Truss Connections – Fabrication Costs

- Minimum weight does not equal minimum cost
- Try to optimize truss depth
  - A truss can be too deep
  - Typical span/depth ratio between 10 and 15
- Keep the number of different sizes small
- Try to minimize number of connections

➔ Warren trusses



Understand effects of joint configuration and connection design criteria before analyzing truss and selecting member sizes!

Fabrication Cost – Effects of Joint Type

Lowest Cost	RHS chord — gap joints	Lowest Joint Strength & Stiffness
↓	RHS chord — 100% overlap joints	↓
	CHS chord — gap joints	
	RHS chord — partial overlap joints	
	CHS chord — 100% overlap joints	
Highest Cost	CHS chord — partial overlap joints	Highest Joint Strength & Stiffness

Matched sizes will have higher fabrication cost versus unmatched

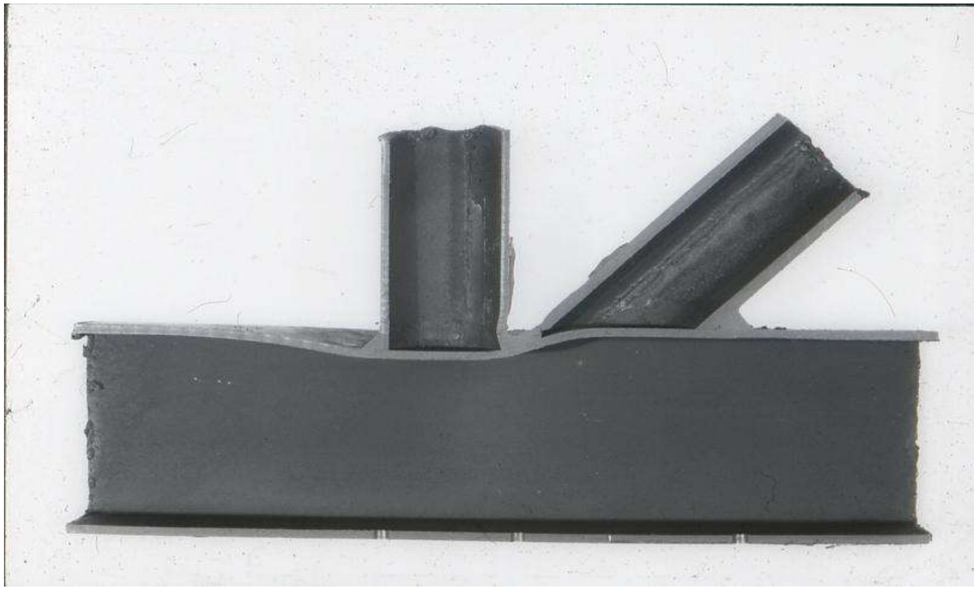
Typical Failure Modes

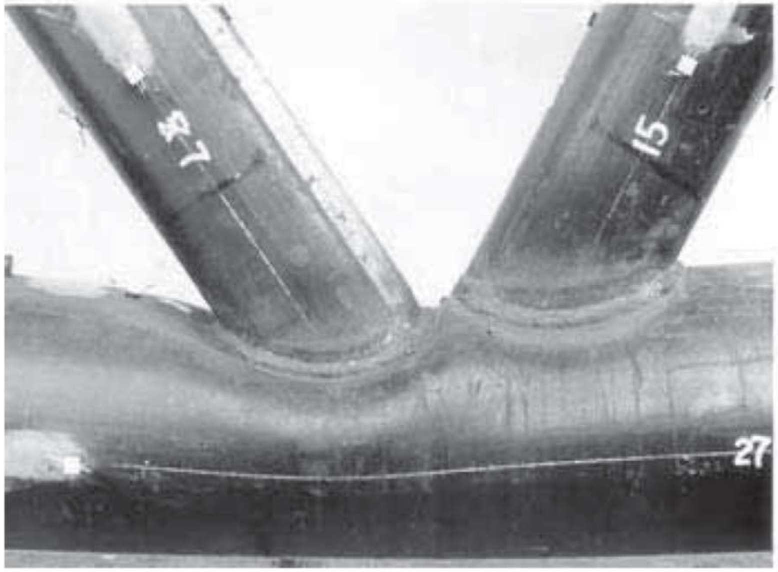
1. Plastification of chord face
2. Chord punching shear
3. Chord sidewall buckling
4. Local brace failure
   - Local yielding of tension brace
   - Local yielding/buckling of compression brace
5. Chord shear failure
6. Chord local buckling

Square/Rect HSS
Modes 1,2,3,4,5

Round HSS
Modes 1,2

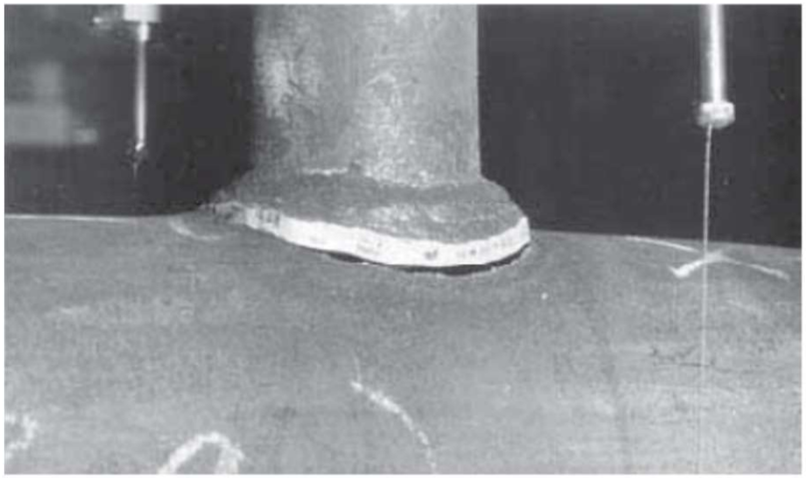
Plastification of Chord Face

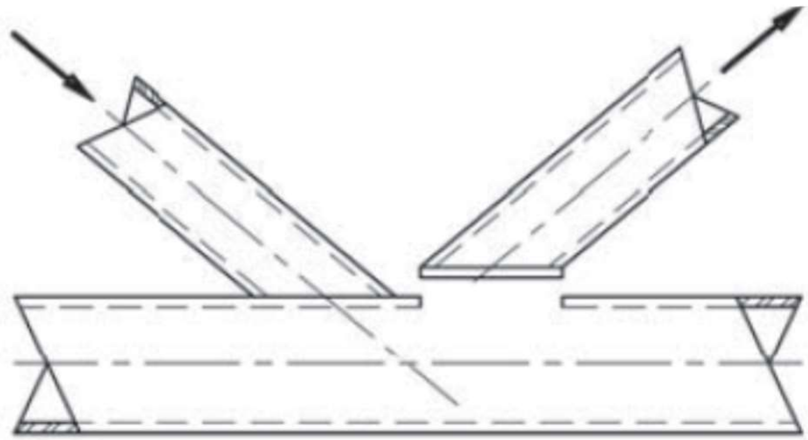




- Most common failure mode in T, Y, X & gap K and N especially when $\beta < 0.85$

Chord Punching Shear



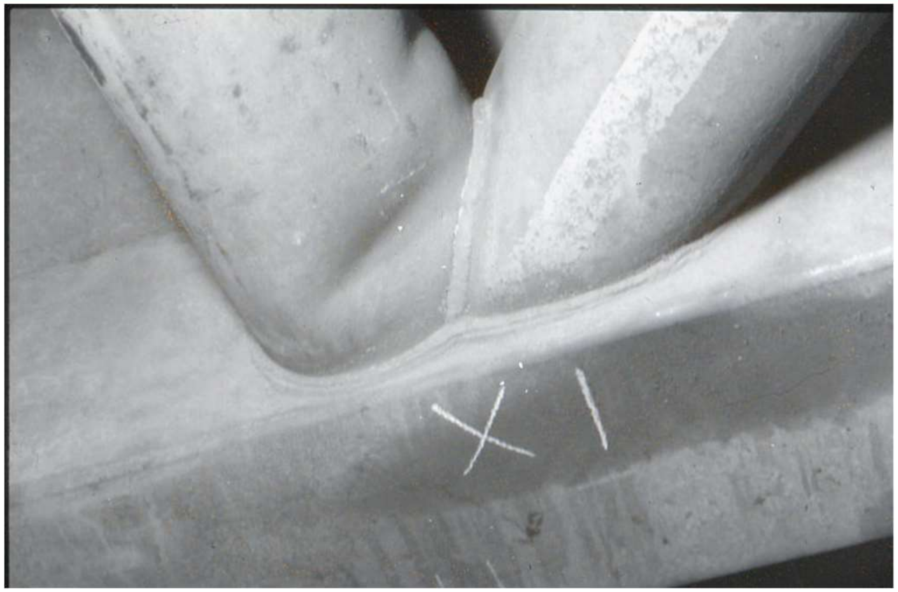


- Based on shear yielding of chord material
- For rectangular HSS, effective width is used due to non-uniform stress (i.e., higher stress closer to edge of chord member
- Circular HSS will have uniform stress around the footprint

Chord Sidewall Buckling/Yielding

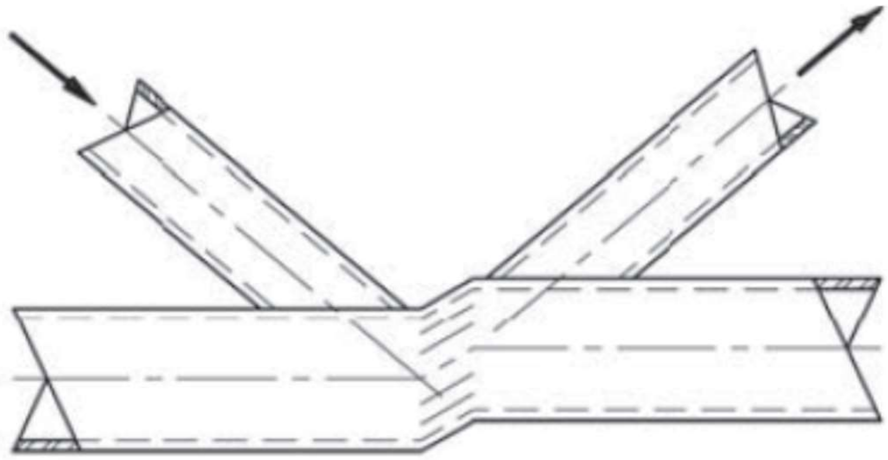
- Potential failure mode for rectangular sections with β close to 1.0 (.i.e., “matched connections”)
- Limit states derived from Chapter J (local yielding & crippling, web buckling) for 2 webs

Brace Local Buckling



- Most common failure mode (compression) for overlapped connections with rectangular HSS. Rarely occurs in circular HSS.
- Can be avoided if joint parameters are met.

Chord Shear



- Can occur in gapped K connections where gap exceeds limits
- Can also occur when chord has a low depth to width ratio (H/B)

Chord Local Buckling

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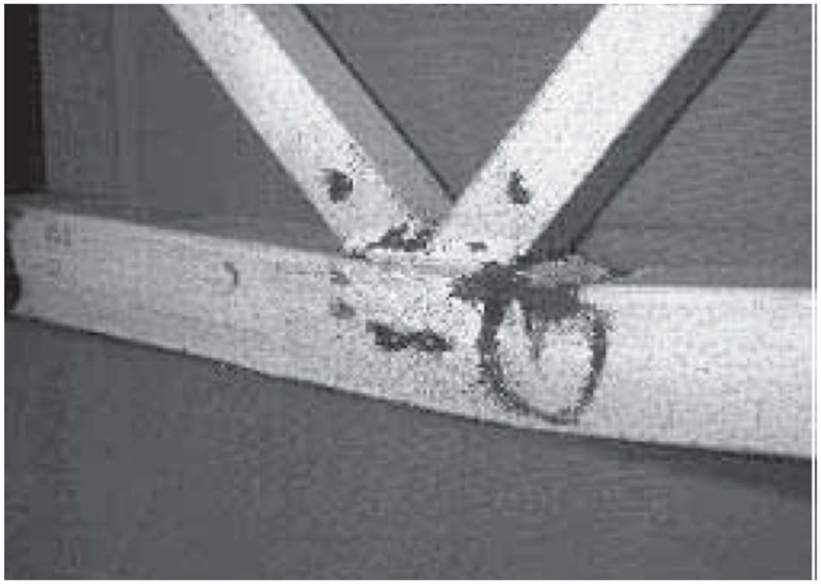

- Failure mode for rectangular HSS in overlapped K connections
- Caused by shear lag effect when high axial force is carried in the connecting face of the chord
- Avoided when following wall slenderness limits for chord

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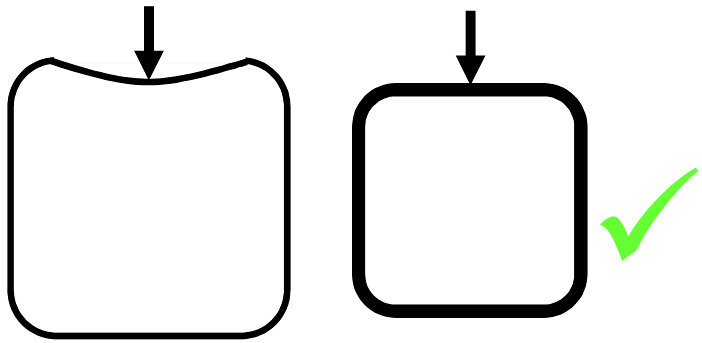
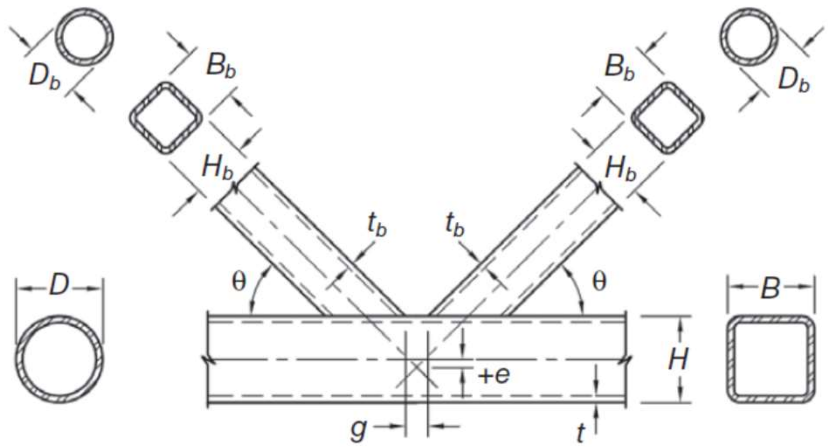
Parameter Effects - Chord width to thickness ratio



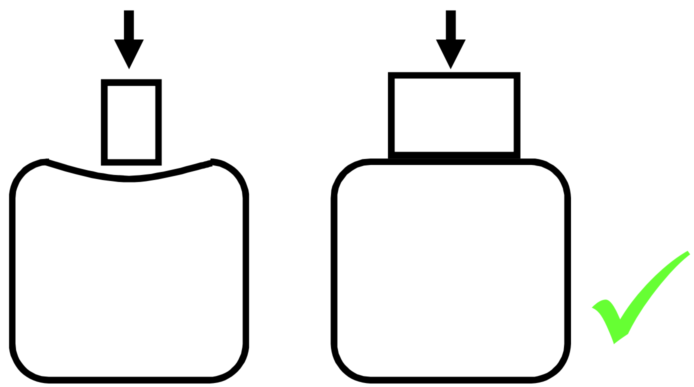
- When D/t or B/t ratio goes down, joint capacity goes up
- Counter to traditional thinking: Natural instinct is to choose thin-walled section with high radius of gyration
- $15 \leq D/t \leq 30$
- $15 \leq B/t \leq 25$

Parameter Effects - Branch width to thickness



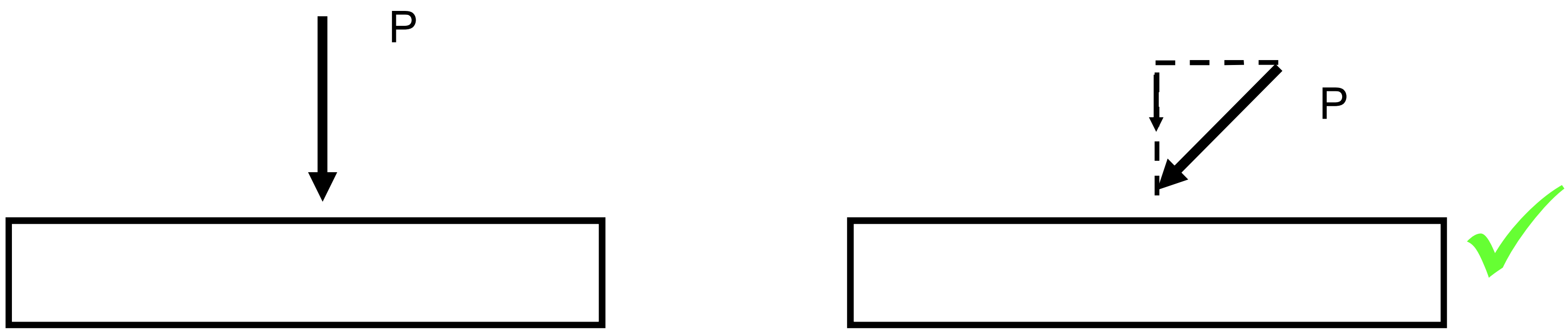
- To maximize connection efficiency, use relatively thin walled branch members relative chord wall
- Use high D/t or B/t ratio for branch members
- Try to keep t_b/t as low as possible and B_b/B as high as possible
- $t_b < t$ improves weld design (avoid welding "thick to thin")

Parameter Effects - Bracing to Chord Width Ratio



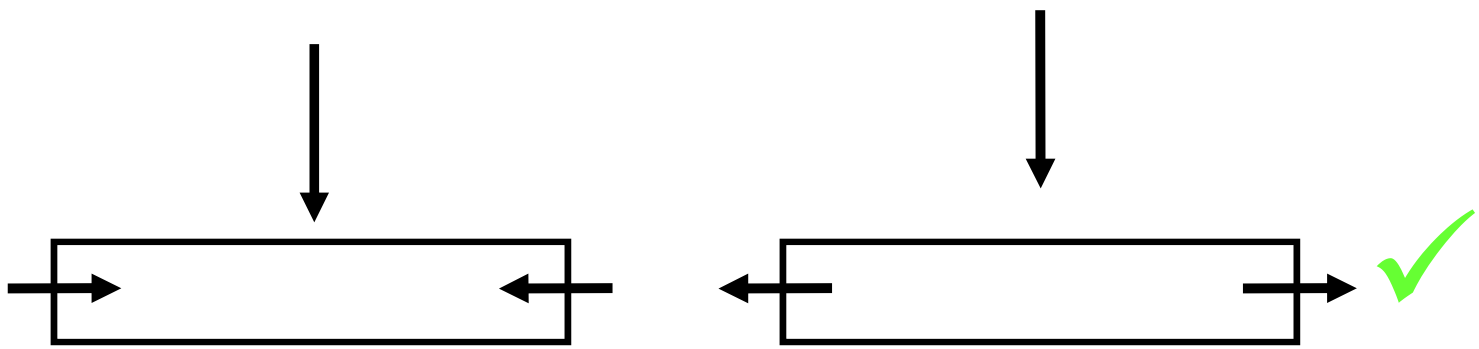
- Keep B_b/B high to increase joint capacity
- Try to keep $B_b < B- 4t$
- Allows for use of fillet welds all around
- Avoids flare bevel welds for "matched" sections

Parameter Effects - Bracing Angle



- Lowering bracing angle will increase joint capacity
- $\theta \geq 30$ degrees is a practical limit. Lower bracing angles are possible but the welding of the heel can become difficult for square/rectangular HSS.

Parameter Effects - Chord Force To Yield Ratio



- Keep ratio of actual force to yield low in compression chord to increase joint capacity
- Achieved by using stocky sections (low D/t or B/t)

Parameter Effects – Overlap Joints Bracing Width to Thickness Ratio

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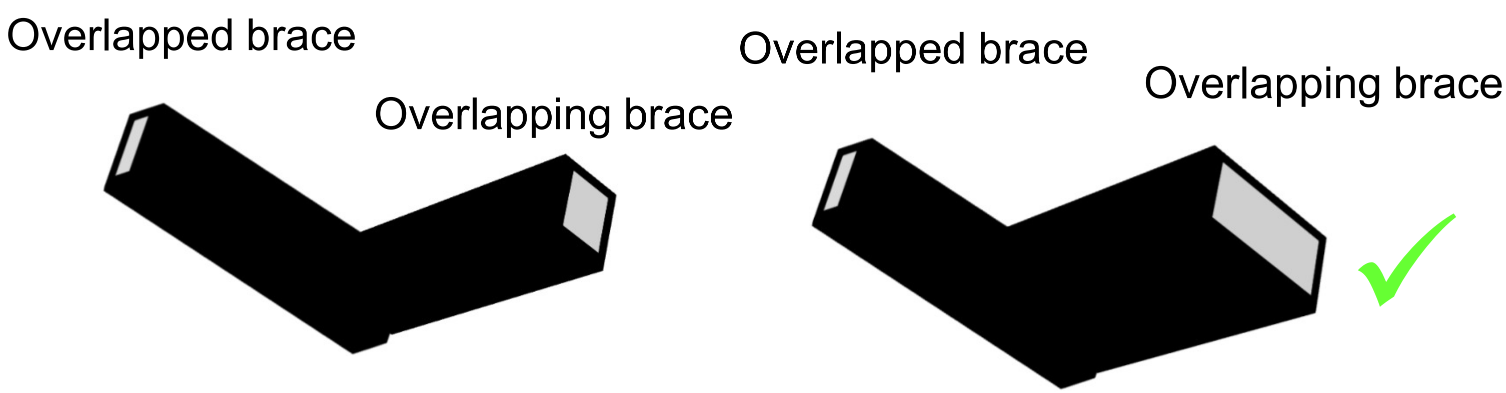

- Joint capacity goes up when overlapping brace is nearly as wide as overlapped brace
- For square/rectangular: $B_{overlapping} \geq 0.75\ B_{overlapped}$
- For all shapes: $t_{b\ overlapping} \leq t_{b\ overlapped}$

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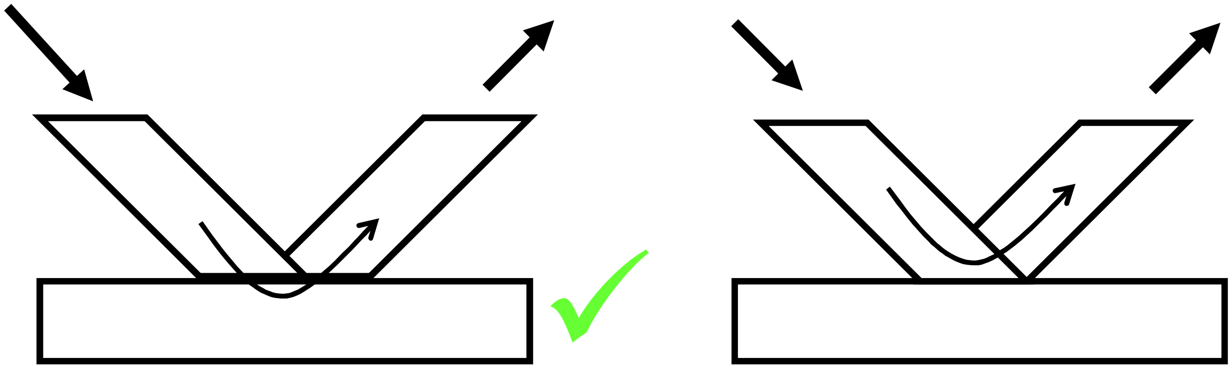
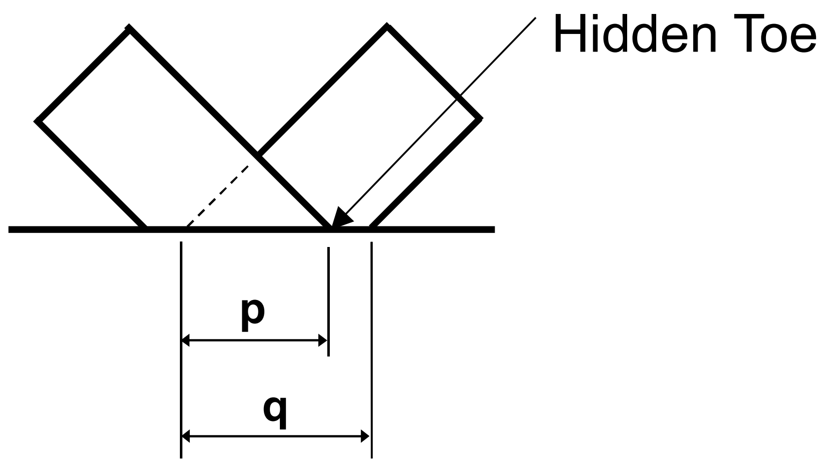
Parameter Effects – Overlap Joints Percent of Overlap



- Overlapped joints have higher strength & stiffness and improved fatigue resistance than gapped joints.
- Partial overlapped have higher capacity than 100% overlap
- Recommend min 25% overlap

Overlap Detail



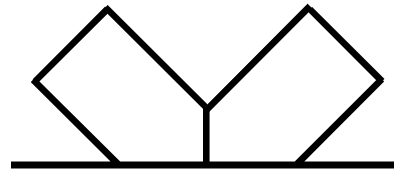
Hidden toe need not be welded (tack weld for fitup)

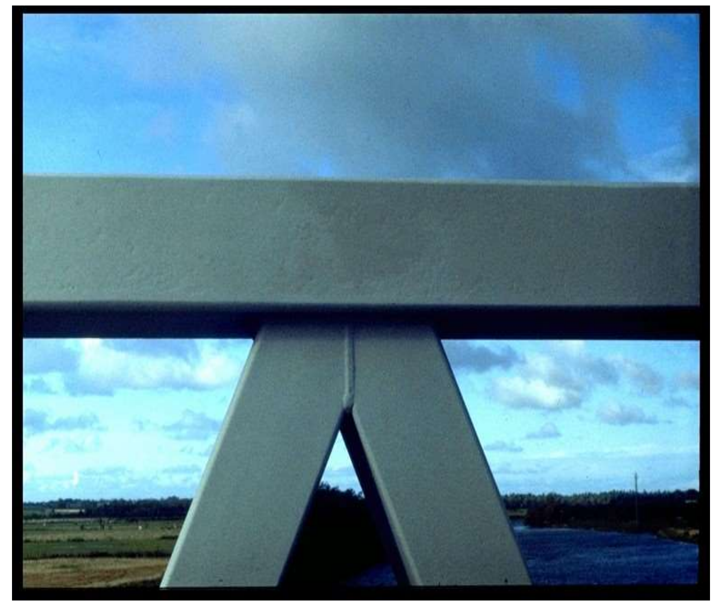
- If vertical components of brace forces do not differ by more than 20%
- Effective weld length approach is not used.

Overlap Detail

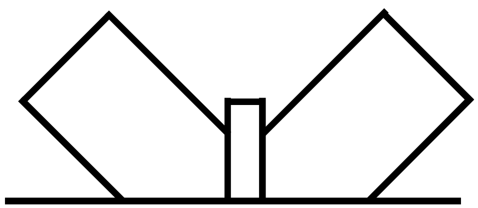
Overlap bracings should **NEVER** be made like this >

- Difficult to fabricate
- Up to 20% weaker





- Use division plate as alternative
- Helps to reinforce joint



Welding

- Types of welds used:
  - Fillet welds
  - Flare bevel welds
  - Partial joint penetration (PJP) welds
  - Complete joint penetration (CJP) welds
- **Generally for economics specify a fillet weld for tubular joints**
- **Avoid CJP welds** - Proper joint design should allow you to avoid complete joint penetration welds
- Do not use the directional strength increase for fillet welds (J2.5) for HSS.

Fillet Weld Size – Design Approach

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Approach 1

Weld proportioned to develop yield strength of connected branch at all locations around the branch.

- Upper limit of weld size
- Conservative
- Appropriate if plastic stress redistribution is required in connection
- Same effective weld size used on all sides, except at “hidden toe” of overlapped connections
- Achieved when:
  - Using prequalified joint details in AWS D1.1 for T, Y & K joints
  - Or effective throat of the fillet weld is 1.1 times the branch wall thickness when $F_y \leq 50$ ksi

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Fillet Weld Size – Design Approach

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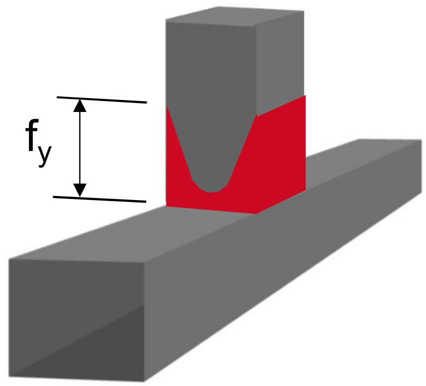
Approach 2

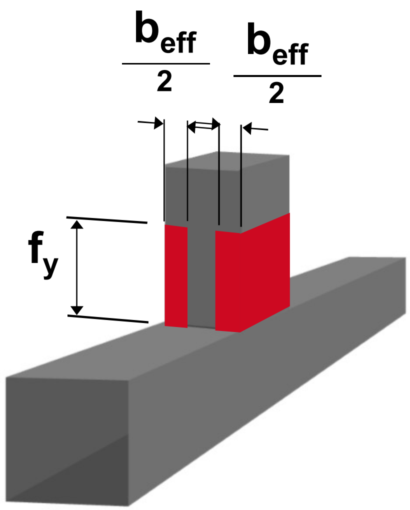
Weld proportioned to resist applied forces

- Need to account for effective weld lengths
- Appropriate if branch forces are low relative to strength
- Same effective weld sized used on all sides, including "hidden toe" of overlapped connections
- Effective weld lengths account for relative stiffnesses of connected elements

Relative Stiffness



Axial stress distribution



Hypothetical axial stress distribution

Fabrication Cost – Effects of Joint Type

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Lowest Cost	RHS chord — gap joints	Lowest Joint Strength & Stiffness
↓	RHS chord — 100% overlap joints	↓
	CHS chord — gap joints	
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Highest Cost	CHS chord — partial overlap joints	Highest Joint Strength & Stiffness

Matched sizes will have higher fabrication cost versus unmatched

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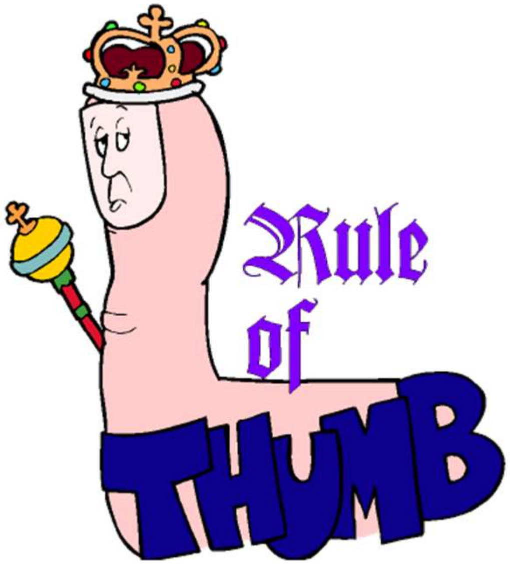
Joint & Connection Efficiency - Rules of Thumb

- Chord members should be relatively stocky. Use low D/t or B/t.
  - Side benefit: Chord will have less surface area, reducing painting costs

- Web/Branch members should have larger diameter and thinner walls (high D/t or B/t). Avoid welding "thick to thin".



Joint & Connection Efficiency - Rules of Thumb

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- Keep fabrication costs to minimum
  - Avoid “least weight” syndrome
  - Use gapped K connections – unless additional stiffness is required
  - Avoid bracing angles less than 30 degrees
  - Use fillet welds
  - Avoid “matched” connections – allows for fillets on all four sides

- **THINK ABOUT JOINTS WHEN CHOOSING YOUR MEMBERS**

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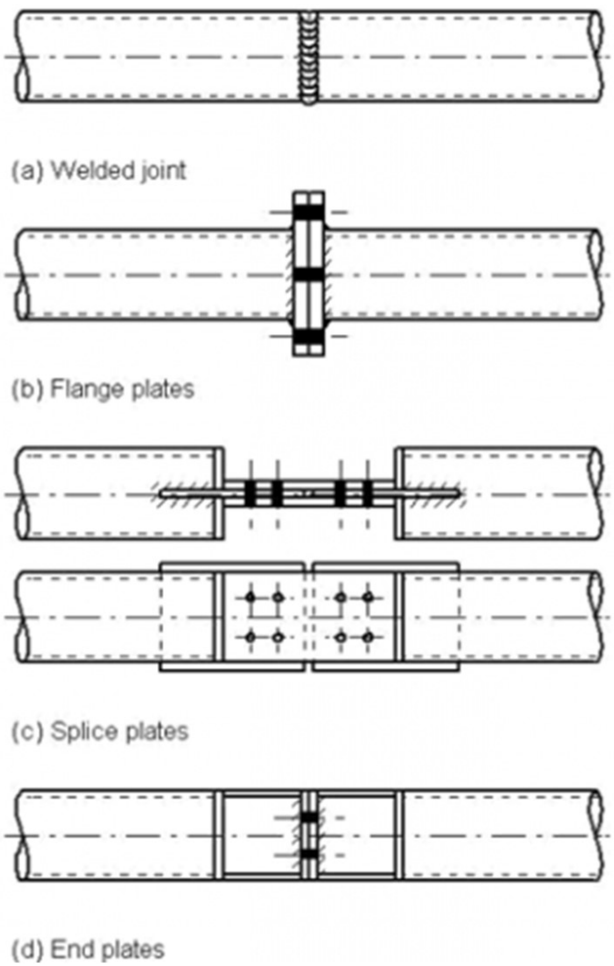
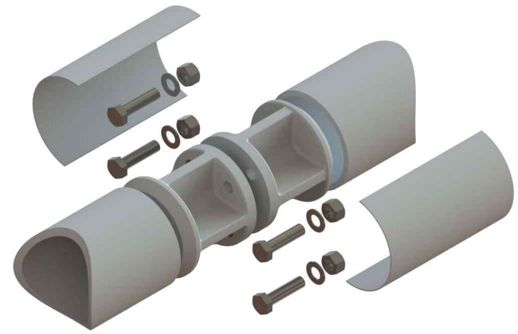
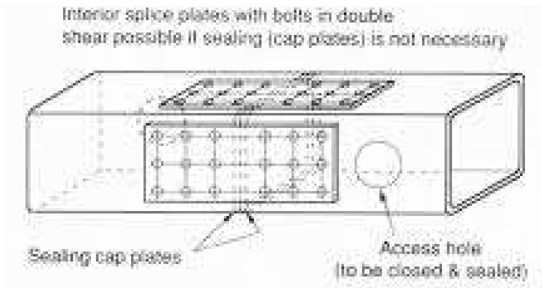
Truss Splices



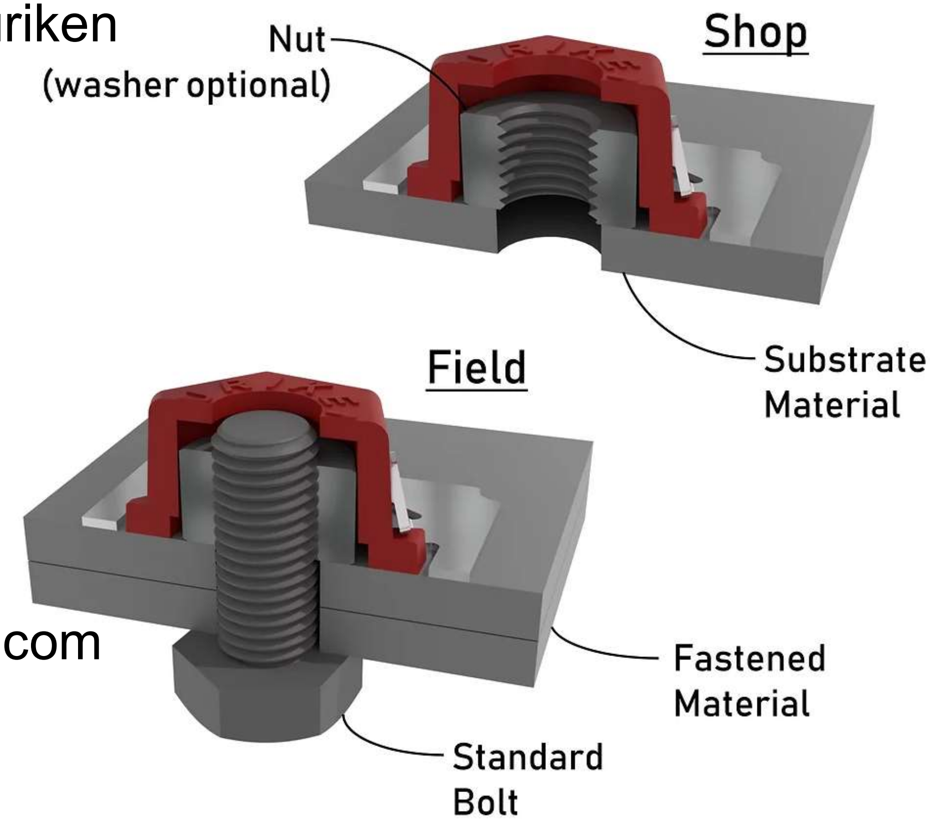
- Bolted splices preferred for speed, safety and ease



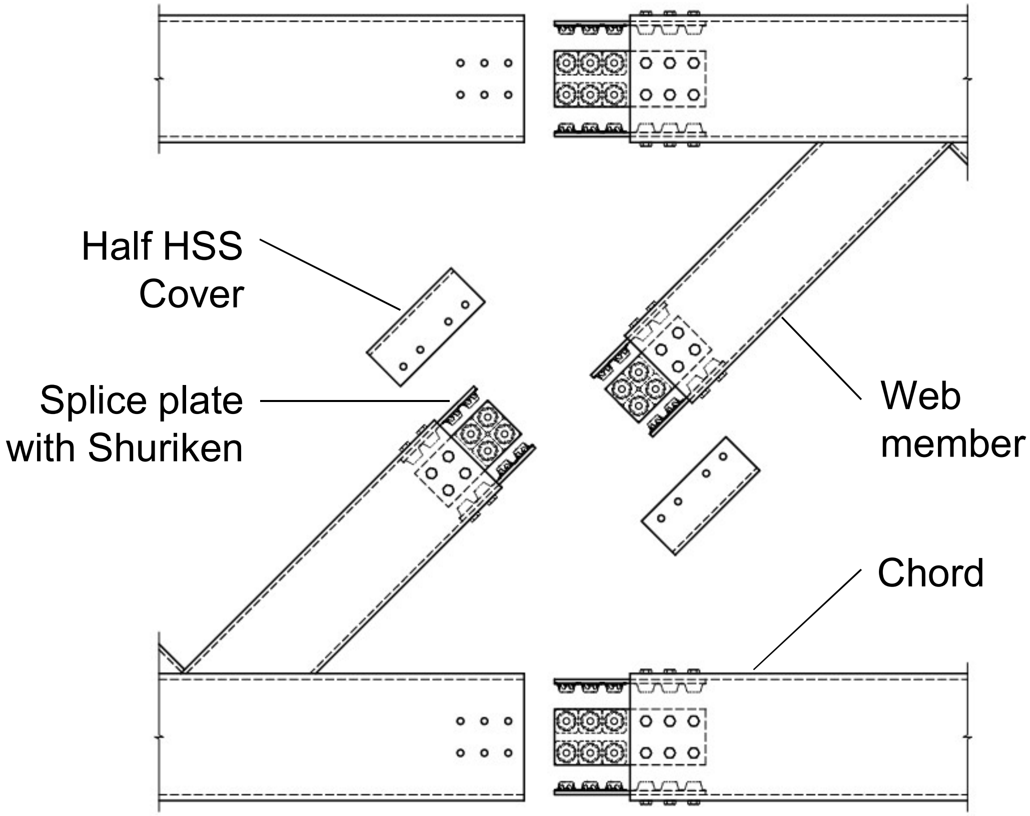


Truss Splices

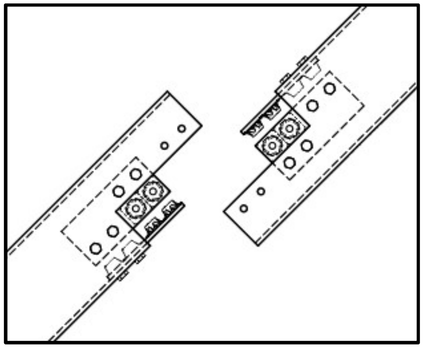
- New technology - Shuriken
- Nut installed in shop
- Bolt installed in field
- Standard nuts & bolts
- Slip-critical OK
- No special tools
- www.TubularConnect.com



Truss Splices



Shuriken Truss Splice



Alternate Web Detail

Multi-planar Joints

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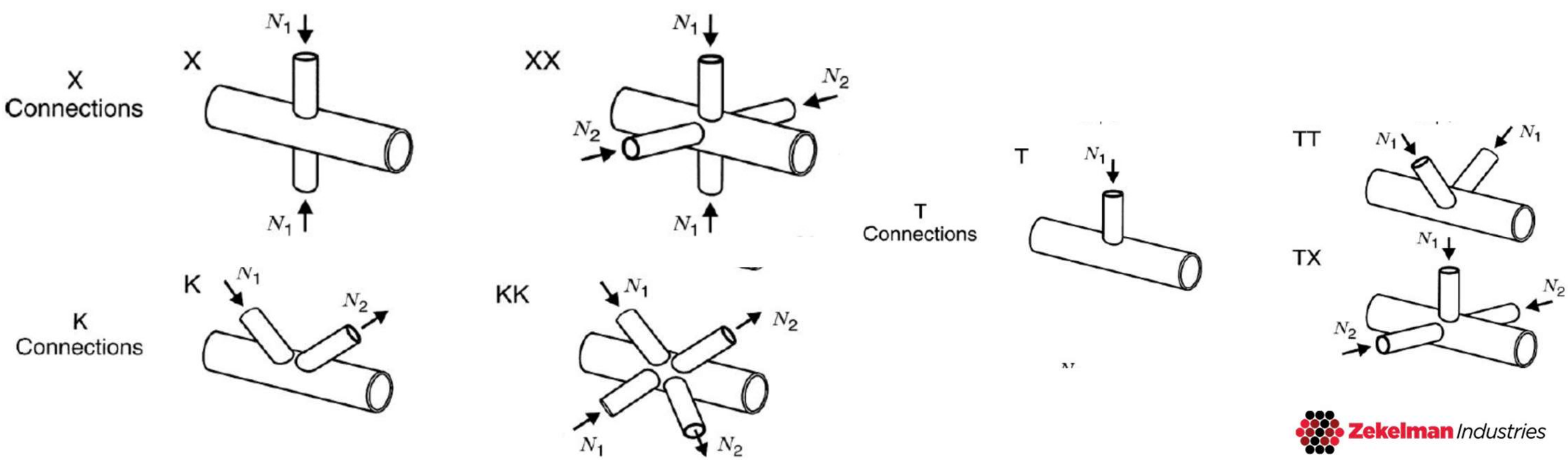
Multi-planar Joints

- Outside the scope of AISC 360
- Design guidance given in CIDECT Design Guides and Steel Tube Institute's HSS Design Manual, Vol 4
- Nomenclature for Joint Type is similar to planar trusses



Multi-planar Joints

- Design approach is to consider connection strength in a single plane and then apply a correction factor for the effect of the other planes of loading
- Correction factors can be calculated per CIDECT Design Guides
- Multi-planar joints are often stronger than planar joints due to the stiffening effect of multiple members welded in the same area

dustries

Multi-planar Joints

- Directionality of the forces will determine if the effect is positive or negative on the joint strength
- Gapped connections can be controlled by chord shear more often in multi-planar joints

HSS Connections - Resources

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AISC 360 — Chapter K

- 2005, 2010, 2016

AISC Design Guide #24

CISC Design Guide 1997

CIDECT Design Guides

- Available for free on AISC website

Steel Tube Institute

- HSS CONNEX Online
- Connection Spreadsheets
- New HSS Design Manual

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Questions?

THANK YOU!

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