

ENCE 455

Design of Steel Structures

II. Tension Members

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Tension Members

Following subjects are covered:

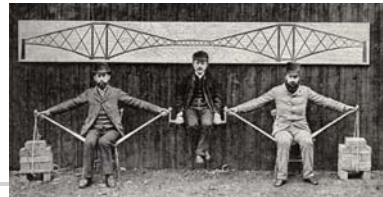
- Introduction
- Design strength
- Net area
- Staggered fasteners
- Block shear
- Design of tension members
- Threaded rods, pin-connected members

Reading:

- Chapters 3 of Salmon & Johnson
- AISC Steel Manual Specifications (Part 16) Chapters B (Design Requirements), D (Tension Members), and J (Connections)

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Introduction

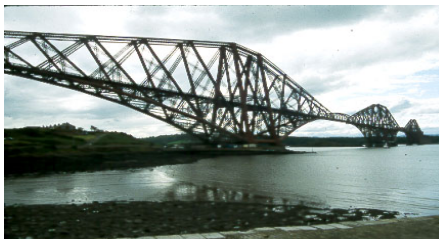


Tension members are structural elements that are subjected to axial tensile forces. Examples include:

- Members in trusses
- Cables in cable-stayed and suspension bridges
- Bracing in frames to resist lateral forces from blast, wind, and earthquake

Forth Bridge
Queensferry, Scotland

Main sections: 5360 ft.
Maximum span: 1710(2), 4 spans total
Built: 1890



Introduction (cont.)

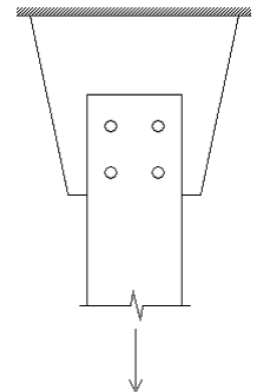
- Stresses (f) in axially loaded members are calculated using the equation

$$f = \frac{P}{A}$$

where P is the load and A is the cross-sectional area normal to the load.

- Design of this component involves calculations for

- Tension member (gross area)
- Tension member at connection (net area)
- Gusset plate at connection (net area)
- Gusset plate at support



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Design Strength

A tension member can fail by

- **Excessive deformation (yielding)** - Excessive deformation is prevented by limiting stresses on the gross section to less than the yield stress. For yielding on the gross section, the nominal strength is:

$$T_n = F_y A_g \quad \text{and} \quad \phi_t = 0.90 \quad (3.2.1)$$

- **Fracture** - Fracture is avoided by limiting stresses on the net section to less than the ultimate tensile strength. For fracture on the net section, the nominal strength is:

$$T_n = F_u A_e = F_u (U A_n) \quad \text{and} \quad \phi_t = 0.75 \quad (3.2.2)$$

where A_e is the effective net area, A_n is the net area and U is the reduction coefficient (an efficient factor)

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Net Area

Net Area -

The performance of a tension member is often governed by the response of its connections. The AISC Steel Manual introduces a measure of connection performance known as joint efficiency, which is a function of

- **Material properties** (ductility)
- **Fastener spacing**
- **Stress concentrations**
- **Shear lag** (Most important of the four and addressed specifically by the AISC Steel Manual)

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Net Area (cont.)

The AISC Steel Manual introduces the concept of effective net area to account for shear lag effects.

- For bolted connections: $A_e = U A_n$ (3.5.1)

- For welded connections: $A_e = U A_g$ (3.5.3)

where

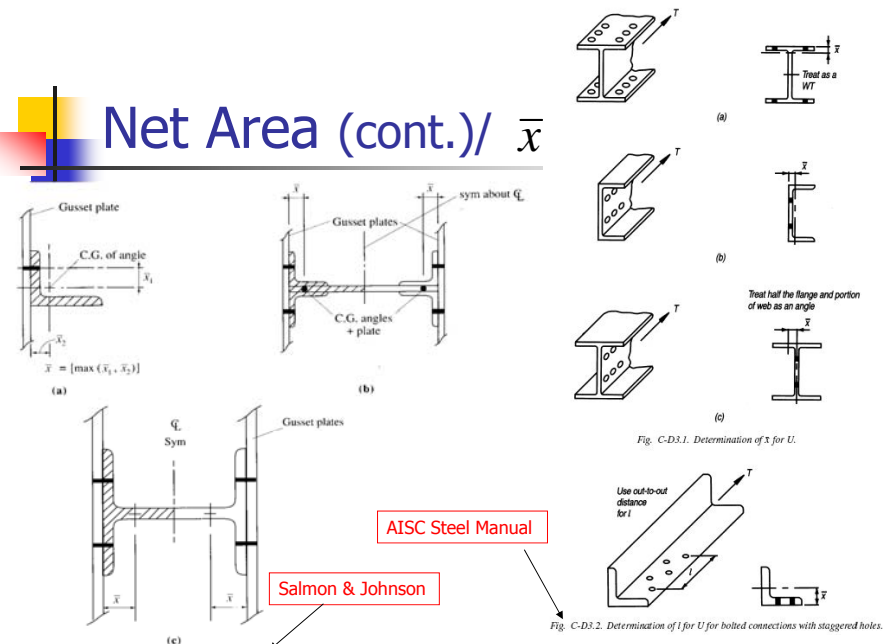
$$U = 1 - \bar{x}/L \leq 0.9 \quad (3.5.2)$$

and \bar{x} is the distance from the plane of the connection to the centroid of the connected member and L is the length of the connection in the direction of the load.

(Salmon & Johnson Example 3.5.1 for U)

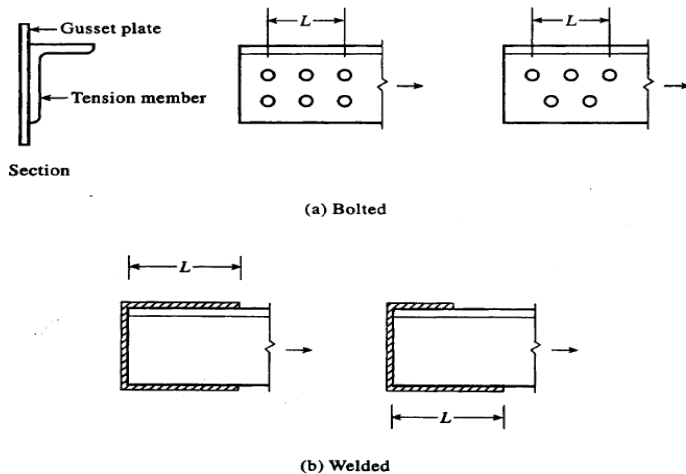
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Net Area (cont.)/ \bar{x}



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Net Area (cont.)/L



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Net Area (cont.)/U

- For **bolted connections**, AISC Table D3.1 gives values for U that can be used in lieu of detailed calculation.

7	W, M, S or HP Shapes or Tees cut from these shapes. (If U is calculated per Case 2, the larger value is permitted to be used)	with flange connected with 3 or more fasteners per line in direction of loading with web connected with 4 or more fasteners in the direction of loading	$b_f \geq 2/3d \dots U = 0.90$ $b_f < 2/3d \dots U = 0.85$ $U = 0.70$	—
8	Single angles (If U is calculated per Case 2, the larger value is permitted to be used)	with 4 or more fasteners per line in direction of loading with 2 or 3 fasteners per line in the direction of loading	$U = 0.80$ $U = 0.60$	—

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Net Area (cont.)/U

- For **welded connections**, AISC Table D3.1 lists

3	All tension members where the tension load is transmitted by transverse welds to some but not all of the cross-sectional elements.	$U = 1.0$ and $A_n = \text{area of the directly connected elements}$	—
4	Plates where the tension load is transmitted by longitudinal welds only.	$l \geq 2w \dots U = 1.0$ $2w > l \geq 1.5w \dots U = 0.87$ $1.5w > l \geq w \dots U = 0.75$	

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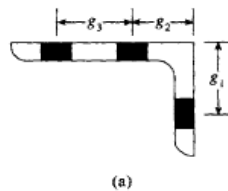
Staggered Fasteners

- Failure line** - When a member has staggered bolt holes, a different approach to finding A_e for the fracture limit state is taken. This is because the effective net area is different as the line of fracture changes due to the stagger in the holes. The test for the yielding limit state remains unchanged (the gross area is still the same).
- For calculation of the effective net area, the Section B2 of the AISC Steel Manual makes use of the product of the plate thickness and the net width. The **net width** is calculated as

$$w_n = w_g - \sum d + \sum \frac{s^2}{4g}$$

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Staggered Fasteners (cont.)



Usual gages for angles (inches)

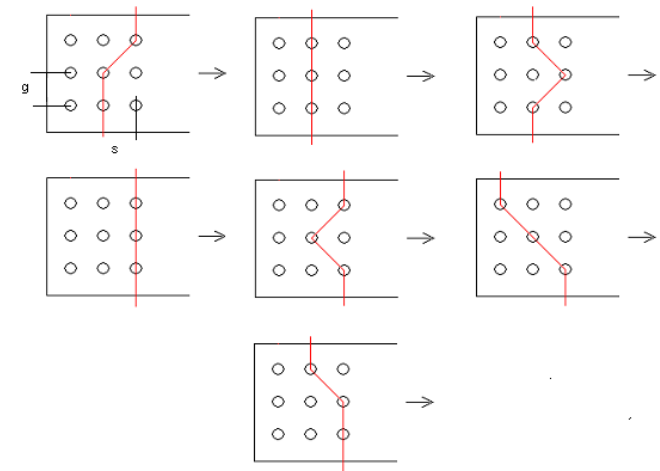
Leg	8	7	6	5	4	3½	3	2½	2	1¾	1½	1⅜	1¼	1
g_1	4½	4	3½	3	2½	2	1¾	1½	1¼	1	¾	¾	¾	¾
g_2	3	2½	2¼	2										
g_3	3	3	2½	1¾										

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Staggered Fasteners (cont.)

All possible failure patterns should be considered.

(Example 3.4.2 for A_n)



Staggered Fasteners (cont.)

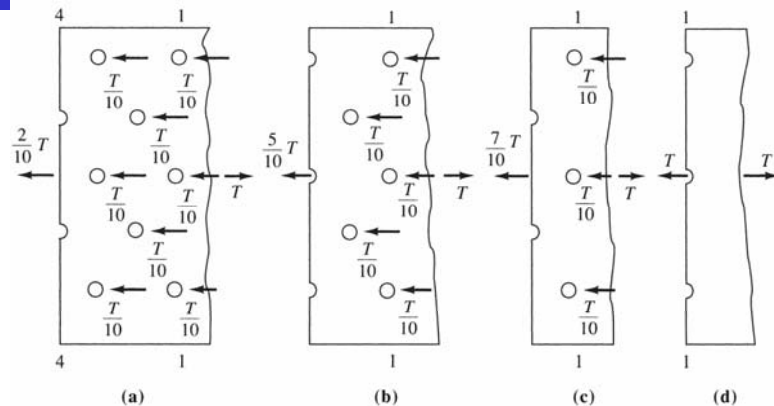
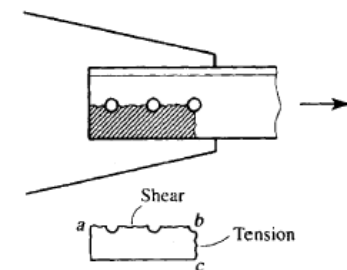


Figure 3.8.2 Load distribution in plate A (Example 3.8.1)

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Block Shear

- Block shear is an important consideration in the design of steel connections. Consider the figure below that shows the connection of a single-angle tension member. The block is shown shaded.



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Block Shear (cont.)

- In this example, the block will fail in shear along **ab** and tension on **bc**. The AISC Steel Manual procedure is based on one of the two failure surfaces yielding and the other fracturing.
 - Fracture on the shear surface is accompanied by yielding on the tension surface
 - Fracture on the tension surface is accompanied by yielding on the shear surface
- Both surfaces contribute to the total resistance.

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Block Shear (cont.)

- The nominal strength in tension is $F_u A_{nt}$ for fracture and $F_y A_{gt}$ for yielding where the second subscript t denotes area on the tension surface (**bc** in the figure above).
 - The yield and ultimate stresses in shear are taken as 60% of the values in tension. The AISC Steel Manual considers two failure modes:
 - Shear yield - tension fracture - $T_n = 0.6F_y A_{gv} + F_u A_{nt}$ (3.6.1)
 - Shear fracture - tension yield - $T_n = 0.6F_u A_{nv} + F_y A_{nt}$ (3.6.2)
 - One equation to cover all

$$T_n = 0.6F_u A_{nv} + U_{bs} F_u A_{nt} \leq 0.6F_y A_{gv} + U_{bs} F_u A_{nt} \quad (AISC J4-5)$$
 - Because the limit state is fracture, the equation with the larger of the two fracture values controls where $\phi_t = 0.75$.
- (Example 3.9.2 for block shear)
 ($U_{bs} = 1$ for uniform; $= 0.5$ for non-uniform tension stress)

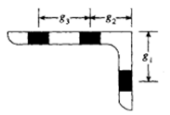
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Design of Tension Members

- The design of a tension member involves selecting a member from the AISC Steel Manual with adequate
 - Gross area
 - Net area
 - Slenderness ($L/r \leq 300$ to prevent vibration, etc; does not apply to cables.)
- If the member has a bolted connection, the choice of cross section must account for the area lost to the bolt holes.
- Because the section size is not known in advance, the default values of U are generally used for preliminary design.

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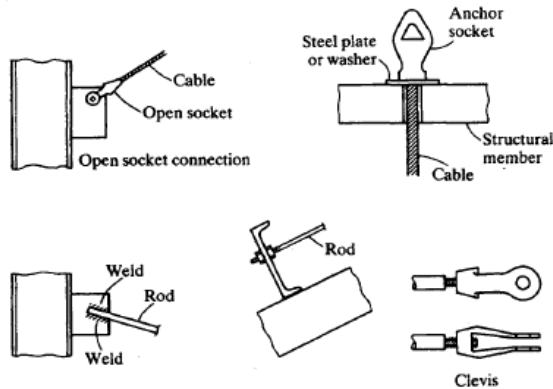
Design of Tension Members (cont.)

- Detailing of connections is a critical part of structural steel design. Connections to angles are generally problematic if there are two lines of bolts.
- 
- Consider the Gages for Angle figure shown earlier that provides some guidance on sizing angles and bolts.
 - Gage distance g_1 applies when there is one line of bolts
 - Gage distances g_2 and g_3 apply when there are two lines

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Design of Tension Members (cont.)/ Thread Rod

Threaded Rod



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Design of Tension Members (cont.)/ Thread Rod

Threaded Rod -

- Tension on the effective net area
 $T_n = A_s F_u = 0.75 A_b F_u$, where A_s is the stress area (threaded portion), A_b is the nominal (unthreaded area), and 0.75 is a lower bound (conservative) factor relating A_s and A_b . See Section J3.6 of the AISC Steel Manual Specification for details.

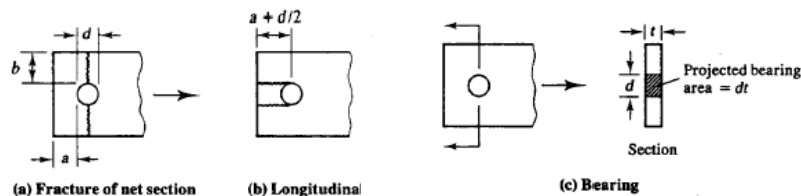
- The design strength of a threaded rod is calculated as
 $\phi T_n = 0.75 T_n$

(Example 3.10.2 for Rod Design)

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Design of Tension Members (cont.)/ Pinned Connections

- Pinned connections transmit no moment (ideally) and often utilize components machined to tight tolerances (plus, minus 0.001").
- The figure shows failure modes for pin-connected members and each failure mode must be checked for design. Specifically, the following limit states must be checked.



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Design of Tension Members (cont.)/ Pinned Connections

The following limit states must be checked.

- Tension on the effective net area**
 $\phi T_n = 0.75(2 t b_{eff} F_u)$ where $b_{eff} = 2t + 0.63 \leq b$ (D5-1)
- Shear on the effective area**
 $\phi T_n = 0.75(0.6 A_{sf} F_u) = 0.75\{0.6[2t(a + d/2)] F_u\}$ (D5-2)
- Bearing on projected area**
 $\phi T_n = 0.75(1.8 A_{pb} F_y) = 0.75[1.8(d t) F_y]$ (J8-1)
 where $1.8 A_{pb} F_y$ is based on a deformation limit state under service loads producing stresses of 90% of yield
- Tension on the gross section**
 $\phi T_n = 0.9(A_g F_y)$ (D1-1)

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