LESSONS 14 and 15: STRUCTURAL STEEL DESIGN

This lesson in CIE 324 covers the following subjects:

- Component shapes
- Tension members
- Member and connection capacity
- Design of tension members

Reading: From *Structures*, see syllabus for page numbers

From *Steel Design*, Chapter 3

COMPONENT SHAPES:

Steel shapes are either a) rolled in a mill, or b) composed of joined plates.

A complete listing of rolled shapes can be found at the class website. Look for AISC Shapes Database v14.1.xls. The American Institute for Steel Construction (AISC) website contains much useful information on structural steel shapes: http://steeldetail.aisc.org/W44.aspx.

- W: wide flange beams, used for beams and columns, flange surfaces are parallel, flanges and web generally have a different thickness

- S: American standard beam, interiors of flanges are sloped

- HP: bearing piles, flanges surfaces are parallel, flanges and web have the same thickness

- C: Channel, C-shaped section, interiors of flanges are sloped

- L: angle shapes, two perpendicular legs, may be of equal length

- WT: Tee-shaped sections cut from W shapes

- ST: Tee-shaped sections cut from S shapes

- Pipe: Circular sections

- HSS: hollow steel shapes, rectangular or square, constant thickness

Pros and cons of different sections:

- Beams: use W or C shapes, depth greater than width

  - Why?

- Columns: use W shapes for uniaxial bending, depth similar to width
  - Why?
- Columns: use HSS shapes for biaxial bending, depth similar to width
  - Why?
- Braces: use L, pipe, HSS, W shapes
  - Why?

TENSION MEMBERS:

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

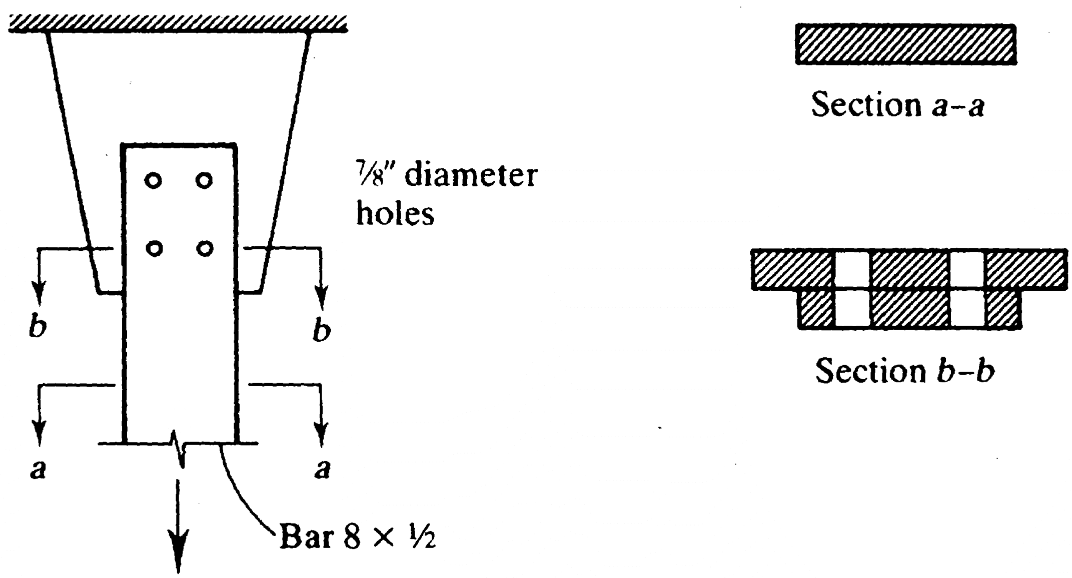
- Members in trusses
- Cables in cable-stayed and suspension bridges
- Bracing in frames to resist lateral forces from blast, wind, and earthquake

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

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

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

Consider the tension member below; the example is from Segui:



Design of this component involves calculations for

- Bar (gross area)
- Bar at connection (net area)
- Gusset plate at connection (net area)

- Gusset plate at support

What are the gross and net areas for the bar?

Gross area:

Net area:

Design strength:

A tension member can fail by

- Excessive deformation (yielding under gravity loads)
- Fracture

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

$$P_n = F_y A_g$$

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:

$$P_n = F_u A_n$$

Resistance (or phi) factors are applied to these nominal strengths

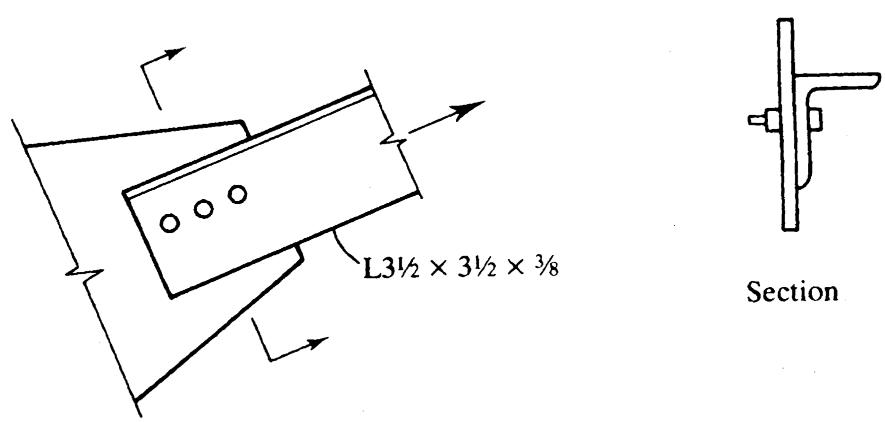
- $\phi = 0.9$ for yielding
- $\phi = 0.75$ for fracture

to calculate design strengths. The smaller of the two calculated strengths:

$$0.9F_yA_g; \quad 0.75F_uA_n$$

is taken as the *design* strength.

Consider the example from the text that is reproduced below. The gusset plate connection is subjected to service dead and live loads of 35 and 15 kips, respectively. Steel is A36. Bolts are 0.875-inch in diameter. Assume that the effective net area is 85% of the computed net area.



SOLUTION The load combinations are

(A4-1): $1.4D = 1.4(35) = 49$ kips

(A4-2): $1.2D + 1.6L = 1.2(35) + 1.6(15) = 66$ kips

The second combination controls; $P_u = 66$ kips.
The design strengths are

Gross section: $A_g = 2.48$ in.^{2} (from Part 1 of the *Manual*)

$\phi_t P_n = \phi_t F_y A_g = 0.90(36)(2.48) = 80.4$ kips

Net section: $A_n = 2.48 - \frac{3}{8}(\frac{7}{8} + \frac{1}{8}) = 2.105$ in.^{2}

$A_e = 0.85(2.105) = 1.789$ in.^{2} (in this example)

$\phi_t P_n = \phi_t F_u A_e = 0.75(58)(1.789) = 77.8$ kips (controls)

ANSWER Since $P_u < \phi_t P_n$ (66 kips < 77.8 kips), the member is satisfactory. ■

Net area:

The performance of a tension member is often governed by the response of its connections. The LRFD Specification 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

The LRFD Specification introduces the concept of effective net area to account for shear lag effects.

For welded connections:

$$A_e = UA_g$$

For bolted connections:

$$A_e = UA_n$$

where

$$U = 1 - \frac{\bar{x}}{L}$$

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. Figures from the Segui are reproduced below to illustrate these definitions.

FIGURE 3.6

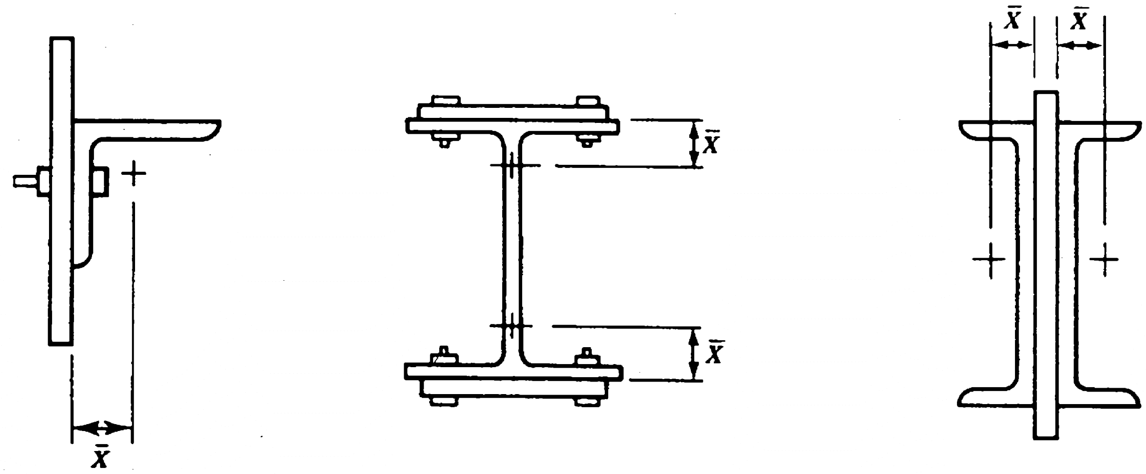
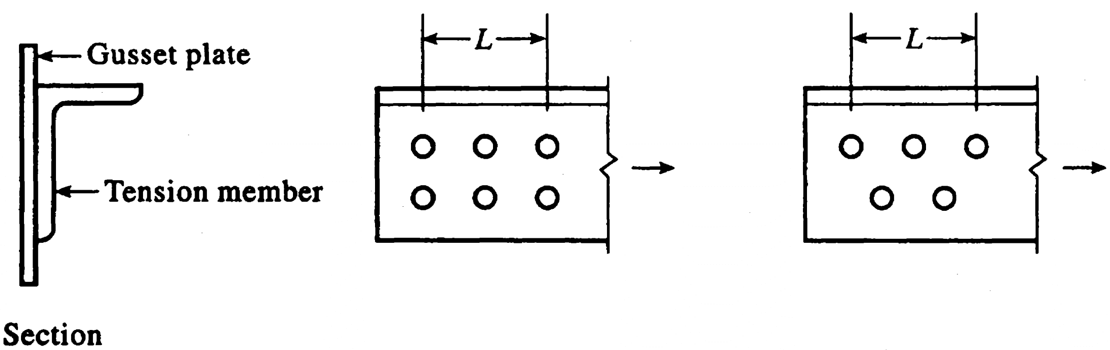
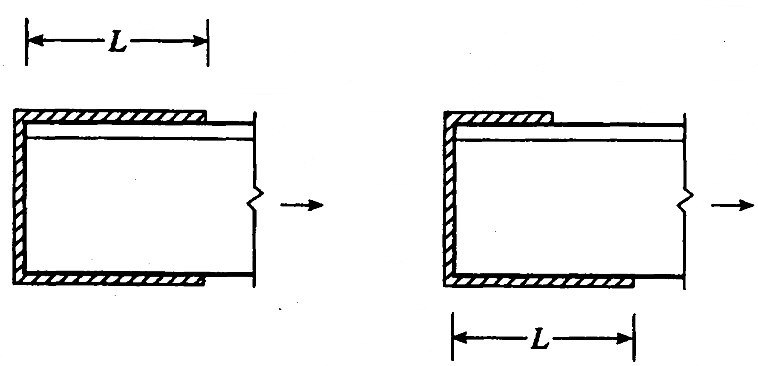


FIGURE 3.7



(a) Bolted



(b) Welded

For bolted connections, the commentary to the LRFD Specification (Section B.3) gives values for U that can be used in lieu of detailed calculation. Different values are given depending on whether there are more or less than two fasteners per line in the direction of loading as follows.

1. For W, M, and S shapes that have a width-to-depth ratio of 0.67 or more and are connected through the flanges with at least three fasteners per line in the direction of the applied load, $U = 0.9$.

2. For other shapes with at least three fasteners per line, $U = 0.85$.

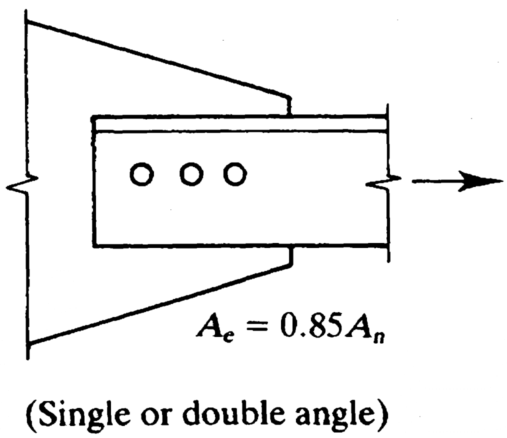
3. For all members with only two fasteners per line, $U = 0.75$.

The average values for welded connections can be taken as:

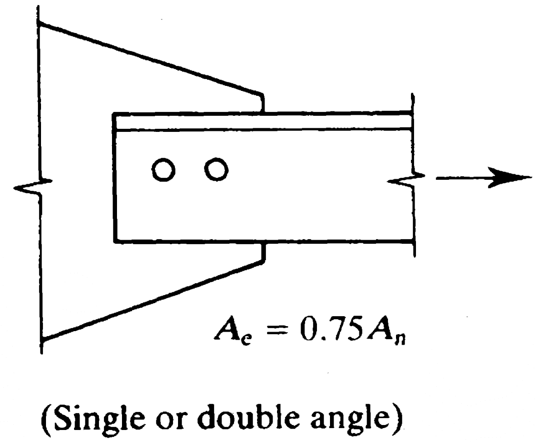
1. For W, M, and S shapes that have a width-to-depth ratio of 0.67 or more and are connected through the flanges, $U = 0.9$.

2. For all other shapes, $U = 0.85$.

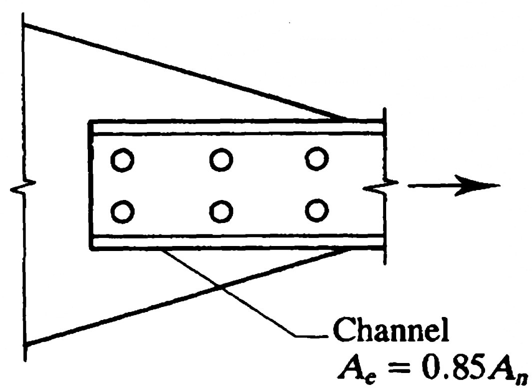
The figure below from Segui illustrates the calculation for bolted connections.



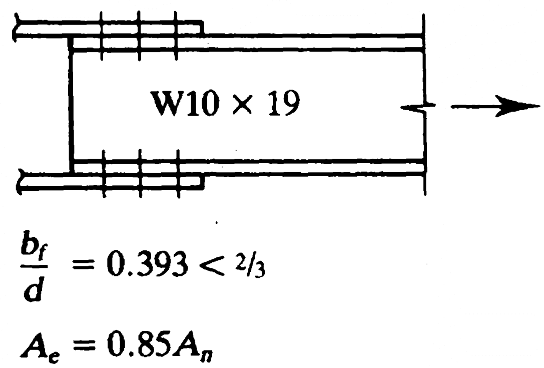
(a)



(b)

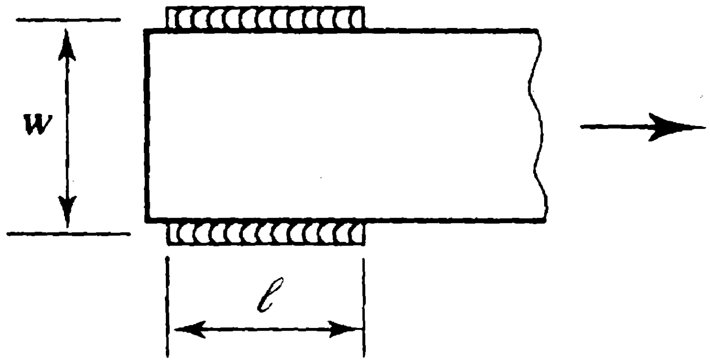


(c)



(d)

The effective net area will only be less than the net area if some elements of the cross-section are not connected. For tension members such as single plates and bars connected by longitudinal fillet welds,



the LRFD Specification writes that $A_e = UA_g$, where U = 1.0, 0.87, and 0.75 for $l \geq 2w, 1.5w \leq l \leq 2w, w \leq l \leq 1.5w$, respectively.

For transverse welds, the LRFD Specification writes that the effective net area is equal to the area of the connected element of the cross section.

Calculations for effective net area are presented in the two examples from Segui.

- Bolted connection
- Welded connection

PLE 3.3

Determine the effective net area for the tension member shown in Figure 3.11.

OLUTION

$$A_n = A_g - A_{\text{holes}}$$
$$= 5.75 - \tfrac{1}{2}(\tfrac{5}{8} + \tfrac{1}{8})(2) = 5.00 \text{ in.}^2$$

Only one element (one leg) of the cross section is connected, so the net area must be reduced. From the properties tables in Part 1 of the *Manual,* the distance from the centroid to the outside face of the leg of an $L6 \times 6 \times \tfrac{1}{2}$ is

$$\bar{x} = 1.68 \text{ in.}$$

The length of the connection is

$$L = 3 + 3 = 6 \text{ in.}$$

$$\therefore\ U = 1 - \left(\frac{\bar{x}}{L}\right) = 1 - \left(\frac{1.68}{6}\right) = 0.720 < 0.9$$

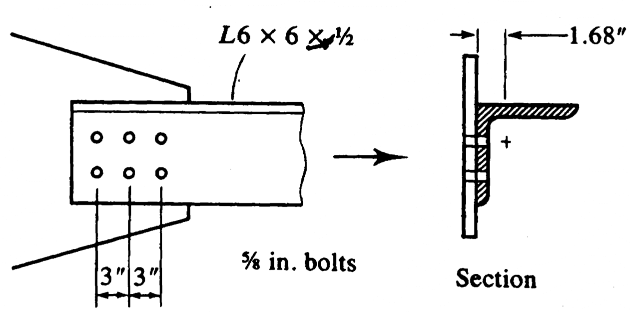
$$A_e = UA_n = 0.720(5.00) = 3.60 \text{ in.}^2$$

The average value of U from the Commentary could also be used. Because this shape is not a W, M, S, or tee and has more than two bolts in the direction of the load, the reduction factor U can be taken as 0.85, and

$$A_e = UA_n = 0.85(5.00) = 4.25 \text{ in.}^2$$

Either U value is acceptable, but the value obtained from AISC Equation B3-2 is more accurate. However, the average values of U are useful during preliminary design, when actual section properties and connection details are not known.

FIGURE 3.11



IPLE 3.4

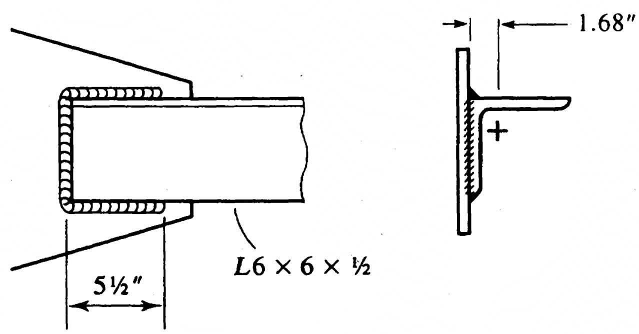
If the tension member of Example 3.3 is welded as shown in Figure 3.12, determine the effective net area.

SOLUTION As in Example 3.3, only part of the cross section is connected, and a reduced effective net area must be used. The connection is made with a combination of longitudinal and transverse welds, so it is not one of the special cases for welded members.

$$U = 1 - \left(\frac{\bar{x}}{L}\right) = 1 - \left(\frac{1.68}{5.5}\right) = 0.695 < 0.9$$

ANSWER $A_e = UA_g = 0.695(5.75) = 4.00 \text{ in.}^2$ ■

■ **FIGURE 3.12**



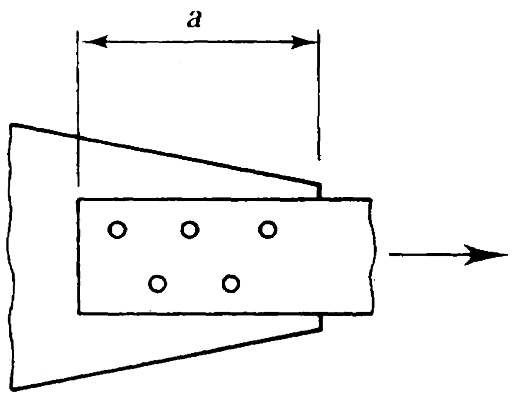
Staggered fasteners:

The presentation to date has focused on regular, non-staggered fastener geometries.

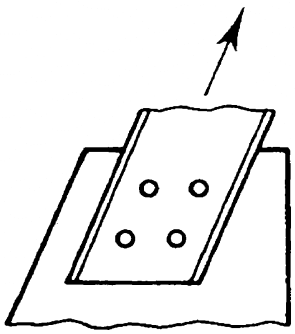
- Net area maximized with fasteners placed in a straight line.

Often, for reasons of connection geometry, fasteners must be placed in more than one line

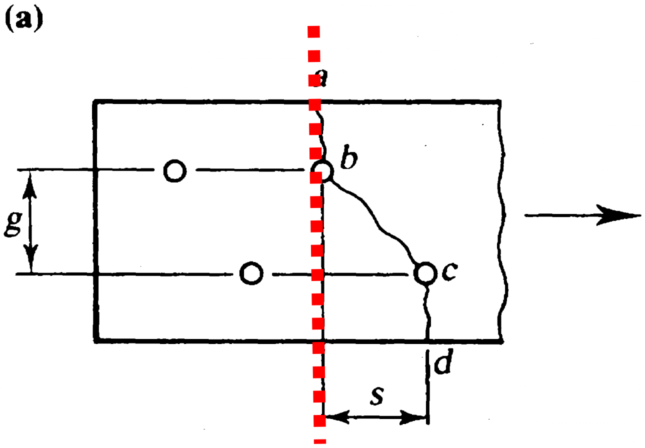
- ➢ Staggered fasteners



(a)



(b)

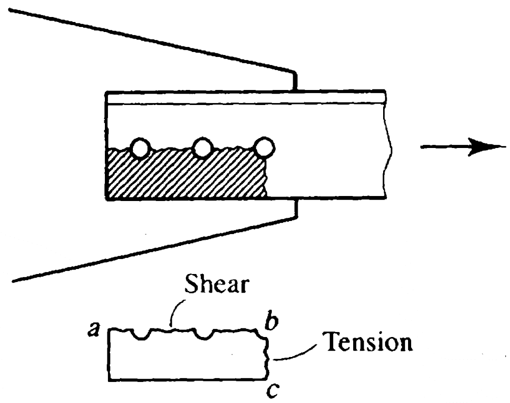


(c)

The design of staggered fasteners will be addressed in CIE 428.

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.



In this example, the block will fail in shear along *ab* and tension on *bc*. The LRFD 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. Block shear resistance must be checked and this topic is covered in CIE 428.

DESIGN OF TENSION MEMBERS:

The design of a tension member involves selecting a member from the LRFD Specification with adequate

- Gross area

- Net area

- Slenderness

  - $\dfrac{L}{r} \leq 300$ to prevent vibration, does not apply to cables.

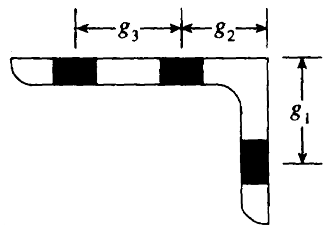
If the member has a bolted connection, the choice of cross section must account for the area lost to the holes.

Because the section size is not known in advance, the default values of U are generally used for preliminary design.

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 figure below 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

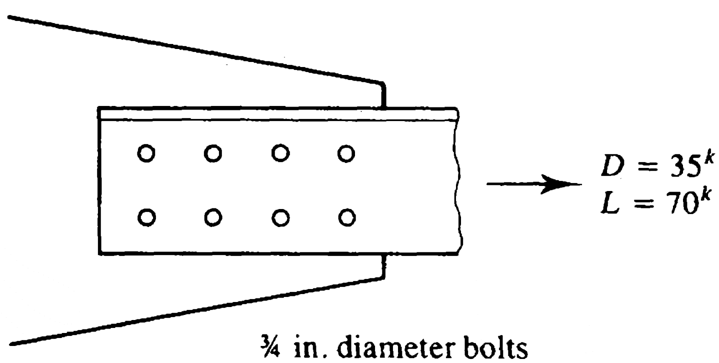


(a)

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	1⅜	1⅛	1	⅞	⅞	¾	⅝
g_2	3	2½	2¼	2										
g_3	3	3	2½	1¾										

As an example, design an *equal* angle tension member, 12 feet long to resist the loads shown. Use A36 steel.



What is the factored load?

What is the minimum value of A_g? A_n?

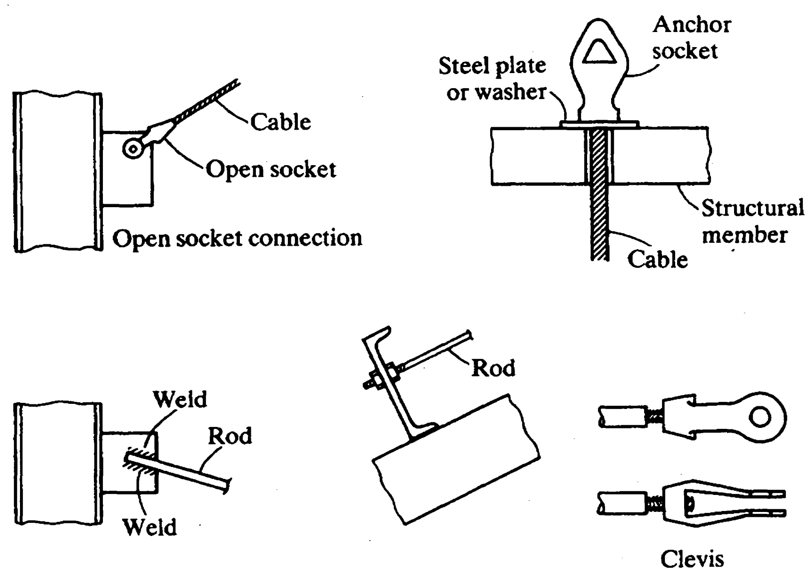
What is minimum value of radius of gyration, *r*?

Pick a section from the LRFD manual based on A_g, r, g_i:

Assume that the angle is connected through the long leg and estimate a value of U (0.85), calculate values of A_n and A_e.

Threaded rods:

The figure below presents applications of threaded rods and cables.



The nominal tensile strength of a threaded rod can be written as

$$P_n = A_s F_u \; ; \; 0.75 A_b F_u$$

where

A_s is the stress area (threaded portion),

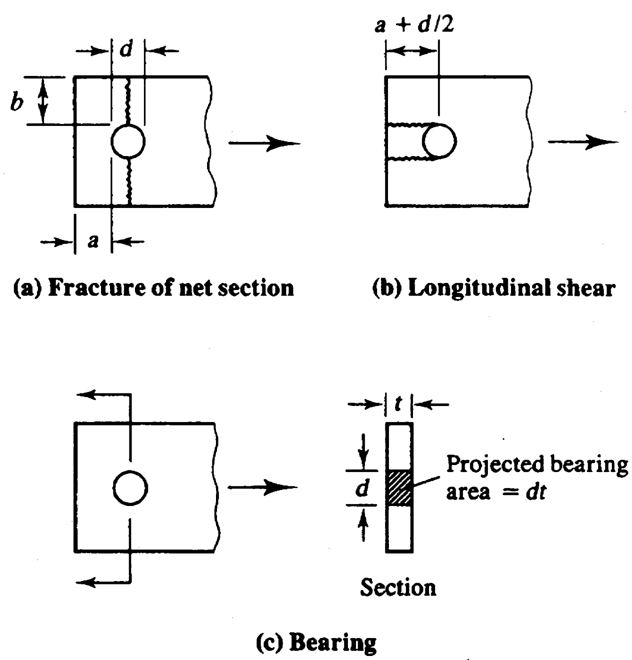
A_b is the nominal (unthreaded) area,

and 0.75 is a lower bound (conservative) factor relating A_s and A_b.

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

Pin-connected members:

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



(a) Fracture of net section (b) Longitudinal shear

(c) Bearing

The design of pin-connected members will be addressed in CIE 428.