3

ANALYSIS OF TENSION MEMBERS

3.1 TYPES OF TENSION MEMBERS

Tension members are structural elements that are subjected to axial tensile forces. They are used in various types of structures and include truss members, bracing for buildings and bridges, cables in suspended roof systems, and cables in suspension and cable-stayed bridges. Any cross-sectional configuration may be used, because for any given material, the only determinant of the strength of a tension member is the cross-sectional area.

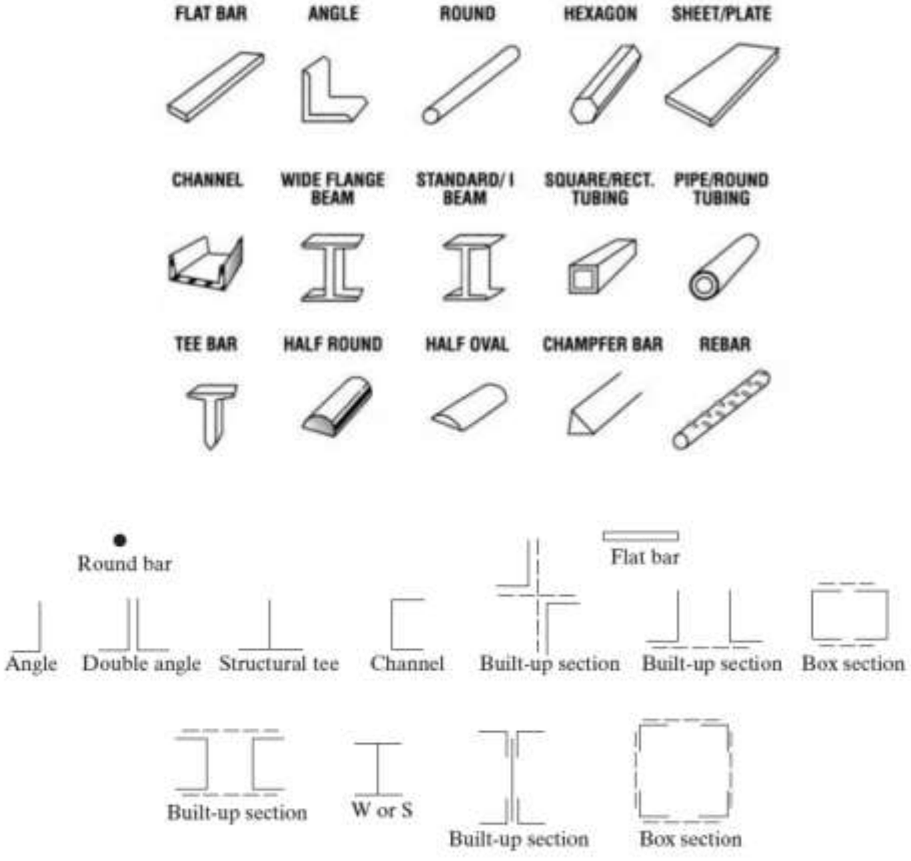


Figure 3-1: Types of Tension Members

3.2 NOMINAL STRENGTHS OF TENSION MEMBERS

The AISC Specification (**AISC D2, Page 26**) states that the nominal strength of a tension member, is to be the smaller of the values obtained by substituting into the following two expressions:

For the limit state of yielding in the gross section (which is intended to prevent excessive elongation of the member),

$$P_n = F_y A_g \qquad \text{(AISC Equation D2-1)}$$

$$\phi_t P_n = \phi_t F_y A_g = \text{design tensile strength by LRFD } (\phi_t = 0.9)$$

$$\boxed{\frac{P_n}{\Omega_t} = \frac{F_y A_g}{\Omega_t} = \text{allowable tensile strength for ASD } (\Omega_t = 1.67)}$$

For tensile rupture in the net section, as where bolt or rivet holes are present,

$$P_n = F_u A_e \qquad \text{(AISC Equation D2-2)}$$

$$\phi_t P_n = \phi_t F_u A_e = \text{design tensile rupture strength for LRFD } (\phi_t = 0.75)$$

$$\boxed{\frac{P_n}{\Omega_t} = \frac{F_u A_e}{\Omega_t} \text{ allowable tensile rupture strength for ASD } (\Omega_t = 2.00)}$$

3.3 NET AREA

- **AREA DETERMINATION,** AISC Chapter D, Page 27

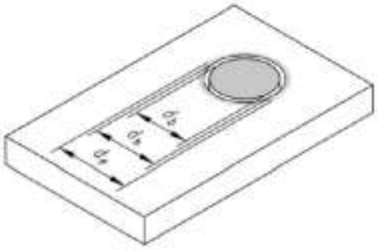
1. **Gross Area**, AISC Chapter D, Page 27

   The gross area, A_g, of a member is the total cross-sectional area.

2. **Net Area**, AISC Chapter D, Page 27

$$A_n = A_g - A_{Holes}$$

$$d_e = d_b + \frac{1}{8}"$$



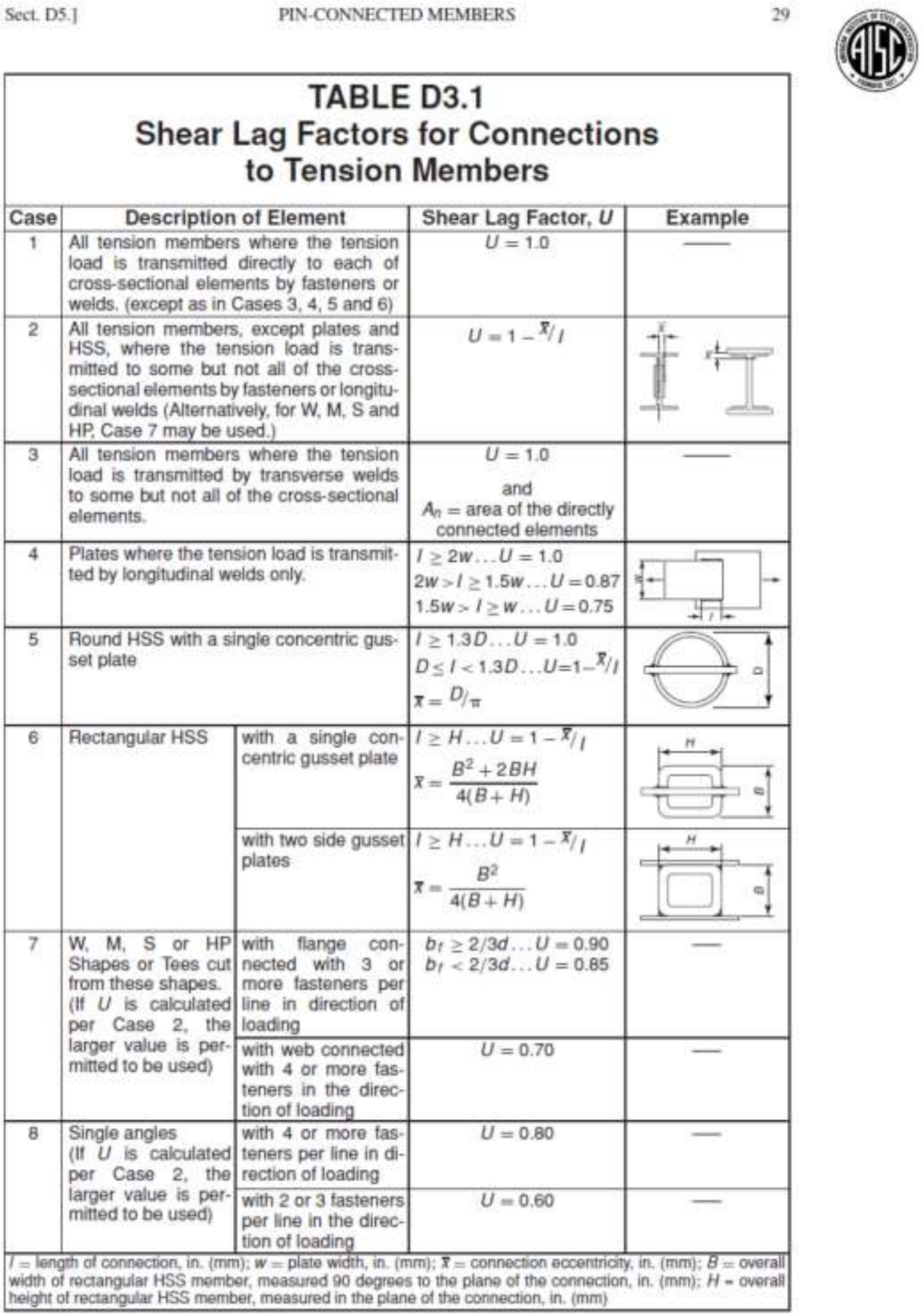


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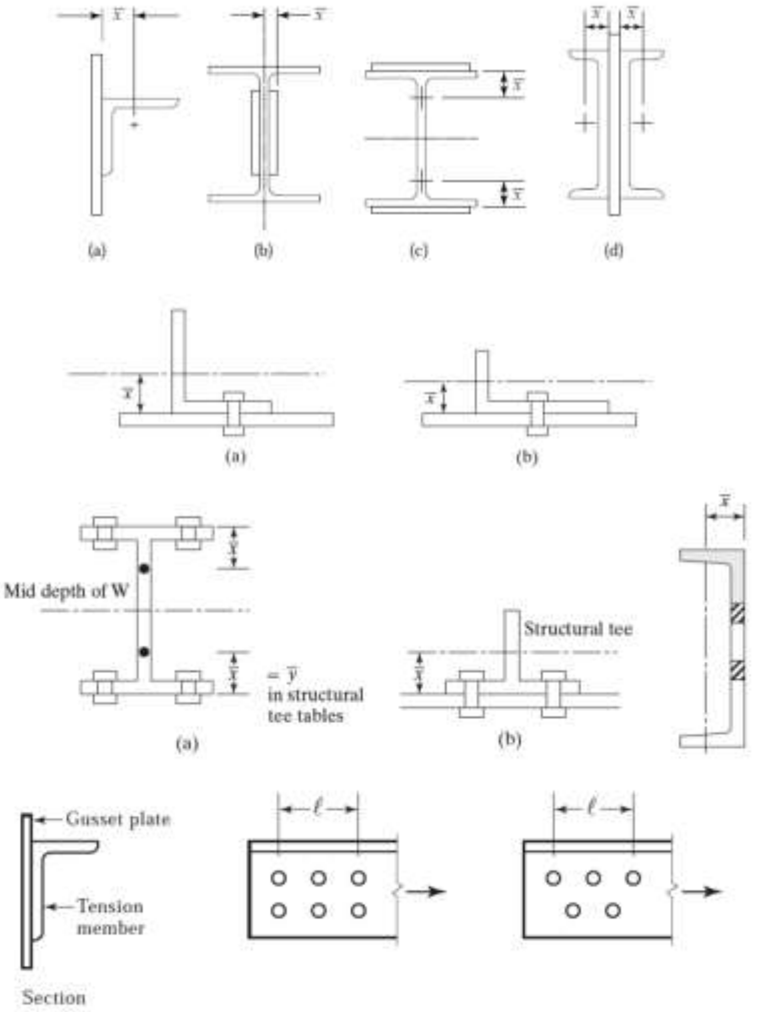
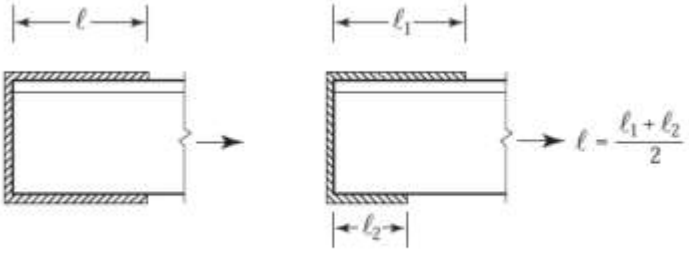
TABLE D3.1
Shear Lag Factors for Connections to Tension Members

Case	Description of Element		Shear Lag Factor, U	Example
1	All tension members where the tension load is transmitted directly to each of cross-sectional elements by fasteners or welds. (except as in Cases 3, 4, 5 and 6)		$U = 1.0$	—
2	All tension members, except plates and HSS, where the tension load is transmitted to some but not all of the cross-sectional elements by fasteners or longitudinal welds (Alternatively, for W, M, S and HP, Case 7 may be used.)		$U = 1 - \bar{x}/l$	
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 = area of the directly connected elements	—
4	Plates where the tension load is transmitted by longitudinal welds only.		$l \geq 2w \ldots U = 1.0$ $2w > l \geq 1.5w \ldots U = 0.87$ $1.5w > l \geq w \ldots U = 0.75$	
5	Round HSS with a single concentric gusset plate		$l \geq 1.3D \ldots U = 1.0$ $D \leq l < 1.3D \ldots U = 1 - \bar{x}/l$ $\bar{x} = D/\pi$	
6	Rectangular HSS	with a single concentric gusset plate	$l \geq H \ldots U = 1 - \bar{x}/l$ $\bar{x} = \dfrac{B^2 + 2BH}{4(B+H)}$	
		with two side gusset plates	$l \geq H \ldots U = 1 - \bar{x}/l$ $\bar{x} = \dfrac{B^2}{4(B+H)}$	
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	$b_f \geq 2/3d \ldots U = 0.90$ $b_f < 2/3d \ldots U = 0.85$	—
		with web connected with 4 or more fasteners in the direction of loading	$U = 0.70$	—
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	$U = 0.80$	—
		with 2 or 3 fasteners per line in the direction of loading	$U = 0.60$	—

l = length of connection, in. (mm); w = plate width, in. (mm); $\bar{x}$ = connection eccentricity, in. (mm); B = overall width of rectangular HSS member, measured 90 degrees to the plane of the connection, in. (mm); H = overall height of rectangular HSS member, measured in the plane of the connection, in. (mm)



(a) Bolted



(b) Welded

Figure 3-2: Connection eccentricity $\bar{x}$ for various cases

1. Bolted Members

Should a tension load be transmitted by bolts, the gross area is reduced to the net area A_n of the member, and U is computed as follows:

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

2. Welded Members

When tension loads are transferred by welds, the rules from **AISC Table D-3.1, Page 29**, that are to be used to determine values for A and U (A_e as for bolted connections = AU) are as follows:

- Should the load be transmitted only by longitudinal welds to other than a plate member, or by longitudinal welds in combination with transverse welds, A is to equal the gross area of the member A_g (**Table 3.2, Case 2**).
- Should a tension load be transmitted only by transverse welds, A is to equal the area of the directly connected elements and U is to equal 1.0 (**Table 3.2, Case 3**).
- Tests have shown that when flat plates or bars connected by longitudinal fillet welds are used as tension members, they may fail prematurely by shear lag at the corners if the welds are too far apart. Therefore, the AISC Specification states that when such situations are encountered, the length of the welds may not be less than the width of the plates or bars. The letter A represents the area of the plate, and UA is the effective net area. For such situations, the values of U to be used (**Table 3.2, Case** 4) are as follows:

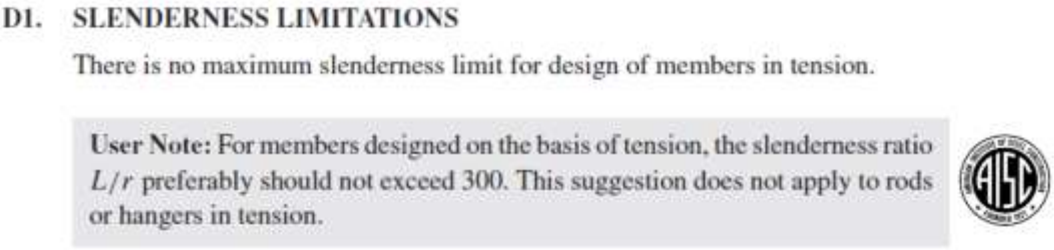
When $l \geq 2w$	$U = 1.0$
When $2w > l \geq 1.5w$	$U = 0.87$
When $1.5w > l \geq w$	$U = 0.75$

Here, l = weld length, in
w = plate width (distance between welds), in

SUMMARY: ANALYSIS OF TENSION MEMBERS

The Steel Construction Manual **AISC Chapter D, Page 26** limit states that will be considered are:

- **SLENDERNESS LIMITATIONS,** AISC Chapter D, Page 26

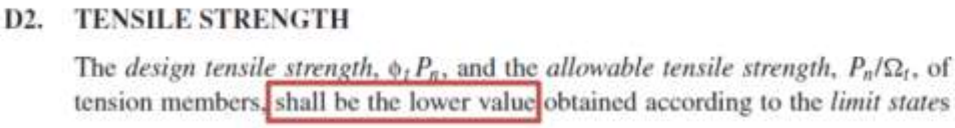


D1. SLENDERNESS LIMITATIONS

There is no maximum slenderness limit for design of members in tension.

User Note: For members designed on the basis of tension, the slenderness ratio L/r preferably should not exceed 300. This suggestion does not apply to rods or hangers in tension.

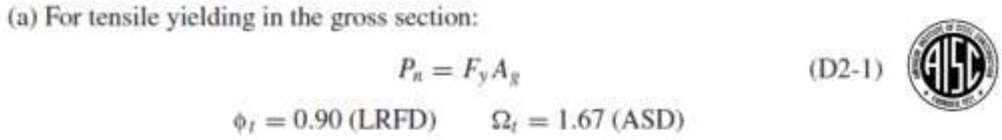
- **TENSILE STRENGTH,** AISC Chapter D, Page 26



D2. TENSILE STRENGTH

The *design tensile strength*, $\phi_t P_n$, and the *allowable tensile strength*, P_n/Ω_t, of tension members, shall be the lower value obtained according to the *limit states*

- **TENSILE YIELDING,** AISC Chapter D, Page 26

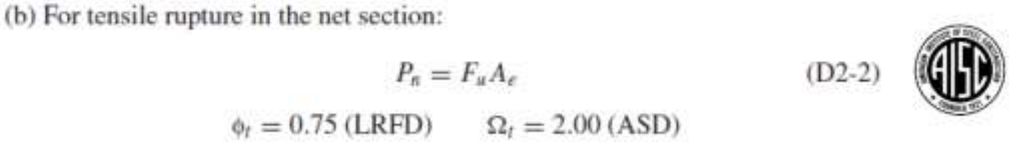


(a) For tensile yielding in the gross section:

$$P_n = F_y A_g \qquad \text{(D2-1)}$$

$$\phi_t = 0.90 \text{ (LRFD)} \qquad \Omega_t = 1.67 \text{ (ASD)}$$

- **TENSILE RUPTURE,** AISC Chapter D, Page 27



(b) For tensile rupture in the net section:

$$P_n = F_u A_e \qquad \text{(D2-2)}$$

$$\phi_t = 0.75 \text{ (LRFD)} \qquad \Omega_t = 2.00 \text{ (ASD)}$$

- **AREA DETERMINATION,** AISC Chapter D, Page 27

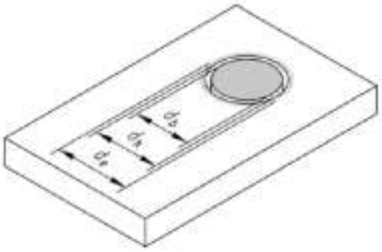
3. **Gross Area**, AISC Chapter D, Page 27

The gross area, A_g, of a member is the total cross-sectional area.

4. **Net Area**, AISC Chapter D, Page 27

$$A_n = A_g - A_{Holes}$$

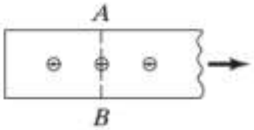
$$d_e = d_b + \frac{1}{8}"$$

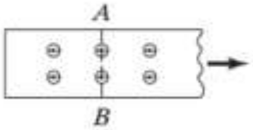


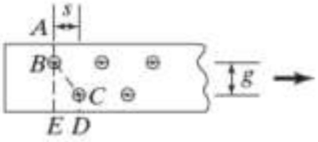
Or

For a chain of holes extending across a part in any diagonal or zigzag line, the net width of the part shall be obtained by deducting from the gross width the sum of the diameters or slot dimensions as provided in Section J3.2, of all holes in the chain, and adding, for each *gage* space in the chain, the quantity $s^2/4g$

$$A_n = A_g - A_{Holes} + \sum_{i=1}^{N} \frac{S_i^2}{4g_i} t\,, \quad N: Number\ of\ zigzag\ lines$$







In determining the net area across plug or *slot welds*, the *weld metal* shall not be considered as adding to the net area.

User Note: Section J4.1(b) limits A_n to a maximum of $0.85A_g$ for splice plates with holes.

$$A_e = A_n \leq 0.85A_g$$

5. **Effective Net Area**, AISC Chapter D, Page 28

3. Effective Net Area

The effective area of tension members shall be determined as follows:

$$A_e = A_n U \quad \text{(D3-1)}$$

where U, the shear lag factor, is determined as shown in Table D3.1.

- **BLOCK SHEAR STRENGTH,** AISC Chapter J, Page 112

3. Block Shear Strength

The *available strength* for the *limit state* of *block shear rupture* along a shear failure path or path(s) and a perpendicular tension failure path shall be taken as

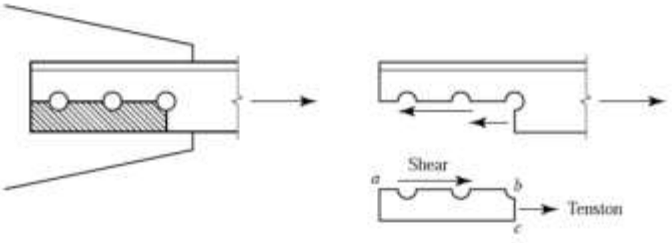
$$R_n = 0.6F_u A_{nv} + U_{bs} F_u A_{nt} \leq 0.6F_y A_{gv} + U_{bs} F_u A_{nt} \qquad \text{(J4-5)}$$

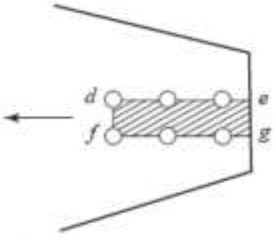
$$\phi = 0.75\,\text{(LRFD)} \qquad \Omega = 2.00\,\text{(ASD)}$$

where

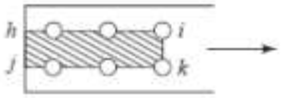
A_{gv} = gross area subject to shear, in.^{2} (mm^2)
A_{nt} = *net area* subject to tension, in.^{2} (mm^2)
A_{nv} = net area subject to shear, in.^{2} (mm^2)

Where the tension *stress* is uniform, $U_{bs} = 1$; where the tension stress is non-uniform, $U_{bs} = 0.5$.





Block shear in gusset plate



Block shear in tension member

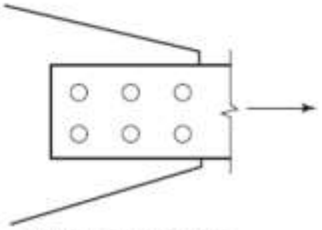
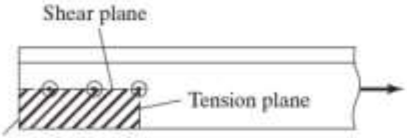
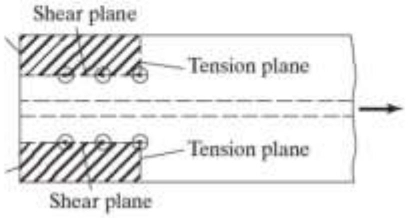


Plate tension member



(a) Bolted angle



(b) Bolted flange of W section

Example 3.1 Analysis of Tension Members

Determine the net area of the 3/8 × 8-in plate shown in Fig. 3.4 The plate is connected at its end with two lines of 3/4-in bolts.

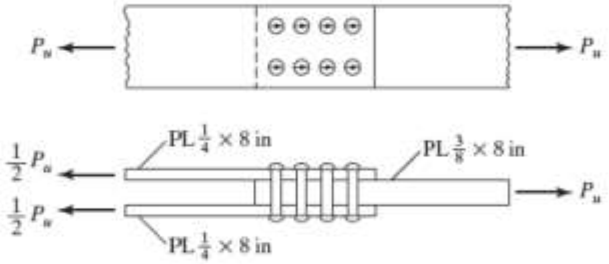


Figure 3-4

Solution

$$A_n = \left(\frac{3}{8}\text{ in}\right)(8\text{ in}) - 2\left(\frac{3}{4}\text{ in} + \frac{1}{8}\text{ in}\right)\left(\frac{3}{8}\text{ in}\right) = 2.34\text{ in}^2\ (1510\text{ mm}^2)$$

Ans.

Example 3.2 Analysis of Tension Members

Determine the critical net area of the 1/2-in-thick plate shown in Fig. 3.5, using the AISC Specification (Section B4.3b). The holes are punched for 3/4-in bolts.

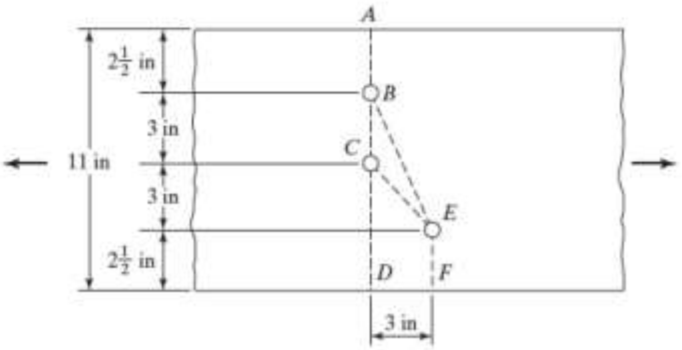


Figure 3-5

Solution

The critical section could possibly be *ABCD*, *ABCEF*, or *ABEF*. Hole diameters to be subtracted are 3/4 + 1/8 = 7/8 in. The net areas for each case are as follows:

$$ABCD = (11\text{ in})\left(\frac{1}{2}\text{ in}\right) - 2\left(\frac{7}{8}\text{ in}\right)\left(\frac{1}{2}\text{ in}\right) = 4.63\text{ in}^2$$

$$ABCEF = (11\text{ in})\left(\frac{1}{2}\text{ in}\right) - 3\left(\frac{7}{8}\text{ in}\right)\left(\frac{1}{2}\text{ in}\right) + \frac{(3\text{ in})^2}{4(3\text{ in})}\left(\frac{1}{2}\text{ in}\right) = 4.56\text{ in}^2 \longleftarrow$$

$$ABEF = (11\text{ in})\left(\frac{1}{2}\text{ in}\right) - 2\left(\frac{7}{8}\text{ in}\right)\left(\frac{1}{2}\text{ in}\right) + \frac{(3\text{ in})^2}{4(6\text{ in})}\left(\frac{1}{2}\text{ in}\right) = 4.81\text{ in}^2$$

Ans. 4.56 in^2

Example 3.3 Analysis of Tension Members

For the two lines of bolt holes shown in Fig. 3.6, determine the pitch that will give a net area *DEFG* equal to the one along *ABC*. The problem may also be stated as follows: Determine the pitch that will give a net area equal to the gross area less one bolt hole. The holes are punched for 3/4-in bolts.

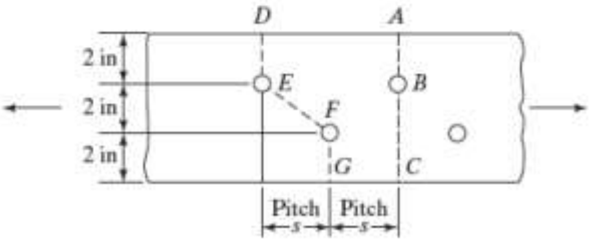


Figure 3-6

Solution

The hole diameters to be subtracted are 3/4 in + 1/8 in = 7/8 in.

$$ABC = 6\text{ in} - (1)\left(\frac{7}{8}\text{ in}\right) = 5.13\text{ in}$$

$$DEFG = 6\text{ in} - 2\left(\frac{7}{8}\text{ in}\right) + \frac{s^2}{4(2\text{ in})} = 4.25\text{ in} + \frac{s^2}{8\text{ in}}$$

$$ABC = DEFG$$

$$5.13 = 4.25 + \frac{s^2}{8} \qquad s = 2.65\text{ in}$$