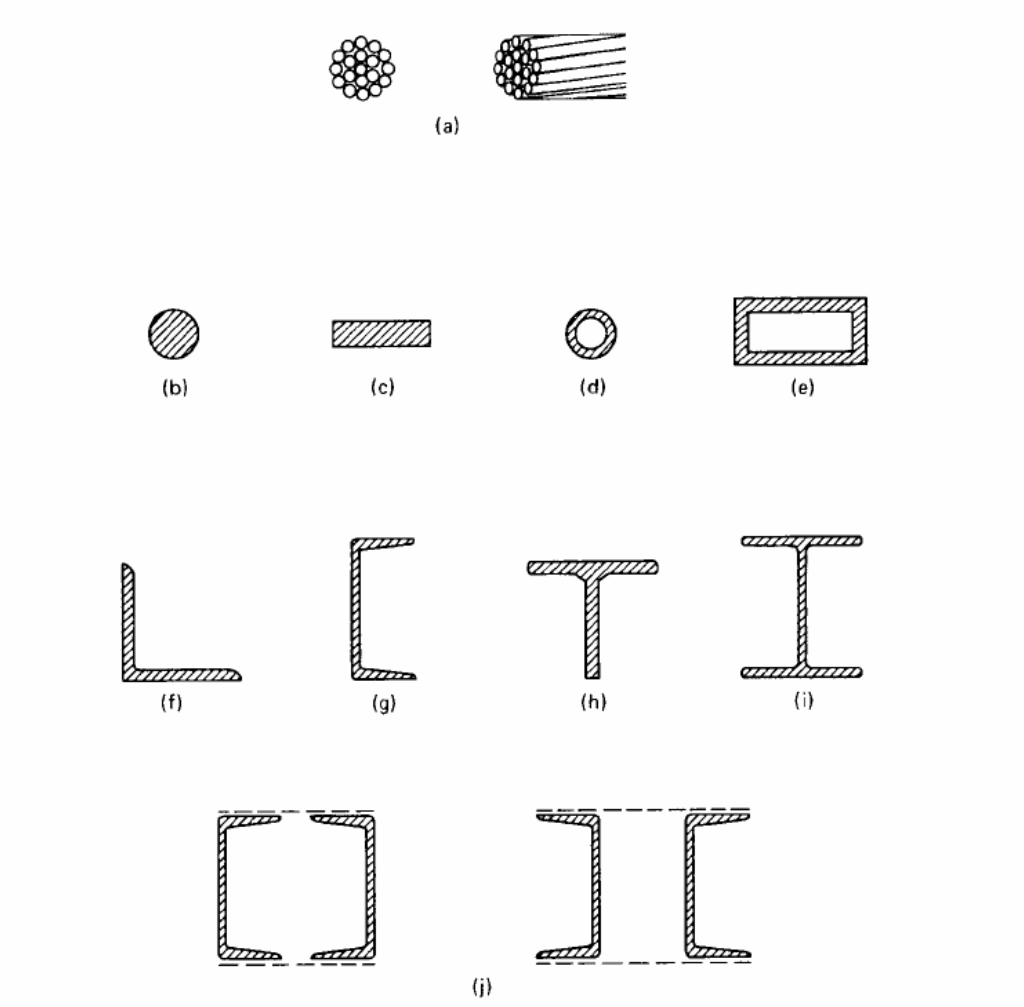
Design of Tension Members
Part 3 of AISC/LRFD Manual
Chapters B, D and J of the Specifications



Three Tension Limit States

1. Yielding failure of the gross cross-section (away from a connection).
2. Fracture of the net cross-section (through the bolt holes at a connection).
3. Slenderness limit.

Notations:

ϕ_t Resistance factor for tension (0.9 for yielding; 0.75 for fracture).

A_g Gross cross-sectional area.

A_e Effective net area (reduction of the net area to account for stress concentrations at holes and shear lag effects where not all the cross-sectional elements are connected to transmit the load).

A_n Net cross-sectional area (gross area minus the areas of the bolt holes).

U *The reduction coefficient*. Whenever the tension is transmitted through some but not all of the cross-sectional elements of the tension member $U = 1 - \bar{x}/l \leq 0.9$ (such as angle section where only one leg of the angle is connected to a gusset plate). Approximate values of U used prior to the current LRFD may also be used according to LRFD Commentary-B3.

$\bar{x}$ Distance from the plane of shear transfer to the centroid of the tension member cross-section.

l Length of the connection in the direction of loading.

F_y Specified minimum yield stress.

F_u Specified minimum ultimate stress.

P_n Nominal axial strength.

P_u Required axial strength.

L Laterally unsupported length of the member.

r Radius of gyration (smallest).

Requirements

The *design strength* $\phi_t P_n$ is taken as the smaller of the yielding limit state and the fracture limit state:

1. Yielding failure of the gross cross-section

   $$\phi_t P_n = \phi_t F_y A_g = 0.90 F_y A_g$$

2. Fracture of the net cross-section

   $$\phi_t P_n = \phi_t F_u A_e = 0.75 F_u A_e$$

   where $A_e = UA_n$.

   Design requirement:

   Required strength ≤ Design strength

   $$P_u \le \phi_t P_n \quad \text{or} \quad \frac{P_u}{\phi_t P_u} \le 1$$

   Slenderness ratio requirement (recommendation) (SPEC B7)

   $$L / r \le 300$$

AISC LRFD also requires the following considerations (Refer to Section J4 of the AISC LRFD Specifications):

1. *Shear Rupture*: $\phi P_n = \phi (0.6 F_u) A_{nv}$
2. *Tension Rupture*: $\phi P_n = \phi F_u A_{nt}$

   A_{nv} is the net area subject to shear

   A_{nt} is the net area subject to tension

   $\phi = 0.75$

3. *Shear-Tension Combination*:

(i) When $F_u A_{nt} \geq 0.6 F_u A_{nv}$

$$\phi P_n = \phi\left(0.6 F_y A_{gv} + F_u A_{nt}\right) \leq \phi\left(0.6 F_u A_{nv} + F_u A_{nt}\right)$$

(ii) When $F_u A_{nt} \leq 0.6 F_u A_{nv}$

$$\phi P_n = \phi\left(0.6 F_u A_{nv} + F_y A_{gt}\right) \leq \phi\left(0.6 F_u A_{nv} + F_u A_{nt}\right)$$

A_{gv} = the gross area subject to shear

A_{gt} = the gross area subject to tension

A_{nv} = the net area subject to shear

A_{nt} = the net area subject to tension

$\phi = 0.75$

The foregoing failure modes are referred to as Block Shear failure. Block shear is a failure phenomenon at the bolted connection for the member. The member or the gusset plate can shear-off and/or rupture in tension. There can be several modes of block shear failure and all of these need to be analyzed. Failure can happen in either yielding or fracture in all modes. We calculate the yield capacity on the gross area and the fracture capacity on the net area. Block shear capacity is the combined shear and tensile capacity of the failure mode (smallest capacity governs).

Design Procedure

Make sure that all three criteria described above are satisfied. There is no standard rule for designing tension members, but it is useful to follow the basic three steps:

1. Calculate the design load P_u.
2. Calculate

   (a) Required gross area (A_g)

   (b) Required (effective) net area (A_n or A_e)

   (c) Radius of gyration (r).
3. Pick a member and try different sections that satisfy the criteria.

   Choose the lightest member.
4. Check other criteria.