2.1 BEHAVIOUR AND DESIGN OF TENSION MEMBERS

Steel tension members are those structural elements that are subjected to direct axial tensile loads, which tend to elongate the members. Tension members are probably the most common and efficient members in steel structures. They occur as components of trusses, bridges, wind bracings and transmission towers. Types, limiting slenderness ratio, behaviour and failure of tension members are discussed further.

Types of Tension Members

A tension member may consist of a single shape or may be built using a number of structural shapes (compound members). A brief of different scenarios where different sections are used is given below.

- Structural T-Sections - chord members of lightly loaded structures
- Structural I-Sections, channel sections, and built-up sections - used when greater rigidity is required i.e., in bridge construction
- Rods and bars - in bracing systems
- Wire (single continuous element cold drawn from a hot-rolled rod) - used as guy wires in suspension bridges

Limiting Slenderness Ratio of Tension Members

Although stiffness is not required for the strength of a tension member, a minimum stiffness is stipulated by limiting the maximum slenderness ratio of the tension member. This limiting slenderness ratio is **required in order to prevent**

undesirable lateral movement or excessive vibration. Maximum values of effective slenderness ratio as per IS 800 is given below.

Behaviour of Tension Members

The load-deformation behaviour of a tension member is similar to the basic material stress-strain behaviour. When a member is subjected to tension, the area of cross-section and gauge length change continuously due to the poison effect and longitudinal strain respectively. Stresses and strains calculated using initial cross-section and gauge length is called engineering stress-strain curve, while that calculated using instantaneous cross-section and gauge length is called a true stress-strain curve.

Modes of Failure of Tension Members

The different modes of failure by which a tension member could fail are listed and explained further.

1. Gross Section Yielding
2. Net Section Rupture
3. Block Shear Failure

1. Gross Section Yielding

Concept:

A tension member without bolt holes can resist loads up to the ultimate load without failure. But such a member will deform in the longitudinal direction before fracture and makes the structure unserviceable. Hence to calculate design strength, yielding of the gross section is considered appropriate.

Formula:

As per *Clause 6.2 Design Strength Due to Yielding of Gross Section of IS 800: 2007*, the design strength of members under axial tension (Tdg) as governed by yielding of the gross section, is given by,

Tdg = (Ag * fy) /γm0,

where,

Ag - gross area of cross-section,

fy - yield stress of the material, and

γm0 - partial safety factor for failure in tension by yielding = 1.1 (refer to Table 5 of IS 800).

2. Net Section Rupture

Concept:

When a tension member is connected using bolts, cross-section reduces because of the holes present and this is referred to as net area. Holes in the members cause stress concentration at service loads. From the theory of elasticity, the tensile stress adjacent to a hole will be about two to three times the average stress on the net area. The ratio of maximum elastic stress to the average stress (fmax/favg) is called the stress concentration factor. Stress concentration is an important factor when a member is subjected to dynamic load where there is a possibility of brittle fracture or when the repeated application of load may lead to fatigue failure.

In static loading of a tension member with a hole, the point adjacent to the hole reaches the field stress (fy) first. With further loading, the stress at that point remains constant at yield stress and each fibre away from the hole progressively reaches the yield stress. Deformations continue with increasing load until rupture/tension failure of the member occurs when the entire net cross-section of the member reaches the ultimate stress (fu).

Formula:

As per *Clause 6.3 Design Strength Due to Rupture of Critical Section of IS 800: 2007*, design strength is given for different members separately as follows.

1. Design Strenght in Tension of a Plate (Tdn)

Tdn = 0.9 * An * fu / γm1,

where,

γm1 - partial safety factor for failure at ultimate stress = 1.25 (refer to Table 5 of IS 800: 2007),

fu - ultimate stress of the material,

An - the net effective area of the member given by,

An = [b - (n * dh) + Σ((Psi^2) / (4 * Gi))] * t,

where,

b, t - breadth and thickness of the plate respectively,

dh- diameter of the bolt hole,

g - gauge length between the bolt holes,

Ps - staggered pitch length between the line of bolt holes,

n - number of bolt holes in the critical section, and

i - subscript for summation of all the inclined legs.

2. Design Strenght in Tension of a Threaded Rods (Tdn)

Tdn = 0.9 * An * fu / γm1,

where,

γm1 - partial safety factor for failure at ultimate stress = 1.25 (refer to Table 5 of IS 800: 2007),

f_u - ultimate stress of the material,

A_n - the net root area at the threaded section.

3. Design Strenght in Tension of a Single Angles (Tdn)

The rupture strength of an angle connected through one leg is affected by shear lag. The design strength (Tdn) as governed by rupture, is given by,

Tdn = (0.9 * Anc * fu / γm1) + (β * Ago * fy / γm0),

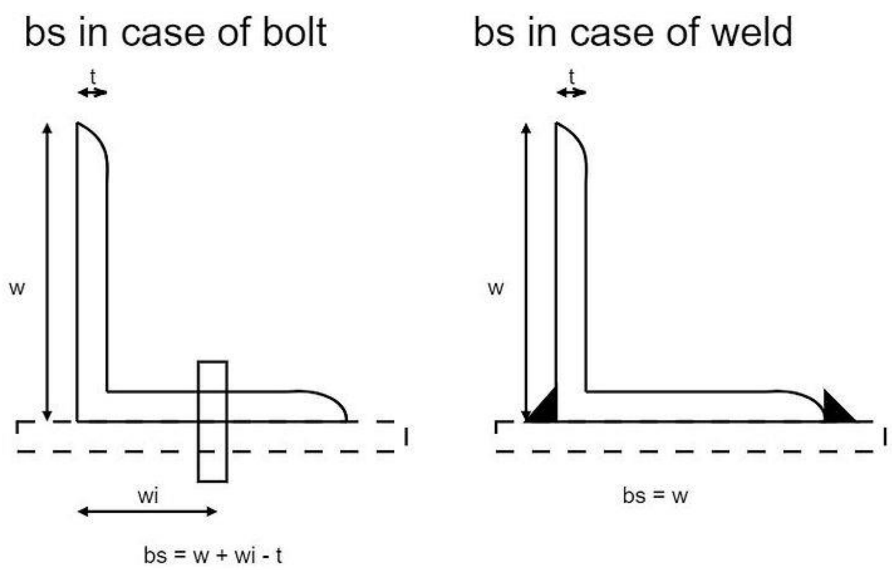
where,

β = 1.4 - 0.076 * (w/t) * (fy/fu) * (bs/Lc) ≤ ((fu*γm0) / (fy*γm1)) and ≥ 0.7,

where,

w - outstand leg width,

bs - shear lag width,



Lc - length of the end connection that is the distance between the outermost bolts in the end joint measured along the load direction or length of the weld along the load direction

An - net area of the total cross-section,

Anc - the net area of the connected leg,

Ago - the gross area of the outstanding leg,

t - thickness of the leg

γm1 - partial safety factor for failure at ultimate stress = 1.25 (refer to Table 5 of IS 800: 2007),

γm0 - partial safety factor for failure governed by yielding = 1.1 (refer to Table 5 of IS 800: 2007),

fu - ultimate stress of the material, and fy - yield strength of the material.

3. Block Shear Failure

Concept:

In this type of failure, the failure of the member occurs along a path involving tension on one plane and shear on a perpendicular plane along with the fasteners. Chances of a block shear failure increase when the material bearing strength and bolt shear strength is higher (but the length of the connection reduces as the number of bolts required for connection decreases).

Formula:

As per Clause 6.4 Design Strength Due to Block Shear of IS 800: 2007, separate methods for bolted connection and welded connection are provided.

1. Bolted Connection

The block shear strength, Tdb of connection shall be taken as smaller of,

$$T_{db} = \left[\frac{A_{vg} \cdot f_y}{\sqrt{3} \cdot \gamma_{m0}} + \frac{0.9 \cdot A_{tn} \cdot f_u}{\gamma_{m1}} \right] \text{ or}$$

$$T_{db} = \left[\frac{0.9 \cdot A_{vn} \cdot f_u}{\sqrt{3} \cdot \gamma_{m1}} + \frac{A_{tg} \cdot f_y}{\gamma_{m0}} \right]$$

where,

Avg, Avn - minimum gross and net area in shear along bolt line parallel to external force, Atg, Atn - minimum gross and net area in tension from the bolt hole to the toe of the angle, end bolt line, perpendicular to the line of the force,

fu, fy - ultimate and yield stress of the material respectively,

γm1 - partial safety factor for failure at ultimate stress = 1.25 (refer to Table 5 of IS 800: 2007), and

γm0 - partial safety factor for failure governed by yielding = 1.1 (refer to Table 5 of IS 800: 2007).

2. Welded Connection

The block shear strength, Tdb shall be checked for welded end connections by taking an appropriate section in the member around the end weld, which can shear off as a block.