Tension Members

Tension members are components of structures that experience axial tensile forces. A tension member is only subjected to direct axial forces that tend to stretch it. Several factors influence the strength of these tension members, including the length of the connection, the size and spacing of fasteners, the net area of the cross-section, shear lag at the end connection, connection eccentricity, and the type of fabrication.

The stress concentration near the holes causes the yielding of the nearby fibers, but the steel's ductility allows for redistribution of overstress in adjoining sections until the fibers away from the holes gradually reach yield stress. As a result, at maximum load, it is reasonable to assume uniform stress distribution.

Types of Tension Members

A tension member is a structural member that is subjected to tensile force in the direction of its longitudinal axis. They are also known as a tie member or just a tie. The type of tension member in structural steel construction is determined by the structure and method of end connections. These types are important for the GATE CE exam. Tension members can be divided into the following four categories:

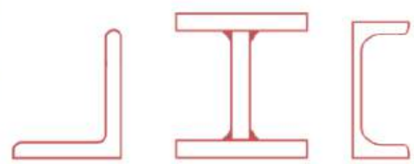
1. Wires and cables: Wires are used solely for hoisting in steel stacks and towers. Wires are helical wounds to form strands and ropes. A strand is made up of individual wires that are wound helically around a central core. These are not recommended for use in bracing systems because they cannot withstand compression. The benefits of wire and cable are their flexibility and strength. The wire types are used in hoists, derricks, rigging slings, guy wires, and suspension bridge hangers.

2. Rods and bars: These are the most basic types of tension members. Bars and rods are frequently used as tension members in bracing systems and as sag rods to support purlins between trusses. Currently, these are not popular among designers due to the large drift they cause during strong winds and the disturbing noise caused by the vibrations.

The square and round bars depicted in the figures are frequently used for small tension members. Pin connections are used at the ends of round bars with threaded ends. To form eye bars, the ends of rectangular bars or plates are enlarged by forging and bored. The eye bars are used in conjunction with pin connections. The rods and bars have the disadvantage of insufficient stiffness, which causes noticeable sag under self-weight.

3. Single Structural Shapes and Plates: As tension members, the single structural shapes shown in the figures, namely angle sections and tee sections, are used. Angle sections are much more rigid than wire ropes, rods, and bars. When the length of the tension member is too long, the single-angle section also becomes flexible.

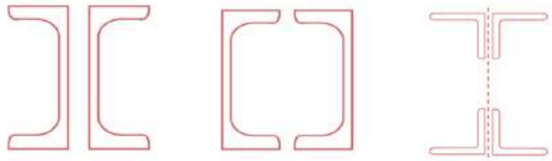
In a riveted connection, single-angle sections have the disadvantage of eccentricity in both planes. In channel sections, only one axis is eccentric. Single channel sections have high rigidity in the web direction and low rigidity in the flange direction. I-sections are occasionally used as tension members. I-sections are more rigid, and single I-

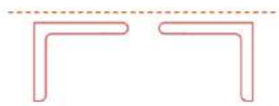


sections are less expensive than built-up sections.

4. Built-up members: Built-up members are made up of two or more members. Built-up sections are used when a single rolled steel section cannot provide the required area. The double-angle sections with unequal legs depicted in the figure are commonly used as tension members in roof trusses. The angle sections are stacked on two sides of a gusset plate. When both angle sections are connected to the same side of the gusset, the built-up section has eccentricity in one plane and is subjected to tension and bending simultaneously.

A built-up section can be composed of two channels joined together by a gusset. These sections are used in a single-plane truss for medium loads. Two channels are arranged at a distance with their flanges turned inward in two-plane trusses. It simplifies transverse connections and reduces lacing. To increase lateral rigidity, the flanges of two channels are kept outwards, as in chord members or long-span girders. Angles and plates make the heavy built-up tension members in bridge girder trusses. Such members can withstand compression when stress is reversed.

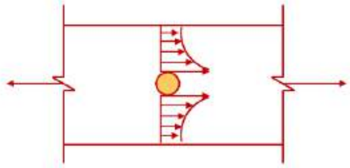




Modes of Failures of Tension Members

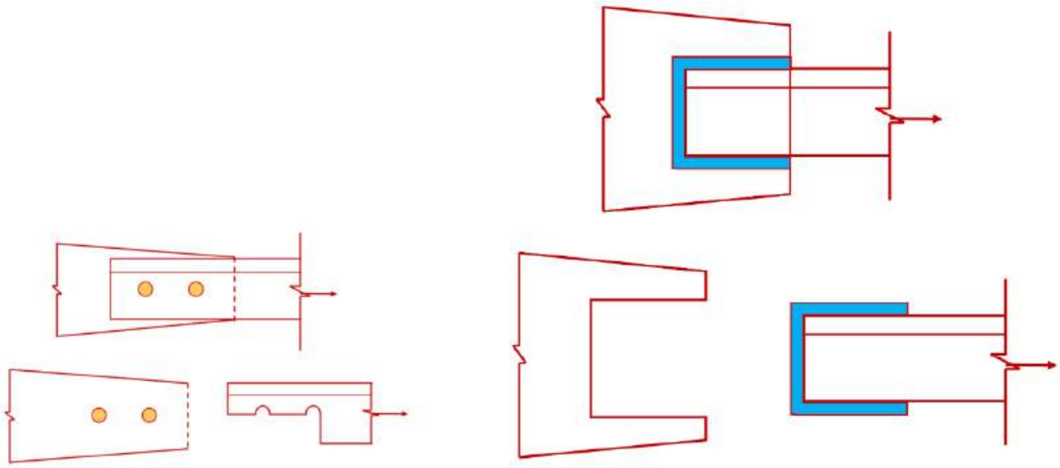
A tension member can fail in a variety of ways, and the section of the member should be designed to prevent failure in any of these ways. The three types of failure in tension members are gross section yielding, net section rupture, and block shear failure.

1. **Gross section yielding:** A tension member can fail due to either excessive deformation or net section rupture. A tension member with no bolt holes, in general, can withstand loads up to the ultimate load without failing. A member of this type will deform significantly in the longitudinal direction before fracture. A structure becomes unusable after such a large deformation. As a result, one of the limiting values in the design strength corresponds to the yielding of the gross cross-section.
2. **Net section rupture:** A tension member is often connected to the main or other members by bolts/welds. The presence of a bolt hole in a tension member causes stress to flow around the hole. This will cause various types of stresses adjacent to the hole to be larger than the average stress at the bolt hole. Since the Bolt holes have reduced the cross-sectional area, these bolts have stress concentration adjacent to bolt holes at service loads.



When a tension member with a hole is loaded statically, the point adjacent to the hole is the first to reach yield stress (f_y). On further loading, the stress at that point remains constant at yield stress, and each fibre away from the hole progressively reaches yield stress (f_y). Deformation continues with an increase in load until, finally, rupture of the member occurs when a net cross-section of the member reaches the ultimate stress(fu). The rupture strength of the net section may be taken as a limit state here.

3. Block shear failure: A piece of the block gets separated from the member in this type of tension member failure. This occurs when the material bearing strength (high-strength plate) and bolt shear strength are higher. Only a few bolts are required when high-strength bolts connect high-strength plates. Due to this, the length of connection required will be less. This increases the probability of block shear failure. In block shear failure, the failure occurs along a path involving tension on one plane and shear on a perpendicular plane (along with the fasteners).



The strength of tension members is first determined under the various modes of failure, namely design strength due to gross section yielding (T_{dg}), critical section rupture (T_{dn}), and block shear strength (T_{db}). The lowest of the three values listed above is the design strength of a member under axial tension (T_d).

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Slenderness Ratio of Tension Members

The slenderness ratio for tension members is the ratio of their unsupported length to the least radius of gyration. However, IS: 800 - 2007 specifies the maximum effective slenderness ratio as the ratio of the effective length of the member to the least radius of gyration. Since buckling is not involved in tension members, theoretically, there is no limit on the slenderness ratio of tension members. However, To avoid buckling tension members when subjected to reversal of stresses, IS 800 has kept a limitation over the maximum value of slenderness of tension members.

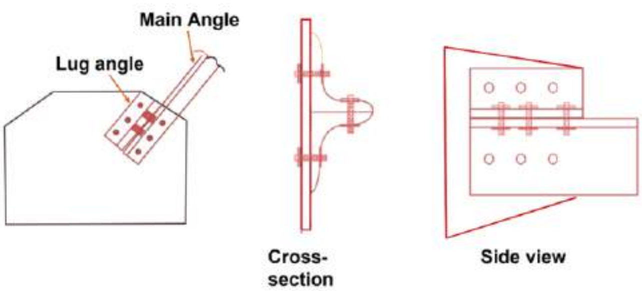
S.No	Type of Member	λ_{max}
1.	A tie member subjected to reversal of direct stresses due to action of loads other than W.L/E.L	180
2.	A member normally acting as a tie member in a roof truss or bracing system, subjected to reversal of stresses due to the action of W.L/E.L	350
3.	A member always under tension (Other than pretensioned members)	400

Lug Angles in Tension Members

A specific length of the tension member and the gusset plate is used to make the connection at joints. If the load is heavy and the number of bolts/weld length required for making the connection is large, the gusset plate size may be uneconomical and awkward. Candidates can attempt MCQs on Tension members to prepare this section well.

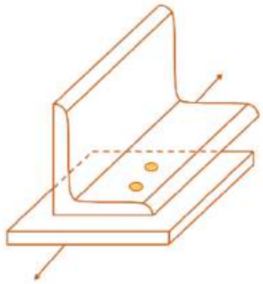
As an alternative, an additional angle is used in conjunction with the tension member to reduce the length of the joint and, as a result, the size of the gusset plate. This type of angle is called a lug angle. The whole area of the member shall be taken as an effective section **(whole area = gross area – bolt holes area)**. The strength of the lug angle and connector between the lug angle and the gusset plate should be at least 20% more than the force in the outstanding leg. The channel section value is 10% more for the above-mentioned case.

The strength of connectors between the lug angle and the main angle shall be at least 40% more than the force in the outstanding leg. For the channel section, this value is 20% more.



Shear Lag Effect on Tension Members

When the tension member is loaded away from the connection, the stress is uniform at every point. As we move closer to the connection, the stresses from the outstanding leg are transferred to the connected leg. Due to this, the connected leg becomes over-stressed, whereas the outstanding leg is under-stressed. As one leg lags behind the other, the outstanding leg is said to be affected by Shear Lag. Due to the shear lag effect, the stress distribution in the outstanding leg becomes non-uniform. Hence, its full strength is not utilized, and the strength of tension members is reduced.



The shear lag effect can be reduced by using unequal angle sections with a longer leg connected and a shorter leg as an outstanding leg. To remove shear lag, the outstanding leg should also be connected. The shear lag effect is called the non-uniform stress distribution that occurs in tension members adjacent to a connection, in which all cross-section elements are not directly connected.