Chapter 2

Tension and Compression Members

CHAPTER HIGHLIGHTS

- *Tension members*
- *Compression members*
- *Column bases*

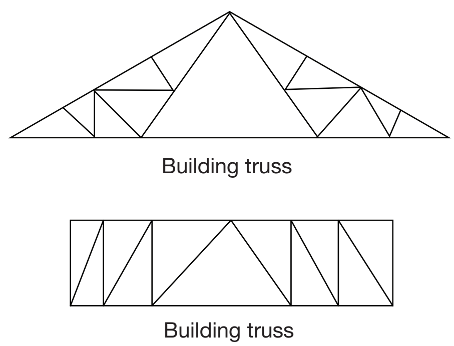
Tension Members

Introduction

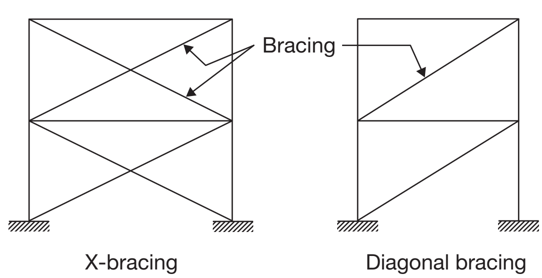
Tension members are structural members subjected to a direct axial tensile forces at its ends. The strength (stress) of a tension member can be determined by dividing the axial load with its cross-sectional area. The strength or efficiency of a tension member may be affected due to bolt holes (end connections), load reversals causing compressive stresses, and bending moments due to the eccentricity in the end connections. Therefore, a member subjected to only axial tension is to be the most efficient and econmical structural element. In these sections, the entire cross-section is subjected to uniform stress only.

Examples of Tension Members

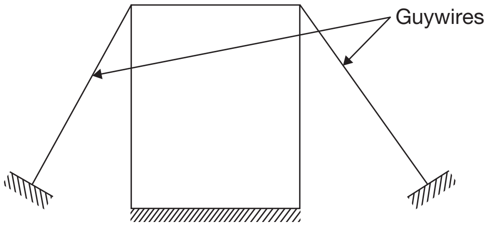
1. Elements of trusses in building and bridges.
2. Communication and satellite towers.
3. Guy wires in steel stacks.
4. Bracing systems in multistorey buildings and Industrial buildings.
5. Main cables and suspenders in suspension bridges and cable stays of cable-stayed bridges.



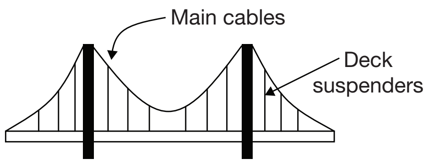
Trusses



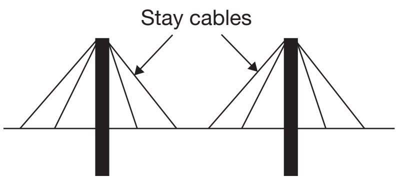
Concentric bracing of multistory building



Guyed steel stack



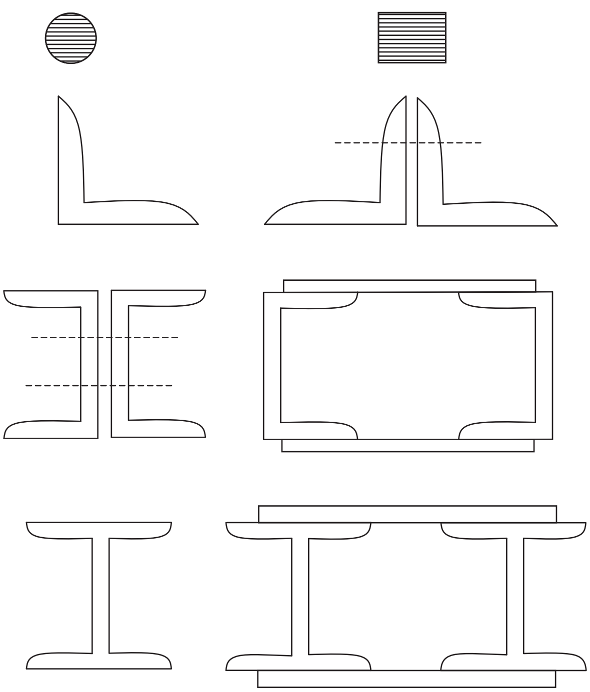
Suspension bridge



Cable stayed bridges

Types of Tension Members

The cross section of some typical tension members are shown below:



Cross-section of tension members

- In light roof trusses, single-angle or double-angle sections are used, whereas in bridge truss, tension members are made of single or built-up channels and I-section.
- Rods and bars are used as tension members in the bracing system.
- I-sections, channel sections, and built-up sections are used when greater rigidity is required.

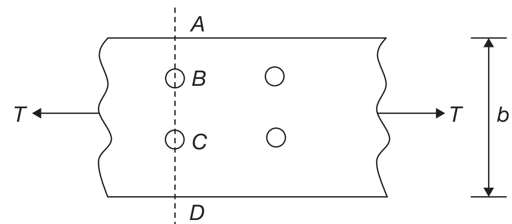
Net Sectional Area

- The net sectional area of tension members is the gross sectional area of the members minus the sectional area of the maximum number of holes.

$$\boxed{A_n = A_g - \text{Sectional area of holes}}$$

Flats and Plates

Case 1: Chain bolting



$$\boxed{A_n = (b - nd_h)t}$$

- For chain pattern of Bolting

Where

A_n = Net sectional area of plate
b = Width of plate
n = Number of bolts ($n = 2$; for above figure)
d_h = Diameter of bolt hole
t = Thickness of plate
A_g = Gross-sectional area of plate

Case 2: Staggered bolting or zig-zag bolting

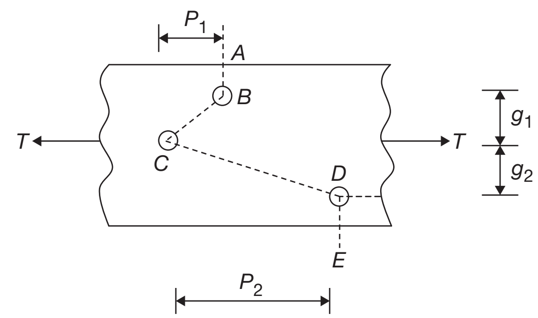
- Is: 800–2007 recommends an empirical equation for staggered bolting.

$$\boxed{A_n = \left[b - nd_h + \frac{n'p^2}{4g}\right]t}$$

Where

p = Staggered pitch
g = Gauge distance
n' = Number of staggered pitches
n = Number of holes in the zig-zag line

- The given formula is used when pitch and gauge distance of bolts are same.
- If bolts are staggered at different pitch and gauge distance, then:



$$\boxed{A_n = \left[b - nd_h + \frac{p_1^2}{4g_1} + \frac{p_2^2}{4g_2}\right] \times t}$$

Types of Failures

The following modes of failure take place in tension members:

1. **Gross section yielding:** The members will considerably deform in the longitudinal direction before it fractures making a structure unserviceable.
2. **Net section rupture (fracture):** A Tension member ruptures (fractures) at its net sectional area (due to the presence of holes) by reaching to the ultimate stress.
3. **Block shear failure:** A block of material is sheared off at the end of members due to the possible use of high bearing strength of steel and high-strength bolts resulting in smaller connection length.
   - The design strength of tension member due to axial tensile load is least of design strength due to gross section yielding (T_{dg}), net section rupture (T_{dn}) and block shear (T_{db}).

Design Strength of Tension Members

Based on Gross Sections (T_{dg})

To prevent deformation (initiated by yielding), the load on the gross section must be small enough, so that the stress on gross section is less than the yield stress.

$$\boxed{\begin{array}{l} \dfrac{T}{A_g} < f_y \\ T < A_g f_y \end{array}}$$

Design tension strength:

$$\boxed{T_{dg} = \frac{T}{\gamma_{mo}} = \frac{A_o f_y}{\gamma_{mo}}}$$

Where

T = The factored design tension

T_{dg} = The design strength

A_g = The gross-sectional area

f_y = The yield strength

γ_{mo} = The partial safety factor (= 1.10)

Based on Net Section Rupture

1. In case of a tension member connected to other member or gusset plate by bolt or weld is given by:

$$T < A_n f_u$$

$$T_{dn} \frac{T}{\gamma_{mo}} = \frac{A_n f_u}{\gamma_{mo}}$$

$$\boxed{T_{dn} = 0.9 \frac{A_n f_u}{\gamma_{m1}}}$$

2. The tearing strength of an angle section connected through one leg is given by:

$$\boxed{T_{dn} = \frac{0.9 A_{nc} f_u}{\gamma_{m1}} + \beta \frac{A_{go} f_y}{\gamma_{mo}}} \quad (1)$$

Where

$$\beta = 1.4 - 0.076 \left(\frac{W}{t}\right) \times \left(\frac{f_y}{f_u}\right) \times \left(\frac{b_s}{L_c}\right)$$

$$\leq \frac{f_u}{f_y} \times \frac{\gamma_{mo}}{\gamma_{m1}}$$

$$\geq 0.7$$

A_n = Effective net area of cross-section

A_{nc} = Net area of connected leg

A_g = Gross area of outstanding leg

t = Thickness of the leg of angle

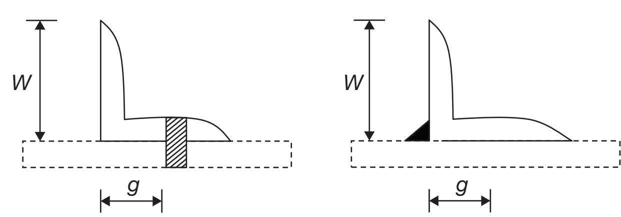
L_c = Length of end connection

(Distance between the outermost bolts in the joint along the length or the longer length of the weld along the load direction.)

f_u = Ultimate strength of material.

Definition of b_s as per the Code

It can be indicated by the following figure.



(a) Bolted connection
$b_s = W + g - t$

(b) Welded connection
$b_s = W$

NOTES

1. For double-angles, channels, I-sections and other rolled section connected by one or more elements to an end gusset, the design strength T_{dn} is given by the same equation as in Eq. (1).
2. For preliminary sizing of a tension member, the tearing strength of net section is given by:

$$\boxed{T_{dn} = \alpha \frac{A_n f_u}{\gamma_{m1}}}$$

Where

γ_{m1} = Partial safety factor governed by ultimate stress (= 1.25)

$\alpha = 0.6$; for number of bolts $\leq 2 = 0.7$; for number of bolts = 3

= 0.8; for number of bolts ≥ 4

= 0.8; for welds

Based on Block Shear

Plates

1. For shear yield and tension fracture:

$$\boxed{T_{db1} = \frac{A_{vg} f_y}{\sqrt{3}\gamma_{mo}} + 0.9 \frac{A_{tn} f_u}{\gamma_{m1}}}$$

2. For tension yield and shear fracture:

$$\boxed{T_{db2} = \frac{A_{tg} f_y}{\gamma_{mo}} + 0.9 \frac{A_{vn} f_u}{\sqrt{3}\gamma_{m1}}}$$

Where

A_{vg} and A_{vn} = Minimum gross and net areas in shear along the line of action of force.

A_{tg} and A_{tn} = Minimum gross and net areas in tension from the hole to the toe of the angle or next last row of bolts in plates perpendicular to the line of force.

Slenderness Ratio (λ)

As per IS:800–2007; maximum effective slenderness ratio to be the ratio of effective length (kL) of the member to the appropriate radius of gyration (r).

The following table shows the maximum slenderness ratio values for tension members.

Member	Maximum Slenderness Ratio
A tension member in which reversal of direct stress due to loads, other than wind or seismic forces occur.	180
A tension member subjected to possible reversal of stresses resulting from the action of the forces of wind or earthquake.	350
Members always under tension (other than pre-tensioned members)	400

Design of Tension Member Subjected to Axial Load

Procedure

1. The net area required A_n to carry the factored load T is given by:

$$A_n = \frac{T}{\frac{0.9 f_u}{\gamma_{m1}}} \text{ or } \frac{T}{\alpha \frac{f_u}{\gamma_{m1}}}$$

2. Increase the net area by 25% to compute the trial gross sectional area.
3. Trial gross-sectional area is also determined from its yield strength by:

$$A_g = \frac{T}{\frac{f_y}{\gamma_{m0}}}$$

4. Select a suitable rolled section or built up section with the computed gross-sectional area.
5. The number of bolts (or weld) required to make the connection is calculated. Arrange them in a suitable pattern and compute the net sectional area.
6. Calculate the design tensile strength (T_d) of trial section (minimum of T_{dg}, T_{dn}, T_{db}).
7. The slenderness ratio of the member is checked.

Lug Angles

An additional angle called 'lug angle' is used along with the tension member to reduce the length of joint and consequently the size of gusset plate. Lug angle may be designed as follows:

1. In case of angle members, the lug angles connected to the gusset or any other supporting member should be capable of developing a strength not less than 20% in excess of force in outstanding leg of the angle. The attachment of lug angle to the angle members should be capacble of developing 40% in excess of that force.
2. In case of channel sections, the lug angles and their connection to the gusset or any supporting member should be capable of developing a strength of not less than 10% in excess of force and the attachment of the lug angles to the member should be capable of developing a strength 20% in excess of that force.
3. Minimum number of bolts to be used for attaching the lug angle to the gusset or another supporting member should be two.
4. In case of lug angles connect to an angle member, the whole area should be taken as effective, and the net

area is calculated by deducting the area of bolt holes from the gross-sectional area.

5. Lug angles should be placed symmetrically with respect to the section of member.

Splices

A tension splice is used when:

- Length of section available is less than that required.
- Size of member changes at different lengths.
- The splice connection should be designed for a force at least 0.3 times the design capacity in tension or the design action, whichever is more.
- If the sections to be spliced are not of same thickness, packing is to be introduced. In such, a case design shear capacity should be decreased by the factor $\beta_{pkg}(t_{pkg} > 6\text{ mm})$.

Compression Members

Introduction

A compression member is a structural member subjected to a direct compressive force at its ends. A compression member will be a truly axially loaded member when the member is perfectly straight, has no crookedness, no imperfections, and the loads are applied uniformly across it, with the centre of gravity of loads coinciding with centre of gravity of the member.

Designation

Compression members, depending upon its position in structures, may be designated in various forms:

- **Column, stanchion or post:** Vertical compression member supporting floors or girders in a building.
- **Sturt:** A compression member used in roof truss and bracing.
  Example: Principal rafter (continuous strut).
- **Boom:** Principal compression member in a crane.

Classification of Columns

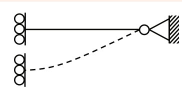
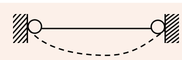
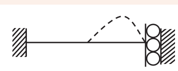
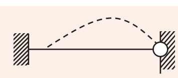
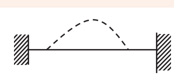
Columns are classified based on slenderness ratio.

- **Long columns:** Fails by elastic buckling.
- **Intermediate columns:** Fails by inelastic bucking (yielding and buckling).
- **Short column:** Fails by crushing or yielding.

Effective Length (*kL*)

- Effective length is obtained by multiplying the actual length with the effective length factors (k).
- 'k' depends on rotational and lateral movement restraint at the end of compression members.
- Smaller the effective length, greater the load carrying capacity and smaller is the danger of lateral buckling.

Effective length of prismatic compression members

Boundary Conditions				Schematic Representation	Effective Length (*kL*)
At One End		At the Other End			
Translation	Rotation	Translation	Rotation		
Restrained	Restrained	Free	Free		2.0 L
Free	Restrained	Restrained	Free		2.0 L
Restrained	Free	Restrained	Free		1.0 L
Restrained	Restrained	Free	Restrained		1.2 L
Restrained	Restrained	Restrained	Free		0.8 L
Restrained	Restrained	Restrained	Restrained		0.65 L

L–Unsupported Length of Compression Member

Slenderness Ratio

- It is the ratio of the effective length to the radius of gyration: $\lambda = \dfrac{kL}{r}$
- It is the measure of tendency of a member to buckle.
- Slenderness ratio should be kept as small as possible to minimize steel requirements in columns.
- Slenderness ratio is limited in taking care of accidental and construction loads, unexpected vibrations, etc.

Maximum slenderness ratio for compression members

S. No.	Type of Member	λ
1.	A member subjected to compressive loads resulting from dead and imposed loads.	180
2.	A member subjected to compressive force resulting only from combination with wind or earthquake actions.	250
3.	Compression flange of a beam restrained against lateral–torsional buckling.	300

Effective length of angle struts

S. No.	Type	Sections	Effective Length	
			In the Plane of Gusset	Perpendicular to the Gusset
1.	Continuous	Single-angle or double-angle.	0.7–1.00 L	1.00 L
2.	Discontinuous	Single-angle, connected with one bolt.	1.00 L	1.00 L
3.	Discontinuous	Single-angle, connected with more than one bolt or welded.	0.85 L	1.00 L
4.	Discontinuous	Double-angle, placed back to back on opposite sides of gusset plate.	0.70–0.85 L	1.00 L
5.	Discontinuous	Double-angles, placed back-to-back on the same side of gusset plate.	0.70–0.85 L	1.00 L

Design Strength of a Compression Member

- The design compressive strength of a member is given by:

$$\boxed{P_d = A_e f_{cd}}$$

Where
A_e = Effective sectional area
f_{cd} = Design stress in compression

- The code recommends the following equation for f_{cd} by considering the effect of residual stresses, initial bow and accidental eccentricities of load.

$$\boxed{f_{cd} = \frac{\dfrac{f_y}{\gamma_{mo}}}{\phi + [\phi^2 - \lambda^2]^{0.5}} = x\frac{f_y}{\gamma_{mo}} \leq \frac{f_y}{\gamma_{mo}}}$$

Where
$\phi = 0.5[1 + \alpha(\lambda - 0.2) + \lambda^2]$
λ = Non-dimensional effective slenderness ratio

$$f_{cc} = \text{Euler buckling stress} = \frac{\pi^2 E}{\left(\dfrac{kL}{r}\right)^2}$$

$$\lambda = \sqrt{\frac{f_y}{f_{cc}}} = \sqrt{f_y \frac{\left(\dfrac{kL}{r}\right)^2}{\pi^2 E}}$$

$\dfrac{kL}{r}$ = Effective slenderness ratio

α = Imperfection factor
x = Stress reduction factor

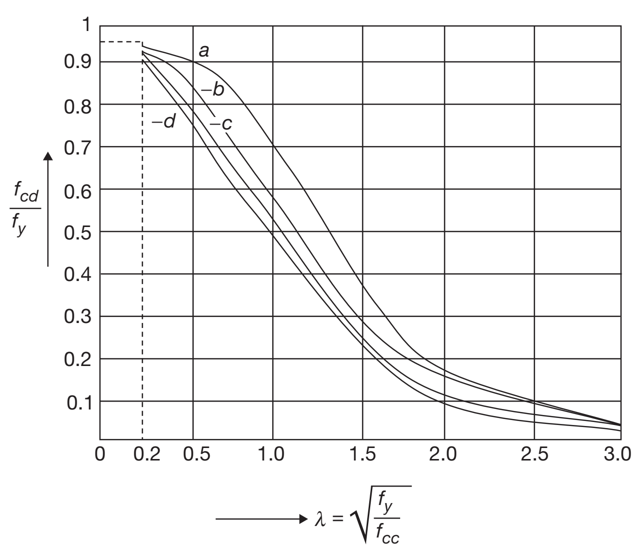
$$= \frac{1}{\phi + \left[\phi^2 - \lambda^2\right]^{0.5}}$$

γ_{mo} = Partial safety factor for material strength

Imperfection factor (α)

Buckling Curve	a	b	c	d
α	0.21	0.34	0.49	0.76

IS:800–2007, based on Perry Robertson approach, proposes multiple column curves a, b, c and d.

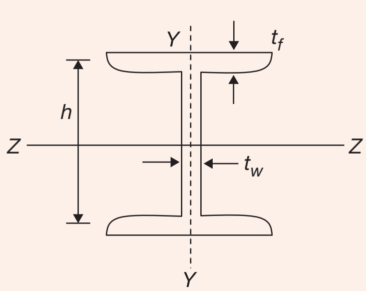
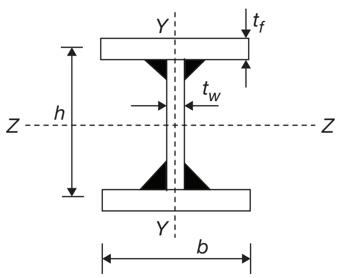
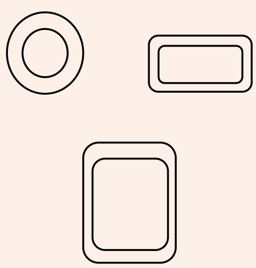
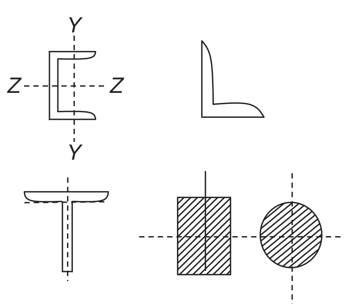
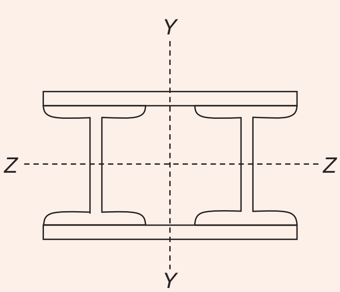


f_{cd} = Design compressive stress
f_{cc} = Euler buckling stress

Column buckling curves

Buckling Curves for Cross-sections

The classification of different sections under different buckling classes are given below:

Cross-section	Limits	Buckling about Axis	Buckling Class
Rolled I-sections 	$\frac{h}{b_f} > 1.2$: $t_f \le 40$ mm	$z - z$	a
		$y - y$	b
	40 mm $< t_f \le 100$ mm	$z - z$	b
		$y - y$	c
	$\frac{h}{b_f} \le 1.2$: $t_f \le 100$ mm	$z - z$	b
		$y - y$	c
	$t_f > 100$ mm	$z - z$	d
		$y - y$	d
Welded I-sections 	$t_f \le 40$ mm	$z - z$	b
		$y - y$	c
	$t_f > 40$ mm	$z - z$	d
		$y - y$	d
Hollow sections 	Hot rolled	Any	a
Channel, angle, T and solid sections 	–	Any	c
Builtup Member 	–	Any	c

Design of Compression Member

1. Based on slenderness ratio, the design stress in compression (f_{cd}) is to be assumed.
2. Compute the cross-sectional area required for the assume f_{cd}.

$$A_g = \frac{P_u}{\text{Assumed compressive stress}}$$

Where

A_g = Tentative cross-sectional area required (mm)^2

P_u = Factored load on column in Newtons.

3. A suitable section is to be selected based on area calculated and, also compute the minimum radius of gyration or selected section.
4. The effective length of column is calculated based on end conditions and slenderness ratio is computed, which should be less than permissible slenderness ratio.
5. For the estimated slenderness ratio, the desing compressive stress (f_{cd}) and design compressive strength of section (P_d), which should be higher than the factored load. If not, repeat the above steps.

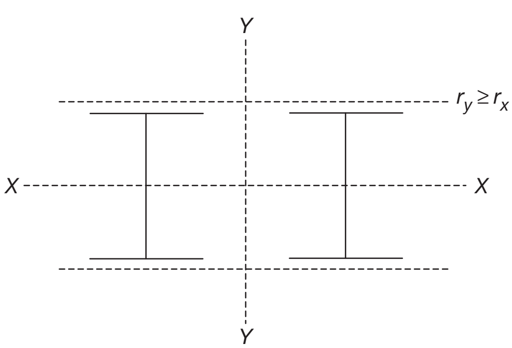
Built-up Columns (Latticed Columns)

- Built up columns are used when the required sectional area is more or large in different directions.
- Commoly used lattice are lacing bars, batten plates, lacing with batten and perforated cover plates.

Lacing System

Generally, flat bars are used for lacing, whereas angle, channel and tubular sections are also used for lacing of very heavy columns.

1. The radius of gyration about the axis perpendicular to the plane of lacing is not less than the radius of gyration in the plane of lacing.



2. Laced compression members should be provided with tie plates at the ends of the lacing system and at the points of interruption.
3. The single laced system on opposite sides of the main component should be in the same direction, so that one should be shadow of the other.
4. Lacing system should not be varied throughout the length of the member.

Design Specification

1. Lacing should be inclined at an angle of 40–70° with the longitudinal axis of column.
2. The slenderness ratio of the lacing bars should not exceed 145. Lacing bars effective length should be taken as follows.

Type of Lacing	Effective Length (l_e)
Single lacing (bolted)	Length between the inner end bolts on lacing bar. (l)
Doub lelacing (Bolted at ends and at intersection)	0.7 times the length between the inner end bolts on lacing bar. ($0.7 \times l$)
Welded lacing	0.7 times the distance between the inner ends of effective length of weld at its ends.

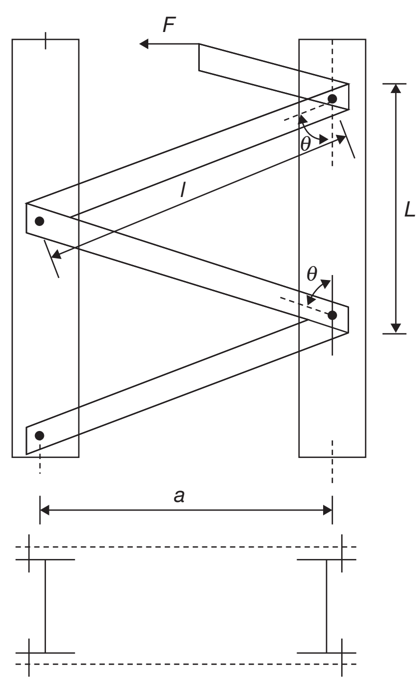
3. For bolted or welded lacing system,

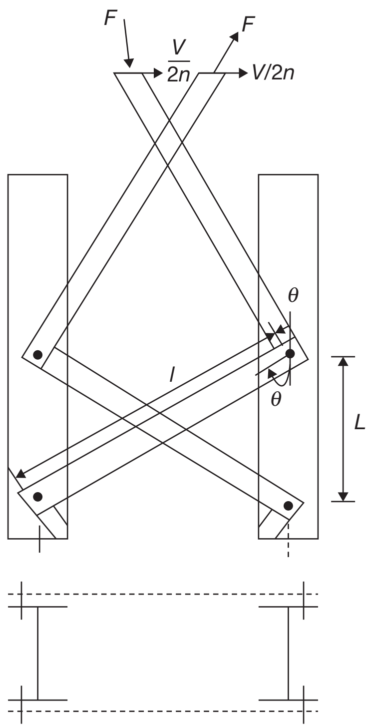
$\frac{L}{r^c_{\min}} \geq$ 50 or 0.7 times maximum slenderness ratio (kL/r) of compression members as a whole, whichever is less.

Where

L = Distance between the centres of connection of lattice bars to each connection.

$r^c_{\min}$ = Minimum radius of gyration of the components of compression member.





4. Minimum width of lacing bars in bolted connection should be as follows.

Shank diameter of bolt (*d*)(mm)	22	20	18	16
Width of lacing bars (mm)	65	60	55	50

5. Minimum thickness of lacing bar:

   $t \leq \frac{l}{40}$, for single lacing.

   $\leq \frac{l}{60}$, for double lacing bolted or welded at intersection.

   Where, l = Length of lacing bar.

6. The lacing should be designed to resist a transverse shear of 2.5% design column load.
7. If compression member carries bending, the lacing should be designed to resist additional shear due to bending.
8. Force (Design compression or deisgn tension) in each lacing bar:

$$F = \frac{V}{N \sin\theta}$$

$N = 2$ for single lacing

$N = 4$ for double lacing

NOTE

The effective slenderness ratio of laced column should be increased by 5% to account for shear deformations due to unbalance horizontal forces.

Battens

General Requirements

- Flat plates are used for battens.
- The number of battens should be such that the member is divided into not less than three parts, longitudinally.
- The effective length of battened column should be increased by 10%.

Design Specifications

1. Spacing of battens 'C' should be such that the slenderness ratio of the lesser main component, $\frac{C}{r^c_{min}} \leq 50$, or 0.7 times the slenderness ratio of a compression members as a whole about x–x axis (parallel to battens), whichever is less.

   Where,

   C = Spacing of battens

   r^c_{min} = Minimum radius of gyration of components

2. Effective depth of battens 'd' shall be taken as the distance between the end bolts or end welds.

   Effective depth, $d > \left(\frac{3}{4}\right)$a for intermediate battens.

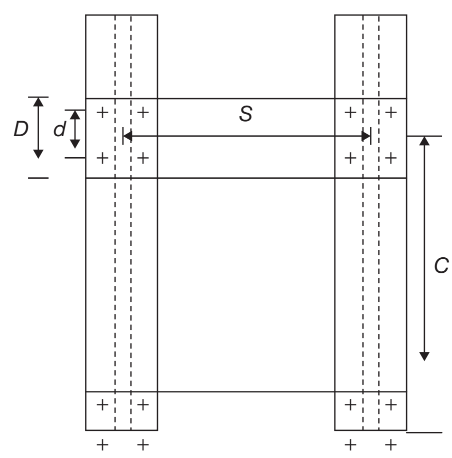
   $d > a$, for end batten.

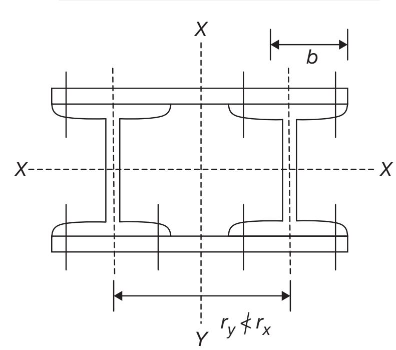
   $d > 2 \times b$, for any batten.

   Where

   a = Centroid distance of members.

   b = Width of member in plane of batten.





3. Thickness of battens, $t > \frac{l_b}{50}$.

   Where, l_b = Distance between inner-most connecting lines of bolts or welds.

4. Battens should be designed to carry bending moment and shear forces arising from a transverse shear (v) 2.5% of total design axial load on member.

   Longitudinal shear on batten, $V_1 = \frac{VC}{NS}$

   Moment on batten, $M = \frac{VC}{2N}$

   Where

   C = Spacing of battens.

   N = Number of parallel planes of battens.

   S = Minimum transverse distance between the centroids of bolt group or welding.

Column Bases

Introduction

Column loads are transferred to concrete block through steel base in order to distribute the column loads to concrete block. If steel base is not provided the concrete block may fail due to heavy load from column. Hence, the steel base is used to distribute load on column as well as maintains the alignment of column and controls the column and frame deflections.

Types of Column Bases

The two prevalent column bases are the slab base and the gusset base.

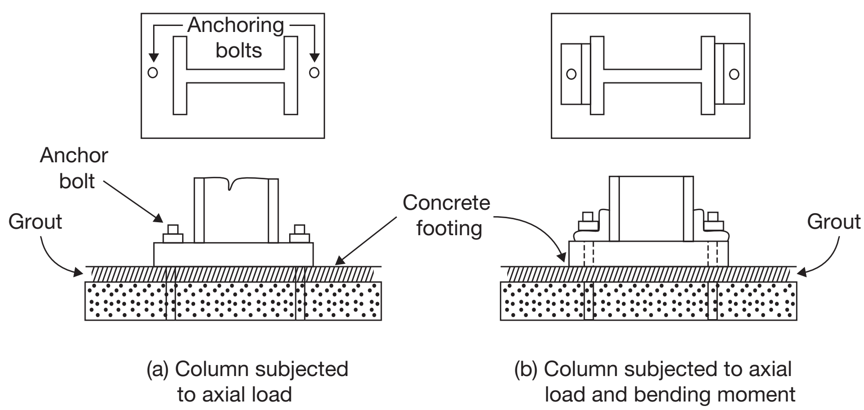
Slab Base

- Suitable for light loaded column only.
- Slab base can be designed by assuming the uniform bearing pressure from below, when the column is subjected to direct loads only.
- The thickness of base plate is designed from considerations of bending of portions of the base plate that extent beyond column profile.

  Base plate thicknes (for I, H, channel, box).

$$t_s = \sqrt{2.5w(a^2 - 0.3b^2)\frac{\gamma_{mo}}{f_y}} > t_y$$

- When the moment is in large in comparison to vertically applied load, a gusset plate is required.



(a) Column subjected to axial load

(b) Column subjected to axial load and bending moment

Column base plates

Design Procedure

Design included finding out the size and thickness of base plate.

The following are the design steps:

1. Compute the bearing strength of concrete by assuming the suitable grade of concrete.

   Bearing strength of concrete = $0.45 f_{ck}$.

2. Slab base area is given by:

$$A = \frac{\text{Factored column load } (p)}{\text{Bearing strength of concrete } (0.45 f_{ck})}$$

3. Generally, a square base plate is provided.
4. Side of square base plate is given by:

$$L = B = \sqrt{A}$$

   If projections of base plate beyond column edges a, b may be kept equal, and the sides can be computed by:

$$(D + 2b) \times (b_f + 2a) = A$$

   Where

   L = Length of base plate in mm.

   B = Width of base plate in mm.

a = Bigger projection of base plate beyond column in mm.

b = Smaller projection of base plate beyond column in mm.

D = Depth of column section in mm.

b_f = Width of flange of column in mm.

5. The intensity of pressure W, from the concrete pedestal is determined by:

$$W = \frac{P}{A_1}$$

Where

W = Intensity of pressure from concrete under the slab base in N/mm^2.

A_1 = Area of base plate provided in mm^2.

6. The slab base thickness calculated (t_s) should not be less than the thickness of column flange (t_f).
7. Holding down bolts, 2 or 4 in numbers and of 20 mm diameter are usually provided. When the base is subjected to only axial compressive load, two bolts will be enough.
8. Welded joint between the column and base plate is designed.

Gusset Base

- A gusset base is provided when column is subjected to axial bending moment in addition to axial load or subjected to heavy column loads.
- Bolted connection of gusset base consists of a base plate, two gusset plates and two gusset angles.
- As compared to slab base, the thickness of gusset base is small due to the gusset materials (increase in bearing area).
- In case of welded connection, gusset angles are not required.

Design Procedure

1. Bearing strength of concrete is computed by 0.45 f_{ck}, where f_{ck}: Grade of concrete (assumed).
2. Compute the area of base plate by the following equation:

$$A = \frac{\text{Factored column load } (P)}{\text{Bearing strength of concrete}}$$

Where

A = Required area of base plate in mm^2.

P = Factored load.

3. For bolted gusset base, assume gusset plate should not be less than 16 mm in thickness, and gusset angles should be of unequal legs in which the vertical leg should accommodate two rows of bolts and one row of bolts in horizontal leg. For welded gusset plate, gusset angles are not required.

Dimension of base plate parallel to flange, $B = \dfrac{A}{L}$

Where

L = Depth of section + 2 (Thickness of gusset plate + Leg of angle + Overhang) (for bolted connection).

Also,

L = Depth of section + 2 × Thickness of gusset plate + Overhang (for welded connections).

4. The intensity of bearing pressure 'W' from the concrete below the base is given by:

Bearing pressure, $W = \dfrac{P}{A_1}$

Where, A_1 = Area of the provided base plate.

5. The thickness of base plate is computed by equating the moment at the critical section to the moment of resistance of the gusset at that section.
6. Design bending strength at the critical section is given by: $M_d = 1.2 \dfrac{f_y}{\gamma_{mo}} Z_e$.
7. Thickness of gusseted base:

$$t = C_1 \sqrt{2.75 \frac{W}{f_y}}$$

Where

t = Aggregate thickness of base plate and the gusset angle for the bolted gusset base and the thickness of the base plate for welded gusset base, at the critical section.

W = Intensity of pressure from concrete under the slab base in N/mm^2.

C_1 = The portion of the base plate acting as a cantilever (in mm).

f_y = Yield stress of the steel in N/mm^2.

8. Holding down bolts, 2 or 4 in number and of 20 mm diameter, are usually provided.
9. Welded joint between the column and base plate is designed.

Exercises

1. Which of the following elements of a pitched roof industrial steel building primarily resists lateral load parallel to the ridge?

(A) Bracings (B) Purlins
(C) Truss (D) Columns

2. In the design of welded tension members, consider the following statements:

I. The entire cross-sectional area of the connected leg is assumed to contribute to the effective area in case of angles.
II. Two angles back-to-back and tack-welded as per code requirements may be assumed to behave as a tee section.
III. A check on slenderness ratio may be necessary in some cases.

The TRUE statements are

(A) only I and II (B) only II and III
(C) only I and III (D) I, II and III

3. The problem of lateral buckling can arise only in those steel beams which have

(A) moment of inertial about the bending axis larger than the other.
(B) moment of inertial about the bending axis smaller than the other.
(C) fully supported compression flange.
(D) None of these.

4. The effective length of a circular electric pole of length L and constant diameters erected on ground is

(A) $0.80L$ (B) $1.20L$
(C) $1.50L$ (D) $2.00L$

5. A steel beam supporting loads from the floor slab as well as from wall is termed as

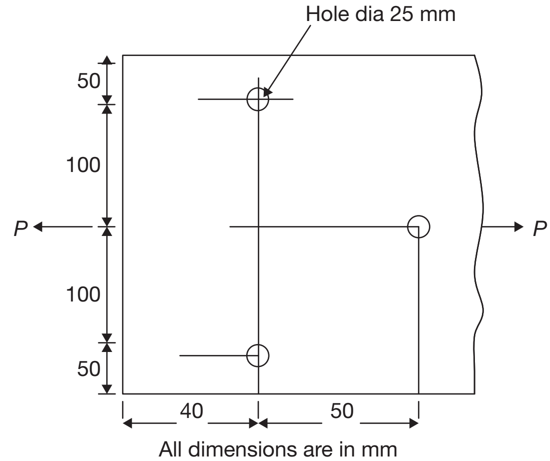
(A) stringer beam.
(B) lintel beam.
(C) spandrel beam.
(D) header beam.

6. Consider the following two statements related to structural steel design, and indentify whether they are True or False.

I. The Euler buckling load of a slender steel column depends on the yield strength of steel.
II. In the design of laced column, the maximum spacing of the lacing does not depend on the slenderness of column as a whole.

(A) Both statements I and II are True.
(B) Statement I is True, and statement II False.
(C) Statement I is False, and statement II is True.
(D) Both statements I and II are False.

7. What is the effective net width of plate shown in the given figure, for carrying tension?



(A) 212.5 mm (B) 237.5 mm
(C) 250 mm (D) 275 mm

8. The slenderness ratio in tension member as per BIS code where reversal of stress is due to loads other than wind or seismic shall not exceed

(A) 350 (B) 180
(C) 100 (D) 60

9. Consider the following statements:

Lug angles are used to

I. increase the length of the end connections of angle section.
II. decrease the length of the end connections of angle section.
III. increase the length of the end connections of channel section.
IV. decrease the length of the end connections of channel section.

Which of these statements are correct?

(A) I and II (B) II and IV
(C) I, III and IV (D) I, II and III

10. Lug angles

(A) are necessarily unequal angles.
(B) are always equal angles.
(C) increase the shear resistance of joint.
(D) reduce the length of joint.

11. How are structural members composed of two angles back to back connected throughout their length?

(A) By locking rivets
(B) By spacing rivets
(C) By gripping rivets
(D) By tacking rivets

12. The best-suited rolled steel section for a tension member is

(A) angle section. (B) T-section.
(C) channel section. (D) flat section.

13. Lacing of compound steel columns
(A) increases the load-carrying capacity.
(B) decreases the chances of local buckling.
(C) decreases overall buckling of the column.
(D) assures unified behavior.

14. Battens provided for a compression member shall be designed to carry a transverse shear equal to
(A) 2.5% of axial force in the member.
(B) 5% of axial force in the member.
(C) 10% of axial force in the member.
(D) 20% of axial force in the member.

15. The maximum length of a tension member with minimum radius of gyration of 20 mm carrying load reversals other than wind or earthquake forces as per IS:800 is ______.
(A) 5.0 m (B) 1.5 m
(C) 3.6 m (D) 6.0 m

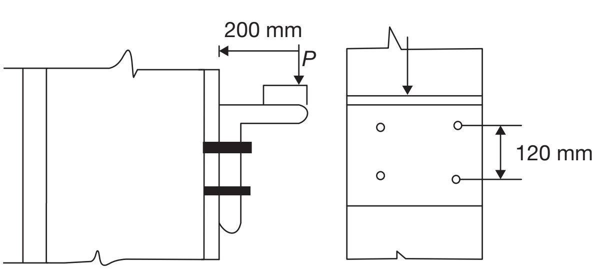
16. Which of the following is the most efficient section for column for a given equal cross section area?
(A) Solid circular section
(B) Angle section
(C) I-section
(D) Tubular section

17. When the column is effectively held in position and restrained against rotation at both ends, the effective length of column is 'K' times the unsupported length (L) of column, where K is _______.
(A) 1.2 (B) 0.8
(C) 0.65 (D) 1.0

18. While designing, for a steel column of Fe250 grade, a base plate resting on a concrete pedestal of M30 grade, the bearing strength of concrete (in N/mm^2) in limit state method of design as per IS:456–2000 is
(A) 3.84 (B) 11
(C) 13.5 (D) 15

19. In a roof truss if pitch is $\frac{\sqrt{3}}{2}$ and slope is $\sqrt{3}$, the angle of inclination with horizontal would be
(A) 60° (B) 30°
(C) 45° (D) 90°

20. Each bolt shown in the figure is capable of resisting design shear capacity of 25 kN and design tension capacity of 20 kN. The interaction equation between of forces as per limit state method of IS:800–2007?



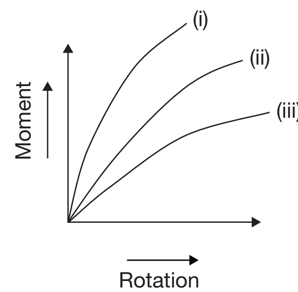
(A) $\left[\frac{P}{100}\right]+\left[\frac{P}{24}\right] \le 10$

(B) $\left[\frac{P}{50}\right]^2+\left[\frac{P}{24}\right]^2 \le 1.0$

(C) $\left[\frac{P}{50}\right]^2+\left[\frac{P}{30}\right]^2 \le 1.0$

(D) $\left[\frac{P}{100}\right]^2+\left[\frac{P}{24}\right]^2 \le 1.0$

21. The moment rotation curve shown in the figure is that of a



(A) (i) semi-rigid joint
(ii) rigid.
(iii) flexible
(B) (i) rigid joint
(ii) semi-rigid.
(iii) flexible
(C) (i) flexible joint
(ii) semi-rigid
(iii) rigid
(D) None of these

22. Determine service axial load on column section ISMB 350. Given that the height of column is 3.2 m and that is fixed on both ends. Assume f_y : 250 MPa, f_u 410 MPa and $E = 2 \times 10^5$ MPa (properties of ISMB 350 are A = 6670 mm^2, t_f = 14.2 mm, t_w = 8.1 mm, b = 140 mm, h = 350 mm, r_{zz} = 143 mm and r_{yy} = 28.4 mm)
(A) 720 kN
(B) 850 kN
(C) 350 kN
(D) None of these

23. A built up column consists of ISMC 300 channels placed back to back at a spacing of 250 mm and carries working load of 2000 kN, the double lacing provided with an angle of 50° with longitudinal axis. As per IS:800–2007 lacing member should be designed to resist design axial load of
(A) 19.5 kN (B) 24.5 kN
(C) 30.8 kN (D) 54.2 kN

24. In laced columns, end tie plates are provided to
(A) check the buckling of column as a whole.
(B) check the buckling of component column.
(C) check the distortion of the column sections at ends because of unbalanced horizontal force from lacings.
(D) keep the column components in position.

25. The effective length of a battened column is
(A) increase by 15%.
(B) increase by 20%.
(C) 0.65 times the unsupported length.
(D) 0.70 times the actual length of the column.

26. Two bolted plates under tension with alternative arrangement of bolt holes are shown in figures 1 and 2. The hole diameter, pitch, and guage length are d, p, g, respectively.

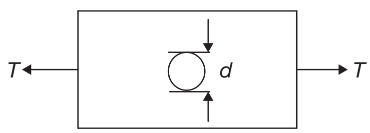


Figure 1

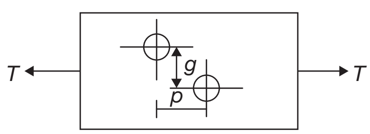
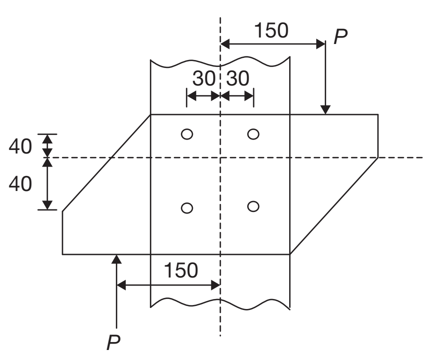


Figure 2

Which one of the following conditions must be ensured to have higher net tensile capacity of configuration shown in figure 2 than that shown in figure 1?
(A) $p^2 > 4gd$ (B) $p^2 < \sqrt{4gd}$
(C) $p^2 > 2gd$ (D) $p > 4gd$

27. A bracket has been attached to flange of a column as shown in the figure. What is the maximum force in the bolt?



All dimensions in mm

(A) P (B) $3\dfrac{P}{2}$
(C) $\dfrac{4P}{2}$ (D) $\dfrac{P}{2}$

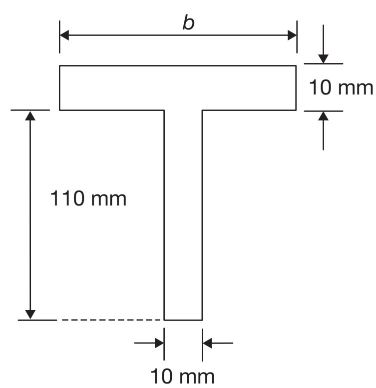
28. Determine the design axial load on column section ISMB 400 having an area of 7500 mm^2 and stress reduction factor calculated from Perry Robertson's approach to be 0.52. Assume f_y to be 250 MPa and f_u to be 410 MPa.
(A) 750 kN (B) 975 kN
(C) 1000 kN (D) 850 kN

29. For a steel built-up column subjected to an axial force of 1500 kN, the lacing system is to be desgined for resisting transverse shear of
(A) 75 kN (B) 37.5 kN
(C) 50 kN (D) 25.5 kN

30. Intermediate vertical stiffeners are provided in plate girder for the purpose of ______.
(A) eliminate local buckling
(B) eliminate web buckling
(C) transfer concentrated loads
(D) prevent excessive deflection

31. A structure has 2-degrees of indeterminancy. The number of plastic hinges that would be formed at complete collapse is ________.
(A) 0 (B) 1
(C) 2 (D) 3

32. The dimensions of a T-section are shown in the figure.



For the depth of plastic neutral axis from the top of T-section to be 9.583 mm, the flange width b must be ________.
(A) 100 mm
(B) 110 mm
(C) 120 mm
(D) 130 mm

Previous Years' Questions

1. Consider the following statements for a compression member: **[GATE, 2007]**

I. The elastic critical stress in compression increases with decrease in slenderness ratio.

II. The effective length depends on the boundary conditions at its ends.

III. The elastic critical stress in compression is independent of the slenderness ratio.

IV. The ratio of the effective length to its radius of gyration is called as slenderness ratio.

Which of the above statements is/are correct?

(A) II and III (B) III and IV

(C) II, III and IV (D) I, II and IV

2. The square root of the ratio of moment of inertia of the cross-section to its cross-sectional area is called **[GATE, 2009]**

(A) second moment of area.

(B) slenderness ratio.

(C) section modulus.

(D) radius gyration.

3. A 16 mm thick plate measuring 650 mm × 420 mm is used as a base plate for an IS:HB 300 column subjected to a factored axial compressive load of 2000 kN. As per IS:456–2000, the minimum grade of concrete that should be used below the base plate for safely carrying the load is **[GATE, 2011]**

(A) M15 (B) M20

(C) M30 (D) M40

4. Two steel columns P (length L and yield strength f_y = 250 MPa) and Q (length $2L$ and yield strength f_y = 500 MPa) have the same cross-sections and end-conditions. The ratio of bukling load of column P to that of column Q is: **[GATE, 2013]**

(A) 0.5 (B) 1.0

(C) 2.0 (D) 4.0

5. A steel member 'M' has reversal of stress due to live loads, whereas another member 'N' has reversal of stress due to wind load. As per IS:800–2007, the maximum slenderness ratio permitted is **[GATE, 2015]**

(A) less for member 'M' than that of member 'N'.

(B) more for member 'M' than for member 'N'.

(C) same for both the members.

(D) not specified in the Code.

6. Prying forces are **[GATE, 2015]**

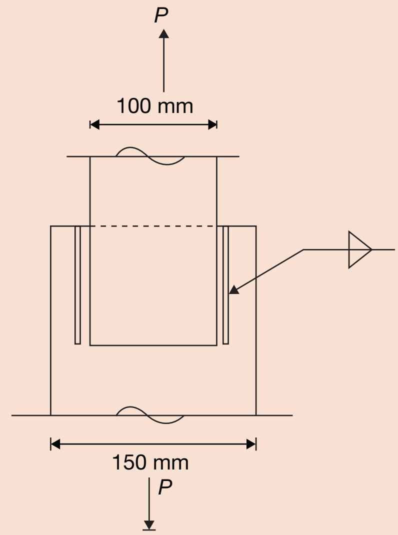
(A) shearing forces on the bolts because of the joints.

(B) tensile forces due to the flexibility of connected parts.

(C) bending forces on the bolts because of the joints.

(D) forces due the friction between connected parts.

7. Two plates are connected by fillet welds of size 10 mm and subjected to tension, as shown in the figure. The thickness of each plate is 12 mm. The yield stress and the ultimate tensile stress of steel are 250 MPa and 410 MPa, respectively. The welding is done in the workshop (γ_{mw} = 1.25). **[GATE, 2016]**



As per the limit state method of IS:800–2007, the minimum length (rounded off to the nearest higher multiple of 5 mm) of each weld to transmit a force P equal to 270 kN (factored), is

(A) 90 mm

(B) 105 mm

(C) 110 mm

(D) 115 mm

8. Two bolted plates under tension with alternative arrangement of bolt holes are shown in Figures 1 and 2. The hole diameter, pitch, and gauge length are d, p and g, respectively. **[GATE, 2016]**

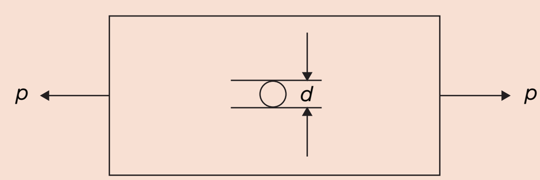


Figure 1

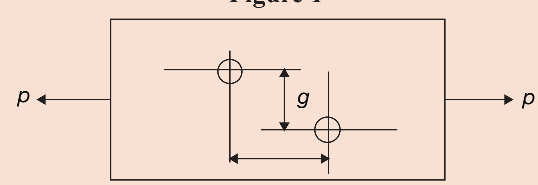


Figure 2

Which one of the following conditions must be ensured to have higher net tensile capacity of configuration shown in Figure 2 than that shown in Figure 1?

(A) $p^2 > 2gd$

(B) $p^2 < \sqrt{4gd}$

(C) $p^2 > 4gd$

(D) $p > 4gd$

Answer Keys

Exercises

1. A	**2.** D	**3.** D	**4.** D	**5.** A	**6.** D	**7.** B	**8.** B	**9.** B	**10.** D
11. D	**12.** B	**13.** D	**14.** A	**15.** C	**16.** D	**17.** C	**18.** C	**19.** A	**20.** D
21. B	**22.** A	**23.** B	**24.** C	**25.** B	**26.** A	**27.** B	**28.** D	**29.** B	**30.** B
31. D	**32.** C								

Previous Years' Questions

1. D	**2.** D	**3.** B	**4.** D	**5.** A	**6.** B	**7.** B	**8.** C