5 Design of Roof Trusses

5.1 : Introduciton

Q.1 What is roof truss ? What are the different parts of roof truss ? ☞ [JNTU : May-17, Marks 3]

Ans. : • A truss is a structure with straight pieces forming triangles to suport a load.

- The members of the triangles are placed under tension and compression but do not bend.
- Roof trusses are widely characterised by an economical use of construction materials (i.e steel, timber)

1) **APEX (Peak) :** The highest point on a truss where the sloping top chords meet.
2) **BOTTOM CHORD (BC) or TIE BEAM :** Horizontal or sloping member that establishes the lower edge of a truss and usually carries combined bending and tension stresses.
3) **CHORD :** One of the main members that form the outline of the truss and that are subject to relatively large axial forces and bending moments.
4) **CLEAR SPAN :** The horizontal distance between interior edges of supports.
5) **HEEL :** The point on a truss at which the top chord and bottom chord intersect.
6) **NOMINAL SPAN :** The horizontal distance between the outside edges of the supports (wall plates)-usually the tie beam length.
7) **TOP CHORD (TC) or RAFTER :** The sloping or horizontal member that establishes the upper edge of a truss.
8) **WEB :** A member that joins the top and bottom chords of a truss, to form a triangular pattern. Webs may carry tensile or compressive forces, depending on their position in the truss.

5.2 : Types of Roof Truss

Q.2 What are different types of roof truss ? Draw sketches.

Ans. : Following are the different types of roof truss :

1) **King post truss - (span upto 8 meters)**

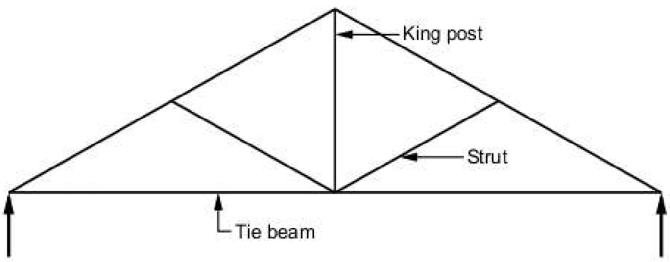


Fig. Q.2.1: King post roof

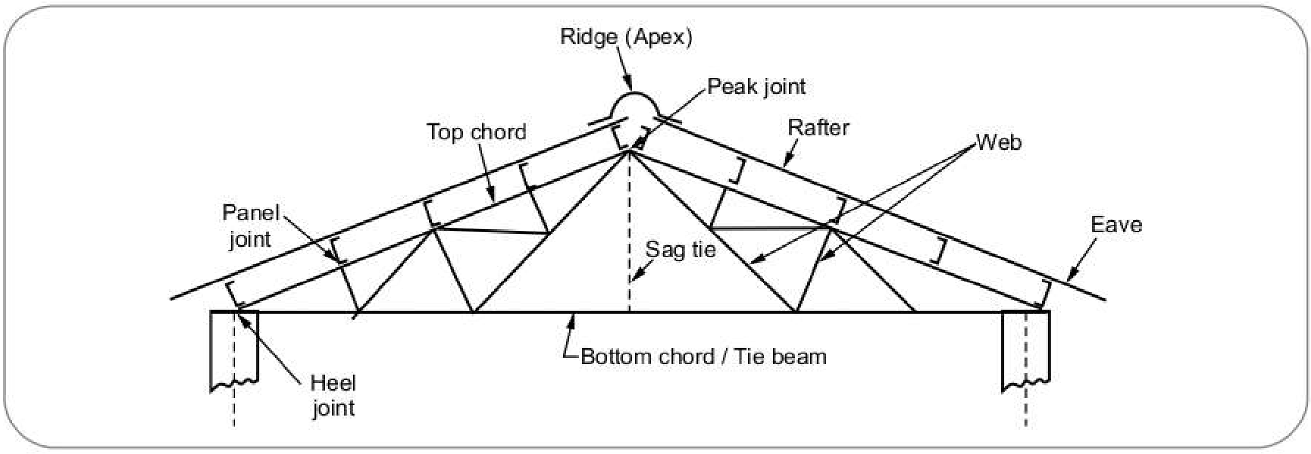


Fig. Q.1.1

2) Queen post truss - (span around 10 meters)

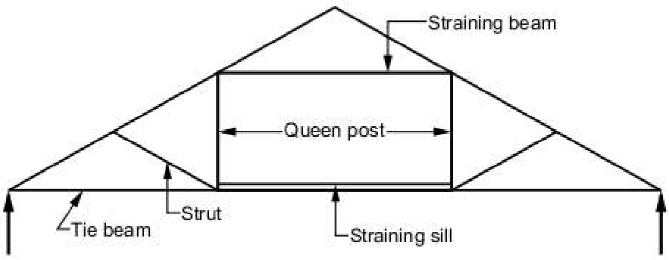


Fig. Q.2.2 Queen post roof

3) Pratt truss - (12 to 20 m)

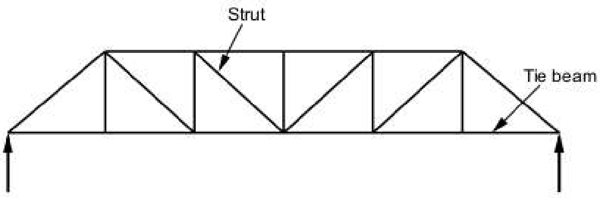


Fig. Q.2.3 Pratt truss

4) Howe truss - (6 to 15 m)

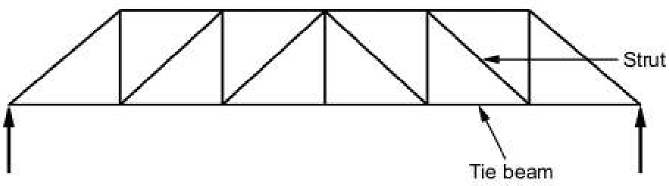


Fig. Q.2.4 Howe truss

5) Fan truss - (12 to 15 m)

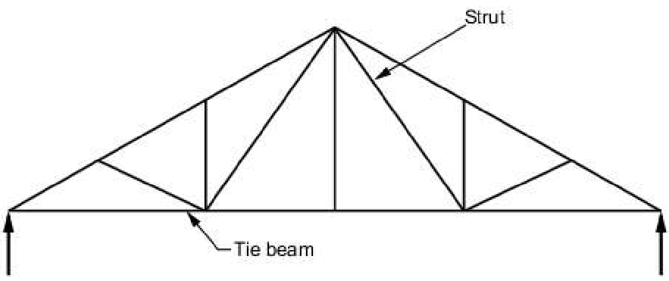


Fig. Q.2.5

6) Pitched fink truss - (12 to 18 m)

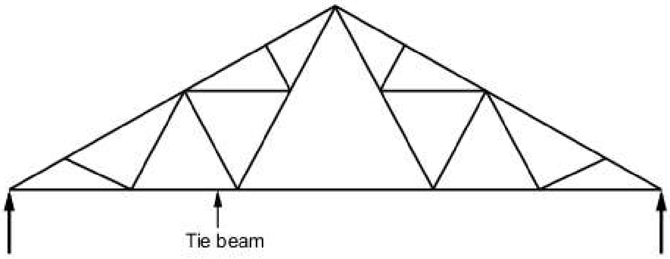


Fig. Q.2.6

5.3 : Loads on Trusses

Q.3 What are the loads on trusses ?

Ans. : The main loads on trusses are

1) Dead loads :

- It includes the weight of purlins, sheeting, bracings, self weight and other loads suspended from trusses.
- In general the roof covering weight including laps, connectors etc. may be taken as,

  i) 100 - 500 N/m^2 - for GI sheeting

  ii) 170 - 200 N/m^2 - for A.C. sheeting
- The following are the two formulae commonly used for a truss of span 'L'.

  i) $w = 20 + 6.6\ L$ N/m^2 for a LL of 2 kN/m^2.
  If live load is more, the above value is to be increased by LL/2.0.

  ii) $w = 10\ \frac{L}{3}\ 5\ \frac{s}{4}$ N/m^2

  Where, s = Spacing of trusses.

2) Imposed load (Live Load) :

- Normally no access is provided for sloping roof with sheets.
- In such cases IS 875 part II makes the following provisions for live loads for the design of sheets and purlins.

  i) Upto 10 slope : 0.75 kN/m^2

  ii) For more than 10 slope : 0.75-0.02 (10)
  where, is slope of sheeting.
- A minimum of 0.4 kN/m^2 live load should be considered in any case.

3) Wind load :

- IS 875 part 3 gives guidelines to determine wind forces on different components of buildings. It consists of the following steps :
    - a) Determine basic wind speed.
    - b) Obtain design wind speed.
    - c) Calculate design wind pressure.
    - d) Calculate wind pressure on roof.

a) Basic wind speed (V_b) :

- For finding basic wind pressure in place in India, IS 875 (part 3) divides the country into 6 zones.
- The values correspond to the speed at 10 m height above ground level and an open terrain.

b) Design wind speed (V_z) :

$$\boxed{V_z = K_1 \; K_2 \; K_3 \; V_b}$$

where,

K_1 = Risk coefficient

K_2 = Terrain, height and structure size factor

K_3 = Topography factor

c) Design wind pressure :

$$\boxed{P_z = 0.6 \; V_z^2 \; N/m^2}$$

where,

P_z = Design wind pressure in N/m^2 at height z and

P_z = Design wind velocity in m/s height z.

d) Wind pressure on roof :

$$\boxed{F = (C_{pe} \quad C_{pi}) A \quad P_z}$$

where,

C_{pe} = External pressure coefficient

C_{pi} = Internal pressure coefficient

A = Surface are of cladding unit in m^2 and

P_{dz} = Design wind pressure

4) Other loads :

- Other possible loads on the structure also should be considered in the design.
- i.e. snow load, etc.

5.4 : Purlin Design

Q.4 What are purlins ? Write its use.

☞[JNTU : May-17, Marks 3]

Ans. : • Purlins are horizontal beams that are used for structural support to roofing sheets.

- Roof purlins are supported either by rafters or building walls and the roof deck is laid over the purlins.
- **Uses** :

1) Purlins are used to support for roof.

2) Most commonly, purlins are major components of roof structures.

3) Roof-deck is laid over purlins.

Q.5 Give basic considerations for designs of purlins.

Ans. :

- As far as possible, purlins should be located on panel points of top chord members.
- However, it depends upon the type of roofing material also.
- Generally the spacing of purlins varuies from 1.35 m to 2.0 m.
- Angle iron purlins are used for smaller spacing i.e. 3 to 4 m.
- For medium spacing (i.e. 4 to 5 m) channels can be used.
- And for larger span I - beams can be used.
- If angles are used, outstanding legs are at top and lug angles are used to connect the purlins to rafters.

5.5 : Truss Design

Q.6 Describe factors which are taken for design of truss.

Ans. : 1) Pitch of trusses :

- It is defined as ratio of height of truss to the span.

- A minimum pitch of 1/6 is to be maintained for GI sheet covering and 1/12 to be maintained for A.C. sheet covering.

2) Spacing of trusses :

- The distance between two consecutive trusses is called spacing of truss.
- The spacing of truss is gioverned by the size of space to be covered by roof.
- Following guidelines may be used in deciding the spacing of trusses.
  a) 3 to 4.5 m upto 15 m span.
  b) 4.5 m to 6 m for 15-30 m span.
  c) For span more than 40 m spacing of 12 to 15 m may be used with cross trusses replacing purlins.

3) Purlins :

- As far as possible purlins should be located on panel points of top chord members.
- Generally the spacing of purlins varies from 1.35 m to 2.0 m.

4) Sheeting :

a) GI sheets :

- Corrugated iron sheets are galvanized for protection against corrosion and are used as roof covering.

a) A.C. sheets :

- Asbestos cement sheets are better insulators for sun's heat compared to GI sheets.
- They are commonly used in the factories and godowns.

5) Load combinations :

- The following load combinations are to be considered in the design of cladding and trusses.
  i) Dead load + Imposed loads.
  ii) Dead load + snow load (if this is expected)
  iii) Dead load + Wind load (wind direction with = 0 or = 90) .
- For each member maximum and minimum design force are to be found, taking tension as positive.

6) Grouping of members :

- From aesthetic point and from the point of fabrication, itis not desirable each and every member for its design forces.
- Usually the following groups are made and the designs are made to maximum design force of a member in that group.
  i) Top chord member
  ii) Bottom chord member
  iii) Main slings
  iv) Main struts
  v) Other minor members
- The following are the commonly used minimum sections in roof trusses :

  Top chord : 2 ISA 7550, 6 mm

  Bottom chord : 2 ISA 7550, 6 mm

  Main sling : 2 ISA 6545 , 6 mm

  Main strut : 2 ISA 6545, 6 mm

  Minor member : ISA 6545 6 mm or ISA 5050, 6 mm

7) Design of members :

- If the design force is tensile for some loading and compression for some other loading, the member may be designed for major force and checked for other force.

5.6 : Design of Joints and End Bearings

Q.7 Describe design of joints and end bearings in trusses.

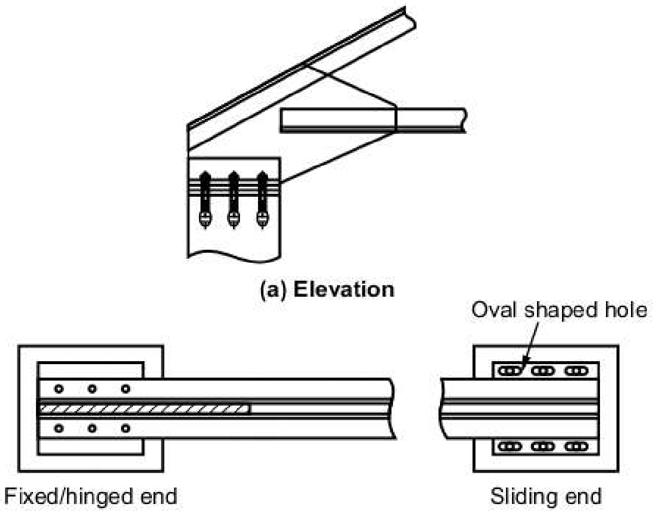
Ans. :

1) Design of joints :

- Gusset plates are used at joints to connect various members at that joint.
- Gusset plate thickness is kept more that the maximum thickness of member meeting at the joint.
- The connections may be welded or bolted.

2) End bearing :

- Roof trusses are supported on steel columns or concrete columns or on walls.
- One end is made hinged and the other sliding so that the horizontal forces on the supporting structures are avoided and at the same time the truss analysis carried as hinged-simply supported and holds good.
- Base plate is designes for bending due to end reaction while anchor bolts are designed to resist uplift forces.



(c) Plan of fixed/hinged end **(c) Plan of sliding end**

Fig. Q.7.1 End bearing in trusses

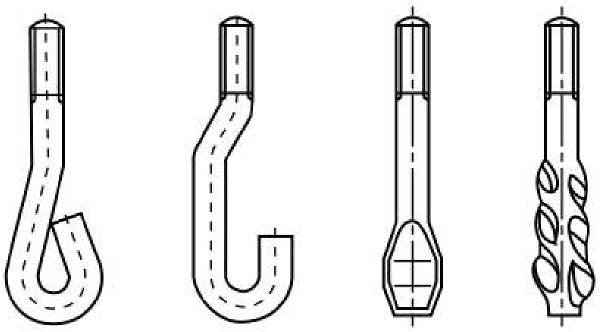


Fig. Q.7.2 Foundation bolts

Q.8 Design a double angle discontinuous strut to carry a factored load of 135 kN. The length of strut is 3 m between intersections. The two angles are placed back to back (with long legs are connected) and are tack bolted. Use steel grade Fe410. a) Angles are placed on opposite side of 12 mm gusset plate. b) Angles apre placed on same side of 12 mm gusset plate.

☞ [JNTU : May-17, Marks 10]

Ans. : 1) For steel of grade Fe 410 : f_y = 250 MPa

Let us assume a slenderness ratio of 110. Corresponding value of design compressive stress from Table 8.7 is 94.6 N/mm^2.

Cross-sectional area required = $\dfrac{135 \quad 10^3}{94.6}$ = **1427** mm^2

2) Angles placed on opposite sides of gusste plate

From IS Handbook No.1, select 2, ISA 65 65 8 mm (weight = 151 N/m)

Area provided = 1952 mm^2

Minimum radius of gyration, $r = r_z$ = 19.6 mm

Effective length, $l = KL = 0.85 \quad 3000 = 2550$ mm

$$\frac{l}{r} = \frac{2550}{19.6} = 130.10 \quad 250$$

For $\dfrac{KL}{r}$ = 130.10, f_y = 250 MPa and buckling curve c, the design compressive stress from Table 8.7,

$$f_{cd} = 74.22 \text{ N/mm}^2$$

The design compressive strength,

$$P_d = A_e\, f_{cd} = 74.22 \quad 1952 \quad 10^{\ 3}$$

$$= \mathbf{144.87 \ kN}$$

$$> \mathbf{135 \ kN}$$

The designer may now try to economize the section.

Try a section having a greater radius of gyration and less weight/m run.

Seklect 2 **ISA 70 70 6 mm (Weight = 123.6 N/m).**

$$A = 1612 \text{ mm}^2$$

- Minimum radius of gyration , r = 21.4 mm

$$= \frac{l}{r} = \frac{2250}{21.4} = 119.1582250$$

- Effective length of the strut perpendicular to the gusset plate, $l = 1 \quad 3000 = 3000$ mm
- From IS Handbook No.1, the radius of gyration for double angle section for spacing of 12 mm = 33.2 mm.
- Slenderlessness ratio,

$$= \frac{3000}{33.2} = \mathbf{90.36 \quad 119.158}$$

The critical slenderness ratio therfore is **119.158.**

For $\dfrac{l}{r}$ = 119.158, f_y = 250 MPa and buckling curve c, the design compressive stress from Table 8.7,

$$f_{cd} = 84.60 \text{ N/mm}^2$$

- **The design compressive strength,**

$$P_d = A_e\, f_{cd} = 1612 \quad 84.60 \quad 10^{\ 3}$$

$$= \mathbf{136.40 \ kN}$$

$$> \mathbf{135 \ kN}$$

which is all right.

Provide **2, ISA 70 70 6 mm** on opposite side of the gusset plate.

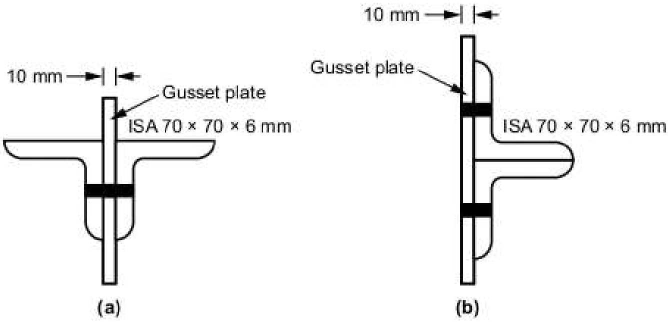


Fig. Q.8.1

4) Angles placed on same side of gusste plate

Let us try the same angles ISA 70 70 6 mm

$$A_e = 1612 \text{ mm}^2$$

Minimum radius of gyration , r = 21.4 mm

$$= \frac{l}{r} = \frac{2550}{21.4} = 119.158 < 250$$

Effective length of the strut perpendicular to the gusset plate, l = 1 3000 = 3000 mm.

From IS Handbook No.1, for double angle section without any spacing (since on same side of gusset plate), radius of gyration,

$$r = 28.8 \text{ mm}$$

Slenderlessness ratio,

$$= \frac{3000}{28.8} = \mathbf{104.17 \quad 119.158}$$

The critical slenderness ratio therefore is 119.158.

For $\frac{l}{r}$ = 119.158, f_y = 250 MPa and buckling curve c, the design compressive stress from Table 8.7,

$$\mathbf{f_{cd} = 84.60 \text{ N/mm}^2}$$

- The design compressive strength,

$$P_d = A_e f_{cd} = 1612 \quad 84.60 \quad 10^{\ 3}$$

$$= \mathbf{136.40 \text{ kN}}$$

$$> \mathbf{135 \text{ kN}}$$

Which is all right

Note : Theoretically, although double unequal angle sections are economical as compared to double equal angle sectins. But, however due to availability of limited rolled unequal angle sections none was found economical. Hence equal angle sections have been tried and provided.

Q.9 Design I section purlin for a trussed roof for the following data : Span of roof = 10 m, Spacing of pulins along slope or truss = 2.5 m, Spacing of truss = 4 m, Slope of roof truss = 1 vertical to 2 horizontal, Wind load on roof surface normal to roof = 1100 N/m², Vertical load from roof sheet = 150 N/m². Sketch the details of the roof. ☞ **[JNTU : May-16, Marks 10]**

Ans. : Assume, grade of steel Fe410,

$$f_y = 250 \text{ MPa}$$

Weight of galvanised corrugated iron sheets

$$= 150 \quad 2.5$$

$$= 375 \text{ N/m}$$

Dead load of purlin = 100 N/m (assume)

∴ Total dead load

$$= 375 + 100 = 475 \text{ N/m}$$

∴ Component of dead load parallel to roof

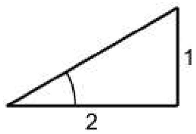


Fig. Q.9.1

$$= 475 \sin 26.56$$

$$= 335.88 \text{ N/m}$$

$$= 212.38 \text{ N/m}$$

$$\tan(\ ) = \frac{1}{2}$$

$$= 26.56$$

Component of dead load normal to roof

$$= 475 \cos 26.56$$

$$= 335.88 \text{ N/m}$$

$$= 424.87 \text{ N/m}$$

Wind load is assumed to act normal to the roof

Wind load $= 110\ N/m^2$

$= 1.1\ kN/m^2$

$= 1.1 \quad 10^3 \quad 2.5 \quad 1$

$= 2.75 \quad 10^3$

$= 2750\ N/m$

Total load normal to the roof

$= 2750 + 424.87$

$= 3174.87\ N/m$

Factored load normal to roof

$= 1.5 \quad 3174.87$

$P = 4762.305\ N/m$ (Table 4.3, $_f$=1.5)

Factored load parallel to roof

$= 1.5 \quad 212.38\ N/m$

$H = 318.57\ N/m$ (Table 4.3, $_f$=1.5)

Maximum moment ,

$$M_{uu} = M_z = \frac{PL}{10}$$

$$= \frac{(4762.305 \quad 4) \quad 4}{10}$$

$= 7.619 \quad 10^3\ N/m$

$= 7.619\ KN/m$

Maximum moment ,

$$M_{vv} = M_y = \frac{HL}{10}$$

$$= \frac{(318.57 \quad 4) \quad 4}{10}$$

$= 0.509 \quad 10^3\ Nm = 0.509\ kNm$

Let us assume,

Flange width, $b_f = 75$ mm, $d = 150$ mm

Plastic section modulus required

$$Z_{pz(req.)} = M_z \frac{m0}{f_y} \quad 2.5 \quad \frac{d}{b} \quad M_y \frac{m0}{f_y}$$

$$= 7.619 \quad 10^6 \quad \frac{1.1}{250} \quad 2.5 \quad \frac{150}{75} \quad 0.509 \quad 0.806 \quad 10^6 \quad \frac{1.1}{250}$$

$$Z_{pz(req.)} = 44.72 \quad 10^3\ mm^3$$

From appendix VIII

- ISMB 150 @146.17 N/m is considered for higher values of I_z and Z_{pz}.
- The sectional properties of ISMB 150 @146.17 N/m.

Area, $A = 1900\ mm^2$

Depth of section, $h = 150$ mm

Width of flange, $b_f = 80$ mm

Thickness of flange, $t_f = 7.6$ mm

Thickness of web, $t_w = 4.8$ mm

Radius at root, $R_1 = 9$ mm

Depth of web,

$$d = h \quad 2(t_f \quad R_1) = 150 \quad 2(7.6 \quad 9)$$

$= 116.8$ mm

Moment of inertia,

$$I_z = 726.4 \quad 10^4\ mm^4$$

$$I_y = 56.4 \quad 10^4\ mm^4$$

Plastic section modulus, $Z_{pz} = 110.48 \quad 10^3\ mm^3$

Plastic section modulus, $Z_{ez} = 96.9 \quad 10^3\ mm^3$

$$= \sqrt{\frac{250}{f_y}} = \sqrt{\frac{250}{250}} = 1$$

Outstand of flange, $b = \frac{b_f}{2} = \frac{80}{2} = 40$ mm

$$\frac{b}{t_f} = \frac{40}{7.6} = 5.226 < 9.4$$

$$\frac{d}{t_w} = \frac{116.8}{4.8} = 24.33 < 84$$

$\therefore$ Section is palstic

Step - 1 : Check for design bending strength

$$M_{dz} = Z_{pz} \frac{f_y}{m0}$$

$$= 110.48 \quad 10^3 \quad \frac{250}{1.1}$$

$= 30.382 \quad 10^6$ N mm

$= 30.382$ kN m

$$1.2\ Z_{ez} \frac{f_y}{m0} = 1.2 \quad 96.9 \quad 10^3 \quad \frac{250}{1.1}$$

$= 26.43 \quad 10^6$ N mm = 26.43 kNm

- Consider least value among above both values

$\therefore \quad M_{dz} = 26.43$ kNm > 7.619 kNm

which is as should be

$$M_{dy} = Z_{py} \frac{f_y}{m_0} \quad {}_f\, Z_{ey} \frac{f_y}{m_0}$$

$$Z_{py} = 2 \;150 \; \frac{4.8}{2} \; \frac{4.8}{2}$$

$$2 \; \frac{80 \;\; 4.8}{2} \; \frac{80 \;\; 4.8}{2} \; \frac{4.8}{2} \quad 7.6$$

$$= 3456 + 22860.8$$

$$Z_{py} = 26.316 \quad 10^3 \text{ mm}^3$$

$$\therefore \quad M_{dy} = 26.316 \; \frac{250}{1.1} \; 10^3$$

$$= 5.98 \quad 10^6 \text{ N mm} = 5.98 \text{ kNm}$$

$$Z_{ey} = \frac{2\,I_y}{b_f} = 2 \; \frac{52.6 \quad 10^4}{80}$$

$$Z_{ey} = 13.2 \quad 10^3 \text{ mm}^3$$

$$\therefore M_{py} \quad 1.5 \quad 13.2 \quad 10^3 \; \frac{250}{1.1}$$

$$4.5 \quad 10^6 \text{ N mm}$$

$$4.5 \text{ kNm}$$

$$\therefore \quad M_{py} = 4.5 \text{ kNm} > 0.509 \text{ kNm}$$

$\therefore$ OK

Step 2 : Check for overall member strength

$$\frac{M_z}{M_{dz}} \; \frac{M_y}{M_{dy}} \quad I$$

$$\frac{7.406}{26.43} \; \frac{0.806}{4.5} \quad I$$

$$0.46 \quad I$$

$\therefore$ OK

Step 3 : Check for deflection

It is checked at service loads

$$_{all} = \frac{l}{180} = \frac{4000}{180} = 22.22 \text{ mm}$$

$$= \frac{5}{384} \quad \frac{l^4}{EI}$$

$$= \frac{5}{384} \quad \frac{3085.88\,(4 \quad 10^3)^4}{10^3 \quad 2 \quad 10^5 \quad 726.4 \quad 10^4}$$

$$= 7.08 \quad 22.22 \text{ m} \qquad \therefore \text{ OK}$$

Review Questions

1. *What is roof truss ? What are the different parts of roof truss ?*
2. *What are the different types of roof truss ? Draw sketches.*
3. *What are the loads on truss ?*
4. *What are purlins ? Write its use.*
5. *Describe factors which are taken for design or truss ?*

Fill in the Blanks for Mid Term Exam

Q.1 The uppermost part of the building which is constructed in the form of a framework to give protection to building against rain, heat, snow etc. is called as ____________.

Q.2 ______ are the inclined member of a truss.

Q.3 The minimum recommended rise of trusses with galvanised iron sheet is___________.

Q.4 The economic spacing of roof truss depends on _______.

Q.5 Economic span of king post truss is upto ________ m.

Multiple Choice Questions for Mid Term Exam

Q.1 ______trusses lie on a plane.

a) Planer
b) 2 D
c) Linear
d) 3 D

Q.2 In case of bridge the load is transferred when _________.

a) stringer > floor beams > joints
b) floor beams > stringers > joints
c) joints > floor beams > stringers
d) stringers > joints > floor beams

Q.3 If n 2j R, then the truss is called as__________.

a perfect truss b redudant truss

c deficient truss d none of above

Q.4 Which of the following conditions is satisfied for cantilever truss ?

a n 2j R b n < 2j R

c n = 2j R d n 2j R

Q.5 Which axial force is determined while analysing a truss ?

a Compressive force

b Tensile force

c Both a and b

d None of the above

Match the Following for Mid Term Exam

	System		Typical span (in m)
1.	Decking	a)	12.5
2.	Wide-flange beams	b)	36
3.	Plate girders	c)	3
4.	Trapezoidal truss	d)	9
5.	Arches	e)	24

Ans. : 1 - c, 2 - d, 3 - a, 4 - e, 5 - b.

Answer Keys for Fill in the Blanks

Q.1	truss	Q.2	Principle rafters
Q.3	1 in 6	Q.4	cost of purlins and cost of roof covering
Q.5	8		

Answer Keys for Multiple Choice Questions

Q.1	a	Q.2	a	Q.3	b
Q.4	c	Q.5	c		

Memory map :