Chapter 4

Plate Girders and Roof Trusses

CHAPTER HIGHLIGHTS

- *Plate girders*
- *Roof trusses*

Plate Girders

Introduction

Plate girders are generally preferred in heavy and long spans, as even the built-up I section cannot provide sufficient moment capacity. Plate girders are generally built-up flexural members and their bending resistance can be increased by increasing the distance between flanges and shear resistance increases, as the web area increases. In case of restriction of depth and also subjected to heavy loads, a welded box plate girder is provided. Box girders have greater resistance to lateral buckling and torsion also.

Elements of Plate Girder

The various elements in plate girder are as follows:

1. Web plate
2. Flange angles with or without flange cover plates for bolted or riveted plate girder and only flange plates for welded girders.
3. Stiffeners: Bearing, transverse and longitudinal
4. Splices: For web and flange

Economical Depth of Plate Girder

It is given by the following equation:

$$\boxed{d = \left[\frac{Mk}{f_y}\right]^{\frac{1}{3}}}$$

Where

$$k = \frac{d}{t_w}$$

d = Depth of the web

t_w = Thickness of the web

- If $\boxed{\dfrac{d}{t_w} \le 67\varepsilon_w}$, then it may be designed as an ordinary beam.

Where, $\boxed{\varepsilon_w = \sqrt{\dfrac{250}{f_{yw}}}}$

Where, f_{yw} = Yield stress of web.

Proportioning of Web

Minimum Web Thickness

It has to meet both serviceability and compression flange buckling criteria.

Serviceability criterion: With respect to provision of stiffeners, the minimum web thickness from serviceability point of view is as follows:

1. When transverse stiffeners are not provided:

   (a) $\frac{d}{t_w} \leq 200\ \varepsilon_w$ (Web connected to flanges along both longitudinal edges.)

   (b) $\frac{d}{t_w} \leq 90\ \varepsilon_w$ (Web connected to flanges along one longitudinal edge only.)

2. When only transverse stiffeners are provided.

   (a) $\frac{d}{t_w} \leq 200\ \varepsilon_w$, for $3d \geq c \geq d$.

   (b) $\frac{c}{t_w} \leq 200\ \varepsilon_w$, for $0.74d \leq c \leq d$.

   (c) $\frac{d}{t_w} \leq 270\ \varepsilon_w$, for $c < 0.74d$.

   For $c > 3d$, the web is considered as unstiffened.

3. When transverse stiffeners are provided along with longitudinal stiffener at one level only, (at $0.2d$ from the compression flange):

   (a) $\frac{d}{t_w} \leq 250\ \varepsilon_w$, for $2.4d \geq c \geq d$.

   (b) $\frac{c}{t_w} \leq 250\ \varepsilon_w$, for $0.74d \leq c \leq d$.

   (c) $\frac{d}{t_w} \leq 340\ \varepsilon_w$, for $c > 0.74d$.

4. When there is a second longitudinal stiffener provided at the neutral axis:

$$\frac{d}{t_w} \leq 400\ \varepsilon_w$$

   Where

   d = Depth of the web.

   t_w = Thickness of the web and Spacing of transverse stiffener.

   $\varepsilon_w = \sqrt{\frac{250}{f_{yw}}}$

   f_{yw} = Yield stress of the web.

NOTE

The above stated criteria are to ensure that the web will not buckle under normal service conditions.

Compression flange buckling criterion: IS 800 specifies the following web thickness requirements:

1. When transverse stiffeners are provided, and:

   (a) $\frac{d}{t_w} \leq 345\ \varepsilon_f^2$, for $c \geq 1.5d$.

   (b) $\frac{d}{t_w} \leq 345\ \varepsilon_f$, for $c > 1.5d$.

   Where

   d = Depth of the web

   t_w = Thickness of the web and Spacing of the transverse stiffener.

   $\varepsilon_f = \sqrt{\frac{250}{f_{yw}}}$

   f_{yf} = Yield stress of compression flange.

Stiffeners

Intermediate Transverse Stiffeners

- These are also called 'vertical stiffeners'.
- Theoretically, the requirement of stiffeners is not necessary when the computed shear stress in web is less than the critical shear stress.
- These increases the buckling resistance of web caused by shear.
- Transverse stiffeners must be proportioned to satisfy the following conditions:
  1. They must be sufficiently stiff so as not to deform appreciably as the web tend to buckle.
  2. Sufficiently strong to resist the shear transmitted by web.
- Angle sections are provided for bolted or riveted constructions of plate girder and flat or plate sections for welded plate girder.
- Spacing of intermediate stiffeners depends on thickness of the web.
- In order to avoid local buckling of transverse stiffener, outstand from face web should not exceed $20t_q\varepsilon$. (Where, t_q is thickness of stiffener).
- Minimum stiffness to transverse web stiffeners: (Not subjected to external loads or moment).

  If $\frac{c}{d} \geq \sqrt{2},\ I_s \geq 0.75\ dt^3_w$

  If $\frac{c}{d} < \sqrt{2},\ I_s \geq 1.5\ dt_w$.

  Where

  d = Depth of the web.

  t_w = Minimum required web thickness.

  C = Atual stiffener spacing.

Intermediate Longitudinal Stiffeners

- Also called 'horizontal stiffeners'.
- These increase the buckling resistance considerably when the web is subjected to bending.
- In case of riveted or bolted plate girder, angle sections are used and plate section for a welded plate girder and are provided in the compression zone of the web.
- Required moment of inertia of the first horizontal stiffener (provided at 0.2d from compression flange) is, $I = ct^3_w$.
- Where, c = actual distance between vertical stiffeners.
  t_w = minimum required thickness of web.
- The moment of inertia of second stiffener (provided at neutral axis) is given by

$$I = d_2 t_w^3$$

Where, d_2 = twice the clear distance from the compression flange angle (or plate in case of welded plate girder) to the neutral axis.

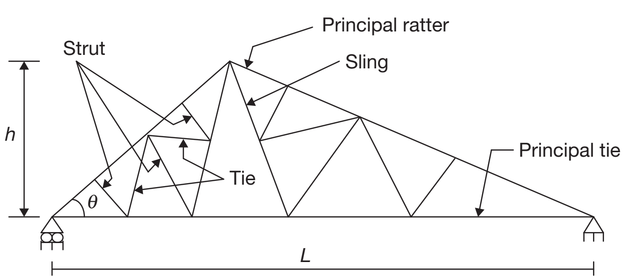
Roof Trusses

Introduction

A truss is a triangular network of compression and tension members. All members in a truss are pin-jointed and, are subjected to axial loads only.

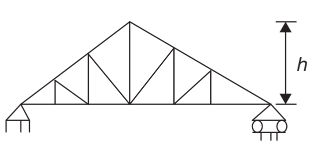
In a plane truss, the external loads and the component members lie in the same plane. Whereas, in a space truss, the component members are oriented in space and loads may act in any direction.

Nomenclature of Truss Member



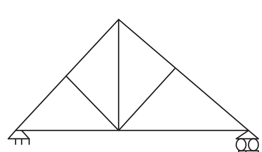
Selection of the Type of Truss

- Generally, pitched trusses are provided in industrial buildings.
- Parallel chord trusses also called 'lattice girder' are used as flat roofs in buildings or floors of steel bridges.



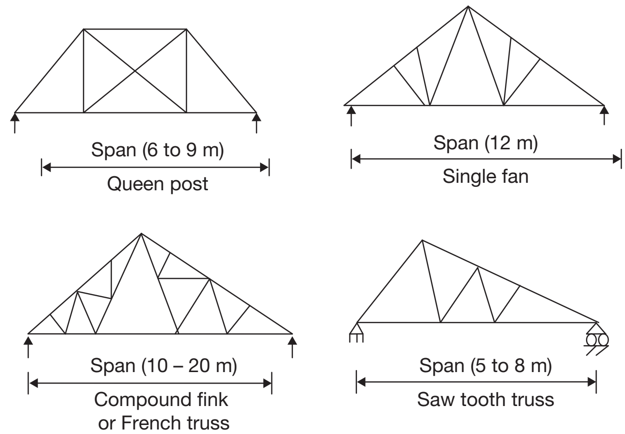
Span (6 to 30 m)

Pratt truss



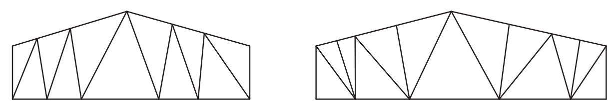
Span (<6 m)

King post



Pitched roof trusses

- A very long pitched truss have generally trapezoidal configuration.
- Fink truss, Pratt and Howe truss, and Warren truss are provided for large, medium and small pitch, respectively.
- The trapezoidal configuration of pitched roof truss is shown below.



(a) Flat pratt truss [Medium pitch large span]

(b) Flat warren truss [Small pitch large span]

- Generally, pitch is defined as the height of truss divided by the span.

$$\text{Pitch} = \frac{\text{Height of truss (Rise)}}{\text{Span}}$$

- Slope is numerically twice the pitch.

$$\text{Slope} = 2 \times \text{pitch}$$

- Pitch depends on the type of roofing material, ventilation and light requirement.

Small pitch: $< \frac{1}{12}$

Medium pitch: $\frac{1}{12}$ to $\frac{1}{5}$

Large pitch: $> \frac{1}{5}$

Pitch for Roof Coverings

- For GI sheets, pitch is $\frac{1}{6}$.
- For AC sheets, pitch is $\frac{1}{12}$.
- For snow load with wind load, pitch: $\frac{1}{4}$.

Spacing of Trusses

- Cost of truss is inversely proportional to the spacing of truss.
- Economic spacing of roof truss can be kept $\frac{1}{4}$ of the span up to 15 m and $\frac{1}{5}$ of the span for 15–30 m span of roof trusses.
- For economic spacing of roof truss:

$$\boxed{\text{Cost of truss} = 2 \times \text{Cost of purlins} + \text{Cost of roof coverings}}$$

Loads on the Roof Truss

- Roof trusses are subjected to dead load, live load, snow load and wind load.

Dead Load

It includes the Dead load of roofing Materials, purlins, trusses and bracing system

- Empirical formula for estimation of dead weight: Approximate dead weight of roof truss in N/m^2

$$= \left(\frac{\text{Span}}{3} + 5\right) \times 10$$

Live Loads

As per IS: 875, the following live loads to be assumed.

Roof Slope	Access	Live Load
≤10°	Provided	1.5 kN/m^2 of plane area.
>10°	Not provided	0.75 kN/m^2 of plane area. For roof membrane sheets or purlins 0.75 kN/m^2 less 0.01 kN/m^2 for every degree increase in slope up to and including 20°, and 0.02 kN/m^2 for every degree increase in slope over 20° ≮ 0.4 kN/m^2.

Snow Loads

- It depends upon pitch of the roof, shape of the roof and roofing material.
- Snow load is taken as 25 N/m^2 per cm depth of snow.
- If roof slope is greater than 50°, the snow load may be neglected.

Wind Load

- Calculated as per IS: 875(part 3)–1987.
- Design wind pressure,

$$\boxed{P_z = 0.6V_z^2}$$

Where

P_z = Design wind pressure in N/m^2 at height, z.
V_z = Design wind velocity in m/s at height, z.

$$\boxed{V_z = V_b \cdot k_1 \cdot k_2 \cdot k_3}$$

Where

V_b = Basic wind speed in m/s at a height of 10 m at the locality.
k_1 = Probability or risk factor.
k_2 = Terrain, height and size factor.
k_3 = Topography factor.

- Wind force is obtained by:

$$\boxed{F = (C_{pe} - C_{pi})\, AP_z}$$

Where

C_{pe} = External pressure coefficient.
C_{pi} = Internal pressure coefficient.
A = Surface area of the element under consideration.
P_z = design wind pressure.

Internal air pressure coefficients for roofs and walls of an industrial building:

Permeability	Openings in Wall Relation to Wall Area	Internal Air Pressure Coefficient (C_{pi})
Zero	0	±0
Normal	< 5	±0.2
Medium	5–20	±0.5
Large	> 20	±0.7

NOTE

Positive wind load indicates that force acting towards the structural element while negative indicates away from it.

Design of Purlins

- Purlins are designed as beams. They support roof covering.
- As per IS:800, purlins are designed as continuous beam subjected to bi-axial bending.
- Except tubular sections, all other sections are subjected to uniaxial loading.

Design Procedure

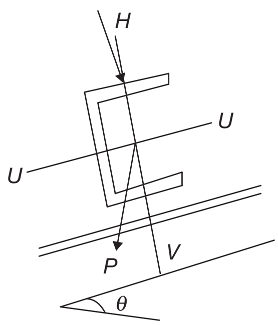
Design Loads

- Dead load due to sheeting = P_1
- Live load and load due to wind = H
- Factored load along V–V axis = $P = \gamma_f(P_1 \cos\theta + H)$ in kN
- Factored load along U–U axis = $\gamma_f(P_1 \sin\theta)$ in kN

Since Purlins are Continuous

Maximum bending moments,

$$M_{UU} = \frac{Pl}{10} \quad M_{VV} = \frac{Hl}{10}$$



l = Span of purlin

= c/c distance between adjacent trusses.

- Design capacities of the section,

$$M_{dz} = Z_{pz} \cdot \frac{f_y}{\gamma_{mo}} \leq 1.2\, Z_{ez} \cdot \frac{f_y}{\gamma_{mo}}$$

$$M_{dy} = Z_{py} \cdot \frac{f_y}{\gamma_{mo}} \leq \gamma_f \cdot Z_{ey} \cdot \frac{f_y}{\gamma_{mo}};$$

[If $\frac{Z_p}{Z_y} > 1.2$, then γ_f is used.]

For safety $M_{dz} \geq M_{zz}(M_{UU})$ and $M_{dy} \geq M_{yy}(M_{VV})$.

1. The local capacity of the section is checked with the interaction equation:

$$\frac{M_{zz}}{M_{dz}} + \frac{M_{yy}}{M_{dy}} \leq 1.0$$

2. The deflection of purlin is calculated which should be less than the deflection limit.

   (Span of purlin/180, for brittle cladding)

   (Span of purlin/150, for elastic cladding)

EXERCISES

1. In a plate girder, the web plate is connected to the flange plates by fillet welding. The size of the fillet welds is designed to safety resist

(A) the bending stresses in the flanges.
(B) the vertical shear force at the section.
(C) the horizontal shear force between the Hanges and the web splice.
(D) the forces causing buckling in the web.

2. Group I contains some elements in design of a simply supported plate girder and Group II gives some qualitative locations on the girder.

Match the items of two lists as per good design practice and relevant codal provisions.

	Group I		Group II
P.	Flange splice	**1.**	at supports (minimum)
Q.	Web splice	**2.**	away from centre of span
R.	Bearing stiffeners	**3.**	away from support
S.	Horizontal stiffener	**4.**	in the middle of span
		5.	longitudinally some where in the compression flange

Codes:

	P	Q	R	S
(A)	2	3	1	5
(B)	4	2	1	3
(C)	3	4	2	1
(D)	1	5	2	3

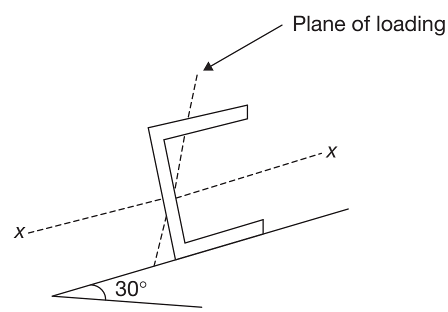
3. Plate girder I section is made by groove welding stress free web plate to two stress-flange plates. After cooling of the welds to the room temperature, the residual stress would be

(A) tension at the free edges of the flanges.
(B) compressive at the free edges of the flanges.
(C) compressive at the flange web intersection.
(D) zero every where.

4. Intermediate vertical stiffeners are provided in palte girders to

(A) eliminate web buckling.
(B) eliminate local buckling.
(C) transfer concentrated loads.
(D) prevent excessive deflection.

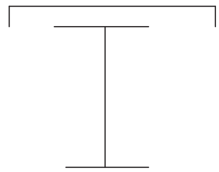
5. A channel section is placed in an inclined position carrying vertical loads as shown in the given figure. If the applied moment for the channel is 'M' due to vertical load, then M_{xx} is given by



(A) $\frac{\sqrt{3}}{2}M$ (B) $\frac{1}{2}M$

(C) $\frac{1}{\sqrt{2}}M$ (D) $2M$

6. The given figure shows a typical section of a crane girder. Consider the following statements in this regard:



The function of top channel is to
I. increase moment of inertia about vertical axis.
II. reduce moment of inertia about horizontal axis.
III. increase torsional stiffness.
IV. increase lateral buckling strength.
Which of these statements are correct?
(A) I and IV (B) II and III
(C) I, II and IV (D) I, III and IV

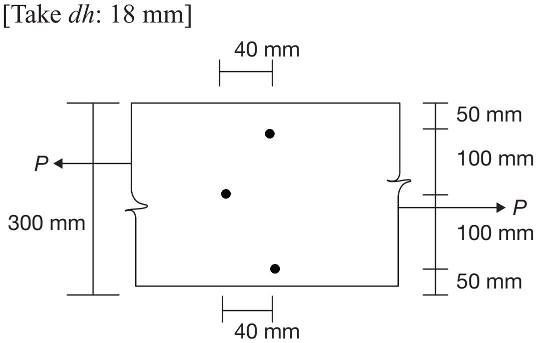
7. The economic spacing of a roof truss depends upon the
(A) cost of purlins and cost of roof covering.
(B) cost of roof covering and dead loads.
(C) dead loads and live loads.
(D) live loads and cost of purlins.

8. Purlins are provided, in industrial buildings, over roof trusses to carry dead loads, live loads and wind loads. As per IS code, what are they assumed to be?
(A) Simply supported (B) Cantilever
(D) Continuous (D) Fixed

9. In a plate girder, the web is primarily designed to resist
(A) torsional moment (B) shear force
(C) bending moment (D) diagonal buckling

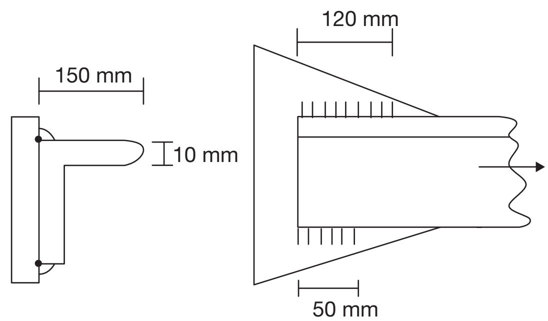
10. In an industrial building gantry girder of effective span 25.0 m carries a manually operated crane of 350 kN. The maximum deflection as per IS:800–2007 is
(A) 50 mm (B) 30 mm
(C) 25 mm (D) 75 mm

11. What is the net effective sectional area of plate of thickness 12 mm as shown in the figure for carrying tension? [Take *dh*: 18 mm]



(A) 2500 mm^2 (B) 3048 mm^2
(C) 2750 mm^2 (D) 3500 mm^2

12. Compute the tensile strength of an angle section ISA 150 × 150 × 10 mm of Fe410 grade of steel connected with guest plate as shown in figure based on gross-sectional yielding.



(A) 450 kN (B) 350 kN
(C) 660 kN (D) None of these

13. The best tension member section will be a
(A) bolted single angle section.
(B) welded single angle section.
(C) channel section.
(D) double angle section on opposite side of gusset plate.

14. The optimum depth of plate girder is given by

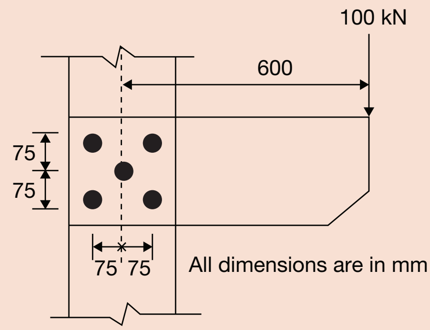
(A) $\left(\frac{MK}{f_y}\right)^{0.33}$ (B) $\left(\frac{M^2K}{f_y}\right)^{0.33}$

(C) $\left(\frac{MK}{f_y}\right)^{0.25}$ (D) $\left(\frac{M^2K^2}{f_y}\right)^{0.33}$

15. Consider the following statements.
I. The economic spacing of a roof truss depends on cost of purlins and cost of roof covering.
II. Bearing stiffeners are provided in a plate girder to prevent web buckling.
III. Purlins provided over roof trusses are designed as a continuous as per IS:800.
The correct statements are
(A) I, II and III are correct
(B) only I and II are correct
(C) II and III are correct
(D) I and III are correct

Previous Years' Questions

1. A bracket plate connected to a column flange transmits a load of 100 kN as shown in the following figure. The maximum force for which the bolts should be designed is ______ kN. **[GATE, 2015]**



Answer Keys

Exercises

1. C	**2.** A	**3.** A	**4.** A	**5.** A	**6.** A	**7.** A	**8.** C	**9.** B	**10.** A
11. B	**12.** C	**13.** D	**14.** A	**15.** A					

Previous Years' Questions

1. 156.2