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Detailed Solutions

ESE-2023 Mains Test Series

Civil Engineering Test No : 8

Section A : Water Resource Engineering + Building Materials + Railway, Airport Tunnelling & Harbour

Q.1 (a) Solution:

River-training covers all those engineering works which are constructed on a river, so as to guide and confine the flow of the river channel and to control and regulate the river bed configuration, thus ensuring safe and effective disposals of floods and sediment loads.

Objectives of river training works:

1. To prevent the river from changing its course and to avoid outflanking of structures like bridges, weirs etc.
2. To protect the river banks by deflecting the river away from the attacked bank.
3. To ensure effective disposal of sediment load.
4. To provide minimum water depth required for navigation.
5. To prevent flooding of surrounding by providing a safe passage for the flood waters without overtopping the banks.

Depending upon the purpose for which a river training programme is undertaken, the river training works can be classified as:

1. **High water training or training for discharge:**

   The primary purpose of it is flood control. It aims at providing sufficient river cross-section for the safe passage of maximum flood by construction of dykes or leaves etc.

2. **Low water training or training for depth:**
The primary purpose of it is to provide sufficient water depth in navigable channel during low water periods. It may be accomplished by the process of bandalling by contracting the width of the channel with the help of gyrones.

3. **Mean water training or training for sediment:**
It aims at efficient disposal of suspended load and bed load and thus to preserve the channel in good shape.

Q.1 (b) Solution:

Given, mix proportion: 1 : 1.7 : 3.2

Water cement ratio = 0.48 by mass

Bulk density of: Cement = 1490 kg/m^3

Coarse aggregate = 1620 kg/m^3

Bulk density of sand = 1740 kg/m^3

Also specific gravity of, Cement = 3.15

Specific gravity of sand = 2.6

Specific gravity of coarse aggregate = 2.62

Percentage of entrained air, V_a = 2%

Total volume = 1 m^3

Let us consider the volume of cement be x m^3

$$\text{Mass of cement} = 1490x$$

$$\text{Mass of sand} = 1740 \times 1.7\, x = 2958\, x$$

$$\text{Mass of coarse aggregates} = 1620 \times 3.2 \times x = 5184\, x$$

$$\text{Mass of water} = 0.48 \times 1490x = 715.2x$$

Now,
$$V_T = V_a + V_w + V_{\text{cement}} + V_{\text{sand}} + V_{C.A.}$$

$$1 = 0.02 + \frac{715.2x}{1000} + \frac{1490x}{3.15 \times 1000} + \frac{2958x}{2.6 \times 1000} + \frac{5184x}{2.62 \times 1000}$$

$\Rightarrow$
$$x = 0.228 \text{ m}^3$$

$\therefore$
$$\text{Weight of cement} = 1490 \times 0.228 = 339.72 \text{ kg}$$

$$\text{Weight of sand} = 2958 \times 0.228 = 674.42 \text{ kg}$$

$$\text{Weight of coarse aggregates} = 5184 \times 0.228 = 1181.95 \text{ kg}$$

$$\text{Weight of water} = 715.2 \times 0.228 = 163.07 \text{ kg}$$

Q.1 (c) Solution:

(i) Plywood: The meaning of term ply is thin layer. The plywoods are boards which are prepared from thin layers of woods or veneers. The number of veneers in plywood is always kept odd for a balanced construction and to prevent shrinkage. This gives rise to 3 ply, 5 ply, 7 ply etc. Plywoods vary in thickness depending upon the number of veneers and the thickness of veneer used. The outside layers of veneer are called faces, the central layer is called core and those between the face and the core are called cross bands. The veneers are held in position by application of suitable adhesives. The placing of veneers normal to each other increases the longitudinal and transverse strengths of plywoods. The plywoods are available in different forms such as batten board, laminated board, three ply, veneered plywood etc.

(ii) Laminated board: It is a board having a core of strips, each strip not exceeding 7 mm in thickness, glued together face to face to form a slab which in turn is glued between two or more outer veneers, with the direction of the grain of the core strip running at right angles to that of the adjacent outer veneers.

(iii) Batten board: It is a board having a core made up of strip of wood usually 8 cm wide, each laid separately or glued or otherwise joined to form a slab which is glued between two or more outer veneers with the direction of the grain of the core running at right angles to that of the adjacent outer veneers.

(iv) Fiber board: It is a rigid board and also known as pressed wood or reconstructed wood. It is made up of wood, cane or other vegetable fibres and chippings. Depending upon their form and composition, the fiber boards are classified as insulating boards, medium hard boards, hard boards, superhard boards and laminated boards. They are also available under various trade names such as Eureka Indiamite, Insulite etc. The fiber boards form an ideal base for practically all types of decorative finishes such as distemper, oil paint, etc.

Q.1 (d) Solution:

Given: $N = 12, G = 1.676 \text{ m}, d = 11.75 \text{ cm} = 0.1175 \text{ m}$

1. Curve lead, (CL) $= 2\,GN$

$$= 2 \times 1.676 \times 12 = 40.224 \text{ m}$$

2. Radius of outer curve of turnout,

$$R_0 = 2GN^2 + 1.5G$$

$$\Rightarrow \quad R_0 = 2 \times 1.676 \times 12^2 + 1.5 \times 1.676$$

$$= 485.202 \text{ m}$$

Radius of centre line of turnout,

$$R = R_0 - \frac{G}{2}$$

$$= 485.202 - \frac{1.676}{2} = 484.364 \text{ m}$$

3. Switch lead, $SL = \sqrt{2R_{od}}$

$$= \sqrt{2 \times 485.202 \times 0.1175} = 10.678 \text{ m}$$

4. Crossing lead, L = C.L. – S.L.

= 40.224 – 10.678 = 29.546 m

Q.1 (e) (i) Solution:

1. Turning radius, $R = \frac{V^2}{125f} = \frac{(40)^2}{125 \times 0.13}$

$$R = 98.46 \text{ m}$$

2. Turning radius as per Horonjeff's equation

$$R = \frac{0.388W^2}{\left[\frac{T}{2} - S\right]}$$

$$S = 6 + \frac{6.6}{2} = 9.3 \text{ m}$$

$$R = \frac{0.388 \times (18)^2}{\left(\frac{22.5}{2} - 9.3\right)}$$ (Taxiway width, T = 22.5 m)

$$= 64.47 \text{ m}$$

3. The absolute minimum turning radius for subsonic aircrafts regardless of any speed = 120 m.

   Selecting the maximum value amongst the three cases, the turning radius to be actually provided = 120 m.

Q.1 (e) (ii) Solution:

The capacity of the gate system, $C = \min \text{ of} \left\{\frac{G_i}{T_i M_i}\right\}$

$$G_i = \text{Number of gates}$$
$$T_i = \text{Occupancy time}$$
$$M_i = \text{Mix proportion}$$

$$(G_C)_B = \left[\frac{3}{25\times 0.10}\times 60\right] = 72 \text{ air craft/hr}$$

$$(G_C)_B = \left[\frac{5}{40\times 0.3}\times 60\right] = 25 \text{ air craft/hr}$$

$$(G_C)_C = \left[\frac{6}{60\times 0.6}\times 60\right] = 10 \text{ air craft/hr}$$

$\therefore$ Gate capacity = 10 aircraft/hr

Q.2 (a) (i) Solution:

$$\text{Maturity, } M = \sum_0^t [T - T_0]\Delta t$$

where,
T = Average concrete temperature
T_0 = Datum temperature (–11°C)
Δt = time interval

$$\therefore \quad M = 7 \times 12[26 - (-11)] + 7\times 12 \times [13 - (-11)]$$
$$= 5124°\text{C hours}$$

$$\text{Strength at maturity, } f = A + B \log_{10}[M \times 10^{-3}]$$

Where A and B are Plowman's coefficient

$\therefore$ A = 42

B = 46.5

$$\therefore \quad f = 42 + 46.5\log_{10}\left[\frac{5124}{10^3}\right] = 75\%$$

Strength of fully matured concrete= 50 MPa

So strength of concrete after 7 days = $50\times\frac{75}{100}$ = 37.5 MPa

Q.2 (a) (ii) Solution:

Tests for building stones:

1. **Acid Test**: A sample of stone is placed in a solution of HCL (one percent strength) for seven days. The solution is agitated at regular intervals. A stone that maintains its sharp edges and keeps its surface free from powder at the end of this period in

considered suitable for building material purposes and if the stone specimen contains calcium carbonate, its edges are broken and powder is formed on the surface and then such a stone possesses poor weathering resistance. This test is more commonly performed on sandstones.

2. **Attrition Test**: This test predicts the rate of wear of stones against the grinding action under traffic. Therefore this test is primarily used for stones to be used in road construction.

   The test procedure in as follow

   (i) Samples of stones are broken into pieces of about 60 mm size.

   (ii) The sample pieces, weighing around 5kg, are put in the two cylinders of Devil's attrition test machine. These cylinders have a diameter of about 20mm and length 340 mm. Their axes of those cylinders make an angle of 30 degree with the horizontal.

   (iii) Cylinders are rotated about the horizontal axis for 5 hours at the rate of 30 rpm.

   (iv) The specimen pieces are then taken out from the cylinders and they are passed through a sieve of 1.5mm mesh.

   (v) The quantity of material retained on the love is weighed

   (vi) Percentage wear is found to judge the stone.

   Percentage wear = loss in weight * 100/initial weight,

3. **Crushing Test**: Stone samples are cut into cubes of size 40 x 40 x 40 mm. Those are finely dressed and finished. The number of samples shall not be loss than three. These specimens are placed in water for about 72 hours prior to test and therefore tested in saturated condition.

   Load bearing surface is then covered with plaster of Paris or a plywood of about 5 mm thickness Load is applied axially on the cube at a rate of $14 N/mm^2$ per minute. Crushing strength of the stone load at which the sample crushes or fails divided by the area of the bearing face of the specimen.

4. **Crystalline Test**: Not less than four cubes of stone with size as 40mm are taken and are dried for 72 hrs and weighed. They are then immersed in a 14% solution of Na_2SO_4 for 2 hours. The cubes are then dried at 100°C and weighed. The difference in weight is noted. This procedure of drying, weighing. Immersion and reweighing is repeated atleast 5 times Each time, change in weight is noted and it is expressed as a percentage of original weight.

   Although $CaSO_4$ crystallization in the pores of stone causes decay of stone due to weathering. But as $CaSO_4$ has low solubility in water, it is not used for test.

5. **Freezing and thawing test**: Stone specimen is kept immersed in water for 24 hours. It is then placed in a freezing machine at 12°C for 24 hours. The specimen is then brought

to atmospheric temperature. This must be done in shade to prevent any effect due to wind, sun rays, rain etc. This procedure is repeated several times and the behavior of stone is carefully observed.

6. **Hardness Test**: A cylinder of diameter 25mm and height 25mm is taken out from the sample of stone and weighed. The sample is placed then in Dorry's testing machine and it is subjected to a pressure of 12.50 N. Annular steel disc of the machine is then rotated at a speed of 28 rpm. Coarse sand of standard specification is sprinkled on the top of disc while rotating The specimen is taken out and weighed after about a thousand revolutions. The coefficient of hardness for the stone specimen is found to judge the suitability for use.

   Coefficient of hardness = 20-(loss in weight in g)/3

7. **Impact Test**: Impact test is used to determine the toughness of a stone sample in this test, a cylindrical specimen of diameter 25 mm and height 25 mm is taken out from the stone and placed on a cast iron anvil. A steel hammer of weight 20 N is them dropped on the cylinder axially. The height of the drop is increased successively from 1 cm to n cm in the nth fall when the specimen breaks. Here "n" gives the toughness index for the stone.

8. **Microscopic Test**: The stone sample examined under a microscope and studied to predict the quality of stone. The properties that are examined are
   (i) Average grain size
   (ii) Existence of pores, fissures, veins and shakes
   (iii) Mineral constituents
   (iv) Nature of cementing material
   (v) Presence of any harmful substance
   (vi) Texture of stone etc.

9. **Smith's Test**: Smith's test is performed to find out the presence of any soluble matter in a stone sample Chips or pieces of store are taken and they are placed in a glass tube filled with clear water After sixty minutes, the tube is vigorously stirred. Presence of earthy matter will convert the clear water into dirty water. If water remains clear, store is considered durable and free from any soluble matter.

10. **Water Absorption Test**: The test procedure is as follows:
   (i) A stone sample, about 50gm weight, is prepared is actual weight is recorded as W_1 qm.
   (ii) Cube is then immersed in distilled water for a period of about 24 hrs After 24 hrs the cube is taken out of water and its surface wiped off of water with a damp cloth
   (iii) it is weighed again Let the weight be W_2 gm.

(iv) The Cube is then suspended freely in water and weighed Let this be W_3 gm.
(v) The specimen is then kept in a boiling water for about the hours.
(vi) Cube is removed and surface water is wiped off with a damp cloth its weight is recorded Let it be W_4 gm.

From the above observations, values of the following properties of stones are obtained.

Percentage absorption by weight after 24 hours = $(W_2 - W_1) \times 100/W_1$

Percentage absorption by weight after 24 hours = $(W_2 - W_1) \times 100/(W_2 - W_3)$

Volume of displaced water = $W_2 - W_3$

Percentage porosity by volume = $(W_4 - W_1) \times 100/(W_2 - W_3)$

Specific gravity = $W_1/(W_2 - W_3)$ kg/m^3

Saturation coefficient = Water absorption/total porosity

= $(W_1 - W_1)(W_4 - W_1)$

Q.2 (b) Solution:

Defects in timber: Defects occurring in timber are grouped into following five divisions:

1. Defects due to conversion
2. Defects due to fungi
3. Defects due to natural forces
4. Defects due to seasoning

Various types of defects under each category are as below:

1. **Defects due to conversion**: During the process of converting timber to commercial form, the following defects may occur:
   (i) Chip mark
   (ii) Diagonal grain
   (iii) Torn grain
   (iv) Wane

   (i) Chip mark: This defect is indicated by the marks or signs placed by chips on the finished surface of timber. They may also be formed by the parts of a planning machine.

   (ii) Diagonal grain: This defect is formed due to improper sawing of timber. It is indicated by diagonal mark on straight granited surface of timber.

   (iii) Torn grain: This defect is caused when a small depression is formed on the finished surface of timber by falling of a tool or so.

   (iv) Wane: This defect is denoted by the presence of original rounded surface on the manufactured piece of timber.

2. **Defects due to fungi**: Fungi are minute microscopic plant organisms. They attack timber only when the following two conditions are satisfied simultaneously:

   (i) The moisture content of timber is above 20 percent.

   (ii) There is presence of air and warmth for the growth of fungi.

If any one of the above conditions is absent, decay of wood due to fungi would not occur. Hence, dry wood having moisture content less than 20 percent will remain sound for centuries. Similarly, wood submerged in water will not be attacked by fungi because of absence of air. Following defects are caused in timber by fungi:

(i) Blue strain
(ii) Brown rot
(iii) Dry rot
(iv) Heart rot
(v) Sap strain
(vi) Wet rot
(vii) White rot

(i) **Blue strain**: Sap of wood is stained to bluish colour by the action of certain type of fungi.

(ii) **Brown rot**: The term rot is used to indicate decay or disease of timber. Certain types of fungi remove cellulose compounds from wood and hence, wood assumes the brown colour. This is known as brown rot.

(iii) **Dry rot**: Certain types of fungi feed on wood and during feeding, they attack on wood and convert it into dry powder form. This is known as dry rot. Following facts in connection with dry rot are to be noted:

(a) Dry rot occurs at places where there is no free circulation of air such as improperly ventilated basements, rooms, etc.
(b) Unseasoned soft woods and sap wood are easily attacked by dry rot.
(c) If timber is not properly stored after being felled down, it is liable for the attack of dry rot.
(d) It is not necessary to have damp conditions for the development of dry rot.
(e) Dry rot is also caused by charring, painting and tarring the unseasoned timber.
(f) Dry rot may be prevented by using well-seasoned timber free from sap.
(g) When part of timber is affected by dry rot, the damaged portion may be completely removed and the remaining unaffected portion should be painted with a solution of copper sulphate.

(iv) **Heart rot**: This is formed when a branch has come out of a tree. In such a case, heart wood is exposed to the attack to atmospheric agents. Ultimately, the tree becomes weak and it gives out hollow sound when struck with a hammer.

(v) Sap strain: Certain types of fungi do not bring about the complete decay of timber. But they feed on cell contents of sap wood. In doing so, sap wood loses its colour. This is known as sap strain and it generally occurs when moisture content goes beyond 25 percent or so.

(vi) Wet rot: Some varieties of fungi cause chemical decomposition of wood of the timber and in doing so, they convert timber into a greyish brown powder. This is known as wet rot. The important facts to be remembered in connection with wet rot are:

(a) Alternate dry and wet conditions favour the development of wet rot.

(b) In unseasoned or improperly seasoned timbers are exposed to rain and wind, they become easily liable for the attack of wet rot.

(c) To prevent wet rot, well-seasoned timber should be used for exterior work or for underground work and it should be covered by tar or paint for protection against moisture.

(vii) White rot : This defect is just the opposite of brown rot. In this case, certain types of fungi attack lignin of wood and wood assumes the appearance of a white mass consisting of cellulose compounds.

3. Defects due to natural forces: The main natural forces responsible for causing defects in timers are two, namely, abnormal growth and rupture of tissues.

Following defects are caused by these forces:

(i) Burls
(ii) Callus
(iii) Chemical strain
(iv) Coarse grain
(v) Dead wood
(vi) Druxines
(vii) Foxiness
(viii) Knots

(i) Burls: These are also known as excrescence and they are particularly formed when a tree has received shock or injury in its young age. Due to such injury, the growth of tree is completely upset and irregular projections appear on the body of timber.

(ii) Callus: It indicates soft tissue or skin which covers the would of a tree.

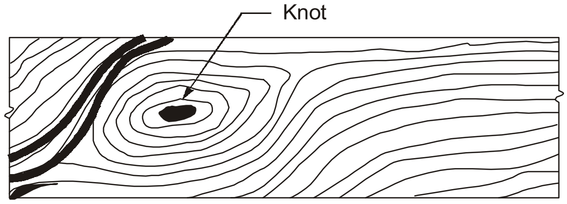
(iii) Chemical strain: Wood is sometimes discoloured by the chemical action caused with it by some external agency. This is known as chemical strain.

(iv) Coarse grain: If a tree grows rapidly, annual rings are widened. It is know as coarse grained timber and such timber possesses less strength.

(v) **Deadwood**: Timber which is obtained from dead standing trees contains wood. It is indicated by light weight and reddish colour.

(vi) **Druxines**: This defect is indicated by white decayed spots which are concealed by healthy wood. They are probably formed for the across of fungi.

(vii) **Foxiness**: This defect is indicated by red or yellow tongue in wood. It is caused either due to poor ventilation during storage or by commencement of decay due to ever-maturity. (viii) Knots: These are the bases of branches or limbs which are broken or cut off from the tree. The portion from which the branch is removed receives nourishment from the stem for a pretty long time and it ultimately results in the formation of dark, hard rings which are known as knots. As continuity of wood fibres is broken by knots, they form a source of weakness shows a typical knot.



4. **Defects Due to Seasoning (Process of drying):** Defects occurring in timber due seasoning process is as follows.

(i) **Bow**: It is a curvature of the timber in the direction of its length due to Caused by grain irregularities in the board and can be eliminated by proper stacking

(ii) **Cup**: A curvature in the transverse direction of the timber due to Unequal shrinking in the radial and tangential direction.

(iii) **Twist**: It is a spiral distortion along the length of the timber.

(iv) **Case hardening**: It is due to the rapid drying (resulting in unequal drying) of the exterior surfaces (under compression) and the interior surfaces (under tension). This happens at heavily loaded bottom stacks kept for seasoning

(v) **Split**: It is separation of the fibres along the grain and extends from one end of the plank to the other.

(vi) **Honey combing:** It is separation of the fibres in the interior due to drying stresses

(vii) **Radial Shakes**: These are radial cracks.

(viii) **Check**: A check is a crack which separates fibres of wood due to rapid drying it does not extend from one end to the other.

(ix) **Collapse**: Due to uneven shrinkage, the wood sometimes flattens during drying

(x) **Wrap**: When a piece of timber has twisted out of shape it is said to be wrapped.

Q.2 (c) (i) Solution:

The required computations are done in a tabular form below:

Crop	Base period (days)	Duty at the field (D) (ha/cumec)	$\Delta = 8.64 \frac{B}{D}$ (m)	Area under crop (A) (ha)	Volume $= \Delta \times A$ (ha.m)
Wheat	120	1800	0.576	600	345.6
Sugarcane	320	800	3.456	700	2419.2
Rice	120	900	1.152	450	518.4
Cotton	200	1600	1.08	1400	1512
Bajra	100	1200	0.72	600	432
				ΣV	5227.2 ha.m

Since, 40% of the water is available from precipitation,

$$\therefore \text{ Capacity of reservoir required } = \frac{0.6 \times 5227.2}{0.8 \times 0.85} = 4612.235 \text{ ha-m}$$

[Due to conveyance and channel losses]

Q.2 (c) (ii) Solution:

Duty represents the irrigating capacity of a unit of water. It is the relation between the area of a crop irrigated and the quantity of irrigation water required during entire period of growth of that crop. In other words, it may be defined as the area in hectares of land irrigated for full growth of a given crop by a supply of one cumecs of water continuously during the entire base period of that crop.

Delta is the total depth of water required by a crop during the entire period, the crop is in the field and is denoted by the symbol Δ.

Duty of irrigation water depends upon the following factors:

- **Type of crop:** Duty will be less for a crop requiring more water and vice-versa.
- **Climate and season:** Duty will be less in hot and summer season.
- **Useful rainfall:** More the usefull rainfall, less will be the requirement of irrigation water and hence, more will be the duty of irrigation water.
- **Types of soil:** If the permeability of soil under irrigated crop is high, the water lost due to percolation will be more and hence, the duty will be less.
- **Efficiency of cultivation method:** If the irrigation water is used economically, then duty of water will improve as the same quantity of water would be able to irrigate more area.

Relation between duty and delta:

Let, there be a crop with base period B days and one cumec of water is applied to this crop on the field for its base period.

Now, the volume of water applied to this crop during B days,

$$V = (1 \times 60 \times 60 \times 24 \times B)\text{m}^3$$
$$= 86400\,B\ (\text{m}^3)$$

By definition of duty, one cubic metre of water supplied for B days irrigates D hectares of land. So, total depth of water applied on this land

$$= \frac{\text{Volume}}{\text{Area}} = \frac{86400B}{10^4 \times D} = \frac{8.64B}{D}\text{meters}$$

Q.3 (a) (i) Solution:

As per Manning's formula,

$$\text{Velocity, } V = \frac{1}{n}R^{2/3}S^{1/2}$$

$$\Rightarrow \quad 2.5 = \frac{1}{0.014}R^{2/3}\left(\frac{1}{4500}\right)^{1/2}$$

$$\therefore \text{ Hydraulic radius, } \quad R = 3.598 \text{ m} \approx 3.6 \text{ m}$$

For a trapezoidal channel of side slope 1.5 H : 1 V, cotθ = 1.5 or, θ = 33.7°

$$= 0.588 \text{ radians} \simeq 0.59 \text{ radians}$$

Now, $$A = y(B + y\theta + y\cot\theta)$$

and, $$P = B + 2y\theta + 2y\cot\theta$$

$$\therefore \quad A = y(B + y \times 0.59 + y \times 1.5)$$

$$\Rightarrow \quad A = y(B + 2.09y)$$

and $$P = B + 2 \times y \times 0.59 + (2 \times y \times 1.5)$$

$$\Rightarrow \quad P = B + 4.18y$$

But, $$A = \frac{Q}{V} = \frac{400}{2.5} = 160\,\text{m}^2$$

$$\therefore \quad 160 = y(B + 2.09y) \quad \text{...(i)}$$

$$\Rightarrow \quad B = \frac{160}{y} - 2.09y$$

But $R = \frac{A}{P} = \frac{160}{B + 4.18y} = 3.6$

$\Rightarrow$ $3.6 = \frac{160}{\left(\frac{160}{y} - 2.09y + 4.18y\right)}$

$\Rightarrow$ $\frac{160}{y} + 2.09y = \frac{160}{3.6}$

$\Rightarrow$ $2.09y^2 - 44.44y + 160 = 0$

$\Rightarrow$ $y = 16.67$ m, 4.59 m

$\therefore$ $y = 4.59$ m (Ignoring unfeasible depth of 16.67 m)

$\therefore$ $B = \frac{160}{y} - 2.09y = \frac{160}{4.59} - 2.09 \times 4.59$

$\Rightarrow$ $B = 25.27$ m

Using free board of 0.75 m, depth of lined channel = 4.59 + 0.75 = 5.34 m

Hence, B = Bed width = 26 m

D = Total depth = 5.5 m

Q.3 (a) (ii) Solution:

A head regulator provided at the head of the off-taking channel, controls the flow of water entering the new channel, while a cross regulator may be required in the main parent channel downstream of the off-taking channel and is operated when necessary so as to head up water on its upstream side, thus to ensure the required supply in the off taking channel even during the periods of low flow in the main channel.

The main functions of a head regulator are:

(i) To regulate or control the supplies entering the off-taking channel.
(ii) To control silt entry into off-taking channel.
(iii) To serve as a meter for measuring discharge.

The main functions of a cross regulator are:

(i) To effectively control the entire canal irrigation system.
(ii) When the water level in the main channel is low, it helps in heading up water on upstream and to feed the off-taking channels to their full demand.
(iii) They help in absorbing fluctuations in various sections of the canal system.
(iv) Cross regulator is often combined with a road bridge, so as to carry the road which may cross the irrigation canal nearby.

Q.3 (b) (i) Solution:

1. **Acid refractory bricks**
   - The silica bricks consist of 95-97% silica and 1-2% lime; and ganister bricks (ganister is a hard coloured sand stone containing 10% clay and 2% of lime), used in lining furnaces having siliceous and acidic slag as in stool industry and coke oven.
   - The softening temperature ranges from 1700 to 1800°C.
   - Silica bricks are hard and also possess good refractoriness. But they have tendency to spall during rapid temperature change therefore, these cannot be used for lining of furnaces which have to be cooled and reheated frequently
2. **Basic refractory bricks**
   - It consists of magnesia bricks (magnesia 85 per cent, calcium oxide 25 per cent and silica 5.5 per cent) and bauxite bricks (85 per cent aluminium oxide and 20 per cent clay).
   - These are highly resistant to corrosion and are used for lining furnaces having basic slag.
   - Due to high thermal expansion and consequent poor resistance to spalling, the use of these bricks is restricted to copper metallurgy and basic open hearths

   Common types are

   (a) Magnesite bricks
   (b) Dolomite bricks
   (c) Bauxite bricks
3. **Neutral refractory bricks**
   - It consists of chromite bricks (50 per cent chrome and iron ore containing 30 per cent iron oxide and bauxite containing 15 per cent aluminium and 5 per cent silica), chrome magnesite bricks (CrO,18 per cent, MgO 30 per cent), spinel and forsterite bricks.
   - The neutral refractory bricks are suitable at places where acidic and basic linings are to be separated, e.g., for lining copper reverberatory furnace.
   - The various types of neutral bricks are
     (a) Chrome bricks
     (b) Chrome-magnesite bricks.
     (c) Spinel
     (d) Forsterite bricks.

Note: A refractory brick is built primarily to withstand high temperature but usually they are used at places where they are subjected to extreme chemical actions, mechanical stresses, dampness etc. and hence they are made to resist these also.

Q.3 (b) (ii) Solution:

Vibrators: These are mechanical devices which are used to compact concrete in the form work. The advantages of vibrators over hand methods are as follows:

1. It is possible by means of vibrators to make a harsh and stiff concrete mix, (with a slump of about 40 mm or less) workable.
2. Quality of concrete can be improved by use of vibrators as less water will be required or in other words, economy can be achieved by adopting leaner mix where vibrators are used.
3. With the help of vibrators, it is possible to deposit concrete in small openings or places where it will be difficult to deposit concrete by hand methods.

Following are the four types of vibrators:

(i) Internal vibrators

(ii) Surface vibrators

(iii) Form vibrators

(iv) Vibrating tables

(i) Internal vibrators: These vibrators consist of a metal rod which is inserted in fresh concrete. The rod vibrates while it is being inserted. Internal vibrators should be inserted and withdrawn slowly and they should be operated continuously while they are being withdrawn. Otherwise holes will be formed inside the concrete. Hence, skilled and experienced personnel should handle internal vibrators. These vibrators have more efficiency than other types of vibrators.

(ii) Surface vibrators: These vibrators are mounted on platform or screeds. They are used to finish concrete surfaces such as bridge floors, road slabs, station platform, etc. Dry mixes can effectively be compacted using surface vibrators.

(iii) Form vibrators: These vibrators are attached to the framework and external centering of walls, columns, etc. The vibrating action is conveyed to concrete through the form work during transmission of vibrations. Hence they are not generally used. But they are very much helpful for concrete sections which are too thin for the use of internal vibrators.

(iv) Vibrating tables: These are in the form of a table and concrete is placed on this table. The vibration of table then brings down the consolidation of concrete. These vibrators are widely used for making precast products.

Q.3 (c) Solution:

Given: Radius of curve $= \frac{1750}{3} = 583.33\,\text{m}$ [∵ Degree of curve is 3]

Equilibrium speed = 80 kmph

Theoretical maximum santioned speed = 125 kmph

Slowest speed = 45 kmph [∵ Speed of goods trains]

Equilibrium super elevation $= \frac{GV_{eq}^2}{127R} = \frac{1.750 \times 80^2}{127 \times 583.33} = 0.1511\,\text{m} = 15.11\,\text{cm}$

We know that $e_{th} = C_a + C_d$

$$\frac{GV_{max.}^2}{127R} = C_a + C_d$$

$$\frac{1.750 \times 125^2}{127 \times 583.33} = 15.11 + C_d$$

$$C_d = 21.8\text{ cm} \not> 7.5\text{ cm} \quad (\text{For } 3° \text{ curve as } V_{max} \not> 100 \text{ kmph})$$

∴ Maximum permissible speed

$$= 0.27\sqrt{(C_a + C_d) \times R} \qquad \text{Where } C_a \text{ and } C_d \text{ is in mm.}$$

$$= 0.27\sqrt{(151.11 + 75) \times 583.33} = 98 \text{ kmph}$$

For slow moving train, required superelevation,

$$e_{slow} = \frac{1.750 \times 45^2}{127 \times 583.37} = 4.785\,\text{m}$$

But, provided superelevation = 15.11 cm

∴ Cant excess = 15.11 – 4.78 = 10.33 cm $\not>$ 705 cm

∴ $C_a = e_{slow} + CE$

$C_a = 4.78 + 7.5 = 12.28$ cm

Now V_{max},

$$V_{max} = 0.27\sqrt{(C_a + C_d)R}$$

$$V_{max} = 0.27\sqrt{(122.8 + 75)583.33}$$

$$= 91.71 \text{ kmph}$$

Now, length of transition curve

$$L_{TC} = 0.72\, C_a = 0.72 \times 122.8 = 88.41 \text{ m}$$

$$L_{TC} = 0.008 C_a V_{max} = 0.008 \times 122.8 \times 91.71 = 90 \text{ m}$$

Where C_a and C_d is in mm

$$L_{TC} = 0.008 C_d V_{max} = 0.008 \times 75 \times 91.71 = 55 \text{ m}$$

$$L_{TC} = \text{maximum}(88.41, 90, 55) = 90 \text{ m}$$

Check $$V_{max} = \frac{134 L_{TC}}{C_a} = \frac{134 \times 90}{122.8} = 98.2 \text{ kmph} > 91.71 \text{ kmph}$$

$$= \frac{134 L_{TC}}{C_d} = \frac{134 \times 90}{75} = 160.8 \text{ kmph}$$

Q.4 (a) (i) Solution:

1. Correction of elevation:

$$= \frac{7}{100} \times 1720 \times \frac{320}{300} = 128.43 \text{ m}$$

Corrected length = 1720 + 128.43 = 1848.43 m

2. Correction for temperature:

Standard atmospheric temperature = 15 – 0.0065 × 320 = 12.92°C

Rise of temperature = 36.5 – 12.92 = 23.58°C

$$\text{Correction} = \frac{23.58}{100} \times 1848.43 = 435.86 \text{ m}$$

Corrected length = 1848.43 + 435.86 = 2284.29 m

3. Total correction in percentage $= \dfrac{2284.29 - 1720}{1720} \times 100 = 32.808\%$

According to ICAO, total correction for elevation plus temperature should not exceed 35 percent. (OK)

4. Correction for gradient: $= \dfrac{20}{100} \times 2284.29 \times 0.2 = 91.37 \text{ m}$

Corrected length = 2284.29 + 91.37 = 2375.66 m (Say 2376 m)

∴ The corrected runway length is 2376 m.

Q.4 (a) (ii) Solution:

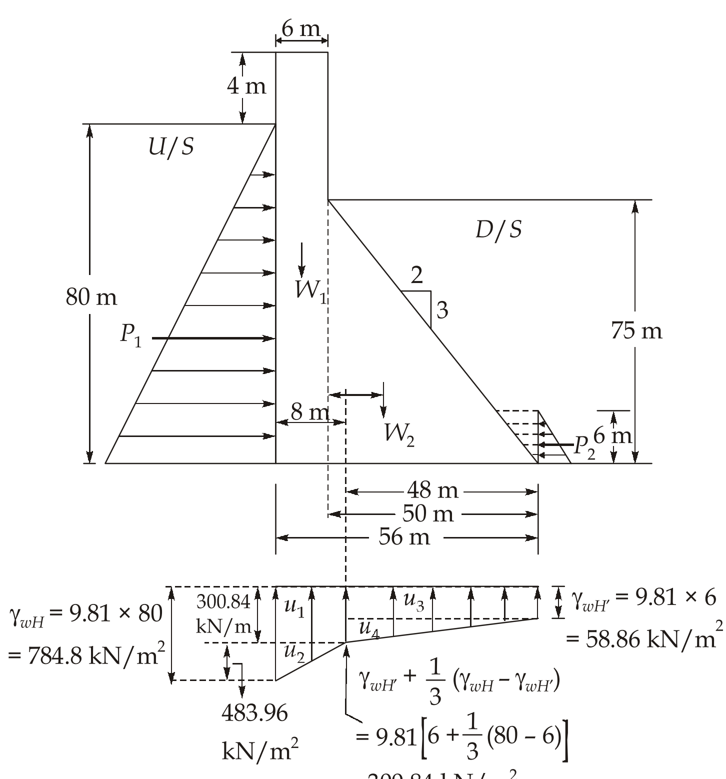
1. **Full face method**: This method is adopted for tunnels whose length is not more than 3 m.
   - Large size tunnels in rocks are always driven by this method.
   - In this method, vertical columns are fixed at the face of the tunnel to which a large number of drills may be mounted at any suitable height.

- A series of drill holes are drilled at about 120 cm centre to center in any number of desired rows, preferably in two rows. The size of holes may vary from 10 to 40 mm.
- These holes are then charged with explosives and ignited.
- The muck is removed before the next operation of drilling holes.

2. **Heading and bench method**:
   - The top portion is known as the heading and the bottom portion as bench. Usually this method is adopted for railway tunnels.
   - The top portion of heading will be about 3.7 to 9.6 m ahead of the bottom portion.
   - In hard rock which may permit the roof to withstand without supports, the top heading usually is advanced by one round of the bottom portion.
   - If the rock is broken then heading may be driven well ahead of the bottom portion and after giving proper support to the roof, the bottom portion is completed.
   - In hard rock the heading is bored first and the drill holes are driven for the bench or bottom portion at the same time as the removal of the muck.
   - If requires less explosive than full face method but due to the development of drill carriage or the jumbo, the use of this method si decreasing.

Q.4 (b) Solution:

The various forces acting on the dam are shown in figure below.



Consider 1 m length of dam.

The various forces and their moments about the toe are then calculated and tabulated below.

Name of forces	Name	Magnitude in kN	Lever arm in m	Moment about toe in kN – m
Vertical forces				
Download weight of dam	W_1	(+) 84 × 6 × 1 × 24 = 12096	53	(+) 641088
	W_2	(+) $\frac{1}{2}$ × 50 × 75 × 24 = 45000	33.33	(+) 1499850
Weight of water supported on d/s face.	-	(+) $\frac{1}{2}$ × 4 × 6 × 1 × 9.81 = 117.72	1.33	(+) 156.57
		ΣV_1 = 57213.72		ΣM_1 = 2141094.57
Uplift pressure	U_1	(–) 300.84 × 8 × 1 = 2406.72	52	(–) 125149.44
	U_2	(–) $\frac{1}{2}$ × 483.96× 8 × 1 = 1935.84	53.33	(–) 103238.35
	U_3	(–) 58.86 × 48 × 1 = 2825.28	24	(–) 67806.72
	U_4	(–) $\frac{1}{2}$ × 248.98× 48 × 1 = 5975.52	32	(–) 191216.64
		ΣV_2 = (–) 13143.36		ΣM_2 = (–) 487411.15
		ΣV = 57213.72 – 13143.36 = 44070.36		
Horizontal water pressure				
on U/s side	P	$\frac{1}{2}$ × 784.8 × 80 × 1 = 31392	26.67	(–) 837224.64
on d/s side	P'	(–) $\frac{1}{2}$ × 58.86 × 6 × 1 = 176.58	2	(+) 353.16
		ΣH = (towards downstream) = 31215.42		Σ = – 836871.48
		ΣM = Net moment = 2141094.57 – 487411.15 – 836871048 = 816811.94		

Now, distance of resultant from toe

$$(\bar{x}) = \frac{\Sigma M}{\Sigma V} = \frac{816811.94}{44070.36} = 18.53\,\text{m}$$

$$\text{Eccentricity, } e = \frac{56}{2} - 18.53 = 9.47\,\text{m}$$

Vertical stresses p_v is given as

$$p_v = \frac{\Sigma V}{B}\left[1 \pm \frac{6e}{B}\right] = \frac{44070.36}{56}\left[1 \pm \frac{6 \times 9.47}{56}\right]$$

$$\therefore \quad p_v = 1585.464 \text{ kN/m}^2 \text{ and } -11.523 \text{ kN/m}^2$$

$$\text{Maximum vertical stress} = p_{max} \text{ at toe} = 1585.464 \text{ kN/m}^2$$

$$\text{Minimum vertical stress} = p_{min} \text{ at heel} = -11.523 \text{ kN/m}^2$$

(ii) Major principal stress at toe (σ) is given by

$$\sigma = p_v(\text{toe})\sec^2\alpha - p' \tan^2\alpha$$

$$p_v(\text{toe}) = 1585.464 \text{ kN/m}^2$$

$$p' = \text{Intensity of water pressure on d/s side} = 58.86 \text{ kN/m}^2$$

$$\tan\alpha = \frac{2}{3}$$

$$\sec^2\alpha = 1 + \tan^2\alpha = 1 + \frac{4}{9} = \frac{13}{9}$$

$$\therefore \quad \sigma = 1585.464 \times \frac{13}{9} - 58.86 \times \frac{4}{9} = 2263.95 \text{ kN/m}^2$$

$$\because \quad \sigma = 2263.95 \text{ kN/m}^2 < 2500 \text{ kN/m}^2 \quad \text{(OK)}$$

(iii) Intensity of shear stress on a horizontal plane near toe is given by

$$\tau_0 = [p_v(\tau_{oe}) - p'] \tan\alpha$$

$$= (1585.464 - 58.86) \times \frac{2}{3}$$

$$= 1017.736 \text{ kN/m}^2$$

Q.4 (c) (i) Solution:

Constituents of portland cement (raw materials)			
Oxide	**Function**	**Composition (%)**	**Average**
Lime, CaO	Controls strength and soundness. Its deficiency reduces strength and setting time. Excess of its cause unsoundness.	60 - 65	63
Silica, SiO_2	Gives strength. Excess of it causes slow setting.	17 - 25	20
Alumina, Al_2O_3	Responsible for quick setting, if in excess, it lowers the strength.	3 - 8	6
Iron oxide, Fe_2O_3	Gives colour and helps in fusion of different ingredients i.e., it acts as a flux	0.5 - 6	3
Magnesia, MgO	Imparts colour and hardness. If in excess, it causes cracks in mortar and concrete and induces unsoundness.	0.5 - 4	2
Soda and/or potash, $Na_2O + K_2O$	These are residues, and if in excess cause efflorescence and cracking,	0.5 - 1	1
Sulphur trioxide, SO_3	Excess of it makes the cement unsound.	1 - 2	1.5

Q.4 (c) (ii) Solution:

High Alumina Cement (IS : 6452)

- It's composition is very different from portland cement.
- The raw materials used for its manufacture consists of 40% bauxite, 40% lime and 15% iron oxide with a little percentage of ferric oxide and silica, magnesia, etc. ground finely at a very high temperature.
- As C_3A is not present, the cement has good resistance against attack by sulphate and some dilute acids, and is particularly suitable to sea and under-water work.

Composition of a typical high alumina cement as per IS: 6452

Composition	Percentage
Al_2O_3	45 (min)
CaO	34 (max)
TiO_2	7 (max)
Fe_2O_3	7 (max)
SiO_2	6.5 (max)
MgO	1 (typical)

- Its rapid hardening properties arises due to $Al_2O_3 \cdot CaO$ (calcium aluminate) as the predominant compound as shown in above table in place of calcium silicate of OPC and for setting and hardening, there is not free hydrated lime as in the case of OPC.
- High alumina cement has very high early compressive strength and has high heat of hydration in comparison to OPC – 43 grade.
- High alumina cement has initial setting time of about 3.5 - 4 hrs and final setting time of 5–5.5 hrs.
- It hardens and develops strength very rapidly. One day strength is 30 N/mm^2 (which is equal to 28 days strength of OPC) and 3 days strength is 35 N/mm^2, giving out a great amount of heat.
- It should not be used in places where temperature exceeds 18°C and it is extremely resistant to action of fire, chemical attack, sea water, acidic water and sulphates.
- High alumina cement is preferred for use in cold regions due to high heat of hydration.
- Fineness $\geq$ 225 m^2/kg.
- Expansion $\leq$ 5 mm.
- It is used for refractory concrete, in industries and is used widely for pre-casting.
- It is not recommended in tropical regions and not mixed with any other type of cement.

Q.4 (c) (iii) Solution:

Autoclave test:

- In India, the occurrence of low magnesia lime stone is limited. So, Indian Standard specifications recommended that cement having a magnesia content greater than 3% be tested for soundness by autoclave test.
- This test is sensitive to both free magnesia and free lime.

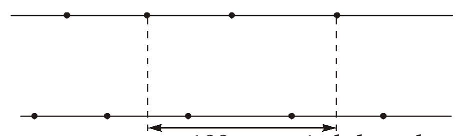
Procedure

- A 25 × 25 × 250 mm specimen is made with neat cement paste.
- The moulded specimen is removed from the moist atmosphere after 24 hours and measured for length.
- It is then placed in an autoclave at room temperature, making sure that four sides of the specimen are exposed to saturated steam.
- The temperature is raised at such rate so as to allow the gauge pressure of the steam to rise from 2.1 N/mm^2 in 1 to 1.25 hours from the moment heat is turned on.
- The pressure is maintained for 3 hours.
- After the heat supply is turned off, the autoclave is cooled at such a rate that pressure is less than 0.1 N/mm^2 after 1 hour.
- The autoclave is opened and test specimen is placed in water at temperature of 90°C which is gradually brought down to 27 ± 2°C in 15 minutes.

- It is then maintained at this temperature for next 15 minutes and then taken out.
- The percent difference in two lengths gives unsoundness of the cement.
- For sound cement the expansion should not exceed 0.8%.

Q.5 (a) Solution:

Number of bolts per 100 mm pitch length = 2



As 4.6 grade M20 bolts are used of diameter = 20 mm

$$\text{Bolt diameter, } d = 20 \text{ mm}$$

$$\text{Hole diameter, } d_0 = 22 \text{ mm}$$

$$f_{ub} = 400 \text{ N/mm}^2$$

$$f_y = 240 \text{ N/mm}^2$$

$$\text{Shear strength of bolt, } V_{dsb} = \frac{n_n \times A_{sb} \times f_{ub}}{\sqrt{3} \times \gamma_{mb}}$$

$$= \frac{1 \times 0.78 \times \frac{\pi}{4} \times 20^2 \times 400}{\sqrt{3} \times 1.25 \times 10^3} \text{ kN} = 45.27 \text{ kN}$$

(i) Strength of joint per pitch length in shear = 2 × 45.27 = 90.54 kN

$$\text{Bearing strength of bolt, } V_{dpb} = 2.5 \times k_b d t \frac{f_{up}}{\gamma_{mb}}$$

$$k_b = \min\left\{\frac{l}{3d_0}, \frac{p}{3d_0} - 0.25, \frac{f_{ub}}{f_{up}}, 1.0\right\}$$

Take $e = 1.5d_0$ (minimum end distance)

$$k_b = \min\left\{0.5, \frac{50 - 0.25}{3 \times 22}, \frac{400}{410}, 1.0\right\}$$

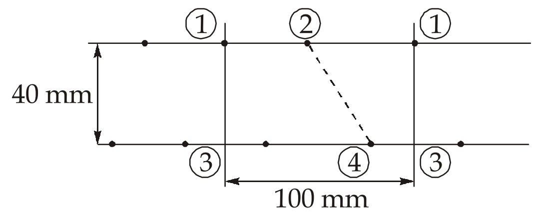
$$= \min\{0.5, 0.51, 0.98, 1\} = 0.5$$

$$\therefore \quad V_{dpb} = 2.5 \times 0.5 \times 20 \times 16 \times \frac{410}{1.25} \times 10^{-3} \text{ kN}$$

$$= 131.2 \text{ kN}$$

(ii) Strength of joint per pitch length in bearing = 2 × 131.2 = 262.4 kN

(iii) Net strength of plate per 100 mm pitch length, T_{dn}.



For 1-2-1, $A_{n1} = (100 - 22) \times 16 = 1248 \text{ mm}^2$

For 1-2-4-3, $A_{n2} = \left(100 - 2\times 22 + \dfrac{40^2}{4\times 50}\right)\times 16 = 1024 \text{ mm}^2$

$$\therefore \quad T_{dn} = \frac{0.9 A_{n\,\min} f_u}{\gamma_{m1}}$$

$$= \frac{0.9\times 1024\times 410\times 10^{-3}}{1.25} \text{ kN} = 302.28 \text{ kN}$$

Gross strength of plate, $T_{dg} = \dfrac{A_g f_y}{\gamma_{mo}}$

$$= \frac{100\times 16\times 250\times 10^{-3}}{1.1} \text{ kN} = 363.64 \text{ kN}$$

Design strength of joint = min{131.2, 262.4 302.28, 363.64} = 131.2 kN

Force on joint due to steam pressure = $\dfrac{pD}{2t}\times 100\times 16$

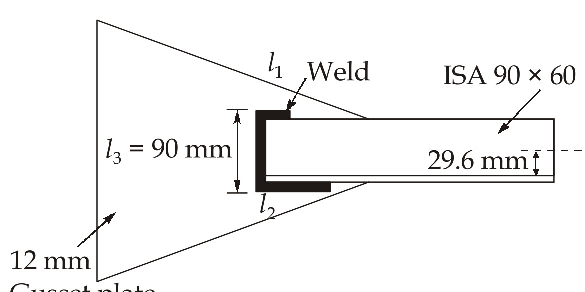
$$= \frac{2\times 1\times 10^3}{2\times 16}\times 100\times 16\times 10^{-3}$$

= 100 kN < 131.2 kN

Hence, the design is safe.

Q.5 (b) Solution:

The situation is as shown. Let l_1, l_2, and l_3 be the length of weld on the three sides.



Design strength of the member governed by yielding of gross section,

$$T_{dg} = \frac{A_g f_y}{\gamma_{mo}} = \frac{1137 \times 250 \times 10^{-3}}{1.1} = 258.41\,\text{kN}$$

Therefore the weld will be designed to transmit a force equal to 258.41 kN.

$$\text{Maximum size of weld} = 8 - 1.5 = 6.5 \text{ mm}$$

$$\text{Minimum size of weld} = 5 \text{ mm}$$

Let us assume a weld size of 6 mm.

Strength of weld per mm length, $T_{dw} = l_w t_t \dfrac{f_u}{\sqrt{3}\gamma_{mw}}$

$$= 1 \times 0.7 \times 6 \times \frac{410}{\sqrt{3} \times 1.5} = 662.8\,\text{N}$$

Equating the strength of weld to the load,

$$(l_1 + l_2 + 90) \times 662.8 = 258.41 \times 10^3$$

$$\Rightarrow \quad l_1 + l_2 = 299.88 \simeq 300 \text{ mm}$$

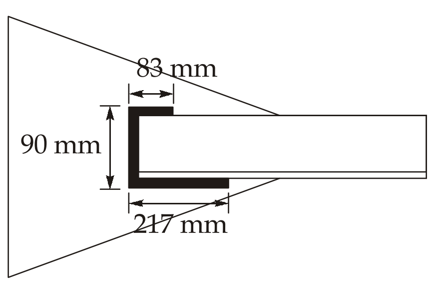
Now, taking moments about top edge of angle section,

$$662.8 \times 90 \times \frac{90}{2} + 662.8 \times l_2 \times 90 = 258.41 \times 10^3 (90 - 29.6)$$

$$\Rightarrow \quad l_2 = 216.65 \simeq 217 \text{ mm}$$

Hence, $l_1 = 300 - 217 = 83$ mm

Provide weld on three sides as shown.



Q.5 (c) (i) Solution:

$$\text{Mean rainfall, } P_m = \frac{\sum_{i=1}^{n} P_i}{n}$$

$$= \frac{112 + 178 + 95 + 139 + 101}{S} = 125 \text{ cm}$$

Now, optimum number of stations can be calculated, as,

$$N = \left(\frac{C_v}{\in}\right)^2$$

where, C_V = Coefficient of Variation of rainfall

$\in$ = Allowable percentage of error in percentage.

where σ_{n-1} is standard deviation

Now, $$C_v = \left(\frac{\sigma_{n-1}}{P_m} \times 100\right)$$

$$\sigma_{n-1} = \sqrt{\sum_{i=1}^{n} \frac{(P_i - P_m)^2}{n-1}}$$

$$= \sqrt{\frac{(112-125)^2 + (178-125)^2 + (95-125)^2 + (139-125)^2 + (101-125)^2}{5-1}}$$

$$= 34.095 \text{ cm}$$

$$C_v = \frac{34.095}{125} \times 100 = 27.276\%$$

$$N = \left(\frac{27.276}{8}\right)^2 = 11.625 \simeq 12$$

In given watershed, 10% of the raingauges stations must be recording type.

So, number of recording raingauges = 2

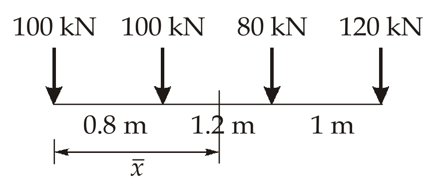
Number of non-recording raingauges = 10

Q.5 (c) (ii) Solution:

Hydrologic cycle: On planet Earth, water is stored in following reservoirs viz. oceans, rivers, soils, glaciers and as groundwater. Hydrologic cycle is a sort of conceptual model that describes the movement of water within the Earth transversing through the hydrosphere (oceans), lithosphere (ground), atmosphere and biosphere. Thus water moves from one reservoir to another by various processes like evaporation, condensation, transpiration, precipitation, runoff, infiltration, melting of ice, groundwater flow etc. all this is described by the Hydrologic cycle. Evaporation of water from these reservoirs occurs due to solar energy. These so formed water vapours rise and get condensed to form clouds. These clouds when become heavy due to condensation then precipitation occurs in various forms. The water from precipitation reaches the earth's surface and joins streams. These streams finally join the sea. Thus this movement of water through the earth's atmosphere is called as hydrologic cycle.

Q.5 (d) Solution:

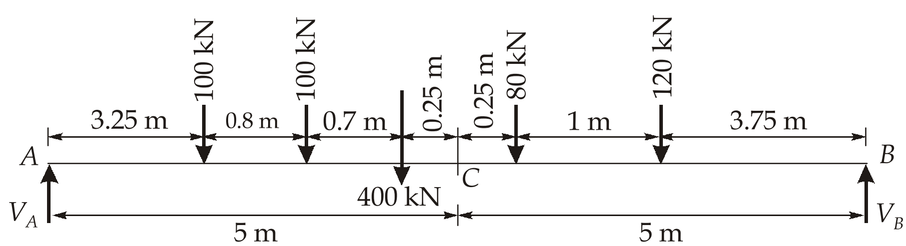
Let us calculate the C.G. of load group first.



$$\bar{x} = \frac{100 \times 0.8 + 80 \times 2 + 120 \times 3}{400} = 1.5\,\text{m}$$

Now, the absolute maximum bending moment will occur either under the 100 kN or the 80 kN load, when the respective load and the resultant of the load system is placed equidistant from the mid-span of the girder.

Under 80 kN load

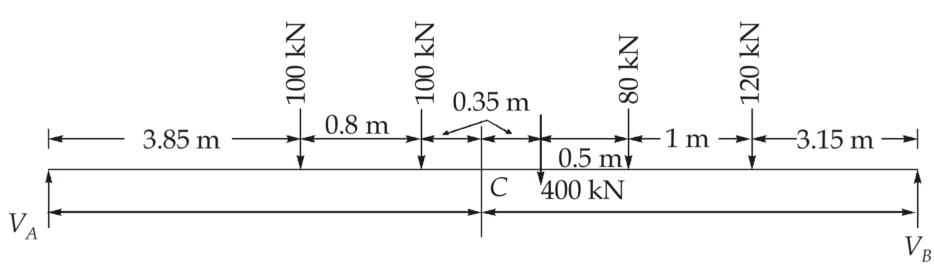


$\Sigma M_A = 0$

$$V_B \times 10 = 400 \times (3.25 + 1.5) = 190 \text{ kN}$$

B.M under 80 kN load, $M_{80} = V_B \times (1 + 3.75) - 120 \times 1$

$$= 190 \times 4.75 - 120 = 782.5 \text{ kNm}$$



$\Sigma M_B = 0$

$$V_A \times 10 = 400 \times 4.65 = 186 \text{ kN}$$

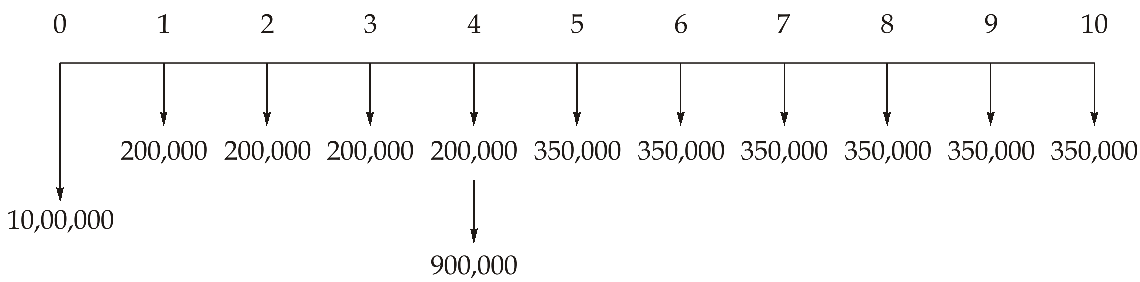
B.M under 100 kN load, $M_{100} = V_A \times (3.85 + 0.8) - 100 \times 0.8$

$$= 186 \times 4.65 - 80 = 784.9 \text{ kNm}$$

Thus, the absolute maximum bending moment on the girder is 784.9 kNm.

Q.5 (e) Solution:

The cash flow diagram of a plan (A) is shown below and its present worth P_A on the basis of 10 years of life is obtained.



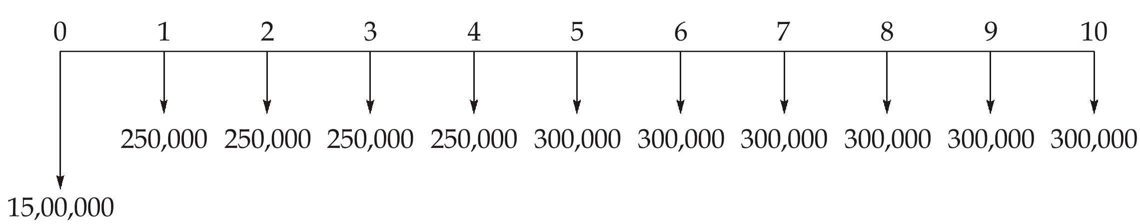
$$P_A = 1000000 + 200,000\left[\frac{P}{A},12\%,4\right] + 900,000\left[\frac{P}{F},12\%,4\right] + 350,000\left[\frac{P}{A},12\%,6\right]\left[\frac{P}{F},12\%,4\right]$$

$$= 1000,000 + 200,000\left[\frac{(1+0.12)^4-1}{(0.12)(1+0.12)^4}\right] + 900,000\left[\frac{1}{(1+0.12)^4}\right] + 350,000\left[\frac{(1+0.12)^6-1}{(0.12)(1+0.12)^6}\right]\left[\frac{1}{(1+0.12)^4}\right]$$

= 1000,000 + 607469.87 + 571966.2706 + 914505.788

$$\therefore \qquad P_A = 3093941.929 \simeq 309342$$

The cash flow diagram of a plan (B) is shown in figure below and its present worth P_B is obtained.



$$P_B = 1500000 + 250,000\left[\frac{P}{A},12\%,4\right] + 300,000\left[\frac{P}{A},12\%,6\right]\left[\frac{P}{F},12\%,4\right]$$

$$= 1500,000 + 250,000\left[\frac{(1+0.12)^4-1}{(0.12)(1+0.12)^4}\right] + 300,000\left[\frac{(1+0.12)^6-1}{(0.12)(1+0.12)^6}\right]\left[\frac{1}{(1+0.12)^4}\right]$$

$$P_B = 1500,000 + 759337.33 + 783862.1045$$

$$\therefore \qquad P_B = 3043199.435 \simeq 3043200$$

Since, $\qquad P_B(10) < P_A(10)$

So, plan B is economical.

Q.6 (a) Solution:

Factored design tensile force, $T = 440$ kN

$$\text{Required net area, } A_n = \frac{T\gamma_{m1}}{0.9 f_u} = \frac{440 \times 10^3 \times 1.25}{0.9 \times 410} = 1490.51 \text{ mm}^2$$

$$\text{Gross area required, } A_g = \frac{T\gamma_{m0}}{f_y} = \frac{440 \times 10^3 \times 1.1}{250} = 1936 \text{ mm}^2$$

Let us try ISA 150 × 75 × 10 mm angle section

$$A_g = 2156 \text{ mm}^2 \ (> 1936 \text{ mm}^2) \text{ (O.K)}$$

M20 diameter bolts are used.

$$\text{Design strength of bolt in shear, } V_{dsb} = (n_s A_s + n_n A_n)\frac{f_{ub}}{\sqrt{3}\gamma_{mb}}$$

$$= 0.78 \times \frac{\pi}{4} \times 20^2 \times \frac{400 \times 10^{-3}}{\sqrt{3} \times 1.25} = 45.27 \text{ kN}$$

$$\text{Design strength of bolt in bearing, } V_{dpb} = 2.5\, k_b\, dt\, f_u/\gamma_{mb}$$

$$k_b = \min\left\{\frac{l}{3d_0}, \frac{p}{3d_0} - 0.25, \frac{f_{ub}}{f_u}, 1\right\}$$

$$e_{min} = 1.5\, d_0 = 1.5 \times 22 = 33 \text{ mm}$$

$$\text{Provide, } e = 40 \text{ mm}$$

$$p_{min} = 2.5d = 2.5 \times 20 = 50 \text{ mm}$$

$$\text{Provide, } p = 50 \text{ mm}$$

$$k_b = \min\left\{\frac{40}{3 \times 22}, \frac{50}{3 \times 22} - 0.25, \frac{400}{410}, 1\right\}$$

$$= \min\{0.61, 0.51, 0.98, 1\} = 0.51$$

$$V_{dpb} = 2.5 \times 0.51 \times 20 \times 10 \times \frac{410}{1.25} \times 10^{-3}$$

$$= 83.64 \text{ kN}$$

$$\therefore \quad \text{Design bolt value} = \min.\{45.27, 83.64\} = 45.27 \text{ kN}$$

$$\text{Number of bolts required} = \frac{440}{45.27} = 9.72 \simeq 10$$

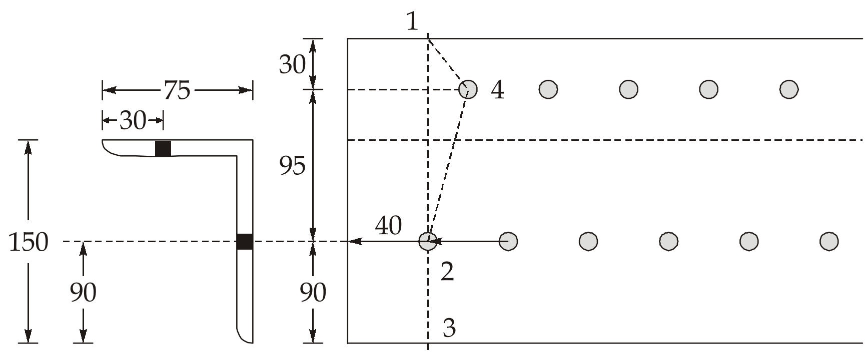
∴ Provide 10 number of bolts.

$$\text{Length of gusset plate required} = 9 \times 50 + 2 \times 40$$

$$= 530 \text{ mm} > 350 \text{ mm}$$

Hence, lug angle will be provided.

Provide 6 bolts for connecting main angle leg with gusset plate and 4 bolts for connecting lug angle leg with main angle as shown. The bolts have been provided in a staggered pattern.



$$\text{Length of gusset plate required} = 5 \times 50 + 2 \times 40 = 330 \text{ mm} < 350 \text{ mm} \quad \text{(O.K)}$$

$$\text{Net area along 1-2-3, } A_{n1} = (215 - 22) \times 10 = 1930 \text{ mm}^2$$

$$\text{Net area along 1-4-2-3, } A_{n2} = \left(215 - 2 \times 22 + \frac{25^2}{4 \times 95}\right) \times 10$$

$$= 1726.45 \text{ mm}^2 > 1490.51 \text{ mm}^2 \quad \text{(O.K)}$$

Design strength of the section,

$$T_{dn} = 0.9\frac{A_n f_u}{\gamma_{m1}} = \frac{0.9 \times 1727.36 \times 410 \times 10^{-3}}{1.25}$$

$$= 509.92 \text{ kN} > 440 \text{ kN (O.K)}$$

Since both the legs of the angles are connected, no reduction of net area is required due to shear lag effect.

Design of lug angle:

$$\text{Gross area of connected leg of main angle} = \left(150 - \frac{10}{2}\right) \times 10 = 1450 \text{ mm}^2$$

$$\text{Gross area of outstanding leg of main angle} = \left(75 - \frac{10}{2}\right) \times 10 = 700 \text{ mm}^2$$

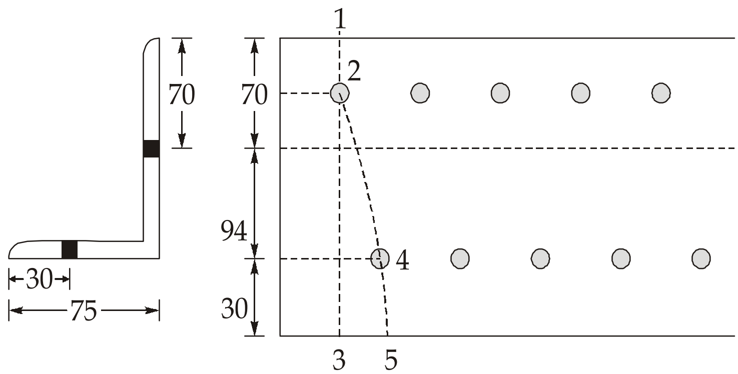
$$\text{Load shared by outstanding leg} = \frac{700}{700 + 1450} \times 440 = 143.26 \text{ kN}$$

$$\text{Design load for lug angle, } T_1 = 1.2 \times 143.26 = 171.9 \text{ kN}$$

Required net area of lug angle, $A_{n2} = \dfrac{T\gamma_{m1}}{0.9 f_u} = \dfrac{171.9 \times 1.25 \times 10^3}{0.9 \times 410} = 582.32 \text{ mm}^2$

Required gross area of lug angle, $A_{g2} = \dfrac{T\gamma_{m0}}{f_y} = \dfrac{171.9 \times 1.1 \times 10^3}{250} = 756.36 \text{ mm}^2$

Let us try ISA 125 × 75 × 6 mm section for lug angle with 125 mm leg connected to the gusset plate.



Section 1-2-3: $A_{n1} = (194 - 22) \times 6 = 1032 \text{ mm}^2$

Section 1-2-4-5: $A_{n2} = \left(194 - 2 \times 22 + \dfrac{25^2}{4 \times 94}\right) \times 6$

$= 909.97 \text{ mm}^2 > 582.32 \text{ mm}^2$ (O.K)

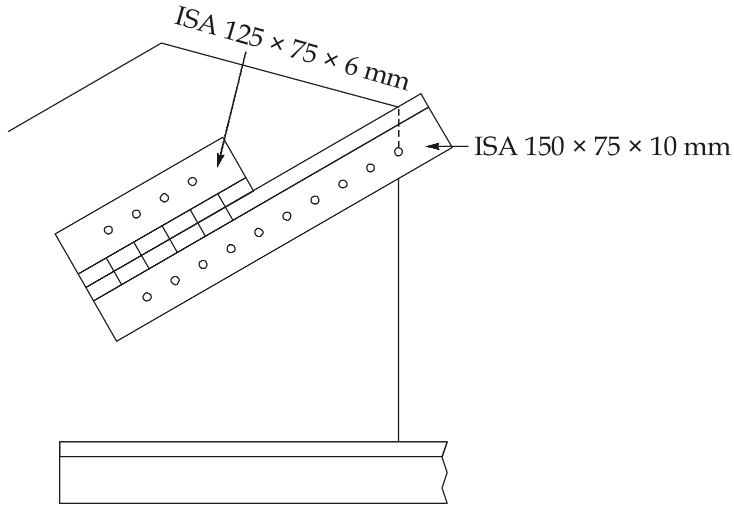
Number of bolts required to connect lug angle to the gusset plate,

$$n_1 = \frac{171.9}{45.27} = 3.8 \simeq 4$$

Number of bolts required to connect outstanding leg of the main angle and the lug angle,

$$n_2 = \frac{1.4 \times 143.26}{45.27} = 4.43 \simeq 5$$

Provide 5 bolts of 20 mm diameter to connect outstanding legs of two angles as shown in figure.



Q.6 (b) (i) Solution:

For first and last sections:

$$\text{Average width, } \bar{W}_{n-1} = \frac{\left[W_n + \frac{W_{n-1}}{2}\right]^2}{2W_n} = \frac{\left[1+\frac{2}{2}\right]^2}{2\times 1} = 2 \text{ m}$$

For the rest of segments,

$$\bar{W} = \left[\frac{2}{2}+\frac{2}{2}\right] = 2\,\text{m}$$

Since the velocity is measured at 0.6 times depth, the measured velocity is the average velocity at that section.

Distance from left edge	Average Width w(cm)	Depth (m)	N_s = Rev./sec.	Velocity V (m/sec.)	Segmental Discharge (ΔQ) : m^3/sec.
0	0	0	0	0.	0
1	2	1.1	0.390	0.2289	0.5036
3	2	2.0	0.580	0.3258	1.3032
5	2	2.5	0.747	0.4110	2.055
7	2	2.0	0.600	0.3360	1.3440
9	2	1.7	0.450	0.2595	0.8823
11	2	1.0	0.300	0.1830	0.3660
12	0	0	0	0	0
					$\Sigma Q = 6.4541$

Q.6 (b) (ii) Solution:

$$\text{Risk} = 15\%$$

$$\text{Life of structure} = 50 \text{ years}$$

Now,
$$\text{Risk} = \left[1-[1-P]^n\right]$$

$$0.15 = \left[1-\left[1-\frac{1}{T}\right]^{50}\right]$$

$$\text{From here, return period, } T = 308.16 \text{ years}$$

Using Gumbel's method,

$$n_T = \bar{n}_T + k\sigma_{n-1}$$

here,
$$k = \frac{y_T - \bar{y}_n}{\sigma_n}$$

here,
$$y_T = -\ln\left[\ln\left[\frac{T}{T-1}\right]\right]$$

$$= -\ln\left[\ln\left[\frac{308.16}{308.16-1}\right]\right] = 5.73$$

Given,
$$y_n = 0.538$$

$$\sigma_n = 1.283$$

$\therefore$
$$k = \frac{5.73-0.538}{1.283} = 4.05$$

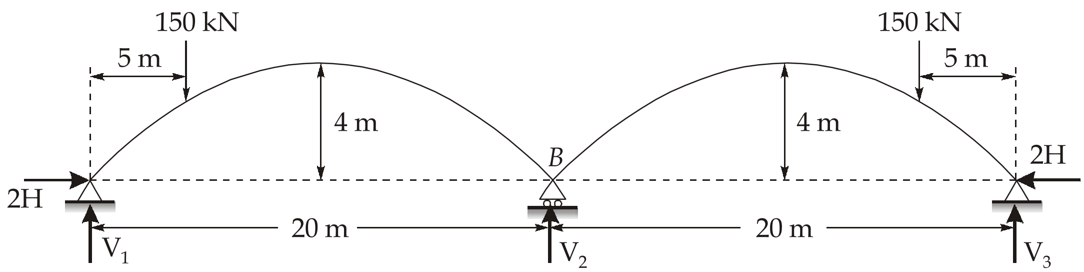
$\therefore$
$$n_T = n_T + k\cdot \sigma_{n-1}$$

$$= 28600 + 4.05 \times 13840 = 84652 \text{ m}^3/\text{sec}$$

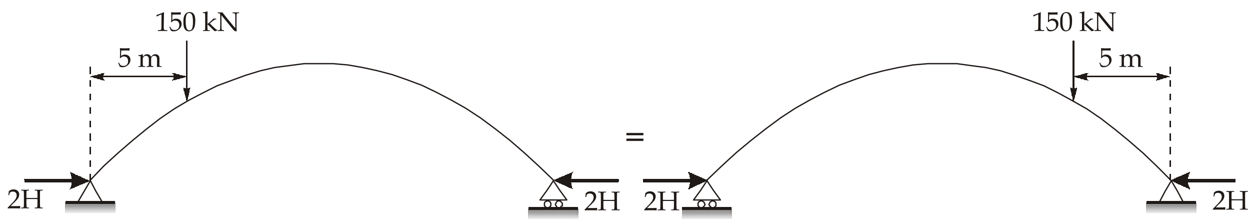
Q.6 (c) Solution:

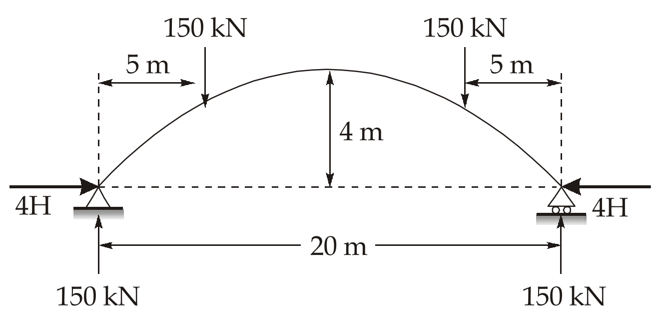
When the load is applied on arch *AB*, the roller support will move by a distance δ towards the right. Similarly, when the load is applied on arch *BC*, at the same distance of 5 m from *C*, the roller support will move by a distance δ towards the left. The horizontal reaction developed in each case will be H.

However, when two point loads of 150 kN each are applied on the arches *AB* and *BC* at a distance of 5 m from *A* and *C* respectively, the horizontal thrust at A and C will be equal to 2H. The roller support will not move laterally and hence each arch can now be considered as a separate two-hinged arch with unyielding supports.



Now, we can again use symmetry to calculate the value of 2H corresponding to the given loading condition.





$$4H = \frac{\int_0^{20} \frac{My\,dx}{EI}}{\int_0^{20} \frac{y^2\,dx}{EI}} \qquad \left[y = \frac{4h}{l^2}x(l-x)\right]$$

$$= \frac{2\left[\int_0^5 (150x)\frac{4h}{l^2}x(l-x)\,dx \int_5^{10} (150\times 5)\frac{4h}{l^2}x(l-x)\,dx\right]}{2\int_0^{10}\left(\frac{4h}{l^2}x(l-x)\right)^2 dx}$$

$$= \frac{\int_0^5 \frac{150\times 4\times 4}{20^2}x^2(20-x)\,dx + \int_5^{10}\frac{150\times 5\times 4\times 4}{20^2}x(20-x)\,dx}{\int_0^{10}\left(\frac{4\times 4}{20^2}\right)^2 x^2\left(20^2+x^2-40x\right)dx}$$

$$= \frac{\frac{150\times 4^2}{20^2}\int_0^5 (20x^2 - x^3)\,dx + \frac{150\times 5\times 4^2}{20}\int_5^{10}(20x - x^2)\,dx}{\left(\frac{4^2}{20^2}\right)^2 \int_0^{10}(400x^2 + x^4 - 40x^3)\,dx}$$

$$= \frac{\frac{150\times 4^2}{20^2}\left[20\frac{x^3}{3} - \frac{x^4}{4}\right]_0^5 + \frac{150\times 5\times 4^2}{20}\left[20\frac{x^2}{2} - \frac{x^3}{3}\right]_5^{10}}{\left(\frac{4^2}{20^2}\right)^2\left[400\frac{x^3}{3} + \frac{x^5}{5} - 40\frac{x^4}{4}\right]_0^{10}}$$

$$= \frac{\frac{150\times 4^2}{20^2}\left[\frac{20}{3}\times 5^3 - \frac{5^4}{4}\right] + \frac{150\times 5\times 4^2}{20^2}\left[\left(10(10^2) - \frac{10^3}{3}\right) - \left(10(5^2) - \frac{5^3}{2}\right)\right]}{\left(\frac{4^2}{20^2}\right)^2\left[400\frac{(10)^3}{3} + \frac{(10)^5}{5} - 10^5\right]}$$

$$= \frac{4062.5 + 13750}{\frac{256}{3}} = 208.74 \text{ kN}$$

$\therefore \quad 4H = 208.74$ kN

$\Rightarrow \quad H = 52.185 \simeq 52.19$ kN

When the arch *AB* or *BC* is loaded, the horizontal thrust, $H = 52.19$ kN.

Q.7 (a) (i) Solution:

(a) Depreciation is defined as the loss in the value of an asset with the passage of time. The main purpose of the depreciation is to provide for the recovery of capital that has been involved in the possession of the physical property.

The term 'Depletion' is used to indicate the decrease in value of the resource. In case of depreciation, the property involved usually is replaced with similar property when it has been fully depreciated. But, in case of depletion of minerals or other natural resources, such replacement is not possible.

(b) The break even point is the volume of output at which neither a profit nor a loss is incurred. The point at which total cost line meets the revenue line is known as break even point.

Certain cost component of an alternative may vary directly with respect to the design variable while others may vary inversely with the design variable. Then, a value of design variable exists that will result in the total cost of the alternative to be minimum. That particular value of design variable for which the total cost is minimum is called minium cost point.

(c) Salvage value is the value of the property at the end of its utility period without being dismantled. It implies that the property has still further utility left. Scrap value is the value of a property realized when it becomes absolutely useless except for sale as junk. The utility of the article is assumed to be zero.

Q.7 (a) (ii) Solution:

Given:

$$C_i = \text{Rs. } 1600$$
$$C_s = \text{Rs. } 150$$
$$n = 5 \text{ years}$$
$$i = 8\%$$

Let,

D_m = Depreciation for mth year.

B_m = Book valve at end of mth year.

$$\therefore \quad D = (C_i - C_s)\left[\frac{i}{(1+i)^n - 1}\right]$$

$$= (1600 - 150)\left[\frac{0.08}{(1.08)^5 - 1}\right] = 247.162$$

Using,

$$D_m = D(1 + i)^{m-1}$$
$$D_1 = 1600 - 247.162 = \text{Rs. } 1352.838$$
$$D_2 = 247.162(1 + 0.08)^{2-1} = \text{Rs. } 266.935$$
$$B_2 = 1352.838 - 266.935 = \text{Rs. } 1085.903$$
$$D_3 = 247.162(1 + 0.08)^{3-1} = \text{Rs. } 288.29$$
$$B_3 = 1085.903 - 288.29 = \text{Rs. } 797.613$$
$$D_4 = 247.162(1 + 0.08)^{4-1} = \text{Rs. } 311.353$$
$$B_4 = 797.613 - 311.353 = \text{Rs. } 486.26$$
$$D_5 = 247.162(1 + 0.08)^{5-1} = \text{Rs. } 336.26$$
$$B_5 = 486.26 - 336.26 = \text{Rs. } 150$$

Q.7 (a) (iii) Solution:

Safety measures taken prior to demolition of buildings are:

(a) Suitable bracing, shoring etc. should be provided to prevent accidental collapse of the building which has already been damaged by fire, flood or earthquake.

(b) All safety devices and PPEs must be issued to the workers.

Safety measures taken during demolition of buildings are:

(a) All materials of fragile nature like glass must be removed first.

(b) Dust must be controlled by suitable means to prevent harm to workmen.

(c) Adequate natural or artificial lighting and ventilation should be provided for the workmen.

(d) Easy exit must be provided to arrange for quick evacuation of the workmen during emergency.

(e) The demolition should always proceed systematically storey by storey in the descending order.

Q.7 (b) Solution:

Let, H = Elevation of water table

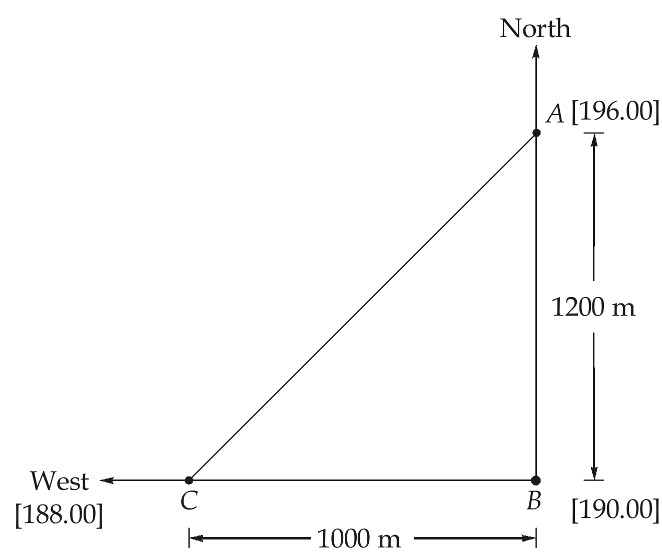
$H_A = 200 - 4 = 196$ m

$H_B = 197 - 7 = 190$ m

$H_C = 202 - 14 = 188$ m

Let BA = North direction, designated as y-direction

The west direction will be called as x-direction.



Along, AB, $\Delta H_y = H_A - H_B = 196 - 190 = 6$ m

$$i_y = \frac{\Delta H_x}{L_{AB}} = \frac{6}{1200} = \frac{1}{200}$$

$$v_y = k \cdot i_y = \frac{k}{200} \text{ m/sec}$$

Along BC [x-direction]

$$\Delta H_x = H_B - H_C$$

$$= 190 - 188 = 2 \text{ m}$$

$$i_x = \frac{\Delta H_x}{L_{BC}} = \frac{2}{1000} = \frac{1}{500}$$

$$v_x = k \cdot i_x = \frac{k}{500} \text{m/sec}$$

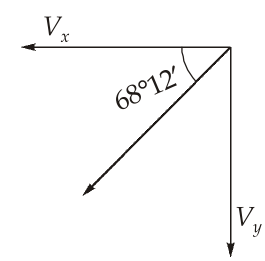
$$v = \sqrt{v_x^2 + v_y^2}$$

$$= \frac{k}{100}\sqrt{\left(\frac{1}{25}\right) + \left(\frac{1}{4}\right)}$$

$$= 5.385 \times 10^{-3} \text{ k m/sec}$$

$$\tan\theta = \frac{v_y}{v_x} = \frac{k}{200} \times \frac{500}{k} = 2.5$$

$$\theta = 68.2° \simeq 68°12'$$



Direction of ground water flow is S21° 48° W.

Q.7 (c) (i) Solution:

$$\text{Density of steel} = 75{,}000 \text{ N/m}^3$$

$$\text{Dip of the cable, } h = \frac{l}{10}$$

where l is the horizontal span

The equation of the cable with the lowest point as origin is,

$$y = \frac{4h}{l^2} \cdot x^2$$

$$\Rightarrow \quad \frac{dy}{dx} = \frac{8h}{l^2} \cdot x$$

$$\text{Length of the cable, } L = \int ds = 2\int_0^{l/2} \sqrt{1 + \left(\frac{dy}{dx}\right)^2} dx$$

$$= 2\int_0^{l/2} \left(1 + \frac{64h^2}{l^4} x^2\right)^{1/2} dx$$

Neglecting higher powers of the expansion,

$$L = 2\int_0^{l/2} \left(1 + \frac{32h^2}{l^4} x^2\right) \cdot dx$$

$$= 2\left[x + \frac{32h^2}{l^4} \cdot \frac{l^3}{3}\right]_0^{l/2}$$

$$= 2\left[\frac{l}{2} + \frac{32h^2}{3l^4} \cdot \frac{l^3}{8}\right] = l + \frac{8h^2}{3l}$$

Note: This relation can be directly applied.

Let A be the area of cross-section of the cable.

∴ Weight of the cable, $W = 75{,}000 \times A \times L$

where, $$L = l + \frac{8}{3l}\left(\frac{l}{10}\right)^2$$

$$= l + \frac{8l}{300} = \frac{308l}{300}$$

$$W = 75{,}000 \times A \times \frac{308l}{300} \text{ N}$$

Vertical reaction at each end, $V = \frac{W}{2}$ N [Due to symmetry]

Horizontal reaction at each end, $H = \frac{Wl}{8h} = \frac{Wl}{8l} \times 10 = \frac{5}{4}W$ N

Max tension, $$T_{max} = \sqrt{V^2 + H^2} = \sqrt{\left(\frac{W}{2}\right)^2 + \left(\frac{5}{4}W\right)^2}$$

$$= 1.346 \text{ W N}$$

Maximum stress, $$f_{max} = \frac{T_{max}}{A} \le 160 \times 10^6 \text{ N/m}^2$$

$$\Rightarrow \quad \frac{1.346W}{A} \le 160 \times 10^6$$

$$\Rightarrow \quad 1.346 \times 75000 \times \frac{308l}{300} \le 160 \times 10^6$$

$$\Rightarrow \quad l \le 1543.78 \text{ m}$$

So, maximum possible span = 1543.78 m

Q.7 (c) (ii) Solution:

1. Stiffness of beam, $k_b = \frac{3EI}{L^3}$

$$= \frac{3 \times 2 \times 10^4 \times 10^6 \times 2 \times 10^{-4}}{4^3}$$

$$= 1.875 \times 10^5 \text{ N/m}$$

Springs have the same displacement and thus they are in parallel connection .

Equivalent spring constant, $k_{eq} = k_b + 2k$

$$= 1.875 \times 10^5 + 2 \times 50 \times 10^3$$

$$= 2.875 \times 10^5 \text{ N/m}$$

$$\text{Mass, } m = 1000 \text{ kg}$$

$$\text{Natural frequency, } w_n = \sqrt{\frac{k_{eq}}{m}} = \sqrt{\frac{2.875 \times 10^5}{1000}} = 16.96 \text{ rad/s}$$

$$\text{Natural period, } T = \frac{2\pi}{w_n} = \frac{2\pi}{16.96} = 0.37 \text{ seconds}$$

2. Stiffness of beam, $k_b = \dfrac{192EI}{L^3}$

$$= \frac{192 \times 25000 \times 10^6 \times 2 \times 10^{-4}}{5^3} = 76.8 \times 10^5 \text{ N/m}$$

In this case, the force is same while the displacement is different. Hence the system is in series.

$$\text{Equivalent spring constant, } \frac{1}{k_{eq}} = \frac{1}{k_b} + \frac{1}{k}$$

$$\Rightarrow \quad \frac{1}{k_{eq}} = \frac{1}{76.8 \times 10^5} + \frac{1}{40 \times 10^3}$$

$$\Rightarrow \quad k_{eq} = 3.979 \times 10^4 \text{ N/m}$$

$$\text{Mass, } m = 3000 \text{ kg}$$

$$\text{Natural frequency, } w_n = \sqrt{\frac{k_{eq}}{m}} = \sqrt{\frac{3.979 \times 10^4}{3000}} = 3.64 \text{ rad/s}$$

$$\text{Natural period, } T = \frac{2\pi}{w_n} = \frac{2\pi}{3.64} = 1.73 \text{ seconds}$$

Q.8 (a) Solution:

For ISMC 350

$$A_g = 5366 \text{ mm}^2$$

Two channels are used, $A_{provided} = 2 \times 5366 = 10732 \text{ mm}^2$

Effective length, $kL = 6.0$ m

$r_z = 136.6$ mm $\qquad I_{zz} = 10008 \times 10^4 \text{ mm}^4$

$r_y = 28.3$ mm $\qquad I_{yy} = 430.6 \times 10^4 \text{ mm}^4$

$C_{yy} = 24.4$ mm

$$\text{Effective slenderness ratio} = 1.1\frac{kL}{r_z} = \frac{1.1\times6\times10^3}{136.6} = 48.32$$

For effective slenderness ratio of 48.32 and buckling class c, the design compressive stress is given by,

$$f_{cd} = 198 - \frac{(198-183)}{(50-40)}\times(48.32-40)$$

$$= 185.52 \text{ N/mm}^2$$

$$\text{Design compressive strength, } P_d = f_{cd} \times A_{\text{provided}}$$

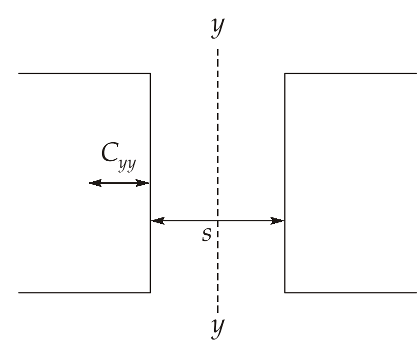
$$= 185.52 \times 10732 \times 10^{-3} \text{ kN}$$

$$= 1991.00 \text{ kN} > 1800 \text{ kN}$$

Which is safe.

Spacing of channels:

$$2I_{zz} = 2\left[I_{yy} + A\left(C_{yy}+\frac{S}{2}\right)^2\right]$$



$$\Rightarrow \quad 2 \times 10008 \times 10^4 = 2\left[430.6\times10^4 + 5366\left(24.4+\frac{S}{2}\right)^2\right]$$

$$\Rightarrow \quad S = 218.4 \simeq 220 \text{ mm}$$

Provide the 2 ISMC 350 at a spacing of 220 mm back to back.

Spacing of battens:

$$\frac{C}{r_y} < 0.7 \times \text{slenderness ratio of column as a whole}$$

$$\Rightarrow \quad C < 0.7 \times 48.32 \times 28.3$$

$$\Rightarrow \quad C < 957.22 \text{ mm}$$

Also, $\frac{C}{r_y} < 50$

$\Rightarrow$ $C < 50 \times 28.3$

$\Rightarrow$ $C < 1415$ mm

Provide battens at a spacing of 950 mm.

Size of end battens:

Overall depth of the batten = Effective depth of the batten

$= S + 2C_{yy}$

$= 220 + 2(24.4)$

$= 268.8 \text{ mm} \simeq 270 \text{ mm} \nless 2b_f\ (= 200 \text{ mm})$

(O.K)

$$\text{Thickness of batten} = \frac{S}{50} = \frac{220}{50} = 4.4\,\text{mm} \simeq 8\,\text{mm} \quad \text{(Say)}$$

Provide a 70 mm overlap of battens on channel flange.

For welding (> 4 × 8 = 32 mm) (O.K.)

Length of batten = 220 + 2 × 70 = 360 mm

Provide 360 × 270 × 8 mm end batten plates.

Design forces:

Transverse shear, V_t = 2.5% of axial load

$$= \frac{2.5}{100} \times 1800\,\text{kN} = 45\,\text{kN}$$

$$\text{Longitudinal shear, } V_b = \frac{V_t C}{NS}$$

$$= \frac{45 \times 950}{2 \times \left(220 + 2 \times \frac{70}{2}\right)} = 73.71\text{ kN}$$

$$\text{Moment, } M = \frac{V_t C}{2N}$$

$$= \frac{45 \times 950 \times 10^{-3}}{2 \times 2} = 10.69\text{ kNm}$$

$$\text{For end battens, shear stress} = \frac{73.71 \times 10^3}{270 \times 8} = 34.13\text{ N/mm}^2$$

$$\left(< \frac{250}{\sqrt{3} \times 1.1} = 131.27 \text{ N/mm}^2 \right)$$

$$\text{Bending stress} = \frac{10.69 \times 10^6 \times 6}{8 \times 270^2} = 110 \text{ N/mm}^2$$

$$\left(< \frac{250}{1.1} = 227.23 \text{ N/mm}^2 \right)$$

Hence, it is safe.

For intermediate battens, shear stress = $\frac{73.7 \times 10^3}{205 \times 8} = 44.94 \text{ N/mm}^2 < 131.22 \text{ N/mm}^2$

$$\text{Bending stress} = \frac{10.69 \times 10^6 \times 6}{8 \times 205^2} = 190.78 \text{ N/mm}^2 < 227.27 \text{ N/mm}^2$$

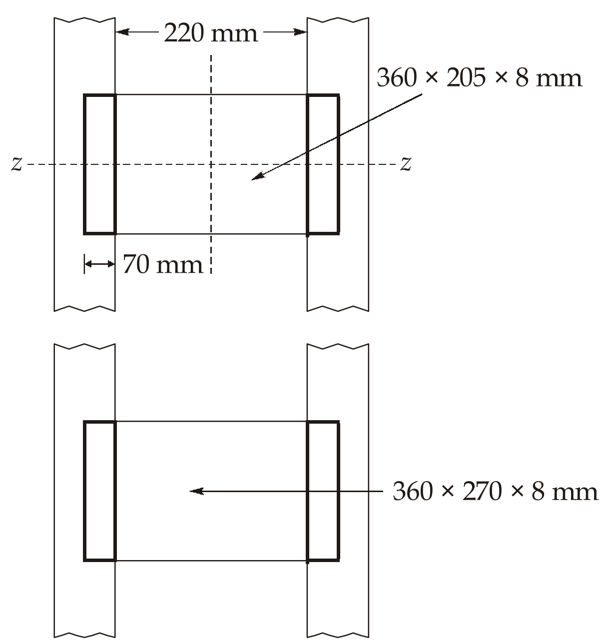
Hence, it is safe.

Design of weld:

Welding is done on all four sides as shown.

Let t_t = throat thickness of weld

$$I_z = 2 \times \left[\frac{70 \times t_t^3}{12} + 70 \times t_t \times \left(\frac{205}{2} \right)^2 \right] + \frac{t_t \times 205^3}{12} \times 2$$



Neglecting $\frac{70 \times t_t^3}{12}$

$$I_z = 290.67 \times 10^4\, t_t \text{ mm}^4$$

$$\text{C.G. of weld, } \bar{z} = \frac{205 \times t_t \times 0 + 2 \times 70 \times t_f \times \frac{70}{2}}{205 t_f + 2 \times 70 \times t_f} = 14.2 \text{ mm}$$

$$I_y = \frac{t_t \times 70^3}{12} \times 2 + 2 \times \left[\frac{205 \times t_t^3}{12} + 205 \times t_t \times 35^2\right]$$

Neglecting $\frac{205 \times t_t^3}{12}$

$$I_y = 55.94 \times 10^4\, t_t \text{ mm}^4$$

$$\text{Polar moment of inertia, } I_p = I_{zz} + I_{yy}$$

$$= 290.67 \times 10^4 t_t + 55.94 \times 10^4\, t_t$$

$$= 346.61 \times 10^4\, \text{t}_t$$

$$r = \sqrt{\left(\frac{205}{2}\right)^2 + \left(\frac{70}{2}\right)^2} = 108.31 \text{ mm}$$

$$\cos\theta = \frac{35}{108.31} = 0.323$$

$$\text{Direct shear stress, } q_1 = \frac{73.71 \times 10^3}{(2 \times 70 + 205) t_t} = \frac{213.65}{t_t}$$

$$\text{Shear stress due to moment, } q_2 = \frac{10.69 \times 10^6 \times 108.31}{346.61 \times 10^4 t_t} = \frac{334.05}{t_t}$$

$$\text{Combined stress} = \sqrt{q_1^2 + q_2^2 + 2 q_1 q_2 \cos\theta} < \frac{f_u}{\sqrt{3} \times 1.5} \quad \text{(Shop weld)}$$

$$\Rightarrow \sqrt{\left(\frac{213.65}{t_t}\right)^2 + \left(\frac{334.05}{t_t}\right)^2 + 2\left(\frac{213.65}{t_t}\right)\left(\frac{334.05}{t_t}\right) 0.323} \le 189.37$$

$$\Rightarrow \frac{450.93}{t_t} = 189.37$$

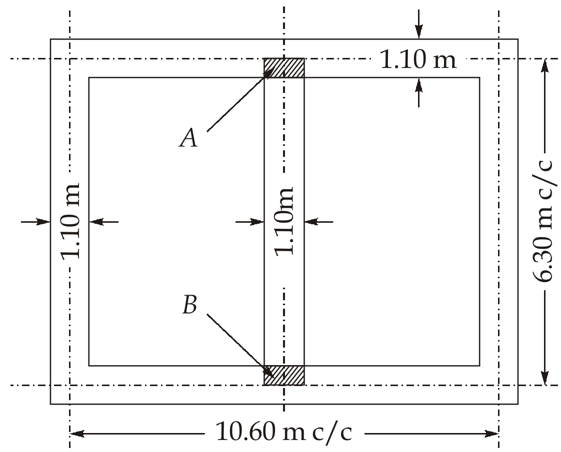
$$\Rightarrow t_t = 2.38 \text{ mm}$$

$$\text{Size of weld} = \frac{2.38}{0.7} = 3.4 \text{ mm} \quad (\not< 5 \text{ mm for 13.5 mm thick flange})$$

Provide a 5 mm weld to make the connections.

Q.8 (b) Solution:

The foundation trench plan is as shown below:



Total centre length of wall = 2 × c/c length of long wall + 3 × c/c length of short wall

= 2 × 10.60 + 3 × 6.30 = 40.10 m

If the total centre length is multiplied by the breadth and depth, at the junction the portions A and B shown by hatched lines come twice. So, these excesses shall have to be deducted. This process is to be done at every stage at that particular level.

Thus, the quantity of earthwork in excavation

$$= \left[\text{Total centre length } - 2\left(\frac{1}{2}\times\text{breadth}\right)\right]\times\text{breadth}\times\text{depth}$$

$$= \left(40.10 - 2\times\frac{1}{2}\times 1.10\right)\times 1.10\times 1.00 = 42.90\,\text{m}^3$$

Details of measurement and calculation of quantities are shown in table given below:

Item No.	Particulars of Items	No.	Length	Breadth	Height or Depth	Quantity	Explanation
1.	Earthwork in excavation in foundation	1	39.00 m	1.10 m	1.00 m	42.90 m^3	Total centre Length = 40.10 m $L = 40.10 - 2 \times \frac{1}{2} 1.10$ = 39.00 m
2.	Lime concrete in foundation	1	39.00 m	1.10 m	0.30 m	12.87 m^3	L same as above
3.	1st Class brick work in 1:6 cement mortar in foundation and plinth						
	1st footing	1	39.3 m	0.80 m	0.20 m	6.29 m^3	$L = 40.10 - 2 \times \frac{0.8}{2}$ = 39.3 m
	2nd footing	1	39.4 m	0.70 m	0.10 m	2.76 m^3	$L = 40.10 - 2 \times \frac{0.70}{2}$ = 39.4 m
	3rd footing	1	39.5 m	0.60 m	0.10 m	2.37 m^3	$L = 40.10 - 2 \times \frac{0.60}{2}$ = 39.5 m
	4th footing	1	39.6 m	0.50 m	0.10 m	1.98 m^3	$L = 40.10 - 2 \times \frac{0.50}{2}$ = 39.6 m
	Plinth wall above footing	1	39.70 m	0.40 m	0.80 m	12.70 m^3	$L = 40.10 - 2 \times \frac{0.40}{2}$ = 39.70 m
4.	Damp proof course 2.5 cm c/c	1	39.70 m	0.40 m	–	15.88 m^3	$L = 40.10 - 2 \times \frac{0.40}{2}$ = 39.70 m
	Deduct door sill	2	1.20 m	0.40 m	–	0.96 m^3	
					Net	14.92 m^3	
5.	First class brick work in lime mortar in superstructure	1	39.80 m	0.30 m	4.2 m	50.15 m^3	$L = 40.10 - 2 \times \frac{0.30}{2}$ = 39.80 m
	Deduct –						
	Door openings	2	0.20 m	0.30 m	2.10 m	1.512 m^3	
	Window openings	4	1.00 m	0.30 m	1.50 m	1.80 m^3	
	Shelves	2	1.00 m	0.20 m	1.50 m	0.60 m^3	Back of shelves 10 cm thick wall
					Net	46.238 m^3	

Q.8 (c) Solution:

Number of joints, $j = 4$

Numbers of members, $m = 5$

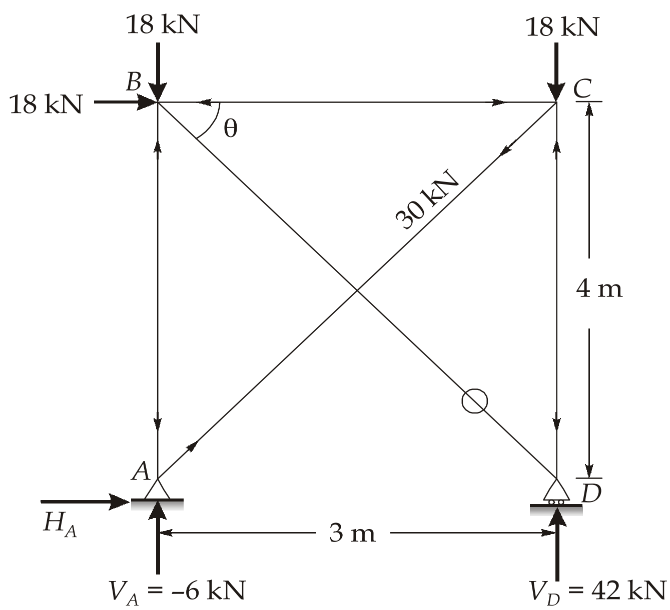
Number of external reactions, $r_e = 4$

Degree of internal static indeterminacy,

$$D_{si} = m - (2j - 3)$$
$$= 5 - (2 \times 4 - 3) = 0$$

Degree of external static indeterminacy, $D_{se} = r - 3 = 4 - 3 = 1$

Thus, the structure is externally indeterminate to one degree. To render the structure to a determinate structure, let one of the supports, say the support at D be changed to a roller support.



Let V_A and H_A be the vertical and horizontal reactions at A respectively and V_D be the vertical reaction at D.

Now $\Sigma M_A = 0$

$\Rightarrow$ $18 \times 4 + 18 \times 3 = V_D \times 3$

$\Rightarrow$ $V_D = 42$ kN

From $\Sigma V = 0$

$\Rightarrow$ $V_A + V_D = 36$ kN

$\Rightarrow$ $V_A = 36 - 42 = -6$ kN or 6 kN downwards

From $\Sigma H = 0$

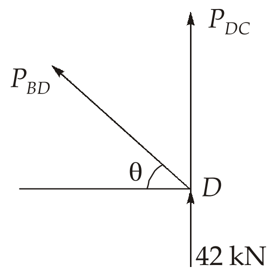
$\Rightarrow$ $18 \times H_A = 0$ $\Rightarrow$ $H_A = -18$ kN or 18 kN ($\leftarrow$)

Now at joint D,

$\Sigma F_y = 0$ and $\Sigma F_x = 0$

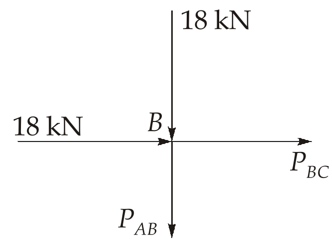
⇒ $P_{BD} = 0$ kN and $P_{DC} = -42$ kN

$= 42$ kN (Compressive)



Now at joint B,

$\Sigma F_x = 0$ and $\Sigma F_y = 0$

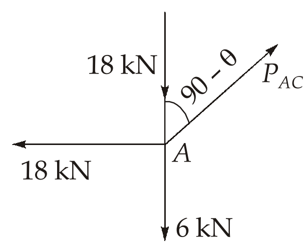


⇒ $P_{BC} = -18$ kN = 18 kN (Compressive)

$P_{AB} = -18$ kN = 18 kN (Compressive)

Now at joint A,

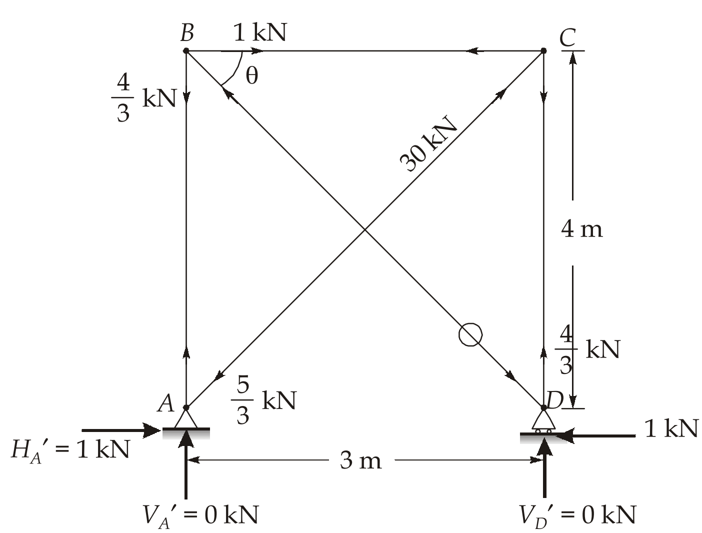
$\Sigma F_y = 0$



⇒ $P_A \cos(90 - \theta) = 24$ kN

⇒ $$P_{AC} = \frac{24}{4} \times 5 = 30\,\text{kN (Tensile)}$$

Now, let us remove the applied loading and let a 1 kN horizontal load be applied at D as shown.



Let V_A' and H_A' be the vertical and horizontal reactions at A respectively and V_D' be the vertical reaction at D.

From $\Sigma M_A = 0$

$$\Rightarrow \quad V_D' = 0$$

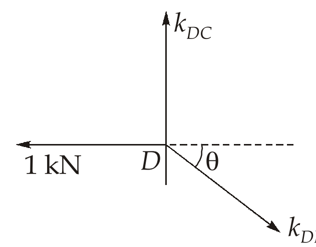
From $\Sigma V = 0$

$$\Rightarrow \quad V_A' = 0$$

From $\Sigma H = 0$

$$\Rightarrow \quad H_A' = 1\text{ kN}$$

Now at joint D,



$\Sigma H = 0$

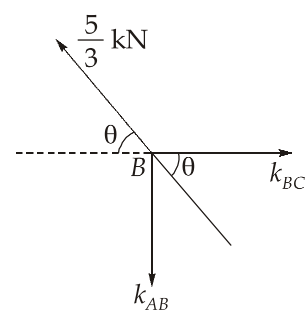
$$\Rightarrow \quad k_{DB}\cos\theta = 1\text{ kN}$$

$$\Rightarrow \quad k_{DB} = \frac{5}{3}\text{kN (Compressive)}$$

$\Sigma V = 0$

$$\Rightarrow \quad k_{DB}\sin\theta = k_{DC}$$

$$\Rightarrow \quad k_{DC} = \frac{5}{3}\times\frac{4}{5} = \frac{4}{3}\text{kN (Tensile)}$$



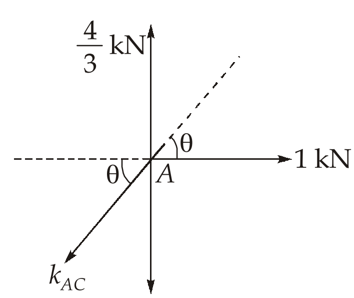
Now at joint B,

$\Sigma H = 0$

$$\Rightarrow \quad k_{BC} = \frac{5}{3}\cos\theta$$

$$\Rightarrow \quad k_{BC} = \frac{5}{3}\times\frac{3}{5} = 1\text{kN (Tensile)}$$

$\Sigma V = 0$



$$\Rightarrow \quad k_{AB} = \frac{5}{3}\sin\theta$$

$$\Rightarrow \quad k_{AB} = \frac{5}{3}\times\frac{4}{5} = \frac{4}{3}\text{kN (Tensile)}$$

Now at joint A,

$\Sigma H = 0$

$$k_{AC}\cos\theta = 1$$

$$\Rightarrow \qquad k_{AC} = \frac{5}{3}\text{kN} \qquad \text{(Compressive)}$$

Actual horizontal reaction at D due to the given loading is,

$$x = \frac{-\Sigma \dfrac{PkL}{AE}}{\Sigma \dfrac{k^2L}{AE}}$$

As E is same for all the members,

$$\therefore \qquad x = \frac{-\Sigma \dfrac{PkL}{A}}{\Sigma \dfrac{k^2L}{A}}$$

The quantities $\dfrac{\Sigma PkL}{A}$ and $\dfrac{\Sigma k^2L}{A}$ are tabulated below wherein (+) denotes tension and (–) denotes compression.

Member	P	k	L(mm)	A(mm^2)	$\frac{PkL}{A}$	$\frac{k^2L}{A}$
AB	–18	$\frac{4}{3}$	4000	4000	–24	$\frac{16}{9}$
BC	–18	1	3000	3000	–18	1
CD	–42	$\frac{4}{3}$	4000	4000	–56	$\frac{16}{9}$
BD	0	$\frac{-5}{3}$	5000	5000	0	$\frac{25}{9}$
AC	30	$\frac{-5}{3}$	5000	5000	–50	$\frac{25}{9}$
				Σ	–148	$\frac{91}{9}$

$$\therefore \qquad x = -\frac{-148}{\frac{91}{9}} = 14.637 \text{ kN} \simeq 14.64 \text{ kN}$$

The positive sign implies that the horizontal reactions at D acts in the direction in which unit load is applied.

The actual force in any member is given by,

$$S = P + kx$$

$$S_{AB} = -18 + \frac{4}{3}(14.64) = 1.52\,\text{kN} \qquad \text{(Tensile)}$$

$$S_{BC} = -18 + 1(14.64) = -3.36 \text{ kN or } 3.36 \text{ kN (Compression)}$$

$$S_{CD} = -42 + \frac{4}{3}(14.64) = -22.48 \text{ kN or } 22.48 \text{ (Compression)}$$

$$S_{BD} = 0 - \frac{5}{3}(14.64) = -24.4 \text{ kN} \text{ or } 24.4 \text{ kN (Compressive)}$$

$$S_{AC} = 30 - \frac{5}{3}(14.64) = 5.6 \text{ kN (Tensile)}$$

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